JSCE Guidelines for Concrete
No.16

STANDARD SPECIFICATIONS FOR CONCRETE STRUCTURES – 2007
"Materials and Construction"

Japan Society of Civil Engineers

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Yotsuya 1-chome, Shinjuku-ku, Tokyo 160-0004, JAPAN
FAX +81-3-5379-2769　E-mail pub@jsce.or.jp
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Preface

Concrete structures have supported our society as infrastructures. The society can only preserve itself in wholesome with tough, beautiful and durable concrete structures. Concrete Committee of Japan Society of Civil Engineers (JSCE), leading organization for investigation, research, technological promotion and education of concrete in Japan, considers the issuance and revision of Standard Specifications for Concrete Structures as its most important activity. Standard Specifications for Concrete Structures (JSCE-SSCS), which show the model for plan, design, execution, maintenance and repair of concrete structures, have been highly recognized in practice and contributed to the development of concrete technology in Japan since its first publication as "Standard Specifications for Reinforced Concrete – 1931."

In order to cope with the development of concrete technology in Japan and the worldwide trend, Concrete Committee converted all Specifications in JSCE-SSCS namely 'Structural Performance Verification', 'Seismic Performance Verification', 'Materials and Construction', 'Maintenance', 'Dam Concrete' and 'Pavement', from the "Prescriptive Code" to "Performance-based Code" and completed the work in 2002.

This revised edition adopts the technological development after 2002 and intends to enhance the performance-based nature in Standard Specifications. For practical efficiency, the three Specifications - 'Design', 'Materials and Construction' and 'Dam Concrete' present not only general provisions for verification of specified performance requirements but also standard methods as simplified methods to achieve the performance requirements under certain conditions. JSCE-SSCS is ready for practical use as it describes the role of each Specification during the plan, design, execution, maintenance and repair phases as well as the relationship among them. And for the first time, it also describes roles of engineers for construction works. This JSCE-SSCS is yet an ultimate one. There are still remaining tasks, such as inclusion of provisions for scenario of concrete structures during service life. What readers can find in this revised edition is rationality with "the performance-based concept" and the applicability for practice, showing the high level of technology in Japan.

This revised JSCE-SSCS consists of five Specifications; 'Design,' which combines the previous 'Structural Performance Verification' and 'Seismic Performance Verification' together, 'Materials and Construction,' 'Maintenance,' 'Dam Concrete' and 'Test Methods and Specifications.' Specification of 'Test Methods and Specifications' was issued separately in May 2007. Specification of 'Pavement' was published as "Standard Specifications for Pavements – 2007" by the Committee on Pavement Engineering of JSCE, which has taken over the issuance and revision works from JSCE-SSCS.

Finally I would like to show my most sincere gratitude to Prof Taketo UOMOTO and Dr Tadayoshi ISHIBASHI, Chairman and Secretary General of Sub-committee on Revision of Standard Specifications for Concrete Structures as well as its Secretaries, Conveners and Members who devoted themselves continuously despite the tight drafting schedule. My gratitude also goes to Advisors, Secretaries, Executive Members and Members of Concrete Committee, who reviewed the draft.

December 2007

Toyoaki MIYAGAWA, Chairman
Concrete Committee of Japan Society of Civil Engineers

Preface to the English Version

The Japan Society of Civil Engineers' (JSCE) Concrete Committee has been publishing the Standard Specifications for Concrete Structures in Japanese since 1931. The English versions were published twice in 1987 and 2005 when the limit state design and the performance-based concept were introduced in the 1986 and 2002 editions of Standard Specifications for Concrete Structures (JSCE-SSCS) for the first time, respectively.

Since 2004 the Concrete Committee has put efforts to enhance information dissemination overseas by presenting various English publications including the series of "JSCE Guidelines for Concrete." Concrete Committee has also decided to prepare the English version of every edition of JSCE-SSCS. This Sub-committee on English Version of Standard Specifications for Concrete Structures was established in 2008.

Our task is to prepare the English version of four Specifications: 'Design,' 'Materials and Construction,' 'Maintenance' and 'Dam Concrete' of the 2007 edition of JSCE-SSCS. Specification of 'Test Methods and Specifications' of JSCE-SSCS is not included in this English version. However, some of these standard test methods and specifications have been translated for publication in a series of "JSCE Guidelines for Concrete." Please visit the website of Concrete Committee at http://www.jsce.or.jp/committee/concrete/e/index.html for the information on the English publications.

This English version includes most of the contents in the original Japanese version. Utmost efforts have been made to ensure that the translation accurately convey the description in the original Japanese version. If there were any discrepancy between the Japanese and English versions, however, reference should be made to the original Japanese version.

Translation of technical work does not only require expertise but a lot of time and dedication. I am grateful to all the members for their tiring efforts. My heartfelt appreciations go to Prof YOKOTA Hiroshi (Secretary General), Dr SHIMOMURA Takumi (Head, WG for Design), Prof SUGIYAMA Takafumi (Head, WG for Materials and Construction), Dr MAEDA Toshiya (Head, WG for Maintenance), Prof AYANO Toshiki (Head, WG for Dam Concrete) and Dr ISHIZUKA Takayuki who proof-read all the translated Specifications. Without them this English version would not have been published.

December 2010

Tamon Ueda

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Application of Standard Specifications for Concrete Structures

Editorial notes for the English Version:

(1) The Standard Specifications for Concrete Structures are a model code which is supposed to be applied in Japan and have no legal bindings.

(2) Therefore, some contents, such as Chapters 2 and 3 of "Application of Standard Specifications for Concrete Structures," may not fit to practical scheme in construction industry in the other countries.

(3) However, it is hoped that the Standard Specifications for Concrete Structures could be a model code for the other countries after necessary modifications of the contents considering the local conditions.

1. Basic concept concerning the organization of the Standard Specifications for Concrete Structures

The Standard Specifications for Concrete Structures are regularly revised reflecting the state-of-the-art concrete technologies developed in Japan and other countries, and provide standards concerning the technical aspects of concrete structures in a series of phases from planning to design, construction and maintenance.

In this revised edition, the "Standard Specifications for Concrete Structures, Design" is composed of the "Standard Specifications for Concrete Structures, Structural Performance Verification" and "Standard Specifications for Concrete Structures, Seismic Performance Verification" to enhance the convenience of design practice. Durability check and initial cracking check, which should be discussed in the "Standard Specifications for Concrete Structures, Design" have been transferred from the "Standard Specifications for Concrete Structures, Materials and Construction" to "Standard Specifications for Concrete Structures, Design". The preparation and revision of the "Standard Specifications for Concrete Structures, Pavement" has been handed over to the Committee on Pavement Engineering, JSCE (Japan Society of Civil Engineers). The results are now published separately under the title of the Standard Specifications for Pavement. Thus, the Standard Specifications for Concrete Structures include five components: Design, Materials and Construction, Maintenance, Dam Concrete, and Test Methods and Specifications.

The General Requirements for "Design", "Materials and Construction" and "Dam Concrete" are described based on the concept of performance-based code. Performance requirements are specified for structures and the methods for checking the compliance with requirements are shown in the General Requirements. In the Standard Methods, standard methods for satisfying the General Requirements under certain conditions are given for more efficient and simpler design and construction. In cases where no conditions specified in the Standard Methods are met, performance verification should be conducted in accordance with the General Requirements. For establishing new standards fitting for structures or regions to which no Standard Methods are applicable, the Standard Methods may be referred to.

Concrete structures are generally constructed for providing services in the phases of planning, design, construction and maintenance in accordance with the respective components of the Standard Specifications. Each type of work is not independent of the others. Data are handed over from an upstream to a downstream phase that are required for carrying out the work downstream to meet the conditions specified upstream. Handing over the data is therefore important to proper implementation of work in respective phases. In the Standard Specifications for Concrete Structures, “Design”, “Materials and Construction” and “Maintenance” are closely interrelated to one another. Then, the required data shown in each Specifications should be accurately handed over to the next phase without fail.

Performance requirements for durability, safety, serviceability and restorability that are specified in the “Standard Specifications for Concrete Structures, Design” are determined in the design phase. Construction and maintenance methods are roughly determined in the phase. The data that affect construction and maintenance should therefore be handed over to the next phase without fail in the form of design drawings.

Construction records that are specified in the “Standard Specifications for Concrete Structures, Materials and Construction” provide important data for assessment, deterioration prediction and implementation of remedial measures in the maintenance phase. Accurate construction records should therefore be handed over to maintenance engineers. Construction plans and various inspection reports should also be provided to engineers as required.

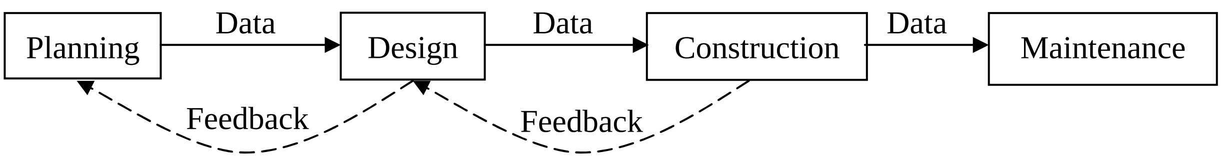

Fig. 1 Flow of work

Figure 1 shows a flow of work from the planning of a concrete structure to service commencement. Data collected in the maintenance phase are not transferred to engineering works in the planning, design or construction phase. It should, however, be taken into consideration that reflecting the data in the maintenance phase in the planning, design and construction of another structure for improvement is important to extend the service life of the structure. The interrelationship is basically the same for design, construction and maintenance described in the “Standard Specifications for Concrete Structures, Dam Concrete.”

Each component of the Standard Specifications for Concrete Structures is described below.

The “Standard Specifications for Concrete Structures, Design” shows standard methods for performance verification of concrete structures such as reinforced concrete, prestressed concrete and steel-concrete composite structures, and stipulates the preconditions for checking and structural details. The revised Standard Specifications for Concrete Structures are not applicable to unreinforced concrete structures. Material design values or other applicable items may, however, be applied to unreinforced concrete structures.

The “Standard Specifications for Concrete Structures, Materials and Construction” provides basic general rules concerning the construction of concrete structures. In the construction phase, the construction method and the performance during the construction work are determined based on the design drawings and restrictions on construction. Then, materials are selected and concrete mix proportions are determined, where a concreting plan is developed so as to meet the requirements for water content, cement amount, cement type and other parameters. Whether the concreting plan meets the construction requirements or performance requirements of the structure or not is verified by an appropriate method. If the requirements are not satisfied, the concreting method is re-specified or the mix proportions are modified as long as the conditions handed over from the design phase are met.

The “Standard Specifications for Concrete Structures, Maintenance” provides general basic principles concerning the maintenance of concrete structures. In the maintenance phase, documents such as the design drawings and maintenance plans handed over from the design phase, and the construction plans, as-built drawings, construction records and inspection reports handed over from the construction phase should be fully used for efficient and effective maintenance work. In cases where the use or functions of the structure change due to social changes, performance verification should be made to verify whether the structure meets the resultant performance requirements or not. If designated performance requirements are not ensured, repair, strengthening or other remedial measures should be considered.

The “Standard Specifications for Concrete Structures, Dam Concrete” stipulates performance and quality requirements for dam concrete, and describes the methods for verifying the compliance with the requirements and the basic design and construction principles. The descriptions concerning design, construction and maintenance in the “Standard Specifications for Concrete Structures, Dam Concrete” are different from the contents of the Standard Specifications “Design”, “Materials and Construction” and “Maintenance” with many respects because of the factors unique to dam concrete such as the unreinforced nature and low or zero slump of dam concrete. The “Standard Specifications for Concrete Structures, Dam Concrete” therefore describes the matters concerning the design, construction and maintenance of dam concrete.

The “Standard Specifications for Concrete Structures, Test Methods and Specifications” lists the Japan Industrial Standards, provisions of JSCE and other standards for the methods mentioned in the other four components of the Standard Specifications. Figures 2 through 4 show work steps in respective phases described in the Standard Specifications for Concrete Structures “Design,” “Materials and Construction” and “Maintenance.”

2. Roles and deployment of responsible engineers

To produce and maintain a reliable structure that meets the performance requirements, the engineers involved should have a capacity to carry out the work and a high level of ethics.

In the planning, design, construction and maintenance of a concrete structure, the engineers should make appropriate decisions under varying work conditions. Therefore, the engineers with required technical skills should be deployed according to the level of difficulty of work. In the planning, design, construction and maintenance, therefore, responsible engineers not only with required technical expertise but also with responsibility and authority should be deployed in organizations of the owner, the consultant and the contractor.

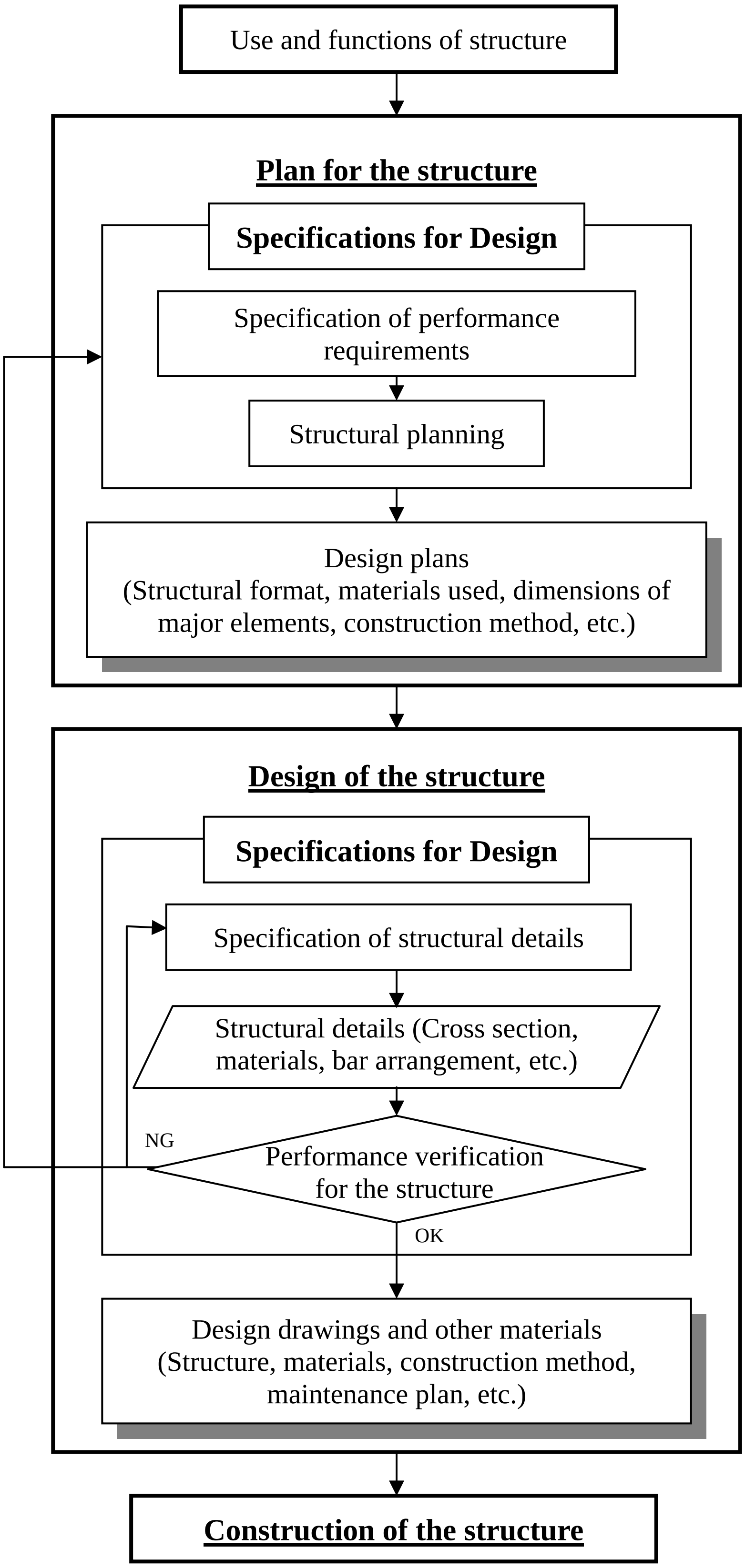

Fig.2 Work steps described in "Specifications for Design"

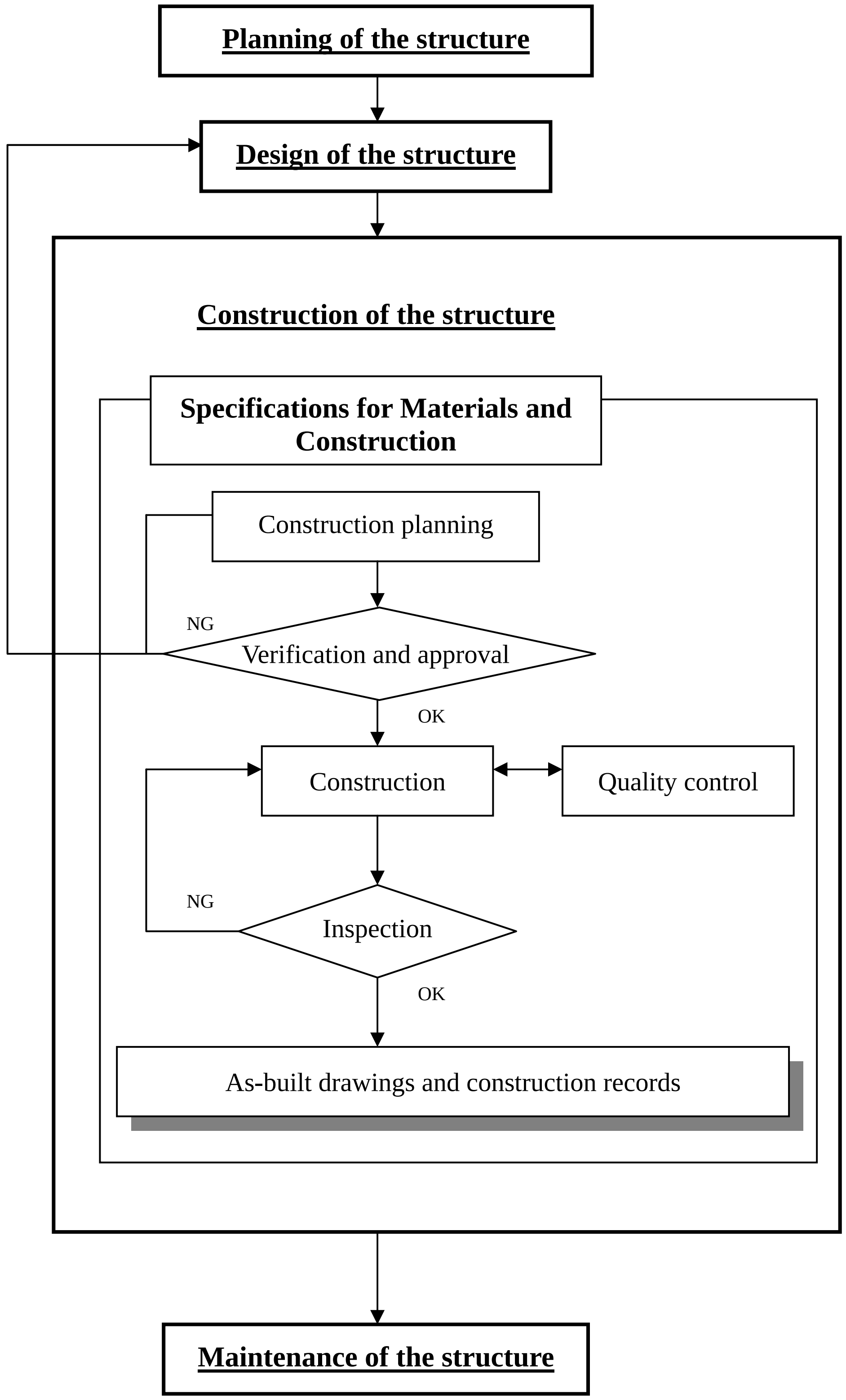

Fig. 3 Work steps described in "Specifications for Materials and Construction"

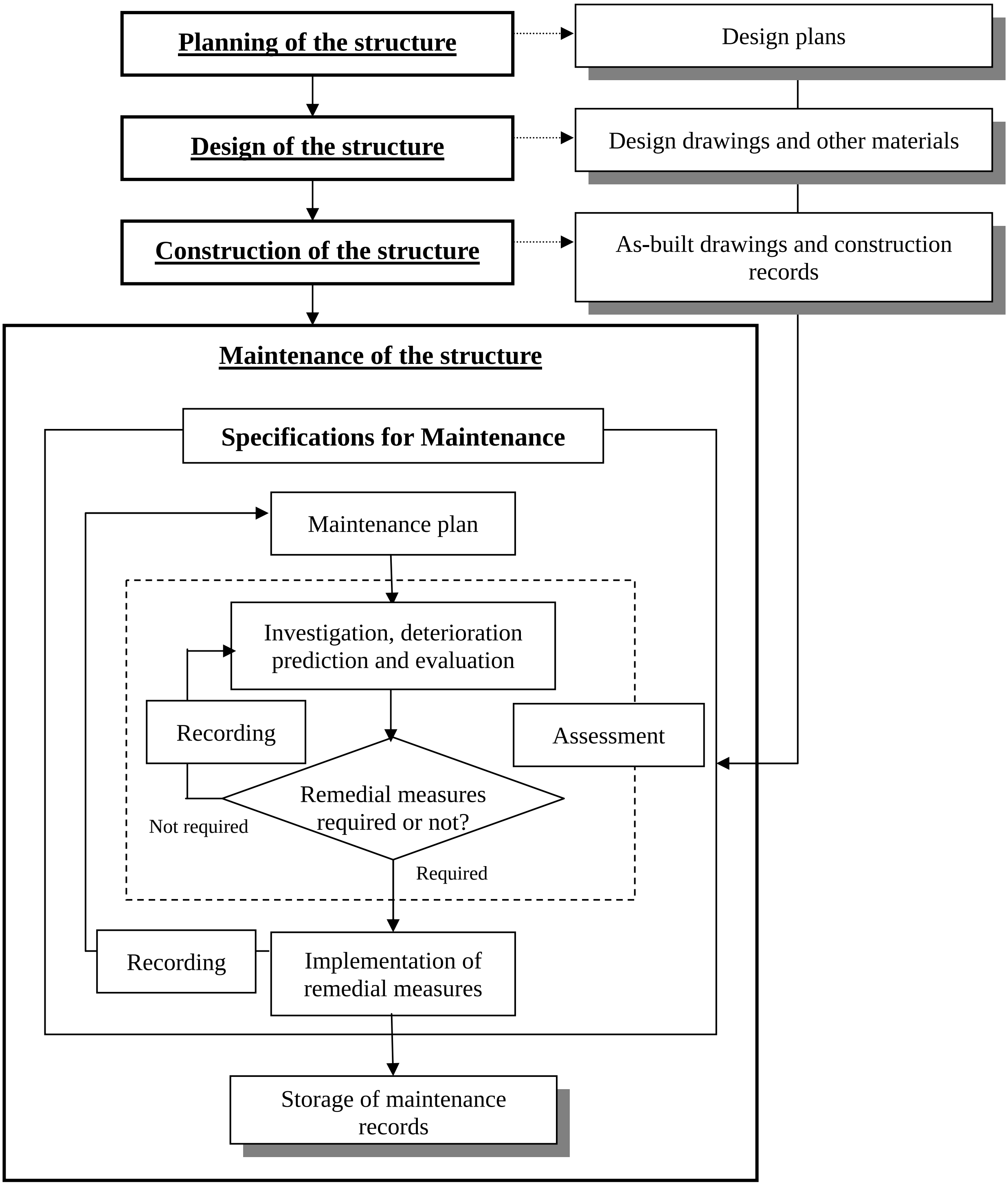

Fig. 4 Work steps described in "Specifications for Maintenance"

The technical skills required for responsible engineers should be defined according to a scale of the work, importance and difficulty of planning, design, construction or maintenance.

As capacity classifications of engineers, engineer qualifications authorized by JSCE are listed in Table 1. The qualifications for the special senior engineers and senior engineers are generally required for responsible engineers.

The JSCE technical qualifications cover several fields. Responsible engineers to be deployed in projects need to have qualifications only for major fields related to the specific project.

Table 1 Engineer qualifications authorized by JSCE

Qualification	Required skills
Executive Professional Civil Engineer	Japan's leading civil engineer with high-level knowledge and experience in his or her field of specialty, or with comprehensive civil engineering expertise
Senior Professional Civil Engineer	Engineer with high-level knowledge and experience in multiple fields or with comprehensive knowledge on civil engineering who can solve key problems as a leader
Professional Civil Engineer	Engineer with knowledge and experience at least in one special field who can carry out task at his or her discretion
Associate Professional Civil Engineer	Civil engineer with required basic knowledge who can carry out assigned task

3. System for ensuring reliability

Many groups are involved in the planning, design, construction and maintenance of a structure. In order to ensure the high reliability of the structure in each work phase, the organizations involved should play their role providing their know-how and assuming due responsibility.

To ensure reliability in the design (and planning) phase, two independent groups should basically check the design. After the design and check by the design company, engineers of the contractor should re-check the design, or request a third party to check the design. Then, fully skilled engineers should be selected for checking so that safety or other reliability parameters may be satisfied. The design drawings serving as a basis for contracting should carry the signatures of responsible engineers of the two groups that assume responsibility.

In the construction phase, reliability is ensured through the quality management by the contractor and the quality verification by the inspector independent of the contractor. Inspections have generally been conducted directly by the Owner and/or Consultant. Completed structures should be inspected wherever possible. If inspecting completed structures is impossible, inspections should be conducted while the structure is being constructed. If the Owner cannot directly inspect the structure under construction, the Owner may request an agent independent of the contractor. Adopting as many highly reliable methods as possible can reduce the labor required for quality management and inspection. In cases where adopting not so reliable methods is inevitable, the level of quality management should be raised or inspections should be conducted more frequently to improve reliability. Inspection items and decision criteria should be specifically presented at the time of contracting because they greatly affect the quality of the structure and the construction cost.

Ensuring safety requires regular investigations. When defects are detected, decision should be made as to remedial measures. For decision making concerning remedial measures for extremely difficult deformation, listening to the opinions of engineers with high skills who have experienced numerous cases is important.

In order for a system for ensuring reliability to work properly, the people or organization with technical skills fit for the specific work should be granted explicit responsibility and authority and assigned to the work. The compensation for the work and time required for the work should also be provided.

General Requirements

CHAPTER 1 GENERAL PROVISIONS

1.1 General

(1) Standard Specifications for Concrete Structures “Materials and Construction: General Requirements” (hereafter referred to as the "Construction: General Requirements” of this Specification) describe basic concepts for the construction of concrete structures specified in design drawings and specifications.

(2) As a general rule, to construct a concrete structure, it is necessary to develop a construction plan based on the design drawings and specifications, construct the structure in accordance with the construction plan while performing proper quality control, and inspect the structure to confirm that the structure has been constructed in accordance with the design drawings and specifications.

(3) If it is not possible to develop a rational construction plan in accordance with the design drawings and specifications, it is mandatory to revert to the design stage and modify the conditions set out in the design drawings and specifications.

(4) For ordinary concrete works, it is advisable to refer to Standard Specifications for Concrete Structures “Materials and Construction: Construction Standards” (hereafter referred to as the "Construction: Construction Standards” of this Specification) and Standard Specifications for Concrete Structures “Materials and Construction: Inspection Standards” (hereafter referred to as the "Construction: Inspection Standards” of this Specification). For concrete works described in Standard Specifications for Concrete Structures “Materials and Construction: Special Concretes” (hereafter referred to as the "Construction: Special Concretes” of this Specification), a construction plan shall be developed with reference to the provisions of the “Construction: Special Concretes” of this Specification.

[Commentary] (1) The “Construction: General Requirements” of this Specification describes basic concepts for developing a rational construction plan and carrying out construction work in accordance with the construction plan in order to construct a concrete structure specified in design drawings and specifications on the assumption that the structure has been designed appropriately so that the performance requirements for the structure can be met.

(2) Design drawings and specifications for a concrete structure, which are the result of a design developed to meet the performance requirements for the structure, show structural drawings, reinforcement drawings, concrete properties, and materials, mix proportions and other details needed to meet these properties. It is a basic requirement, therefore, to plan the construction of a concrete structure in accordance with the design drawings and specifications. In cases where a construction plan can be drawn up in accordance with the “Construction: Construction Standards” or “Construction: Special Concretes” of this Specification, it may be assumed that the concrete structure as described in the design drawings and specifications can be constructed.

Fig. C1.1.1 illustrates the scope of the Construction section of this Specification and the flow of the construction process.

A construction plan drawn up in accordance with the design drawings and specifications must be confirmed and approved before construction is started. All tasks in the construction process must be performed in accordance with the construction plan after proper quality checks are done at each stage. The completed structure is taken over by the owner after it is confirmed through inspection that the structure has been constructed as designed.

(3) The conditions assumed for construction planning at the design stage may differ from the actual construction conditions. In such cases, conditions such as the selection of materials, mix design and plans at each stage of construction are altered to the extent that the properties indicated in the design drawings and specifications are achieved. If, however, it is difficult to develop a rational construction plan while achieving the properties indicated in the design drawings and specifications, it is necessary to return to the design stage and alter the design and prepare new design drawings and specifications so that the performance requirements for the structure can be met.

(4) The “Construction: Construction Standards” of this Specification applies to ordinary concreting that involves few or no special requirements. The “Construction: Inspection Standards” of this Specification describes an inspection system corresponding to such concreting. If these requirements are met, it may be construed that the requirements described in the “Construction: General Requirements” of this Specification are met.

The “Construction: Special Concretes” of this Specification deals with the types of concrete that have proven performance but are not covered by the “Construction: Construction Standards” of this Specification. It is therefore necessary to fully understand the indicated requirements and incorporate them into the construction plan.

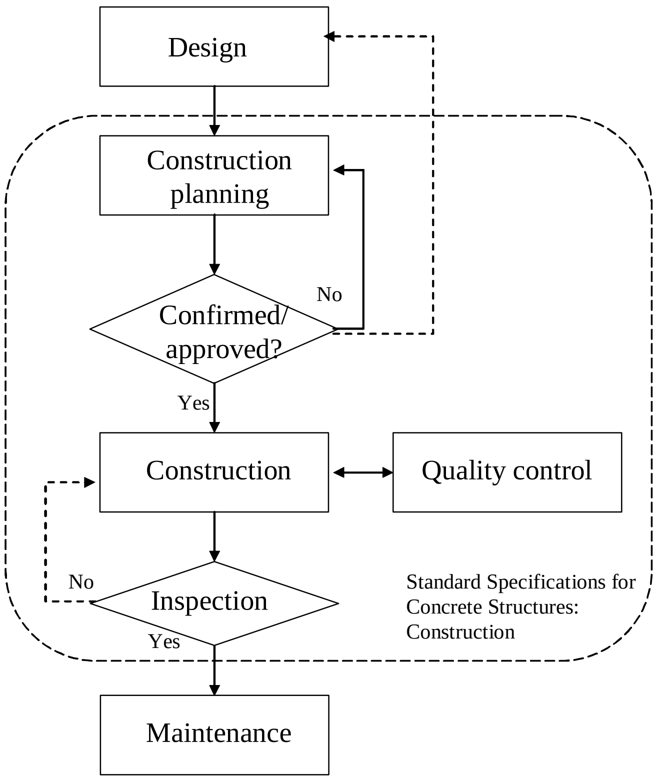

Fig. C1.1.1 Scope of Construction: General Requirements and the flow of the concrete structure construction process

1.2 Definitions

The terms used in Standard Specifications for Concrete Structures "Construction: General Requirements" are defined as follows:

Verification – The act of judging whether something meets performance requirements through experiments using full-scale specimens, empirically and theoretically proven analysis methods, etc.

Inspection – The act of judging whether the quality satisfies the required criteria

Quality control – Effective and organized technical activities for quality assurance performed at all stages of construction work in order to economically construct a concrete structure that matches its purpose

Domain engineer – A person who is authorized by the responsible engineer and perform part of his responsibilities

[Commentary] Quality control, which is carried out to make a concrete structure that meets performance requirements, should be performed by a method that is as economical as possible.

A person who has been ordered to assume part of the responsibility and authority of the Contractor for particular construction work to be carried out in connection with the construction of a concrete structure is referred to as a "domain engineer." Before carrying out construction work, it is necessary to clearly define the scope of responsibility and authority of each domain engineer. A domain engineer must be a person who is qualified as a First-Class Civil Engineer certified by the Japan Society of Civil Engineers, First-Class Civil Engineering Works Execution Managing Engineer (Japan Federation of Civil Engineering Works Execution Managing Engineers Associations), Chief Concrete Engineer (Japan Concrete Institute), Concrete Engineer (Japan Concrete Institute), key technician specializing in a particular type of construction-related work or a person with equivalent expertise.

CHAPTER 2 CONSTRUCTION PLAN

2.1 General

(1) An appropriate construction plan shall be prepared to construct a concrete structure indicated in the design drawings and the specifications.

(2) The construction plan shall meet the requirements for the construction work concerned and shall be approved by the Owner after it is confirmed that the concrete structure indicated in the design drawings and specifications can be constructed.

[Commentary] Preparation for an appropriate construction plan and carrying out the construction work in accordance with the construction plan are essential for the construction of a concrete structure that has the performance attributes (e.g., safety, serviceability, restorability, durability) specified at the design stage.

Fig. C2.1.1 shows the flow of the process from the design of a structure through the development and approval of a construction plan to construction.

In order to construct a concrete structure indicated in the design drawings and specifications, appropriate concreting methods and construction performance of concrete must be determined, and a construction plan is drawn up taking into consideration the construction requirements, namely, quality, construction safety, economy, construction period and environmental loading.

Information to be provided by the designer to the Contractor consists of characteristic values for concrete determined according to the performance requirements for the structure, the maximum size of coarse aggregate and reference values related to concrete mix proportions such as cement content and the water-to-cement ratio. When developing a construction plan, it is necessary to concretely specify the concrete performance requirements and mix proportions determined at the design stage.

The Contractor prepares a construction plan in accordance with the design drawings and specifications and submit the construction plan to the Owner. After the construction plan is approved by the Owner, construction work is carried out according to the plan.

Structural performance does not need to be verified again if the construction conditions determined in this chapter are the same as the conditions assumed at the design stage or if a standard construction method indicated in the Construction Standards section of this Specification is used. If, however, the actual construction conditions differ significantly from the conditions assumed at the design stage, the performance of the structure must be verified again on the basis of the actual construction conditions. If the verification has revealed that the structure does not meet the performance requirements, the construction plan needs to be altered according to the situation.

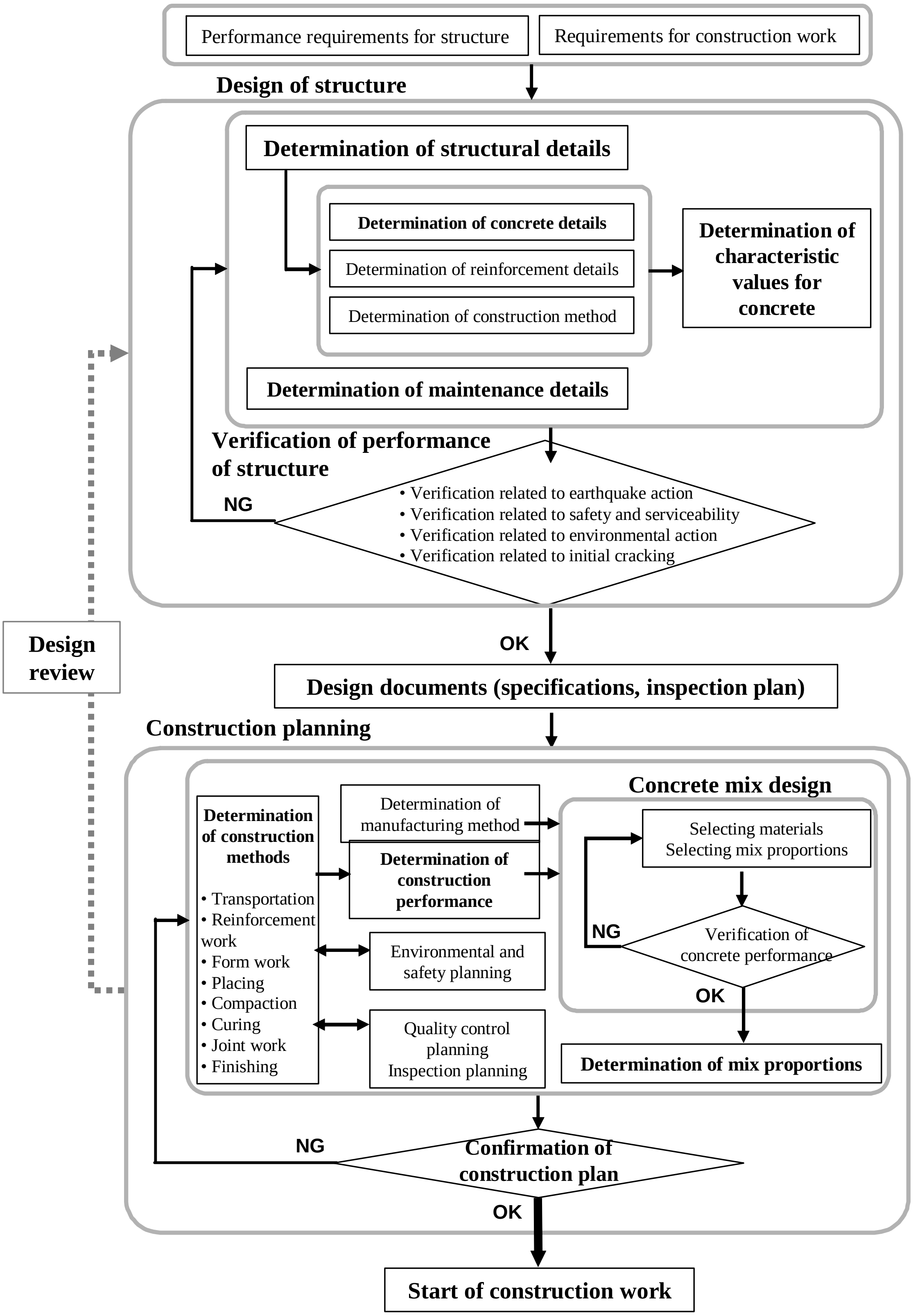

Fig. C2.1.1 Flow of structure design and construction planning

2.2 Considerations in Construction Planning

The construction plan shall be prepared taking into consideration the environmental conditions and construction conditions at the construction site, giving consideration to construction safety and environmental loading and developing plans for details such as the overall schedule, construction methods, concrete manufacturing methods, construction performance of concrete, concrete mix proportions, quality control, inspection, environmental impact and safety.

[Commentary] A construction plan must be developed in due consideration of quality achievement, construction period, safety, economy and environmental impact so that the construction can be carried out successfully. Safety measures against risks expected at the construction stage must be carefully studied in advance. Environmental conservation plans must comply with all environmental laws and regulations and standards related to the construction work. It is also good practice, when preparing a construction plan, to take into consideration items for which there is as yet no standard to meet so that environmental loading can be minimized. Table C2.2.1 lists examples of items to consider when drawing up a construction plan.

Table C2.2.1 Examples of considerations in construction planning

Item	Description
1. Plan for transporting and receiving concrete	Plans for assigning and operating agitator trucks; haul roads, onsite tests, inspection areas; inspection of concrete mix proportions (slump, air content, water content, water-to-cement ratio), etc.
2. Haul road plan	Hauling method, concrete supply capacity, standby pump trucks, etc.
3. Placement plan	Construction organization (organization chart), placing intervals, hourly placing rate, safety, etc.
4. Compaction plan	Type and number of vibrators corresponding to hourly placing rate of concrete, personnel requirements, preparation of standby vibrators, replacement personnel, etc.
5. Finishing plan	Skill level of finishing workers, plan for time of finishing, finish accuracy plan, confirmation of equipment to be used for finishing work, etc.
6. Curing plan	Time of initiation of curing, curing method, confirmation of curing period, confirmation of curing equipment, confirmation of persons responsible for concrete curing control, etc.
7. Jointing plan	Jointing method, treatment method, equipment, time of jointing, etc.
8. Reinforcement work plan	Confirmation of reinforcing bar diameters, spacing, method for ensuring concrete cover, assembling method, type of reinforcing steel, fabrication method, skill level of reinforcement workers, etc.
9. Formwork and falsework plan	Design of formwork (lateral pressure), confirmation of formwork materials and falsework materials, formwork designer, timing of form removal, timing of falsework removal, lateral pressure control method, etc.
10. Environmental conservation plan	Washing water, curing water, drainage of bleeding water etc., checks on noise and vibration, dust, and environmental impact, etc., at and around jobsite
11. Safety and health plan	Confirmation of matters related to safety and health of construction workers, etc.
12. Others	Confirmation of troubleshooting methods, etc.

2.3　Determination of Concreting Method

(1) Appropriate methods of concreting including hauling, placing, compacting, finishing, curing, etc., at the construction site shall be selected in due consideration of the influence on the quality of the concrete in the structure.

(2) In cases where a new construction method that is thought to be more suitable for the construction work concerned than a standard construction method assumed as the design stage is used, the influence of the new method on the quality of the concrete in the structure shall be ascertained through experiments or by other means.

[Commentary]　(1) and (2) In order to achieve the required quality of concrete, it is important to employ an appropriate construction method and carry it out in a reliable way. At the design stage, structural details and various material properties are determined assuming the use of a widely used standard construction method. As construction details such as construction requirements, weather conditions, environmental conditions and concreting-related conditions become concrete and specific, however, it may be more appropriate to alter the construction method. It is good practice, therefore, to take a flexible approach and select the most appropriate method in view of the conditions of the construction project. Decisions on construction methods in such cases may be made with reference to the construction methods described in the Construction Standard section. If a newly developed, poorly field-tested method is to be used, it is necessary to conduct construction tests, etc., under realistic conditions in advance to fully ascertain the quality of concrete in the structure that can be achieved by that method.

2.4　Determination of Construction Performance of Concreting

(1) Appropriate construction performance of concrete shall be specified according to the construction method to be used.

(2) If construction performance of concrete cannot be specified, previously determined details such as the construction method shall be reconsidered.

[Commentary]　(1) Construction performance of concrete includes workability such as filling ability and pumpability, setting properties and strength development properties. It is important to specify construction performance of concrete needed at different stages of construction in due consideration of changes over time in the properties of fresh concrete.

Concrete with appropriate workability is easy to handle, pour and compact appropriately according to the conditions such as the placing site location, the cross-sectional shapes and dimensions of members and the reinforcing steel arrangement. Workability, however, is a property that can change over time at different stages of construction from manufacturing, transportation, pouring and compaction. Changes over time in slump vary considerably depending on concrete mix proportions, the types of materials used and the environmental and weather conditions during construction. Workability must be specified, therefore, after carefully considering such time-dependent changes.

In cases where concrete is pumped at the construction site, it is desirable that concrete can be pumped at the required rate under the planned pumping conditions without encountering the clogging of piping, and the quality of fresh concrete be not severely affected by pumping. Concrete with excellent pumpability is concrete that has a well-balanced combination of three properties, namely, the ability to flow smoothly in straight pipes (fluidity), the ability to pass through bent pipes and tapered pipes (deformability) and the resistance to segregation due to changing pressures in pipes (segregation resistance).

Setting properties are related to conditions such as the compaction of concrete, lateral pressure acting on the formwork, placement intervals and the timing of finishing. In the case of hot weather concrete or cold weather concrete, it may be necessary to adjust setting properties appropriately to accelerate or retard setting.

Appropriate strength development properties are needed to ensure safety of the structure being constructed against loading expected during the construction of the structure and achieve rational construction and the required performance of the completed structure.

Concrete strength during construction is under the influence of factors such as placing temperature, the material of formwork, curing method and ambient temperature. It is therefore necessary to take these into consideration when deciding on the timing of formwork and falsework removal. Strength development properties may be necessary in order to remove formwork and falsework or achieve early initiation of prestressing tendon tensioning for prestressed concrete.

(2) If the required construction performance of concrete cannot be achieved, the construction method must be reconsidered. For example, if the required workability or pumpability cannot be achieved by carrying out a long-distance pumping plan, it is necessary to revert to the concreting method determination stage and make necessary changes such as changing the concrete hauling method within the construction site.

2.5 Materials

Only materials of proven quality shall be used as concrete materials.

[Commentary] Using appropriate materials is very important for producing concrete with the required performance. Whether particular materials are suitable for use can be judged from test results or past performance data. In general, materials conforming to JIS, JSCE standards or other quality standards may be deemed to be materials of proven quality. It is possible, however, to meet the performance requirements for concrete even if materials not conforming to quality standards are used. If such materials are used, it must be ascertained in advance that the performance requirements for the concrete structure can be met.

Concrete materials of any quality may be used as long as the concrete made by using those materials meets the performance requirements. In the case of poorly field-tested materials, however, it is necessary to carefully evaluate their quality and the performance of the concrete, including long-term stability of quality and the influence on the durability of the structure, made of those materials.

2.6 Concrete Mix Design

Concrete mix proportions shall be determined, taking into consideration of such factors as constraints related concrete plants, availability of materials and economy including transportation cost, so that the required performance of concrete can be

achieved.

[Commentary] Mix design refers to a series of tasks performed to specify materials and their mix proportions so that performance requirements for concrete can be met. Usually, in the mix design process, materials and their mix proportions are assumed and trial mixing is carried out, and this cycle is repeated until it is confirmed that the concrete mixes made in this way meet all performance requirements (characteristic values). Because there are many combinations of materials and their mix proportions that meet performance requirements, what is to be done in the mix design stage is to select appropriate ones from those combinations. Performance attributes required of concrete here include the characteristic values for concrete indicated by the design and construction performance of concrete, material conditions and mix requirements shown for reference only.

2.7 Verification of Concrete Performance

(1) It shall be verified that the concrete made with the selected materials and mix proportions meets the characteristic value criteria indicated by the design.

(2) If the design indicates reference-only values related to construction besides characteristic values, it shall be verified that the selected materials and mix proportions meet the reference-only values or meet the concrete performance requirements on which the reference-only values are based.

[Commentary] Commonly used methods of concrete performance verification as of this writing include experiment-based methods and the method of making inference from past performance data.

Characteristic values for concrete to be verified include strength, carbonation rate coefficient, diffusion coefficient of chloride ions, freeze–thaw resistance, chemical attack resistance, alkali–silica reaction resistance, water permeability coefficient, fire resistance and drying shrinkage strain. Values indicated for reference only, such as material conditions and mix requirements and the workability, pumpability, setting properties, strength development properties, etc., specified in the construction plan, also need to be verified. The following criteria may be used for verification:

$$\gamma_p \frac{A_p}{A_k} \leq 1.0, \quad or \quad \gamma_p \frac{A_k}{A_p} \leq 1.0 \tag{C2.7.1}$$

where A_k: characteristic value for a performance attribute of concrete, A_p: predicted value for a performance attribute of concrete, γ_p: factor of safety for accuracy of A_p

If even a single characteristic value among the specified values is not met, the selected materials and mix proportions are altered and verification is performed again. If rational mix proportions for concrete cannot be determined by this method, all conditions including the structural conditions, reinforcement material conditions, concrete manufacturing conditions, placement conditions and maintenance conditions shall be reconsidered.

2.8 Confirmation and Alteration of Construction Plan

(1) It must be confirmed by an appropriate method that the concrete construction plan meets the requirements for the construction work and that the performance requirements for the structure are met.

(2) Any change in the construction plan should be made so as to minimize its influence. As a general rule, changes in the construction plan should be limited to concrete mix proportions and construction methods.

(3) If the construction plan differs from the reference values indicated at the design stage, cracking checks at the construction stage shall be made again under conditions reflecting the construction plan.

[Commentary] (1) The construction plan must meet the requirements for the construction work and must be such that the concrete structure built in accordance with the plan meet the performance requirements. The Contractor submits a construction plan in writing to the Owner, and the Owner checks whether the structure shown in the design drawings and specifications can really be constructed, and approves the construction plan. To be more specific, it is necessary to check each task in accordance with the items and descriptions shown in Table C2.2.1 to determine whether the standard construction methods specified in the "Construction: Construction Standards of this Specification" are used, whether the plan has an adequate margin of safety against variable factors expected in connection with each task, whether the plan incorporates troubleshooting methods, etc. If new technologies or new construction methods are to be used, it is necessary to evaluate their feasibility and reliability by referring to reliable documents or conducting full-scale field trials.

(2) If the construction plan is to be changed, resultant changes in other conditions should be minimized. A realistic way is to stay within the framework of reconsidering the construction plan instead of reverting to the design of the concrete structure. Usually, making changes in the concrete mix proportions or construction methods specified in the construction plan suffices.

(3) At the design stage, concrete and its placement methods are assumed, checks are made on initial cracking, and characteristic values for concrete are determined. If these conditions in the construction plan differ from the conditions assumed at the design stage, verification on cracking shall be made again, on an as-needed basis, at the construction stage.

CHAPTER 3 CONSTRUCTION

3.1 General

(1) The construction of a concrete structure shall be carried out in accordance with the construction plan.

(2) The construction of a concrete structure shall be carried out under the supervision of a domain engineer with sufficient knowledge and experience in the construction of concrete structures stationed at the construction site.

(3) If the construction plan cannot be followed at the construction stage, appropriate measures shall be taken so that the performance requirements determined at the design stage can be met.

[Commentary] (1) The basic rule for construction is to carry out construction work economically and efficiently by using an appropriate construction method on condition that construction safety is maintained. Because concreting work involves a variety of tasks such as tasks related to formwork, reinforcing steel and the placing of concrete, it is desirable that concreting work be thoroughly coordinated with other types of work so that the construction work can be carried out efficiently.

To construct a concrete structure, the constructor prepares a construction plan that details necessary construction processes based on the design drawings and specifications. The construction of the concrete structure, therefore, must be carried out in accordance with the construction plan.

(2) In general, the quality of construction is heavily dependent on human factors such as the experiences and qualities of constructors. It is very important, therefore, to station domain engineers with sufficient knowledge and experience in the field of the construction of concrete structures at the construction site so that the construction work carried out under the direction of those domain engineers.

(3) In a construction project, incidents not expected at the planning stage may occur at the construction stage. It is not always possible, therefore, to carry out construction in accordance with the construction plan. If it is difficult to follow the construction plan in a real construction project, appropriate measures must be taken, following the domain engineers' instructions, so that the required performance can be achieved.

CHAPTER 4 QUALITY CONTROL

4.1 General

(1) The Contractor shall perform quality control at each stage of construction in order to create a concrete structure that meets the performance requirements.

(2) Quality control shall be performed, as a voluntary activity of the Contractor, by using a method that can be expected to be effective.

(3) If quality control has revealed a possible quality problem, appropriate measures shall be taken, in accordance with a domain engineer's instructions, so that the performance requirements specified at the design stage can be met.

[Commentary] (1) In order to create a concrete structure that meets the performance requirements, the Contractor must carry out construction in accordance with the construction plan and perform quality control by appropriate methods for appropriate items such as concrete materials, reinforcing materials, equipment and construction methods to ensure that the required quality is achieved at each stage of construction.

It is advisable, however, to perform quality control only for necessary items only as often as necessary, instead of conducting many types of tests and collecting a large amount of data. One way to check on quality on the basis of test results, besides actually conducting tests, is to examine manufacturers' test reports as in the case of JIS-conforming products.

Usually, wide variations in the quality of concrete placed to build a structure not only increases the possibility of occurrence of problems at the construction stage but also necessitates the use of a large factor of safety at the mix design stage so as to achieve the required strength. That makes the construction process uneconomical and, in many cases, causes decreases in durability, cracking resistance and appearance. Always producing concrete of stable quality, therefore, is essential, and it is important to control the quality of materials and the concrete manufacturing process carefully.

(2) The Contractor must prepare a reliable, efficient and economical quality control plan in accordance with the construction plan and carry out the construction work in accordance with the quality control plan. Quality control results may be used as substitutes for the results of inspection conducted by the owner at each stage of construction. It is desirable, therefore, that quality control be performed, wherever possible, by a technically or otherwise proven method.

(3) If quality control has revealed a sign of considerable variation in quality, it is necessary to conduct an investigation to identify the cause of such variation and take corrective measures so that variations can be kept within the predetermined range. In the event of an abnormality or a possible quality problem, appropriate measures must be taken in a timely manner in accordance with a domain engineer's instructions.

CHAPTER 5 INSPECTION

5.1 General

(1) The Owner shall conduct inspection at each stage of construction and upon completion of a structure on the Owner's own responsibility.

(2) The Owner of a structure shall draw up an inspection plan in accordance with the design drawings and specifications, taking into consideration the degree of importance, intended use and purpose of the structure.

(3) Inspection shall be conducted in accordance with the inspection plan by a method of proven reliability.

(4) If inspection is failed, corrective measures to be taken shall be considered. If corrective measures cannot be taken, the stage of construction that failed to pass the inspection shall be redone.

(5) The inspection plan and inspection results shall be maintained during the service period of the structure.

[Commentary] (1) In order to construct a concrete structure as indicated in the design drawings and specifications, inspection is conducted at each stage of construction to check whether the construction work being carried out is adequate. The required performance of the concrete structure can be ensured by checking on the performance requirements such as safety at the design stage and conducting inspection at the construction stage. Inspection, therefore, must be conducted on the responsibility of the Owner of the structure.

The performance of a newly completed concrete structure should ideally be inspected directly. The items related to a concrete structure that can be inspected, however, are limited to only a fraction (e.g., concrete surface condition, the locations, shapes, dimensions, etc., of structural members) of all inspection items. A realistic approach, therefore, is to conduct necessary inspections at each stage of construction to make sure, through a series of inspections, that the concrete structure is being constructed as indicated in the design drawings and specifications.

(2) The Owner of the structure needs to draw up a reliable, efficient and economical inspection plan with reference to the design drawings and specifications in view of the degree of importance, intended use and purpose of the structure. In general, inspection is planned taking into consideration such factors as the type and scale of construction work, staffing, timing of construction, construction period, reliability of the materials and construction methods used, skill level of construction workers, the degree of influence on the work schedules at subsequent stages, and efficiency. The inspection plan must describe things to be done, inspection criteria, etc.

It is not practical that the Owner inspects all items because inspection items are diverse at each construction stages. In this way the Contractor inspects quality inspection items for materials except for inspections related to construction works and the structure on their own responsibility and the Owner ensures the inspection results. To make this practice worked the Owner should discuss inspection methods with the Contractor before actual construction begins. Results of the discussion should be recorded with written documents where the Owner records on an inspection planning document while the Contractor records on a construction planning document.

(3) Because the Owner of the structure has to judge the acceptability of the concrete structure through inspection, the reliability of the inspection method needs to be ensured by supportive technical information or other evidence. Acceptability criteria are one of the important items agreed upon in the contract, so they must be objective. Common practice is to use methods specified in the Japanese Industrial Standards (JIS) or the JSCE standards. The Construction: Inspection Standards of this Specification indicates standard inspection methods and criteria for evaluating the acceptability of inspection results based on those standards and specifications.

The Owner specifies, in advance, inspection-related requirements such as inspection items, inspection methods and acceptability criteria in the contract documents, etc., and, as a general rule, specifies all requirements in the contract documents. Since, however, inspections that need to be conducted at different stages of construction involve a wide range of inspection items, it is desirable that studies be conducted in advance on such details as inspection items, inspection methods, timing, frequency, staffing, cost and required time and agreement be reached with the Contractor concerning particularly detailed matters so that inspections can be conducted in a reliable, efficient and economical way. If a newly developed construction method or material is used, conventional inspection methods may not be adequate. It is therefore important for the Owner to draw up an inspection in consultation with the contractor.

(4) If an inspection has been failed at a stage of construction, it is necessary either to redo the stage of construction or take corrective measures. In this case, it must be confirmed that the required performance of the concrete structure can be achieved by taking the corrective measures. The Contractor, therefore, needs to carefully determine construction procedures and details in advance in connection with construction tasks that are difficult to redo.

If an inspection has been failed and neither taking corrective measures nor redoing construction is possible, it is necessary to evaluate the influence of the problem on the required performance of the concrete structure and take appropriate measures such as demolishing and reconstructing the structure or altering the maintenance plan and using the existing structure.

(5) Inspection records are documents that certify that the concrete structure has been constructed in accordance with the construction plan and as indicated in the design drawings and specifications. Inspection records, therefore, must be maintained during the service period of the concrete structure. If an inspection is failed at one or more stages of construction, it is important to record in detail the facts including the corrective measures taken.

5.2 Inspection Plan

(1) The inspection plan shall specify inspection items, inspection methods and requirements such as acceptance criteria, timing and frequency of inspection and staffing requirements needed to ascertain that the structure concerned is being constructed as indicated in the design drawings and specifications.

(2) In the event of any change in the design drawings or specifications, the inspection plan shall be reviewed.

[Commentary] (1) Inspection items, inspection methods and requirements such as acceptance criteria, timing and frequency of inspection and staffing requirements needed to ascertain that the structure concerned is being constructed as indicated in the design drawings and specifications must be determined and specified in the inspection plan.

Standard inspections usually consist of the following:

(i) Inspection of the quality of concrete materials

(ii) Inspection of the performance of concrete plant

(iii) Inspection of the quality of concrete

(iv) Inspection of the quality of reinforcing materials

(v) Inspection of construction

(vi) Inspection of structure

A series of inspections conducted in connection with the construction of a concrete structure includes the inspection of materials (concrete and reinforcing bars) conducted to ensure that the materials used are appropriate, the inspection of construction conducted mainly to ensure that the structure and its members meet the dimensional requirements, specified reinforcing bars have been placed at specified locations, concrete has been uniformly placed and compacted, and curing has been carried out as required, and the inspection of the concrete structure. After these inspections are passed, it may be judged that the concrete structure has been constructed as indicated in the design drawings and specifications.

It is desirable that inspections be conducted only for essential items in view of construction efficiency and economy. Inspections that are deemed necessary in order to check whether the concrete structure indicated in the design drawings and specifications can be constructed must be conducted after their reliability is ascertained. For example, if it is thought likely that the adequacy of construction when newly developed materials or construction methods are used cannot be judged by means of the inspections (i) through (vi) listed above, inspection methods suitable for such materials or construction methods must be adopted. In such cases, it is very important to confirm inspection details through in-depth discussion between the Owner and the Contractor.

(2) Because the inspection plan is drawn up on the basis of the design drawings and specifications, if the inspection plan has been changed, it must, of course, be reviewed.

5.3 Conduct of Inspection

(1) Inspection shall be conducted in accordance with the inspection plan.

(2) The person responsible for inspection shall judge the acceptability of inspection results according to predetermined evaluation criteria.

[Commentary] (1) Basically, the inspection of a structure must be conducted by the Owner of the structure on the responsibility of the Owner in accordance with the inspection plan. Inspection tasks need to be performed under the direction of a person who has experience in working in the construction work concerned or who has technical experience.

(2) If an inspection at a stage of construction has been failed, either the construction work concerned is redone or corrective measures are taken after discussion between the Owner and the Contractor. Inspection methods used after corrective measures are taken must also be technically-proven, reliable methods. The person responsible for inspection must be the Owner or the Owner's agent and needs to be a senior professional engineer certified by the Japan Society of Civil Engineers, consulting engineer (concrete specialist), chief concrete engineer or an equally competent person.

5.4 Maintenance of Inspection Records

(1) Inspection records shall be maintained during the service period of the concrete structure.

(2) Inspection records covering necessary items shall be maintained in an appropriate format with reference to the maintenance guidelines.

[Commentary] (1) Inspection records are important records confirming the required performance of a concrete structure. Like the design drawings and specifications and the inspection plan, therefore, inspection records must be maintained. If an inspection has been failed and corrective measures have been taken, the records regarding their details must also be maintained.

(2) Because inspection records are important as the initial values for the maintenance of a newly completed concrete structure, they must be maintained as a source of reference information so that the safety, serviceability, etc., of the concrete structure can be ascertained.

CHAPTER 6 CONSTRUCTION RECORDS

6.1 General

The Owner of a concrete structure shall maintain the construction records during the service period of the concrete structure.

[Commentary] The term "construction records" here refers to the design drawings and specifications (including changes), the construction plan (including changes), the inspection plan (including changes) and the inspection records. It is also good practice to maintain records concerning construction management depending on the degree of importance and necessity.

These documents contain all information concerning the newly constructed concrete structure that can be used as basic data for ensuring the required performance of the structure during its service period. It is desirable that these documents indicate the affiliations, names, etc., of the persons who performed the relevant tasks.

Construction Standards

CHAPTER 1 GENERAL

1.1 General

(1) The purpose of this Specification "Materials and Construction: Construction Standards" of the Standard Specifications for Concrete Structures is to make it possible, in concreting work for new construction of an ordinary civil engineering structure, to construct a concrete structure of a certain level of quality by carrying out the items indicated herein without paying painstaking attention.

(2) Prior to the commencement of concreting work, it is necessary to fully understand the content of the design drawings and specifications and prepare an appropriate construction plan.

(3) If details such as the materials used, construction conditions, construction environment or construction methods deviate from the conditions indicated in the "Construction: Construction Standards" of this Specification, a construction plan consistent with the "Construction: General Requirements" of this Specification shall be prepared and construction shall be carried out accordingly. For the items indicated in the "Construction: Special Concretes" of this Specification should be referred to.

[Commentary] (1) Concreting work varies very widely because of diverse elements and conditions such as the type of structure, materials used, construction conditions, construction environment and equipment used for construction. It is also true, however, that most of concrete construction projects involve very few special items. Numerous concrete construction projects of this type have already been successfully carried out. In many cases, therefore, it is rational to adopt a construction plan that can be drawn up by making minor modifications to an ordinary construction plan to suit the site-specific conditions. The "Construction: Construction Standards" of this Specification is intended for application to such ordinary concreting work as a standard guideline.

The "Construction: General Requirements", "Construction: Construction Standards" and "Construction: Special Concretes" of this Specification should be used as follows:

The "Construction: Construction Standards" (i.e., this document) indicates typical items to be carried out in connection with the types of structure, materials used, construction equipment and construction conditions within the range applicable to a typical civil engineering construction project. The 2002 edition of the Construction section of this Specification had an independent chapter on inspection. The other chapters dealt with items to be carried out by the Contractor, while the chapter on inspection dealt extensively with items to be carried out by the Owner of the structure. The Construction section of the current Specification, therefore, has separate volumes "Construction: Construction Standards" and "Construction: Inspection Standards" for "construction" and "inspection" to clarify the responsibilities of each party and make this Specification easier to use. Inspection-related items to be carried out by the constructor, such as items related to receiving of materials, are described in "Construction: Construction Standards". "Construction: Construction Standards" and "Construction: Inspection Standards" are designed for use as a kind of "standard specifications" for many construction projects.

Typical construction work to which the "Construction: Construction Standards" of this Specification is applicable involves, for example, specified strengths of concrete of up to about 60

N/mm^2, minimum slump at the time of placement of 16 cm or less, the use of agitator trucks for off-site transportation, the use of pumps for on-site transportation over equivalent horizontal pumping distances of about 150 m or less, and the use of internal vibrators for compaction (see Table C4.4.1). Among the items related to materials, construction conditions, construction environment beyond these ranges, those that have been field-tested to a certain extent are described in the “Construction: Special Concretes” of this Specification. It is assumed that in cases where items related to materials, construction conditions and construction environment beyond these ranges are involved, in cases where special attention is required or in cases where special expertise is to be used effectively, a construction plan is drawn up on a case-by-case basis in accordance with the “Construction: General Requirements” of this Specification, verification is made, and then construction is carried out.

(2) In all civil engineering construction projects, it is important to draw up an appropriate construction plan according to the site-specific conditions prior to the commencement of construction. In concreting work, it is necessary to fully understand the content of the design drawings and specifications and draw up an appropriate construction plan prior to the commencement of construction, taking into consideration such factors as the functionality, strength and durability required of the structure and important things to keep in mind in carrying out construction work. As mentioned in the explanation about Commentary (1), however, concreting work in most cases consists of a combination of more or less standard tasks that include very few special items. Furthermore, in cases where the concrete structure to be constructed has been carefully designed so as to avoid special construction conditions such as excessively dense reinforcement patterns, a sufficient level of quality can usually be achieved by performing standard construction management. In such cases, a rational approach is to use the items indicated in the “Construction: Construction Standards” of this Specification by making minor changes to those items. By following the procedures described herein, it is not necessary at many construction sites to draw up a special construction plan.

Many troubles encountered in connection with the construction of concrete structures result from inadequate attention paid to construction at the design stage. The designer and the constructor, therefore, need to know the assumptions made by the other party within their respective scopes of work. In the case of the construction of an ordinary concrete structure, design and construction are usually performed separately, and information is seldom exchanged directly between the designer and the constructor. In an ordinary project, therefore, the designer needs to perform design tasks with a full understanding of the scope of the “Construction: Construction Standards” of this Specification. If design tasks are to be performed on the basis of assumptions that deviate from that scope, it is necessary to clearly indicate it in the design drawings and specifications in order to prevent problems at the construction stage.

(3) When using special materials, production or construction methods that are not covered in the ″Construction: Special Concretes″ of this Specification, separate specifications in which the provisions of this specification are appropriately reflected shall be prepared. For reference, the following list provides guidelines and manuals dealing with special materials and construction methods, published by the JSCE.

“Recommended Practice for Concrete Made by Continuous mixer”, 1986 (In Japanese)

“Recommendations for Design and Construction of Reinforced Concrete Structure Using D57 and D64 Large-diameter Threaded Reinforcing Bars”, 1992

“Recommended Practice for Concrete Containing Air-entraining and High-range Water-reducing

Agents – Recommendations for construction of high fluidity concrete", 1993

"Guideline for Construction Using Blast-furnace Slag Aggregate", 1993

"Recommendations for Design and Construction of Concrete Structures Using Silica Fume in Concrete -Draft-", 1995

"Recommendation for Construction of Concrete Using Ferro-nickel Slag Fine Aggregate", 1998 (In Japanese)

"Recommendation for Construction of Concrete Using Copper Slag Fine Aggregate", 1998 (In Japanese)

"Recommendation for Construction of Concrete containing Fly Ash", 1999 (In Japanese)

"Recommendation for Concrete Pumping", 2000 (In Japanese)

"Recommendations for Design and Construction of Concrete Structures Using Electric Arc Furnace Oxidizing Slag Aggregate", 2003

"Recommendations for Design and Construction of Reinforced Concrete Structures Using Epoxy-Coated Reinforcing Steel Bars", 2003

"Recommendations for Mix Design and Construction of Concrete Based on Placeability", 2007

"Recommendations for Design, Fabrication and Evaluation of Anchorages and Joints in Reinforcing Bars", 2007

"Recommendations for Concrete Repair and Surface Protection of Concrete Structures", 2005

1.2 Definitions

The terms used in Standard Specifications for Concrete Structures "Construction: Construction Standards" are defined as follows:

Concrete - A composite material, or its hardened form, consisting of materials such as cement, water, fine aggregate, coarse aggregate, and admixtures added if necessary, to be blended together by mixing or other methods.

Mortar - A composite material, or its hardened form, consisting of materials such as cement, water, fine aggregate, and admixtures added if necessary, to be blended together by mixing or other methods.

Cement paste - A composite material, or its hardened form, consisting of materials such as cement, water, and admixtures added if necessary, to be blended together by mixing or other methods.

Plain concrete - Concrete without reinforcing materials, including concrete containing only secondary reinforcement as a precaution against cracking due to shrinkage or other reasons.

Reinforced concrete - Concrete strengthened by reinforcing bars, designed on the assumption that the two materials act together in resisting external forces.

Prestressed concrete - A type of reinforced concrete prestressed by means of prestressing

steel, etc.

Aggregate - Sand, gravel, sea sand, crushed sand, crushed stone, blast-furnace slag fine aggregate, blast-furnace slag coarse aggregate and other similar materials which are mixed with cement and water to produce mortar or concrete.

Sieve – A wire sieve specified in JIS Z 8801-1 used for tests of concrete and concrete materials

Fine aggregate - Aggregate entirely passing the 10 mm sieve with more than 85 % of its weight passing the 5mm sieve.

Coarse aggregate - Aggregate with more than 85 % of its weight retained on the 5 mm sieve.

Sand - Fine aggregate formed from rocks through natural processes.

Gravel - Coarse aggregate formed from rocks through natural processes.

Recycled aggregate – Aggregate for use as a concrete material manufactured by performing crushing and other processing of concrete fragments recovered from demolished structures.

Grading of aggregate - The size distribution of aggregate particles.

Fineness modulus of aggregate (F. M.) - A factor obtained by adding the total percentages by weight of an aggregate sample retained on each of a specified set of sieves, i.e., 80, 40, 20, 10, 5, 2.5, 1.2, 0.6, 0.3, 0.15mm, and dividing the sum by 100.

Solid volume percentage of bulk aggregate - The ratio of the solid volume of aggregate filled in a container to the volume of that container, expressed as a percentage.

Maximum size of coarse aggregate - The size of coarse aggregate specified by the nominal size of the smallest of all the sieves through which at least 90% of the aggregate by weight passes.

Surface moisture of aggregate - Free water retained on the surface of aggregate particles. It is accounted for as a portion of mixing water and obtained by subtracting the amount of water absorbed inside aggregate particles from the total amount of water retained by the aggregate.

Surface-dry state of aggregate - The state of aggregate particles in which there is no water on the exposed surfaces and the permeable voids inside are filled with water. (Saturated surface-dry state for ordinary aggregate)

Oven-dry State of aggregate - The state of aggregate particles in which all of water contained in their permeable voids is removed by drying at the temperature between 100 and 110 degree C. until their mass becomes constant.

Density of surface-dry aggregate - The density obtained by dividing the weight of aggregate in saturated surface-dry state into its absolute volume.

Density of oven-dry state aggregate - The density obtained by dividing the weight of aggregate in oven-dry state into its absolute volume.

Total moisture content of aggregate - The percentage of the total weight of water inside and on the surfaces of aggregate to the weight of aggregate in oven-dry state.

Absorption capacity of aggregate - The percentage of the total weight of water in the surface-dry state of aggregate to the weight of aggregate in oven-dry state.

Effective absorption of aggregate - The percentage of the weight of the water that aggregate absorbs to reach saturated surface-dry state to the weight of aggregate in oven-dry state.

Surface moisture content of aggregate - The percentage of surface moisture of aggregate to the weight of aggregate in saturated surface-dry state.

Powdery material – A collective term for cement or other solid material used as a concrete material that is as fine as or finer than cement.

Binder - Generic name for materials which react with water or/and participate in the strength development of concrete such as cement, granulated blast-furnace slag fine powder, fly ash, etc.

Admixture - Materials other than cement, water and aggregates, added to concrete before placing to impart special properties.

Mineral admixture – Kinds of admixture which are used in comparatively large quantities and the volumes of which are taken into account in calculating the mix proportion of concrete.

Chemical admixture - Kinds of admixture which are used in small quantities and the volumes of which are neglected in calculating the mix proportion of concrete.

Entrained air - Tiny isolated air bubbles introduced in concrete by using air entraining agents or chemical admixtures.

Entrapped air - Air bubbles formed in concrete naturally without the use of chemical admixtures.

Air-entrained concrete - Concrete that contains entrained air.

Steel - A general term for structural carbon steel consisting of iron as its principal ingredient. This includes steel bars for reinforced concrete, prestressing tendon, hot rolled section steel, steel plates.

Reinforcing bar - Steel bars embedded in concrete for reinforcing purpose.

Plain bars - Circular steel bars with uniform round cross section.

Deformed reinforcing bar, deformed rebar - Steel bars that have surface projections such as ribs to improve the bond with concrete.

Prestress - Stress introduced in concrete before application of service loads to reduce tensile stresses induced in concrete by loads.

Prestressing Steel - High strength steel used for prestress concrete.

Spacer - Devices used to provide a given cover to the reinforcing bar, tendons or sheaths etc. and maintain the correct space between them. .

Creep - Time-dependent phenomenon in which the deformation (except elastic strain and drying shrinkage strain) increases under constant sustained load.

Clearance - Clear distance between adjacent reinforcing bars.

Cover - Concrete thickness expressed by the least distance between the outer surface of

concrete and the surface of steel or sheaths.

Mix proportion - Proportion or quantity of constituent materials to produce a desired quantity of concrete or mortar.

Trial mixing – Mixing carried out to determine whether a specified concrete can be obtained from a designed mix.

Characteristic compressive strength of concrete - The strength on which structural design is based. Generally it is the compressive strength at 28days. Notation : f'_{ck}

Mix proportioning strength (target strength) - Compressive strength used to select the mix proportion of concrete. Generally it is a compressive strength at 28 days. Notation :f'_{cr}

Allowance factor - A factor by which the specified average strength is multiplied to take into account the variations of material quality in determining target strength.

Water-cement ratio - The ratio by weight of water to cement in cement paste in fresh concrete or fresh mortar. It is generally expressed in percentage.

Unit content - Quantity of material used for producing one cubic meter of concrete or mortar (i.e. unit cement content, unit water content, unit weight of coarse aggregate, unit weight of fine aggregate, unit weight of admixture mineral and unit weight of admixture).

Powdery material content – A total quantity of powdery material used to make one cubic meter of concrete or mortar.

Cementitious material content – The quantity of cementitious material used to make one cubic meter of concrete or mortar.

Sand-aggregate ratio - The ratio of the absolute volume of fine aggregate to that of total aggregate, expressed in percentage. Notation : s/a

Unit volume of dry-rodded coarse aggregate - The bulk volume of coarse aggregate to produce one cubic meter of concrete. It is obtained by dividing the unit weight of coarse aggregate into its weight per unit bulk volume (bulk density).

Fresh concrete, Fresh mortar, Fresh paste - Concrete, mortar or paste which has not hardened yet, respectively.

Slump – An indicator of the degree of softness of fresh concrete measured as the distance by which the concrete surface falls after the slump cone is lifted.

Bleeding - The phenomenon in which a portion of mixed water emerges from fresh concrete, mortar or paste due to sedimentation or segregation of solid materials.

Laitance - A relatively weak layer formed on the surface of concrete, mortar or cement paste by tiny particles brought to the surface during bleeding.

Consistency - The property of fresh concrete, fresh mortar, or fresh paste, which is mainly dependent of water content, shown by the degree of resistance to its movement or deformation.

Workability - The property indicating the level for a fresh concrete to be easily transported, cast, compacted and finished without occurrence of material segregation.

Filling ability – Among workability attributes, the ability of concrete to densely fill the cover regions and corners of concrete forms without undergoing segregation.

Pumpability – The degree of ease with which fresh concrete or fresh mortar can be transported by a concrete pump.

Placing height – The height of concrete placed in one lift.

Free fall height – The height from which concrete falls in an exposed condition from a chute or pipe end when concrete is placed.

Compaction height – The maximum height from the bottom of the concrete form or the surface of previously placed concrete to the surface on which construction workers stand while performing the compaction of concrete.

Durability - The resistance to degradation with time in performance of concrete structure.

Alkali-aggregate reaction - The phenomenon in which alkali-reactive aggregates react with cement or other alkali components in concrete over a long time, causing expansion cracks or pop-out.

Freeze-thaw resistance - The resistance against repeated freezing and thawing action.

Frost damage - The damage of concrete due to freezing action in the initial period of setting and hardening.

Chemical attack – Dissolution or deterioration due to the generation of expansive compounds of concrete caused by erosive substances such as acids and sulfates. Chemical attack may cause a loss of concrete cross section or volumetric expansion and may even cause cracking, spalling of cover concrete and steel corrosion.

Water-tightness - The property of having low water and moisture permeation.

Autogeneous shrinkage - The phenomenon in which concrete, mortar and cement paste shrink due to reduction in volume during cement hydration.

Crack resistance - The resistance of concrete to crack initiation

Placement interval – The time from the completion of the placement of concrete in the underlying layer to the initiation of the placement of concrete in the overlying layer.

Cold joint – A discontinuity between a previously placed layer of concrete and the next layer of concrete.

Batch mixer - A type of mixer in which the materials for concrete, mortar or paste are mixed for each batch.

Continuous mixer - Mixing equipment which contains a set of devices for batching, supplying, and mixing materials for concrete, and therefore can produce fresh concrete continuously.

Ready-mixed concrete - Fresh concrete that can be purchased at anytime from plants which possess facilities for manufacturing concrete with desired properties.

Sheathing - Wooden, metal or plastic panel-type formwork directly adjacent to concrete.

Equivalent horizontal conveying distance - Total distance of horizontal concrete pipe and the equivalent horizontal distance converted from the length of vertical pipe, bending pipe, taper pipe, flexible hose etc.

Quality control - Effective and systematic technical activities for ensuring the quality of concrete in each stage of construction so that functional requirements of concrete

structures are satisfied.

Inspection - The work of judging whether the quality of concrete meets required criteria or not.

Control chart - Chart used to determine whether the construction is proceeding as scheduled, or to maintain a steady construction process

Mass concrete - Concrete member or structure whose size is relatively large and the consideration of temperature rise due to heat of hydration is of great concern during design and construction.

Plasticized concrete - An already-mixed concrete is called plasticized concrete if superplasticizer is added into it and a thorough mixing is carried out afterward to increase the flowability.

Standard curing - A method of curing in water or in a moist condition under nearly 100% of humidity while temperature is kept at 20±3°C.

Moist curing - A method of curing where concrete is kept in a moist condition for a certain period of time after placing.

Temperature controlled curing - A method of curing where the temperature of concrete is controlled for a certain period of time after placing. .

Insulated curing - A method of curing where the necessary temperature is maintained by utilizing the heat of hydration of cement and preventing escape of heat to the utmost, by covering the surface of concrete with highly insulating materials

Heat curing - A curing method in which concrete is heated by any source of heat during a period of curing.

Accelerated curing - A curing method used to accelerate the hardening process and strength development of concrete.

Centrifugal compaction - Compaction of concrete by centrifugal force using a formwork revolving at an extremely high speed.

Casting - Production of factory products by placing concrete into a form and applying compaction to the placed concrete.

Instant demolding - Removal of a part or all of the formworks for concrete with an extremely stiff consistency immediately after placing and compacting using strong vibration or pressure.

[Commentary] Reinforced concrete: Reinforced concrete, in a wide sense, also includes prestressed concrete, steel framed reinforced concrete in which hot rolled section steel and shaped steel are used as reinforcing materials. However, in this Specification, the term refers to concrete containing reinforcing steel bars specified in JIS G 3112 or similar steel bars.

Sieves: “Standard Sieves for Concrete” of JSCE-C 501 is a series of the net-like sieves for the sieve analysis of aggregate chosen from the sieves specified in JIS Z 8801 “Standard Sieve”. In the JSCE Standard, only their nominal sizes are given for convenience, although their actual mesh sizes, diameters of wires, openings, and so forth are the same as those specified in JIS Z 8801.

Fine aggregate and coarse aggregate: The distinction between fine aggregate and coarse aggregate is quite freely decided, and has no theoretical grounds. These definitions were made

Table C1.2.1 Example of the calculation of fineness modulus of aggregate

	Fine Aggregate	Coarse Aggregate
Quantity of sample retained on 80 mm	0%	0%
40 mm	0%	0%
20 mm	0%	28%
10 mm	0%	78%
5 mm	1%	97%
2.5 mm	16%	100%
1.2 mm	38%	100%
600 μm	61%	100%
300 μm	82%	100%
150 μm	97%	100%

$$\text{Fineness modulus of fine aggregate} = \frac{0+0+0+0+1+16+38+61+82+97}{100} = 2.95$$

$$\text{Fineness modulus of coarse aggregate} = \frac{28+78+97+100+100+100+100+100}{100} = 7.03$$

considering the customary practice. As the aggregate prepared on the construction site is not screened thoroughly, aggregate particles passing the 5 mm sieve are frequently included in coarse aggregate and particles retained on the 5 mm sieve in fine aggregate. Therefore, a 15 % allowance in each case has been given.

Sand: In a broad sense, sand is used as a synonym of fine aggregate, but it treated as generic name for natural fine aggregates in this specification.

Grading of aggregate: This term represents the degree that small and large size aggregates are mixed moderately. It is expressed by the volume ratio of particles. However, for simplification, it is generally expressed by the cumulative weight percentage of aggregates passing each size of sieve. When aggregates with different densities are mixed together, the cumulative weight percentage is also converted to the volume percentage in order to adjust the grain size distribution.

Fineness modulus of aggregate: For example, the sum of the total percentage by weight of aggregate retained on the 10mm sieve means the sum of the weight percentages of sample retained on each of the 80, 40, 20 and 10mm sieves. Table C1.8.1 shows an example of the calculation of fineness modulus from the result of the sieve analysis of coarse aggregate. Fineness modulus is a practical index to show the approximate grading of aggregate, and it is conveniently used to judge the state of change in the grading of aggregate and to estimate the unit water content in the mix design of concrete. However, attention shall be paid that the grading of aggregate which has the same fineness modulus is unlimited.

Maximum size of coarse aggregate: Attention shall be paid that the maximum size of coarse aggregate does not represent the maximum size of the largest particle. It is defined so based on the fact that coarse aggregates actually compose of thin and/or slender particles, the maximum size of the largest particle therefore does not represent the characteristics of all aggregate particles.

Surface moisture of aggregate: Water contained in aggregate (moisture of aggregate) is distinguished between the surface moisture and the absorbed water inside aggregate particles. The surface moisture of aggregate shall be counted as a part of mixing water of concrete.

Densities of surface-dry aggregate and oven-dry aggregate: The term “density” mentioned here is not the actual one obtained using powdered aggregate, but the apparent one. In determining the mix proportions of concrete, density of aggregates in saturated surface-dry state is usually needed, because the saturated surface-dry state is defined as the standard one. However, in case of light weight aggregate, it is more appropriate to regard the apparent density in oven-dry state as the standard one, so the density in oven-dry state is used.

Powdery material: Powdery materials (cementitious materials) include not only materials that contribute to the strength development of concrete by reacting with water, such as cement, blast furnace slag and fly ash, but also nonreactive mineral powder such as limestone powder.

Binder: It, in a broad sense, means materials which bind aggregates together. For example, in case of asphalt concrete, it indicates asphalt. Cement paste is also treated as binder in cement concrete, but in the narrow sense, it indicates powder which is responsible for cement hydration. In this specification, binder is a generic name of powders which binds other materials such as cement, granulated blast-furnace slag fine powder, fly ash, silica fume, expansive admixture etc.

Admixture: Several kinds of admixtures are available on the market. Their types, properties and purposes of use differ widely. In this Specification, admixtures are classified into mineral admixtures and chemical admixtures according to their amount to be used in concrete.

Mineral admixture: Fly ash, ground granulated blast-furnace slag and expansive admixtures are typical mineral admixtures.

Chemical admixture: Air-entraining agent, water-reducing agent, air-entraining and water-reducing agent, superplasticizer, high-range water reducing agent, retarder, accelerator, corrosion inhibitor for reinforcing steel, gas generating agent, waterproofing agent are the examples of chemical admixtures.

Entrained air and entrapped air: Entrained air means microscopic and independent air bubbles distributed uniformly in concrete intentionally, by using an air-entraining agent or an air-entraining and water-reducing agent, for the purpose of improving the quality of concrete. Entrapped air means air contained in concrete naturally without using any air-entraining agent, and the sizes of the air bubble are larger than those of entrained air. Although about 1-2 % entrapped air may be usually contained in air-entrained concrete, it is difficult to distinguish between entrained air and entrapped air. Therefore, air content of air-entrained concrete means the sum of the amount of entrained air and entrapped air in the concrete.

Reinforcing bars: In a wide sense, reinforcing bars include all kinds of steel bars embedded in concrete to reinforce concrete. However, generally it means steel bars for reinforced concrete specified in JIS G 3112 and steel bars with equivalent quality as those in the JIS. This Specification makes it a rule to use only steel bars that conform to the JIS except those confirmed usable by a test. Prestressing steel used for prestressing and rolled section steel used for steel frame are not called reinforcing bars in this Specification.

Deformed bars: In a wide sense, deformed bars are any kinds of steel bars which possess surface deformations such as ribs. In this Specification, however, it is prescribed that only the bars conforming to hot- rolled deformed bars specified in JIS G 3112 or those confirmed by tests are to be used.

Mix proportion: In the definition, the term “materials” means cement, water, fine aggregate, coarse aggregate and admixture.

Characteristic compressive strength of concrete: In this Specification, the compressive strength of cylindrical specimens is used as the standard one to represent the strength and the quality of concrete. Generally, the characteristic compressive strength is determined on the basis of the compressive strength at 28 days. The compressive strength of concrete varies to a certain degree according to the quality of materials, construction condition, etc. Therefore, the mix proportioning strength shall be determined on the condition its probability of being equal to or higher than the characteristic compressive strength is higher than a pre-determined margin. In the case where the design is based on the tensile strength or flexural strength of concrete, characteristic tensile strength or characteristic flexural strength is used. In the case where the design is based on the strength of specimens tested at 91 days, or 7 days, the strength is called the characteristic strength at 91 days or 7 days, respectively. However, characteristic strength generally implies the strength at 28 days.

Mix proportioning strength: Mix proportioning strength is the desired strength in determining the mix proportion of concrete. It is obtained by multiplying the characteristic compressive strength to the overdesign factor, taking into account the variation in the quality of concrete.

Unit content: The term “unit content” is used for making short “the quantity of a specific constituent material used for producing 1 m^3 of concrete or mortar”. Unit cement content (C), unit water content (W), unit content of aggregate, unit content of fine aggregate (S), unit content of coarse aggregate (G), unit content of air entraining agent, unit content of Pozzolan, and so on are used.

Powdery material content and cementitious material content: The powdery material content is the total of the unit contents of different powdery materials including cement and other cementitious materials and admixtures (Fig. C1.2.1) and is regarded as a major indicator of segregation resistance. The cementitious material content and the cement content may be thought to as indicators used to evaluate strength development properties, heat of hydration and durability. Mixed cement may be described, strictly speaking, as a binder, but it is conventional practice to classify mixed cement as cement, and the term "cement content" may be used.

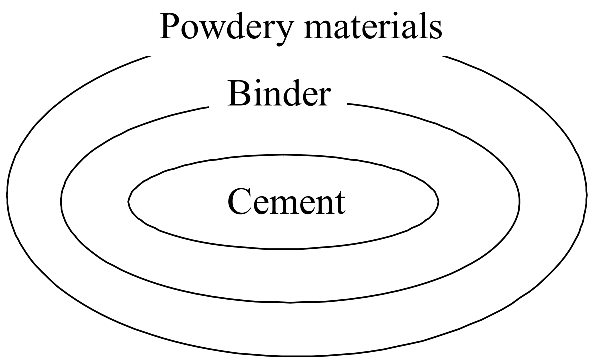

Fig.C1.2.1 Definition of powdery materials, binder and cement

Slump: Slump is measured in accordance with JIS A 1101. Although the concept of "minimum slump at the time of placement" is indicated in the Construction: Construction Standards of this Specification, unless otherwise specified herein, the term "slump" is construed to mean the average of measured slumps.

Consistency and workability: Consistency is an important factor of workability and can be measured fairly accurately by the slump test. Although many testing methods for measuring workability were studied and proposed in the past, there are no testing methods universally adaptable in field. Therefore, workability suitable for a work needs to be judged by an expert. Slump test is effectively used as a supplementary mean of judging the workability of concrete.

Pumpability: Factors determining pumpability include the ability to achieve a high pumping rate under a light pumping load and the ability to resist clogging of concrete piping.

Placing height and compaction height: In conventional concreting projects, the placing height for each layer or lift of concrete is specified, but placeability varies widely depending on how compaction is done. “Construction: Construction Standards” of this Specification, therefore, defines the new term "compaction height" to distinguish it from "placing height." For example, to place concrete for wall members or column members in a typical project, workers enter the concrete forms to perform compaction. Depending on member sizes and reinforcement patterns, however, this method of compaction may be difficult to perform, and placing height per layer or lift differs from compaction height.

Durability: External actions which adversely affect the durability of concrete include freezing and thawing action, attack by chemical substances, and rubbing action. Furthermore, when materials of poor quality are used, the long-term stability of concrete is deteriorated. In the case of members of reinforced concrete and prestressed concrete, corrosion of embedded steel progresses and their durability is damaged, if their concrete is neutralized or chloride is accumulated beyond a certain limit in the members.

Alkali-aggregate reaction: Alkali aggregate reaction is classified broadly into alkali-silica reaction and alkali-carbonate reaction depending on the kind of mineral substance which reacts with alkali, but most of the reported cases of alkali-aggregate reaction in Japan are alkali-silica reaction. When alkali-silica reaction occurs, cracks develop in concrete because the resulting alkali-silica gel swells when absorbing water

Freeze-thaw resistance: When concrete and/or aggregate particles containing water are frozen, expansive pressure develops due to the freezing of free water inside these materials. Freezing and thawing action induces slack or damage in the structure of materials due to the expansive pressure. The degree of damage increases with the repetition of freezing and thawing action. Entrained air in concrete plays a role of relieving the expansive pressure during the freezing of concrete.

Crack resistance: It is very difficult to avoid cracking but controlling the number of cracks and the crack width is comparatively simple. Controlling crack is very important as long as the durability of concrete, water-tightness and its appearance are concerned. Cracks may be induced by many causes, but it is possible to improve the crack resistance by properly selecting materials, mix proportion, construction method. In addition, appropriate design of concrete structure is also very effective in crack controlling.

Inspection: The inspection is carried out on the qualities of materials, concrete, construction process and constructed structure, using various inspection systems. Generally, the inspection of material and product is carried out by the purchaser. In many cases, the structure owner just confirms the inspecting results based on inspecting records afterward. In case of ready-mixed concrete, the constructor usually carries out the inspection because they purchase materials. However, designated inspector often carries out inspection when ready-mixed concrete of JIS is used. Inspections during construction or at completion are commonly carried out by the structure owner.

Moist curing: It is to ensure the necessary amount of water for the hydration of cement in concrete since it is not sufficient just by preventing the evaporation of water from the placed concrete. This curing method is also effective in preventing cracking due to drying shrinkage during initial hardening stage.

Temperature controlled curing: This curing method is to control the temperature in each part of the concrete to facilitate the normal hardening process and to avoid the cracking after hardening as well as and the development of excessive internal stress. In utilizing this curing method, it is necessary to take into account both the size of members and the effect of construction condition.

Accelerated curing: There are some curing methods to accelerate the hardening rate of concrete, such as steam curing, autoclave curing, hot water curing, electrical curing, infrared curing, and high frequency curing. However, in general, steam curing is widely used.

CHAPTER 2 QUALITY OF CONCRETE

2.1 General

The concrete used shall be one that has consistent quality and workability suitable for the construction tasks to be performed and, after hardening, has the required properties such as strength, durability, water-tightness and cracking resistance.

[Commentary] In order to create a concrete structure that has the required performance attributes, it is necessary to use concrete that provides the structure with those performance attributes and makes proper concreting possible. In accordance with this principle, this chapter specifies basic quality requirements for concrete.

The basic quality requirements for concrete specified in this chapter are qualitative consistency, workability, strength, durability, water-tightness and cracking resistance.

(a) Qualitative consistency: Highly variable quality of concrete supplied for the construction of a structure not only increases the possibility of occurrence of defects during construction but also necessitates the use of a large factor of safety in mix design to achieve the required strength, making the construction project uneconomical. Inconsistent quality of concrete may also degrade durability, cracking resistance and appearance. When manufacturing concrete, therefore, it is very important to secure a supply of concrete of stable quality. To do that, it is important to perform thorough material quality control and concrete manufacturing control.

(b) Workability: In order to carry out construction work efficiently and create a concrete structure with as few defects as possible, the concrete used shall have the type of workability suitable for such tasks as hauling, placing, compacting and finishing. In other words, workability attributes such as filling ability by which to completely cast formwork including the regions around reinforcing steel and corners, pumpability necessary for on-site pumping, and appropriate setting properties are very important in order to carry out construction appropriately and efficiently and construct a concrete structure with as few defects as possible.

(c) Strength: If a concrete structure is to maintain the required safety and serviceability during its service period, the concrete used shall have the strength assumed at the design stage, that is, the design strength. Initial strength development properties are an important factor affecting the speed of construction.

(d) Durability: If a concrete structure is to maintain the required safety and serviceability during its service period, the concrete used shall have the required durability as well as the design strength. In order for the reinforcing steel placed in the concrete structure to perform the required functions over a long period of time, the concrete needs to be capable of effectively protecting the reinforcing steel from corrosion. The durability attributes required of concrete can be classified into (1) physical action such as freeze–thaw action, (2) chemical action caused by sulfates, acids, etc., (3) durability of concrete itself against its own deterioration attributable to the quality of the materials used such as alkali–silica reaction, and (4) the ability to protect steel from the action of chloride ions, carbon dioxide, etc., that accelerate steel corrosion by infiltrating the concrete. It is therefore necessary to take these into consideration on an as-needed basis.

(e) Water-tightness: Water-tightness is a quality attribute indicating resistance to water or moisture permeability. Concrete structures that require water-tightness are structures whose safety, durability, functionality, maintenance, appearance, etc., are affected by water permeability. Examples are storage facilities, underground structures, hydraulic structures, water storage tanks, drinking water and sewer facilities, and tunnels. Leaching of calcium from concrete might also cause performance degradation of the structure over a long period of time. Thus, water-tightness is a quality attribute that needs to be taken into account when considering structures that come into contact with water.

(f) Cracking resistance: Excessive cracking in a concrete structure not only has adverse effects on durability and water-tightness but also degrades the appearance of the structure. It is very important, therefore, to use concrete that is highly resistant to cracking.

There may be cases, depending on the type of structure or member, where quality attributes of concrete other than those described in this chapter are required. In such cases, the quality of concrete shall be determined so that the required performance of the structure can be achieved.

2.2 Qualitative Consistency

Concrete shall be reasonably consistent in terms of the quality of materials and manufacture and shall have consistent quality.

[Commentary] Great variation in the quality of materials used to manufacture concrete and the quality of manufacture could make it difficult to supply concrete of the required quality in a consistent way, causing adverse effects on the performance of the resultant concrete structure. In manufacturing concrete, therefore, it is important to control the quality of materials and the manufacture of concrete carefully so that batch-to-batch variation in the quality of concrete can be minimized and concrete of consistent quality is always available. Quality attributes such as the content of fines attached to the surfaces of aggregate particles, the surface water content of fine aggregate, and the grading of fine aggregate and coarse aggregate are highly variable and are factors that could greatly affect the quality of concrete. In order to ensure qualitative consistency, therefore, it is important to control those quality attributes so that their variations can be minimized.

2.3 Workability

Concrete shall have workability suitable for the works to be performed such as hauling, placing, compacting and finishing according to the construction, structural and environmental conditions.

[Commentary] In order to construct a concrete structure with the required performance, it is necessary to perform construction. Since these tasks greatly affect the quality and setting properties of fresh concrete, concrete needs to have workability suitable for the tasks to be performed such as hauling, placing, compacting and finishing. Although workability includes all items related to the degree of ease of placement of fresh concrete until it hardens, it is difficult to describe all of them in detail. In the construction: Construction Standards in this specification, therefore, importance is attached to smooth execution of construction work in ordinary concreting projects, and filling ability, pumpability and setting properties are described as workability attributes.

2.3 1 Filling ability

(1) Filling ability is defined as a performance attribute that can be obtained through the interaction of fluidity and segregation resistance in the case of vibrating compaction. Filling ability shall be determined by considering both terms. Slump is used as an indicator of fluidity, and the cement content or powdery material content is used as an indicator of segregation resistance.

(2) Filling ability shall be specified within a practical range in view of the type of structure, the type and size of member, reinforcement conditions such as the amount of reinforcing steel and the minimum steel spacing, on-site transportation methods and compaction methods.

(3) It shall be assumed that the fluidity needed to fill formwork with concrete smoothly and completely, and can be achieved by securing the minimum slump for placement. The minimum slump for placement shall be determined after carefully considering the details of construction method such as placing locations, the parts of the structure to be concreted, compaction height, internal vibrator spacing, placing height per concreting cycle, and the placing rate in advance, so that slump can be made as small as practicable.

[Commentary] (1): Filling ability required of concrete is the ability of concrete to pass through reinforcing bars without undergoing segregation and completely fill complicated regions such as concrete cover regions, internal corners or prestressing tendon zones. It is generally known from experience that filling ability is determined by the interaction of fluidity and segregation resistance during vibratory compaction. It is assumed here, therefore, the quality of filling ability is determined by the balance between fluidity and segregation resistance as shown in Fig. C2.3.1.

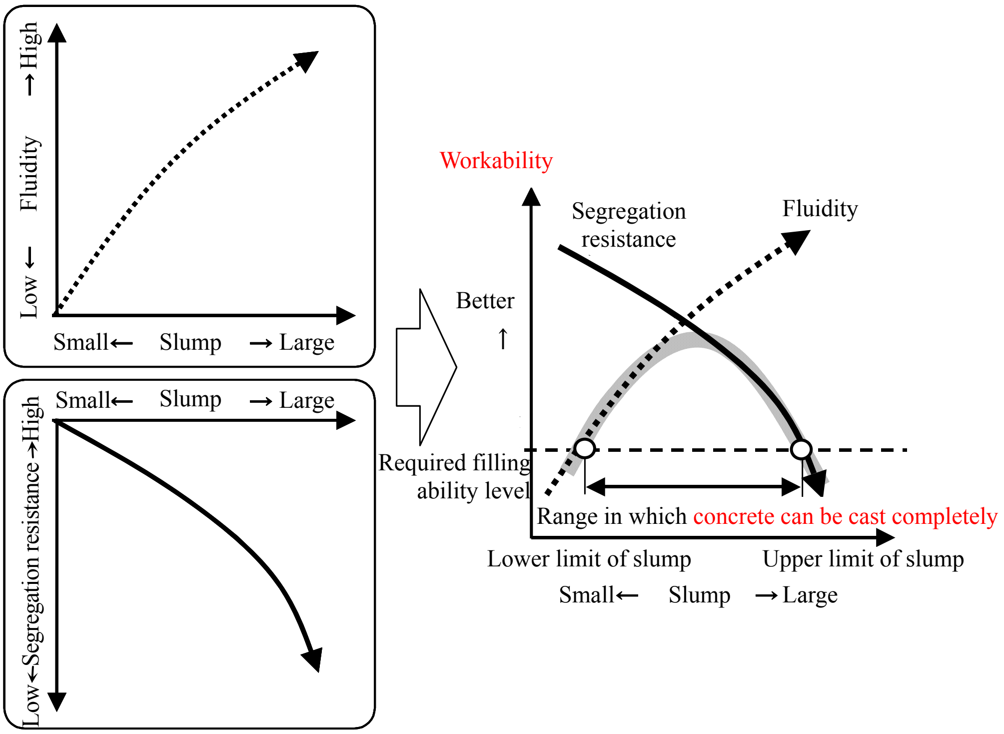

Fig. C2.3.1 Concept of workability of concrete

Fluidity and segregation resistance are affected by not only the water content, cement content and the powdery material content (hereinafter powder content) but also other factors such as the type of cement or powder, grading and shapes of fine and coarse aggregate, and the types of chemical admixtures. In general, segregation resistance can be quantified by use of plastic viscosity and a rheological constant such as the yield value. In this specification (Construction Standards), in view of engineering practice, fluidity is expressed with slump, and the powder content is used as an indicator of segregation resistance. The powder content is the total of the unit contents in concrete of powdery materials, whether reactive or nonreactive, such as cement, ground granulated blast furnace slag, fly ash, limestone powder, etc. In the case of concrete that uses only cement, the powder content is synonymous with the cement content. As mentioned earlier, the powder content is an indicator of segregation resistance, while the cement content and the cementitious material content, which indicate the contents of only reactive powdery materials, are indicators related to the heat of hydration, strength, durability, etc.

It is assumed that the filling ability of concrete is not uniquely determined by slump as a representative indicator of the consistency of fresh concrete and that it can be evaluated quantitatively in terms of a combination of slump, the powder content as an indicator of segregation resistance, and the structural conditions and construction conditions. On this assumption, Chapter 4, Mix Design, describes detailed concrete mix design methods. Chapter 4 requires that the standard value of the minimum slump during placement be selected from the construction conditions, and the powder content be determined according to slump, taking the construction conditions into consideration. The powder content, however, needs to be greater than a certain value in order to prevent initial defects resulting from segregation. The lower limit is 270 kg/m^3, and 300 kg/m^3 or more is recommended. The balance with the filling ability is also important. The reason is that the cement content cannot be increased infinitely because of the need to prevent thermal cracking and economy-related problems. Methods for attaining the required powder content in cases where the heat of hydration is an important consideration include the method of using low-reactivity powder such as fly ash or limestone powder. Setting the fine aggregate content at an appropriate level is also effective in improving segregation resistance. For further details on the determination of the fine aggregate content, refer to the values shown in Section 4.5.4.

(2) and (3): Filling ability requirements vary with the conditions for different tasks. It is therefore necessary to determine the required slump and corresponding powder content in view of various construction conditions. As shown in Fig. C2.3.2, slump varies depending on the time from the manufacture of concrete to the placement of concrete and the transportation of concrete. In order to ensure the required placing performance of concrete, slump needs to be at or higher than the level required during placement. However, Construction Standards of this Specification requires that the fluidity needed to achieve the required filling ability be determined according to the minimum slump during placement.

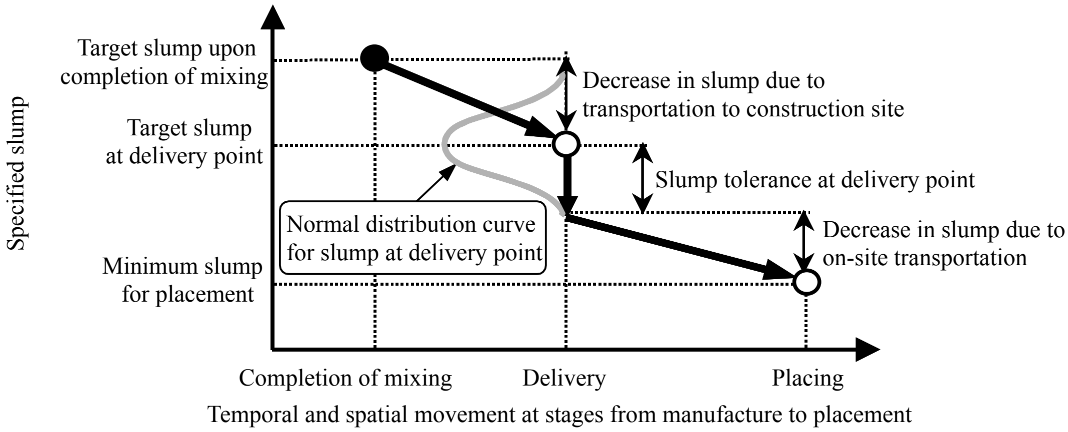

Fig. C2.3.2 Relationship between specified slump at each stage of construction and changes in slump over time

If the required minimum slump for placement is to be achieved, it is necessary to determine the slump upon completion of mixing and the slump at the delivery point in view of various conditions (e.g., transportation method, time from completion of mixing to completion of placing, ambient temperature). To be more specific, the slump upon completion of mixing is determined in view of the slump loss during transportation so that the required slump is achieved at the delivery point, and the slump at the delivery point is determined in view of the decrease at the construction site (due to the elapse of time and on-site transportation) so that the required slump can be achieved at the placing point. Since the slump loss due to the elapse of time or transportation varies depending on various conditions, it is important to appropriately allow for decreases in slump by carefully considering the construction conditions in advance. The procedure for determining slump at each stage is described in detail in Section 4.4.2.

As mentioned above, different slumps are required at the placing site, at the delivery and upon completion of mixing. In order to secure the required workability at the placing site, therefore, it is necessary to achieve quality control goals by requiring greater values for the slump upon completion of mixing and the slump at the delivery than the slump at the placing site. Strictly speaking, however, mix proportions differ depending on how long it takes before placing assumed for the purposes of mix design optimization (i.e., upon completion of mixing, at the time of delivery or at the time of placing). The basis concept: Construction Standards of this Specification is to determine mix proportions so that the optimum workability can be achieved at the placing site. If, however, the target slump upon completion of mixing or at the delivery is considerably larger than the required minimum slump for placement as when the amount of slump loss due to off-site transportation or the elapse of time is long or when the amount of decrease in slump during on-site transportation by means of pumping is expected to be large, it is necessary to select appropriate mix proportions. It should be taking into consideration such factors as segregation at the time of manufacture or during off-site transportation and possible decreases in pumpability due to, for example, clogging of pipes during on-site pumping. In such cases, it is good practice to determine mix proportions, in terms of target slumps upon completion of mixing or at the delivery, so that concrete with excellent workability can be obtained, in order to prevent problems related to manufacturing control, quality control or acceptance inspection at the delivery. If ready-mixed concrete is used, it is good practice to specify a slump that is the same as the target slump at the time of delivery so that the required minimum slump for placement can be achieved.

The minimum slump for placement is determined in view of the structural conditions such as the types and sizes of structural members and reinforcement (reinforcing bars and other reinforcing steel) patterns and the construction conditions such as on-site transportation methods (type of concrete pumper truck, pumping distance, piping direction), placing methods (drop height, height of layer of concrete to be placed) and compaction methods (type of vibrator, spacing, insertion depth, vibration time, compaction height).

There may be cases where construction workers can enter the formwork to perform compaction work near the concrete placement surface or where construction workers cannot enter the formwork but to perform compaction work from locations relatively far from the concrete placement surface. Thus, the conditions under which compaction work is carried out vary with the cross section of the structural member concerned and the density of steel reinforcement, and the difficulty in performing construction tasks also varies. Usually, the term "placing height" is used to refer to the height of a layer or lift of concrete to be placed. In the Construction: Construction Standards of this Specification, the commonly used term "placing height" and the working height related to the difficulty in performing compaction work are distinguished, and, as shown in Fig. C2.3.3, the height from the surface of the worker's platform to the bottom of the formwork or the concrete placement surface is defined as the "compaction height."

It is a basic rule that the minimum slump for placement corresponding to the compaction height should be determined after carefully considering construction method details such as placing locations and areas, compaction height, internal vibrator spacing, the height of concrete placed in a single cycle, and the placing rate so that slump can be made as small as practically possible.

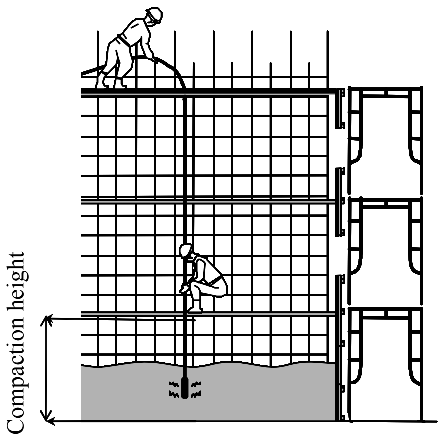

Fig. C2.3.3 Example of compaction height in case where a construction worker enters the formwork for a concrete member

2.3.2 Pumpability

(1) When concrete is pumped, fresh concrete shall have a slump suitable for the task.

(2) Proper segregation resistance during pumping shall be achieved so that pipes used for pumping are not clogged.

[Commentary] <u>(1) and (2)</u>: When concrete is pumped, it is necessary to achieve the required pumping rate under the planned pumping conditions without clogging the piping. The quality of fresh concrete, therefore, should not change substantially during pumping. Ideally, in order to meet these requirements, an appropriate set of conditions should be selected by considering alterations in not only concrete performance but also construction conditions such as the type of pump, the diameter of pipes and the transportation distance. The properties of fresh concrete keep changing a series of tasks from manufacturing and shipping through transportation to the construction site and on-site transportation to placement and compaction. Since slump may decrease considerably if concrete is pumped for on-site transportation, it is necessary to select mix proportions allowing for decreases in slump due to pumping so that the workability required for placement can be achieved. The slump loss due to pumping should be estimated by referring to Table 4.4.7 or other data.

Clogging of piping is a phenomenon peculiar to pumping. It is necessary to select mix proportions for excellent pumpability so that clogging of piping can be prevented and then estimate the slump loss due to pumping appropriately. The powder content (or the cement content if cement is the only powdery material used) and the fine aggregate ratio required careful attention because an excessively low powder content or fine aggregate ratio increases the possibility of pipe clogging. Since, however, the viscosity of concrete increases and the pumping load increases as the powder content increases, it is important to find an appropriate balance. More information on concrete pumping planning can be found in Recommendations for Placement of Concrete by Pumping (2000).

Standard slumps and powder contents needed to achieve good pumpability range from 8 to 18 cm and about 270 kg/m^3 to 300 kg/m^3 or more, respectively. Because the water content needed to obtain the required slump may be excessively high depending on the quality of aggregate or other factors, it is important to make the water content as low as possible by making proper use of chemical admixtures such as air-entraining water reducers and air-entraining high-range water reducers.

In cases where clogging of piping does not occur, pumpability can be expressed in the form of the relationship between the discharge rate and the pressure loss in pipe, and the pumpability thus obtained is used as an indicator of whether the required amount of concrete can be transported efficiently. The relationship mentioned above is shown in Section 7.3.2 of Chapter 7.

2.3.3 Setting properties

Setting properties of fresh concrete shall be suitable for the construction tasks to be performed such as compaction, placing on fresh concrete and finishing.

[Commentary] Setting properties are related to the compaction of concrete, allowable placing time interval, timing of finishing, lateral pressure acting on the formwork, etc. For hot-weather concrete and cold-weather concrete, it is necessary to control setting properties by, for example, delaying or accelerating setting according to the timing of placing and placing temperature.

Setting properties are evaluated in terms of the time of the start of setting and the time of the end of setting. In the construction of an ordinary concrete structure, the time to the start of setting and the time to the end of setting as determined in accordance with JIS A 1147, Method of Test for Time of Setting of Concrete Mixtures by Penetration Resistance, are roughly 5 to 7 hours and 6 to 10 hours, respectively. The time of setting of concrete can be controlled to some extent by using appropriate types of chemical admixtures, but it is common practice to decide on construction plans and construction methods according to the time of setting.

2.4 Strength

(1) The strength of concrete at a specified age shall not be lower than the design strength with a probability equal to or higher than a specified percentage.

(2) As a standard practice, the strength of concrete should be expressed with a measured value for a standard curing specimen at a material age of 28 days.

(3) Compressive strength tests and tensile strength tests on concrete shall be conducted in accordance with JIS A 1108 and JIS A 1113, respectively. Specimens for these tests shall be prepared in accordance with JIS A 1132.

(4) The strength development properties of concrete required at each stage of construction shall be checked on an as-needed basis.

[Commentary] (1): While in service, a concrete structure shall be sufficiently safe against the loads considered at the design stage. The quality of the concrete used, therefore, shall be high enough to meet the strength requirements for the structure specified at the design stage. Since, however, the quality of concrete, like other types of materials, inevitably varies, in theory it is not possible to ensure that the strength of any part of the structure is higher than the design strength. The Design: General Requirements of this Specification, therefore, defines a material strength as a value that guarantees that a measured value becomes smaller than that with a certain probability, and uses that value as design strength. This provision has been adopted to ensure that the strength considered when a structure is designed is attained with a predetermined probability. For the probability with which a measured value becomes smaller than the design strength, usually a value of 5% is used in view of economy and other factors.

(2): If concrete has been properly cured in a wet condition, the strength of the concrete increases as it ages. In the case of an ordinary structure, however, in many cases curing of concrete cannot be expected to be performed in such a way that the curing period is more/less than 28 days. In view of this, the strength of concrete at the start of use of the structure is expressed, as a standard practice, with a measured value of strength obtained from a 28-day specimen cured by the standard curing method.

In the case of a structure to be subjected to loading at a relatively early stage, the strength of specimens at an earlier-than-28-day material age shall be used as a standard of reference in view of such factors as the nature of working loads, the dimensions of structural members and the curing conditions. If concrete whose strength increases considerably over a long period of time is used and the curing period before loads begin to act is long, the strength of an older-than-28-day specimen may be used as a standard of reference. This may make it possible to reduce the cement content so that the occurrence of cracking due to the heat of hydration can be prevented.

There are cases where strength test specimens are cured at the construction site in order to accurately reflect the effect of the field curing conditions on concrete strength. For example, strength development of specimens are delayed at low temperatures in winter, but in the case of a structure with a large cross section, strength development of the structure may occur relatively fast because of the temperature rise due to the heat generated by the hydration of cement. Thus, care needs to be taken because field curing results do not always indicate the strength development characteristics of structural concrete, and evaluation based on standard curing may be more appropriate.

In the case of high-strength concrete with a high cement content, early-stage exposure to high temperature may result in poor strength development at the subsequent stages. The influence of this is described in detail in the Construction: Special Concretes of this Specification (Chapter 6, High-Strength Concrete).

Concrete strengths used in the design of structures includes compressive strength, tensile strength, flexural strength, shear strength, bearing strength and the strength of bond with steel. It is common practice to use compressive strength as a standard of reference because compressive strength is easy to test and measured values are large enough to indicate changes in quality clearly. Strengths other than compressive strength are not necessarily proportional to compressive strength, but they can be judged in many cases by evaluating compressive strength. Thus, compressive strength is widely used as a convenient indicator because it accurately reflects the quality of concrete. Except in the case of certain types of concrete such as pavement concrete designed on the basis of flexural strength, therefore, compressive strength can be usually used as a standard of reference of concrete strength.

(3): Concrete strength varies with concrete mix proportions, curing methods and material ages, and measured values of concrete strength also vary with such factors as the shapes and dimensions of specimens and loading methods. The compressive strength and tensile strength used in this Specification, therefore, shall be determined by the test methods described in JIS.

Preparing test specimens and testing the strength of concrete strictly by the JIS-specified methods is very important in order to minimize test error.

(4): In-process strength checks are necessary in cases where, for example, formwork or falsework is removed or the tensioning of prestressing tendons for prestressed concrete is carried out early. In these cases, strength development properties shall be checked in view of the influence of placing temperature, ambient temperature, etc.

2.5 Durability

2.5.1 General

Concrete shall be sufficiently durable against various physical and chemical actions to which a concrete structure is exposed during its service period and shall be capable of protecting steel.

[Commentary] Concrete used in a concrete structure shall have the durability needed by the structure to perform necessary functions during the specified period. To do this, concrete needs to be durable and capable of protecting the reinforcing steel in the concrete. Factors impairing the durability of concrete include freeze–thaw cycles, chemical attack and alkali–silica reaction. If one or more of performance attributes such as freeze–thaw resistance, chemical resistance and alkali–silica reaction resistance are required, concrete of the quality that meet all performance requirements shall be used. Major factors contributing to the corrosion of the steel in the concrete include chloride attack and carbonation, and cracking is also a contributing factor because it could accelerate those phenomena.

Various durability verification techniques have been proposed as methods for ascertaining that a concrete structure or the concrete itself is sufficiently durable against those degradation phenomena, and some of those methods are described in the Design: General Requirements of this Specification

(Chapter 8, Verification of Durability). The design drawings and specifications indicate design values for materials based on verification and reference values related to the materials used and mix proportions for achieving the design values, so construction can be carried out in accordance with those values. If changes have been made in the materials to be used or mix proportions at the construction stage, it is necessary to return to the design stage and make durability verification again. Since, however, verification methods for alkali–silica reactivity are not described in the Design: General Requirements of this Specification, control measures described in the explanation (Item (1)) in Section 2.5.2 need to be taken.

2.5.2 Durability of concrete

(1) Materials used in concrete shall not be ones that have adverse effects on the required durability of the concrete.

(2) As a general rule, the water/cement ratio of concrete should be 65% or less.

(3) As a general rule, the concrete used should be air-entraining concrete.

[Commentary] (1): The durability of concrete is determined by environmental action, materials used, mix proportions and construction work. The materials used, therefore, shall not have adverse effects on the durability of concrete, and mix proportions need to be selected properly. As a general rule, materials that meet the requirements described in Chapter 3, Materials, should be used.

In order to prevent alkali–silica reaction from reaching a harmful level during the service period, one of these three methods shall be used: (1) reducing the total alkali content of the concrete, (2) using Type B mixed cement that is effective in suppressing alkali–silica reaction and (3) using aggregate that is classified as Category A (harmless) in an alkali–silica reactivity test. Further details of control methods are described in Section 3.2. If the intrusion of alkalis from an external source is inevitable as in a marine environment or in a region where deicing agents are used and if the use of alkali-reducing measures relying solely on materials used is deemed to be inadequate, it is necessary to consider the use of additional measures such as surface covering.

(2): The water/cement ratio is the most important mix-proportion-related factor affecting the durability of concrete. As the water/cement ratio increases, concrete becomes less durable. Because the water/cement ratio of concrete that is required to have durability is usually lower than 65%, this section requires that the maximum water/cement ratio of ordinary concrete be, as a general rule, 65%. The water/cement ratio to be actually used varies depending on expected degradation factors, and specific details of the determination method are described in the Design: General Requirements of this Specification (Chapter 8, Verification of Durability). It should be kept in mind, however, that if the water/cement ratio is too low, the cement content becomes relatively large and the heat of hydration and autogenous shrinkage increase so that the durability of concrete adversely affected depending on the type of structure. The water/cement ratio of concrete subjected to chemical attack shall meet the requirements described in Section 4.3.4 of Chapter 4.

Verification as to whether a concrete structure meets the freeze–thaw resistance requirements is made by use of the relative dynamic modulus of elasticity in freeze–thaw testing. Reference values shown in the design drawings and specifications are water/cement ratios that meet the required relative dynamic modulus of elasticity in the Design: General Requirements of this Specification (Chapter 5, Design Values for Materials). The water/cement ratio, therefore, may be determined on the basis of those reference values.

(3): In an environment under the influence of freeze–thaw cycles, entrained air bubbles reduce water pressure increases due to freezing of internal water. The use of air-entrained concrete, therefore, is very effective in improving freeze–thaw resistance. Furthermore, the use of air-entrained concrete substantially reduces the amount of water needed to achieve the required workability so as to facilitate complete filling with concrete and improve durability attributes other than freeze–thaw resistance. This is why it is required, as a general rule, that air-entrained concrete be used not only in cases where severe weather action is involved but also in cases where severe weather action is not involved.

2.5.3 Steel protection performance

(1) Concrete shall be capable of protecting the steel placed in the concrete so that the steel can perform its intended functions during the service period.

(2) As a general rule, the total amount of chloride ions contained in concrete when it is mixed should not exceed 0.30 kg/m^3.

[Commentary] (1): Concrete has the function of protecting the steel in the concrete from external corrosion factors and heat from fires and other heat sources. Many of the concrete structures have reinforcing bars and other reinforcing steel in the concrete. If the reinforcing steel corrodes, therefore, the durability of those concrete structures decreases considerably. The reason why the protective function of concrete is lost is the protective passive film on the steel surface is destroyed. The destruction of the protective passive film is caused mainly by a decrease in alkalinity due to carbonation and the presence of chloride ions in the concrete. If, therefore, the protective function of concrete is to be performed effectively, the depth of carbonation of concrete shall not reach the critical depth for steel corrosion, which is the level at which steel corrosion occurs, during the service period, and the chloride ion content of the concrete at the steel location shall not exceed the level at which the protective passive film on the steel is destroyed. Thus, from the viewpoint of the protection of steel, it is necessary to select materials and mix proportions so that concrete is provided with appropriate mass transfer resistance according to the concrete cover determined at the design stage. The water/cement ratio is determined at the design stage along with the concrete cover, and whether the required durability is achieved is verified. It is a general rule, therefore, to use a water/cement ratio not greater than the value used for the purpose of verification.

The use of air-entraining agents, water reducers, air-entraining water reducers, superplasticizer, etc., improves workability and reduces segregation such as bleeding so that homogeneous concrete with relatively few defects can be obtained. The use of those chemical admixtures, therefore, is effective in improving the steel protection function of concrete.

Also, if blast furnace cement or fly ash cement is used or if an appropriate amount of high-quality pozzolan is used as an admixture, fine-textured concrete is obtained. If blast furnace cement is used, the ability to fix chloride ions in the concrete is enhanced. Thus, the use of these admixtures can be expected to reduce the intrusion of elements that cause steel corrosion into the concrete. It should be kept in mind, however, that the steel protection performance in the cases where these types of cement or pozzolan is used can be achieved only if a sufficient initial wet curing period is secured.

Cracks in the cover concrete can considerably degrade steel protection performance. It is therefore necessary to achieve durability by exercising control so that the critical crack width (see Section 8.3.2 of the Design: General Requirements of this Specification) for steel corrosion is not exceeded.

If the measures mentioned above are not effective enough to protect the steel or if it is thought that the maintenance or repair of the structure is difficult to perform, measures such as using epoxy-coated reinforcing bars or coating or finishing the concrete surface should be taken. It is advisable to refer to the Recommendations for Design and Construction of Reinforced Concrete Structures Using Epoxy-Coated Reinforcing Steel Bars (Revised Edition) if epoxy-coated reinforcing bars are used and the Recommendations for Concrete Repair and Surface Protection of Concrete Structures if the concrete surface is protected to reduce the infiltration of chlorides.

(2): If chlorides exist in concrete in a quantity exceeding a certain limit, the corrosion of the steel in the concrete is accelerated so that early deterioration of the structure results. Such chlorides may enter the concrete from an external environment such as a marine environment or be supplied to the concrete from materials such as cement, aggregate, chemical admixtures and mixing water. In order to achieve the steel protection performance of the concrete, therefore, it is very important to control and keep the total quantity of chloride ions supplied to the concrete from those materials within the range that does not cause steel corrosion. The Construction: Construction Standards of this Specification requires, therefore, that the total quantity of chloride ions be controlled in terms of the total chloride ion content of concrete during mixing. The total chloride ion content of concrete during mixing is the total of the quantities of chloride ions that are thought to be supplied from the materials used to the concrete calculated on the basis of mix proportions. When mixing concrete, therefore, it is necessary to know in advance the chloride ion content of each material. If tap water is used as mixing water and the chloride ion content of that water is not known, the quantity of chloride ions supplied from the mixing water to the concrete may be assumed to be 0.04 kg/m^3.

If the total quantity of chloride ions calculated on the basis of mix proportions is greater than the allowable limit, part or all of the materials to be used shall be changed. As a result of the recent JIS revision, the allowable upper limit of the chloride ion content of normal Portland cement has been increased from 0.02% to 0.035%, the amount of increase in the chloride content of concrete is not large enough to cause a serious problem unless the cement content is extremely high.

The limit value stipulated in this section, namely, the chloride ion content of 0.30 kg/m^3, is not intended to guarantee that steel corrosion will never occur. Instead, the value has been determined, on the basis of research and study results, as a feasible value that can keep the deterioration of a structure due to steel corrosion at or below an acceptable degree. Therefore, in the case of, for example, prestressed concrete subject to stress corrosion or reinforced concrete that is used in an environment with chloride attack due to chloride ion intrusion or electrolytic corrosion and that is required to be highly durable, the quantity of chlorides in the concrete should be made as small as possible in comparison with the specified value.

In the case of reinforced concrete or plain concrete with nonstructural reinforcement to be used under normal conditions, if materials with a low chloride content are very difficult to obtain, the allowable upper limit of the total chloride ion content of concrete may be raised to 0.60 kg/m^3. In this case, however, it is necessary to carefully carry out construction, taking particular care, among other things, to make the water/cement content or the water content as small as possible and place concrete properly.

The provision of this section does not apply to a structure built with plain concrete without nonstructural reinforcement. It has been pointed out, however, that even in the case of concrete used for structures of this type, there may be adverse effects such as poor strength development over a long period of time and increased proneness to efflorescence deposition as the chloride ion content increases. The total quantity of chloride ions, therefore, should be minimized.

2.6 Water-tightness

Concrete shall have the required water-tightness so that the functions of the structure are not lost because of water permeation.

[Commentary] Water-tightness includes the water-tightness of concrete and the water-tightness of a structure or member. In general, the former is evaluated in terms of the permeability coefficient of concrete, and the latter in terms of the permeation rate.

The permeability coefficient is basically dependent on the solidity of concrete, and concrete with high solidity, that is, concrete with a small permeability coefficient is desirable from the viewpoint of durability, too. The permeability coefficient is governed by the degree of compactness of hardened porous cement, void structure characteristics such as void continuity, and the nature of the relatively-coarse-textured transition zones formed around aggregate particles. The void structure of hardened cement is usually dependent on the water/cement (cementitious material) ratio and the type of cementitious material. Transition zone formation and continuity vary with the water/cement ratio and the degree of segregation (bleeding), and as the width of the transition zone increases and the distance between aggregate particles decreases, the continuity of transition zones tends to increase and the permeability coefficient of the concrete tends to increase. It is generally known that as the water/cement ratio increases, the permeability coefficient of concrete increases exponentially. In order to achieve the required permeability coefficient, therefore, it is effective to reduce the water/cement ratio and the water content to the extent that workability suitable for the construction tasks to be performed can be achieved by using admixtures, etc., appropriately so that homogeneous and compact concrete can be obtained. Past experience confirms that water-tightness required of ordinary concrete can be achieved if the water/cement (cementitious material) ratio is 55% or less.

Whether the functionality of a structure is not hampered by water permeation is verified as described in the Design: General Requirements of this Specification (Section 10.6, Verification of Water-tightness). Because the permeation rates are indicated in the design drawings and specifications as characteristic values, it is necessary to carry out construction so that those values are met. The water-tightness of a concrete structure is closely related to not only the water-tightness of the sound regions of concrete but also the water-tightness of discontinuous surfaces such as crack and joint regions. In general, the rate of permeation through cracks and vertical construction joints tends to be much higher than the rate of permeation in sound regions of concrete. If water-tightness is required of a structure, therefore, the occurrence of cracking should be prevented. The use of reinforcing bars for crack control and expansive admixtures is effective in controlling the occurrence of cracking and crack width. Also, it is a basic rule to treat construction joints properly and use waterstops at vertical construction joints (see Chapter 9, Joints). Construction-related measures that can be taken include laying waterproof membrane in regions where water-tightness is required, and using crack-inducing joints and taking appropriate waterproofing measures after cracking. When taking these measures, it is important to properly evaluate those measures including the maintenance plan and decide on details accordingly because the effectiveness of such measures differ depending on factors as the materials and methods used.

2.7 Cracking Resistance

Concrete used shall be one that is free as much as possible from settlement cracking, plastic shrinkage cracking, thermal cracking, autogenous cracking, drying shrinkage

cracking, etc.

[Commentary] Many cracks that have occurred at the surface of a concrete structure may mar the appearance of the structure or cause the performance of the concrete such as durability, steel protection performance, water-tightness and airtightness to be degraded severely. Cracks resulting from excessive shrinkage may also have adverse effects on the stiffness and deflection of structural members. The influence of cracks occurring at the construction stage on the performance of a structure during its service period has not yet been fully understood. The verification, however, of various performances attributes described in the Design: General Requirements of this Specification assumes that initial cracking that is so harmful as to affect the required performance of the structure does not occur at the construction stage. It is necessary, therefore, to minimize the occurrence of cracking and control cracks so that they do not affect performance, that is, keep crack width within tolerance. The intent of the Construction: Construction Standards of this Specification is not to completely prevent cracking. Instead, it is to prevent harmful cracks that degrade the performance of concrete.

Possible causes of cracking of concrete include those attributable to materials or mix proportions, those attributable to construction work and those attributable to external forces. Causes of cracking attributable to external forces can be taken into consideration at the design stage, and there are even types of cracking such as flexural cracking that are allowed to some degree.

The initial cracking verified in the Design: General Requirements of this Specification (Chapter 12, Verification of Initial Cracking) is cracking due to the hydration of cement and cracking due to shrinkage. The intent is to verify that these types of initial cracks do not affect the required performance of the structure. Since the design drawings and specifications indicate design values for materials based on verification and reference values related to the materials used and mix proportions, construction can be carried out according to those values as in the cases where durability is to be achieved. The occurrence of these types of cracks, however, is attributable to not only the nature of concrete determined by such factors as materials and mix proportions but also various other factors such as environmental conditions, the dimensions and shape of the structure, and construction methods, and there may even be cases where other factors that cannot be expected at the design stage are involved. It is therefore necessary to select concrete materials, mix proportions and construction methods after careful consideration of those factors and their effects.

In order to reduce rises in concrete temperature, it is important to make the cement content (cementitious material content) as small as possible. Taking measures such as keeping material temperature low is a good construction practice.

From previous studies, it has shown that autogenous shrinkage increases while the water/cement is low and that the amount of shrinkage varies widely depending on the type of cement and the admixtures used. In the case of high-strength concrete with a smaller-than-normal water/cement ratio, it is important to select appropriate materials and mix proportions. In order to control drying shrinkage, it is important to make the water content as small as possible. It is also important not to use high-absorption aggregate or aggregate with a small Young's modulus.

It should be kept in mind that shrinkage strain should be small, but it is important to ascertain in advance by referring to past construction data or reliable literature that the concrete materials and mix proportions to be used are free from cracking due to shrinkage. The Design: General Requirements of this Specification requires that the maximum allowable shrinkage strain in concrete should be 1,200 μ if past construction data or other relevant information is not available concerning the shrinkage of the concrete to be used. This value was obtained by assuming that measured values of length change obtained by water-curing 100×100×400 mm specimens for 7 days at 20±2°C and measuring length changes at 20±2°C and relative humidities of 60±5% in accordance with JIS A 1129, Methods of Test for Length Change of Mortar and Concrete, are 1,000 μ or less and that autogenous shrinkage occurring during the water curing and the subsequent six months is 200 μ.

Judging from past construction data, it may be thought that shrinkage strain in ordinary ready-mixed concrete is not greater than the maximum value mentioned above. If, however, a very important structure is involved or shrinkage cracking has a serious impact on the performance of the structure concerned or if a smaller shrinkage strain is specified at the design stage, the value mentioned above needs to be verified through testing.

Common types of cracks that occur at the construction stage besides the shrinkage-induced cracks mentioned above include settlement cracks and plastic shrinkage cracks. An effective way to prevent settlement crack is to use admixtures with a water-reducing agent and mix proportions with a low water content. Cracking can also be prevented by careful construction, and settlement cracking can be prevented by reducing bleeding and carrying out tamping or revibration at appropriate timing. Plastic shrinkage cracking can usually be prevented if rapid drying from the surface following the placement of concrete is prevented. Plastic shrinkage cracking may occur when the rate of evaporation of water from the surface is higher than the rate of rise of bleeding water. In the case of high-strength concrete that is relatively free from bleeding, therefore, it is important to prevent the dissipation of moisture.

CHAPTER 3 CONSTITUENT MATERIALS

3.1 General

Constituent materials used for concrete, of which quality has been confirmed, shall be selected.

[Commentary] Choice of appropriate constituent materials is very important in ensuring that the concrete meeting the required performance criteria is made. The suitability of the constituent materials can be confirmed using by quality control tests or service records. Also constituent materials conforming to standards of quality such as those laid down by JIS or JSCE Standards may be confirmed as good quality materials. Materials to be used for concrete shall be determined so as to satisfy the required performance taking into consideration of the limitations of the production plant, economy including ease of material procurement and cost of transportation, etc.(6.1 General).

3.2 Cement

(1) Appropriate cement shall be selected according to the intended use.

(2) Cements shall comply with the requirements of JIS R 5210 or JIS R 5211 or JIS R 5212 or JIS R 5213.

(3) When cement other than the types of cement mentioned in Item (2) is used, it shall be ascertained that the performance requirements for concrete are met.

[Commentary] (1) It is necessary to select the most appropriate cement for construction by considering the types, sizes and locations of structures, weather conditions, time and duration of construction, construction procedures, etc. to produce concrete of required performance steadily and economically.

(2) The types of cement specified in JIS include normal, high-early-strength, very-high-early-strength, moderate-heat, low-heat, and sulfate-resistant Portland cement conforming to JIS R 5210, Portland Cement, blended cement conforming to JIS R 5211, Portland Blast-furnace Slag Cement, JIS R 5212, Portland Pozzolan Cement, and JIS R5213, Portland Fly-ash Cement, and cement conforming to JIS R 5214, Ecocement. In many projects, normal Portland cement is used. Other widely used types of cement include high-early-strength and moderate-heat cement in the Portland cement category and blast furnace slag cement and fly ash cement in the blended cement category. In recent years, the use of Type B blast furnace slag cement has increased. Today, cement is being expected to contribute to the realization of a zero waste society by making it possible to reuse by-products from other industries. In 2003, in order to meet growing demand for industrial by-products that can be used as materials for normal Portland cement, the allowable upper limit to the chloride ion content was raised from 0.02% to 0.035%.

In general, the use of high-early-strength Portland cement in a low temperature environment decreases the degree of delay in strength development at early material ages in the case of low temperature curing, thereby making the concrete less susceptible to the damage by freeze–thaw cycles. The use of high-early-strength Portland cement in a high temperature environment, in contrast, contributes to a rise in concrete temperature because of a large amount of heat generated by hydration, making spreading of concrete more difficult because of stiffness of concrete resulting from high temperature and making the concrete more prone to cracking. In a high temperature environment, therefore, it is desirable that low-heat, moderate-heat or normal Portland cement or Type B blended cement be used so as to reduce the amount of concrete temperature rise and subsequent cracking due to temperature fall.

Type B blast furnace slag cement is effective in reducing alkali–silica reaction and chloride infiltration. Type B blast furnace slag cement in recent years, however, tends to be formulated so that, depending on the slag content, the powder content, etc., the initial strength becomes high. Consequently, there are cases where the adiabatic temperature rise rate of concrete is higher than that of normal Portland cement, and there have been reports of increases of cracks due to thermal stress depending on member sizes, constraint conditions, environmental conditions, etc. Since Type B blast furnace slag cement includes low-heat types, it is important, when using it, to check on its thermal and other properties and guarantee strength at a relatively old material age.

Thanks to recent advancements in production technology, today it is possible to achieve the required strength of cement even if the water/cement ratio is high. Cement today, therefore, is capable of meeting high-early-strength-oriented performance requirements aiming to achieve the required strength at a material age of 28 days. Some point out, however, that as a result, durability suffers. In the coming years, there will be a need for cement that develops appropriate strength at the water/cement ratio determined by durability, that is, cement that has different strengths for concrete with different strengths. In this case, however, curing that takes early-age strength development into consideration is important.

Ecocement, which was newly standardized in 2002, can be largely classified into two types: normal ecocement and rapid-hardening ecocement. Ecocement, which contains chloride ions in the quantity equal to 0.1% or less of the mass of cement, has properties similar to those of normal Portland cement. Ecocement has made application to ordinary reinforced concrete possible.

If the quantity of Na_2O or K_2O contained in cement is large, particular types of minerals in the aggregate may cause alkali–silica reaction under certain conditions, thereby causing the deterioration of the concrete. Appendix 2 (regulation), Methods for Suppressing Alkali–Silica Reaction, of JIS A 5308 describe three methods for preventing or reducing such alkali–silica reaction to choose from: (1) reducing the total alkali content (total quantity of alkalis supplied by various materials) of concrete to an Na_2O equivalent of 3.0 kg/m^3 or less, (2) using blended cement containing a reaction-suppressing effect such as Type B or Type C blast furnace slag cement or Type B or Type C fly ash cement and (3) using aggregate that has been judged to be harmless with respect to alkali–silica reaction. Reaction control methods are described in greater detail in the explanation about Item (4) of Section 4.3.4.

(3) Cement used mainly for civil engineering projects includes not only the types specified in JIS but also cement with special performance characteristics.

The use of ultra-rapid-hardening cement makes it possible to achieve high strength in a short period of time and begin to use the structure in only several hours even in winter. Since the consolidation and hardening properties of cement of this type vary considerably depending on the quantity of hardening time modifiers used, it is necessary to obtain accurate information on the consolidation properties at the temperatures at which the cement is used. Other special types of cement include ultra-fine cement, alumina cement, oil well cement, geothermal well cement, white Portland cement and colored cement. When deciding on using these special types of cement, it is good practice to carefully study past construction records and conduct thorough tests in advance. The use of a combination of two or more types of cement may result in an unexpected result such as quick setting of a mixture of alumina cement and Portland cement. When mixtures of different types of cement are used, it is necessary to ascertain that such mixtures would not have adverse effects on the performance of concrete.

3. 3　Mixing Water

(1) Mixing water should be tap water complying with the provisions of JSCE-B101 or Appendix 3 of JIS A5308, as standard.

(2) Recovered water shall meet the requirements described in Appendix 3 of JIS A 5308.

(3) Sea water should not be used as mixing water in general.

[Commentary] (1) Mixing water must not contain substances that cause the consolidation or hardening or concrete, strength development, volume changes, degradation in quality such as workability, or steel corrosion in harmful quantities. In many cases, water that does not have any unusual taste, odor, color or turbidity and that is suitable for drinking can be used for mixing of concrete.

Service water, water from rivers and lakes, groundwater, industrial water, etc. may be used as mixing water. River, pond or lake water may be contaminated by industrial waste water or sewage and may contain sulfates, iodides, phosphates, borates, carbonates, compounds of lead, zinc, copper, tin, manganese, etc., inorganic alkali compounds, organic impurities such as sugar pulp waste water or corrosive materials. The presence of even very small amounts of these impurities in the mixing water, of concrete may have adverse effects on concrete properties such as the setting, hardening, strength development, volume change, workability, etc. When mixing water containing chlorides, nitrates, sulfates, etc. is used for concrete, the corrosion of steel may be accelerated. In particular, for highly stressed prestressing tendons in prestressed concrete, stress corrosion is likely to occur. In steel where a stray current is flowing, electrolytic corrosion may be accelerated. Therefore, in cases of using water other than service water as mixing water, the water should conform to the requirements of JSCE-B101 “Recommended Practice for Quality of Mixing Water for Concrete" or Appendix 3 of JIS A 5308 “Water for Mixing of Ready-Mixed Concrete”.

(2) The supernatant liquid of washing water in mixers, truck agitators, etc., at ready-mixed concrete plants or precast concrete plants may be used as mixing water if it has been ascertained that there will be no adverse effect on the strength, workability, etc., of the concrete. Sludge water with suspensions of cement and other fine particles generated when aggregates are covered form excess concrete or mortar may be used as mixing water, if its suspension concentration, the ratio of the quantity of suspended solids to the cement content, etc., can be controlled adequately, only after it is ascertained that there will be no adverse effect on the quality of concrete. Since, however, recovered water contains chlorides and alkalis, it is necessary to consider their concentrations before using recovered water. Thus, only recovered water meeting the requirements described in Appendix 3 of JIS A 5308 may be used.

(3) If seawater is used, old-age strength of concrete becomes smaller, concrete becomes more prone to efflorescence, and concrete become less durable. The use of seawater, therefore, is usually not permissible. Since well water near a seacoast often contains chlorides, seawater may be used only after the chloride content is checked. In the case of plain concrete without nonstructural reinforcement, seawater may be used as mixing water after ascertaining that there will be no

adverse effect on the quality of concrete.

3.4 Aggregates

3.4.1 Fine aggregate

(1) Fine aggregates shall be clean, hard, firm, durable, chemically or physically sound and not contain a harmful amount of dust, mud, organic impurities, chlorides, etc.

(2) Fine aggregates should comply with Table 3.4.1.

Table 3.4.1 Properties of fine aggregate

Item	Quality	Test method
▪ Oven-dry particle density g/cm^3	≥2.5	JIS A 1109
▪ Water absorption %	≤3.5	JIS A 1109
▪ Clay lumps %	≤1.0 [1)]	JIS A 1137
▪ Particles passing standard sieve size of 75μm		JIS A 1103
/ When concrete surface is subjected to abrasion %	≤3.0 [2)]	
/ Other than the above %	≤5.0 [2)]	
▪ Organic impurities	Darker than the standard color or sample color	JIS A 1105
▪ Content of chlorides %	≤0.04 [3)]	JSCS C 502
▪ Soundness %	≤10	JIS A 1122

1) Test samples are the residual materials retained on the sieve after the test JIS A 1103.

2) In the case of crushed sand or slag fine aggregate, if the washed-out materials consist of dust from fracturing, and are essentially free from clay or shale, these limits may be increased to 5.0 and 7.0%, respectively.

3) This value is a percentage for oven-dry mass of a fine aggregate, and it is shown as the value converted into NaCl.

(3) Crushed sand should comply with the provisions specified in JIS A 5005.

(4) Blast-furnace slag fine aggregate, ferro-nickel slag fine aggregate, copper slag fine aggregate and electric arc furnace reducing slag fine aggregate should comply with the provisions specified in JIS A 5011-1, JIS A 5011-2, JIS A 5011-3 and JIS A 5011-4 respectively.

(5) Recycled fine aggregate should comply with the provisions specified in JIS A 5021.

(6) Grading of fine aggregate should lie in the range specified in Table 3.4.2 with appropriate mix conditions of large and small particles.

Table 3.4.2 Standard grading of fine aggregate

Nominal openings of sieve (mm)	Percentage of mass passing through sieve	Nominal openings of sieve (mm)	Percentage of mass passing through sieve
10.0	100	0.6	20 – 65
5.0	90 – 100	0.3	10 – 35
2.5	80 – 100	0.15	2 –10 [1)]
1.2	50 - 90		

1) When only crushed sand or slag fine aggregate is used as fine aggregate, this range may be 2-15%. When mixed fine aggregate is used and most of passing through 0.15 mm sieve are crushed sand or slag fine aggregate, 15% may be accepted.

2) It is desirable that the percentage of aggregate remained between two successive sieves may not be larger than 45%.

(7) When using mixtures of different types of aggregate, the quality of each type of aggregate before mixture should comply with (2), (3), (4) and (5). As for the content of chlorides and grading, mixed fine aggregate should comply with the provisions in Table 3.4.1 and Table 3.4.2.

[Commentary] (1) As a standard requirement, this item stipulates that fine aggregates that meet the requirements related to the grading of fine aggregate stipulated in Item (6) and the requirements related to the limits of the contents of harmful substances such as organic impurities and chlorides and the durability of fine aggregates stipulated in Item (2) should be used. The degree of hardness of fine aggregates should be judged from the results of strength and other tests for mortar or concrete produced by using those fine aggregates because there is as yet no standard for appropriate testing methods. It has been reported that even in the case of aggregate conforming to the quality standard of JIS, the shrinkage of concrete increases as the aggregate shrinks if the aggregate is porous and the specific surface area of interval voids is large. Although there is still room for argument, when selecting aggregate, it is important to ascertain, on the basis of past construction records or reliable literature, that the aggregate under consideration is a material that does not pose any shrinkage-related problem in a actual structure.

One item related to the chemical stability of aggregate is alkali–aggregate reaction. Concrete has undergone alkali–aggregate reaction expands considerably and cracks in a characteristic way. Alkali–aggregate reaction, therefore, can greatly reduce the durability of a structure. The types of aggregate that are subject to alkali–aggregate reaction include those described below. In most cases, concrete with typical mix proportions can be used by taking the control measures described in Section 4.3.4.

Alkali–aggregate reaction used to be classified largely into alkali–silica reaction and alkali–carbonate reaction according to the type of minerals that react with alkalis. Recent research, however, has made widely accepted the hypothesis that the phenomenon that was once believed to be alkali–carbonate reaction is actually alkali–silica reaction by microcrystalline silica in limestone.

Minerals which may cause alkali-silica reaction are opal, chalcedony, cristobalite, tridimite, volcanic glass, quartz with deformed crystal lattice, cryto-crystalline quartz and so on. There are many types of rocks which contain these minerals, such as andesite, ducite, rhyolite and their tuff, basalt, slate, sandstone, chert, muddy slate and so on. It is impossible to judge the reactivity by only the type of rock.

Usually, soundness for the alkali-silica reaction is tested by the method specified in Appendix 7 of JIS A 5308 "Method of Test for Reactivity of Aggregate for Alkali-Silica Reaction (Chemical Method)" or Appendix 8 of JIS A 5308 "Method of Test for Reactivity of Aggregate for Alkali-Silica Reaction (Mortar Bar Method)". The petrological tests as polarization microscopy and powder X-ray diffraction method can be used for detection of the reactive minerals.

In case of the alkali silica reaction, when non-reactive aggregate was mixed with reactive aggregate, the expansion of mortar or concrete may become a maximum. This is called pessimum phenomenon. The region of "Potentially Reactive" (region where Sc and Rc are high together) in the chart of ASTM C 289 (Chemical Method) shows the region confirmed by the mortar bar method where the most of aggregates have high reactivity and cause the pessimum phenomenon. When the aggregate in this region was used with non-reactive aggregate, harmful expansion may take place at a mix ratio (below 50%). In Japan, the aggregate in the region of "Potentially Reactive" are considered as "Low-reactive aggregate". But, it is "essentially harmful aggregate" which causes the pessimum phenomenon, since the reactivity is very high. Therefore, it is necessary to test the alkali-aggregate reaction of each aggregate by chemical method for the case in which aggregates are mixed. The mortar bar method on the aggregate, which is mixed at the ratio used, actually is necessary in order to examine the reactivity, when even one result with "Not harmless" is obtained by the chemical method. Aggregates in the "Reactive" area of ASTM C 289 do not show the pessimum phenomenon in the mortar bar test, and it causes the harmful expansion. Unsoundness minerals except for the alkali-aggregate reactivity are smectites, laumontite, ferruginous brucite, pyrite, etc.

Various chemically and physically unsound minerals mentioned above may be included in aggregate. It is important therefore to examine various points mentioned above in order not to lower, the quality of the concrete when the aggregate without practical application is used.

(2) The low density and high water absorption means that a fine aggregate particle generally is porous and the strength is low. The low strength of the aggregate particle results in increased unit cement content for making the concrete with the required strength in addition to the decreased crack resistance against drying shrinkage and less predicted value of Young's modulus of elasticity from the compressive strength of concrete. And, the porous particle of fine aggregate may cause deterioration of concrete due to freezing and thawing action, even if the recommended amount of entrained air is incorporated. Therefore, a natural fine aggregate should conform to JIS A 5308 Appendix 1 "Aggregate for Ready Mixed Concrete". However, the sand may be used, when it has been confirmed that the concrete made from it conform to the required performance through practical applications in the past or appropriate performance verification, even if it is the sand which does not conform to these regulations.

Clay is not always harmful to concrete of low cement content, if that clay in fine aggregate is distributed evenly without adhering firmly to particle surface. But if clay adheres firmly to particle surfaces, it prevents bonding between cement paste and sand. When clay remains in concrete as lumps, their destruction by wetting and drying or freezing and thawing may leave cavities in concrete, or concrete surface may be stained. In the test for the content of clay lumps, the residual materials retained on the sieve for amount of materials passing standard sieve 75μ test are used as its sample in order to clarify the harmful clay lumps. The amount of clay or other fine materials which are not in lump form and do not adhere firmly to particle surfaces of fine aggregate can be determined by the amount of materials passing standard sieve 75μ test. In the case of natural fine aggregates, however, fine grains and clay in many cases have similar influence on concrete.

In the Standard Specification: Materials and Construction in 2002 the item on the substances, like coal and lignite, lighter than liquid having a specific gravity of 1.95 was specified. However the case where river sand and other aggregates that are delivered by a train used to transport coal contain coal and lignite becomes less and less. This is why this item is removed in this specification. In case where JIS A 1141 Test Method for Substances Lighter than Liquid Having a Specific Gravity of 1.95 is conducted, chemical agents specified in this JIS A 1141 are harmful to the environment and human body precautions must be taken in their handling.

Organic impurities contained in fine aggregates are tested in accordance with JIS A 1105, Method of Test for Organic Impurities in Fine Aggregate. In this case, the standard method is to use fine aggregate that produces a supernatant color lighter than the standard color. In cases where the color of the supernatant over the sand is darker than the standard color, if the compressive strength of mortar specimens made by using the sand is equal to or higher than 90% of the compressive strength of mortar specimens made by washing the sand in a 3% sodium hydroxide solution and then washing the sand thoroughly with water, the sand may be used. The test for sand by the compressive strength of mortar must be conducted in accordance with JIS A 1142, Method of Test for Fine Aggregate Containing Organic Impurities by Compressive Strength of Mortar.

As a fine aggregate including the chloride, there are sea sand and mixed sand including sea sand collected from seabed, beach, river mouth, etc. Sea sand has been used in the west part of Japan around the Setouchi-Sea area but the using of sea sand is tend to be prohibited from the environmental view point. In case of the concrete using a fine aggregate including the chloride, the most part of the chloride content in the concrete is supplied from a fine aggregate. And generally, the chloride content in the concrete may exceed allowable limit 0.30kg/m^3, which is decided for the steel product protection, when a fine aggregate including the chloride was used. Therefore, it is necessary to establish some restrictions for chloride content in fine aggregate in order to keep the chloride content in the concrete under the allowed value. In Table 3.4.1, the upper limit of chloride content for fine aggregate is a value determined which the regulation for the chloride content in the concrete was almost satisfied in synthetic consideration with actual condition of salt removal processing of sea sand and reliability of test for quality control.

It is necessary to consider not only the water to cement ratios and air content but also quality of fine aggregate for acquiring a durable concrete against freezing and thawing. The durability of the fine aggregate may be judged by the results of test such as JIS A 1122 "Soundness Test of Aggregate Using Sodium Sulfate". The fine aggregate to be used for concrete requiring the resistance freezing and thawing action should have a weight loss of not larger than 10% after being subjected to 5 repetitions of the test procedure prescribed in the test for soundness using sodium sulfate. However, fine aggregate may be accepted, provided it is proved that concrete made up of a similar aggregate obtained from the same source has satisfactory freeze-thaw resistance when exposed to weather conditions similar to those to be encountered, or provided that the concrete composed of the fine aggregate shows satisfactory results in the freezing and thawing tests, even if the weight loss of fine aggregate is larger than 10%.

There are lime, Pelli cress, hauyne, anhydrite (calcium sulfate anhydrite) as the result, which brings about the harmful effect for the concrete, when it is entrapped in a fine aggregate. Lime and Pelli cress may be included for materials such as calcined lime, plaster, lime system expanding material, baking fertilizer, dolomite clinker, fire brick, converter slag, artificial light-weight aggregate. If these lumps exist in the concrete, pop-out at the concrete surface is caused by hydration reaction. Therefore, the attention is needed so that it may not entrap these in a fine aggregate. The damage may be received after several years, when the Pelli cress is included for a fine aggregate since the hydration of Pelli cress is slower than that of lime.

(3) Crushed sand has angular particle shape and often contains a large amount of rock powder. For these reasons, when crushed sand is used, the unit water content shall be increased appropriately to acquire the required workability. The shape of the particles of crushed sand varies according to the types of the original rocks or crushing processes in production. The shapes of sand particles have a strong influence on the required unit water content or the workability of concrete. When crushed sand is used, it is better not only to confirm the quality of the original rocks but also to select sand, which is of particles of low angularity and contains little amount of slender or flat particles. JIS A 5005 "Crushed Stone and Manufactured Sand for Concrete" specifies the method of test for measuring the solid volume percentage of bulk aggregate in order to judge the adaptability of sand by particle shapes, specifying that the value shall not be less than 53%.

The Blaine specific surface area of rock powder in crushed sand is generally in the range of 1500-8000cm^2/g. Although the powder increases the unit water content, it also prevents the segregation of concrete materials. For this reason, when crushed sand is used, it is rather desirable to use crushed sand, which contains 3-5% of rock powder. However, it shall be also noted that excessive amount of rock powder in crushed sand will greatly increase unit water content for a same slump value, decrease concrete strength and increase the rate of drying shrinkage. The weight loss of crushed sand in test of fine particle amount, which results from the washing out of rock powder, etc., is also specified to be not larger than 7%. If crushed sand conforms to these specifications, particle shape and rock powder content pose no significant problem as far as the quality of concrete is concerned.

(4) Blast-furnace slag fine aggregate may be used alone as fine aggregate. However, in general use, it is frequently blended with other fine aggregates such as mountain sand to a percentage by weight of 20-60% for the purpose of adjusting grading, decreasing the chloride content, etc. Considering such blended use, JIS A 5011-1 "Granulated Blast-Furnace-Slag Fine Aggregate for Concrete" classifies blast-furnace slag fine aggregate into 4 types according to grading. When any specific type of blast-furnace slag fine aggregate is used for concrete, the final grading of fine aggregate shall conform to the requirements in Table 3.4.2.

As blast-furnace slag fine aggregate has latent hydraulicity, when the daily mean temperature is over 20˚C, it may be adhered in stock bins, causing a difficulty in its drawing. Therefore, under these conditions, it is advised to select blast-furnace slag fine aggregates rated as grade A by "The Test for Soundness in Storing Blast-Furnace Slag" in Appendix 2 of JIS A 5011-1 which rarely form lumps. It is necessary to avoid storing them for a long period. It is necessary to care the case of the combination of alumina cement and blast-furnace slag fine aggregate, as it may occur the rapid hardening. When blast-furnace slag is used, "Recommendation for Blast-Furnace Slag Aggregate Concrete" should be referred to.

Ferro-nickel slag fine aggregate, copper slag fine aggregate and electric arc furnace reducing slag fine aggregate are frequently blended with mountain sand as same as blast-furnace slag fine aggregate. JIS A 5011-2, JIS A 5011-3 and JIS A 5011-4 classify these fine aggregates into 4 types according to grading. Ferro-nickel slag fine aggregate and copper slag fine aggregate are an advantageous materials for precast concrete armor units, concrete blocks for revetment, etc. because the density is very high. When ferro-nickel slag is used, "Recommendation for Ferro-Nickel Slag Fine Aggregate Concrete" should be referred to. When copper slag fine aggregate is used, "Recommendation for Copper Slag Fine Aggregate Concrete" should be referred to. In general, electric arc furnace reducing slag tends to cause expansive reaction because it contains a large amount of quicklime. Furthermore, because the composition of electric arc furnace reducing slag varies widely among different types of steel to be refined, it is difficult to achieve consistent quality. It is therefore necessary to use electric arc furnace oxidizing slag aggregates produced at factories where measures are taken to keep electric arc furnace reducing slag away. For more information on considerations in using electric arc furnace reducing slag fine aggregates, refer to Recommendations for Design and Construction of Concrete Structures Using Electric Arc Furnace Oxidizing Slag Aggregate.

(5) JIS classifies recycled aggregate, according to processing methods and the quality of aggregate, into four classes, namely, H, M and L. JIS A 5021, Recycled Aggregate for Concrete—Class H, specifies the quality of Class H recycled aggregate, and JIS A 5022, Recycled Concrete Using Recycled Aggregate Class M, and JIS A 5023, Recycled Concrete Using Recycled Aggregate Class L, specify the quality of Class M aggregate and Class L aggregate and the quality of concrete made with aggregate in those classes.

Class H recycled aggregate is aggregate for concrete applications produced through sophisticated processing such as crushing, milling and grading of concrete fragments. Class H recycled aggregate is nearly comparable in quality to ordinary aggregate and can be used in ready-mixed concrete. Test methods for the alkali–silica reactivity of Class H recycled aggregate include JIS A 1145, Method of Test for Alkali–Silica Reactivity of Aggregates by Chemical Method, JIS A 1146, Method of Test for Alkali–Silica Reactivity of Aggregates by Mortar-Bar Method, and JIS A 1804, Methods of Test for Production Control of Concrete—Method of Rapid Test for Identification of Alkali–Silica Reactivity of Aggregate. If Class H recycled aggregate that has not been preprocessed is subjected to a test conducted in accordance with JIS A 1145 (chemical method), even a very small amount of cement paste sticking to aggregate surfaces causes alkali consumption and silica dissolution to increase so that the evaluation of test results is affected. It is therefore necessary to take measures in advance such as removing cement paste sticking to aggregate surfaces by use of hydrochloric acid. It is also necessary to ascertain by use of go/no-go samples that the total quantity of impurities does not exceed 3% of the total mass of aggregate because debris of demolished structures may contain impurities such as tiles, brick, ceramic ware fragments, asphalt concrete fragments, glass fragments, gypsum board fragments, plastic fragments, wood fragments and waste paper.

Class M and Class L recycled aggregate is produced by methods different from the method used to produce Class H recycled aggregate from the economic point of view. The quality of Class M and Class L recycled aggregate, therefore, differs from that of Class H recycled aggregate in that considerable amounts of cement paste and mortar are sticking to the surfaces of aggregate particles. For this reason, Class M and Class L recycled aggregate and Class H recycle aggregate are covered by different JIS specifications, and the former is specified not as aggregate but as concrete (JIS A 5022, JIS A 5023). The upper limits of nominal strength and slump of concrete made with Class M recycled aggregate are 36 and 18 cm, respectively. The upper limits of nominal strength and slump of concrete made with Class L recycled aggregate for civil engineering construction and building construction are 24 and 10 cm and 18 cm, respectively. The use of concrete made with Class L recycled aggregate is limited to plain concrete structures that do not need to be highly durable, easily replaceable members, small reinforced concrete structures, concrete blocks reinforced with steel bars, etc. The use of concrete made with Class M recycled aggregate is limited to members that are relatively free from drying shrinkage and freeze–thaw cycles because concrete of this type may not be durable enough although the quality of concrete is higher than that of concrete made with Class L recycled aggregate.

It is for these reasons that Class H recycled fine aggregate conforming to JIS A 5021 must be used if recycled fine aggregate is to be used.

(6) When properly graded fine aggregate with large and small particles is used, it is rather easy to make concrete of the required quality economically and with relatively low unit cement content, as opposed to using aggregate with single-size sand particles or sand having an excessive amount of fine particles. As far as fine aggregate conforming to the specified grading range in Table 3.4.2 is used, concrete of required qualities can be made economically.

Since slag fine aggregate conforming to JIS A 5011 "Slag Aggregate for Concrete" is glassy and has a smooth particle surface, its water retaining capacity is smaller than that of natural sand. Crushed sand or crushed slag fine aggregate conforming to JIS A 5005 "Crashed Sand and Crashed Stone for Concrete" contain more angular particles. In cases when such aggregates are used as fine aggregates, there is an improvement in the workability and bleeding characteristics of concrete provided the mineral fines content is slightly higher. In the case of slag fine aggregate, the finer the particles, the greater the density. Thus, when the particle size distribution of the aggregate by volume is kept equal to that of other types of fine aggregates, the numerical value of the weight percentage of the finer part becomes greater. Considering the above characteristics, in cases where only crushed sand or slag fine aggregate is used, the upper limit of percentage by weight of fine particles passing a 0.15 mm sieve has been set at a value higher than that for other types of fine aggregates.

According to the definition of the terminology, grading means "the degree of the distribution of particle size". Therefore, it should be shown as the volume fraction of the particles. However, in real practices or JIS, the grading in mass percentage has been adopted, because the maximum difference between volume percentage and mass percentage is about 1%, when the difference of density of used fine aggregates is under $0.2 g/cm^3$. However, it is desirable that mass percentage of Table 3.4.2 is replaced in the volume percentage, when used fine aggregates in which the density differs over $0.2 g/cm^3$.

(7) With the declining availability of high-quality aggregate for concrete, a growing number of construction projects are using mixtures of two or more types of aggregate in order to achieve the required quality and secure the required quantity of aggregate. In cases where mixtures of different types of aggregate are used, the quality of mixtures is greatly affected by the quality of the different types of aggregate used. When using mixtures of different types of aggregate, therefore, it is necessary to ascertain the quality of each type of aggregate as described in Appendix 1 of JIS A 5308.

3.4.2 Coarse aggregate

(1) Coarse aggregates shall be clean, hard, firm, durable, chemically or physically sound and not contain a harmful amount of dust, mud, organic impurities, chlorides, etc. When fire resistance is specially required, fire resistant coarse aggregates should be used.

(2) Coarse aggregates should comply with Table 3.4.3.

Table 3.4.3 Properties of coarse aggregate

Item	Quality	Test method
▪ Oven-dry particle density g/cm^3	≥2.5	JIS A 1109
▪ Water absorption %	≤3.0	JIS A 1109

▪ Clay lumps %	≤0.25 [1)]	JIS A 1137
▪ Particles passing standard sieve size of 75μ %	≤1.0 [2)]	JIS A 1103
▪ Soundness %	≤12	JIS A 1122
▪ Weight loss by abrasion %	≤35	JIS A 1121

1) Test samples shall be drawn from the residue retained on the sieve after the test for determining the amount of materials passing standard sieve 75μ test of coarse aggregate has been carried out in accordance with JIS A 1103.

2) In the case of crushed stone, the limit may be increased to 1.5%, provided the washed-out material consists of dust from fracturing.

3) In the case of blast-furnace slag coarse aggregate, it may be increased to 5.0%.

(3) Crushed stone should comply with the provisions specified in JIS A 5005.

(4) Blast-furnace slag coarse aggregate and electric arc furnace reducing slag fine aggregate should comply with the provisions specified in JIS A 5011-1 and JIS A 5011-4 respectively.

(5) Recycled coarse aggregate should comply with the provisions specified in JIS A 5021.

(6) Grading of coarse aggregate should lie in the range specified in Table 3.4.4 with appropriate mix conditions of large and small particles.

Table 3.4.4 Standard grading of coarse aggregate

	Nominal openings of sieve (mm)	Percentage of mass passing through sieve								
		50	40	30	25	20	15	10	5	2.5
Max. size of coarse aggregates (mm)	40	100	95-100	·	·	35-70	·	10-30	0-5	·
	25	·	·	100	95-100	·	30-70	·	0-10	0-5
	20	·	·	·	100	90-100	·	20-55	0-10	0-5
	10	·	·	·	·	·	100	90-100	0-40	0-10

(7) When using mixtures of different types of aggregate, the quality of each type of aggregate before mixture should comply with (2), (3), (4) and (5). As for the grading, mixed coarse aggregate should comply with the provisions in Table 3.4.4.

[Commentary] (1) The hardness and firmness may be judged from the results of adequate tests such as JIS A 1121 "Method of Test for the Abrasion of Coarse Aggregate by Use of Los Angeles Machine", JIS A 1126 "The Method of Test for Soft Particles in Coarse Aggregate", JIS A

1110 “Method of Test for Specific Gravity and absorption of Coarse Aggregate” or a strength test of concrete made with that coarse aggregate. As for chemical soundness, comment of Section 3.4.1 for fine aggregate should be referred to.

The fire resistance of concrete is largely affected by the properties of aggregates used. Granite and quartziferous sandstone are inferior in durability. For concrete requiring not only fire resistance but also strength and durability, it is advisable to use blast-furnace slag coarse aggregate, durable andesite, basalt, hard tuff, etc.

(2) The reasons for prescribing these limits are similar to those given in the comments for Section 3.4.1 in the case of fine aggregate. It has been reported in previous experiments that even though the weight loss in the soundness test (Appendix 2 of JIS A 6204 “Chemical Admixtures for Concrete”) is as higher as 12-40%, but the water absorption is less than 3%, or when the weight loss less than 12%, but water absorption rate is around 5%, the durability factor (300 cycles) of concrete can be higher than 60. In cases when concrete is required to have freezing-thawing resistance, the coarse aggregate used should have a weight loss not larger than 12%, when subjected to 5 cycles of soundness test in accordance with JIS A 1122.

(3) As far as crushed stone is produced from durable basalt, andesite, hard and stone, hard tuff or rocks similar to these, there is no intrinsic difference between crushed stone and river gravel as concrete aggregate. Crushed stone aggregate is rather superior to river gravel as far as the uniformity of particles and its effect on the strength of concrete are concerned. However, because of the angular shape and rough surface texture of its particles, it is necessary to increase the unit water content and sand-aggregate ratio of concrete in order to acquire a concrete of the same workability as that of concrete with river gravel. Since these effects become quite significant especially when the particles are flat and/or slender, it is necessary to examine the suitability of particle shapes whenever the use of crushed stone is considered.

JIS A 5005 “Crushed Stone and Manufactured Sand for Concrete” prescribes a method of test for solid volume percentage of bulk aggregate in order to judge the suitability of the aggregate by particle shape, and specifies that the value shall be not less than 55% for crushed stone aggregate whose maximum size is 20 mm. When the maximum size is around 40 mm, the value is equivalent to 58%.

(4) Blast-furnace slag coarse aggregate is produced by crushing air-cooled blast-furnace slag. Some blast-furnace slag coarse aggregates may not possess adequate quality as concrete aggregate depending on the processes such as cooling and crushing during their production. Even when the blast-furnace slag coarse aggregate is produced in the same steel plant, the quality may be different according to the time of production. In JIS A 5011-1 “Air-Cooled Iron- Blast-Furnace Slag Aggregate for Concrete”, blast-furnace slag coarse aggregate is classified into the classes L and N. Generally, blast-furnace slag coarse aggregate of Class N is used. Class L aggregate is used only in concrete whose freeze-thaw resistance needs not be so high and characteristics compressive strength is less than 21 N/mm^2.

It shall be noted that flash setting may be caused when high alumina cement is used together with blast-furnace slag aggregate. When using blast-furnace slag coarse aggregate, the “Recommendation for Blast-furnace Slag Aggregate Concrete” should be referred.

(5) It is a standard requirement that Class H recycled coarse aggregate conforming to JIS A 5021 be used if recycled coarse aggregate is to be used. In order to produce Class H recycled coarse aggregate with stable quality, it is important to check on the quality of at least the original concrete and the original aggregate contained in the concrete by referring to past records, literature, etc. If

such information is not available, it is necessary to take concrete samples from the structure at appropriate frequencies and observe the color, shape, size, etc., of the samples.

If the particle size range of Class H recycled coarse aggregate is too wide, the aggregate becomes prone to segregation between coarse particles and fine particles at the production and storage stages so as to greatly affect the water content of concrete. JIS A 5021 defines six particle size classes of recycle coarse aggregate, namely, H2505, H2005, H1505, H4020, H2515 and H2015. Care needs to be taken here because there is no wide particle size category such as 4005. In the case of Class H recycled coarse aggregate, the abrasion loss is affected by the amount of mortar sticking to the aggregate surface. The abrasion loss, therefore, is not suitable for use as an indicator of physical properties. It may be thought that because of actions similar to abrasion tests such as crushing and milling, Class H recycled coarse aggregate is free from weak regions. This is why abrasion loss requirements are not specified except in cases where recycled coarse aggregate in this class is used in pavement slabs.

(6) The effects of grading of coarse aggregate on the workability of concrete are not so significant when compared with those of fine aggregate. But it is advisable to use coarse aggregate with properly mixed large and small particles to make concrete of the required properties economically. When coarse aggregates conforming to the grading in Table 3.4.4 are used, concrete with the required qualities can generally be made economically. For some precast concrete products, it is better to use coarse aggregate whose maximum size is 10 mm. Therefore, the standard grading of coarse aggregate whose size is 10-5 mm is also specified.

(7) This clause is provided due to the same reason as that shown in the comment for fine aggregate.

3.5 Admixtures

3.5.1 General

Chemical admixtures and mineral admixtures used for concrete shall be of confirmed quality.

[Commentary] The advantage of properly using quality mineral admixtures and chemical admixtures has been confirmed by their application records. It is recommended to improve concrete quality by the positive use of admixtures of confirmed quality and effect. However, there are also many admixtures which only have insufficient application records and are not specified in JIS or JSCE Standards. Such admixture shall be used after thoroughly confirming their quality by examining their performance records or by testing.

In addition those admixtures are classified depending on their dosages, they may be further sub-classified as follows according to their usage.

▪ Mineral admixtures

(a) Those to which pozzolanic activity can be expected: Fly ash, Silica fume, Volcanic ash, Siliceous white clay, Diatomite

(b) Those which latent hydraulicity can be expected: Ground granulated blast-furnace slag.

(c) Those which cause expansion in hardening process: Expansive admixtures

(d) Those which contribute in gaining high strength during autoclave curing: Siliceous fine powder

(e) Those for coloring: Pigments

(f) Those which decrease material segregation and/or bleeding of concrete with high flowability: Lime stone powder

(g) Miscellaneous: Admixtures for high strength, polymers, fillers, etc.

▪ Chemical admixtures

(a) Those for improving workability and freeze-thaw resistance: Air-entraining agent, air-entraining and water-reducing agents

(b) Those for improving workability, reducing unit water content and unit cement content: Water-reducing agents, air-entraining and water-reducing agents

(c) Those for increasing strength greatly by reducing water: High-range water reducing agent, air-entraining and high-range water reducing agent

(d) Those for considerably reducing unit water content and improving freeze-thaw resistance: High-range water reducing and air-entraining agent

(e) Those for considerably improving flowability without changing mix proportions or quality of hardened concrete: Superplasticizers

(f) Those for controlling material segregation in underwater concreting by increasing viscosity: Antiwashout agents for underwater concrete

(g) Those for controlling setting and hardening time: Accelerators, fast-set agents, retarders, retarders for construction joint

(h) Those for improving the filling-up ability or controlling density by introducing foam: Foaming agents and gas generating agents

(i) Those for controlling material segregation by increasing viscosity or by controlling cohesion: Agents for improving pumpability, segregation-reduction agents, and viscosity-modifying admixture

(j) Those for increasing filling-up ability and the strength development of concrete by providing proper expansion and improving flowability: Agents for preplaced concrete aggregate concrete, Agents for high-strength preplaced aggregate concrete, Agents for grouting mortar

(k) Those for preventing corrosion of reinforcing bars by chloride: Corrosion inhibitors for reinforcing bars in concrete

(l) Miscellaneous: Water-proofing agents, Nonfreezing agents, Drying shrinkage reducing agents, Agents for controlling heat of hydration, Dust-reducing agents, etc.

Chemical admixtures generally used for hot weather concreting are air-entraining agents, water-reducing agents, air-entraining and water-reducing agents and air-entraining and high-range water reducing agents. When using water-reducing agent, air-entraining and water-reducing agent or air-entraining-high-range water reducing agent, a retarding type rather than a ordinary type is effective and practical. When a retarding agent is applied with the purpose of preventing cold joints, the method shall be fully considered and especially, its dosage shall be determined properly. When air-entraining and high-range water reducing agent is used for hot weather concreting, it is also possible to considerably reduce unit water content and unit cement content. However, it is necessary to pay the attention to the possible loss in slump value with time for some type of high-range water reducing agent.

For mass concrete, there are fly ash and blast-furnace slag as mineral admixtures, and air-entraining agents, water-reducing agents, air-entraining and water-reducing agents and air-entraining and high-range water reducing agents as chemical admixtures. Using of fly ash with sufficient quality has many advantageous effects on the properties of concrete such as improvement in workability, reduction of unit water content, increase in long-term strength. Besides, fly ash is an advantageous material in order to control cracking due to thermal stresses, because the temperature rise resulting from hydration heat of concrete becomes lower. When blast-furnace slag with quality is properly used, it becomes possible not only to increase long-term strength but also slow the generation rate of heat of hydration. (see “Recommendation for Blast-furnace Slag Concrete”)

On the other hand, when a air-entraining agent, water-reducing agent, air-entraining and water-reducing agent or air-entraining high-range water reducing agent is properly used, it is possible to reduce unit water content and unit cement content, since the workability of the concrete is improved. And this results in lower temperature rise of the concrete. When a large quantity of concrete is placed, a retarding type of a water-reducing agent or air-entraining and water-reducing agent may be used in order to slow the generation rate of heat of hydration and prevent cold joints. However, in this case, it is important to confirm the effect on the degree of set-retarding and strength development of concrete by testing and so on prior to the application, because the setting time may be considerably retarded according to combined effect of using admixtures and temperature condition at the application.

3.5.2 Mineral admixtures

(1) Fly ash used as mineral admixture should comply with the provisions specified in JIS A 6201.

(2) Expansive admixtures used as mineral admixtures should comply with the provisions specified in JIS A 6202.

(3) Ground granulated blast-furnace slag used as mineral admixture should comply with the provisions specified in JIS A 6206.

(4) Silica fume used as mineral admixture should comply with the provisions specified in JIS A 6207.

(5) The quality and utilization method of mineral admixtures other than Clauses (1), (2), (3) and (4) shall be investigated thoroughly.

[Commentary] (1) When properly used, high quality fly ash has many excellent effects on the properties of concrete such as improving workability, reducing unit water content, controlling heat of hydration, increasing long-term strength, reducing drying shrinkage, improving water tightness and improving resistance to chemical attack, etc. However, the quality of fly ash widely varies according to the quality of coal, combustion mechanism and processes of collection. Therefore, the fly ash used should comply with the provisions specified in JIS A 6201 “Fly Ash.” Recently, production of fly ash has been increasing, but except for some regions, it is difficult to obtain a large amount of fly ash with quality continuously. Therefore, it is advised to confirm whether or not a required amount of fly ash can be supplied. When fly ash is used, “Recommendation for Fly Ash Concrete” should be referred to.

(2) By properly using expansive admixtures, it is possible to reduce cracking of concrete caused by hardening shrinkage or to increase cracking strength of concrete by introducing chemical prestress. As these effects vary according to chemical composition, fineness, etc. of expansive admixtures, expansive admixtures to be used should comply with the provisions specified in JIS A 6202 “Expansive Admixtures for Concrete“ (see Chapter 4 in the part of special concrete and the “Recommendation for Expansive Cement Concrete”) as standard.

(3) By using properly ground powder of granulated blast-furnace slag, which has been cooled rapidly and has a glassy quality, it is possible to produce concrete having higher long-term strength, lower heat of hydration, better water-tightness and permeation of chloride ion into concrete, higher chemical resistance to sulfates or sea water, and also possible to suppress alkali-aggregate reaction and obtain higher strength. Moreover, the workability of concrete is not adversely affected by its use, and unit water content needs no to be increased even when very finely ground slag is used. But these effects vary according to the chemical compositions of slag, cooling rate, fineness and dosages of ground slag, the addition or non-addition of gypsum, the quality of cement to be mixed with, unit cementitious material contents, etc., so that this material should comply with the provisions specified in JIS A 6206 “Blast-furnace Slag“. As the quality of concrete containing ground slag is easily affected by the curing temperature and the term of wet curing, if construction methods are not suitable for the concrete, insufficient development of the required strength or the rapid carbonation of concrete may be induced. In addition, since the unit dosage of ground slag is quite large in comparison to that of other admixtures and ground slag is expected to play a important role as a cementitious material, if batching and mixing machines are unsuitable or control of the work-process is not adequate, concretes of the required qualities can not be acquired. This point shall be sufficiently taken into account during the planning and execution of construction. (see the “Recommendation for Blast-furnace Slag Concrete”)

At present, 3 types of ground granulated blast-furnace slag are specified in JIS. They are blast-furnace slag 4000, 6000 and 8000. Therefore, it is necessary to determine the type of blast-furnace slag and its replacing ratio in consideration with the purpose of use. Generally, blast-furnace slag 4000 is used in many cases. For the special applications, i.e. strength improvement in early ages, blast-furnace slag 6000 or 8000 may be used.

(4) Silica fume is a by-product of silicone or ferro-silicone production and consists of super-fine spherical particles. The average particle size is about 0.1μm, specific surface area (by gas absorption method) is about 20 m^2/g and density is about 2.2 g/cm^3. The main component of silica fume is amorphous SiO_2. Mixing silica fume in concrete has some advantages such as the prevention of material segregation, the reduction of bleeding, a remarkable increase of strength, and the improvement of water-tightness and chemical durability in comparison to ordinary concrete. On the other hand, it has disadvantages such as increasing the unit water content and increasing drying shrinkage. Therefore, in application, it is necessary to take some counter-measures such as using high-range water-reducing admixtures. The quality of silica fume is considerably different by localities, stock periods and form of the product, - powder or grain-, etc. because most part of the supply depends on the import. It is important to confirm that the silica fume used should comply with the provisions specified in JIS A 6207 “Silica Fume for Concrete”. When silica fume is used, the “Recommendation for Silica-Fume Concrete” should be referred to.

(5) As mineral admixtures other than Clauses (1), (2), (3) and (4), there are siliceous fine powder, pozzolans, limestone fine powder admixtures for high strength and so on. There is at present, no specification of quality for these mineral admixtures, and methods of their use are

different. When using these materials, therefore, it is necessary to confirm their quality and investigate the methods of use by referring to information and by testing. In other words, it is necessary to investigate not only their quality, performance, service records, uniformity, prices and other items, but also the effects of their use on the workability, strength, durability, water-tightness, volume change, capability of protecting steel and prices of concrete.

Siliceous fines, which are composed mainly of quartz, are often used to provide concrete to be cure in an autoclave with extra strength. Other pozzolans that generate calcium silicate hydrates by reacting with calcium hydrate at room temperature include the fly ash and silica fume mentioned above and natural materials such as siliceous white clay, volcanic ash and diatomite, and artificial materials such as burnt clay.

Limestone powder is a powdery material produced by grinding limestone so that the Blaine specific surface area becomes 3000 to 7000 cm^2/g. Limestone powder is used to prevent segregation and bleeding of concrete. It has been reported that limestone powder reacts with C_3A, etc., to generate hydrates such as monocarbonates (C_3A, $CaCO_3$, $11H_2O$). This Specification, however, does not regard limestone powder as a binder because the reaction with C_3A in cement and the relationship between the generation of C_3A and strength are as yet not clarified. Standards for limestone powder that can be used as guides include JCI-SLP, Standard for Quality of Limestone Powder for Concrete, JIS A 5008, Limestone Filler for Bituminous Paving Mixtures, and standards proposed by other organizations such as the former Honshu–Shikoku Bridge Authority and the former Japan Railway Construction Public Corporation.

3.5.3 Chemical admixtures

(1) Air-entraining agents, water-reducing agents, air-entraining and water-reducing agents and air-entraining, high-range water reducing agents and superplasticizers used as chemical admixtures should comply with the provisions specified in JIS A 6204.

(2) Corrosion inhibitors for reinforcing steel used as chemical admixtures should comply with the provisions specified in JIS A 6205.

(3) The quality and utilization method of chemical admixtures other than Clause (1) and (2), shall be investigated thoroughly.

[Commentary] (1) Though several types of air-entraining agents, water-reducing agents, air-entraining and water-reducing agents or air-entraining and high-range water reducing agents are available, their quality and performance are quite different. Therefore, only good quality chemical admixtures conforming to the requirements of JIS A 6204 “Chemical Admixtures for Concrete” should be used. In JIS A 6204, chemical admixtures for concrete are classified into air-entraining agents, water-reducing agents (standard, retarding and accelerating types), air-entraining and water-reducing agents (standard, retarding and accelerating types) and air-entraining and high-range water reducing agents (standard and retarding types). And, chemical admixtures are also classified into the types 1, 2, and 3 by the amount of chloride ions supplied from admixtures to concrete. Therefore, when chemical admixtures are used, the adequate type of chemical admixture shall be selected in consideration with purpose of its use, setting time, hardening rate or limit of chloride content in concrete, etc. Proper use of air-entraining agents, water-reducing agents, air-entraining and water-reducing agents and air-entraining and high-range water reducing agents in concrete may results is many desirable effects such as reduction of unit water content, improvement of workability, increase in resistance to freezing and thawing, improvement in water-tightness, etc.

The effect of these agents may, however, vary depending on the quality of cement, aggregates and the agents themselves, mix proportions, method of construction, etc. Even in cases when the air content is the same, the effect may actually be different depending upon the average size of air voids or their distribution.

Air-entraining and high-range water reducing agent has an ability of air-entraining itself. It can decrease water content more than ordinary air-entraining and water-reducing agents, and slump loss becomes small. Therefore, it is possible not only to reduce the unit water content rather than when using ordinary air-entraining and water-reducing agents, but also to make the concrete which has the same flowability as superplasticized concrete in ready-mixed plants. And, it is possible to choose the dosage for its purpose of use within the wide range. However, when air-entraining and high-range water reducing agent is used, performance of concrete such as less change in slump or workability is easily affected by service conditions like as atmospheric temperature, materials and so on in comparison with ordinary concrete. Therefore, when using air-entraining and high-range water reducing agent, the characteristics of concrete and the limit of the effect must be sufficiently understood. And, it must be sufficiently examined that the appropriate usage of air-entraining and high-range water reducing agent in order to surely obtain the effect for the purpose prior to the real application. And, it is also important to appropriately treat the concrete with air-entraining and high-range water reducing agent, because of the different workability from the ordinary using usual air-entraining and water reducing agent. (see "Recommended Practice for Concrete used Air-entraining and High-range Water-reducing Agents")

High-range water-reducers are characterized by high water-reducing, low set-retarding and low air-entraining effects and can be classified, according to chemical composition into a number of groups including polycarboxylic acid, naphthalene, melamine and other types. With their high water-reducing and low air-entraining effects, high-range water reducers make it possible to easily obtain high-strength concrete with a compressive strength of about 80 to 100 N/mm^2. If, however, naphthalene and melamine type high-range water reducers are used, care needs to be taken because a large slump loss may occur or freeze–thaw resistance may become low if an air-entraining agent is not used.

Standard-type superplasticizers are used in ordinary concreting work and have been used in many projects. Retarder-type superplasticizers have both a superplasticizing effect and a set-retarding effect and are used to reduce post-superplasticization slump losses when concrete is place under hot weather or the transportation of concrete takes long time. Since the setting delay time of a set-retarding type superplasticizer varies with the quantity of the admixture used, it may not be possible to achieve the required set-retarding effect depending on the service conditions or mix proportions of concrete. It is good practice to trying to control the set-retarding effect suitable for the purpose by paying attention to chemical admixtures added to the base concrete. Care needs to be taken because the setting of concrete containing a retarder-type superplasticizer may be excessively delayed under the influence of the chemical admixtures added to the base concrete so that the durability of the concrete decreases (see Recommended Practice for Concrete Containing Superplasticizers).

(2) Corrosion inhibitors for reinforcing bars in concrete are chemical admixtures to be used for suppressing the corrosion caused by chloride from the use of sea sand. Corrosion inhibitors may be classified into the following 3 types : (i) Corrosion inhibitors of passive film-forming type, (ii) Corrosion inhibitors of precipitation film-forming type and (iii) Corrosion inhibitors of adsorption film-forming type. At present, all of the inhibitors available in the market have a nitrite component as main constituent and suppress corrosion by oxidizing the metal surface and form the passive film. All types of inhibitors are required not only to inhibit corrosion sufficiently for a long time, but also

not to disturb the setting, hardening and durability of concrete. Moreover, they are required to be easy to use and not to contain harmful components to the human body. Some papers report that local corrosion of steel becomes remarkable under the environment where much chloride ions permeate from outside of concrete structure because of insufficient effect of inhibitors even if the required quantity of inhibitors for corrosion protection of steel against chloride in sea sand is added. Therefore, when a inhibitor is applied for construction of concrete structures under these environmental conditions, the dosage and the effect of inhibitor shall be examined sufficiently.

(3) For chemical admixtures other than Clauses (1) and (2), there are no specifications on their quality, and the methods of use are different. It is necessary in the employment of them to confirm their quality and investigate the methods of use by researching the service records and doing sufficient tests. That is to say, it is necessary to research the quality, performance, service records, uniformity, price, etc., and to investigate their effects on workability, strength, durability, water-tightness, volume change, steel-protective quality, and cost of concrete.

3.6 Reinforcing Materials

3.6.1 Reinforcing bars

(1) It is a standard requirement that all reinforcing bars used conform to JIS G 3112, JIS G 3117 or JSCE-E 121.

(2) If reinforcing bars not conforming to JIS G 23112 or JIS G 3117 are to be used, tests shall be conducted to verify that the design values are met and determine the method of using those reinforcing bars.

(3) It is a standard requirement that all epoxy-coated reinforcing bars used conform to JSCE-E 102.

[Commentary] (1) It must be ascertained that all reinforcing bars used meet the values specified in JIS G 3112, Steel Bars for Concrete Reinforcement, JIS G 3117, Rerolled Bars for Concrete Reinforcement, and JSCE-E 121, Standard for Quality of D57and D64 Threaded and Ribbed Steel Bars for Concrete Reinforcement. Steel bars used for concrete reinforcement can be classified into two types, namely, those made from pig iron and those made from steel scraps by using blast furnaces. Most of the steel bars for concrete reinforcement in use today are those made by use of blast furnaces. Rerolled steel bars for concrete reinforcement are steel bars made from iron scraps by cold rolling. Steel bars of this type are seldom used today because of concern about their quality.

JIS G 3112 specifies (1) chemical composition, (2) mechanical properties and (3) shapes, dimensions, masses and tolerances for seven types of steel bars, namely, SR235, SR295, SD295A, SD295B, SD345, SD390 and SD490. For SD295B, SD345, SD390 and SD490, JIS G 3112 specifies not only lower limits but also upper limits to the yield point and 0.2% strength.

In JIS G 3117 “Rerolled Steel Bars for Concrete Reinforcement” mechanical properties, shapes and dimension, mass, allowable difference and so on are specified for SRR235, SRR295, SDR235, SDR295 and SDR345. These specifications are used as its quality. The specifications of shape and dimension and mass are the same as those of JIS G 3112. In addition specifications of the mechanical properties of SRR235, SRR295 and SDR295 are the same as those of SR235, SR295 and SD295A, respectively.

Nominal diameter, cross section area, unit mass and so on are specified for D6 to D51 in the JIS G 3112. Their allowance limits are also provided. Recently a steel bar of D51 or larger diameters has been used with constructions of larger sizes to implement a rational design. For the use of D57 or D64 the JSCE-E121 “Quality Specification for Larger Size Steel Bars of D57 and D64” is referred for the specification. Chemical constituents, upper limit and lower limit of yield strength, elongation, inside radius of a moment curvature and so on are specified for SD295-N, SD345-N, SD390-N and SD490-N. In the case of using steel bars of D57 or D64, design values and method to use should be determined by the Standard Specifications for Concrete Structures “Design”.

(2) Reinforcing steel bars that do not conform to JIS G 3112 and JIS G 3117 may not only be unreliable in terms of quality but also have inappropriate details such as inappropriate rib shapes. For steel bars that do not conform to JIS G 3112 and JIS G 3117, it is important for the responsible engineer to verify by conducting reliable tests in advance that the specified design values are met and, on the basis of the results thus obtained, judge the usability of the steel bars and specify the method of using them.

Using epoxy-coated reinforcing bar may be beneficial for reinforced concrete structures in a marine environment as to prevents chloride ions from directly reaching the surface of the steel bar. Powder type epoxy coating is applied to the surface of a steel bar using static powder coating technique. Performance of epoxy coated reinforcing bars in terms of corrosion inhibition depends on the quality of epoxy coating, surface preparation of steel, thickness of coating and the presence of pinholes. Impact and bending of bars could cause cracking and delamination of the coating, and adversely affect the corrosion inhibition performance. Details of the materials used and the relevant test methods are described in JSCE-E 102 “Quality Specification for Epoxy Coated Reinforced Bar (Draft)”. Therefore, an epoxy coated reinforcing bar that complies with the provisions of JSCE-E102 may be considered to be suitable for use. Epoxy coated reinforcing bar used shall comply with the provisions of the “Recommendation for Design and Construction of Concrete Structures Using Epoxy-coated Reinforced Steel Bar”.

3.6.2 Prestressing steel

(1) The prestressing wires and strands should conform to JIS G 3536 in general.

(2) The prestressing bars should conform to either JIS G 3109 or JIS G 3137 in general.

(3) When prestressing steel that is not mentioned in Item (1) or (2) is, tests shall be conducted to verify that the design values are met and determine the method of using the prestressing steel.

(4) In cases when prestressing steel is reprocessed, or heat-treated for use in anchoring, coupling, assembling or layout, it shall be experimentally ensured that the quality of the prestressing bars has not been adversely affected.

[Commentary] (1) JIS G 3536 “Prestressing Wires and Strands” describes the mechanical properties, shapes, dimensions, tolerances, etc. for two types of prestressing wires and five types of prestressing strands. These descriptions may be used as the quality specification. Mechanical properties have been specified in terms of loads corresponding to 0.2% permanent elongation, tensile capacity of load, elongation and the ratio of relaxation. The surface irregularities of a deformed prestressing wire aren’t particularly specified. However the bond strength and fatigue strength of wire itself often depend on the surface irregularities. Therefore, the characteristic strength should be determined by tests.

(2) In JIS G 3109 “Steel Bar for Prestressed Concrete” and JIS G 3137 “Deformed Prestressing Bars of Small Diameter”, the descriptions relating to a)chemical constituents, b)mechanical properties and c)shapes, dimension, and tolerances are shown for three types of prestressing steel bars and three types of deformed prestressing steel bars of small diameter, respectively. These descriptions may be used as the quality specification. Mechanical properties of different types of prestressing steel have been specified in terms of stress corresponding to 0.2% permanent elongation, tensile strength, elongation, and the ratio of relaxation.

Although the strength of prestressing steel bars is normally lower than those of prestressing wires and prestressing strands the modification of the ends of prestressing steel bars results in beneficial effects that anchoring is easily achieved. The relaxation of prestressing steel bars is lower than those of normally used prestressing wires and prestressing strands but is similar to those of particular ones with lower relaxation. Prestressing steel bars of larger diameter exhibit larger reductions of the quality due to bending. In addition the quality of the portion that is modified for anchoring must be examined if it can ensure sufficient performance. It is sometimes encountered that prestressing steel bars are hardly normal to anchoring cross section in the anchoring portion and becomes never straight at the portion with connection devices. For those cases a local bending of the prestressing steel bars will be induced resulting in rapture due to stress corrosion or delayed failure. To avoid those it is recommended that prestressing steel bars of large elongation capacity and ductility be used.

When an end of the prestressing steel bar is threaded for anchoring or coupling roll-threading must be conducted instead of thread-cutting because the thread-cutting reduces the effective diameter of the threaded portion, thereby largely adversely affecting the tensile strength of the bar. When large-diameter prestressing steel bars are threaded using the roll-threading method, only minor reduction of the effective diameter occurs and the tensile load carrying capacity at the threaded portion may be increased due to the effect of cold-working. In case of small-diameter prestressing steel bars, however, major reduction of the effective diameter occurs, which may cause reduction of the tensile load carrying capacity at the threaded portion. In this case, the threaded portion may not meet the standard of the prestressing steel bars. Therefore, the prestressing steel bars must be tested to confirm that they satisfy the design requirements. The design tensile load carrying capacity of the prestressing steel bars may be calculated by multiplying the tensile strength and the nominal sectional area specified in JIS G 3109. When the roll-threaded or headed portion of the bar does not meet the specified tensile load carrying capacity of the bar itself the design values must be modified in the same manner as prescribed in Clause (4) of this Section.

(3) Usually, JIS-specified prestressing steel is the safest and is also economical. If special prestressing tendons that are not described in Item (1) or (2) of Section 3.6.2 are used, it is necessary to determine the variability of quality by conducting tests on a sufficient number of specimens. In such cases, it must be ascertained on the basis of values reflecting an appropriate defect percentage in accordance with JIS Z 9004, Single Sampling Inspection Plans Having Desired Operating Characteristics by Variables (Standard Deviation Unknown and Single Limit Specified) that the specified design values are met. The requirements related to tensioning materials other than prestressing tendons are described in Section 3.6.4, Other Reinforcing Materials.

(4) When prestressing steel bar is subjected to grinding or bending, or rolled-threaded, headed or heated for anchoring, coupling, assembling and arranging the strength and the other quality of the steel may deteriorate depending on the treatments. If the deterioration is minor it can be coped with in consideration of the proper arrangement of the prestressing steel, anchorage or couplers. In turn if

the deterioration occurs on a large scale it is difficult to make up for this by only such consideration. Therefore, for the deteriorated steel the strength and the other design values shall be modified by tests, if needed.

In case for the prestressing steel bar treated of re-bending or heated, following considerations may be referred for a new specification corresponding to the reduction rate of the strength of the treated prestressing steel bars.

(a) In a case when the strength reduction is equal to or less than 5 %: if the tensile strength of prestressing steel bars which have been re-bent or heated is equal to or greater than 95 % of the original value can be applied in the design under condition that the proper arrangement of prestressing steel, anchorages and couplers is implemented.

(b) In a case when the strength reduction is greater than 5 % but less than 10 %: if the tensile strength of prestressing steel which has been re-bent or heated is more than 90 % but less than 95 % of the original standard value, the standard value to be used in the design shall be modified by testing.

(c) In a case when the strength reduction is equal to or more than 10 %: if the tensile strength of prestressing steel bar which has been re-bent or heated is equal to or less than 90 % of the original standard value, such re-bending or heating method must be generally avoided.

3.6.3 Structural steel

The structural steel should conform to JIS G 3101, JIS G3106 or JIS G 3136 in general.

[Commentary] JIS G 3101 "Rolled Steels for General Structures" specifies for four types of rolled steels, SS330, SS400, SS490 and SS540 on a) chemical constituents, b) mechanical properties, c) shapes, dimensions and mass, and their allowances. Similarly JIS G 3106 "Rolled Steels for Welded Structures" specifies for eleven types of the rolled steels ranging from SM400A to SM570 and JIS A 3136 "Rolled Steels for Building Structures" that has been standardized in 1996 specifies for the heated rolled steels that are used mainly for steel-made structures of buildings. These specification described in each standard may be considered to be the quality of the rolled steels. The mechanical properties include yielded strength or load carrying capacity, tensile strength, elongation, and inner radius of the bent-over. Steel bars for steel-reinforced concrete structures are in principal selected on the basis of its yielded strength similar to that of reinforcement bar used together.

3.6.4 Other reinforcing steel

The quality of other reinforcing steel shall be appropriately confirmed and careful attention paid to the method of using them.

[Commentary] There are many reinforcing materials, other than those mentioned above, for which there is as yet no quality standard, and there are many types and many methods for using them. When using those reinforcing materials, therefore, it is necessary to conduct thorough studies and tests to ascertain quality and identify methods for using those materials.

There are cases where reinforcing materials composed partially of fibers are used with the aim of achieving higher quality of hardened concrete or preventing spalling of concrete used in tunnels or other structures. Fibers used in such cases can be largely classified into two categories: short fibers and continuous fibers. Examples of short fibers are inorganic fibers including metal fibers such as steel fibers and stainless steel fibers, glass fibers, carbon fibers and ceramic fibers. There are also organic fibers such as aramid, nylon, vinylon, polyethylene and polypropylene. When using short fibers, it is good practice to conduct tests in advance to check on the quality of the fibers to be used because suitable diameters, lengths and shapes vary with the intended use of the fibers. JSCE-E 101, Standard for Quality of Steel Fibers for Concrete, can be used as a guide for the quality of steel fibers. Concerning the production of short fiber-reinforced concrete, the Construction: Special Concretes of this Specification (Chapter 5, Short Fiber Reinforced Concrete) can be used as a guide.

Continuous fiber reinforcing materials are continuous fibers cemented either into bars to be used as substitutes for steel bars or prestressing tendons or into sheets. The former are used mainly as concrete reinforcing or tensioning members, while the latter are used for the repair or reinforcement of concrete. There are five types of fibers used in continuous fiber reinforcing materials: carbon fibers, aramid fibers, glass fibers, vinylon fibers and their mixtures. Continuous fiber reinforcing materials can also be broadly classified, according to shapes, into five types: rod, strand, braid, mesh, and rectangular plate. Because the material, shape, quality and other characteristics of continuous fiber reinforcing materials vary widely among different types, it is recommended that standard-conforming tests be conducted in advance as in the case of steel fibers to verify quality (see the standard section of this Specification). Also, when producing continuous fiber reinforced concrete, it is good practice to refer to the Construction: Special Concretes of this Specification (Chapter 4, Continuous Fiber Reinforced Concrete).

Continuous fiber reinforcing materials are easily damaged when placed directly on the ground or floor surface and are subject to quality degradation. Furthermore, continuous fiber reinforcing materials may deteriorate, depending on the type of fiber, if placed at a place exposed to high temperature or ultraviolet rays or under the influence of chemicals. When storing continuous fiber reinforcing materials, therefore, it is necessary to protect them from those influences.

3.7 Storage of Materials

3.7.1 Storage of cement

(1) Different types of cement shall be stored separately in damp-proof silos, warehouses or other storage facilities.

(2) Silos shall be designed so that there is no dead storage area near the bottom of the storage space.

(3) When cement that has been stored for a long period of time is, the cement shall be tested to ascertain its quality prior to the use.

(4) When the temperature of cement is excessively high, the temperature of the cement shall be lowered prior to the use.

[Commentary] (1) When in contact with air while in storage, cement undergoes light hydration by absorbing moisture from the air and simultaneously reacts with carbon dioxide in the air. This process is referred to as weathering of cement. As cement weathers, the ignition loss increases and density decreases so that setting is delayed or strength decreases with the progress of weathering. It is necessary, therefore, not only to keep moisture away from cement but also to store cement in an unventilated condition. If cement is stored in a highly airtight silo designed to prevent internal condensation, the quality of the cement hardly changes even if the cement is stored for a relatively long period of time. It is desirable that the capacity of a silo be equal to or greater than three times the average quantity of cement used in one day. If cement can be supplied smoothly because there is a concrete mixing plant at a relatively short distance from the cement service station, silo capacity can be made smaller.

If bags of cement are stored for a relatively long period of time or during a high-humidity period, it is good practice to take weathering prevention measures such as using bags lined with a damp-proof membrane. In order to protect bags of cement in storage from moisture from the ground, the warehouse floor needs to be kept a sufficient distance away from the ground. In the case of a wooden warehouse, for example, at least 30 cm is required. In order to protect cement in storage from condensation due to rain or the difference between internal and external temperatures, it is important to stack bags of cement so that they do not come into contact with the warehouse walls. If bags of cement are stacked while in storage, the cement in the lower bags might consolidate. A recommended limit to the number of layers of stacked bags of cement, therefore, is about 13.

(2) Cement silos should have features or provisions to prevent the occurrence of dead storage areas where stored cement does not flow out or is stuck, such as nonsymmetrical structure, a steep bottom cone to facilitate flow, or vibrators or aerators to facilitate flow movement. It is also necessary to inspect and clean silos at appropriate frequencies.

(3) Needless to say, cement containing lumps formed while the cement is storage must not be used. In the case of cement that may have been exposed to moisture because of storage over a long period of time, it is necessary to conduct tests (e.g., mortar tests) and evaluate the usability of the cement.

(4) As the temperature of cement changes by 8°C, the as-mixed temperature concrete rises or falls by 1°C. The influence of cement temperature on concrete temperature is smaller than the influence of aggregate and water. If, however, cement with an excessively high temperature is used, the as-mixed temperature of concrete may rise so as to cause abnormal consolidation or a decrease in slump. It may be necessary, therefore, to impose limits on cement temperature at the time of shipping from a factory or at the time of delivery at the construction site. The temperature of delivered cement varies with the transportation route from the cement factory and the time of year. For example, the average temperature of cement shipped directly from a cement factory ranges from 50 to 80°C. If cement is transported by ship or stored at a service station, cement temperature tends to be slightly lower. In general, no problem arises if cement with a temperature of 50°C or lower is used.

3.7.2 Storage of aggregates

(1) Fine aggregate and coarse aggregate and aggregate of different types, from different places of origin or of different particle sizes shall be isolated and stored separately.

(2) Aggregates shall be received, stored and handled carefully by using machinery and equipment of appropriate structure in order to prevent problems such as the separation of large and small particles, the inclusion of foreign matter and damage to coarse aggregate.

(3) Aggregate storage facilities shall be provided with appropriate drainage facilities so that surface moisture conditions become uniform.

(4) In times of cold weather, aggregates shall be stored by use of appropriate facilities to prevent the inclusion of ice and snow and freezing.

(5) Aggregates shall be stored by use of appropriate facilities to, for example, keep cement away from direct sunlight in order to prevent aggregate from drying and temperature from rising under hot weather.

[Commentary] (1) In order to produce concrete of consistent quality, it is necessary to make sure that the quality of aggregate used is always consistent. Different types of aggregate such as gravel, sand, crushed stone, blast furnace slag aggregate and lightweight aggregate, aggregate of different particle sizes or maximum particle sizes, aggregate that has been graded in advance, and the like must be isolated from one another by using appropriate dividing devices and be stored separately. If the particle sizes of coarse aggregate fall within the range from 20 to 5 mm, it is good practice to divide the aggregate into two classes, namely, 20 to 10 mm and 10 to 5 mm, and store them separately. Similar care needs to be taken in connection with the receiving of delivered aggregate and the handling of aggregate from the storage area to the mixing area.

(2) In order to prevent the segregation of aggregate, it is necessary to take preventive measures such as avoiding a sloping area where aggregate rolls down. One way to prevent the inclusion of foreign matter is to store aggregate on a concrete floor and surround the storage area with trenches or walls. Care should be taken to make sure that mud and other foreign matter sticking to the tires of aggregate hauling vehicles is not mix into the aggregate. Shovel loaders with rubber tires should be used to handle aggregate because crawler-mounted loaders crush aggregate and wear the concrete floor. Top-feed bottom-discharge silos are recommended.

(3) If concrete of consistent quality is to be produced, it is desirable that aggregate with consistent particle size distribution be used and the surface moisture content of aggregate be stable so that the water content can be kept constant. If the surface moisture content of aggregate is not constant, it is necessary to adjust the water content on a batch-by-batch basis, making production control almost impossible to perform. The basic rule, therefore, is to store aggregate so that the surface moisture content of aggregate can be kept uniform. If delivered aggregate is used immediately, it is difficult to cope with changing particle size distributions and surface moisture contents by, for example, changing mix proportions. Good practice, therefore, is to use storage facilities of appropriate capacity and provide drainage facilities so that the surface moisture conditions become uniform. It is therefore important to prepare facilities and perform management so that delivered aggregate is used in the order of delivery.

In cases where blast furnace slag aggregate or lightweight aggregate is stored, it is desirable that watering devices such as sprinklers as well as drainage facilities be provided. The reason is that because pumping of concrete has increased in recent years, in the case of blast furnace slag aggregate or lightweight aggregate, both of which are more absorptive than gravel and crushed stone, the slump of concrete may decrease considerably during pumping if water is not sprayed to some extent in advance.

(4) If frozen aggregate or aggregate containing ice or snow is used as is under cold weather, the temperature of concrete may decrease so that concrete freezes or the water content increases. In order to prevent the intrusion of ice and snow, therefore, it is important to cover aggregate with something or store aggregate in roofed storage facilities.

(5) If aggregate that has been exposed to baking heat under hot weather for a long period of time is used, concrete temperature may rise. If this occurs, workability may change considerably while the concrete is being transported or handled or consolidation may be extremely accelerated so that satisfactory construction work cannot be carried out. In order to prevent this problem, it is important to provide appropriate covering or water spraying facilities at the places where aggregate is stored. If blast furnace slag fine aggregate is to be stored for a long period of time during a period in which daily mean temperature exceeds 20°C, it is necessary to pay careful attention to the management of its storage. In the case of a cylindrical silo made of corrugated metal members or other materials that greatly reduces work efficiency in the event of consolidation, the silo should be designed to prevent the occurrence of near-bottom dead storage areas from which stored aggregate cannot be extracted, and attention should also be paid to the level of consolidation control.

3.7.3 Storage of admixtures

(1) Different types of admixtures shall be stored separately in damp-proof silos, warehouses or other storage facilities.

(2) When an admixture that has been stored for a long period of time is used, the admixture shall be tested to ascertain its quality prior to the use.

(3) Admixtures shall be handled carefully so that they are not scattered about.

[Commentary] (1) Admixtures are usually absorptive, and an admixture that has absorbed moisture may consolidate or deteriorate in performance so that the required quality cannot be achieved. For example, fly ash consolidates when a very small amount of gypsum contained in the fly ash absorbs moisture, and silica fume, which is very fine-grained, is more absorptive than other admixtures and is therefore prone to consolidation. Because expansive admixtures for concrete contain a large quantity of free calcium oxide, they are more prone to weathering than cement. If different types of admixtures are mixed together, it may not be possible to attain the expected effect. It is therefore necessary to separate different types of admixtures and store them separately in damp-proof silos, warehouses or other storage facilities. Bagged, canned or otherwise packaged admixtures must be stored so that the packages are not broken or damaged and can be easily identified and inspected.

(2) If admixtures are stored for a long period of time, the quality of the admixtures may change even if they are carefully stored. If, therefore, the storage period has become long, the usability of the admixture must be evaluated after conducting a test again and ascertaining the degree of influence of the long storage period on the concrete.

(3) Powdered admixtures tend to be scattered about in bag splitting areas and around silo outlets so as to cause measuring instruments to break down. During humid periods, scattered powder tends to stick to the surfaces of silos and transportation equipment. It is important, therefore, to carefully handle powdered admixtures so that powder is not scattered about. It may also be necessary to provide dust control equipment.

3.7.4 Storage of chemical admixtures

(1) Chemical admixtures shall be stored so that impurities such as waste materials are not mixed into the admixtures. Liquid chemical admixtures shall be stored so that neither segregation nor alteration results. Powdered chemical admixtures shall be stored so that they do not absorb water moisture or consolidate.

(2) Chemical admixtures that have been in storage for a long period of time or that have been found to be in an anomalous condition shall be tested prior to the use to make sure that their performance had not deteriorated.

[Commentary] (1) Impurities such as waste materials in a chemical admixture may alter the quality of the chemical admixture so that the expected effect cannot be achieved. In the case of a chemical admixture that is used in very small quantities such as an air-entraining agent, impurities could hamper accurate measurement of required quantities. Impurities in a liquid chemical admixture could cause malfunctioning of feed pumps or instrument valves. When storing chemical admixtures, therefore, it is necessary to exercise due care to prevent the inclusion of waste materials and other impurities. In the case of a liquid chemical admixture, not only the inclusion of impurities but also changes in concentration due to the evaporation of moisture or the intrusion of rainwater can be prevented by storing the admixture in a closed tank. When different types of chemical admixtures are stored, it is necessary to exercise due care so as not to use the same containers for more than one type of chemical admixture or inadvertently mix different types of chemical admixtures.

When a chemical admixture freezes, segregation of ingredients occurs. It is therefore necessary in winter to take measures to prevent chemical admixtures from freezing. It is in many cases possible, however, to restore the performance of a chemical admixture that has undergone segregation because of freezing by completely melting and remixing the frozen admixture. Powdered chemical admixtures are highly hygroscopic, and certain types of powdered chemical admixtures even deliquesce. These types of chemical admixtures must be stored in damp-proof, unventilated storage facilities.

In view of these factors, when storing chemical admixtures, it is necessary to take meticulous preventive measures such as shielding sunlight, keeping fire away and preventing freezing.

(2) If chemical admixtures are stored for a long period of time, the quality of the admixtures may change even if they are carefully stored. For example, storing a liquid chemical admixture for a long period of time may result in not only segregation but also decomposition or alteration due to rust forming on iron containers. The evaporation of moisture may result in a higher concentration and the solidification of the surface layer. If, therefore, chemical admixtures have been stored for a long period of time or have been found to be in an anomalous condition, it is necessary to evaluate the influence on the concrete by testing them again and determine whether they can be used. Even if the quantity of a chemical admixture used is small, its influence on the concrete is great. Care must be taken because even a small change in the quality of a chemical admixture may result in a significant difference in the quality of concrete.

3.7.5 Storage of steel

(1) Reinforcing bars and structural steel shall be supported at appropriate spacing and stored in storage facilities or, if stored outdoors, under appropriate cover instead of being

placed directly on the ground surface.

(2) Prestressing steel shall be supported at appropriate spacing and stored in storage facilities or, if stored outdoors, under appropriate cover for protection from harmful substances such as oil, chlorides and waste materials and harmful processes and effects such as corrosion, damage and deformation.

[Commentary] (1) The reason why steel reinforcing bars and structural steel must not be placed directly on the ground surface is that they need to be protected from rusting or contamination. The reason why reinforcing bars and structural steel are stored in storage facilities or under appropriate cover is that the corrosion of reinforcing bars and structural steel due to rain, condensation, corrosive salt air, etc., needs to be prevented. When storing steel reinforcing bars and structural steel, it is necessary to support them at appropriate spacing for easy handling and convenience in inspection. Steel reinforcing bars and structural steel of different material types should be stored separately. Steel reinforcing bars of different diameters and structural steel items of different cross-sectional shapes and dimensions should also be stored separately.

(2) When storing prestressing steel, it is necessary not only to be as careful as with steel reinforcing bars and structural steel but also to make special arrangements. The reason why prestressing steel must not be placed directly on the ground surface is that it is necessary not only to prevent rusting and corrosion due to moisture and prevent foreign matter such as oil, waste materials and mud from sticking to prestressing steel but also to make handing of prestressing steel easier. The reason why prestressing steel must be stored in storage facilities or under appropriate cover is that rusting and corrosion due to rain, condensation, corrosive salt air, etc., needs to be prevented.

Prestressing steel requires careful attention because oil, waste materials, mud, etc., sticking to steel surfaces may cause steel–concrete bond strength to decrease. Because threaded portions of steel items are particularly prone to strength loss due to corrosion, they must be stored so that they are perfectly protected from corrosion. If coils of prestressing steel wire and prestressing steel strand are stacked in multiple layers for storage, harmful flexural loading from the upper coils may cause stress-induced corrosion. It is therefore necessary to take such measures as restricting the number of stacked layers. In the case of prestressing steel wire and prestressing steel strand, which are shipped in the form of coils, the property of restoring linearity when unwound is important from the viewpoint of efficiency in construction. In order to prevent wire or strand from being bent so that their ability to return to the original shape is lost, it is desirable that the coil diameter be kept at or greater than 150 times the diameter of the steel wire or strand.

The quality of prestressing steel may be altered if it is heated to about 300°C or higher. Care must be taken, therefore, to keep prestressing steel away from fire.

CHAPTER 4 MIX DESIGN

4.1 General

(1) In mix design, unit quantities shall be determined after specifying mix requirements such as the slump, required strength and water/cement ratio of concrete so that the workability, strength and durability requirements can be met.

(2) Concrete mix proportions shall be determined by minimizing the water content in order to meet the performance requirements.

[Commentary] (1): This chapter describes methods for determining concrete mix proportions to meet three performance requirements. Those are workability, specified strength and durability for concrete. The mix design methods described in this chapter are applicable to concrete whose specified strength is about 60 N/mm^2 or lower and whose workability in a fresh state is evaluated in terms of slump. In cases where concrete is to be placed under unusual conditions such as when placing concrete into constricted spaces or through densely packed reinforcing steel or when placing a new layer of concrete under a previously placed layer of concrete (inverted construction method), high-fluidity concrete with self-compacting ability should be used. Mix proportions for high-fluidity concrete (self-compacting concrete) shall be determined as described in the Special Concrete section of this Specification (Chapter 7, High-Fluidity Concrete). If concrete with a slump of 21 cm or less is inadequate in terms of filling ability but performance as high as that of high-fluidity concrete is not necessary, mix proportions somewhere in-between should be selected under the guidance of an expert well versed in concrete mix design and construction technology.

When designing concrete mixes, it is necessary not only to meet the requirements for the specified strength necessary for the purpose of structural design and the durability requirements but also to select mix proportions that ensure workability suitable for the structural and construction requirements for the structure to be constructed. The design drawings and specifications indicate the ranges of reference values (e.g., maximum size of coarse aggregate, slump, water/cement ratio, type of cement, cement content) to be reflected in actual mix designs, derived on the basis of the verification of structural performance, durability of various types, water-tightness, cracking resistance, steel protection performance. Mix design in this chapter, therefore, is the act of determining unit quantities of various materials including the water content suitable for the materials to be actually used at the construction stage and the construction requirements on the basis of the reference values indicated on the design drawings and specifications mentioned above.

Figure C4.1.1 illustrates the concept for the determination of mix proportions to meet the workability, specified strength and durability requirements for concrete. Workability, which is an indicator of ease of construction by use of concrete, is a performance attribute needed for ensuring smooth and reliable execution of a series of tasks including hauling, placing, compacting and finishing. This chapter focuses mainly on the ability of concrete to smoothly pass through the space between reinforcing steel and completely fill the concrete cover regions, corners in formwork and prestressed concrete anchorage zones (filling ability) without undergoing the segregation of ingredients.

Filling ability is a performance attribute determined by the interaction between fluidity and segregation resistance. In order to obtain concrete with satisfactory filling ability, it is necessary to provide appropriate segregation resistance according to fluidity. Fluidity and segregation resistance are affected by not only the water content, binder content and the water/binder ratio but also other factors such as the type of the powder used, the particle sizes and shapes of fine and coarse aggregate, and the type of chemical admixture. In the Construction: Construction Standards, slump is used as an indicator of fluidity in view of practical convenience. In general, segregation resistance is numerically expressed with rheological constants such as plastic viscosity and the yield value. Since, however, segregation resistance can be controlled with relative ease by increasing or decreasing the binder content, the binder content is used as a practical indicator of segregation resistance.

In Fig. C4.1.1, the basic mix design approach to be taken in order to achieve the desired performance of concrete is to use a water/cement ratio not higher than the ratio indicated in the design specifications. Cement content is also not higher than the upper limit indicated in the design specifications, and the water content should be minimized to the extent that the binder content needed to achieve complete and smooth filling is secured. In mix design, it is also very important to achieve appropriate segregation resistance by increasing or decreasing the binder content according to slump instead of simply increasing or decreasing the water content according to the specified slump.

Figure C4.1.2 illustrates the concept of mix proportion in the case where the cement content indicated in the design specifications is lower than the binder content needed to achieve the required filling ability. This case may occur when it is desired that the cement content be lowered as much as possible in order to minimize the heat generated by hydration as in the case of mass concrete. With this cement content, however, excellent filling ability from the viewpoint of workability cannot be achieved. In this case, it is necessary to use concrete of the type generates a smaller quantity of heat or blended cement or use admixtures such as limestone powder in order to increase the powder content to the level needed to achieve the required filling ability.

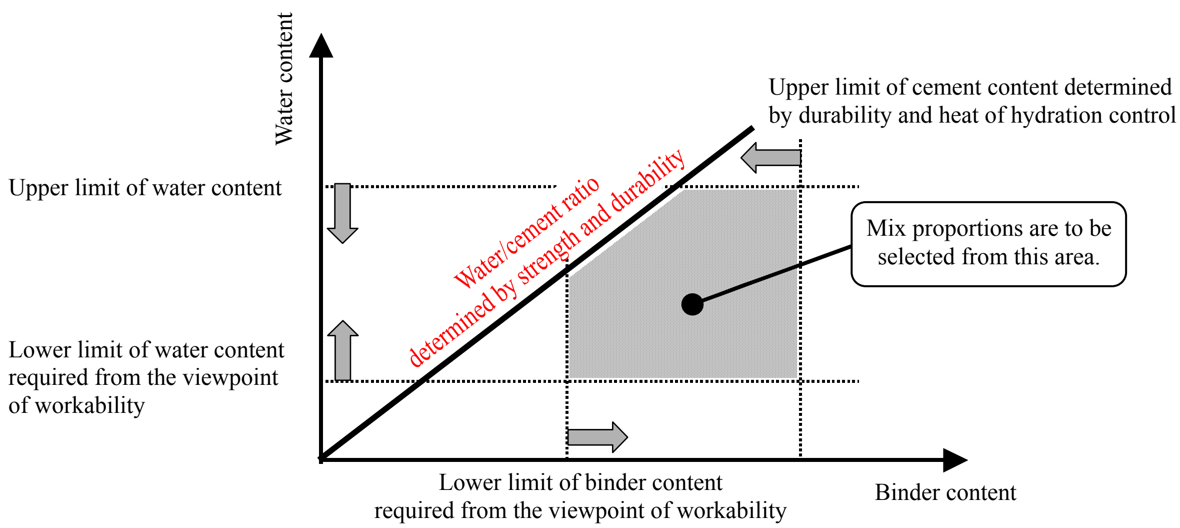

Fig. C4.1.1 Concept of mix proportioning (in normal case)

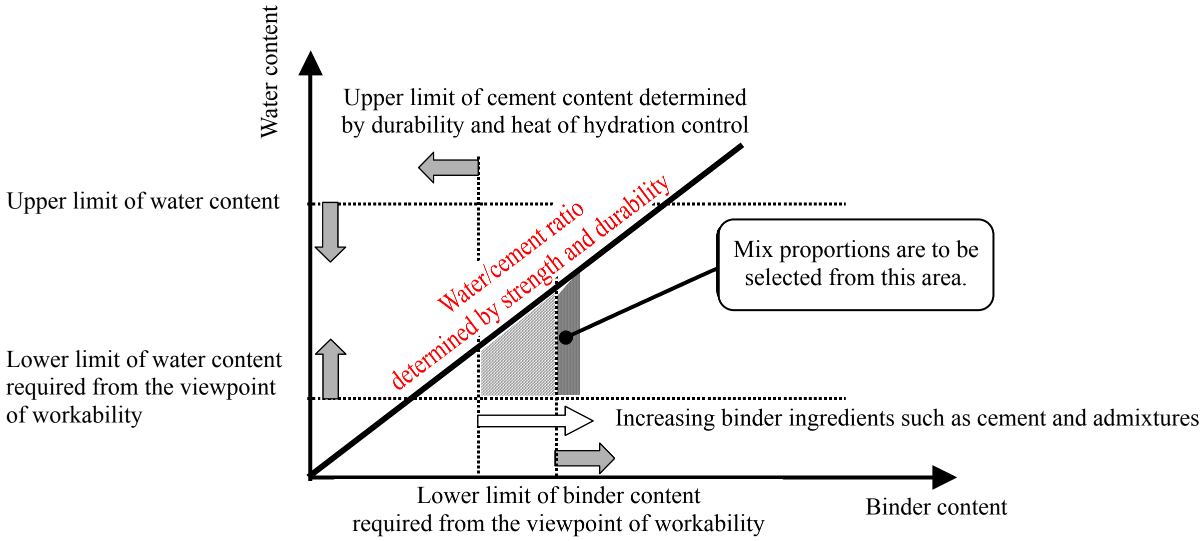

Fig. C4.1.2 Concept of mix proportioning
(in the case where the powder content is too low from the viewpoint of filling ability)

In almost all ordinary concreting projects, ready-mixed concrete is used. Even in such cases, it is important to select mix proportions on the basis of the mix design methods described in this chapter and select appropriate mixes from available types of ready-mixed concrete with reference to the mix proportions thus selected.

(2): A high water content not only makes uneconomical concrete that requires a high cement content to achieve the same water/cement ratio but also makes concrete prone to segregation so as to make it difficult to produce homogeneous and relatively defect-free concrete. Reducing the water content to the extent that suitability for the construction work to be carried out is not compromised makes it possible to use a lower cement content so as to achieve the required concrete quality and to enhance cracking resistance. An excessively low water content, however, makes the concrete very difficult to place, increasing the possibility of initial defects such as incomplete filling. In order to produce concrete that has the required levels of strength, durability, water-tightness, cracking resistance and steel protection performance, it is very important to make the water content as low as possible to the extent that the concrete is suitable for the construction work to be carried out and is capable of filling the formwork completely.

4.2 Mix Design Procedure

(1) In mix design, characteristic values related to the strength and durability of concrete described in the design specifications, as well as the maximum sizes of coarse aggregate, slumps, water/cement ratios, cement types and cement contents indicated as reference values, are ascertained.

(2) Mix proportions are determined on the basis of the reference values for concrete indicated in the design specifications mentioned in Item (1) above.

(3) Provisional mix proportions to be used as reference mix proportions for trial mixes are determined according to the mix proportions determined as mentioned above.

(4) On the basis of the provisional mix proportions thus determined, trial mixes are prepared by using materials identical to the materials to be used to ascertain that the performance requirements for concrete can be met. If trial mixing has revealed that the performance requirements cannot be met, the materials or mix proportions to be used are changed, and mix proportions needed to achieve the required quality are determined.

[Commentary] (1): The design specifications indicate characteristic values for concrete determined on the basis of the structural performance and durability of structures such as the specified strength of concrete, the carbonation rate and the chloride ion diffusion coefficient. The design specifications also indicate the maximum sizes of coarse aggregate, slumps, water/cement ratios, cement types and cement contents as reference values to be used in cases where proven concrete mix proportions are used or mix design is conducted concretely. In mix design, therefore, it is necessary as the first step to check on these characteristic values and reference values indicated in the design drawings and specifications.

(2): Fig. C4.2.1 shows the concrete mix design procedure at the construction stage. As shown in the figure, mix requirements such as the maximum size of coarse aggregate, slump, required strength, water/cement ratio and the air content are determined on the basis of the reference values indicated in the design specifications. If the reference values indicated in the design specifications are thought to be inadequate in view of the materials to be actually used or the construction requirements, it is necessary to change those values into the values suitable for the actual conditions after ascertaining that the characteristic values for concrete indicated in the design specifications are met.

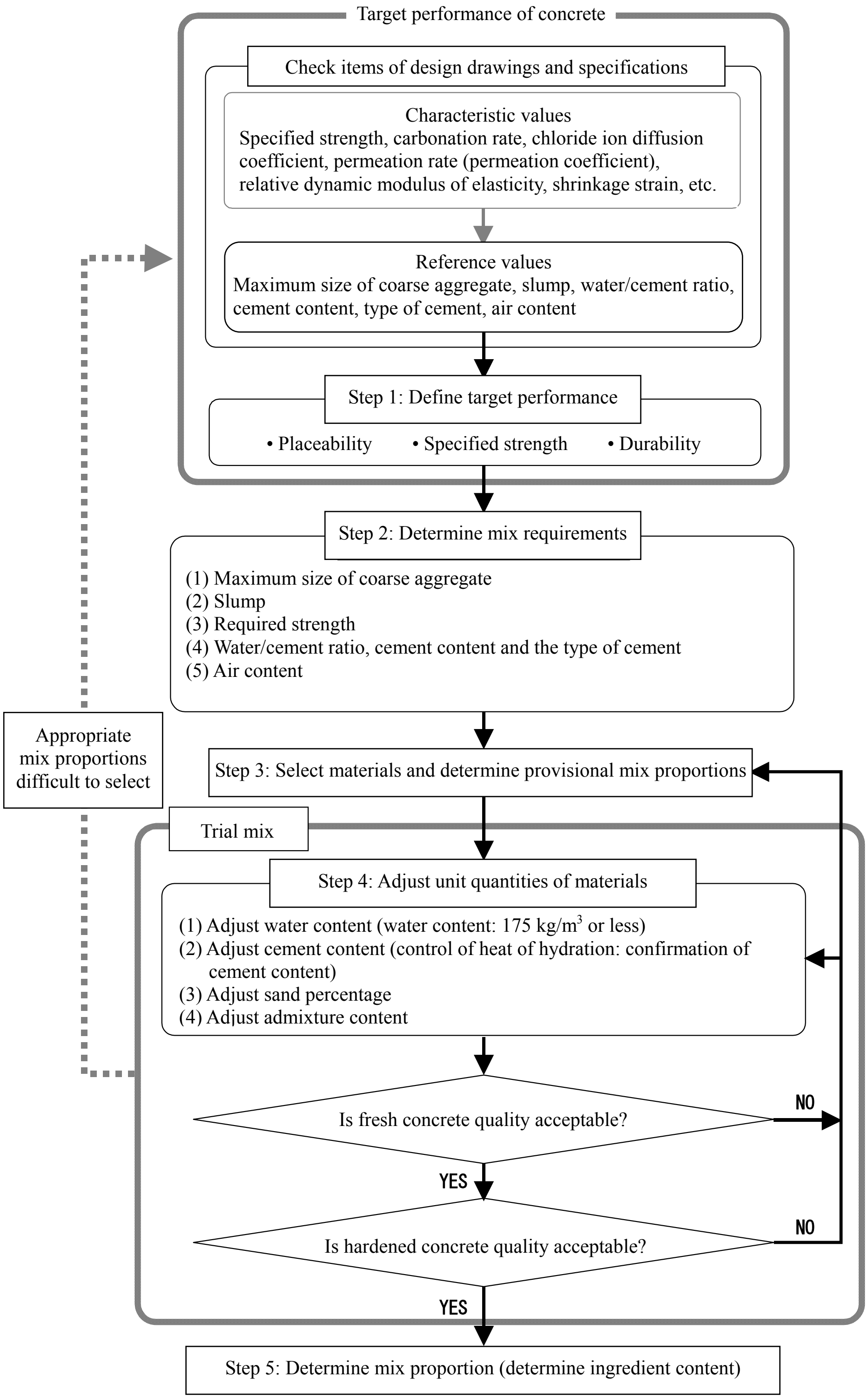

Fig. C4.2.1 Mix Design Flow

<u>(3) and (4):</u> According to the determined mix requirements, provisional mix proportions for concrete consisting of the materials to be actually used are determined. After that, trial mixes are prepared to make sure the mix proportion thus determined meets the performance requirements. If the performance requirements are not met, the mix proportion is modified, and trial mixing is carried out again. If the performance requirements cannot be met by mix proportional modification alone, the materials to be used are changed, and this process is repeated until the performance

requirements are met.

If trial mixing has revealed that the water content needed to achieve the required consistency would increase considerably, it is important to reconsider and modify the physical properties of aggregate by, for example, using other types of aggregate, increasing the solid content or adjusting the particle size distribution. If the water content of concrete containing an air-entraining water-reducing agent exceeds the upper limit (175 kg/m^3; see Section 4.5.1), the water content should be reduced by using a superplasticizer. As a means of enhancing cracking resistance, measures such as changing the type of cement used to a low-heat type or using expansive admixtures should be taken.

4.3 Target Performance of Concrete

4.3.1 Defining target performance

On the basis of the characteristic values and reference values for concrete indicated in the design specifications, workability, specified strength and durability suitable for the environmental conditions, construction requirements and the materials used are defined as the target performance of concrete.

[Commentary] The target performance of concrete to be taken into consideration in mix design consists of workability, specified strength and durability. Mix design is a series of tasks performed to specify concrete ingredients and their mix proportions reflecting the actual environmental conditions, construction requirements and the characteristics of the materials used on the basis of the reference values indicated in the design drawings and specifications determined so as to achieve the target performance of concrete. Concrete ingredients and mix proportions are determined, and the concrete performance verification process by the trial mix method is repeated until the performance requirements for concrete are met. In mix design, the upper and lower limits or ranges of parameters such as slump, water/cement ratio, water content and the cement content are specified as mix requirements so that the workability, specified strength and durability requirements are met.

Commonly used indicators of concrete durability include the carbonation rate, the chloride ion diffusion coefficient, freeze–thaw resistance, chemical attack resistance and fire resistance. The reference values indicated in the design specifications are values determined on the basis of durability-related indicators such as the carbonation rate, the chloride ion diffusion coefficient, freeze–thaw resistance and the permeability coefficient (permeation rate). If, therefore, mix requirements are determined according to the reference values indicated in the design specifications such as the water/cement ratio, the type of cement and the cement content, it may be assumed that the required durability related to carbonation, chloride attack, freeze–thaw damage and water-tightness can be met.

4.3.2 Workability of concrete

(1) Filling ability is determined as described in Section 2.3.1.

(2) Pumpability is determined as described in Section 2.3.2.

(3) Setting properties are determined as described in Section 2.3.3.

[Commentary] (1), (2) and (3) In order to construct a concrete structure with the required performance, it is necessary to specify requirements in accordance with Sections 2.3.1 to 2.3.3 appropriately so that the concrete has the filling ability, pumpability and setting properties suitable for construction tasks such as hauling, pouring, compacting and finishing.

4.3.3 Specified strength

Specified strength is determined based on characteristic values given in the design drawing.

[Commentary] Specified strength indicated in the design specifications, etc., mix requirements such as required strength and the water/cement ratio are determined in view of the materials used, production equipment and the variability of concrete quality in past projects.

4.3.4 Durability

(1) Durability is specified in accordance with section 2.5.

(2) Appropriate mix requirements and materials to be used are determined on the basis of the durability-related reference values indicated in the design drawings and specifications so that the required durability against carbonation, chloride attack and freeze–thaw cycles can be achieved.

(3) If the reference values indicated in the design drawings and specifications are not used as a reference, either past mix proportion data or other reliable data are used as a reference or appropriate mix requirements are determined after conducting tests in advance and ascertaining that the characteristic values indicated in the design drawings and specifications are met.

(4) Appropriate control measures are taken against alkali–silica reaction.

(5) Appropriate mix requirements are specified so that the required durability can be achieved against chemical attack and in terms of water-tightness.

[Commentary] (1), (2) and (3): The reference values indicated in the design specifications are values determined on the basis of durability-related characteristic values such as the carbonation rate, chloride ion diffusion coefficient and the relative dynamic modulus of elasticity. Appropriate mix requirements and materials to be used, therefore, are determined on the basis of the reference values indicated in the design specifications such as the water/cement ratio, cement content and the type of cement so that the required durability can be achieved. The reference values indicated in the design drawings and specifications assumes the case in which concrete with an appropriate amount of entrained air and adequate filling ability is carefully placed, compacted and cured at appropriate temperature and under adequate humidity conditions.

If different types of materials are used or if it is necessary to specify mix requirements other than the reference values indicated in the design drawings and specifications in order to achieve durability other than the durability against carbonation, chloride attack and freeze–thaw cycles, it is necessary either to refer to past mix proportion data or other reliable data or ascertain through trial mix or other tests conducted in advance that the characteristic values indicated in the design specifications can be attained.

(4): There is as yet no established method for appropriately checking on alkali–silica reaction in a short period of time, and the characteristic values and reference values indicated in the design specifications do not reflect study results on alkali–silica reaction. In the Construction: Construction Standards, therefore, it is assumed that the durability against alkali–silica reaction is achieved if one of the three control measures described below is taken.

(a) Controlling the total alkali content of concrete

Portland cement, etc., whose total alkali content is indicated in test records is used so that the total quantity of alkalis including the alkalis contained in chemical admixtures in a cubic meter of concrete is 3.0 kg or less (Na_2O equivalent).

(b) Using blended cement with the alkali–aggregate reaction control effect

Type B (slag content: 40% or more) or Type C blast furnace slag cement conforming to JIS R 5211, Portland Blast-Furnace Slag Cement, or Type B (fly ash content: 15% or more) or Type C fly ash cement conforming to JIS R 5213, Portland Fly-Ash Cement, is used; or a cementitious material that is composed of portland cement and admixtures such as blast-furnace slag or fly ash and that has a proven alkali–aggregate reaction control effect is used.

(c) Using aggregate rated as Category A (harmless) in alkali–silica reactivity test

Aggregate that has been rated as "harmless" in a test conducted in accordance with JIS A 1145, Method of Test for Alkali–Silica Reactivity of Aggregates by Chemical Method, and JIS A 1146, Method of Test for Alkali–Silica Reactivity of Aggregates by Mortar-Bar Method, is used.

If ready-mixed concrete is used, the basic rule is to take control measure (a) or control measure (b). If the intrusion of alkalis from external sources is unavoidable as in a marine environment or in a region where deicing agents are used, Category B aggregates are used, and alkali reduction measures are taken on condition that there is little or no possibility of intrusion of alkali metal ions from an external source.

(5): If it is required that chemical attack should not affect the required structural performance, the water/cement ratio should be set at or below the levels shown in Table C4.3.1 depending on the deterioration-causing environmental conditions in order to achieve the required chemical attack resistance.

Table C4.3.1 Maximum water/cement ratio for ensuring chemical attack resistance

Deterioration-causing environment	Maximum water/cement ratio (%)
When in contact with soil or water containing 0.2% or more sulfate (SO_4)	50
When deicing agent is used	45

Note: If verification can be made by using past project data, research results, etc., a value of 5 to 10 may be added to the values shown above.

Water-tightness includes the water-tightness of the concrete itself evaluated in terms of the permeability coefficient and the water-tightness evaluated in terms of the permeation rate by taking into account such factors as cracking in the structure or its members. In mix design, it is necessary to take into account the former, namely, the water-tightness of the concrete itself. The permeability coefficient is governed by such factors as the density of hardened cement with many fine voids, void structure characteristics such as void continuity, and the nature of relatively rough-textured transition zones formed around aggregate particles. In general, the void structure of hardened cement is dependent on the water/cement ratio and the type of cement. In order to achieve the required permeability coefficient, therefore, it is good practice to reduce the water/cement ratio and thereby reduce the water content so as to produce homogeneous and voidless concrete to the extent that the filling ability suitable for concreting work can be maintained. Past research results have shown that the water-tightness of concrete required for ordinary concrete structures can be attained if the water/cement ratio is 55% or less.

In the case of a concrete structure that is required to be watertight, the permeability coefficient and the permeation rate are verified at the design stage. When the water/cement ratio needs to be determined from the viewpoint of water-tightness, therefore, it may be determined on the basis of the reference values for the water/cement ratio, cement content, type of cement, etc., indicated in the design specifications.

4.4 Determination of Mix Requirements

4.4.1 Maximum size of coarse aggregate

(1) The maximum size of coarse aggregate is determined, taking into account the sizes of structural members and reinforcing bar spacing, so that defects such as honeycombing and incomplete filling do not occur.

(2) The maximum size of coarse aggregate shall not exceed one-fifth of the smallest member size, three-fourths of the smallest reinforcing bar spacing and three-fourths of the concrete cover. The maximum size of coarse aggregate shall not exceed 20 or 25 mm for ordinary members, 40 mm for large-cross-section members, and 40 mm or one-fourth of the smallest dimension of the member.

(3) The maximum size of coarse aggregate should be as shown in Table 4.4.1 as a standard.

Table 4.4.1 Maximum size of coarse aggregate

Structural conditions	Maximum size of coarse aggregate
If the smallest dimension of the cross section is 1,000 mm or larger and three-fourths of the smallest reinforcing bar spacing and the concrete cover is greater than 40 mm	40mm
In other cases	20 mm or 25 mm

[Commentary] (1), (2) and (3): In general, increasing the maximum size of coarse aggregate is advantageous in producing concrete economically. If, however, the amount of steel is large or reinforcing bar spacing is small, coarse aggregate of a large maximum size obstructs concrete flow between reinforcing bars, causing the possibility of occurrence of defects such as honeycombing and incomplete filling. This section, therefore, specifies the conditions to be met and indicates the maximum sizes of coarse aggregate that are deemed appropriate judging from past project data and experience. In the case of plain concrete, coarse aggregate of considerably larger sizes may be usable because cross sections tend to be large. In general, however, coarse aggregate with a particle size of around 40 mm are commonly used.

4.4.2 Slump

(1) Prior to slump determination, thorough studies shall be conducted on construction method details such as placing locations and sites, compaction height, spacing of internal vibrators, placing height per cycle and the placing rate so as to reduce slump as much as practically possible.

(2) Slump shall be determined so as to prevent segregation to the extent suitable for concreting tasks such as transportation, placing and compacting.

(3) In mix design, as the first step, the minimum slump for placement shown in Item (4) below is determined. As the next step, by using the minimum slump as a criterion, target slumps for unloading and mixing are determined, allowing for the decrease in slump due to on-site transportation, the change in slump during the period from production to placement, the change in slump due to transportation to the construction site and the quality tolerance at the production stage.

(4) The minimum slump for placement is determined according to the type of structure, the type of member, reinforcement conditions such as the amount of steel and steel spacing, and other conditions such as compaction height by selecting an appropriate value from Tables 4.4.2 to 4.4.6, which show slump values under different combinations of these conditions for different types of structural members. The term "minimum slump for placement" refers to the minimum slump needed to place concrete smoothly and voidlessly into the formwork.

Table 4.4.2 Typical values of minimum slump for placement of slabs

Amount of steel[1)] (kg/m^3)	Minimum steel spacing[1)] (mm)	Placement interval[2)]	Compaction height		
			Less than 0.5 m	0.5 m to less than 1.5 m	3.0 m or less
100 to 150	100 to 150	At any location	5	7	–
		2 to 3 m	–	–	10
		3 to 4 m	–	–	12

1) The amount of steel shall be 100 to 150 kg/m^3, and the minimum steel spacing shall be 100 to 150 mm as standard.

2) The drop height of concrete shall be 1.5 m or less as standard.

Table 4.4.3 Typical values of minimum slump for placement of columns

Effective equivalent amount of steel in the concrete cover zone[1)]	Minimum steel spacing	Compaction height		
		Less than 3 m	3 m to less than 5 m	5 m or more
Less than 700 kg/m^3	50 mm or more	5	7	12
	Less than 50 mm	7	9	15
700 kg/m^3 or more	50 mm or more	7	9	15
	Less than 50 mm	9	12	15

1) The effective equivalent amount of steel in the concrete cover zone is the amount of steel per unit volume in the regions shown below.

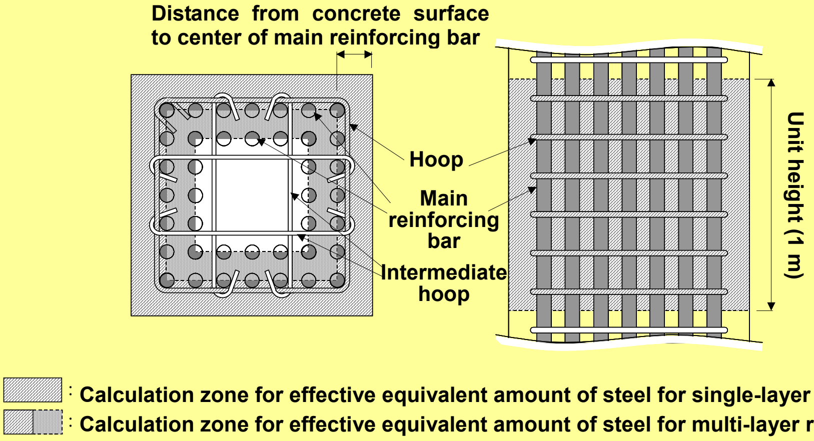

Table 4.4.4 Typical values of minimum slump for concrete placement of beams

Minimum steel spacing	Compaction height[1]		
	Less than 0.5 m	0.5 m to less than 1.5 m	1.5 m or more
150 mm or more	5	6	8
100 mm to less than 150 mm	6	8	10
80 mm to less than 100 mm	8	10	12
60 mm to less than 80 mm	10	12	14
Less than 60 mm	12	14	16

1) Examples of members for which different compaction heights are used

- Less than 0.5 m: small beams, etc.
  0.5 m to less than 1.5 m: standard beams
  1.5 m or more: deep beams, etc.
- The minimum slump for placement is selected according to whether it can be judged that adequate compaction can be done by inserting bar-shaped vibrators about 40 mm in diameter.
  (i) If it is judged that adequate compaction can be done, a minimum slump for placement of 14 cm is used.
  (ii) If it is judged that adequate compaction cannot be done, high-fluidity concrete is used.
- If slump exceeds 21 cm, high-fluidity concrete should be used in order to achieve the required segregation resistance and place concrete voidlessly.

Table 4.4.5 Typical values of minimum slump for concrete placement of walls

Amount of steel	Minimum steel spacing	Compaction height		
		Less than 3 m	3 m to less than 5 m	5 m or more
Less than 200 kg/m^3	100 mm or more	8	10	15
	Less than 100 mm	10	12	15
200 kg/m^3 to less than 350 kg/m^3	100 mm or more	10	12	15
	Less than 100 mm	12	12	15
350 kg/m^3 or more	—	15	15	15

Table 4.4.6 Typical values of minimum slump for concrete placement of prestressed concrete members

Type of structure	Average amount of reinforcing steel[1)]	Design strength of concrete	Minimum slump for placement
Girder[3)] of prestressed concrete superstructure tensioned mainly with internal tendons	Less than 120 kg/m^3 (reinforced concrete equivalent[2)]: less than about 250 kg/m^3)	36 or 40	7
	120 kg/m^3 to less than 140 kg/m^3 (reinforced concrete equivalent[2)]: about 250 to less than 300 kg/m^3)		9
	140 kg/m^3 to less than 170 kg/m^3 (reinforced concrete equivalent[2)]: about 300 to less than 350 kg/m^3)		12
	170 kg/m^3 to less than 200 kg/m^3 (reinforced concrete equivalent[2)]: about 350 to less than 400 kg/m^3)		15
	200 kg/m^3 or more (reinforced concrete equivalent[2)]: about 400 kg/m^3 or more)		—
	Less than 170 kg/m^3 (reinforced concrete equivalent[2)]: less than about 350 kg/m^3)	50	12
	170 kg/m^3 to less than 200 kg/m^3 (reinforced concrete equivalent[2)]: about 350 to less than 400 kg/m^3)		15
	200 kg/m^3 or more (reinforced concrete equivalent[2)]: about 400 kg/m^3 or more)		—
Cross beams and unsupported floor slabs of a T-girder bridge	-	30	7
Unsupported floor slabs other than those mentioned above	-	30	5
Members including densely reinforced regions[4)]	300 kg/m^3 or more (reinforced concrete equivalent[2)]: about 500 kg/m^3 or more)	—	—

1) The average amount of reinforcing steel is a value obtained by dividing the amount of reinforcing steel in a section in which concrete is placed continuously by the volume of concrete.

2) The reinforced concrete equivalent amount of reinforcing steel is a reference value calculated by assuming that the entire cross section of the sheath is equivalent to reinforcing steel.

3) Girders include the superstructure of a hollow slab bridge. Prestressed reinforced concrete bridges are not included in the table. Since it is difficult to determine the standard value, the amount of prestressing steel is relatively small compared with the amount of reinforcing steel.

4) "Densely reinforced regions" are regions where the amount of reinforcing steel is particularly large such as anchorage zones of cable stayed bridges and structures prestressed with external tendons.

(5) When a number of concrete members can be cast separately, the minimum slump for placement shall be specified for each member. If it is not possible to change slumps during the placement process as when a number of members are to be cast consecutively, the method of using the largest of the minimum slump values required for placement should be used as a standard.

(6) When concrete to be placed is pumped for on-site transportation, slump loss under different conditions such as the pumping conditions, minimum slumps and the environmental conditions shown in Table 4.4.7 shall be considered.

Table 4.4.7 Typical slumps under different conditions

Construction conditions	Slump loss	
Pumping distance (equivalent horizontal distance)	When the minimum slump is smaller than 12 cm	When the minimum slump is 12 cm or greater
Less than 150 m (including placement by bucket, etc.)	—	—
150 m to less than 300 m	1 cm	—
300 m to less than 500 m	2 cm to 3 cm	1 cm
500 m or more	To be determined on the basis of past project data or field trial results	

For reference, when daily average temperature exceeds 25°C (during summer), it is recommended that 1 cm be added to each of the values shown above.

[Commentary] (1) and (2): When determining slump requirements, it is necessary to take into account not only structural conditions such as the type and dimensions of the member concerned and the arrangement of reinforcing materials (reinforcing bars and other steel) but also construction conditions such as on-site transportation methods (type of concrete pumper, pumping distance, piping direction), concrete placement methods (drop height, height of each layer of concrete to be placed) and compaction methods (type of internal vibrator, vibrator spacing, insertion depth, vibration time). The basic rule is to minimize slump of the concrete being placed to the extent that workability requirements can be met. It is important to carefully consider construction methods such as concrete placement methods (drop height, height of each layer to be placed) and compaction methods (compaction height, type of internal vibrator, vibrator spacing, insertion depth, vibration time).

(3): The slump and other properties of fresh concrete continue to change throughout the process from the transportation from the concrete plant to the construction site, on-site transportation, placement and compaction. In order to achieve smooth and complete filling, it is important to make sure, in view of the changes during these stages of construction work, that appropriate filling ability is retained at the stages of placement and compaction. The Construction: Construction Standards, therefore, first defines the minimum slump necessary at the time of placement and requires that a target slump to be used for quality control at the unloading location and a target slump upon completion of mixing (production) to be used for quality control at the production stage be specified as criteria for the minimum slump.

Slumps at the placement, unloading and production stages determined in mix design are determined, in view of the occurrence of slump changes as shown in Fig. E4.4.2, by following the procedure described below (Fig. C4.4.1).

Step 1: Determine minimum slump for placement

Select the minimum slump needed to fill the formwork reliably and completely according to the structural conditions such as the type of member, the amount of reinforcing steel and reinforcing bar spacing and the construction conditions such as compaction height (see Table 4.4.2 to Table 4.4.6).

Step 2: Determine target slump at unloading location

Determine a target slump at the unloading location on the basis of the minimum slump for placement in view of the slump loss during on-site transportation such as pumping, changes in slump due to the passage of time during the process from unloading to placement, and quality variation at the production stage. As for JIS-certified articles, as a standard procedure, the quality control and acceptance inspection of concrete are performed with respect to this target slump at the unloading location.

The slump loss (compensation) due to on-site transportation such as pumping is selected from Table 4.4.7 (shown below) according to the construction conditions such as pumping distance. The amount of quality variation at the production stage is determined appropriately according to the conditions of the production equipment and the quality control within the allowable ranges (2.5 cm for 8 to 18 cm slump; 1.5 to 2 cm for 21 cm slump) for JIS-certified articles. Changes in slump due to the passage of time during the process from unloading to placement are estimated from past project data or time-dependent changes observed during trial mixing mentioned in Section 4.7. However, the decrease in slump over time during the period of time necessary for construction work should be minimized. It is therefore important to select mix proportions, at the trial mixing stage, that make it possible to retain the required slump by, for example, using appropriate chemical admixtures.

Step 3: Determine target slump for freshly mixed concrete

Determine a target slump for freshly mixed concrete, taking into account the decrease in slump due to off-site transportation to the unloading location. A rule of thumb about the relationship between the time required for transportation to the construction site and slump is that the amount of decrease in slump during spring and autumn is about 1 cm per 30 minutes of transportation. In winter, the slump loss due to an increase in transportation time is low, and the slump loss is about 1 to 1.5 cm per 60 minutes of transportation. However, during summer (hot weather), the concrete shall be taken care, because the slump loss over time tends to be higher (about 1.5 cm per 30 minutes of transportation).

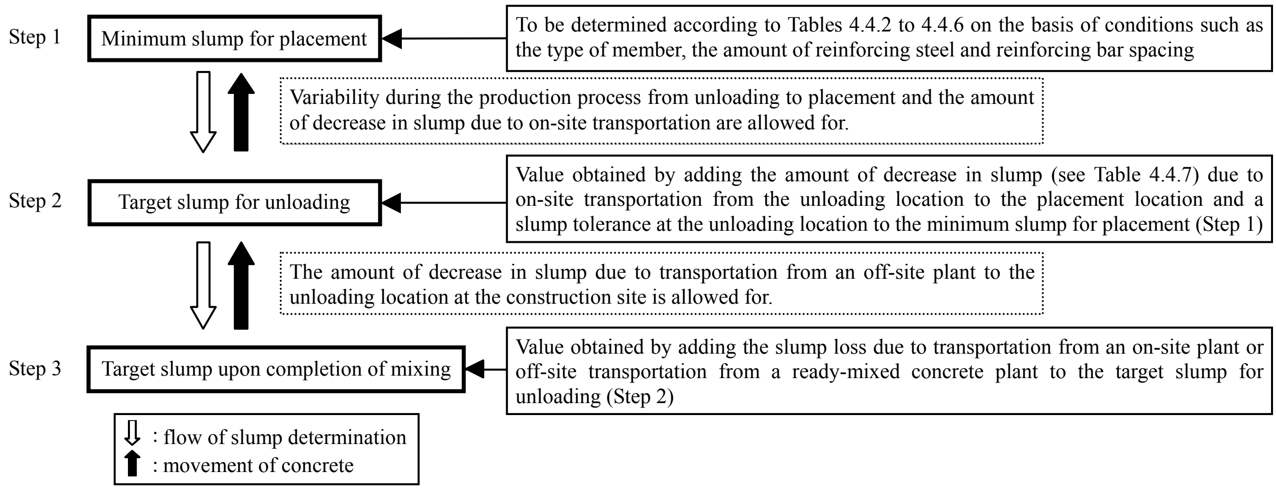

Fig. C4.4.1 Flow chart for slump determination at different stages

In mix design, it is a basic rule to secure the required minimum slump for placement so as to achieve good filling ability. If, however, a large amount of decrease in slump is expected because the construction tasks such as the transportation to the construction site and a series of tasks from unloading to placement are time consuming or if slump loss due to pumping is expected, it may be necessary to set a target slump at the unloading location or upon completion of mixing that is larger than the target slump. In such cases, simply increasing the slump at the unloading location or upon completion of mixing might cause segregation during production or off-site transportation, resulting in not only quality control and acceptance inspection problems at the unloading location but also clogging of piping during pumping. In order to prevent these problems, mix proportions may be adjusted so that the concrete has good workability at the target slump at the unloading location.

The same mix-design procedure may be used in cases where ready-mixed concrete is used. As the first step, the minimum slump for placement is determined, and the target slump upon unloading is determined so that the minimum slump for placement can be achieved. This target slump upon unloading is used as the specified slump for ready-mixed concrete. A simple method for specifying this target slump upon unloading for JIS-certified items is described in JSCE's Recommendations for Design and Placement of Concrete Based on Placeability.

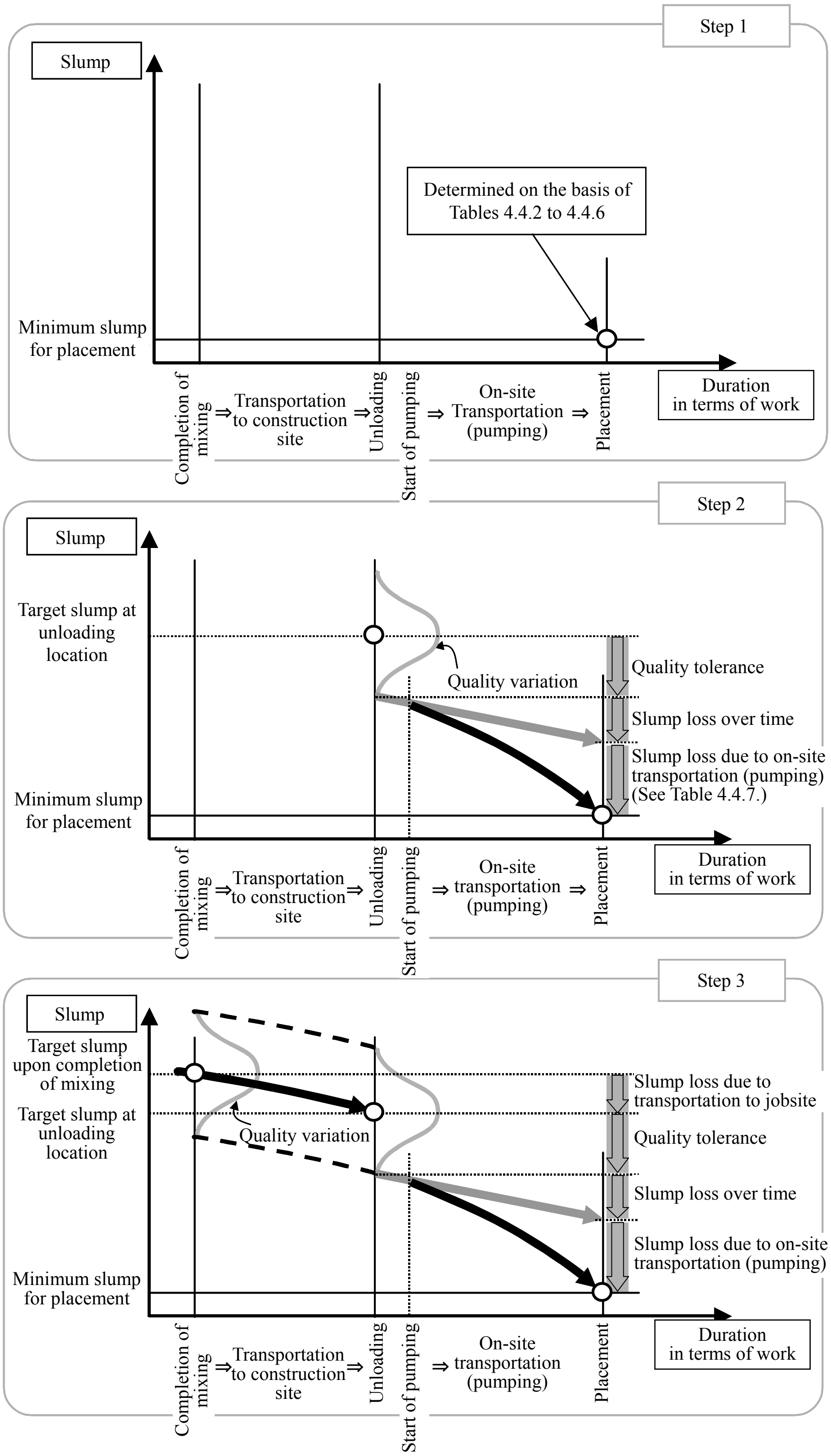

Fig. C4.4.2 Changes in slump over time at different stages of construction

<u>(4)</u>: In order to construct a highly durable and densely cast concrete structure, it is necessary to provide concrete with workability suitable for the structural conditions. The Construction: Construction Standards shows typical values of the minimum slump for placement suitable for the structural conditions for different types of structure or member. Tables 4.4.2 to 4.4.6 show typical

minimum slumps needed at the placing location for different types of structural members determined on the basis of past construction experience, etc., on condition that standard construction methods shown in Table C4.4.1 are practiced. From this table, standard values of the minimum slump for placement can be selected according to the structural conditions of the structure to be constructed.

Table C4.4.1 Standard construction methods specified in the construction: construction standards of this specification

Task category	Item		Standard method
Transportation	Transportation to construction site		Agitator
	On-site transportation		Concrete pump
Placement	Dropping height		Within 1.5 m
	Placing height per layer		40 to 50cm
	Allowable placement interval	Outdoor air temperature: 25°C or below	2.5 hours
		Outdoor air temperature: higher than 25°C	2.0 hours
Compaction	Compaction method		Internal vibrator
	Vibrator spacing		About 50 cm
	Vibrator depth		About 10 cm in the underlying layer of concrete
	Vibration time per point		5 to 15 sec

In the Construction: Construction Standards, compaction height, which is related to the degree of ease/difficulty of compaction, and placing height, which is a widely used term, are distinguished. As shown in Fig. C4.4.3, "compaction height" is defined as the height from the working platform on which construction workers stand to the lower end of the formwork or the upper surface of previously cast concrete layer. If concrete is placed continuously and compaction is performed while moving upward as the height of newly placed concrete increases, the distance from the moved working platform to the surface of the previously placed concrete is the compaction distance.

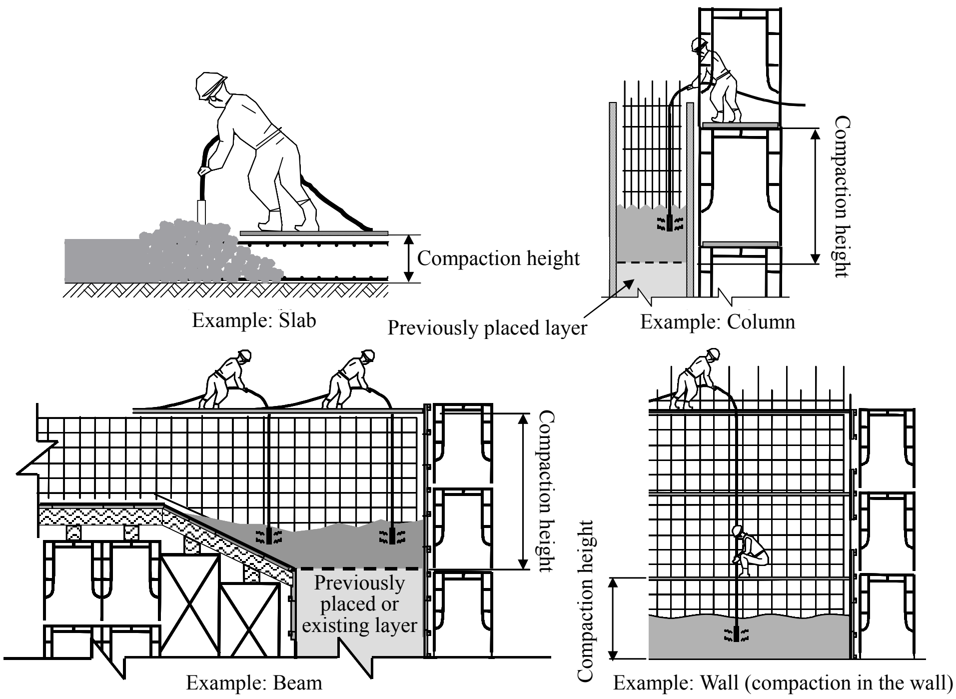

Fig. C4.4.3 Examples of compaction height

(5): The minimum slump for placement is determined for each type of member. The use of different types of concrete mixes with different slumps, however, when different types of members such as columns, beams, walls and slabs are cast continuously would make construction work and management cumbersome and lower construction efficiency. A rational approach in such cases is to select concrete mixes suitable for members that are relatively difficult to construct and require relatively large minimum slumps for placement. It is important, however, to carefully consider in advance whether problems can be prevented by modifying concreting-related arrangements such as concrete placement and compaction methods.

(6): In order to keep the performance of fresh concrete necessary for placement, it is necessary to predict changes in concrete quality due to the influence of pumping conditions and environmental temperature and allow for such changes in determining slump requirements. Typical changes in slump corresponding to different construction conditions such as pumping conditions are shown in Table 4.4.7. If relevant information such as past construction records and pumping test results is available, slump requirements should be determined on the basis of such information.

4.4.3 Required strength

(1) The required strength of concrete is determined in view of the specified strength and the variability of concrete quality at the construction site.

(2) The required strength f'cr of concrete is determined so that the probability that a measured value of the compressive strength of concrete obtained as an on-site test result is smaller than the specified strength is 5% or less.

[Commentary] (1): Usually, the quality of concrete at a construction site varies during the construction period depending on such factors as changes in the quality of aggregate, cement, etc., measuring errors and changes in the way concrete ingredients are mixed. The required strength of concrete, therefore, needs to be made higher than the specified strength according to the variability of concrete quality at the construction site, in order to ensure that the compressive strength of concrete in any part of the structure is not lower than the compressive strength assumed when designing the structure. The required strength of concrete needed relative to the specified strength is usually determined in accordance with the conditions described in Item (2).

(2): This clause describes the compressive strength requirements for test specimens to be used to achieve the specified strength of concrete. Inevitably, measured values of the compressive strength of concrete vary to some extent depending on changes in the quality of cement, aggregate, etc., measuring errors, differences the conditions under which mixing and other tasks are performed, test errors, etc. It is known from experience that variations in the compressive strength of concrete under ordinary quality control conditions are more or less distributed normally. Assuming a stochastic distribution, therefore, this guideline requires the probability that a measured value of the compressive strength of concrete used for an ordinary structure is smaller than the specified strength be 5% or less. A measured value of the compressive strength of concrete obtained as an on-site test result is the average value of compressive strength obtained through standard curing of three concrete specimens sampled at the construction site.

In order to ensure that the probability that a measured value of compressive strength is smaller than the specified strength is not higher than a predetermined percentage, it is necessary to select a strength value obtained by increasing the specified strength appropriately according to the variation in measured values of compressive strength as a required strength. Fig. C4.4.4 shows the relationship between the coefficient of variation and the overdesign factor in the case in which the predetermined percentage mentioned above is 5%. A recommended standard procedure is to determine the overdesign factor corresponding to the coefficient of variation in the compressive strength of concrete at the construction site from the figure mentioned above. After that, the overdesign factor and the specified strength or an appropriate value are selected, and it should not be smaller than the required strength of that structure.

In the case of concrete to be used for a very important structure, the abovementioned predetermined percentage should be reduced to a smaller value, and another overdesign factor determined from that percentage and the coefficient of variation in compressive strength should be used.

As mentioned above, in order to determine the required strength of concrete, it is necessary to find out the coefficient of variation of measured compressive strengths of concrete at the construction site and determine the overdesign factor accordingly. This value should be determined by past experience, equipment at the construction site, variations in the quality of the materials used, the skill levels of construction workers, etc. At early stages of construction, however, it is not uncommon that it is difficult to estimate the coefficient of variation appropriately because there is dearth of information on the equipment at the construction site, variations in the quality of materials, etc. An appropriate method to be used in such cases is to determine the required strength by using a somewhat larger overdesign factor. After concrete work is started, the required strength can be modified according to the actual coefficient of variation.

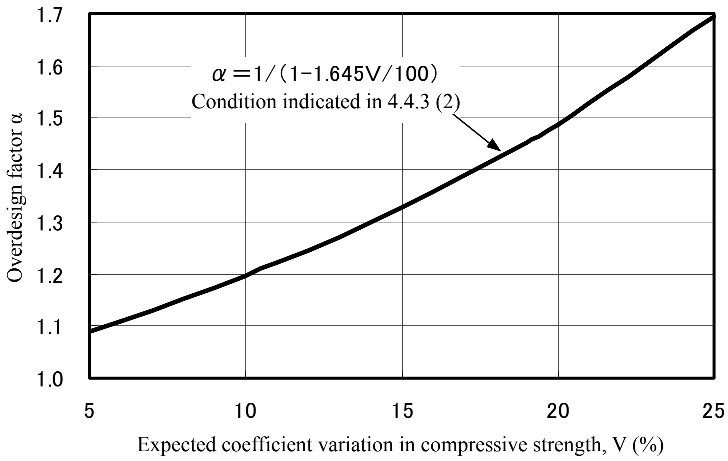

Fig. C4.4.4 Overdesign factor in a normal case

4.4.4 Water/cement ratio

(1) The water/cement ratio is determined by selecting the smallest values determined in view of the strength, durability, water-tightness, cracking resistance and steel protection performance required of concrete on the basis of the reference values indicated in the design specifications.

(2) When the water/cement ratio is determined on the basis of the compressive strength of concrete, it is determined as follows:

(a) As a general rule, the relationship between compressive strength and the water/cement ratio shall be determined experimentally. The testing age is 28 days as standard. Other testing ages, however, may be used depending on the type of cement to be used if high-early-strength cement is used or if low-heat cement is used for the purpose of thermal stress control.

(b) The water/cement ratio to be used for mix proportion shall be the reciprocal of the cement–water ratio corresponding to the required strength f'cr in the relationship between the cement/water ratio (C/W) and compressive strength f'c at the reference age.

(3) In cases where the water/cement ratio is determined in view of the durability of concrete against carbonation, chloride attack and freeze–thaw cycles, the water/cement ratio is determined so that it is not greater than the reference values indicated in the design specifications.

(4) In cases where the water/cement ratio is determined in view of the durability of concrete against chemical attack, the water/cement ratio shall be determined on the basis of Table E4.3.1. The water/cement ratio in the case where water-tightness is taken into account should be set at 55% or less as a standard.

[Commentary] (1): The water/cement ratio to be used shall be the smallest among the water/cement ratios determined from the required strength, durability, water-tightness, cracking resistance and steel protection performance of concrete. Under normal conditions, the water/cement ratio determined taking the abovementioned factors into account rarely exceeds 65%. Since, however, many of the problems encountered in the past occurred in structures built with concrete with a water/cement ratio exceeding 65%, it is a basic rule to specify a water/cement ratio of 65% or less. When determining the water/cement ratio for concrete to be used for offshore structures, the Construction: Special Concretes (Chapter 11, Offshore Concrete) of this Specification should be used as a guide.

The water/cement ratio is to be determined on the basis of the reference values indicated in the design specifications such as the upper and lower limits or range of the water/cement ratio, the cement content and the type of cement. If it is judged that these values and ranges are not adequate because of the quality of the materials to be used, the system for supplying materials or other factors, it is necessary to select an appropriate realistic value after ascertaining that the characteristic value requirements specified in the design specifications are met.

(2) (a): The fact that the cement/water ratio (C/W) and compressive strength (f'c) are linearly related within a certain range can be used to determine the relationship between the compressive strength of concrete and the water/cement ratio. A universal linear formula applicable to any type of material, however, has not yet been derived for determining the relationship between the cement/water ratio and compressive strength. As a general rule, therefore, this specification requires that the relationship between the compressive strength of concrete and the cement/water ratio be determined experimentally.

The C/W–f'c relationship is determined as follows:

Three or more types of concrete mixes with different cement/water ratios are tested within a range that is deemed appropriate to derive C/W–f'c curves. In the case of air-entrained concrete, test specimens are prepared by using concrete mixes with the required air content.

In order to minimize errors in mix tests, the average value for specimens prepared from two or more batches of concrete should be used as the value of f'c for each C/W. If a mineral admixture that can be expected to act as a binder such as ground granulated blast furnace slag or fly ash is used, the numerator of C/W may be taken as the sum of the mass of the cement and the mass of the admixture.

In the case of air-entrained concrete, the relationship between C/W and f'c varies depending on the air content, but if the air content remains constant, the relationship between C/W and f'c can be approximated by a linear equation.

In the cases where the specified strength age is not 28 days and where mix proportions need to be determined early and the 28-day strength and the relationship with the strength at that age is known, the water/cement ratio may be determined by using a reference age other than 28 days.

If the relationship between the cement/water ratio and the compressive strength at the age of 28 days has been fully ascertained, the abovementioned tests may be downscaled or omitted.

(2) (b): If homogeneous concrete is to be made, it is necessary to use homogeneous materials, measure them accurately and mix them sufficiently. Even if these tasks are performed, however, the variation in the quality of concrete is inevitable. In order to ensure the level of safety considered at the structural design stage, therefore, it is necessary to determine a required strength value by increasing the specified strength according to the variation as a compressive strength value needed when the relationship between the cement/water ratio and compressive strength mentioned in Item (a).

(3): In the cases where the durability of concrete against carbonation, chloride attack and freeze–thaw cycles must be taken into account for design purposes, verification is made as described in the Design: General Requirements (Chapter 8, Verification of Durability) of this Specification, and the necessary upper limit of the water/cement ratio is indicated in the design specifications as reference values. It is necessary, therefore, to determine the water/cement ratio so that the value is not exceeded. When a high-quality mineral admixture is used appropriately, the denominator of the water/cement ratio needed from the viewpoint of durability may be taken as the sum of the mass of cement and the mass of the admixture (binder content).

(4): When coming into contact with soil or water containing a substantial quantity of sulfate, concrete is eroded by chemical reaction. The aim of this clause is to ensure that strong and voidless concrete that is highly durable against such chemical reaction can be obtained.

4.4.5 Air content in air-entrained concrete

(1) The air content in air-entrained concrete should be 4 to 7% of the concrete volume depending on the maximum size of coarse aggregate and other conditions as a standard.

(2) Air content tests for concrete shall be conducted in accordance with JIS A 1116, JIS A 1118 or JIS A 1128.

[Commentary] (1): Concrete with an appropriate amount of entrained air is highly durable against freeze–thaw cycles. As a general rule, therefore, air-entrained concrete shall be used in cases where concrete is to be subjected to severe weather conditions. It is common practice to specify a standard air content of about 4 to 7% of the concrete volume upon completion of mixing. The air content during the production process shall be determined in view of time-dependent changes during the process from production to placement and changes during transportation.

Entrained air is highly effective in improving the workability of concrete. By using air-entrained concrete, therefore, the water content needed to achieve the required level of workability can be reduced substantially. The strength of concrete, however, decreases as the air content increases, and the variability of concrete quality tends to increase as the air content increases. It is advisable, therefore, not to increase the air content excessively if weather conditions are not severe.

The air content of air-entrained concrete varies considerably depending on various conditions even if the air entraining agent content remains unchanged. An air content test shall be conducted, therefore, prior to the placement of air-entrained concrete.

(2): Air content tests may be conducted by the mass method (JIS A 1116), the volumetric method (JIS A 1118) or the pressure method (JIS A 1128).

4.5 Determination of Provisional Mix Proportions

4.5.1 Water content

(1) The water content is determined experimentally and be made as low as possible to the extent that concreting tasks can be performed.

(2) The upper limit of the water content of concrete should be 175 kg/m^3 as a standard. If the water content exceeds this upper limit, it shall be ascertained that the required durability is attained.

[Commentary] (1): A higher water content tends to result in a degradation in the quality of concrete such as a degradation in segregation resistance and an increase in drying shrinkage. It is therefore necessary to make the water content as low as possible to the extent that concreting tasks can be performed. Because the water content of concrete needed to achieve the required slump differs depending on such conditions as the maximum size of coarse aggregate, the particle size distribution and particle shape of aggregate, the type of admixture, and the air content of concrete, this Specification requires that the water content be determined through trial mixing by use of materials to be actually used for construction.

The water content can be reduced considerably by making appropriate use of air-entraining agents, air-entraining water-reducing agents, superplasticizer, etc. The percentage of water reduction, which varies depending on the air content, the type of admixture, concrete mix proportions, etc., is about 6 to 10% for air-entraining agents conforming to JIS A 6204, Chemical Admixtures for Concrete; 10 to 14% for standard-type or retarder-type air-entraining water-reducing agents; 8 to 12% for accelerator-type agents; and 16 to 20% for superplasticizer. The water content in the case where crushed stone or blast furnace slag coarse aggregate is used is about 10% higher than in the case where gravel is used although it varies depending on the shape of particles.

(2): Because the water content greatly affects the quality and durability of concrete, this Specification requires that the water content be specified at or below the upper limit of 175 kg/m^3 as standard. In this Specification, the water content of concrete refers to the water content specified at the mix design stage. It does not mean, therefore, that the upper limit of the water content reflecting the quality variations in actual construction work is 175 kg/m^3.

If the water content of concrete containing an air-entraining water-reducing agent exceeds 175 kg/m^3, a superplasticizer instead of an ordinary air-entraining water-reducing agent should be used so that the water content becomes 175 kg/m^3 or less. In the case of plain concrete, however, or in the case where it can be ascertained that the durability of concrete will not be adversely affected, a water content higher than 175 kg/m^3 may be adopted.

The lower limit of the water content is not specified, but a water content should be 145 kg/m^3 or higher when using crushed stone or crushed sand. Table C4.5.1 shows the recommended ranges of the water content. If the water content of ordinary concrete deviates from the ranges shown in Table C4.5.1, appropriate actions such as using a high-performance water-reducing admixture such as an air-entraining water-reducing agent or super plasticizer should be taken. In the case of concrete whose fluidity is evaluated in terms of slump flow such as high-fluidity concrete, too, the water content should be determined with reference to the ranges shown in Table C4.5.1.

Table C4.5.1 Recommend ranges of the water content of concrete

Maximum size of coarse aggregate (mm)	Range of water content (kg/m^3)
20 to 25	155 to 175
40	145 to 165

4.5.2 Cement content

The cement content shall be determined on the basis of the reference values indicated in the design specifications. If an upper or lower limit is specified for the cement content, that specification shall be met.

[Commentary] The cement content shall be determined on the basis of the reference values indicated in the design drawings and specifications. If an upper or lower limit is specified for the cement content, it shall be ascertained that the cement content determined from the water content and the water/cement ratio falls between the upper and lower limits specified for the water content. If it does not fall within the range between the upper and lower limits, it is necessary to change the materials used or the mix proportion. In the case of concrete made by using a superplasticizer, and if the cement content is too small, it tends to result in poor workability and a degradation in slump over time increases. It is recommended, therefore, that if the maximum size of coarse aggregate is 20 to 25 mm, a cement content of at least 270 kg/m^3 (250 kg/m^3 if the maximum size of coarse aggregate is 40 mm) and preferably 300 kg/m^3 or more be secured.

By increasing the cement content, the cracking due to hydration of cement may cause the problem. To solve this problem, the chemically-inactive powder, such as limestone powder, can be applied. In the case of mass concrete, which is subject to cracking due to the hydration of cement, it is necessary to determine an appropriate cement content with reference to Chapter 14, Mass Concrete. If the cement content does not fall within the upper and lower limits indicated in the design specifications or if the type of cement to be used is changed, verification needs to be conducted again concerning cracking due to the hydration of cement.

The cement content of offshore concrete and underwater concrete shall be determined as stipulated in the Construction: Special Concretes (Chapter 10, Underwater Concrete, and Chapter 11, Offshore Concrete) of this Specification.

4.5.3 Powdery material content

(1) The powdery material content is determined so that segregation resistance appropriate for the slump can be attained.

(2) The powdery material content is determined within the range appropriate for pumping and placement.

(3) If a lower or upper limit is specified for the powdery material content, all of such specifications shall be met.

[Commentary] (1): "Powder" is a collective term for any material with a fineness equivalent or higher than that of cement including not only cement but also blast furnace slag, fly ash, silica fume and limestone powder. The powdery material content (hereinafter powder content) is the sum of the contents of those powdery materials, and the powder content is a primary mix design factor affecting the segregation resistance of concrete. If only cement (including blended cement) is used, the powder content is the same as the cement content.

Concrete ingredients are prone to segregation if a powder content appropriate for slump is not secured, and an inappropriate powder content may result in defects at the construction stage such as honeycombing and incomplete filling. In order to achieve excellent pumpability and placeability, therefore, it is recommended that a powder content of at least 270 kg/m^3 be kept if the maximum size of coarse aggregate is 20 to 25 mm (at least 250 kg/m^3 if the maximum size of coarse aggregate is 40 mm) and preferably a powder content of 300 kg/m^3 or more be secured in order to ensure construction safety. The fine grains contained in aggregate are not taken into consideration here. An excessively high fine grain content of aggregate, however, may result in excessively viscosity of concrete so that workability declines. If, therefore, the fine grain content of the aggregate to be used is high, the powder content is reduced on as-needed basis.

It is recommended that when determining a rough level of the powder content appropriate for the specified slump, Chapter 2 of JSCE's Recommendations for Mix Design and Construction of Concrete Based on Placeability be used as a guide.

(2): In order to perform smooth, clogging-free pumping, it is necessary to keep the powder content at or above a certain level.

(3): If the design specifications indicate an upper or lower limit of the cement content, it is necessary to compare that upper or lower limit with the powder contents determined as described in Items (2) and (3) above and determine the powder content so that both requirements are met. If it is judged that meeting both requirements is not possible, the materials or mix proportions to be used need to be changed.

4.5.4 Sand-aggregate ratio

The sand-aggregate ratio is determined experimentally so that the water content can be made as small as possible to the extent the required workability can be attained.

[Commentary] In the mix design of concrete, an appropriate sand percentage shall be selected. In general, as the sand-aggregate ratio is reduced, the water content needed to obtain concrete with the required slump tends to decrease so that the cement content decreases accordingly and the mix proportion becomes more economical. If the sand percentage is reduced excessively, the resultant concrete may tend toward segregation, so it may cause poor workability of concrete. For a given combination of fine aggregate and coarse aggregate, there is an optimum sand percentage that provides the required workability and minimizes the water content. Because this sand percentage varies depending on the particle size distribution of fine aggregate, the air content of concrete, the cement content, the type of mineral admixture, etc., the sand percentage needs to be determined so that the water content is minimized. It shall be kept in mind that the sand percentage is the percentage by absolute volume, not by mass, of fine aggregate in total amount of aggregate in concrete.

The particle size distribution of aggregate should remain stable throughout the construction period. If the fineness modulus has deviated by 0.20 or more from that of the fine aggregate actually used for mix proportion during construction, workability is also affected considerably. In such cases, the mix proportions need to be modified. On such occasions, the validity of sand percentage values should also be verified by testing.

In the case of concrete pumping, it is necessary to select an appropriate sand percentage, on the basis of available data and past construction data, according to concrete pump performance, piping, pumping distance, etc. If superplasticized concrete is used, the sand percentage needs to be determined taking into account the workability of superplasticized concrete (see Recommended Practice for Concrete Containing Superplasticizers).

In the case of concrete containing a superplasticizer, a satisfactory result can often be obtained by using a sand percentage that is 1 to 2 percent higher than that of concrete that contains an ordinary air-entraining water-reducing agent and has the same water/cement ratio and slump (see Recommended Practice for Concrete Containing Air-Entraining High-Range Water-Reducing Agents).

The percentages of fine aggregate (sand) and coarse aggregate may be determined on the basis of the unit mass of coarse aggregate instead of the sand percentage as mentioned above. If slump is large, the relationship between the sand percentage and workability tends to become unclear. There are cases, therefore, where appropriate mix proportions can be better selected by determining the unit mass of coarse aggregate first. By using this method, in the case of plastic concrete, the bulk volume of coarse aggregate per cubic meter of concrete (unit bulk volume of coarse aggregate) can be made nearly constant, regardless of slump and the water/cement ratio, according to the maximum size of coarse aggregate and the particle size distribution of fine aggregate so that the coarse aggregate content can be determined easily even when using angular aggregate such as crushed stone.

Table C4.5.2 shows typical values of the unit bulk volume of coarse aggregate, the sand percentage and the water content for concrete with a water/cement ratio of about 55% and a slump of about 8 cm. When air-entrained concrete is used in ordinary reinforced concrete construction, a concrete mix obtained from the unit bulk volume of coarse aggregate tends to contain a somewhat high percentage of sand. Table C4.5.3 shows approximate amounts of correction for the sand percentage and the water content in the cases where the materials used and concrete quality shown in Table C4.5.2 are changed. In general, as the sand percentage decreases and the coarse aggregate content increases, the workability of concrete such as pumpability and void-penetrating ability decreases. It is necessary, therefore, to select appropriate minimum values of the sand percentage and appropriate maximum values of the coarse aggregate content appropriate for the specified slumps. When determining a sand percentage or coarse aggregate content appropriate for a slump, it is recommended that Table C4.5.2 and Table C4.5.3 and Chapter 4 of JSCE's Recommendations for Mix Design and Construction of Concrete Based on Placeability be used as guides.

Table C4.5.2 Approximate values of the unit bulk volume of coarse aggregate, sand percentage and water content of concrete

Maximum size of coarse aggregate	Unit bulk volume of coarse aggregate	Air-entrained concrete				
		Air content	With air-entraining agent		With air-entraining water-reducing agent	
			Sand percentage s/a	Water content W	Sand percentage s/a	Water content W
(mm)	(m^3/m^3)	(%)	(%)	(kg)	(%)	(kg)
15	0.58	7.0	47	180	48	170
20	0.62	6.0	44	175	45	165
25	0.67	5.0	42	170	43	160
40	0.72	4.5	39	165	40	155

The values shown above are average values determined with reference to the standard mix proportions adopted by ready-mixed concrete industrial associations in Japan and are for concrete made by using sand of an ordinary particle size distribution (fineness modulus: about 2.80) and crushed stone.

Table C4.5.3 Approximate amounts of correction for the sand percentage and the water content due to variations in the quality of materials used or concrete

Category	Correction of s/a (%)	Correction of W
For every 0.1 in fineness modulus of sand greater (smaller) than reference value	Increase (decrease) by 0.5.	No correction
For every 1 cm in slump greater (smaller) than reference value	No correction	Increase (decrease) by 1.2%.
For every 1% in air content higher (lower) than reference value	Decrease (increase) by 0.5 to 1.	Decrease (increase) by 3%.
For every 0.05 in water/cement ratio higher (lower) than reference value	Increase (decrease) by 1.	No correction
For every 1% in s/a higher (lower) than reference value	—	Increase (decrease) by 1.5 kg.
When river gravel is used	Decrease by 3 o 5.	Decrease by 9 to 15 kg.

If the unit bulk volume of coarse aggregate is used, the unit bulk volume of coarse aggregate is decreased (increased) by 1% for every 0.1 in the fineness modulus of sand greater (smaller) than the reference value.

4.5.5 Unit quantities of admixtures

The unit quantities of admixtures are determined so that the required effect can be obtained.

[Commentary] The effect of admixtures varies depending on not only the characteristics of each admixture but also the nature of cement and aggregate, the type of other admixtures used, concrete mix proportions, construction conditions, environmental conditions, etc. The quantities of admixtures to be used, therefore, need to be determined according to these conditions by testing their performance under realistic service conditions or consulting literature or experience. Combined use of two or more types of admixtures may have unexpected adverse affects on the properties of fresh concrete and the performance of hardened concrete. When using a new combination of admixtures, therefore, a thorough study should be conducted in advance.

4.6 Trial Mixing

4.6.1 General

(1) Concrete mix proportions shall be determined through trial mixing so that concrete that meets the mix requirements can be obtained.

(2) Trial mixing of concrete should be conducted in the form of laboratory testing as a standard.

(3) Trial mixing may be omitted if it can be ascertained from performance data, etc., that the planned mix proportion meets the mix requirements.

[Commentary] (1): Trial mixing shall be conducted in order to ascertain that the mix proportion determined at the mix design stage meets the mix requirements. Concrete performance changes under the influence of various factors. The performance of fresh concrete is subject to considerable change depending on the time after completion of mixing, ambient temperature, on-site transportation methods, etc. When designing concrete mixes, therefore, it is important to set quality goals at each stage (i.e., production and unloading) so that concrete workability needed at the placement stage can be attained. This section requires, therefore, that concrete mix proportions be determined through trial mixing prior to the placement of concrete so that concrete that meets the performance requirements can be obtained. Trial mixing shall be conducted, on an as-needed basis, under the direction of a Chief Concrete Engineer or Concrete Engineer certified by the Japan Concrete Institute or an equally qualified engineer.

(2) and (3): In order to determine concrete mix proportions through trial mixing, it is necessary to measure materials of proven quality accurately and mix them thoroughly. This is why laboratory testing is required as a standard method. If, however, the conditions under which concrete is produced in a laboratory test environment differ from the conditions under which concrete is to be produced for construction or if changes in concrete quality over time are to be evaluated, trial mixing of concrete should be conducted by using real mixers.

4.6.2 Trial mixing method

(1) Trial mixing is conducted in the form of laboratory testing so that concrete that meets the mix requirements can be obtained.

(2) When trial mixing is conducted in a laboratory test, workability upon completion of mixing is evaluated taking into account the difference in slump from the results of tests conducted by use of real equipment, concrete temperature at the time of construction, mixing performance, transportation time, etc.

(3) Trial mixing of concrete should be conducted at 20±2°C as a standard. If trial mixing cannot be carried out under such test conditions, mix proportions shall be determined after making corrections for temperature differences.

(4) In a mix test using a test mixer, appropriate test items shall be selected so as to evaluate the workability of concrete.

[Commentary] (1) and (2): At the mix design stage, the target slump at the unloading location and the target slump upon completion of mixing shall be determined on the basis of the minimum slump for placement, taking into account transportation time, waiting time at the construction site and the decrease in slump due to on-site transportation. In trial mixing conducted in the form of laboratory testing, therefore, it is necessary to make repeated corrections for mix proportions to achieve the target slump at the unloading location or the target slump upon completion of mixing until the required minimum slump for placement can be attained, taking into account the decreases in slump not only immediately after completion of mixing but also after the passage of time. Concerning mix proportion corrections, Table E4.5.2 should be used as a guide.

If a large amount of decrease in slump is assumed at the mix design stage, time-dependent changes in slump during the time from the completion of mixing to the placement of concrete should be estimated. If trial mixing has indicated the possibility of a large amount of decrease in slump over time, it is important to select mix proportions with an excellent slump-retaining property and take necessary measures such as using appropriate chemical admixtures so that the minimum slump for placement can be attained. In general, the amount of decrease in slump of a concrete mix uninterruptedly agitated in a mixer tends to be smaller than that of small-batch concrete kept in a static state in a laboratory test. As a rule of thumb, it may be assumed that slump retention time in a mixer test is about 30 minutes longer than that in a laboratory test.

Mixing performance varies widely depending on mixer types so that the quality of freshly mixed concrete and subsequent changes in quality are greatly affected. Mixers used in laboratory testing, therefore, should be of the same type as the mixers used for construction.

(3): Trial mixing in a laboratory test should be conducted at constant temperature conditions (20±2°C). If the time of year when trial mixing is conducted differs from the time of year when construction is carried out and a considerable difference in placing temperature is expected, mix proportions need to be determined taking into account that temperature difference. It is also good practice to conduct trial mixing by using mixers and correct mix proportions derived through laboratory testing.

(4): Concrete shall be provided with workability suitable for construction tasks such as hauling, placing, compacting and finishing according to the construction requirements, structural requirements and the environmental conditions. In concrete mix tests, it is important to check whether the mix proportions specified at the mix design stage have the targeted performance with respect to filling ability, pumpability, setting properties and strength development characteristics.

4.7 Representation of Mix Proportions

As a general rule, mix proportions should be presented as shown in Table 4.7.1.

Table 4.7.1 Representation of mix proportions

Maximum size of coarse aggregate	Slump[1]	Air content	Water/cement ratio[2] *W/C*	Sand percentage *s/a*	Content (kg/m³)						
					Water	Cement[3]	Mineral admixture[3)4)]	Fine aggregate	Coarse aggregate G		Chemical admixture[5]
(mm)	(cm)	(%)	(%)	(%)	*W*	*C*	*F*	*S*	(mm)	(mm)	*A*

Notes 1) The standard method is to indicate the target slump at the unloading location. If necessary, the minimum slump for placement and the target slump upon completion of mixing are also indicated.

2) If a mineral admixture with pozzolan reactivity or latent hydraulic property is used, the water/cement ratio becomes the water/binder ratio.

3) The powder content should be indicated as the combined content of cement and mineral admixtures as an approximate indicator of segregation resistance.

4) If two or more types of mineral admixtures are used, mix proportions for different types are indicated separately on an as-needed basis.

5) The chemical admixture content is indicated in ml/m³ or g/m³, and the quantity of undiluted and undissolved liquid must be indicated.

[Commentary] As a general rule, mix proportions should be indicated by mass, and the content of each ingredient used in each cubic meter of mixed concrete must be indicated in the form of a mix table like Table 4.7.1. Mix tables should also show information such as the type of structure, specified strength, required strength, the type of cement, the fineness modulus of fine aggregate, the type of coarse aggregate, the solid content of coarse aggregate, transportation time and the time of year of construction. A recommended standard practice is to indicate the target slump at the unloading location in mix tables and, if necessary, determine the slump at each stage of construction from immediately after completion of mixing to the placement of concrete. It is also good practice to indicate the combined content of powdery materials such cement and mineral admixtures to show whether segregation resistance appropriate for the slump level is being maintained.

CHAPTER 5 CONCRETE PRODUCTION

5.1 General

(1) Concrete with the required quality shall be produced.

(2) Equipment used for the storage, batching and mixing of materials shall be one that has been verified to have the required performance.

(3) Methods of storing, batching and mixing materials by using equipment with the requirement performance shall be determined prior the production of concrete.

(4) Specialists with sufficient knowledge and experience shall be assigned to the production of concrete to control the quality of concrete materials, production equipment and concrete.

[Commentary] (1): In order to produce concrete with the required quality, it is important to use equipment with the required performance, use appropriate production methods and have specialists capable of ensuring stable quality of concrete perform quality control.

(2) and (3): Use of equipment with the required performance is most fundamental and important for the production of concrete. Even if the concrete materials meet the quality requirements specified in Chapter 3, inadequate production equipment increases the possibility of fluctuations or degradation of the quality of stored materials, fluctuations in mix proportions due to batching errors, and fluctuations of the properties of mixed concrete, thereby making it difficult to obtain concrete with the required quality stably. Even when the storage, batching and mixing equipment meet the performance requirements, it is difficult to obtain concrete with the required quality if concrete is produced without ascertaining in advance that the storing, batching and mixing methods are appropriate as in the case where inadequate equipment is used. The performance requirements for production equipment are described in Section 5.2, and appropriate production methods are described in Sections 3.7, 5.3 and 5.4.

(4): Even when production equipment meets the performance requirements and appropriate production methods are used, it is difficult to obtain concrete of stable quality if production specialists lack the ability to control the quality of concrete stably. Since the quality of concrete is easily affected by various factors, it is important for the specialists who produce concrete to have expert knowledge and experience related to the quality and production of concrete. For example, it is important that a specialist qualified as a Chief Concrete Engineer or a Concrete Engineer stay at the construction site and perform quality control. Since the operation and maintenance of production equipment requires specialized knowledge about mechanical and electrical equipment, it is good practice to make effort to enhance the operators' ability and knowledge about operation and consider ways to contact outside specialists so that troubleshooting actions can be taken in times of equipment failures.

5.2 Production Plant

5.2.1 Storage facilities

(1) Storage facilities for cement and mineral admixtures shall have a structure to keep the inside free of moisture, and the cement and admixtures shall be stored separately according to their types.

(2) Storage facilities for aggregates shall have a structure that stores aggregates separately according to their type, size and grading such that they do not segregate in the size easily. Also, the storage facilities shall have an adequate drainage such that the surface moisture content of aggregate can be maintained at a uniform level.

(3) Storage facilities for chemical admixtures shall have a structure that stores the admixtures separately according to their types, and shall prevent any contamination with impurities, changes in properties, segregation in liquid admixtures, etc.

[Commentary] (1): In general, cements and mineral admixtures should be stored in storage facilities equipped with a structure to keep the inside free of moisture. The volume of a silo should be more than three times the average volume of use per day. A storage silo for cements and mineral admixtures should be of structure as to have no dead stock of cement at the bottom, and be equipped with vibrators, knockers or an aeration system in the vicinity of the bottom to prevent the arch formation of the powder particles and to ensure a smooth discharge of the materials.

In case when using the cement silo of which inside is separated into some smaller storage by the steel plate separators etc., attention need to be paid for the leakage of cement from the welding part. Furthermore, it shall be prevented that different types of cements or mineral admixtures mix each other through a hole due to corrosion on the steel separator.

If cement cannot be sent directly from a cement silo to a batching bin, it is necessary to install a storage bin over the batching bin. Two or more cement storage bins should be available. If mineral admixtures that are not used for the production of ordinary concrete are stored as when high-fluidity concrete is produced, care shall be taken to prevent problems such as clogging or malfunctioning of level indicators due to the compaction of admixtures resulting from long-term storage.

(2): It is important that aggregate storage facilities be capable of storing aggregates of different types or different sizes separately and have sufficient capacity so that stored aggregate can be used on a first come, first used basis. The storage facilities shall also be structurally designed so that aggregates do not become segregated when they are received or handled. Since the quality of concrete is easily affected by fluctuations in the surface moisture content of aggregate, control measures need to be taken so that the surface moisture content of aggregate is kept uniform.

Aggregate storage facilities include stockyard types and silo types. For stockyard type storage facilities, it is important to provide roofing so that aggregate is not affected by rains and direct sunlight, prevent the intrusion of other aggregates, mud, dead leaves, ice, snow, etc., and provide a gentle drainage slope for effective drainage. For silo type storage facilities, the bottom of a fine aggregate storage silo should be designed for efficient drainage, and devices such as air blasters should be provided so that the aggregate accumulated at the bottom of the silo can be removed. Even for silo type storage facilities, if the hopper for receiving aggregate from a transportation vehicle is located outdoors, it is important to provide a roof over the hopper to prevent the intrusion of rain and the accumulation of aggregate in the hoppers.

In order to minimize fluctuations in the particle size distribution of aggregate, for example, 20 to 5 mm aggregate should be divided into 20 to 10 mm aggregate and 10 to 5 mm aggregate and be stored and batched separately. It is also necessary to take measures so as to prevent the freezing of aggregate or a rise in temperature of aggregate because of outdoor air temperature.

Aggregates stored in stockyard facilities or silos are transported by a belt conveyor to the concrete plant, distributed by turn chutes, and dropped into the aggregate storage bins. These facilities shall be inspected periodically for problems such as clogging of drainage troughs, leakage from the gates, intrusion of water into the aggregate carried on the belt conveyor, or the accumulation of aggregate on the belt conveyor or in the storage bins.

If highly absorptive aggregates such as artificial lightweight aggregates or blast furnace slag coarse aggregates are stored, watering facilities such as sprinklers should be provided in addition to drainage facilities. Concerning the storage of artificial lightweight aggregate, Construction: Special Concretes (Chapter 2, Lightweight Aggregate Concrete) of this Specification should be consulted. Because of its latent hydraulic property, blast furnace slag fine aggregate may become difficult to withdraw during the time of year when daily mean temperature exceeds 20°C so that consolidation occurs in the aggregate storage facilities or storage bins. It is therefore necessary to avoid long-term storage during such periods. When producing concrete by using blast furnace slag fine aggregate, the Guidelines for Construction Using Blast-Furnace Slag Aggregate Concrete should be consulted.

(3): Chemical admixtures shall be stored in such a way as to prevent the incursion of dirt or other impurities. Chemical admixtures of liquid form shall be stored so as to prevent their segregation, quality change or freezing. Chemical admixtures of powder form shall be stored so as to prevent their moisture absorption and lumping. Chemical admixtures which have been stored for a long time or are found to be of unsure quality shall be tested to confirm their quality before use.

The storage facilities for the chemical admixtures of liquid form shall be of structure that can protect from the contamination of impurities, and should have a mixer or a circulator protecting from the segregation due to sedimentation. In case that the storage tanks or the transportation pipes are made of steel, attention needs to be paid for corrosion. Though the liquid type of chemical admixtures is, generally, controlled its pH to neutral or week alkali condition, special attention should be required for use of the acid admixture.

For storage facilities (tanks) for water and liquid chemical admixtures, it is also important to take measures to reduce batching errors by using the automatic water supply method or overflow piping to keep water pressure, water level or concentration constant or protection measures to prevent freeze damage to the piping from the storage tanks to the storage bins and a breakdown due clogging of electromagnetic valves because of foreign matter or precipitates.

5.2.2 Measuring equipment

(1) Equipment used to weigh each material shall be compatible to the production of concrete, and be capable of batching each material within the required accuracy.

(2) Equipment used to weigh each material shall be periodically inspected before and during the operation, and appropriately adjusted.

[Commentary] (1): It is necessary to choose the measuring equipment suitable for producing volume of concrete, the scale and importance of the construction, etc. Furthermore, the equipments used to weigh each material shall be capable of batching each material within the required accuracy.

Though there are both mechanical and electrical types of measuring equipment, the most popular is the electrical type because remotely-monitoring can be operated and a digital control is done with an analog digital converter, at present.

Since the setting of batching values is fundamental to batching, batching equipment needs to be capable of performing batching correctly according to the mix proportion settings. Punch card equipment is used for the setting of batching values, but today most plants use CPU-memory type equipment based on computer keyboard entry. Recent years saw widespread use of operation room equipment with comprehensive quality control capability, as well as batching control, that incorporates various other systems such as automatic material feed control systems, automatic surface moisture content measuring systems and automatic batching value correction systems.

Chemical admixtures such as air-entraining water-reducing agents greatly affect the quality of concrete. Devices for preventing excessive water flow may be installed at the water inlets.

(2): The batching equipment for each material shall be checked before the start of the use and adjusted so as to weigh each material within the prescribed limits for errors in batching. Even when batching equipment is adjusted in this way, the accuracy deteriorates with time. Therefore, the equipment shall be regularly checked and readjusted as required.

If the inside surface of the aggregate batching bin is not smooth, residual aggregate may lower batching accuracy. It is therefore necessary to make improvements such as bonding rubber sheets.

5.2.3 Mixers

(1) As a general rule, batch mixers should conform to JIS A 8603.

(2) Continuous mixers shall be ones that have been verified to have the required mixing through a mixing performance test conducted in accordance with JSCE-I 502.

[Commentary]　(1): Batch mixers are classified into two types; the gravity type and the forced mixing type. Regarding the gravity type, there are tilting and drum mixers. Forced mixing type batch mixers come in pan types, single- horizontal- axis and double-horizontal-axis types. Mixing efficiency is tested on mixed concrete by a compressive strength test, an air content test and a slump test, in accordance with JIS A 1119 “Method of Test for Variability of Constituents in Freshly Mixed Concrete” and JIS A 8603 “Concrete Mixer”. When the testing results do not satisfy the threshold values shown in Table C5.2.1, it is often considered that the structure of the mixer is not appropriate, or the blade for mixing is abraded.

Table C 5.2.1 Mixing Capacity of batch mixer

Items		Mixing volume of concrete	
		Nominal volume	A half of nominal volume
Variability of mass per unit volume of mortar in concrete		0.8% or less	0.8% or less
Variability of content of coarse aggregate in concrete		5% or less	5% or less
Variability from average value	Compressive strength	7.5% or less	—
	Air content	10% or less	—
	Slump value	15% or less	—

In the upper bound of the nominal capacity of the mixer targeted by JIS A 8603 "Cement mixer", both the gravity type mixer and the forced mixing type mixer are $3m^3$. The suitability should be judged by applying regulations of JIS A 8603 correspondingly about the mixer for nominal capacity to exceed this. Recently, a mass mixer of nominal capacity $6m^3$ has come to be used.

The forced mixing type mixer is suitable for the stiff concrete, the concrete of the rich mix and the Special Concretes (Chapter3 Lightweight Aggregate Concrete, Chapter6 High Strength Concrete, Chapter7 High Fluidity Concrete, etc). In general, the forced mixing type mixer can shorten necessary mixing time than the case of the tilting mixer.

(2): Continuous mixers may be used when large-scale production equipment cannot be installed at the sites of tunnel construction, rehabilitation, offshore construction, etc. Concrete production by use of continuous mixers, however, differ in many ways from concrete production by use of batch mixers (e.g., the batching of materials by volume, sufficient calibration necessary for stable supply, the possibility of poor quality concrete output immediately after the commencement of operation). Continuous mixers, therefore, shall be used after referring to the Recommendations for Job-Mixed Concrete Construction Using Continuous Mixers to fully understand the characteristics of continuous mixers and conducting a test in accordance with JSCE-I 502, Method of Test for Mixing Performance of Continuous Mixers.

5.3 Measurement of Materials

(1) Materials shall be batched according to mix proportions modified in view of such factors as the state of materials, concrete temperature and slump retention time so that concrete with the required quality can be obtained.

(2) The size of batch shall be determined considering the type and properties of concrete, performance of mixing equipment, method of transportation, type of construction, quantity of concrete to be placed, etc.

(3) All materials for each batch shall be measured by weight. Errors in batching for each measurement shall not be greater than the values given in Table 5.3.1.

Table 5.3.1 Permissible errors in measurements

Material	Error in measurements (%)
Water	1
Cement	1
Aggregate	3
Mineral admixture	2 [1)]
Chemical admixture	3

1) In case of finely ground blast furnace slag, the error in batching shall be taken as 1.

(4) In cases when a continuous mixer is used, the materials may be measured by volume. The error in measurement shall not be greater than the values given in Table 5.3.1 in which the error should be calculated in mass weight that is converted from the volume of each material per an appropriate specified period depending on the capacity of the mixer. The measured volume of each material per the specified period shall be properly determined on the basis of the type of concrete mixer, mixing time, etc.

[Commentary] (1): The materials in storage should be in as stable a state as possible, but the surface moisture content and particle size distribution of aggregate, for example, are always in a state of change. The temperature of freshly mixed concrete also varies depending on such factors as the temperature of the materials in storage and outdoor air temperature. These various changes affect the slump and air content of freshly mixed or subsequent concrete. Concrete materials to be used, therefore, shall be batched after corrections for such changes are made so that concrete of the required quality can be obtained.

The surface moisture content and effective absorption of aggregate change easily, and such changes affect the slump and water/cement ratio of concrete. The surface moisture content or effective absorption, therefore, shall be measured at an appropriate frequency and the measurement results shall be reflected in batching. The surface moisture content shall be tested in accordance with JIS A 1111, JIS A 1125 or other appropriate method, and particle size distribution shall be tested in accordance with JIS A 1102 or other appropriate method. Effective absorption values in the cases where aggregate is dry shall be determined after letting the aggregate absorb water for an appropriate period of time.

Methods for testing the surface moisture content include JIS A 1111, Method of Test for Surface Moisture in Fine Aggregate, and JIS A 1125, Method of Test for Moisture Content of Aggregate and Surface Moisture in Aggregate in Drying. Other methods include the graduated cylinder method, methods using infrared rays or other means for drying, methods using electrical resistance or the dielectric constant, neutron-based methods and many other methods. Test methods most appropriate for the jobsite should be selected in view of factors such as the time required for the task to be performed, the number of test cycles, test accuracy and economic efficiency. In recent years, it has become possible to make water and aggregate batching corrections for all batches of fine aggregate according to changing surface moisture contents by installing surface moisture sensors in the aggregate storage bins and at their outlets.

The water used for the dissolution or dilution of chemical admixtures is deemed to be included in the water content. The solids contained in chemical admixtures may be ignored for the purpose of concrete volume calculation.

(2): As the size of each batch of concrete produced especially in a plant at the construction site is closely related to the efficiency of work and construction cost, it is important that the proper size is determined considering the type of work, concrete quantity to be placed, the capacity of mixing plant and transportation method.

(3): As a general rule, materials shall be batched by weight. However, water and the liquid chemical admixtures may be measured by volume, in the case where they are confirmed to be within the acceptable error described in Table 5.3.1. In the case where cement and mineral admixtures are supplied in bags, and the difference between the net mass of 1bag and the printed value on the mass is confirmed to be within the acceptable error described in Table 5.3.1, they may be batched on the basis of the number of bags. However, a quantity which is less than 1 bag shall be measured by mass.

Material batching errors include errors attributable to the batching equipment and errors that occur when materials are fed to the batchers. Errors of the former type can be reduced sufficiently by the daily inspection and maintenance of the batchers because the inaccuracy of the batchers can be determined by use of the proof mass. In general, the accuracy of batchers used for concrete construction is about 0.5% of the maximum capacity. Errors attributable to material feeders, etc., however, can only be reduced to a limited extent. Batching devices, therefore, shall be managed so that material batching errors of the batching system including the measuring instrument and the feeder can be kept within an appropriate range in relation to the target value. JIS A 5308 requires that cement and mineral admixtures be batched by use of separate measuring instruments.

The batching errors specified in this article are the maximum limits of batching error allowable at general construction sites. In the case of important structures, proper batching methods whose batching error is less than the value shown in Table 5.3.1 should be adopted. As batching error become large particularly when the quantity to be measured is small in comparison with the capacity of the batching machine, it is necessary to confirm that a batching machine can measure the quantity of each batch accurately. The finely ground blast furnace slag is usually used for concrete in the range of 30 to 70 % in the total mass of binder, and is the mineral admixture having a latent hydraulic property. Therefore, the error in batching of the slag shall be taken as 1% or less, which is same regulation as the cement.

In a case of the batching in construction site, it is important to provide such supply equipment that batching errors does not increase. Furthermore, it is important to prescribe the capacity of a batching machine so as to measure the quantity of each batch accurately and to modify the equipment as required. Particularly the batching machine for water needs to be devised to improve its accuracy. Since the batching machine often get out of order due to dust, they shall always be kept clean by installing a dust collector and so on. Then the batching value should be controlled by a printing record.

(4): In the case of the continuous mixer, which is different from the batch mixer, the quantity of materials is usually measured by volume by adjusting the quantities of the supply of aggregate, water and admixtures according to mix proportions on the basis of the quantity of supply of cement per unit hour. If a continuous mixer is used, its measuring equipment shall necessarily be inspected prior to the commencement of work by using materials which are to be used for the work. This inspection shall be conducted by measuring the weight of each material supplied during a fixed time. Measuring by volume generally results in more measuring errors than measuring by weight.

Therefore, when the inspection is performed, in order to obtain quantity-per-prescribed-time most accurately, it is important that the capacity of the measuring machine is properly determined and the measuring equipment is adjusted as required, to reduce measuring errors to the utmost, so that measuring errors for each material will be within the allowable limits.

5.4 Mixing

(1) Constituent materials of concrete shall be thoroughly mixed until a uniform concrete is obtained.

(2) The sequence of charging materials into the mixer shall be appropriately examined and decided in advance.

(3) As a general rule, time for mixing should be determined through experiments.

(4) Mixing shall not be continued for more than three times the predetermined time of mixing.

(5) As a general rule, the inner surface of the mixer should be covered with mortar before commencing mixing.

(6) Materials for a new batch shall not be loaded into the mixer before the previous batch has been completely discharged.

(7) Mixers shall be properly washed prior to and after the use.

(8) When a continuous mixer is used, the first portion of discharged concrete shall not be used.

[Commentary] (1): In order to obtain a uniform concrete, mixing needs to be performed using a mixer with high efficiency by feeding the materials in the proper order and mixing them for a proper period of time.

(2): Since the suitable order of changing materials into the mixer varied depending on the type of mixer, mixing time, type and grading of aggregate, unit water content, unit cement content and type of admixtures, this should be determined with reference to the past experience or the results of the test performed in accordance with JIS A 1119, strength test and bleeding tests.

(3): Since the time necessary for sufficient mixing in batch mixers varies considerably depending on the type of mixer, mixer capacity, concrete mix proportions, type of admixture and order of feeding materials, it shall be determined based on the results of test of JIS A 1119 and other tests as a general rule.

In the case where the difference in the mass of the unit volume of mortar is less than 0.8% and the difference in the content of coarse aggregate is less than 5%, which are specified in JIS A 1119, it can generally be considered that satisfactory mixing has been carried out. Furthermore, if the relationship between the load current of the mixer and the operation time can be measured, the time until the load current changes in the stable condition after some amount of increasing and decreasing will be suggestive to determine the mixing time.

If tests for mixing time are not performed, the minimum time may be set at 1.5 minutes for tilting batch mixers and 1 minute for compulsory batch mixer. These are maximum value based on the results of investigation of batching equipment and mixers in use conducted in 1984, and the average time which can obtain by the test are about 70% of those times.

In the case of small-slump concrete, concrete made by using lightweight aggregate or admixtures or high-strength concrete, it is in many cases appropriate to use long mixing time. When lightweight aggregate concrete, high-strength concrete, etc., are mixed, Construction: Special Concretes of this Specification should be used as a guide.

(4): If concrete is mixed for a long time, especially in the case where mixer capacity is large, or the aggregate is not stiff and its maximum size is large, not only the workability of concrete at discharging time is reduced but also its slump loss with time becomes larger, because the aggregate is crushed to increase the amount of powder and the air content deceases during the prolonged mixing period. Therefore, it is specified that the mixer shall not be continued for more than three times the predetermined mixing time.

(5): The concrete of the required mix proportions can not be obtained in the first batch since a part of its mortar component will adhere to the bare surface of the mixer. Therefore, an appropriate amount of concrete should be mixed to adhere its mortar to the inside of the mixer, and the prescribed materials should be charged into the mixer to be mixed after discharging the prior concrete.

(6): If new materials are put into a mixer in which there is residual concrete and mixed together, concrete of the required quality cannot be obtained because inadequate mixing occurs locally. Mixing of new materials, therefore, shall not be started until it is confirmed that previously mixed concrete is completely discharged.

(7): In cases where the quality of mixed concrete may vary because of differences in the materials used in different batches, the measures described in Item (6) in this section should be taken after the mixer is cleaned.

(8): When a continuous mixer is used, since the concrete of undesirable quality may be discharged at the start of its operation, such concrete shall not be used. The amount of concrete to be disposed of shall be greater than the volume of mixing part as standard. This precaution needs to be taken also when the mix proportions are changed (see the JSCE Recommendation "Recommended Practice for Field Mixed Concrete by Continuous Mixer").

5.5 Plasticization of Concrete

Plasticization of concrete shall be carried out after considering details such as materials, mix proportions, fluidity-enhancing method, and the time until the completion of placement so that the quality requirements for concrete can be met.

[Commentary] Slump can be increased by adding plasticizer to the concrete in the drum of the truck agitator that has transported the concrete from the concrete plant to the construction site and stirring the mix until it becomes homogeneous. The use of plasticizers is effective when the required slump cannot be maintained until the placement of concrete is completed. Superplasticized concrete with a slump comparable to that of ordinary concrete helps prevent thermal cracking and achieve higher quality because the water content and the cement can be reduced. Changes in slump of superplasticized concrete over time, however, differ considerably from those of ordinary concrete, and excessive use of plasticizers may have adverse effects, such as segregation and changes in the air content, on the quality of concrete. When trying to increase the fluidity of concrete, therefore, it is necessary to carefully study details such as materials, mix proportions, fluidity-enhancing method (e.g., timing, the quantity of superplasticizer to be added, mixing time and method), the management of time until the completion of placement taking into account the slump retention time after plasticization, and noise control so that the quality requirements for concrete can be met.

Chemical admixtures added to concrete before plasticization may not go well with plasticizers, and there may be adverse effects on their respective effects. Undesirable combinations, therefore, need to be identified in advance. The amount of increase in slump needs to be kept within the range that does not cause segregation of plasticized concrete. As a general rule, therefore, the amount of increase in slump shall not exceed 10 cm, and 5 cm to 8 cm shall be regarded as standard values.

Post-plasticization slump varies widely depending on the pre-plasticization quality of concrete, the type and dosage of superplasticizer, concrete temperature, etc. Because slump retention time may become shorter, the time until completion of placement should be managed by checking in advance on the slump retention time.

Re-flowing of the plasticized concrete may generate the segregation or the delay of setting time of concrete due to an oversupply of plasiticizer, and consequently, have a bad influence on the performances of hardened concrete, such as durability, strength in the long term and so on. Therefore, the re-flowing should be avoided in the plasticized concrete.

There are also many other considerations such as methods of adding plasticizers, noise due to high-speed rotation of truck agitators, and exhaust gas control. When using plasticized concrete, the Recommended Practice for Concrete Containing Plasticizers should be consulted in advance.

CHAPTER 6 READY-MIXED CONCRETE

6.1 General

(1) As a general rule, ready-mixed concrete used should be one that conforms to JIS A 5308 and bears a JIS Mark indicating JIS certification (hereafter referred to as a "JIS-certified product").

(2) Prior to purchasing ready-mixed concrete, a plant shall be selected so that the required quality of concrete can be obtained, and the requirements specified in JIS A 5308 such as materials, quality and mix proportions shall be discussed with the producer.

[Commentary] (1) and (2) JIS A 5308, Ready-Mixed Concrete, specifies requirements such as the type and quality of ready-mixed concrete, mix proportions, materials, manufacturing, quality control, and test methods, and the appendices specify details such as the requirements for aggregates to be used for ready-mixed concrete and test methods to be used. Although JIS A 5308 does not necessarily agree with this Specification, the requirements specified in JIS A 5308 are designed to cover a wide range of requirements. It is usually possible, therefore, to procure concrete of the quality specified in this Specification by purchasing JIS-certified ready-mixed concrete conforming to JIS A 5308.

When purchasing JIS-certified ready-mixed concrete, it is necessary to carefully consider the quality of concrete specified in this Specification and select a plant, specify quality requirements and conduct acceptance inspections so that the concrete of the required concrete can be obtained. If the provisions in this Specification differ from the provisions of JIS A 5308, the standard method is to follow the more stringent of the two sets of provisions, but the constructor needs to make an informed decision with the full understanding of the differences between the two sets of provisions and the reasons for those differences.

If concrete that does not conform to JIS A 5308 in terms of materials, mix proportions, quality criteria, etc., is purchased for reasons such as the purpose of use of concrete or construction conditions, mix requirements and other details must be fully discussed with the producer and trial mixing must be conducted on an as-needed basis to verify quality and determine mix proportions. With respect to matters not specified in this Specification or relevant JSCE guidelines, JIS A 5308 should be followed. In other words, even in cases where ready-mixed concrete that does not conform to JIS A 5308 is used, it is necessary to select a plant that manufactures JIS-certified products. For matters not specified, it is necessary to determine specifications in due consideration of the intent of the JIS A 5308 provisions and select plants, specify quality requirements and conduct acceptance inspections accordingly.

Although JIS A 5308 includes provisions related to pavement concrete, this chapter does not include provisions related to pavement concrete because this Specification does not deal with pavement work.

6.2 Selection of Plants

(1) Ready-mixed concrete plants shall be selected from JIS-certified plants, and preferably from plants that have been permitted by the Namakon Quality Control Inspector Conference to use its certification mark. If other plants need to be selected, a certified Chief Concrete Engineer or Concrete Engineer or an equally knowledgeable and experienced engineer shall be permanently posted, and plants shall be selected from those capable of performing mix design and quality control appropriately.

(2) Matters to be considered for the selection of concrete plants shall include the transportation time to sites, unloading time, concrete production capacity, number of transporting vehicles, manufacturing equipment condition of quality control and so on.

[Commentary] (1) Ready-mixed concrete plants vary widely in terms of production facilities, production technology, quality control, etc. Under the Industrial Standardization Act, therefore, at the request of ready-mixed concrete plants, state-authorized private-sector certifying organizations examine the plants in accordance with JIS Q 1001, Conformity Assessment—Conformity Assessment for Japanese Industrial Standards —General Guidance on a Third-Party Certification System for Products, and JIS Q 1011, Conformity assessment− Conformity Assessment for Japanese Industrial Standards—Guidance on a Third-Party Certification System for Ready-Mixed Concrete Products, and authorize the certified plants to put a JIS mark on their JIS-conforming products. This plant certification shows that the certified plant meets the equipment, operation, management and other requirements for the production of JIS-conforming ready-mixed concrete and ready-mixed concrete produced at the plant conforms to JIS.

The number of JIS-certified plants has reached about 3,800, and the state of quality control differs considerably even among the certified plants. National Ready-Mixed Concrete Industrial Association, therefore, upgraded the national uniform quality control audit system administered jointly by an industry–government–academia organization. Under the new system, regional quality control audit conferences established in each prefecture conduct on-site audits of plants every year in accordance with the uniform audit criteria adopted by the Namakon Quality Control Inspector Conference. The plants that have passed these audits are granted a certificate and are permitted to use a certification mark after undergoing an deliberation by the National Ready-Mixed Concrete Industrial Association. The newly introduced system has enhanced transparency and fairness in the quality control of ready-mixed concrete and has made it possible to supply even more reliable concrete. According to 2006 survey results, the plants that have been permitted by the Namakon Quality Control Inspector Conference to use its certification mark accounts for 80% of all ready-mixed concrete plants.

In view of this situation, this Specification requires, as a general rule, that ready-mixed concrete plants be selected from JIS-certified plants and recommends that ready-mixed concrete plants be selected from the plants that have been permitted by the Namakon Quality Control Inspector Conference to use its certification mark. If other plants need to be selected for reasons related to plant locations or other reasons, a Chief Concrete Engineer or Concrete Engineer or an equally knowledgeable and experienced engineer must be permanently posted, and plants that are capable of performing concrete mix design, quality control, etc., appropriately.

(2) Besides the considerations mentioned in Item (1), the time required for transportation to the construction site is also an important consideration in selecting plants. In view of changes in the quality of concrete during transportation, transportation time should be made as short as possible. Since transportation time varies depending on the traffic conditions of the transportation route,

weather, etc., it is also necessary to take varying transportation time into account. In the case of JIS-certified concrete, a plant located within a distance that makes it possible to transport and unload concrete within the time limit specified in JIS A 5308 must be selected. Even in the case of concrete that does not conform to JIS A 5308, it is good practice to select a plant in accordance with that standard. Chapter 6 of this Specification specifies the time limit for completing the placement of concrete. The constructor must select plants and transportation routes, taking into consideration the time from unloading to the completion of concrete placement.

In order to perform concrete placement smoothly, it is necessary to supply ready-mixed concrete at a rate appropriate for the rate of concrete placement. When selecting plants, therefore, such factors as production capacity and transportation capacity must also be taken into consideration. If the capacity of a plant is not sufficiently large, it is necessary to purchase ready-mixed concrete produced at two or more plants. Since the quality of materials, concrete mix proportions, slump, air content, quality control systems, etc., differ from plant to plant, the constructor must ascertain those differences and plan and manage vehicle arrangements and concrete placement appropriately.

6.3 Specification of Qualities

(1) When JIS-certified ready-mixed concrete is purchased, the type of ready-mixed concrete and other necessary specification items shall be specified so that concrete of the required quality can be obtained.

(a) Type of ready-mixed concrete

The type of ready-mixed concrete shall be specified on the basis of the maximum size of coarse aggregate, nominal strength, the target slump or target slump flow at the unloading location and the type of cement in view of the requirements for fresh concrete such as filling ability, segregation resistance, and changes in quality during transportation and during the process from unloading to placement.

(b) Specification items

The type of cement, the type of aggregate, the maximum size of coarse aggregate and the method of alkali–silica reaction control shall be specified through consultation with the producer. Details such as the age for nominal strength guarantee, the upper limits of the water/cementitious material ratio and the water content, the upper or lower limit of the cement content, and the air content shall be specified through consultation with the producer on an as-needed basis in view of such factors as the specified strength age, durability and cracking resistance.

(2) When non-JIS-certified ready-mixed concrete is ordered, details such as nominal strength, the target slump or target slump flow at the unloading location, and the maximum size of coarse aggregate shall be specified as set forth in Item (1) so that concrete of the required quality can be obtained.

[Commentary] The types of ready-mixed concrete specified in JIS A 5308 are determined by a combination of the specification items shown in Table C6.3.1, namely, the type of concrete, the maximum size of coarse aggregate, the target slump or target slump flow at the unloading location, and nominal strength. The type of ready-mixed concrete, therefore, must be selected from their combinations so that concrete of the quality specified in this Specification can be obtained. In this Specification, the lightweight concrete and high-strength concrete shown in Table C6.3.1 are dealt with in Chapter 3, Lightweight Aggregate Concrete, and Chapter 6, High-Strength Concrete, of the part regarding special concretes. It should be kept in mind that for high-strength concrete, for example, specified strengths ranging from 60 N/mm2 to 100 N/mm2 are considered, and the specifications regarding slump, slump flow, air content, etc., do not necessarily the same as the JIS specifications.

Table C6.3.1 Types of ready-mixed concrete specified in JIS A 5308 (normal concrete, lightweight concrete, high-strength concrete)

Types of concrete	Maximum size of coarse aggregate (mm)	Slump or slump flow (cm)	Nominal Strength												
			18	21	24	27	30	33	36	40	42	45	50	55	60
Ordinary concrete	20,25	8, 10, 12 15, 18	○	○	○	○	○	○	○	○	○	○	-	-	-
		21	-	○	○	○	○	○	○	○	○	○	-	-	-
	40	5, 8, 10, 12, 15	○	○	○	○	○	-	-	-	-	-	-	-	-
Lightweight concrete	15	8, 10, 12, 15, 18, 21	○	○	○	○	○	○	○	○	-	-	-	-	-
High-strength concrete	20,25	10, 15, 18	-	-	-	-	-	-	-	-	-	-	○	-	-
		50, 60	-	-	-	-	-	-	-	-	-	-	○	○	○

The specification specifies standard values of the minimum slump for placement in Section 4.4.2. The target slump at the unloading location needs to be selected in view of changes in and the tolerance for slump expected to occur until concrete is placed. The JIS specifications refer to concrete with a slump of 21 cm and slump flows of 50 cm and 60 cm as shown in Table C6.3.1, but the Materials and Construction: Construction Standards of this Specification does not assume the use of those kinds of concrete. The quality of those concretes must be determined in accordance with the Materials and Construction: Standard Specification before their uses.

Strength requirements are often indicated in terms of "specified strength." "Nominal strength," which is a term used for distinction from the "specified strength" used in this Specification, is a dimensionless number indicating the strength guaranteed under the conditions indicated in Section 4, Quality, of JIS A 5308.

In the Materials and Construction: Construction Standard the target strength for mix proportions is determined so as to satisfy the condition that the probability that the test value set forth in Section 4.4.3 becomes 5% or less. On the other hand in the JIS A5308 the target strength is determined so as to satisfy the percent defective under the quality requirements that is 0.0013% (about 1/741). Therefore, the target strength that is determined by the JIS A5308 is larger than that by this standard as shown in Fig. C6.3.1. In this way by regarding the specified strength of concrete as nominal strength, the probability that the strength of ready-mixed concrete becomes lower than the specified strength can be made to remain at or below the probability specified in Section 4.5 (2) of this Specification.

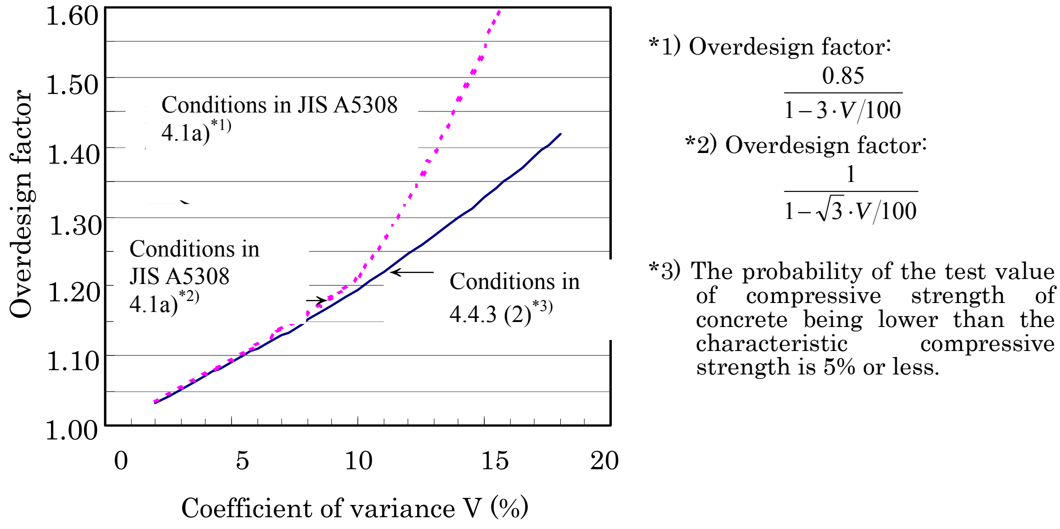

Fig. C6.3.1 Comparison of overdesign factors

JIS A 5308 allows items a) to d) and, on an as-needed basis, items e) to q) to specified through consultation with producers. It is required, however, that items a) to h) be specified within the ranges stipulated in JIS A 5308. Even if specifying types is not enough, concrete of the required quality can be obtained by specifying necessary items among these items.

a) Type of cement

b) Type of aggregate

c) Maximum size of coarse aggregate

d) Alkali–silica reaction control method

e) Classification of aggregate by alkali–silica reactivity

f) Classification of water

g) Type and quantity of mineral admixture

h) Upper limit of chloride content (if different from standard upper limit)

i) Age at which nominal strength is guaranteed

j) Air content (if different from standard air content)

k) Unit mass of concrete (in the case of lightweight concrete)

l) Highest or lowest temperature of concrete

m) Upper limit of water/cementitious material ratio

n) Upper limit of water content

o) Lower limit or upper limit of cement content

p) Amount of increase in slump from that of ready-mixed concrete before fluidization (in the case of superplasticized concrete)

q) Other necessary items

Since the specified strength of concrete is usually indicated in terms of 28-day strength, nominal strength used in JIS A 5308 is also based on measured values at the age of 28 days. In the case, however, of concrete that requires high initial strength and is made by using high-early-strength cement such as prestressed concrete or in the case of mass concrete made by using low-heat cement, etc., it may be necessary to use an age other than 28 days as the reference age for the specified strength of concrete and secure the required strength at that age. In such cases, the reference age for the specified strength must be specified as the age at which nominal strength is guaranteed.

In cases where the upper limit of the water/cementitious material ratio needs to be controlled in order to secure the durability, watertightness, chemical resistance, etc., of concrete, the limit value must be specified.

Standard air contents in this Specification are 4 to 7% depending on the maximum size of coarse aggregate. In JIS A 5308, standard values are 4.5% for normal concrete and high-strength concrete, and 5.0% for lightweight concrete. If the air content is to be made higher than the JIS value in order to enhance freeze–thaw resistance, the value must be specified. In Section 6.4.3 of the Materials and Construction: Special Concretes of this Specification, the air content of high-strength concrete is specified for the freeze–thaw resistance.

As stipulated in Section 4.5.2, the cement content is usually determined from the water/cementitious material ratio and the water content. In cases, however, where the cement content needs to be reduced for the purpose of thermal cracking control or where the type of cement or concrete temperature requires special consideration, it is necessary to specify the upper limit of the cement content, the type of cement or concrete temperature through consultation with the producer. If placeability determines the lower limit of the cement content in Chapter 4, Mix Design, the cement content must be specified through consultation with the producer.

In order to prevent alkali–silica reaction of aggregate, it is necessary to take any of the alkali–silica reaction control measures (listed below) stipulated in Appendix 2 of JIS A 5308. The alkali–silica reaction control method must be specified through consultation with the producer.

a) Measures to control the total alkali content of concrete

b) Control measures using blended cement or other materials that are effective in controlling alkali–silica reaction

c) Control measures using aggregate that is deemed safe

6.4 Receiving

(1) For smooth placement of concrete, consultation shall be held with the producer, and details such as the delivery date, the type and quantity of ready-mixed concrete, unloading location and the rate of delivery shall be determined.

(2) Planning and management shall be performed so that transportation vehicles do not stay long at the construction site.

(3) Good communication with the producer shall be maintained even during the placement of concrete so that the placement work is not interrupted.

(4) Unloading shall be done at a location where the transportation vehicle can safely and smoothly enter and exit and unloading work can be performed easily.

(5) Unloading shall be done by a method that minimizes the segregation of concrete materials.

(6) Receiving inspections of ready-mixed concrete shall be conducted in accordance with Chapter 5 of Materials and Construction: Inspection Standards of these Specifications.

[Commentary] (1), (2), (3) and (4) In many cases, ready-mixed concrete plants are considerably distant from construction sites. In order to carry out the placement of concrete as planned, it is very important to discuss arrangements in detail with the producer, taking into consideration such factors as the production capacity of the ready-mixed concrete plant, transportation capacity, transportation time, receiving facilities, placing rate, waiting time, and their possible changes.

With respect to transportation time, JIS A 5308 requires that transportation be carried out so that unloading can be done within 1.5 hours after mixing is started. This Specification (Chapter 6), however, requires as a standard method that the process from mixing to concrete placement be completed within 2 hours when outdoor air temperature is 25°C or lower and 1.5 hours when it is higher than 25°C. In view of unpredictable circumstances such as traffic regulation, traffic congestion and emergencies on the transportation routes, it will be difficult to complete concrete construction within those spaces of time when outdoor air temperature is high unless effort is made to complete transportation to the construction site in one hour. It is important for the constructor to select a plant with a short transportation time, keep an eye on time-dependent changes in concrete, draw up a plan so as not to keep truck agitators that have arrived at the job site waiting long, and perform time management by keeping in close contact with the producer.

It is important to take measures in advance such as organizing the construction site, securing access roads for transportation vehicles and deploying traffic control personnel to guide transportation vehicles to the unloading location appropriately so that transportation vehicles can safely and smoothly arrive at and leave the concrete unloading location and perform unloading tasks easily.

If concrete is to be plasticized on-site by using a truck agitator, it is necessary to discuss the procedure in detail with the producer and the person in charge of plasticization in due consideration of the transportation capacity in the case where the load capacity of the agitator is reduced in view of its agitating performance, transportation time of base concrete, receiving facilities, the rate of placement, etc. (Refer to Section 5.5)

(5) Transportation vehicles used must be ones that minimize the segregation of concrete during unloading. In the case of ready-mixed concrete as per JIS A 5308, problems seldom arise because truck agitators that have passed a performance test are used. Ready-mixed concrete that is found to have undergone segregation, even if slightly, at the initial stage of discharge from a truck agitator

should be agitated for a short period of time at a high speed in the agitator before unloading. In the case of high-viscosity concrete, however, high-speed agitation may cause air entrainment. In such cases, preventive measures such as reducing the rotation speed need to be taken.

CHAPTER 7 TRANSPORTATION, PLACEMENT, COMPACTION AND FINISHING

7.1 General

(1) Transportation, placement and finishing tasks shall be determined so as to satisfy the required quality of concrete structures by specifying each methods in details.

(2) Transportation, placement, compaction and finishing shall be performed by methods that make it possible to obtain the required quality of concrete.

[Commentary] **(1)** The construction plan drawn up prior to the commencement of construction work outlines each construction task to be carried out with reference to similar types of construction work carried out in the past. In the course of construction work, the content of construction work may deviate from the construction plan, or methods better than the planned methods may be found. Before starting the transportation, placement and finishing tasks, therefore, it is necessary to discuss details with the people who will be engaged in those tasks to find better methods.

It is also important to double-check the content of not only the construction plan but also the design drawings and specifications. For example, it is of course necessary to install formwork and perform reinforcement and joint construction just as designed. It is also necessary, however, to double-check whether there are any areas where the placement or compaction of concrete is difficult to carry out by comparing the design drawings and specifications with the actual state of concrete construction. If such preconstruction studies and preparatory measures are inadequate, the possibility of occurrence of defects during or after construction increases. Changes from the initial construction plan may affect the overall construction schedule, cause structural design problems that cannot be predicted by the constructor, or affect the contracts or other arrangements with the local community such as traffic regulation, noise and vibration control, environmental measures, etc. Both the owner and the designer, therefore, must participate in discussions and take appropriate measures.

Major considerations are summarized as follows:

(a) Concreting schedule

The schedule for concreting work should be determined taking into account various factors such as the type and shape of the structure to be constructed, the relationship with other construction tasks in the overall construction schedule, the total quantity of concrete, the method of obtaining concrete, the quantity of concrete that can be obtained at a time, the difficulty level of construction, the influence on previously placed concrete, season and weather.

(b) Equipment and personnel deployment for transportation, placement and finishing

The type, model, capacity and number of equipment necessary for transportation, placement and other tasks and personnel deployment should be determined in view of such factors as the conditions at the construction site, the type and shape of the structure, transportation distance, concreting block size, the quantity of concrete to be placed, the order of placing, the rate of placing, availability of concrete, compaction capacity, materials used and mix proportions. It is necessary to select a concrete transportation method that makes it possible to transport concrete speedily and economically while minimizing changes in workability and other properties due to the segregation of concrete, changes in air content, decreases in slump, etc.

On-site pumping of concrete greatly affects not only the quality of hardened concrete but also pumpability and causes the rate of placing higher than in other methods. It is therefore important to draw up a well-balanced plan for a series of construction tasks. On-site pumping, therefore, requires prior studies on details such as concrete mix proportions, the type and number of concrete pumps, pump locations, piping, and pumping conditions.

Surface finishing of newly placed concrete needs to be planned so that it can be carried out at an appropriate time, judging from various factors such as outdoor air temperature, humidity, solar radiation and other construction environment conditions, the amount of bleeding of concrete, setting time, the length of time after the placement of concrete in each concreting block. If concreting blocks are large, work efficiency can be improved by using finishing equipment. Care should be taken, however, because surface finishing adjustments may be more difficult to make in machine finishing than in manual finishing.

(c) Transportation route

Transportation routes should be determined so that concrete can be transported easily, speedily and smoothly and transportation time and transportation distance can be minimized.

(d) Concreting blocks, joint locations and construction joint treatment methods

Concreting blocks should be determined according to the volume of concrete that can be placed in one day with reasonable effort after studying conditions such as concrete supply capacity, construction schedule, the shape of the structure, placing capacity, allowable placement interval, formwork and construction joints. Consideration should also be given to cracking due to heat generated by the hydration of cement, autogenous shrinkage and drying shrinkage. If construction joints that are not indicated on the design drawings are to be provided, the location of construction joints and joint treatment methods need to be determined after carefully considering such factors as the structural performance of the structure, durability and reinforcing patterns. Thus, it is important to determine concreting blocks, construction joint locations and joint treatment methods in view of the structural performance requirements, durability and cracking instead of solely on the basis of the placeability of concrete.

(e) Order and rate of concrete placement

The order and rate of placement in each concreting block must be determined in view of the shape of the structure, the state of supply of concrete, placing capacity, allowable placement interval, the organizational system for concrete placement, formwork and falsework deformation, etc. Common practice when placing concrete in a large concreting block is to begin at the end far from the source of concrete supply and end at the near end.

In the cases of certain types of structures such as continuous girders and arches, the placement of concrete may have adverse effects on previously placed concrete or change the dimensions of the completed structure because of formwork or falsework deformation. The order and rate of placement, therefore, must be determined taking those possibilities into consideration. There were projects in which falsework collapsed because of careless placement of concrete. The order of placement needs to be determined so that loads on falsework can be distributed as evenly as possible.

(2) The quality of fresh concrete is easily affected by not only time as mentioned in Item (1) but

also the transportation method. In general, the use of truck agitators is effective in maintaining slump and preventing segregation when transporting concrete from the plant to the construction site. In some cases such as when the volume of concrete being transported is small or when the concrete is exposed to sunlight during transportation, the amount of decrease in slump may be large. Methods of on-site transportation include the concrete pump, bucket and chute methods. When a concrete pump is used, it is necessary to take into account slump and powder content settings allowing for pumpability and decreases in slump during pumping as mentioned in Chapter 4, Mix Design. In transportation by use of buckets, which do not have an agitating function, there may be cases where changes in slump over time are larger than the changes assumed in Item (1) or vibration causes segregation. It is therefore necessary to select a transportation method so that the required quality of concrete can be attained.

Even in cases where mix proportions are appropriate, if the method of transportation, placement, compaction or finishing is not appropriate, the segregation of concrete may result during any of those tasks. During transportation, placement, compaction and finishing, concrete needs to be protected from sunlight and weather. It is also important to consider the order of placement in order to prevent cold joints by placing concrete within the allowable placement interval.

7.2 Time from Mixing to Finishing the Placement

As a standard, the time from the completion of mixing to the completion of placement should be 2 hours or less or 1.5 hours or less when outdoor air temperature is 25°C or lower or higher than 25°C, respectively.(

[Commentary] Since the quality of fresh concrete changes over time after completion of mixing, it is desirable that transportation, placement and compaction be completed as soon as possible. In concreting work, however, it is often not possible to complete the placement of concrete in a short time after it is mixed because of transportation-related constraints concerning available plants, available transportation routes, the location of the structure, etc., and placement- and compaction-related constraints concerning the shape of the structure, reinforcement patterns, available personnel and equipment, etc. It is therefore important to perform planning and management, taking those constraints into consideration, so that various tasks can be smoothly carried out within scheduled time frames and to check in advance on changes in the quality of fresh concrete over time. Because the limit of time within which the placement of concrete can be completed after completion of mixing varies depending on conditions such as concrete mix proportions, materials used, temperature, humidity and transportation methods, good practice is to set a limit suitable for each concreting work in view of these conditions. In general, the time limit is about 2 hours at or below 25°C and 1.5 hours when outdoor air temperature is higher than 25°C. These time limits, therefore, are specified in this Specification.

If the minimum slump for placement cannot be achieved by the time the placement of concrete is completed, it is necessary to take measures such as considering the use of a construction method for completing the task in a shorter time than the specified standard time, modifying the mix proportion so as to reduce changes in slump over time or increasing the slump upon completion of mixing. An effective method for reducing changes in slump over time is to use a chemical admixture that excels in slump retention such as an air-entraining high-range water-reducing agent. If slump upon completion of mixing is to be increased, it is advisable to consider a switch to a chemical admixture that functions as an effective water reducer such as an air-entraining high-range water-reducing agent because the water content tends to increase if slump upon completion of mixing is increased. When taking these measures, it is necessary to conduct studies on those measures well in advance to verify their effectiveness.

7. 3 Transportation

7.3.1 Transportation to the construction site

(1) In cases where ready-mixed concrete is used, the provisions of JIS A 5308 regarding transportation shall be followed.

(2) In cases other than those mentioned in Item (1), it shall be ascertained that the transportation method used permits easy unloading, causes little segregation during transportation and minimizes changes in slump, air content, etc.

[Commentary] (1) JIS A 5308, Ready-Mixed Concrete, specifies the performance of transportation vehicles and requires that as a general rule, the process from mixing to unloading be completed within 1.5 hours. Since, however, this Specification requires that when outdoor air temperature is higher than 25°C, after completion of mixing, the placement of concrete, as a general rule, be completed within 1.5 hours, it is recommended that the transportation from the plant to the construction site be completed in about one hour.

(2) If the transportation distance is long or the slump of concrete is large, truck mixers with an agitation function or truck agitators must be used for transportation. In cases where concrete with a slump of 5 cm or less is transported over a distance of 10 km or less or such concrete can be transported within one hour, the method of using dump trucks or dumpers or buckets loaded on automobiles may be used after ascertaining that segregation does not occur and changes in slump, air content, etc., are small. In cases where there is no empirical knowledge about combinations of concrete quality and transportation methods, it is necessary to conduct tests under realistic conditions to determine the influence on changes in the quality of concrete.

7.3.2 On-site transportation

7.3.2.1 Concrete pump

(1) Prior to the pumping of concrete, details such as the type of concrete pump, pipe diameter, piping route and discharge rate shall be determined, taking the pumpability of concrete into consideration, so that concrete of the required quality can be obtained.

(2) Pipe diameters shall be selected in view of the type and quality of concrete, the maximum size of coarse aggregate, pumping conditions, ease of pumping, safety, etc., so that pumping capacity is sufficiently large. It is desirable that concrete pump locations and piping routes should be determined so that the piping distance and the number of bends are minimized.

(3) The type and number of concrete pumps shall be determined in view of pumping load, discharge rate, the rate of placement and the environmental conditions at the job

site.

(4) If difficulty in pumping is expected, test pumping shall be conducted in advance to check on the pumpability and quality of concrete.

(5) It is recommended that prior to the pumping of concrete, mortar with a mix proportion equivalent to that of the mortar in the concrete should be pumped so that mortar sticks to the inside surfaces of the concrete hopper and piping. As a general rule, however, the mortar should not be pumped into the formwork.

(6) Pumping shall be planned and controlled so that pumping can be carried out as continuously as possible. When pumping needs to be interrupted for a long period of time, appropriate measures shall be taken so that the pumpability and quality of concrete are not lost after pumping is resumed.

[Commentary] (1) Concrete to be pumped must have pumpability suitable for pumping. This Specification, therefore, provides for mix requirements such as the powder content in Chapter 4, Mix Design, and requires that slumps be determined taking into account changes over time and decreases due to pumping. Prior to the pumping of concrete, the type, locations and number of concrete pumps, piping routes, the diameter and type of pipe, discharge rates, etc., must be determined appropriately so that the assumed conditions are met.

It is also important that not only the slump but also the air content, unit mass, temperature, etc., of pumped concrete be within the required ranges. If changes in the quality of pumped concrete fall outside the expected ranges, it is necessary to reconsider the concrete mix proportion, slump, pumping methods, etc., and take appropriate measures.

For matters not described in this section, the Recommendations for Placement of Concrete by Pumping should be consulted.

(2) Piping diameters should be determined after considering the maximum size of coarse aggregate, the amount of pumping load, etc. As the pipe diameter increases, the pumping load decreases. The use of large-diameter pipes, therefore, is desirable, but it is recommended that pipe diameters be determined in view of the fact that large-diameter pipes lower the efficiency of work associated with the handling of pipes.

In concrete pumping, pipes with a nominal diameter of 100A (4B) or 125A (5B) are used in many cases. In large-scale construction, 150A (6B) pipes may be used. In general, pipes with a nominal diameter of 100A (4B) can be used in cases where the maximum size of coarse aggregate is 25 mm or less and the piping distance is relatively short. The "nominal diameter" here refers to the inside diameter of pipe expressed in millimeters and inches. For example, "100A (4B)" means an inside diameter of about 100 mm, or about 4 inches.

In order to reduce the overall pumping load and prevent the clogging of piping, it is desirable that concrete pump locations and piping routes be determined so that the piping distance and the number of bends in piping are minimized. The pipe sections near bent or tapered pipe sections are particularly subject to flow velocity fluctuations, pressure loss and clogging. Good practice, therefore, is use bent pipes with a large radius of curvature and gently tapered pipes.

In order to perform stable pumping, it is necessary to inspect the pipes for deposits on their inside surfaces, wear, etc., and consider vehicle allocation methods for smoothly supplying concrete from the transportation vehicles to the concrete pumps and methods for facilitating tasks such as assembling the pipes for pumping, washing the inside surfaces of the pipes after pumping and moving and removing the pipes. Appropriate piping routes, pipe support methods, working platforms, etc., need to be selected so that the formwork, reinforcement and previously placed concrete are not adversely affected by the vibration and loads from the pipes during pumping operations.

(3) Selection of the type of concrete pump is the most important item for carrying on placement of concrete with pump smoothly. The maximum pumping load on the concrete pump (P_{max}) can be established on a basis of the result in the similar type of construction site or the one from the preliminary pumping test. However, in general, P_{max} is calculated by using a following equation, then the type of concrete pump is selected in a manner that the calculated maximum pumping load is no more than 80 % of the pump capacity. If some restraints may exist in a size of the setting yard, the size and dimension are also decisive conditions for selecting the pump type.

P_{max} = (Loss in pressure per 1m length of horizontal pipe) x (Equivalent horizontal pumping distance)

Pressure loss per 1meter length of the horizontal pipe can be decided by using data of the type and quality of cement, rate of pumping, diameter of the pipe, and the loss is larger with the smaller value of slump, the smaller value of transportation pipes and the larger rate of pumping. Fig. C 7.3.1 shows the standard values of the loss in pressure in the case of concrete using 20~25mm of maximum size of coarse aggregates. When using the coarse aggregates having 40 mm of maximum size, the values should be increased 10% from the values shown in this figure. Here, as for the equivalent horizontal pipe length for each type of pipe, which is for calculating the equivalent horizontal pipe distance, the values shown in Table C7.3.1 can be used.

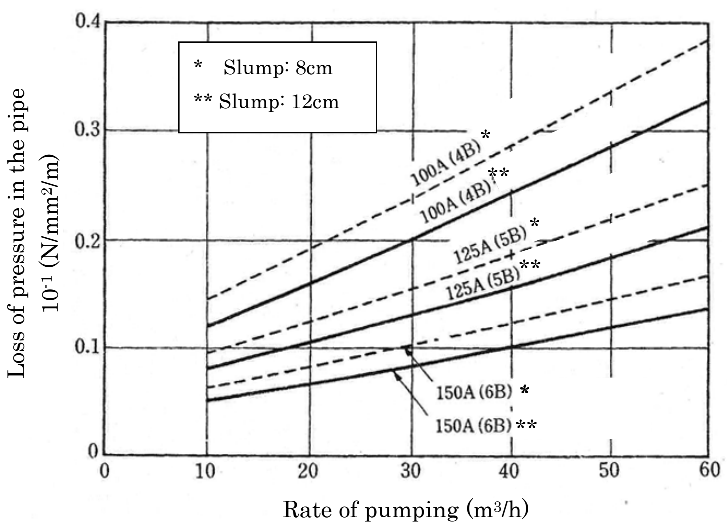

Fig. C7.3.1 Standard values of the loss in pressure

(maximum size of coarse aggregate: 20 to 25 mm, cement content: about 300 kg/m3, air-entraining water-reducing agent used)

Table C7.3.1 Equivalent horizontal pipe length

Item	Unit	Nominal diameter of pipe	Equivalent horizontal pipe length* (m)
Vertical pipe	1 meter	100A(4B) 125A(5B) 150A(6B)	3 4 5
Tapered pipe**	1 piece	175A(4B)->150A 150A(5B)->125A 125A(6B)->100A	3
Bent pipe	1 piece	90 ° r＝0.5 m r＝1.0 m	6
Flexible hose	5~8 m/one piece		20

* The value for the pumping of the normal concrete
** The value for Tapered pipe with 1m of the length as the standard, and established on the basis of the diameter of the smaller pipe

The volumetric efficiency of a pump varies depending on concrete mix proportions, the properties of fresh concrete, etc., and the actual discharge rate is smaller than the theoretical discharge rate. Since the rate of placement in the construction plan is the average rate of placement work including such tasks as moving the pipe end and compacting the concrete, the actual discharge rate is higher than the rate of placement. The discharge rate assumed for calculation purposes, therefore, must be a value reflecting the volumetric efficiency of the pump and work efficiency, and it is necessary to draw up a plan so that pumping can be performed smoothly even at that discharge rate. The number of concrete pumps is determined in view of the rate of pumping, the discharge rate for the type of pump to be used, the size of concreting blocks, the volume of concrete to be placed, the order of placement, the rate of placement, the state of supply of concrete, compaction capacity, the number of placing locations, etc. For concreting work that requires continuous placement of concrete, it is good practice to prepare backup concrete pumps.

(4) If difficulty is expected in the pumping of concrete, it is necessary to check the functioning of concrete pumps, pumping loads, the condition of discharged concrete, etc., by taking appropriate measures in advance such as conducting test pumping under realistic piping conditions.

Pressure losses in pipes and changes in the quality of concrete due to pumping are largely unknown because they vary depending on the type of concrete used, construction conditions and environmental conditions. The types of concrete and the construction and environmental conditions that require careful consideration in connection with pumping include the following:

(a) Pumping of lean concrete with a cement content of less than about 270 kg/m^3 or rich concrete with a cement content of more than about 350 kg/m^3

(b) Pumping of concrete with a pre-pumping slump of less than 8 cm

(c) Pumping of concrete containing plasticizer or air-entraining high-range water-reducing agent

(d) Pumping of concrete in a construction environment described in Chapter 12, Cold-weather Concrete, or Chapter 13, Hot-weather Concrete

(e) Pumping from a higher point to a lower point or over a long distance

(f) Pumping or lightweight aggregate concrete, high-strength concrete, high-fluidity concrete, fiber-reinforced concrete, antiwashout underwater concrete or shotcrete for tunnel construction mentioned in the Construction: Special Concretes of this Specification

If difficulty in the pumping of concrete is expected, it is desirable that test pumping be conducted under realistic piping conditions in advance to check on how concrete pump operation, pumping loads, the condition of discharged concrete, etc. If test pumping under realistic conditions is not possible because of constraints associated, for example, with cost, time or site conditions, pumpability may be evaluated on the basis of available pumping data obtained under similar conditions or by conducting test pumping under short piping conditions. Simple methods for evaluating the pumpability of fresh concrete in advance include JSCE-F 502, Method of Test of Bleeding under Pressure.

(5) Prior to the pumping of concrete, measures to prevent interruption due to clogging, such as pumping mortar in advance, for the purpose of lubricating the inside surfaces of concrete pumps and pipes. Although the quantity of mortar pumped in advance is small, the mortar, as a general rule, must not be pumped into the formwork.

(6) Concrete leaving inside of pipe during an interruption of pumping may causes blocking due to the decrease of pumpability because of segregation and loss of workability. Also, quality of the concrete may be adversely affected. Therefore, concrete sent to hopper of concrete pump should be pumped continuously, and placed and compacted rapidly. In cases when an interruption cannot be avoided because of segregation and loss of workability. Also, quality of the concrete may be adversely affected. Therefore, concrete conveyed to hopper of concrete pump should be pumped continuously, and placed and compacted rapidly. In cases when an interruption is not avoidable because of movement of pipes, shift of workers, a rainfall, or any other unexpected situations, a resuming time should be informed to the persons concerned. In the case of interruption over a long period, interval operations shall be done to prevent blocking. If possibility of occurring blocking is high due to the interruption of pumping for a long time, all of the concrete in the pipes shall be discharged.

7.3.2.2 Buckets

Buckets shall be fabricated so that segregation is minimized when concrete is poured in and discharged, concrete can be easily discharged, and, when closed, concrete and mortar do not leak.

[Commentary] The method of receiving concrete discharged from a mixer with an appropriately structured bucket and immediately transporting the bucket to the placing location is convenient because concrete can be transported to the placing location by moving it in the vertical and horizontal directions easily.

For the bucket method of placement, as shown in Table 4.4.6, slump correction values under different construction conditions are not specified as for the concrete pump method. Bucket transportation, however, is often more time-consuming than concrete pumping. The method of moving a bucket with a crane is one of the transportation methods that are effective in reducing the segregation of concrete. If concrete is left in a bucket, which does not have an agitating function, for a long time, the possibility of segregation and the occurrence of changes in workability increases.

When using the bucket method of transportation, therefore, it is necessary to draw up a plan and perform quality control in view of the rate of placement in the bucket method and changes in the quality of concrete. A bucket used in this method should have an outlet at the center of the bottom because an outlet located off-center tends to cause segregation when the concrete is discharged.

7.3.2.3 Chutes

(1) As a general rule, a vertical chute should be used if the chute method is used.

(2) When an inclined chute has to be used, as a general rule, the slope of the chute shall be steep enough to prevent the segregation of concrete and should not be gentler than 1 vertical to 2 horizontal.

(3) The structure and method of use of a chute shall be conducive to the prevention of the segregation of concrete.

[Commentary] (1) and (2) Concrete transported in an inclined chute is prone to segregation. The tendency to use large-slump concrete with the aim of facilitating concrete flow may aggravates segregation. It is required as a standard practice, therefore, that when a chute is used, a vertical one should be used. Depending on construction conditions, however, there may be cases where an inclined chute needs to be used. In such cases, the slope of the chute must be steep enough to prevent the segregation of concrete, and must not be gentler than 1 vertical to 2 horizontal. If concrete does not flow down the chute smoothly, it may be necessary to change the inclination of chute or modify the concrete mix proportions. It is desirable, therefore that the condition of concrete flow be observed in advance by using the planned chute and concrete.

(3) Chutes must be structured to minimize the segregation of concrete. Vertical chutes include ones that has a funnel tube and ones made by using flexible tubes. Vertical chute joints must be sufficiently strong so that they do not come off because of the impact of falling concrete. Inclined chutes include iron chutes, chutes with sheet iron linings, chutes consisting of iron pipes and flexible tubes, and lightweight FRP chutes. When using an inclined chute, it is necessary to provide the outlet with a funnel tube and baffle plates to reduce segregation.

It is good practice, when using a chute, to wash it with water before and after it is used and let mortar flow down the chute before using it. Care should be taken, however, so as not to let the water or mortar that has flowed down the chute flow into the concrete or the formwork.

The lower end of the funnel tube needs to be kept as close to the concrete placement surface as possible. Because pouring too much concrete at one location would necessitate moving concrete laterally and cause segregation, it is necessary to carefully consider details such as the spacing of concrete inlets and the order of pouring. If concrete transported in an inclined chute is found to have segregated, it is necessary to receive the concrete at the outlet and remix the concrete before using it.

7.3.2.4 Other transportation equipment

(1) If a pneumatic concrete placer is used, careful studies shall be conducted to decide on which concrete placer to use and the method of use because the transportation

distance varies depending on the model and type of concrete placer.

(2) If a belt conveyor is used, appropriate measures shall be taken for protection from sunlight and weather, and, in order to prevent the segregation of concrete, baffle plates and a funnel tube shall be provided at the discharge end of the conveyor.

(3) When wheelbarrows, tramcars, etc. is used, the transportation distance shall not be longer than 50 to 100 m, if a flat haul way can be provided and if the segregation of concrete can be prevented.

[Commentary] (1) Like a concrete pump, a pneumatic concrete placer, which pumps concrete in the conveyance pipe by compressed air, is useful in delivering concrete to a constricted space such as a tunnel. The distance over which concrete can be transported with a pneumatic concrete placer varies with air pressure, air consumption, etc. The model, type and other details of a pneumatic concrete placer to be used, therefore, need to be selected after careful study.

The number of bends in conveyance piping should be minimized. Only horizontal or upward sloping piping must be used, and downward sloping piping must not be used. In a downward sloping pipe, concrete moves under its own weight and the state of flow in which the pipe is filled with concrete is destroyed so that pumping becomes difficult and a blowout of compressed air may result.

If the segregation of concrete occurs when concrete is discharged from the pipe, it is good practice to take such measures as mitigating the impact at the time of discharge and letting the discharged concrete hit a straw mat, hemp cloth or other similar material suspended in front of the outlet of the conveyance pipe. Using highly viscous concrete, that is, concrete with a high sand percentage and a relatively high mortar content may be effective in reducing segregation.

(2) A belt conveyor is convenient for the continuous conveyance of concrete. In the arrangement of conveyors, not only the difference in each conveyor level should be as small as possible, but also the conveyors should keep their slope within a certain level in which any segregation does not occur in concrete. The longer the conveyance distance, the longer the concrete is exposed to air, causing drying, or changing of its slump. Therefore, steps must be taken to top the belt conveyor with a cover. A device shall be installed at the end of the conveyor to prevent the deposition of mortar on the return belt. Provision of baffle plates and a funnel tube is effective to prevent the segregation of concrete. If the concrete is deposited in a set position by the belt conveyor, it must be shifted laterally within the forms resulting in a larger segregation, therefore, the end of the belt conveyor shall be able to be moved.

7. 4 Placement

7.4.1 Preparation

(1) Prior to the placement of concrete, it shall be ascertained that the reinforcing steel, formwork and others have been placed in accordance with the construction plan.

(2) Just before the placement of concrete is started, the insides of the transportation equipment, placing equipment and formwork shall be cleaned, and the intrusion of wood fragments or other foreign matter shall be prevented. Any thing that may absorb water when in contact with concrete shall be wetted in advance.

(3) Water remained in the formwork shall be removed prior to the placement of concrete. Appropriate measures shall be taken so that water flows into the formwork to wash newly placed concrete.

[Commentary] (1) Besides the checks to be made prior to the placement of concrete, it is necessary to ascertain that neither the reinforcing steel nor the formwork is likely to be moved by the concrete placement work, the pressure from the concrete being placed, etc. (see Chapter 10, Reinforcement, and Chapter 11, Formwork and Falsework).

(2) If transportation equipment is dry, concrete may stick to the equipment so that transportation becomes difficult to carry out. If the moisture in newly placed concrete is absorbed by the formwork, it is often not possible to obtain a good surface finish after the formwork is removed. It is therefore necessary to moisten the potentially water-absorbent regions in advance. Care must be taken, however, not to be excessive in wetting so that pools of water form.

(3) If concrete is poured into the formwork where there is a pool of water due to rain, groundwater inflow, curing water, bleeding water from previously placed concrete, etc., the quality or integrity of concrete may be lost. Such water, therefore, needs to be removed before the placement of concrete. If rainwater or groundwater enters the formwork, the concrete surface may be washed. It is therefore necessary to take rainproofing or waterproofing measures in advance.

7.4.2 Placement

(1) Concrete shall be placed carefully so that neither the reinforcing bars nor the formwork move out of position.

(2) Placed concrete shall not be moved laterally in the formwork.

(3) If severe segregation is identified during the placement of concrete, the placement shall be stopped, and a method for reducing segregation shall be determined and implemented.

(4) Except at planned construction joints, the placement of concrete shall be carried out continuously until the placement is completed.

(5) As a general rule, concrete should be placed so that the surface of the newly placed concrete becomes nearly horizontal. The standard lift height for concrete placement shall not be greater than 0.4 to 0.5 m in view of the performance of the internal vibrators used.

(6) If concrete is placed in two or more layers, placement shall be carried out so that an overlying layer becomes integral with an underlying layer. The area of each concreting zone, concrete supply capacity, allowable placement interval, etc., shall be determined so that cold joints do not result. The term "allowable placement interval" is the time after completion of the placement and compaction of the underlying layer of concrete until the overlying layer of concrete is placed after a period of standing time. Standard allowable placement intervals are shown in Table 7.4.1. When a new layer of concrete is placed on a previously placed layer, vibrators shall be inserted into the underlying layer, too, for

compaction in accordance with Section 7.5 (4)..

Table 7.4.1 Standard for the allowable time lag between two placing lifts

Temperature in the environment	Allowable time lag between two placing lifts
Over 25˚C	2.0 hours
25˚C or less	2.5 hours

(7) When placing concrete into high formwork, the inlet shall be positioned in the formwork, or the discharge location of the vertical chute or pipe shall be lowered close to the surface. In such cases, the distance of the surface of placing from the outlet of the chute, pipe, bucket, hopper or other devices, should, in principle, not exceed 1.5m.

(8) In cases when bleeding water appears at the surface during the placement of concrete, the water shall be removed using appropriate methods, before placing more concrete.

(9) The standard rate of placement under normal conditions is about 1 to 1.5 m per 30 minutes. It is desirable, however, that adjustments should be made according to the size of the cross section, concrete mix proportions, compaction methods, etc.

(10) If the concrete of a slab or beam is continuous with the concrete of a wall or column, it is a standard requirement that the placement of the concrete of the slab or beam should be started after the settlement of the concrete of the wall or column has largely ended in order to prevent settlement cracking.

(11) In cases when concrete is to be placed directly onto the ground, a layer of leveling concrete should be placed beforehand.

[Commentary] (1) As concrete placing may disturb the reinforcement and forms arrangements, it shall be placed carefully, and it is also desirable that reinforcement workers stand by during placing, in preparation for reinforcement disturbance by any chance.

(2) If concrete is deposited at the point far away from the intended casting place, it needs to be moved again to the planned point. As segregation is likely to occur after each handling, it is important to deposit the concrete at the placement point to avoid segregation.

(3) If severe case of segregation is observed during placement, it is difficult to obtain homogeneous concrete by remixing. Therefore, the placing of the concrete into the form must be discontinued and the cause of the segregation studied and corrected for subsequent concrete placement.

(4) Since construction joints tend to become structural weak spots, it is necessary to draw up a plan for continuous placement of concrete and control vehicle operation and placement work so that construction joints are not made except at the planned locations.

(5) To obtain uniform concrete, it is necessary that the concrete be placed as to result in a nearly

flat surface within the forms and be uniformly compacted by vibration. In case when a lot of concrete is placed in the large area, it is recommended to limit the concrete placing rate at one point according to the capacity of compaction by preparing the placing points as many as possible, so that the surface of concrete in the whole area for placing should keep its flat level. If the number of the placing points is a few, the placing rate in each point tends to increase, and the works may change to be rough. Consequently, the possibility not to place the dense concrete becomes high. Therefore, it is important that the balance between number of the placing points and the placing speed is controlled properly.

If the height of a layer is about 0.4 to 0.5 m or less, which is smaller than the length of the vibrating part of an internal vibrator, lateral movement of concrete can be reduced. This is why that range is specified as a standard ranged in this Specification. If a layer exceeding that range is placed, it must be ascertained, for example by conducting a test, etc., using a realistic structural model, that there will be no adverse effect, and an appropriate construction method must be determined.

(6) This clause is given to ensure a consolidated condition between layers when concrete is placed in separate layers. Cold joints may develop if the upper layer is placed when concrete of the lower layer has begun to harden. For preventing the cold joint, it is important that the time span until placing new concrete on consolidated fresh concrete shall be specified and controlled, in consideration of the effects of type and, quality or performance of concrete, elapsed time between the start of mixing concrete to the finishing of placing, concrete temperature, compaction method and so on. Especially, due to rapid setting, the possibility of the occurrence of cold joints in hot weather concrete is higher than that of normal condition concrete. In case when a lot of concrete is placed in the large area, the same attention should be paid for taking long time until placing concrete on previous compacted concrete.

The available time elapsed for placing concrete on previously compacted concrete is different depending on type of cement, type and dosage of chemical admixture, concrete temperature, temperature in atmosphere and etc. and etc. for normal concrete. Values given in Table 7.3.1 should be taken as standard for the time elapsed for placing concrete on previous compacted one. If the cold joint is highly susceptible to occur, some of countermeasures shall be taken; such as use of a retarding type of air-entraining and water-reducing admixture, reduction of the height of one lifts and so on. As the method to establish the available time elapsed for placing concrete on previously compacted concrete before construction and to judge the possibility of continuation of the placing under the problem in construction, there are Proctor penetration resistance test and the method inserting the reinforcing bar or the steel bar for slump test to concrete at the construction site. When these methods are carried out, Concrete Library ”Cold joint in concrete structures and its’ countermeasures” should be referred to.

(7) When concrete is deposited from high position or discharged from above to build a high wall and so forth, segregation is often caused due to striking of concrete, forms and reinforcing bars. It is also possible that concrete deposited on the forms and bars subsequently harden, causing interference to subsequent jobs or becoming a defect in the structure. In such a case, it is necessary to provide an opening in the form or to lower the discharging outlet of the vertical chute or to move the pump pipe closer to the surface of placement. Therefore, to prevent material segregation being caused by dropping concrete from overhead, the falling distance from the discharge outlet to the placement surface must be defined.

(8) If water left on the surface of newly placed concrete is not removed, it may wash the surface in contact with the formwork and cause sand streaking and the formation of a weak layer near the concrete surface. It is therefore necessary to remove water by appropriate means such as sponges,

ladles and small submersible pumps.

(9) When concrete is placed continuously to build a high wall or column, it is possible that large pressure will be applied to the form or adverse effects due to bleeding will arise if the concrete is placed too quickly, making the upper concrete weak or drastically reducing the bonding strength of the horizontal reinforcing bars. To avoid this defect, the placing speed must be adjusted. It is desirable that the speed be changed in accordance with the size of the cross section, concrete mix proportion, method of compaction and so on, but ordinarily a speed of 2 m to 3 m per an hour is desirable.

(10) In the case of certain types of concrete cast in the shape of a cantilevered member and concrete cast as a wall or column continuous with a slab or beam, the degree of settlement of concrete differs at different parts of the concrete with different cross sections. Consequently, if concrete is placed at a time, cracking tends to occur in the boundary zones between different cross sections. This Specification requires, therefore, that the placement of concrete be interrupted at a location where the cross section changes, and after the settlement of the concrete has largely ended, the placement of an overlying lying lay of concrete, such as concrete to be cast in the shape of a cantilever, be started. The time needed for the settlement of concrete varies with the materials used, temperature, etc., and cannot be indicated specifically, but it is usually 1 to 2 hours.

7. 5 Compaction

(1) In principle, internal vibrators should be used for compacting concrete. Form vibrators may be used for such structures as thin walls where the use of internal vibrators is difficult.

(2) Scaffold installation and concreting methods shall be determined so that the compaction height does not exceed the planned value.

(3) Concrete adjacent to the sheathing board shall be properly compacted around the sheathing board to ensure that the final concrete surface is as flat as possible.

(4) During compaction using vibration, the internal vibrator shall be inserted about 10cm into the lower layer of concrete.

(5) The spacing of interval vibrators and the vibration time at each location shall be determined so that concrete can be adequately compacted. Internal vibrators shall be withdrawn gradually so that holes are not left in the concrete.

(6) The time for revibration should be as late as possible to the extent that the compaction of concrete is possible and there is no adverse effect such as cracking on the concrete.

[Commentary] (1) Civil engineering structures are built with relatively thick members, often made of stiff concrete. As a general rule, therefore, this Specification requires the use of internal vibrators for compaction. Because there are many types of vibrators and performance varies among different types, it is necessary to use vibrators suitable for the construction work to be carried out. Internal concrete vibrators are specified in JIS A 8610, Internal Vibrators for Concrete, and concrete form vibrators are specified in JIS A 8611, External Vibrators for Concrete. When using external (form) vibrators, it is important, among other things, to select vibrators of an appropriate type, firmly secure the vibrators to the formwork and select appropriate installation locations and vibrator-moving methods.

(2) In order to achieve the required quality and filling ability of concrete, it is necessary to pour concrete from an appropriate height and determine a compaction height from which the filling process can be visually observed. Chapter 2 and Chapter 4 of the Construction: Construction Standards of this Specification require that an appropriate slump be determined in view of the compaction height. It is important to determine scaffold installation and concreting methods so that the compaction height does not exceed the planned value.

Details such as concrete mix proportions and workability are determined according to the dimensions of structural members and reinforcement patterns. In regions that are difficult to fill with concrete such as densely reinforced regions, therefore, it is necessary to carefully compact concrete before the workability of concrete decreases.

(3) Exposed surfaces of concrete must be flat. This is important not only for appearance but also for the durability and water-tightness of the structure. It is therefore necessary to make sure that sheeting surfaces are flat and mortar does not leak through sheeting joints and carefully place and compact concrete.

(4) The aim of this provision is make sure that a newly placed layer of concrete is integrated with the underlying layer.

(5) It is necessary to determine internal vibrator spacing and vibration time at each location so that newly placed concrete is vibrated uniformly and to inform the construction workers of them in advance. Important considerations in using vibrators include the following:

(i) Internal vibrators should be inserted as vertically as possible at a uniform spacing. The spacing should not be greater than a diameter in the range in which vibration is effective, which is usually 50 cm or less for concrete with the average level of fluidity and viscosity. The range in which vibration is effective, however, varies depending on various factors such as the diameter of internal vibrators, compaction capacity at different frequencies, the fluidity (slump) and viscosity of concrete, the dimensions of structural members, and reinforcement patterns. Decisions must be made, therefore, paying attention to the filling ability and segregation of concrete.

(ii) The appearance of a cement paste line along the concrete–sheeting interface is an indicator of adequate compaction. There are also other indicators: for example, the volume of concrete ceases to decrease, the surface becomes glossy, and the entire concrete increasingly looks like a uniformly blended mixture. As a rule of thumb, vibration time is about 5 to 15 seconds. Pulling out vibrators slowly is very important in order to make sure that holes are not left in the concrete.

(iii) Internal vibrators must not be used for lateral movement, which may cause segregation.

(iv) The type, size and number of vibrators need to be suitable for the compaction of the entire volume of concrete to be compacted at a time. To this end, it is necessary to select the type, size and number of vibrators according to the thickness and area of structural member cross sections, the maximum volume placed per hour, the maximum size of coarse aggregate, mix proportion (particularly the sand percentage), the slump of concrete, etc. Although the volume of concrete that can be compacted with a single internal vibrator varies depending on the site conditions, it is about 4 to 8 cubic meters per hour for concrete to be used for an ordinary structure.

(6) Re-vibration refers to the second application of vibrations at a certain time after the first compaction of concrete, and to do this, the timing has to be adequately determined. Re-vibration given at the proper time plasticizes the concrete again to reduce air/water cavities in the concrete. It is also effective in enhancing the concrete strength and the bonding strength to the reinforcement, and preventing the development of settlement cracks. The benefits of the re-vibration are best attained when it is done as late as possible while the concrete still holds its plasticity. However problems such as the development of cracks within the concrete will arise if re-vibration is done too late. Moreover, it shall be confirmed that the vibration transporting to reinforcing bars does not injure the concrete that has already been in the setting condition.

7. 6 Finishing

7.6.1 Surface finish of placed concrete

(1) Upon completion of compaction, the upper surface of concrete shall be leveled at the specified height and shaped as specified, and the finishing procedure shall be repeated while removing the water on the upper surface of the concrete until the water having seeped out from the concrete is completely removed. This finishing work, however, shall be performed carefully so that it is not excessive.

(2) Cracks that have occurred after finishing work until the concrete begins to set shall be repaired by tamping or refinishing.

(3) When a smooth and dense surface is required, the surface finishing shall be delayed to the possible extent and carried out by applying reasonable pressure using a steel trowel.

[Commentary] (1) It is necessary to remove the excess bleeding water accumulated at the top. A layer of laitance or fine cracks at the top may exist when the excess bleeding water remains after finishing.

Normally surface finishing is roughly done by a wooden float followed by finished with a steel trowel if necessary. However excessive finishing tends to cause shrinkage cracking because of the accumulation of cement paste at the top. Furthermore, a layer of laitance may be formed and reduce abrasion resistance.

The use of equipment capable of smoothly finishing the entire concrete surface is helpful in obtaining a densely compacted concrete surface finish. Because finishing equipment is easy to work with, it is possible that regions of concrete in different states of surface due to differences in the time elapsed after placement and the degree of drying are finished in a similar way. Before using finishing equipment, therefore, it is necessary to conduct careful studies on the quality of concrete, the performance of equipment and construction methods.

In cases where the water/cementitious material ratio is low or high-early-strength portland cement is used, a small amount of bleeding may result in localized hardening of the concrete surface from immediately after placement. For details about the finishing of low-bleeding concrete, refer to Chapter 6, High-Strength Concrete, of the Construction: Special Concretes of this Specification.

(2) About the time when bleeding water disappears from the concrete surface, the concrete becomes subject to cracking due to factors such as shrinkage caused by rapid drying of the surface. It is important to carry out appropriate curing in accordance with Chapter 8, Curing, in order to reduce drying due to sunlight or wind. Surface areas near reinforcing bars are particularly prone to cracking due to the subsidence of concrete. The time needed before the settlement of concrete ends, which cannot be indicated clearly because it varies depending on such factors as concrete mix proportions, materials used and temperature, is usually one to two hours. Measures that can be taken against cracks include tamping with a trowel and revibration by use of vibrators, etc. Revibration needs to be carried out carefully in accordance with Section 7.5 so as not to cause a degradation in quality.

(3) Finishing with steel trowels may be commenced when the surface has hardened enough to the degree that the surface remains without leaving an indentation when pressed with the finger. The mixture proportions, weather conditions, atmospheric temperature and other factors influence the timing for the commencement of finishing operation. This operation shall be performed with heavy pressure to consolidate the surface cement paste and produce the dense and hard surface.

In certain types of concrete such as low-bleeding concrete, even if the surface of newly placed concrete hardens because of the evaporation of moisture, the inner part of the concrete may still be soft and water may seep out as the concrete surface is troweled. The time for final finishing needs to be determined in view of the setting time, the degree of dryness of concrete, etc.

7.6.2 Correction of surface finish defects

If a hardened surface is not in a satisfactory condition or if cracking has occurred, appropriate repairs shall be performed on an as-needed basis.

[Commentary] Protrusions, streaks, etc., on the surface of concrete must be removed to make the surface flat. Honeycombed surfaces, cross-sectional loss regions, etc., must be repaired by selecting appropriate materials and repair methods on an as-needed basis in view of such factors as durability, appearance and safety. If a cross-sectional restoration method of surface treatment method is used, refer to the Recommendations for Concrete Repair and Surface Protection of Concrete Structures. Possible causes of cracking during construction include those attributable to materials used or mix proportions, those attributable to construction methods and those attributable to design. The cause of cracking must be identified, and appropriate repairs must be made if necessary. For the estimation of the causes of cracking and the selection of repair methods, refer to the Practical Guideline for Investigation, Repair and Strengthening of Cracked Concrete Structures (Japan Concrete Institute). It is desirable that records of problem locations, their causes and repair methods be kept for reference at the maintenance stage.

7.6.3 Special finishing

(1) When the surface is subjected to abrasion, concrete having the required strength shall be fully compacted and finished flat. After finishing, it shall be kept moist for a period longer than normal concrete and adequately cured.

(2) When special finishing is carried out, it shall not cause reduction in the

cross-section or loosening of the concrete, which may adversely affect the whole structure.

[Commentary] (1) Finished surfaces of water channels, sediment flush channels, etc., may be required to be resistant to abrasion. The use of hard and highly friction resistant high-quality aggregate and concrete with a low water/cementitious material ratio is helpful in increasing the abrasion resistance of concrete. In order to obtain well-compacted, homogeneous concrete, careful compaction and adequate curing must be carried out. Abrasion resistance can be enhanced by extending the curing period because the hydration of cement progresses that much.

When using abrasion-resistant materials such as silica fume, iron powder, iron aggregate, polymer and steel fibers, it is important to carefully check in advance on the quality of concrete made by using those materials and methods for producing and placing concrete made with those materials.

Rough surfaces or joints of concrete make the concrete prone to abrasion and cavitation. Regions of concrete in contact with inclined form surfaces tend to attract air bubbles so that weak layers are formed. Because it may be possible to alleviate this problem by using devices such as permeable forms and absorptive sheeting, such devices should be used after verifying their effectiveness by conducting realistic model tests.

(2) When producing a special finish or washed finish, it is necessary to be careful so as not to cause adverse effects on the structure such as a reduction in cross-sectional area or loosening of concrete. Since there are various methods of producing special finishes and various rules associated with them, it is also necessary to follow those rules when producing special finishes. If a surface treatment (protection) method is used for the purpose of enhancing durability, appearance, etc., refer to the Recommendations for Concrete Repair and Surface Protection of Concrete Structures.

CHAPTER 8 CURING

8.1 General

For the curing of concrete, a method that maintains the temperature and humidity required by concrete to harden for a certain period of time after the placement of concrete and is not adversely affected by the environmental conditions shall be selected.

[Commentary] In order for concrete to develop, through hydration, its required performance such as strength, durability, cracking resistance, water-tightness and protection of steel, it is necessary to keep the newly-placed concrete in a sufficiently wet condition at an appropriate temperature for a certain period of time after the placement of concrete and to protect the concrete from adverse effects. The series of tasks performed for this purpose is referred to as "curing."

Fig. C8.1.1 classifies curing tasks into three categories – keeping concrete in a wet condition, controlling the temperature of concrete and protecting concrete from adverse effects – , and summarizes the curing method in each category. Some of the curing methods are interrelated, and curing is often carried out for two or more purposes.

It is important to determine specific curing methods and the number of days required for curing considering project-specific conditions such as the type of structure, construction conditions, site conditions and environmental conditions in accordance with the applicable provisions. For further information on curing methods for cold-weather concrete, hot-weather concrete and mass concrete, refer to Chapters 12, 13 and 15, respectively. For details of accelerated curing by use of steam, etc., refer to Chapter 14, Industrial Products, of the Construction: Special Concretes of this Specification.

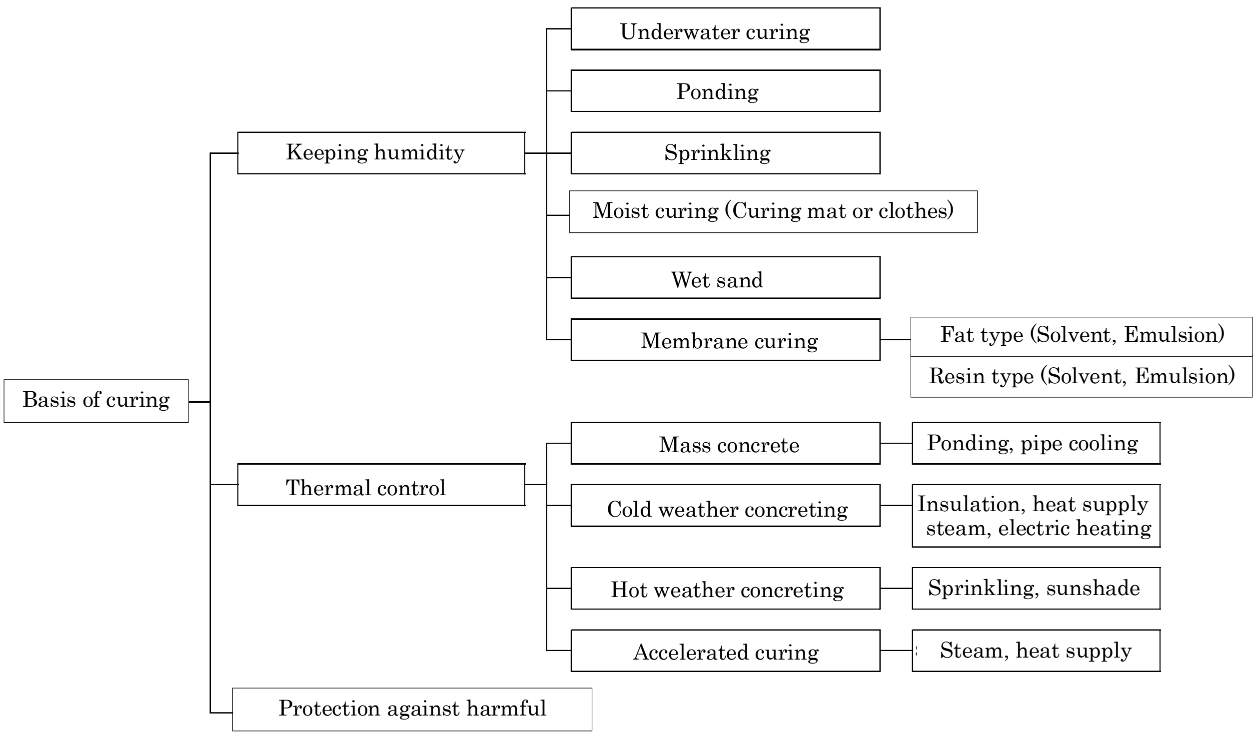

Fig. C8.1.1 Basis of Curing

8.2　Moist Curing

(1) After placing, the loss of moisture due to exposure to sunshine and wind shall be prevented until the concrete begins to harden.

(2) When the concrete hardens to the extent that further activities can be undertaken without damaging its surface, the exposed surface shall be kept wet using methods such as covering with a moist curing mat, clothes, etc., sprinkling or ponding with water. The periods of time given in Table 8.2.1 should be taken as the standard duration for maintaining the wet condition.

Table 8.2.1 Standard curing duration

Daily mean temperature	Ordinary portland cement	Blended cement B	High-early-strength cement
More than 15˚C	5days	7days	3days
More than 10˚C	7days	9days	4days
More than 5˚C	9days	12days	5days

(3) If membrane curing is carried out, it is necessary to clarify the purpose of use, use a liquid membrane-forming compound with proven quality, effectiveness and ease of use, and shall uniformly apply the membrane-forming compound in the specified quantity at an appropriate time.

[Commentary]　(1) If the concrete surface becomes dry relatively quickly after placing and its moisture is lost, the hydration reaction of cement does not progress satisfactorily, and if the surface alone is quickly dried by exposure to sunshine and wind, cracks may be induced. Therefore, it is desirable to provide a shelter made of sheets, etc., over the top of newly-placed concrete. Thus, it is necessary to proceed with the curing of concrete concurrently with not only the post-hardening construction tasks but also the pre-hardening tasks at the placement and finishing stages.

(2) To improve quality of concrete such as strength, durability and other performances, it is desirable to keep the concrete wet as long as possible. As a result, concrete can harden sufficiently and drying shrinkage during hardening can be minimized. However, for general structures it is both difficult and uneconomical to perform moist curing for a long period. In addition, most effects of moist curing are limited to the early age of curing. Therefore, standard periods for curing are determined as in the table mentioned above, although the effect of curing might be different depending on the curing temperature. Even in cases where the compressive strength required for formwork and shoring removal shown in Table C11.8.1 has been obtained at an early stage, the concrete needs to be kept in a wet condition during the curing period shown in Table 8.2.1.

Today, various types of cement, such as low-heat portland cement, moderate-heat portland cement and three-component cement, other than the types shown in Table 8.2.1 are in use. There are also cases where the curing period for concrete needs to be determined according to the construction period, construction methods, etc. It is difficult to specify curing periods for different types of cement, construction methods, etc., in this Specification. It is desirable, therefore, that the curing period be determined in view of factors such as the type of cement, cement content, the type and location of the structure, and weather conditions by conducting, if necessary, tests for verification. If concrete is likely to be subjected to seawater, alkalis, acidic soil or water or other erosive substances, it is necessary to use a longer curing period than in ordinary cases. If concrete is likely to be exposed to seawater, refer to Chapter 11, Offshore Concrete, of the Construction: Special Concretes of this Specification.

(3) Membrane curing is a curing method in which the evaporation of water is prevented by applying a liquid membrane-forming compound to the concrete surface. Membrane curing is usually used in cases where wet curing by means of moist curing (curing mat or clothes) or water spraying is difficult to perform or there is a need to prevent the dissipation of moisture for a long period of time after the specified wet curing is carried out. Membrane curing may also be used to reduce the evaporation of water after the placement of concrete or, in the case of high-viscosity concrete such as high-strength concrete, to assist in finishing the concrete surface.

In order to form a watertight membrane, it is necessary to uniformly apply a sufficient quantity of liquid membrane-forming compound at an appropriate time. In general, it is necessary to carry out membrane curing immediately after the gloss of the water on the concrete surface disappears. If membrane-forming compound cannot be applied immediately, the concrete surface needs to be kept in a wet condition until membrane-forming compound is applied. If the membrane-forming compound has adverse effects on the bond between concrete and reinforcing steel or between concrete surfaces, the membrane-forming compound shall be applied so that it does not stick to the reinforcing bars or the construction joints. In cases where surface treatment of the finished surface is carried out, if the membrane-forming compound could have adverse effects on the bond between the finished surface and the coating material, it is necessary to perform appropriate surface preparation, such as polishing the membrane-cured finished surface to remove the membrane-forming compound, after performing the required curing.

Requirements for liquid membrane-forming compounds include (1) impermeability to humidity (moisture), (2) ease of application, workability and no harm to human health, (3) excellent bond to concrete, (4) excellent durability against weather and sunlight and (5) the absence of adverse effects on the bond to coating materials, etc. When using liquid membrane-forming compounds, it is good practice to clarify the purpose of use, select liquid membrane-forming compounds appropriate for the purpose of use and the performance requirements, and ascertain the dosage, construction methods and other details needed to meet the performance requirements by referring to reliable literature or conducting tests.

8.3 Temperature-Controlled Curing

(1) Until the concrete has hardened to a certain extent, it shall be maintained under temperature conditions required for hardening. Temperature-controlled curing shall be carried out if required to protect concrete from the harmful effects of low and high temperatures, as well as sudden changes in temperature.

(2) When temperature-controlled curing is carried out, the temperature-controlling method, curing control method and duration shall be appropriately determined taking into account the type of concrete, the shape and size of the structure, construction method, and environmental conditions.

[Commentary] (1) and (2) Cement hydration is remarkably influenced by the curing temperature of concrete. Except in special cases, the concrete temperature begins to be influenced by the outside temperature just after the concrete is mixed. In particular, concrete surfaces or thin members such as walls and slabs are easily affected by the outside temperature. In general, the relationship between curing temperature, concrete age and compressive strength can be expressed by the concept of maturity. When the curing temperature is lower, the period to obtain necessary compressive strength becomes longer; on the other hand, when the curing temperature is higher it becomes shorter (see Chapter 12). However, the effect of curing temperature depends on the type of cement. Blended cements such as fly ash cement or blast furnace cement tend to be sensitive to the curing temperature. Therefore, for blended cements, a longer curing period than ordinary portland cement is required, especially when the curing temperature is low. The hydration of ground granulated blast furnace slag is highly dependent on temperature, and the temperature history and strength development properties of structural members may differ considerably depending on factors such as the dimensions of the members and the heat insulation property of the formwork.

Very low temperatures interfere with the hydration reaction of cement and may delay the development of strength. The concrete may also be subjected to initial frost damage. It is therefore necessary to perform temperature control by heat supply or heat insulation for a given period to maintain the necessary temperature conditions. For cases when the daily mean temperature is less than 4℃, it needs to be treated as cold weather concreting (see Chapter 12).

If the atmospheric temperature is extremely high, initial strength tends to develop quickly. However, increase of strength over the long term tends to be small and durability or water-tightness is sometimes inferior. In addition, special attention needs to be paid to keeping the concrete surface wet. For cases when the daily mean temperature is greater than 25 ℃, it needs to be treated as hot weather concreting (see Chapter 13).

If the member size is large and a considerable temperature increase according to hydration is anticipated, or if a big temperature differential is anticipated, cracks may be induced by thermal stress. Therefore, the concrete temperature and temperature differential have to be controlled by pipe cooling, surface heat insulation or a combination of both. Furthermore, when the atmospheric temperature is high, the additional effect due to the acceleration of cement hydration needs to be considered (see Chapter 14).

Accelerated curing includes atmospheric-pressure steam curing, autoclave curing and heat curing. For further information on atmospheric-pressure steam curing and autoclave curing, which are widely used for the factory production of concrete, refer to Chapter 14, Factory-Made Products, of the Construction: Special Concretes of this Specification. When heat curing is carried out by using heater mats, jet heaters, etc., the concrete surface is subject to drying and cracking. In such cases humidifying devices may be used. In accelerated curing, care needs to be taken because cracking may result if the temperature is not lowered gradually after the completion of curing.

8.4 Protection Against Harmful Effects

Concrete shall be protected against harmful effects, such as vibration, impact and other loads, etc., that are likely to arise during the curing period.

[Commentary] Concrete which has not yet sufficiently hardened is likely to suffer damage, including cracks, due to impacts, excessive loads, vibrations, etc. Therefore, it is necessary to avoid placing material or dropping heavy articles on the surface of the concrete during the hardening period. Harmful conditions also include rain showers during placement, poor quality of curing water, overheating during heat supply curing, etc. It is necessary to prevent the occurrence of these harmful effects with full understanding of the properties of early-age concrete or, if it is unavoidable, to protect the concrete from their influences. If concrete is likely to be exposed to seawater, refer to Chapter 11, Offshore Concrete, of the Construction: Special Concretes of this Specification.

CHAPTER 9 JOINTS

9.1 General

(1) Joints shall be located and structured as specified in the design drawings and the specifications.

(2) If joints not specified in the design are to be provided, their locations, directions and construction methods shall be specified in the construction plan so that the strength, durability, watertightness and appearance of the structure are not degraded.

[Commentary] (1) Joints in a structure greatly affect the strength, durability and appearance of the structure. Joints shall be provided carefully because they may become structural weak links in the event of an earthquake. Since the location and structure of joints are determined at the design stage considering factors such as the strength, durability, appearance and constructability of the structure, joints shall be located and structured in accordance with the design drawings and specifications.

(2) If joints are to be located or structured in ways that are not specified in the design, their locations, directions, structure and construction methods are to be specified in the construction plan after ascertaining that the performance requirements for the structure are met through consultation with the designer.

9.2 Construction Joints

(1) A construction joint should, in general, be designed at the position where the shear force is as small as possible. The joint surface should be perpendicular to the direction of the compressive force acting in the member.

(2) Construction joints shall be planned taking into consideration cracking due to thermal stress, drying shrinkage, etc.

(3) When the concrete structure is required to be watertight, construction joints shall be made at appropriate intervals to ensure necessary water-tightness.

(4) In concrete structures which could be damaged by external chloride attack, such as marine and port structures, it is highly recommended that construction joints are not provided. In cases when construction joints cannot be avoided, it should, in general, be ensured that the construction joints do not impair the durability of the structure.

[Commentary] (1) The construction joint often proves to be a weak point for the acting shear force. It is therefore necessary to form construction joints in locations at which the shearing force is small and to maximize the shearing resistance of the construction joint by positioning the construction joint at right angles to the direction along which the compressive force acts in the member. If a construction joint is provided for a compelling reason at a location where large shear force occurs, measures to ensure safety against shear force may be taken, such as using mortise-and-tenon or groove-and-tenon type shear keys or reinforcing construction joints with dowel bars or other types of reinforcing bars. These measures need to taken after verifying at the design stage that the performance requirements are met.

(2) Construction joints need to be located and structured by predicting the possible occurrence of cracking due to thermal stress caused by changing outdoor air temperature, drying shrinkage, etc.

(3) When concrete is placed in considerably large blocks at a time, the expected property of structures which require water-tightness cannot be achieved due to cracks caused by dry shrinkage or thermal stress. Therefore, this requirement is prescribed.

(4) The use of construction joints in marine and port concrete structures should be avoided as much as possible because external chlorides may penetrate through the construction joints to cause the corrosion of reinforcing bars. For further information about the jointing of marine concrete structures, refer to Chapter 11, Marine Concrete, of the Construction: Special Concretes of this Specification.

9.3 Horizontal Construction Joints

(1) If appearance requirements need to be met, the lines formed by horizontal construction joints in contact with the formwork should be made as straight horizontal lines wherever possible.

(2) Before fresh concrete is placed, laitance, poor-quality concrete, loosened aggregate, etc. on the old concrete (previously placed concrete) surface shall be completely removed, and the surface of the old concrete shall be wetted sufficiently.

(3) In cases when concrete is inversely placed, construction joints shall be provided in a manner that concrete layers at the joint position are well integrated, with due consideration to bleeding and settlement.

[Commentary] (1) For good appearance, attention shall be paid to ensure the line of a horizontal joint on the concrete surface looks straight. To this end, it is appropriate that the joint positions coincide with form panel joints or markers showing the height of the construction joint should be used.

(2) To produce a construction joint of sufficient strength, durability and water-tightness, it is necessary to remove any laitance, poor-quality concrete, loosened particles of aggregate, etc., on the old concrete surface before placing the fresh concrete.

For processing the joint surfaces on old concrete, pre-hardening processing, post-hardening processing or a combination of both can be used.

A common method of pre-hardening processing is to expose the coarse aggregate by removing the thin film on the concrete surface with high-pressure air and water after the final set of concrete. If the surface of the construction joint is large, this processing method proves to be efficient. However this method may spoil the concrete unless it is performed in a proper manner and at the proper time after concrete placing. The program has to be carefully controlled during processing. In general, the possible working time to process construction joints is short. If construction joint treatment cannot be done during this period, it may become difficult to attain the required joint performance because of problems such as excessively high concrete strength that makes it difficult to expose coarse aggregate grains and weakening of the matrix around coarse aggregate grains caused by excessive scraping. To ease this working restriction, it is effective to apply a retarder, of which the principal ingredient is sodium gluconate, on the surface of concrete to process the construction joints. By using this kind of retarder, processing time can be extended because hardening of the concrete joint surface is intentionally delayed.

In the case of post-hardening processing, the surface is roughened with either high-pressure air and water sprayed for careful cleaning or a wire brush with pouring water if the old concrete surface is not too hard. If the old concrete is hard, the most reliable way to prepare the surface is to wash it with water after scraping the surface with a wire brush or sandblasting. Incidentally, the remaining water on the old concrete surface has to be removed before placing fresh concrete.

If mortar is laid just before a new layer of concrete is placed, the water-cement ratio of this mortar should be lower than that of the concrete used.

(3) In the case of the inversely placed concrete, a construction joint is always located under the old concrete and the surfaces of the construction joint are not usually integrated because of bleeding or settlement of the newly-placed concrete. In the case of the inversely-placed concrete, methods of construction in Fig.C9.3.1 are employed to ensure the integration of the surfaces of construction joint. Regardless of which method is used, it is necessary to remove laitance and dirt from the construction joint surfaces in order to achieve the structural integrity of the newly- and previously-placed concrete.

In the direct method, the lower end of the previously-placed layer of concrete is used as a construction joint surface to achieve close contact with a newly-placed layer of concrete. In this method, the lower end of the previously-placed layer of concrete is often formed as a single-slope surface or a double-slope (V-shaped surface) in order to help air bubbles and bleeding water escape easily. The mix proportion of the newly-placed concrete is designed to minimize the bleeding and settlement and it should be sufficiently compacted by a vibrator. In this case, hanging parts shall be removed at a proper time after construction to prevent falling during the service life of the structure, or shall be checked regularly for safety according to in-service maintenance control. If aluminum powder is mixed into newly placed concrete to give the concrete a pre-hardening expansion property and thereby achieve the structural integrity of the newly- and previously-placed concrete, it shall use concrete forms that are strong enough to confine the expansive concrete.

In the filling method, the pouring of newly-placed concrete is stopped a little below the jointing surface and a hollow between the old and newly placed concrete is filled with mortar containing an expansive agent or aluminum powder. As in the direct method, concrete forms that are strong enough to withstand expansion pressure are necessary.

The injection method is used either independently or in conjunction with the direct method. The injection tube for grouting is arranged beforehand, and after the newly-placed concrete is hardened, cement paste, resin, or another material is injected. A cement paste or resin which is fluid and mixed with an expansive agent is recommended for injection to thoroughly fill small spaces.

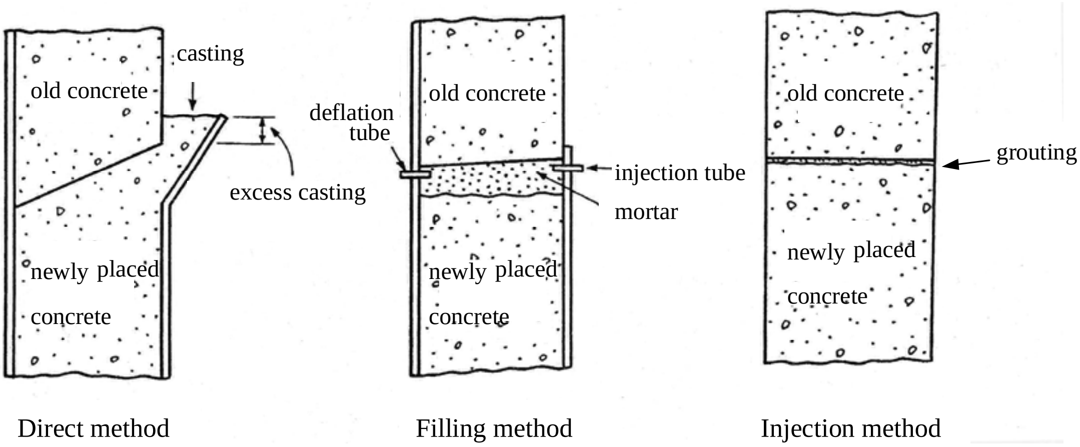

Fig. C 9.3.1 Construction joint of inversely placed concrete

9.4 Vertical Construction Joints

(1) The formwork of vertical construction joints shall be firmly supported.

(2) Before placing the fresh concrete, the surface of the old concrete shall be sufficiently moistened and coated with cement paste, mortar or epoxy resin after roughening the surface by scraping with a wire brush or chipping.

(3) Placement and compaction shall be performed so that newly-placed concrete reaches every corner of the joint surface to achieve close contact with the joint surface.

(4) As a general rule, a water stop should be used for vertical construction joints in concrete structures that require water-tightness.

[Commentary] (1) Formwork for vertical construction joins must be designed to prevent the spilling of mortar and must be supported firmly.

(2) The typical method to roughen the surface of old concrete is wire brushing, hand picking, picking by machine and so on. Another method is processing construction joints before hardening with a spreading retarder, of which the principal ingredient is sodium gluconate, on the surface of formwork prior to placing concrete. In this case, processing time is properly adjusted by intentional delay of hardening time at the concrete surface. Furthermore, an alternative method to roughen the vertical construction joints is using wire net as formwork at construction joints (see Fig. C9.4.1). If a new layer of concrete is to be placed after the surface of the previously-placed layer of concrete is roughened, structural integrity can be enhanced by applying cement paste, mortar or epoxy resin to a wet surface just before the placement of the new layer. A recently-developed method attachs set-retarding sheets to concrete forms and washing them away after removing the forms. When using these methods it is necessary to check, in advance, their effectiveness and practicality by conducting tests or referring to reliable literature.

(4) Since it is very difficult to achieve water-tightness without a water stop, a water stopper should be used in vertical construction joints. When a water stop is used, special attention shall be paid to the installation work, otherwise water-tightness might be worse than the case where a water stop was not used.

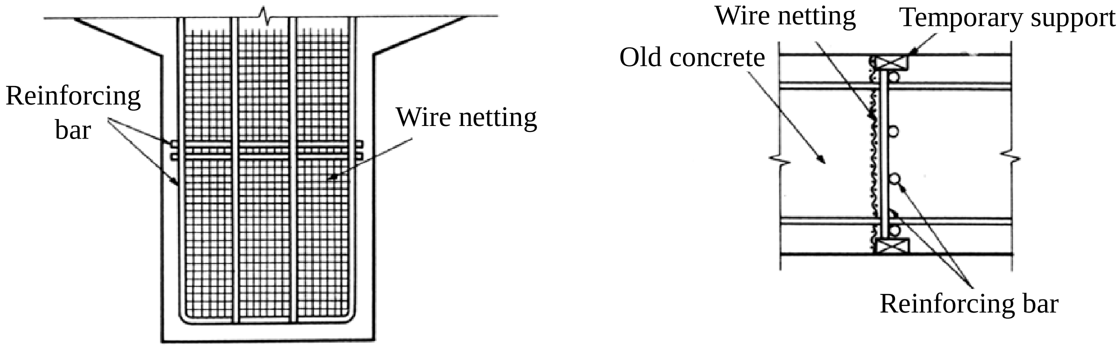

Fig. C 9.4.1 Vertical joint using wire net

9.5 Construction Joints in Columns and Walls Integrated with Floor Systems

(1) Construction joints in a column or wall integrated with a floor system should be formed adjacent to the border between them.

(2) Concrete in haunches shall be placed at the same time as the floor concrete.

(3) Similar procedures shall be used in structures with an overhang.

[Commentary] Concrete of the haunch must be placed in continuity with the floor construction in view of the fact that, as it is directly supported with shuttering, it cannot shrink or settle together with concrete of the column or wall, so the haunch behaves as part of the slab.

9.6 Construction Joints in Floor Systems

(1) Construction joints in floor systems should be made in the middle of the slab or beam.

(2) In cases when a beam crosses a joist at the middle of the span, the construction joint in the beam shall be provided at a position apart from the joist by about twice the width of the joist. The construction joint shall be reinforced against shear by providing additional diagonal tensile reinforcements crossing the joint.

[Commentary] A construction joint is formed in the middle of a slab or beam because the shearing force in this area is usually small and the compressive stress works at right angles to the vertical construction joint, hence the formation of a construction joint has little effect on the strength capacity of the slab or beam. If a joist crosses the beam at the middle of its span, however, it is advisable to position the construction joint at about twice the width of the joist away from the joist in order to avoid coincidence of the construction joint with a point at which the stress changes sharply. As a considerable shear force is applied to the construction joint in that case, the joint has to be reinforced using tension bars that cross the construction joint at an angle of 45˚ (see Fig. C9.6.1).

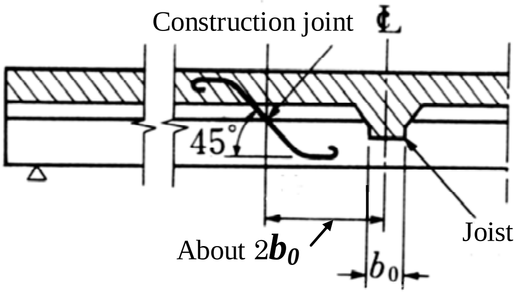

Fig. C 9.6.1 Reinforcement for construction joint

9.7 Construction Joints in Arches

(1) Construction joints in arches should, be provided at a right angle to the axis of the arch.

(2) In cases when a construction joint is obliged to be parallel to the axis of the arch, the location, reinforcing methods for strengthening, etc. shall be carefully examined.

[Commentary] (1) Since the shear force acts along the joint when the construction joint in the arch is not formed at right angles to the arch axis, the joint is likely to be a structural weak point. Therefore, this requirement is prescribed for the purpose of avoiding shear force acting along the joint.

(2) If a vertical construction joint is formed parallel to the arch axis, an action such as eccentric live loads might cause shear force along the joint. Therefore, sufficient countermeasures against these problems are required.

9.8 Expansion Joints

(1) The structure of expansion joints shall be such that the structures or members on both sides can be free from restraint.

(2) Joint filler, water stop, etc. shall be provided at expansion joints, if necessary.

(3) In cases when evenness at the expansion joint is required, a protrusion or groove should be introduced or dowel bars provided.

[Commentary] (1) To form an expansion joint, either both joined structures must be perfectly discontinuous or, depending on the type of structure and the location of the installation, the concrete may be discontinuous and the reinforcing bars may remain continuous (see Fig. C9.8.1).

(2) If an expansion joint gap is likely to become filled with soil, sand and so forth, joint filler materials shall be used. Examples of the filling materials are sheets of asphalt, rubber foam, resin foam,, or other sealing and filling materials. For the expansion joint of a structure that requires water-tightness, a water stop with proper flexibility must be used. Examples of a water stopper are copper plates, stainless plates, vinyl chloride resin sheets and rubber sheets.

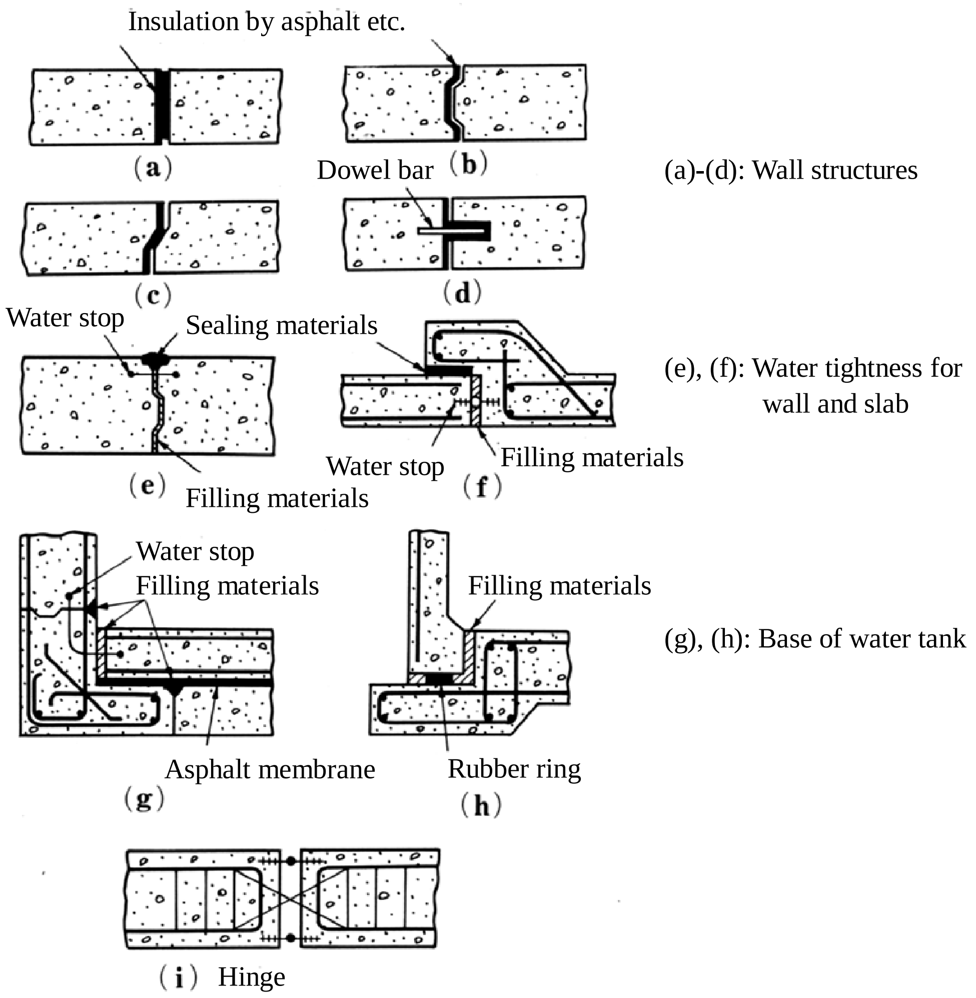

Fig. C 9.8.1 Examples of expansion joints

9.9 Joints to Control Cracking

In cases when a joint is introduced to control cracking, its structure and location shall be in accordance with the design documents.

[Commentary] In the case of a concrete structure, there are many factors that cause deformation besides applied forces, including the temperature change due to the heat of hydration and the outer temperature, drying shrinkage and so on. Cracks may develop if such deformation is restrained. It is therefore desirable to control the cracks by forming notches in the cross section at given intervals in order to concentrate cracks in a given area. Crack-inducing joints need to be considered at the design stage. If the design drawings and specifications do not deal with crack-inducing joints, it is necessary to refer to the Design section of this Specification and provide appropriately-located and -structured crack-inducing joints through consultation with the designer.

When the joint to control cracking is used, sufficient consideration is necessary to decide the spacing intervals, the reduction ratio of cross section, the method to prevent steel corrosion, and the method to assure required cover and filling material in the notches. In general, spacing interval of joints may be 1 to 2 times the wall height, and the reduction ratio of cross section is advisable to be more than 30 to 50%.

Some examples of joints to control cracking in wall structures are shown in Fig. C9.9.1. In these figures, the notches are vertically arranged on the both side of the wall and the insulation is embedded in the wall, if necessary, to obtain the required cross section reduction ratio. Examples (c), (e), and (g) show that vinyl chloride pipe, pre-cast concrete block and steel plate with remover on their surfaces are respectively arranged in the wall to cut the bond of concrete and to induce stress concentration. The cross section reduction rate of is defined as the value obtained by dividing the additional depth of the notches on both sides and width of the embedded insulation by the original wall thickness. If a crack-control joint is formed in a water-tightness structure, it is advisable to take proper water-preventive measures, including the advance installation of a water stopper. In the case of mass concrete, see Section14.5.5.

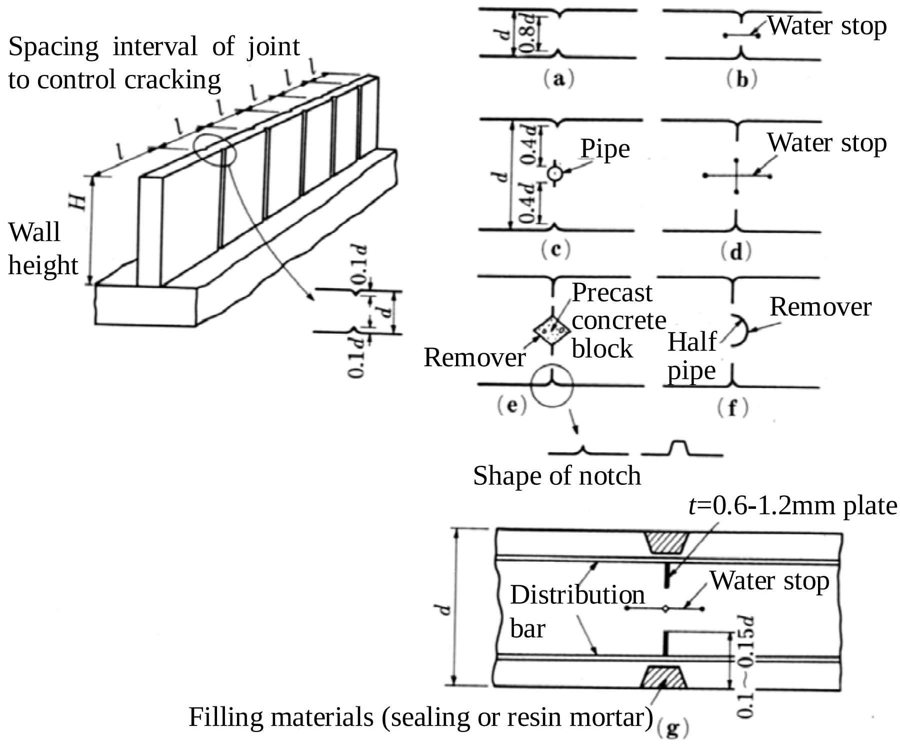

Fig. C 9.9.1 Examples of joints to control cracking

CHAPTER 10 REINFORCEMENT

10.1 General

Reinforcing bars shall be fabricated to the shape and size specified in the design documents using appropriate methods that do not cause any damage to the quality of the bars. Furthermore, the reinforcing bars shall be accurately placed in the required position and securely fixed in place.

[Commentary] The main matters which should be examined in general reinforcement work are explained as follows.

(1) Master planning

Prior to reinforcement work, a plan shall be drawn up after carefully considering the schedule for reinforcement work, personnel requirements, storage locations for reinforcing bars, bar processing equipment, and so forth. Those involved in reinforcement work should preferably have sufficient knowledge and experience associated with reinforcement work, the quality of reinforcing bars, the preparation of reinforcement drawings, the fabrication and assembling of reinforcing bars, and so forth. There are a variety of jointing methods, and each method requires specialized knowledge and experience. It is desirable, therefore, that the personnel for reinforcement work include persons with officially recognized qualifications, such as Certified Reinforcing Steel Erectors, various technicians certified by Japan Pressure Welding Society or Japan Welding Engineering Society, or other equally knowledgeable and experienced persons.

It is necessary to check the requirements indicated in the design drawings and specifications such as concrete cover, clearance, bending configuration, anchorage, joints and nonstructural reinforcement and verify that the reinforcing bars can be erected as designed. Reinforcement drawings are supposed to have been thoroughly checked at the design stage, but there may have been errors at the drafting stage. If the designer does not understand the actual tasks involved in reinforcement work or form work, it may not be possible to place reinforcing bars as indicated on the drawings at the erection stage. It is important, therefore, to correctly understand the design drawings and specifications and confirm the tasks to be performed together with the technicians who will be involved in the reinforcement work before the construction work begins. If, as a result, placing the reinforcing bars as specified in the design turns out to be difficult to perform, it is necessary to decide on the measures to be taken through consultation with the owner and the designer.

(2) Ordering, delivery and storage of reinforcement

It is necessary to check the type, diameter, length and quantity of reinforcing bars before ordering reinforcing bars and after they are delivered. Since the quality of reinforcing materials such as reinforcing bars is described in Section 3.6, it is important to refer to and understand the relevant JIS and JSCE standards in advance. It is also necessary to refer to Section 3.7.5 for information on the storage of reinforcing bars and other steel products and take measures to protect reinforcing bars from corrosion and dirt in order to maintain their quality.

(3) Fabrication of reinforcement

In connection with the fabrication of reinforcing bars, fabrication instructions shall be given to construction workers in accordance with Section 10.2 so that there will be no error in the type of reinforcing bars, inside bend radius, etc. After reinforcing bars are fabricated their type, number and fabrication accuracy need to be checked. Fabrication accuracy shall be kept within the tolerance indicated in Chapter 7 of the Construction: Inspection Standards of this Specification.

(4) Placement and assembly of reinforcing bars

In connection with the placement and assembly of reinforcement, checks must be made in accordance with Sections 10.3, 10.4 and 10.5 on details such as fixing by use of spacers and tie wire, relationship with formwork, specified locations and bar spacing, effective depth, concrete cover, development length, adequacy of joint method and the treatment of pressure-welded bar ends. Assembly accuracy needs to be controlled so that it can be kept within the range indicated in Chapter 7 of the Construction: Inspection Standards of this Specification.

10.2 Fabrication of Reinforcement

(1) Reinforcing bars shall be fabricated to the shape and size specified in the design documents using methods that do not cause any damage. As a general rule, bars that have been bent once should not be re-bent.

(2) Epoxy resin-coated reinforcing bars shall be processed by an appropriate method suitable for their characteristics.

(3) As a general rule, reinforcing bars shall not be welded. If reinforcing bars are welded for a compelling reason and welded reinforcing bars are bent, the welded portions of the bars shall not be bent. As a general rule, bending should not be done within a distance calculated as 10 times the bar diameter.

(4) If the bend radius requirements for reinforcing bars are not indicated in the design drawings and the specifications, reinforcing bars shall not be bent with a radius smaller than the inside bend radius indicated in the Design section of this Specification.

(5) Reinforcing bars should be fabricated at a normal temperature.

[Commentary] (1) It shall refer to the shapes and dimensions indicated in the design drawings and specifications and fabricate reinforcing bars so that their dimensions fall within the specified dimensional tolerance. In order to fabricate reinforcing bars so that their dimensions fall within the tolerance, it is desirable that equipment suitable for the type of reinforcing bars be used for bar bending.

Re-bending of bent bars may have adverse effects on the quality of the bars. Re-bending, therefore, shall be avoided as much as possible. If reinforcing bars are provisionally bent at a location such as a construction joint and later bent back into the specified position, it is necessary either to bend and re-bend the bars at the largest possible radius or to heat the bars to 900 to 1,000°C before bending.

(2) Fabrication and assembly of epoxy resin-coated reinforcing bars shall be done by an appropriate method so that the quality of the coating film is not degraded. Because this requires specialized knowledge about epoxy resin-coated reinforcing bars, refer to the Recommendations for Design and Construction of Reinforced Concrete Structures Using Epoxy-Coated Reinforcing Steel

Bars.

(3) Reinforcing bars shall not be welded, in general, because it may harm the quality of the bars. When it is impossible to avoid the bending for repair or strengthening, effects of welding on welded reinforcement and performance of the structure should be investigated sufficiently. On-site welding should necessarily be sufficiently managed. No bending should be made at a location closer than 10 times the bar diameter to the nearest welded portion because of its fabricability and reliability.

(5) As a bar bending machine facilitates the bending work of bars even with large diameters under normal temperature, bending shall, in general, be carried out at normal temperature. When heat must be applied to normal hot rolled reinforcing bars, it shall be within the temperature range of 900 to 1000℃. Rapid cooling should be avoided. As bars might be harmed by an inadequate heating temperature, rate of cooling, or bending procedures, it is important to control the heating temperature sufficiently and avoid rapid cooling for bending of bars with large diameters.

10.3 Assembly of Reinforcing Bars

(1) Before being assembled, the reinforcing bars shall be cleaned, and rust or any other foreign matters, which may adversely affect the bond between the bar and concrete, shall be removed.

(2) Reinforcing bars shall be accurately placed and secured against any movement during the placement. For this purpose, erection bars shall be used if necessary. In addition, annealed wire having a diameter of not less than 0.8mm or appropriate clips shall be used at the intersection of the reinforcing bars to keep them in position.

(3) Spacers shall be provided at required intervals to achieve the required concrete cover for the reinforcing bars. In selecting and placing the spacers, conditions at the location of the spacers, the method used for fixing the spacers, amount of reinforcing bars, and working loads should be considered.

(4) As a general rule, spacers in contact with formwork should be made of mortar or concrete.

(5) If part of the assembled reinforcement is exposed to the air for a long time, the reinforcing bars should, be rust-proofed.

(6) If a considerable amount of time has passed after reinforcing bars are assembled, the surfaces of the reinforcing bars should be cleaned again before the placement of concrete.

[Commentary] (1) Rust, mud, oil, paint, etc. may adversely affect the bond strength of reinforcing bars with concrete. Hardened mortar adhered to reinforcing bars shall be removed by wire brush.

(2) This provision has been made because the strength of reinforced concrete members may be affected and their durability may be degraded if reinforcing bars are not located as specified in the design drawings and specifications.

In some design drawings, positions of reinforcing bars are shown only in their central lines, and the cover may not be appropriately displayed. Therefore, the accuracy of the reinforcing bars' arrangement should be confirmed beforehand by the preparation of the assembly diagram in consideration of outer diameter and bending radius, assembly sequence of reinforcing bars, etc.

Erection bars are required for not only preventing bars from movement but also for facilitating erection. Sometimes, erection bars are not shown in design drawings but it is recommended that they be used. From the viewpoint of durability, the cover of erection bars should also be ensured.

To ensure the correct spacing of bars, intersections of bars are usually tied up with wires of diameter 0.8 mm or greater. To fix intersections, clips of various types or spot welding can be utilized instead of wire. Spot welding may damage the quality of the bars and lower the fatigue strength considerably due to local heating. Therefore, care should be taken to ensure that harmful effects do not occur to the bars in consideration of the type of loads, the importance of the structure, the materials and diameters of bars, inadequate bar diameter, welding workmanship or welding method.

(3) and (4) Spacers which are made of proper materials for use position should be placed at the appropriate position in order to retain reinforcing bars for the appropriate position and to ensure the required cover. Generally, spacers made of mortar, concrete, steel, plastic or ceramic are used. Materials for spacers should be determined in consideration of the site location and environmental condition. The mortar or concrete spacers shall, in general, be used in this Specification. The dimension of the spacers used shall be appropriately selected in order to ensure the minimum required cover and to place reinforcing bars at the position within the tolerance.

If steel spacers are exposed at the concrete surface, the portions in contact with the formwork begin to rust even if they have been rust-proofed. Consequently, those portions may cause the corrosion of the inner portions of the reinforcing bars, create corrosion-vulnerable regions, and degrade the appearance of the structure. In a highly corrosive environment, steel spacers are particularly prone to rusting, and rusty water may turn the concrete surface brown. Steel spacers must not be used, therefore, in highly corrosive environments. Although there are corrosion-resistant spacers made of stainless steel or other materials, there are still unknown factors such as corrosion due to the contact between different kinds of metal. Plastic spacers pose other types of problems such as differences in the coefficient of thermal conductivity from concrete and insufficiency in bond and load-carrying capacity. As a general rule, therefore, this Specification shall require the use of mortar or concrete spacers. The quality of mortar or concrete spacers used shall be equivalent to or higher than that of the structural concrete.

Generally, the number of spacers is about 4 per 1 m^2 in beams and slabs, and between 2 to 4 per 1 m^2 in webs, walls and columns. Spacers should be placed in zigzag with an interval of 50 cm when the number of spacers is 4 per 1 m^2. The position of spacers should be described in the drawing in which the reduced scale is large for arrangement of reinforcing bars.

"Spacer Design and Construction Guideline for the Reinforcement Work" by the Japan Civil Engineering Contractors' Association shall be referred to for selection and placement of spacers.

(5) and (6) If assembled reinforcing bars are left un-concreted for a long time, they collect loose rust, dirt, oil, etc. As a general rule, therefore, if the time after completion of reinforcing bar assembly until the placement of concrete is expected to be long, the reinforcing bars shall be either rust-proofed or protected with sheeting or other devices. If a long time has passed after reinforcing bars are assembled until the placement of concrete, the reinforcing bars shall, in general, be cleaned again.

10.4 Joints of Reinforcing Bars

(1) Reinforcing bar joint locations and jointing methods shall conform to the design drawings and specifications. If a reinforcing bar joint that is not indicated in the design drawings and specifications needs to be provided, the location of the joint and the jointing method shall be determined in accordance with the Design section of this Specification.

(2) In a lapping joint, the reinforcing bars should be lapped over the required lapping length, and be tied at several points with annealed wires having a diameter of at least 0.8mm.

(3) If lap joints, gas pressure welded joints, welded joints or mechanical joints are used for reinforcing bars, the Recommendations for Design, Fabrication and Evaluation of Anchorages and Joints in Reinforcing Bars should be followed.

(4) Reinforcing bars extending out of finished concrete shall be protected against possible damage and corrosion to ensure good continuity with further construction.

[Commentary] (1) When selecting a joint method it shall consider the type of reinforcing bar, diameter, state of stress, joint location, joint performance requirements, etc. At the design stage, joint locations are specified in the design drawings and specifications in due consideration of those factors. For this reason, the design drawings and specifications shall be followed with respect to reinforcing bar joint locations and joint methods. It may become necessary, however, at the construction stage to provide reinforcing bar joints that are not indicated in the design drawings and specifications. In such cases, the Design section of this Specification must be followed with respect to joint locations and joint methods, and decisions are to be made through consultation with the owner and the designer.

(2) Lap length requirements for lap joints are specified in the Design section of this Specification. It is important to firmly connect the lapped portions with iron wire. The length of the section wound by annealed iron wire should be made as short as possible because an excessive length may cause a decrease in bond strength between concrete and reinforcing bars and, as a consequence, a decrease in the strength of the joint.

(3) The Recommendations for Design, Fabrication and Evaluation of Anchorages and Joints in Reinforcing Bars specify gas pressure welding joints (manual gas pressure welding joints, automatic gas pressure welding joints, gas pressure welding and hot shearing joints), welding joints (butt welding joints, butt arc stud welding joints, butt resistance welding joints, flare welding joints) and mechanical joints (crimped sleeve joints, crimped sleeve screw joints, threaded deformed bar joints, mortar grouted joints, friction welding screw joints, wedged joints, combination joints). This Specification provides for the equipment and methods for construction and inspection, qualification requirements for inspectors, reliability attributable to these factors, etc. Construction and inspection, therefore, need to be carried out with prior understanding of those provisions.

(4) To prevent the corrosion of bars, methods such as cement paste coating on bars or coating with high polymeric film are generally used. Such materials may cause a reduction in bond strength with the concrete and should therefore be removed completely before jointing is undertaken. It is effective to put a vinyl bag on the jointing part of reinforcing bars to protect them from rainwater.

10.5 Placement of Pre-assembled Reinforcing Bars

(1) Pre-assembled reinforcing bars shall be placed accurately at the specified locations in the formwork.

(2) Pre-assembled reinforcing bar segments shall be connected together by a method that makes it possible to achieve the required joint performance.

[Commentary] (1) In cases where pre-assembled reinforcing bars are to be placed at a specified location, it is necessary to select an appropriate lifting method, such as providing lifting frames or steel reinforcements for lifting, in due consideration of safety so that there are no adverse effects such as irregularities in the shape or dimensions or excessive deformation of the pre-assembled reinforcement cage due to lifting.

In order to place pre-assembled reinforcing bars accurately into position, it is recommended that positioning marks be indicated on the upper part of the formwork or other appropriate places.

(2) In order to achieve the required strength of the structure, it is important to connect together pre-assembled reinforcing bar segments by a highly reliable method. Lap joints must be placed so that the lapped portions of the reinforcing bars are in contact with each other. If it is difficult to place reinforcing bars to be connected so that they are in contact with each other as in the case of a diaphragm wall, it is necessary to ascertain that the joint meets the performance requirements. For further information about pre-assembled reinforcing bars for diaphragm walls, refer to Section 10.4.2 of the Construction: Special Concretes of this Specification.

CHAPTER 11 FORMWORK AND SHORING

11.1 General

(1) Construction plans for formwork and shoring shall be prepared in advance and formwork and shoring shall be designed and constructed in accordance with those plans so that the concrete structure has the shape and dimensions indicated in the design drawings and specifications.

(2) Formwork and shoring shall be designed and constructed so as to ensure the required strength and rigidity against loads specified in Section 11.2 and also to ensure the required shape and dimensions of the structure.

(3) In order to achieve the required accuracy of the concrete structure, the accuracy of assembled formwork and shoring shall be confirmed before placing concrete.

(4) In addition to the provisions of this Standard Specification, the design and construction of formwork and shoring shall also comply with the "Ordinance on Industrial Safety and Health" issued by Ministry of Health, Welfare and Labor of Japan.

[Commentary] It is usually not necessary to allow for a very large factor of safety when designing formwork and shoring because the period from the placement of concrete to its hardening is short. There must, however, be neither adverse effects on the structure nor unsafe practices. Formwork and shoring are important for obtaining a structure that meets the positional and dimensional requirements and ensures the safety of the workers involved in compaction and other construction tasks and the engineers who manage those tasks. Formwork and shoring, therefore, need to be designed by engineers who have specialized knowledge about formwork design. It is also desirable that those construction tasks be performed by experienced and skilled technicians who are capable of determining whether anomalous erection work is in progress – for example, persons certified as chief assembly technicians by a public institution.

11. 2 Load

11.2.1 General

Formwork and shoring shall be designed considering the type, scale and importance of the structure and the conditions of construction and environment, referring to Section 11.2.2 to 11.2.5 for the various loads. Not only strength but also deformation shall be considered in the design of shoring.

[Commentary] The loads imposed on the formwork and shoring are complicated. However, for the convenience of design, they are categorized into four cases, such as vertical loads, horizontal loads, lateral pressure of concrete, and special loads. Minimum values are given for the specified loads in Section 11.2.2 through Section 11.2.5. These values should be increased properly taking into account structural conditions.

11.2.2 Vertical loads

(1) The mass of formwork, shoring, concrete, reinforcing bars, workers, construction machinery and equipment, temporary facilities, and any impact, shall be considered.

(2) It shall be a standard requirement to assume a unit mass of 2,400 kg/m^3 for concrete in formwork and shoring calculations. In the case of reinforced concrete, it shall be a standard requirement to assume a mass of 150 kg/m^3 for reinforcing steel in calculations associated with ordinary structures.

(3) The unit mass of concrete made with aggregate consisting solely or partially of artificial lightweight shall be determined appropriately with reference to the Construction: Special Concretes (Chapter 3, Lightweight Aggregate Concrete) of this Specification.

(4) Other than the dead loads, working and impact loads should, in general, be taken at least 2.50kN/m^2.

[Commentary] (1) and (2) In the case of an ordinary structure, vertical loads may be calculated on the basis of the values indicated in the provisions. If the amount of steel is greater than in ordinary cases or if the actual mass is known, calculation shall be performed taking those factors into account. Although the Design section of this Specification specifies unit weights for hardened concrete of 22.5 to 23.0 kN/m^3 and unit weights for reinforced concrete of 24.5 kN/m^3, more conservative values (unit weight = 23.5 kN/m^3) are required as standard in formwork and shoring calculation.

(4) Generally, it is difficult to assume the values of working and impact loads. However, these loads can be assumed as uniform loads for the convenience of design.

11.2.3 Horizontal loads

(1) Horizontal loads shall include loads caused by inclination of formwork, vibration, impact, commonly used eccentric loads, loads due to erection errors, loads due to wind pressure, hydrostatic water pressure and earthquakes, etc., depending on the requirements.

(2) In design, the horizontal load, which actually acts on formwork, should be taken into consideration. However, in cases when actually acting horizontal load is smaller than the reference horizontal load, the latter shall be used to evaluate the safety.

(3) In cases when the formwork is almost level and shoring is assembled using pipe support, a single pipe support, steel pillar, a shoring beam, etc., reference horizontal load acting at the top of shoring, shall be taken to be 5% of the design vertical load. When a shoring is assembled using framed steel-pipe support with factory accuracy, the horizontal load equivalent to 2.5% of design vertical load shall be assumed. Formwork for walls such as retaining walls shall be designed for a horizontal load of at least 500N /m^2.

[Commentary] (1) As collapse of shoring is mainly caused by horizontal load, it is necessary to carefully assume this load in the design. It is thought that the horizontal load acting on shoring acts on the top of shoring or horizontally on the side.

(2) The reference horizontal load should be used in order to secure the rigidity and stability of formwork and shoring against horizontal force, even when horizontal load does not actually act.

(3) This clause is based on Article 240 (3) (iii) and (iv) of the Ordinance on Industrial Safety and Health. This is based on the empirically known fact that a collapse often results from inadequate consideration of horizontal loads. In normal cases, horizontal loads may be determined on the basis of the values indicated in this clause, but it is desirable that they be determined after carefully considering factors such as the degree of importance of the structure, construction conditions and the construction period.

11.2.4 Lateral pressure of concrete

(1) Formwork shall be designed taking into consideration the lateral pressure of concrete.

(2) Since the lateral pressure of concrete varies depending on the structural conditions, concrete conditions and construction conditions, its value shall be determined taking these factors into consideration.

[Commentary] The lateral pressure acting on the formwork differs depending on the structural conditions, concrete conditions and construction conditions. Major factors affecting lateral pressure include the following:

(a) Structural conditions: cross-sectional dimensions of structural members, the amount of reinforcement, etc.

(b) Concrete conditions: materials used, mix proportion, slump and its retention time, setting time, concrete temperature, etc.

(c) Construction conditions: placing rate, placing height, compaction method, whether re-vibration is to be performed, etc.

If factors contributing to an increase in lateral pressure are involved, it is necessary to appropriately increase lateral pressure values used for calculation. The setting time, temperature and placing rate of concrete vary considerably depending on outdoor air temperature, materials used, production and construction conditions, etc. If slump retention time is long, setting is delayed or the placing rate is increased as in the case of concrete placement during winter, care needs to be taken because higher-than-expected lateral pressure may act on the formwork.

It is difficult to indicate, in the Construction: Construction Standards of this Specification, a lateral pressure formula reflecting the influence of various factors affecting lateral pressures. Lateral pressure values to be used for formwork design shall be determined appropriately on the constructor's own responsibility, taking into consideration the construction speed, economy, safety and other requirements of the constructor and various factors affecting them. One way to do this is to design formwork by measuring actual lateral pressure by installing lateral pressure cells or check on lateral pressure during the placement of concrete.

One way to design conservatively is to determine the lateral pressure acting on the formwork by regarding lateral pressure as fluid pressure. The term "fluid pressure" refers to pressure (hydrostatic pressure) in the case where gravity acts on fluid in a stationary state. Fluid pressure is calculated by assuming concrete as fluid and multiplying the unit mass of concrete by gravitational acceleration and the placing height as follows:

$$p_w = W_C H \tag{C11.2.1}$$

where,

p_w: fluid pressure (kN/m^2)

W_C: unit weight determined by multiplying the unit mass of concrete by gravitational acceleration (23.5 kN/m^3 when unit mass = 2,400 kg/m^3)

H: placing height of fresh concrete (m)

Measured lateral pressures of high-fluidity concrete such as self-compacting concrete and high-strength concrete often show distribution patterns resembling those of fluid. The Construction: Special Concretes (Chapter 6, High-Strength Concrete, and Chapter 7, High-Fluidity Concrete)therefore require, as a general rule, that design be conducted assuming fluid pressure. If the unit mass of concrete has been determined, it may be substituted in the equation, taking its changes into account.

Designing formwork assuming fluid pressure is a conservative approach, and this approach is neither economical nor practical if the actual lateral pressure is substantially lower than the fluid pressure. If relatively-low-slump concrete as mentioned in the Construction: Construction Standards (Chapter 4 and Chapter 7) is placed under certain conditions, such in layers of thickness 0.4 to 0.5 m or less and at a placing rate of about 1.0 to 1.5 m, the lateral pressure acting on the formwork is often substantially lower than the fluid pressure. Various practical lateral pressure formulas have therefore been proposed based on the results of experiments paying attention to various factors affecting lateral pressure. The equations shown below are long-used practical formulas for roughly calculating lateral pressure in the case where normal Portland cement is used and concrete with a slump of about 10 cm or less is poured into formwork and compacted by use of internal vibrators. Fig.C11.2.1 and Fig.C11.2.2 show the relationship of the lateral pressure calculated by using these formulas with the placing rate and concrete temperature.

In view of the experiment conditions under which the formulas were derived, the upper limit of the values calculated from the formulas is 150 kN/m^2 for columns and 100 kN/m^2 for walls. Because these formulas do not consider the final placing height, calculated lateral pressure values may become greater than fluid pressure values depending on the placing rate, concrete temperature and the final placing height. Since, however, the maximum value of the lateral pressure is usually not greater than the fluid pressure, the fluid pressure is used when the calculated value is greater than the fluid pressure. In the case of a wall, there are no significant differences from the lateral pressures for a column. The formula for columns, therefore, may also be used for walls.

(a) Column

$$p = \frac{W_C}{3}\left(1 + \frac{100R}{T+20}\right) \quad \leq 150 \tag{C11.2.2}$$

(b) Wall

(i) R ≥ 2m/h

$$p = \frac{W_C}{3}\left(1 + \frac{150 + 30R}{T + 20}\right) \quad \leq 100 \qquad \text{(C11.2.3)}$$

(ii) If R < 2m/h, the formula for columns may be used.

where,

p: lateral pressure (kN/m^2); but if the calculated value of p becomes greater than p_w, p is assumed to be equal to p_w.

p_w: fluid pressure (kN/m^2)

W_C: unit weight obtained by multiplying the unit mass of concrete by gravitational acceleration (kN/m^3)

R: placing rate (m/h)

T: concrete temperature in formwork (°C)

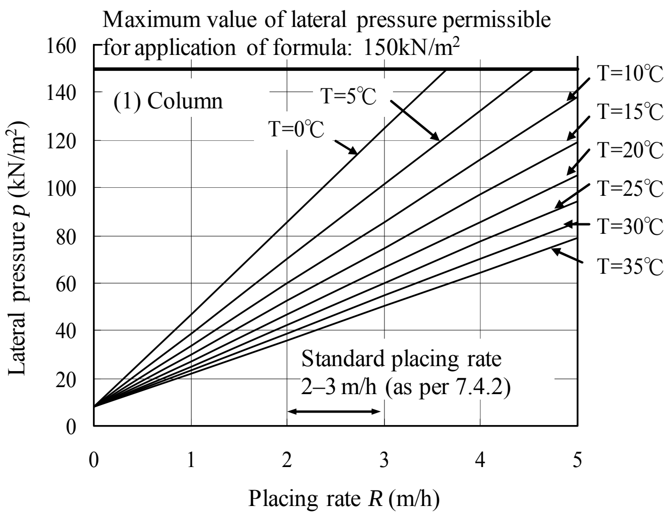

Fig. C11.2.1 Lateral pressure of concrete with a slump of about 10 cm or less (column)

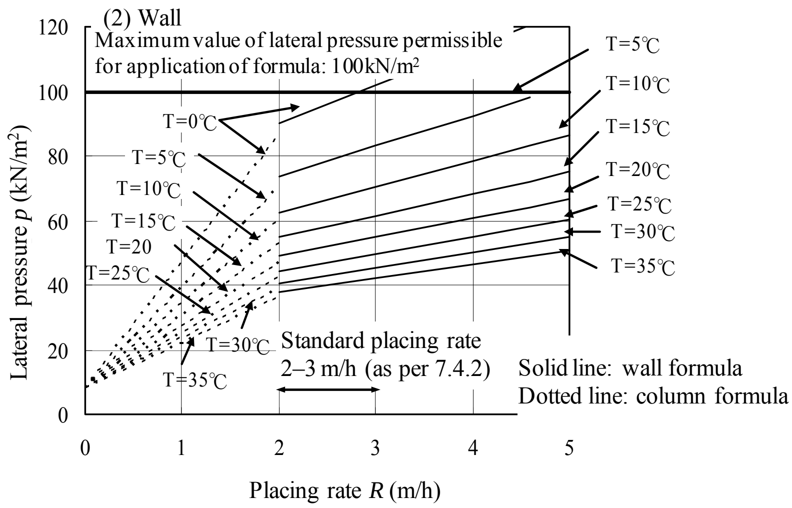

Fig. C11.2.2 Lateral pressure of concrete with a slump of about 10 cm or less (wall)

Fig. C11.2.3 shows the changes in the distribution of the lateral pressure due to concrete. As indicated by the formula, lateral pressure increases as the placing height increases. If two or more 0.4–0.5 meter-thick layers of low-slump concrete are placed one on top of another, the increase in lateral pressure is in many cases hampered, especially at locations lower than a certain level, because of a decrease in the slump of concrete in the formwork, the progress of setting, bonding with reinforcing bars, etc. In view of the possibility of such changes, therefore, if tall forms are used, formwork is sometimes designed assuming that lateral pressure is constant at or below a certain height. This assumption is based on the fact that because the abovementioned formulas for calculating lateral pressure from the placing rate and concrete temperature do not include a term for the placing height, calculated lateral pressures remain constant. Thus, formwork is designed assuming that the calculated lateral pressure is the maximum value.

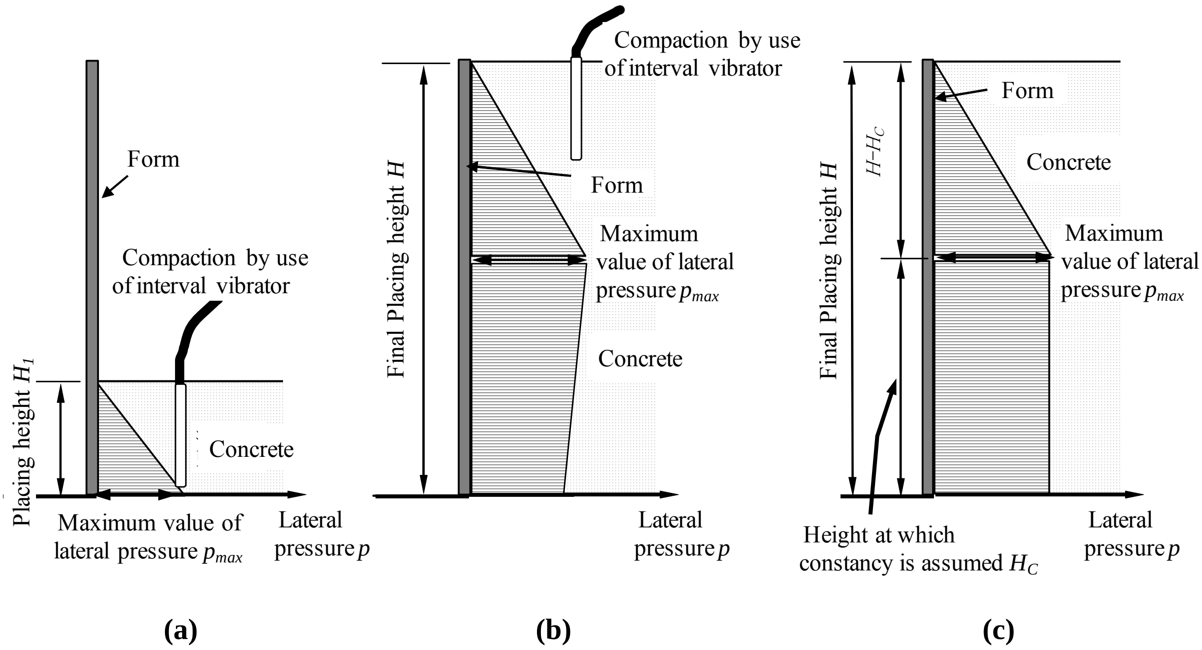

Fig. C11.2.3 Distribution of lateral pressure of concrete with a slump of about 10 cm or less

(a) Lateral pressure distribution at initial stage of placement, (b) Lateral pressure distribution upon completion of placement, (c) Lateral pressure distribution calculated at design stage

Chapter 4 of the Construction: Construction Standards of this Specification specifies a method for determining the appropriate minimum slump for placement considering the concrete structure and reinforcement conditions. It is therefore possible that concrete with a larger slump than that of conventional concrete will be used in civil engineering projects. Because the minimum slump needs to be retained until the placement of concrete is completed, the slump of the concrete at the time when it is actually placed becomes greater than the minimum slump. Since the lateral pressure of concrete tends to increase with slump, it is necessary to determine lateral pressure in view of predetermined slump values and tolerance during construction planning.

The equations shown below are practical formulas for calculating lateral pressure in the case where high-slump (about 18 cm) concrete is placed at a rate of 10 m/h or less and at a final placing height of 4 m or less. Fig.C11.2.4 shows distributions of lateral pressures calculated by using the formulas. These distributions can be used as reference data when considering the lateral pressure of high-slump concrete. Note, however, that the formulas reflect neither placing rates lower than 10 m/h nor the influence of concrete temperature. In general, lateral pressure increases with slump. If, therefore, the lateral pressure calculated by using these formulas is equal to or smaller than a calculated lateral pressure of concrete with a slump of about 10 cm or less, it is desirable that lateral pressure be determined taking a factor of safety into consideration.

(a) If the placing height is in the range of 0 m to 1.5 m, it is assumed that fluid pressure acts.

(b) If the placing height is greater than 1.5 m and not greater than 4.0 m, lateral pressure is calculated for each structural type using the following formulas:

(i) Column: $$p = 1.5W_C + 0.6W_C(H - 1.5) \qquad \text{(C11.2.4)}$$

(ii) Wall (with length 3 m or less): $$p = 1.5W_C + 0.2W_C(H - 1.5) \qquad \text{(C11.2.5)}$$

(iii) Wall (with length greater than 3 m): $$p = 1.5W_C \qquad \text{(C11.2.6)}$$

where,

p: lateral pressure (kN/m^2)

W_C: unit weight determined by multiplying the unit mass of concrete by gravitational acceleration (kN/m^3)

H: placing height (m)

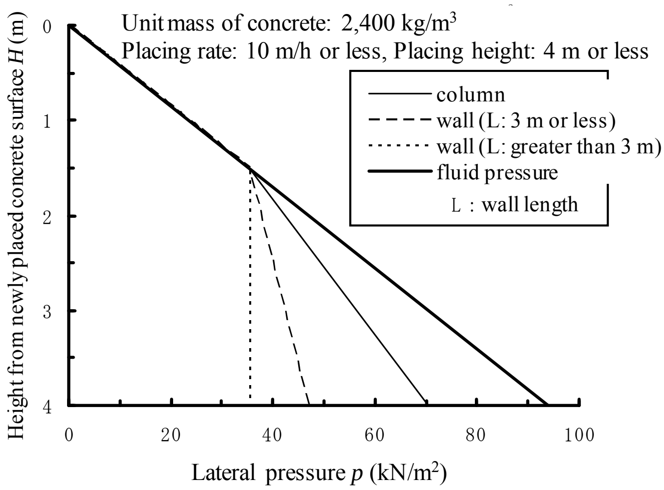

Fig. C11.2.4 Distributions of lateral pressure of concrete with a slump of about 18 cm

11.2.5 Special loads

If the influence of special loads expected to occur during construction cannot be ignored, those loads shall be taken into consideration when designing formwork and shoring.

[Commentary] Special loads defined here are eccentric loads caused by the unsymmetrical placement of concrete, horizontal component forces at the placement caused by inclination of form bottoms, uplift force effective to the embedded sheaths in hollow slabs, and other forces. Such special loads shall also be considered in the design where their effect may be anticipated.

11.3 Materials

(1) Materials used for formwork and shoring shall be selected taking into account strength, rigidity, durability, workability, effect on the placed fresh concrete, aesthetics and economy of concrete structures.

(2) Materials such as timber, plywood and steel plate used for formwork should meet the requirements of the relevant JIS or JAS (Japanese Agricultural Standard) standards.

(3) In cases when the concrete structure requires water-tightness, formwork bolts shall be such that they do not impair the water-tightness.

[Commentary] (1) Formwork and shoring tend to be damaged, deformed and corroded through repeated use and relatively large loads. However, the selection conditions differ depending on the type of structure, the frequency of use, or the importance of the location where the formwork and shoring are to be used. Therefore, the most suitable material should be selected after taking into consideration the factors described in this section.

Formwork shall meet the required performance, construction accuracy and construction safety. Although formwork are usually used more than once, the maximum usage should be about 5 times for plywood, about 20 times for plastic forms, and about 30 times for steel forms.

(2) Specifications for pipe support, steel panel for formwork and plywood for concrete formwork are provided in JIS A 8651 "Tubular Steel Adjustable Shore," JIS A 8652 "Metal Panels for Concrete Panel," and in the Japanese Agricultural Standard, respectively.

Recently, there is a trend to change the plywood formwork material, from trees such as the lauan in Southeast Asia to needle-leaf trees, as part of the countermeasures against global environment problems. In the case of formwork made from needle-leaf trees, it is necessary to consider that needle-leaf trees have many knots and formwork made from these trees may curve easily, resulting in inadequate hardening of the concrete. Compound plywood made of lauan for the surface layer and needle-leaf tree on the inside, or with surface painting or other methods, may be used so as to prevent adverse effect on concrete quality.

A plastic form can serve not only as a substitute for timber from Southeast Asia but is also effective for construction management.

Clause No. 241 of the "Ordinance on Industrial Safety and Health" specifies the allowable stress of materials for formwork and shoring as follows;

1) Allowable bending stress and allowable compressive stress of steel members shall not exceed two-thirds of the lower of the following values: the yield strength or three-fourths of the tensile strength.

2) Allowable shear stress shall not exceed thirty eight-hundredths of the lower of the following values: the yield strength or three-fourths of the tensile strength.

3) Allowable buckling stress of steel members shall not exceed the value calculated by the following formulas

for $l/i \leq \Lambda$,

$$\sigma_c = \frac{1 - 0.4(l/i/\Lambda)^2}{\nu} F$$

for $l/i > \Lambda$,

$$\sigma_c = \frac{0.29}{(l/i/\Lambda)^2} F$$

where, l : effective length of support (the longest span of restrained positions, if the support is restrained from lateral displacement) (mm)

i : minimum radius of gyration of the support section (mm)

Λ : limit ratio of length to width = $\sqrt{\pi^2 E / 0.6F}$

π : the ratio of the circumference of a circle to its diameter

E : Young's modulus of steel member (N/mm^2)

σ_c : allowable buckling stress (N/mm^2)

ν : safety factor = $1.5 + 0.57(l / i / \Lambda)^2$

F : lower of the following values: the yield strength or three-fourths of tensile strength (N/mm^2)

4) The value of allowable bending stress, allowable compressive stress and allowable shear stress of timber parallel to the grain of various species of timber shall not exceed those listed in Table C10.7.1.

Table C11.3.1 Standard allowable stress of materials for formwork and shoring

Species		Allowable stress (N/mm^2)		
		Bending stress	Compressive stress	Shear stress
Needle-leaf trees	Japanese red pine, Japanese black pine, Japanese larch, Arborvitae, Japanese cypress, Japanese hemlock, Oregon pine, Port Orford cedar	13.5	12.0	1.0
	Japanese cedar, Fir, Japanese spruce, Abies, Western red cedar, Western hemlock	10.5	9.0	0.7
Broad-leaf trees	Oak	19.5	13.5	2.1
	Chestnut tree, Japanese oak, Beech, Zelkova tree	15.0	10.5	1.5

5) Allowable buckling stress of timber parallel to the grain shall not exceed the value calculated by the following formulas,

for $l_k / i \leq 100$,

$$f_k = f_c(1 - 0.007 l_k / i) f_k$$

for $l_k / i > 100$,

$$f_k = \frac{0.3 f_c}{(l_k / 100i)^2}$$

where, l_k : effective length of support (the longest span of restrained positions, if the support is restrained from lateral displacement) (mm)

i : minimum radius of gyration of the support section (mm)

f_c: allowable compressive stress (N/mm^2)

f_k: allowable buckling stress (N/mm^2)

(3) Bleeding water accumulates under the bolts and steel bars used as tie members and causes water leakage after the hardening of concrete. Therefore, it is efficient to attach a brim so as to lengthen the waterway. The hole at the concrete surface should be carefully filled using resin mortar or other materials while taking into consideration the water-tightness requirements of the whole structure.

11.4 Design of Formwork

(1) Formwork shall be able to maintain its shape and position accurately under the action of loads by using appropriate bolts.

(2) The structure of formwork shall be such that it can be easily erected and removed. Vibration or impact resulting from the removal shall not adversely affect the concrete, etc. Joints in the sheathing or form panels should, as much as possible, be at right angles or parallel to the member axis and be sealed to prevent mortar from leaking.

(3) Even if not specified, formwork should be designed to incorporate chamfers at all corners.

(4) If necessary, temporary openings shall be provided at appropriate positions in the formwork to facilitate cleaning, inspection, and placement of concrete.

[Commentary] (2) It is important to erect boards or panels at right angles or parallel to the member axis so as to ensure the accuracy of formwork position, shape and dimension, and also to prevent mortar leakage from sheathing joints or form panels.

(3) The proper chamfer strip at the corner of formwork is useful for protection against impact damage during removal work or after the completion of construction. Furthermore, such chamfers are effective in order to minimize the effect due to atmospheric conditions or physical action. Chamfer is sometimes used at joints in consideration of appearance and constructability.

(4) This requirement is necessary when the inside of formwork is blockaded cleaning and inspection are difficult after assembly or before concrete placing, or when the height of formwork is high and predetermined placing height cannot be secured during placement.

11.5 Design of Shoring

(1) Shoring shall be appropriately designed to ensure that all loads acting on it are transmitted to the foundation.

(2) Shoring shall be easy to erect and remove, with joints and connections being appropriately designed to carry all loads.

(3) Foundations of shoring shall be such that excessive and differential settlement does not occur.

(4) Additional measures to appropriately raise the shoring shall be provided to offset any settlement and/or deformation during or after placing of concrete.

[Commentary] (1) It is necessary for the shoring members to stabilize the supports using sufficient lateral or diagonal bracing so as to possess sufficient strength and to be safe against buckling under vertical loads. When the variance of load distribution occurs with the differential settlement of foundation, temporary beams or other members should be used to distribute loads to all vertical supports.

Shoring should be designed to resist horizontal loads by fixing both sides of the beam at the upper part of shoring onto existing structures or other supports, or by employing lateral and diagonal bracing. Also, for inclined formwork, care should be taken to ensure that shoring should not deform adversely under concrete pressure.

(2) Shoring should be designed to be removed easily and safely without any impact on the structures due to jacks, wedge anchors, or other measures.

For load transmission at joints and connections, it is effective to firmly fix the supports using butt joint or plug joint and the connections and intersections between the steel materials using metal devices such as bolt and clamp.

Beams of considerable height should be connected together with lateral bracings to prevent rotation and collapse.

(3) To avoid the settlement of foundations in soft ground conditions, the distribution of loads or adequate strengthening of foundations should be required.

(4) Deflection of the structure or settlement of shoring caused by the weight of concrete may affect the settlement or deformation of the structure during construction. Therefore, it is required that the shoring be raised to ensure that the structure is constructed in conformity with the design drawings.

Also, deflection caused by creep after construction may also require shoring adjustment. Generally, it is necessary to show the amount of additional lift in the design drawings.

The settlement and deformation of shoring is normally caused by the settlement of foundations, compressive deformation and deflection of shoring members, looseness of joints or connections in the shoring, and the thrust of contact faces. The amount of settlement and deflection should be estimated by calculations, past experiences or a simple field measurement, etc., and be taken into consideration in construction, if necessary.

Generally, the looseness at joints or connections, the thrust of contact faces, etc. in the shoring may be approximately 1 mm to 2 mm per location.

11.6 Preparation of Formwork

(1) Formwork should be secured using bolts or steel bars. These bolts or bars shall not remain on the surface of the concrete after the removal of formwork.

(2) Contact surfaces of formwork should be coated with a form release agent.

(3) The dimensions of the formwork and any defects therein shall be appropriately managed prior to and during the placing of concrete.

[Commentary] (1) Steel wire in particular shall not be used for tying members of important structures because it may easily expand or be cut.

When bolts and steel bars are exposed to concrete surfaces, the exposed portion may cause water infiltration, rust spots, or cracks on the concrete surface. Embedded parts of bolts or steel bars within 2.5 cm of the concrete surface should be removed after chipping the concrete. The hole created by the chipping should be filled up with high quality mortar.

(2) The form release agent should efficiently prevent the formwork from adhering to the concrete surface and facilitate the removal work of the formwork. For the form release agent, many kinds of products are marketed for use with wood, steel, or other forms. The main components of form release agents are classified into paraffin, mineral oil, animal oil, vegetable oil, synthetic resin and surface-active agents, among others. Each form release agent differs widely in usage, application amount, maximum number of applications, etc. Depending on the type or usage, a form release agent may flow out by washing with water at the time of cleaning, rain, etc., so that the form release effect may decrease. Also, construction joints may be polluted, or a form release agent may be entrapped in the concrete during placement. Therefore, it is important to first confirm the property and usage before using a form release agent.

(3) Formwork shall be erected so that the completed structure is within the tolerances specified in Section 15.7.3 of the Construction: Inspection Standards of this Specification. There may be deflection of formwork, leakage of mortar, movement, inclination, settlement, looseness of connections, etc. caused by formwork prior to and during the placement of concrete. When such troubles arise, it is important to take suitable measures immediately, if necessary, to prevent danger.

11.7 Preparation of Shoring

(1) Shoring shall be prepared in a manner that ensures sufficient strength and stability.

(2) The dimensions of the shoring and any defects therein shall be appropriately managed prior to and during the placing of concrete.

[Commentary] (1) In order to provide sufficient strength and stability for shoring, prior to the shoring erection adequate preparation and strengthening of the ground should be completed so as to provide the required bearing capacity or to avoid differential settlement. Sufficient compaction should be applied to back-filled soil when it is used as the foundation material. When there is the possibility that water may erode the underside of a shoring, precautions for treatment of water shall be taken. Care should always be taken to the inclination, height, alignment and other factors so as to ensure that there will be sufficient strength and stability during the erection of shoring.

Joints, connections and intersections of the members should be tight and free from gap and looseness. All joints should be aligned correctly.

(2) There may be movement, inclination, settlement, etc. caused by the shoring prior to and during the placement of concrete. When such troubles arise, it is important to take suitable measures immediately, if necessary, to prevent danger.

Shoring shall be erected so that the completed structure is within the tolerances specified in Section 15.7.3 of the Construction: Inspection Standards of this Specification. Even in cases where the tolerance for each part of shoring is small enough to be commonly acceptable, if there is any part that is affected by the cumulative effect of such tolerances it is necessary to evaluate such effects and specify tolerances considering the cumulative error.

11.8 Removal of Formwork and Shoring

(1) Formwork and shoring shall not be removed until the concrete has achieved sufficient strength to carry its own weight and any loads superimposed during the course of further construction.

(2) The timing and sequence of the removal shall be determined taking the strength of concrete, the structure type and importance, member types and dimensions, loads imposed on all members, temperature, weather and ventilation, etc. into appropriate consideration.

(3) In cases when the structure is subjected to loads immediately after the removal of formwork and shoring, the concrete strength, the structure type, and the characteristic and value of imposed loads shall be carefully considered in order to avoid harmful cracks and other damage to the structure.

[Commentary] (1) The removal of formwork and shoring should be carried out after the concrete has achieved sufficient strength. Removal of formwork and shoring should be carried out carefully so as not to damage the structure.

The timing of removal should be determined considering the compressive strength of concrete specimens cured under the same condition as the actual structure. Since specimens tend to be influenced by outside temperature or dryness, it is desirable to judge the timing of the removal based on the curing method in consideration of these effects.

(2) It is difficult to provide general criteria for removal time of formwork and shoring because the various factors mentioned in this section may greatly influence the removal time. As many construction accidents can be attributed to erroneous judgment of removal time, sufficient consideration is required for the removal work.

Table C11.8.1 provides the suggested compressive strengths for the determination of the removal time of formwork for RC structures. When the total load acting on a structure consists almost entirely of dead load, a longer period of curing may be required than that given in Table C11.8.1. Even after the compressive strength shown in Table C11.8.1 is achieved and the formwork is removed, wet curing needs to be continued for the period shown in Table 8.4.1.

Generally, the parts of formwork which bear relatively smaller loads should be removed prior to other parts which are more important and bear more load. For example, the formwork for vertical members like columns and walls can be removed before those for horizontal ones like slabs and beams. The formwork on the lateral sides of beams can be removed before those at the bottom.

Table C11.8.1 Reference values of compressive strength of concrete required for the removal of formwork and shoring

Type and position of surface	Example	Compressive strength (N/mm^2)
Vertical or almost vertical surfaces of thick member Upper surfaces of inclined members Outside surfaces of small arch structures	Sides of footings	3.5
Vertical or almost vertical surfaces of thin member Lower surfaces of members inclined at 45 degrees or more Inside surfaces of small arch structures	Sides of columns, wall and beams	5.0
Slabs and beams of bridges and buildings Lower surfaces of members inclined at 45 degree or less	Bottoms of slabs and beams, Inside surfaces of arch structures	14.0

(3) Immediately after the removal of formwork, the concrete structure may not yet have acquired the specified concrete compressive strength and the structural system may be different from the one expected in the design. Loading may cause harmful cracks or damage to the structure due to excessive stress. Therefore, it should be confirmed that loads imposed immediately after the removal of formwork and shoring will have no harmful effect on the structure.

11.9 Special Formwork and Shoring

11.9.1 General

Various types of special formwork such as slip forms, embedment forms, vented forms, water absorbing forms, etc. are available. Various types of special shoring such as moving shores, erection cars, etc. are also available. These formwork and shoring shall be used in accordance with the special requirements for their use.

[Commentary] There are various types of special formwork; for instance, slip forms which move vertically for the construction of high bridge piers and water tanks, forms which move horizontally or diagonally for waterways, tunnel forms for secondary lining, and so on. And there are various types of special shores such as a moving or truss shores for viaducts and erection cars for cantilever erection of arch bridges. Formwork which is made from polymer cement mortar, polymer-impregnated concrete, fiber reinforced concrete, etc., and is used as a part of member, as well as vented forms and water-absorbing forms which decrease surface air bubbles and rock pockets while reducing the water cement ratio at the concrete surface and raise the impermeability of the surface part of a structure, are used in environments where high durability is required. In addition, when using vented forms or water-absorbing forms for a thin concrete member, it is especially important to delay the removal or to assure sufficient curing in order to avoid drying at the initial stage. When using such forms care should be taken to meet the special requirements for the use.

Since an embedment form is generally a thin component, cracks and chips may occur due to its own weight, impact, etc. during conveyance and installation. Therefore it is necessary to pay attention to the conveyance method or the method of hanging. Also, since rigidity of an embedment form is generally small, it should be sufficiently examined in advance and, if necessary, reinforced so that cracks do not occur due to lateral pressure of concrete.

Fiber sheet attached to forms for the purpose of water permeation or water absorption should be securely fixed to the forms with adhesive tape, stapler, etc. so that neither slack nor wrinkle may arise. When the fiber sheet is reused, any attached waste shall be removed and the sheet properly cleaned to ensure full functional performance of the fiber sheet.

11.9.2 Slipform

(1) In the design of slipform, in addition to loads referred to Section 11. 2, special loads, such as frictional forces, shall be appropriately considered.

(2) The slipform shall be moved continuously until the structure is completed or construction of the planned section is finished.

(3) The formwork system shall have sufficient strength and rigidity, and all ancillaries should have the required capacity and be safe for use. Formwork made of metal plates should be used.

(4) The rate of movement of slipform shall be determined in a manner that ensures that the strength of concrete immediately after the removal of slipform is sufficient to resist all possible loads, taking into account the quality of concrete and the conditions of construction.

(5) Appropriate measures for securing concrete durability shall be taken when constructing using slipform.

[Commentary] (1) When a slipform is used, in addition to the loads expected on general construction methods, the following special loads shall be considered at the top of steel frames or jacking rods during placing of concrete: the weight of deck, the friction between concrete and formwork, the weight of reinforcing bars temporarily placed on the deck, and the weight of concrete acting on the temporary deck or working deck which can be used as shores or bottom formwork.

When the theoretical loads are difficult to calculate, the design should be based on the result from an experiment unless the safety of the formwork has been proven from previous experience.

(2) and (3) Formwork system should have sufficient rigidity so as to ensure that deformations of the structure do not exceed the tolerance during sliding operations.

The yoke, a member like a gate frame supporting the formwork and working deck, should be able to resist the lateral pressure of concrete, and to transmit the full weight of shuttering, accessories and decks to the jacks. The yoke should also secure adequate clearance to enable embedded material to be located correctly prior to being arranged in the rising concrete. In the design of a vertical slipform, in which jacks are supported on vertical rods, care should be taken to place jacks in such a manner that the vertical loads to each jacks are as nearly equal as possible and that the capacity of the jacks are not exceeded. The jacking system should also provide for the precise simultaneous movement of the entire form at a constant sliding rate.

When placing of concrete is interrupted, before resuming construction it is necessary to perform joint treatment. This is necessary in order to prevent a weak point in the concrete which may reduce the durability performance.

(4) In general, the required compressive strength of concrete immediately after removal of formwork should be more than two times larger than the stress induced by the full loads. As the sliding rate is greatly affected by the type of cement used, mixture proportion, temperature of fresh concrete and other factors, the intended standard rate should be determined based on preliminary tests. When the concrete immediately after removal is not expected to achieve the required strength due to changes in the weather or construction conditions, it is necessary to alter the rate of movement or to take proper measures to achieve adequate strength. In addition, if concrete strength becomes too large, slip resistance may also increase and may exceed the capacity of the jack. Therefore, sufficient attention shall be paid to the rate of movement.

(5) Since the removal of slipforms will be carried out at an early age and it is hard to carry out sufficient curing in slipform method compared with general construction method, the curing method should be fully examined beforehand in order to secure the durability of concrete. Moreover, there is a possibility that wrinkles may arise with movement of slipform. Since this will have an adverse effect not only on appearance but also on durability, when a fault is discovered after movement of slipform the extent of the fault shall be evaluated and measures shall be taken, if necessary.

11.9.3 Movable shores

(1) Movable shores shall be designed to have sufficient strength, safety and required performance.

(2) In cases when loads from movable shores are to be supported by existing structures, safety of such structures shall be confirmed for all load conditions.

(3) All supports on the movable shores shall be regularly inspected after erection and during the period of operation to ensure their performance and safety.

(4) Movement of movable shores shall be carried out accurately and safely.

(5) In cases when movable shores are used, it shall be ensured that assembly and operation will not cause any adverse deformation in concrete.

(6) Adequate camber shall be provided for movable shores, depending on the requirement.

[Commentary] (1) Movable shores referred to here involve movable shores, movable suspended shores, working cars for overhanging erection, movable erection beams, and so on. Movable shores consist of formwork, shoring beams, extending beams, supporting posts transmitting the loads to the existing part or ground, other supports for horizontal or vertical movements, and combined apparatus, if necessary. Movable shores, because of their long service period, shall be designed for stability against the uplift force of wind as well as horizontal loads due to seismic and wind loads.

(2) In general, the structure may face unstable conditions during the movement of the shores. Therefore, care should be taken.

(3) If necessary, loading tests should be conducted after the erection of shores to confirm their safety.

(4) Movable shores should be moved while monitoring the direction, height, and other factors to ensure that the specified positions are obtained accurately and safely.

(5) If the shores are moved before the concrete achieves the specified elastic modulus, the concrete beam may be harmfully deformed. Consideration should be taken to avoid such a situation before the commencement of construction work.

(6) The value of the camber should be determined based on the deflection caused by the weight of concrete and other factors. Especially for prestressed concrete beams, the camber should be determined considering the elastic deformation and creep caused by the prestressing. For information on the placement of prestressed concrete, refer to the Construction: Special Concretes (Chapter 12, Prestressed Concrete) of this Specification.

CHAPTER 12　COLD WEATHER CONCRETING

12.1　General

(1) When the mean daily temperature is likely to drop below 4℃, the provisions for cold weather concreting shall apply.

(2) In cold weather concreting, adequate care shall be taken in regards to transportation to the site, placing, curing, formwork and shoring, etc. to ensure that fresh concrete does not freeze and that it has the required qualities despite being placed in cold weather.

[Commentary]　(1) Under weather conditions when the mean daily temperature is 4˚C or below, the casting of concrete should be carried out according to the provisions for cold weather concreting since the setting and hardening reactions of the concrete are markedly retarded and the concrete may freeze even in the daytime as well as at night or early in the morning. When concrete is exposed to temperatures below freezing before hardening, it easily freezes, expands and suffers from frost damage at early ages. Concrete having suffered from the frost damage at early ages will never be restored to its strength even if followed by adequate curing. Consequently properties as such as durability and water-tightness will be greatly deteriorated. When concrete is exposed to low temperature of about 5˚C or below, the setting and hardening reactions are considerably retarded, even though no freezing occurs. Hence, in structures subjected to an early application of construction loads, problems such as cracks and residual deformation will arise. When the wind blows directly against exposed surface or steel-made shuttering, the temperature fall in the concrete becomes much larger.

The freezing temperature of concrete is about -0.5 to -2.0˚C, although it slightly varies depending upon the water-cement ratio and the type and amount of admixtures. According to temperature data in Japan, freezing of concrete may occur not only in Hokkaido and Tohoku but also in other parts of the country, including Shikoku and Kyushu.

(2) Important actions during cold weather concreting are to prevent the concrete from freezing and to take necessary measures to prevent the quality of concrete from deteriorating even under cold weather. Particularly important considerations when trying to achieve these goals are as follows:

1) Concrete shall be protected from freezing at the early stage of setting and hardening.

2) Concrete shall be given sufficient resistance against freezing and thawing action during the period from completion of curing till the weather gets warm.

3) Sufficient strength shall be provided to withstand possible loads at different stages of construction.

12.2　Materials

(1) It is a standard requirement that portland cement or Type B blended cement should be used.

(2) Neither frozen aggregate nor aggregate containing ice or snow shall be used in that

state.

(3) Chemical admixtures shall be selected so that stable concrete quality can be obtained. Chemical admixtures whose quality is not specified in JIS or JSCE standards, such as freeze-preventing additives and cold-resistant additives, may be used only when their quality and the quality of concrete made by using such additives are fully verified.

(4) If materials are to be heated, only water or aggregate shall be heated; cement shall not be heated directly under any circumstances. Aggregate shall be heated uniformly and by a method that does not cause the aggregate to become dry.

[Commentary] (1) The use of portland cement or Type B blended cement is required as standard for cold weather concreting because the degree of delay in strength development at early ages of concrete is low even when the concrete is cured at low temperature.

In the case of normal portland cement, it is difficult to attain the required curing temperature and initial strength. In the absence of problems associated with cracking due to heat generated by hydration, it is desirable that high-early-strength portland cement be used.

(2) If frozen aggregate or aggregate containing ice or snow is used in that state, concrete mixes become prone to problems such as lower mix temperature and fluctuations in water content such that the concrete quality is adversely affected. When conducting cold weather concreting, therefore, it is desirable that aggregates are stored in facilities where freezing and the intrusion of ice and snow can be prevented.

(3) It is a standard requirement that chemical admixtures to be used for cold weather concreting be selected from those that meet the requirements specified in JIS A 6204, Chemical Admixtures for Concrete, or the JSCE standard. Chemical admixtures to be used shall also ensure stable quality of concrete even at low temperatures. Lowering the water-cement ratio by using an air-entraining high-range water-reducing agent is effective for enhancing freezing resistance. Concrete made using an air-entraining high-range water-reducing agent has a smaller slump at lower temperatures than at higher temperatures after mixing, but the slump of such concrete may become larger over time. It is therefore important to exercise care in using air-entraining high-range water-reducing agents and pay close attention to water-reducing performance at low temperatures, changes in workability, etc.

Besides the chemical admixtures mentioned above, other chemical admixtures that may be used include freeze-preventing and cold-resistant additives, accelerator-type air-entraining water-reducing agents, and accelerators used to accelerate strength development. When using these chemical admixtures, it shall conduct careful studies on their composition, effects, etc., and ascertain their quality. For liquid chemical admixtures, it is also necessary to take measures to prevent them from freezing because segregation occurs when they freeze.

(4) If high-temperature cement is allowed to come into contact with water, the cement may harden quickly, with adverse effects on the concrete. Cement, therefore, shall not be heated. If materials are to be heated, it is desirable that water also be heated because it is simple to perform and the heat capacity of water is large. The temperature of heated water shall be controlled so that cement does not harden quickly. The capacity of the equipment and methods used to heat water needs to be sufficiently large so that the temperature of the materials to be heated is raised uniformly and the target temperature can be obtained for the selected materials

Raising the temperature of aggregate to 65°C or higher may make the aggregate difficult to handle and cause cement to harden quickly. In general, these problems can be prevented by keeping the temperature of water–aggregate mixtures at or below 40°C. The method of using steam to heat aggregate is relatively easy to control.

When materials are heated, the concrete temperature (°C) just after mixing can be calculated by the following equation;

$$T = \frac{c_s(T_a W_a + T_c W_c) + T_m W_m}{c_s(W_a + W_c) + W_m} \qquad \text{(C12.2.1)}$$

where,

W_a, T_a: weight and temperature of aggregate in kg and ºC, respectively,

W_c, T_c: weight and temperature of cement in kg and ºC, respectively,

W_m, T_m: weight and temperature of mixing water in kg and ºC, respectively,

c_s: specific heat of cement and aggregate, assumed to be 0.2.

12.3 Mix Proportions

(1) As a general rule, concrete placed under cold weather should be air-entrained concrete.

(2) In order to prevent initial freeze damage, the water content shall be made as low as possible while maintaining the required workability.

[Commentary] (1) The use of an air-entraining agent or air-entraining water-reducing agent makes it possible to entrain air bubbles so as to reduce the water content needed to attain the required workability and to reduce adverse effects due to the freezing of water in concrete. This is why it is required that air-entrained concrete be used when concrete is to be placed under cold weather. The standard air content is 4% to 7% of the volume of concrete upon completion of mixing. In cases where concrete is likely to be subjected to freeze–thaw cycles over a long period of time – for example, in a cold region – it is good practice to use an air content of about 6% after confirming that the strength requirements are met.

(2) In general, slump increases as concrete temperature rises. When concrete is produced in winter, therefore, the water content tends to be lowered to attain the required slump. Lowering the water content not only reduces the amount of water that can freeze but also reduces bleeding, which tends to increase considerably at lower temperatures, and prevents concrete temperature from falling. The basic rule, therefore, is to reduce the water content as much as possible to the extent that the required workability can be achieved.

12.4 Mixing

(1) Concrete temperature just after mixing shall be such that the required temperature at the time of placing can be obtained, taking into consideration the effect of weather

conditions, time of transportation, etc.

(2) In the case that heated materials are used, the order in which the materials are put into the mixer shall be decided such that cement does not harden quickly.

(3) The concrete temperature just after mixing shall be controlled so as to minimize batch-to-batch variations.

[Commentary] (1) Concrete temperature at completion of placing is lower than that just after mixing in a mixer due to heat loss during transportation and placing. The extent of the concrete temperature drop is usually regarded to be about 15% of the difference in the temperature between the concrete and ambient air for each hour of transportation and placing. It can be calculated by the following equation;

$$T_2 = T_1 - 0.15(T_1 - T_0)t \tag{C12.4.1}$$

where,

T_0 : ambient air temperature, in °C,

T_1 : concrete temperature just after mixing , in °C

T_2 : concrete temperature at completion of placing, in °C

t : time from mixing to completion of placing, in h.

Therefore, the concrete temperature at mixing needs to be the sum of the required placing temperature and heat loss during transportation and placement. In the selection of ready-mixed concrete plants, such factors as temperature drop during transportation, transportation time and the heating capacity of the plant facilities shall be considered.

(2) Cement may harden quickly if high-temperature water comes into contact with cement. A recommended procedure, therefore, is to put heated water and coarse aggregate and then fine aggregate into the mixer and finally, after the temperature of the materials in the mixer becomes 40°C or lower, put cement into the mixer.

(3) If the rate of supply of concrete exceeds the capacity of the heating equipment, it is no longer possible to attain the required as-mixed temperature. When planning for concrete placement, therefore, it shall take material-heating capacity into consideration. It shall also take considerable care with the first batch of the day because low equipment temperature may result in low as-mixed temperature.

12.5 Transportation and Placing

(1) Concrete shall be transported and placed so as to minimize the reduction in temperature of the concrete. The reduction in concrete temperature during transportation and placing shall be prevented by reducing the time elapsed between mixing and placing of concrete as much as possible.

(2) The temperature of concrete at placement shall be in the range of 5 to 20°C considering of the cross-sectional dimensions of the structure and the weather conditions.

(3) It shall be ensured that snow and/or ice are not adhering to the reinforcement, formwork, etc., at placing.

(4) In cases when the surface of concrete at a construction joint is frozen, it shall be appropriately thawed and fresh concrete shall be placed in accordance with provisions given in Chapter 9 of this specification..

(5) Surfaces of freshly-placed concrete shall be protected from exposure to the atmosphere for a long time.

[Commentary] (1) It is necessary to check on the time required for the transportation from the plant to the construction site, for waiting at the construction site, and for the process from unloading to the completion of placement as well as temperature falls during those processes and to take appropriate measures on an as-needed basis. When a concrete pump is used, if the temperature of the conveyance pipe is too low, frozen mortar may stick to the inside surface of the pipe and may result in unexpected trouble. In order to prevent such trouble, it is necessary to carefully perform tasks such as maintaining the temperature of piping, preheating by use of heated water prior to placement and cleaning after the completion of placement. Concreting tasks need to be controlled so that the placement of concrete is not interrupted.

(2) For cold weather concreting the hardening of concrete may be retarded remarkably and the concrete is likely to freeze when ambient air temperature drops rapidly. Therefore, adequate concrete temperatures shall be secured at placing of concrete considering the type and size of the structures, weather conditions, the ambient air temperature and the curing method. For the case of severe weather conditions and a thin concrete member, the minimum temperature at the placement shall be secured at around 10˚C. On the other hand, for a thick concrete member, thermal cracking tends to occur due to the heat generated by cement hydration when the temperature of placing concrete becomes higher. Therefore, the temperature at the placement of concrete may be controlled at 5˚C or slightly higher for thick concrete members. When the temperature is overly high the unit water content normally increases and the hardening process of the concrete is accelerated resulting in decrease of strength at later ages. Furthermore, the concrete surface becomes susceptible to drying and may cause cracking. Hence, considering such factors as the size of structural members and the weather conditions, concrete temperature at placing should be determined to within a range of 5 to 20˚C so that freshly-placed concrete will not be subjected to frost damage at early ages. Since low concrete temperature may cause lateral pressure and bleeding to increase, it shall pay attention to the placing rate, placing height, etc.

(3) It is effective to spray hot water or steam on reinforcement and shuttering to melt the ice and/or snow. However, in the case of lower temperatures precautions should be taken because re-freezing of the water may cause adverse effects. The combined use of such equipment as burners and heaters with propane gas or kerosene is also effective. Melted water and the water used for melting shall be removed prior to the placement of concrete.

In cases where concrete is placed on the ground, if the ground is frozen concrete temperature falls sharply and the frozen ground melts so that the concrete settles. When placing concrete on the ground, therefore, it is necessary to cover the ground with sheeting, etc., and, if necessary, use floodlighting equipment, heater, etc., to prevent the ground from freezing before the placement of concrete and prevent water inflow. In cases when the ground is already frozen concreting shall be carried out after it is properly melted.

(4) To state herein that concrete is frozen does not mean that the concrete is subjected to frost

damage, but just describes the state of concrete.

(5) It is likely that the temperature of the concrete surface may rapidly drop during the elapsed time between the completion of placing and the start of curing. Therefore, the concrete surfaces shall be covered immediately after placing with appropriate materials such as a plastic sheet. It is especially important to protect the concrete surface from the wind.

12.6 Curing

(1) The method and duration of curing shall be decided considering such factors as the ambient air temperature, mix proportions and the type and size of the structures.

(2) During the early age after placement, freshly-placed concrete shall be sufficiently protected from being frozen, particularly from wind. Furthermore, during construction the temperatures of concrete and the surrounding atmosphere shall be periodically measured and the plan for construction may be changed accordingly, if necessary.

(3) The temperature of concrete exposed to severe weather should be maintained at 5°C or higher until the compressive strength reaches the values given in Table 12.6.1, and at 0°C or higher for a further period of two days.

Table 12.6.1 Required compressive strength of concrete at the end of curing under severe weather conditions (N/mm^2)

Exposure condition of structure \ Sections	Thin	Ordinary	Thick
(1) Portions continuously or frequently saturated with water	15	12	10
(2) Portions exposed to ordinary conditions other than (1)	5	5	5

(4) When heating up concrete, rapid drying of concrete shall be avoided and heating shall be conducted uniformly in the concrete.

(5) Concrete shall be cured until it achieves required strength that can withstand possible loads during construction.

(6) After completion of insulation curing or heat curing, concrete shall not be cooled rapidly.

[Commentary] (1) Curing methods for cold weather concreting are classified into insulated curing and heat curing. Regarding insulated curing, the concrete's surroundings are covered with materials of high insulation performance and curing is continued until the required strength develops by utilizing the heat of hydration of the cement itself. Heat curing is conducted for lower ambient air temperatures and thin concrete sections when it is impossible to adequately keep the temperature above the freezing point by insulation alone. It is recommended to combine the heat curing with insulated curing using sheets in order to optimize its effectiveness. Heating apparatuses of various properties are available, and the effectiveness of their capacities, the number of apparatus to be used and the arrangement of the locations need to be examined. Since carbon monoxide may be produced depending on the types of apparatuses used, close attention shall be paid to the safety control. When curing temperature increases, the strength development of concrete is expedited and the duration of curing can be shortened though cracking is likely to occur during the cool-down period after the termination of curing. On the other hand, when the curing temperature decreases, the curing time until the required concrete strength is achieved is prolonged. Therefore, it shall plan the curing method, duration and curing temperature while considering concrete mixture proportions, strength, structural type, thickness of cross-sectional area, ambient air temperature, and so on.

(2) Once concrete suffers frost damage at early ages the strength develops only slightly even if curing is continually performed. Therefore prevention of concrete freezing placed at any location shall be implemented until required strength is obtained. Particular care should be taken for the curing of corners and edges of concrete structures, as these locations are the most difficult to properly insulate and are vulnerable to frost damage at early ages. For cold weather concreting the temperature of both concrete and its surrounding atmospheric air should always be monitored so as to avoid any problems related to the concrete strength development. When the construction conditions differ from the plans such that the concrete may be adversely affected, necessary countermeasures such as increased temperatures of concrete materials, insulated curing and heat curing shall be taken.

Since wind expedites moisture evaporation from the concrete surface and lowers the concrete temperature at and near the surface, the surface concrete shall be protected from the cold wind immediately after placing.

(3) It shall determine curing temperature considering mixture proportions, ambient air temperature, structuralsize and dimensions, curing methods and their periods and temperature control systems. The lowest curing temperature with regard to the protection from the frost damage at early ages is 5˚C. However, for severe cold weather or a thin concrete member it may be increased to 10˚C. Rapid cooling after curing shall be avoided for concrete with a thick cross section since the temperature sometimes increases up to 20˚C due to the heat of hydration. In general appropriate curing methods are required so as not to increase the temperature of the surface concrete higher than 20˚C.

Since concrete suffers from frost damage depending on factors such as strength, moisture content and the amount, size and distribution of entrained air, the required performance to withstand frost damage cannot be specified by strength alone. However, it is reported that concrete with a compressive strength of not less than 4 N/mm^2 rarely suffers from frost damage after several freezing and thawing cycles. However, in the case of wet concrete continuously subjected to severe weather conditions, the curing shall be continued until further strength development is achieved. Concrete strength necessary to withstand frost damage at the end of curing depends on factors such as weather conditions, size of members, exposure conditions, etc. Standard concrete strength is provided in Table 12.6.1 according to the classification prescribed therein. These strength values are specified to ensure that the post-curing concrete can resist the freezing and thawing actions. For the prevention of concrete under rapid cooling, it has been concluded that the concrete temperature should be kept above 0˚C for the following two consecutive days after the end of curing. When the curing practice prescribed herein is carried out, resistance against the long-term weather actions is generally considered to be satisfactory owing to the proper development of the strength.

In principle, curing period should be determined by testing since the types of cement, mixture proportions and curing temperature affect the curing period necessary to achieve the strength specified in Table 12.6.1. Table C 12.6.1 shows general curing criteria at 5 and 10˚C. In order to maintain wet conditions, the periods specified in Section 8.2 for wet curing shall be satisfied as well.

Table C 12.6.1 Criteria for curing periods to achieve specified compressive strength

Exposure condition of surface \ Section / Types of cement / Curing Temp.		Ordinary portland	High-early strength portland	Blended cement (type B)
(1) Portions continuously or frequently saturated with water	5˚C	9days	5days	12 days
	10 ˚C	7days	4days	9days
(2) Portions exposed to ordinary conditions other than (1)	5˚C	4days	3days	5days
	10˚C	3days	2days	4days

Note: Applicable to W/C＝0.55. Need to be modified for different W/Cs

(4) When heat is provided to concrete, it shall keep the concrete at the appropriate temperature and provide the concrete with sufficient moisture so as to prevent the concrete from drying. When concrete is heated, evaporation of water from the concrete is accelerated. It is therefore necessary to prevent the concrete from drying by taking appropriate measures such as watering. In this sense, the method of heating concrete by use of steam is advantageous, but water needs to be supplied because drying can result even if the steam method is used.

In heat supply curing, it is important to avoid local heating since it may increase the possibility of cracking due to temperature gradients generated within the concrete.

(5) Concrete placed in cold weather is exposed to low temperatures after insulated or heat curing, and the successive strength development is slow. Therefore, except for cases when the time of load application is considerably late, it is recommended that the curing be continued after the strength of concrete reaches the requirement for resistance against frost damage at early ages until it can sustain an anticipated load.

(6) Cracking may occur at the concrete surface when concrete of relatively higher temperature after insulated or heat curing is quickly exposed to the cold air. The concrete surface shall be protected by an appropriate method so as to be gradually cooled down. In cases when concrete is vulnerable to freezing under cold air after the end of curing, watering just before the termination of curing shall not be done.

12.7 Formwork and Shoring

(1) The formwork should have good heat retention.

(2) Lateral pressure acting on formwork shall be determined, taking concrete temperature into consideration, with reference to Section 11.2.4.

(3) Shoring shall be placed firmly on the ground without any deformation on account of frost heaving of the ground or thawing of the frozen ground.

(4) Removal of formwork shall be carried out in a manner that the temperature of concrete does not drop rapidly.

[Commentary] (1) Compared with steel forms, wooden forms have lower thermal conductivity and therefore provide better heat retention. If the concrete section is thick it is efficient to take advantage of the effect of temperature rise due to the heat of hydration of cement. Even when the concrete section is thin it may be possible to provide insulation without a heat supply by the combined use of foamed resin and shuttering. When steel forms are used, it is necessary to pay sufficient attention to the insulation since the steel is readily influenced by rapid change in ambient air temperature.

(2) As concrete temperature falls, lateral pressure acting on formwork tends to increase. It is necessary, therefore, to determine lateral pressure values to be used in formwork design taking this tendency into consideration, with reference to Section 11.2.4.

(3) When shoring is directly based on the ground, the proper location, configuration or dimensions of the structure may not be secured due to the frost heaving or thawing of the ground; in some cases the shoring may collapse. Therefore, when the above-mentioned is predicted, it shall prevent frost heaving or to avoid the adverse effect of displacement caused by frost heaving or thawing by adopting measures such as a pile foundation.

(4) The inner temperature of a structure with a thick section rises considerably due to the heat of hydration. Temperature differences may develop when the concrete is rapidly cooled down after the shuttering removal and cracking may occur. Therefore, it is desirable to remove shuttering after minimizing the temperature differences by adjusting the temperature within the enclosures or to retain the shuttering until the concrete surface will not be subjected to rapid cooling even after the specified strength for the removal has developed. For example the maximum allowance on a temperature drop within 24 hours after the end of curing is 22 to 28˚C for a thin section and 17˚C for a thick section.

CHAPTER 13 HOT WEATHER CONCRETING

13.1 General

(1) When the mean daily temperature is likely to exceed 25°C, the provisions of hot-weather concreting should apply.

(2) In hot-weather concreting, appropriate measures shall be adopted during transportation within the site, placing, and curing, so that the quality of concrete is not impaired due to high temperatures.

[Commentary] (1) It is quite difficult to accurately define in which period of the year hot-weather concreting should be applied. It is desirable, however, to prepare for hot-weather concreting when the mean daily temperature exceeds 25˚C because the characteristics of hot-weather concreting become remarkable if the temperature at placing time exceeds 30˚C. Measures to be taken in connection with hot weather concreting should be implemented well in advance.

(2) High (atmospheric) temperatures result in high concrete temperature and large slump loss during transportation as well as loss of entrained air. High temperatures also increase the risk of cold joint development, cracking due to the rapid evaporation of water on concrete surface, thermal cracking, etc. Therefore, in order to minimize the concrete temperature during and after placing, special care should be given to handling materials, mixing, transporting, placing, and curing concrete.

It is also desirable that a construction plan be drawn up and construction work be controlled appropriately in due consideration of the fact that in a higher-than-normal-temperature environment, work efficiency tends to decline and workers are susceptible to heat stroke.

13.2 Materials

(1) When the required concrete temperature cannot be attained, a method for lowering the temperature of materials shall be determined and its effectiveness verified in advance.

(2) It is a standard requirement that air-entraining water-reducing agents and super-plasticizers used should be retarder type admixtures conforming to JIS A 6204. It is also a standard requirement that air-entraining high-range water-reducing agents used should conform to JIS A 6204.

[Commentary] (1) The temperature of cement upon delivery may be quite high temperature depending on the shipping conditions from the factory. Although the temperature of the cement does not severely affect the temperature of the concrete (in general, ±1ºC in concrete temperature), the use of high temperature cement under hot weather conditions is unfavorable as it raises the temperature of concrete.

The temperature of the aggregates affect the temperature of concrete greatly (in general, ±2ºC change in aggregate temperature corresponds to ±1ºC in concrete temperature); therefore, the use of aggregates exposed to sunlight for an extended time period may produce a concrete temperature over 40ºC. This will cause an increase in unit water content, an increased rate of slump loss during transporting and an increased rate of setting after concrete placement. Thus, the aggregate should be kept away from direct sunlight using adequate facilities or kept in an appropriate condition by watering them. In general, the purpose of the method of watering over coarse aggregate is to lower the temperature by means of water evaporation. The method can be made even more effective by directly cooling coarse aggregate by use of cold water. The method of lowering the temperature of aggregate by use of liquid nitrogen is used in some cases. Because of its latent hydraulic property, ground granulated blast furnace slag may consolidate in aggregate storage facilities or storage bins during periods when daily mean temperature is higher than 20°C, thereby making it difficult to remove from the storage facilities or storage bins. During such periods, it is important to avoid long-term storage.

In order to reduce the temperature of mixed concrete, it is desirable that the mixing water be as cool as possible (in general, ±4ºC change in water temperature corresponds to ±1ºCin concrete temperature). It is necessary for water-storage tanks and pipelines to keep the water temperature low by means of adequate methods such as shading, painting storage silos white, and so on. The use of ice is a very effective means of reducing the concrete temperature though it is generally not easy to possess ice-crushing facilities.

(2) When water-reducing agents or air-entraining water-reducing agents are used, retarder-type agents instead of standard types should be used. If retarder-type admixtures, etc., are used with the aim of preventing cold joints, it is necessary to carefully consider how to use them and determine the quantity to be used appropriately. Air-entraining high-range water-reducing agents substantially reduce the water content and the cement content even in the case of hot weather concreting. Depending on the type of admixtures, however, the amount of decrease in slump over time may be large at high temperatures. Regardless of the type of chemical admixture to be used, therefore, it is important to select chemical admixtures that make it possible to maintain the required minimum slump until the planned time of completion of placement.

Super-plasticized concrete dramatically improves the placeability and quality of concrete. In general, however, the slump of super-plasticized concrete decreases considerably over time, and this tendency may become particularly pronounced under hot weather. It is therefore desirable that either retarder type super-plasticizers are used for hot weather concreting or retarder-type water-reducing agents, air-entraining water-reducing agents or other similar admixtures be used for base concrete.

13.3 Mix Proportions

In the mix design of hot weather concreting, appropriate measures shall be taken so that the water content and the cement content do not become too high to the extent that the required strength and workability can be attained.

[Commentary] There is a certain relationship between the water content needed to attain the required workability and concrete temperature just after mixing. In general, the water content tends to increase by 2% to 5% for every 10°C of temperature rise. In many cases, as concrete temperature rises the amount of change in slump and air content also increases. Consequently, when slump is adjusted by using such methods as adjusting the surface moisture content of aggregate without taking control measures associated with hot weather concreting, concrete with higher water content and lower compressive strength than that of low temperature seasons might be placed. When the water-cement ratio is kept constant and the cement content is increased according to the increase in the water content with the aim of attaining the required compressive strength, conditions that are disadvantageous in preventing cracking due to the hydration of cement result. It is necessary, therefore, to take appropriate measures (after conducting prior studies) to prevent the water content and the cement content from becoming excessively high to the extent that the required strength and workability can be obtained. To be more specific, it is necessary to determine the amount of decrease in slump due to temperature rise and changes in slump over time and check whether the required minimum slump can be attained until the completion of placement. If the water content needs to be increased substantially, it is necessary to take appropriate measures such as increasing the usage of chemical admixtures, switching from air-entraining agents to air-entraining high-range water-reducing agents or adding super-plasticizers.

13.4 Mixing

Concrete temperature just after mixing shall be such that the required temperature at the time of placing can be obtained while taking into consideration the effect of weather conditions, time of transportation, etc.

[Commentary] Lowering the temperature of concrete materials is a good way to lower the concrete temperature just after mixing. When, however, ice is used as part of mixing water, it is necessary to ascertain in advance that ice melts completely during mixing. There are also other methods such as the method of injecting liquid nitrogen into the mixer to lower concrete temperature directly. The temperature of mixers installed in a poorly-ventilated plant with high indoor temperature due to solar radiation and heat generated by machinery might also be affected by heat supplied by premixed concrete. Such mixers need to be cooled on an as-needed basis.

In order to deduce the temperature of fresh concrete from the temperatures of the materials with which the concrete is made, the equation shown in Eq. C.12.2.1 may be applied. However, the equation does not consider the effect of the heat of hydration and the frictional heat during mixing, so that the actual concrete temperature under hot weather conditions may be about 1ºC higher than the calculated temperature.

The rise in concrete temperature during transportation is generally 2 to 4ºC, and 1 to 5ºC for pre-cooled concrete. When calculating the temperature increase during the period between the finish of mixing and the finish of transportation or placing concrete, Eq. C.13.4.1 may be applicable.

$$T_2 = T_1 + 0.15(T_0 - T_1)t \qquad \text{C13.4.1}$$

where,

T_0 : ambient air temperature, in degree C.

T_1 : concrete temperature just after mixing , in degree C.

T_2 : concreter temperature at completion of placing, in degree C.

t : time from mixing to completion of placing, in hours.

13.5 Transportation

Transportation of concrete shall be carried out using means and methods so that the concrete does not dry or get heated during transportation.

[Commentary] Concrete shall be transported using means and methods that minimize concrete temperature rise and drying of concrete. To do that, it is good practice to transport and place concrete as quickly as possible. For ready-mixed concrete, it is required that the process from mixing to unloading be completed in 1.5 hours. Section 13.6, however, requires as a general rule that the placement of hot weather concreting be completed in 1.5 hours. At the construction planning stage, therefore, it is necessary to check whether construction work needs to be carried out during a hot weather concreting period and, if concreting during such a period is expected, determine the plant and transportation routes to be used, estimate transportation time and take appropriate measures, through consultation with the plant, so that transportation time can be made as short as possible. It is also important to plan and control vehicle operation so that truck agitators will not be kept waiting for a long time under hot weather. In connection with on-site transportation, it is necessary to study and find, in advance, methods for transporting and placing concrete as quickly as possible. Care shall be taken, however, so that a higher transportation speed does not increase pipe pressure such that pumping becomes difficult or there is a delay in compaction, finishing and curing. If concrete is transported by pumping, it is important, for example, to select locations so that pipes are not exposed directly to sunlight, to prevent pipe temperature from rising by covering the pipes with wet cloth and to avoid interruption in order to prevent clogging due to a decrease in slump.

13.6 Placing

(1) In areas where water absorption is expected, such as on the ground or in formwork, the areas shall be saturated with water prior to placing. Furthermore, when the temperature of formwork or reinforcement is anticipated to rise substantially due to direct exposure to sunlight, appropriate measures such as water sprinkling or covering shall be taken.

(2) Concrete placing shall be completed as promptly as possible and the elapsed time from start of mixing to completion of placing should, in general, not exceed 1 and a half (1.5) hours.

(3) Temperature of concrete at the time of placing shall not exceed 35°C. Furthermore, during construction, the temperatures of concrete and surrounding atmosphere shall be periodically measured and the plan for construction may be changedaccordingly, if necessary.

[Commentary] (1) When placing concrete in high temperature conditions, areas such as the ground and formwork may easily dry out; this drying process affects the flowability of concrete by absorbing concrete water. Therefore, it is necessary to saturate these portions with water before placing concrete. The temperature of the formwork and reinforcing bars may rise substantially under direct exposure to sunlight. This results in quick-setting of concrete and adversely affects the quality of hardened concrete; therefore, covering or sprinkling should be carried out to keep the formwork and reinforcing bars at a low temperature. It is necessary, however, to avoid excessive watering so that water is not left in the formwork and to observe the condition in the formwork and shall remove water left in the formwork before placing concrete.

(2) The slump of hot weather concreting is highly susceptible to decreases over time. Consequently, concrete that has been left unplaced after being mixed may become difficult to place. If, therefore, construction during a period when outdoor air temperature is higher than 25°C is expected, it is important to check on the time-dependent changeability of concrete in advance so that the required minimum slump for placement defined in Section 4 can be met. In general, the amount of decrease in slump is small for 1.5 hours after the completion of mixing, and concrete can be placed without any problem during that period. Since, however, such changes in quality tend to increase as air temperature rises, it is desirable that concrete be placed continuously and as quickly as possible so as not to cause problems such as cold joints. Although Table 7.4.1 shows that the allowable placement interval at an outside air temperature exceeding 25°C is 2.0 hours or less, it is desirable in the case of hot-weather concrete that a shorter placement interval be specified in order to prevent the occurrence of cold joints.

(3) The temperature at concrete placing time shall be as low as possible in order to prevent adverse effects. The upper limit of concrete temperature at placing time has been determined to be lower than 35°C based on the following reasons. 1) When temperature is lower than 30°C, the adverse effect of temperature on concrete quality is relatively small; under hot weather conditions, it has been observed that the temperature of ready-mixed concrete at the point of discharge is between 30 to 33°C and this temperature rises approximately 2°C during transportation of concrete to the site. 2) With currently-available facilities, it is difficult for concrete plants to cool down concrete materials before mixing. 3) The required concrete quality can be assured if the concrete temperature is kept between 30 to 35°C by using a retarding agent or by rapid construction. When the development of thermal cracks is anticipated, verification of thermal cracking shall be carried out and concrete placing temperature determined.

In hot weather concreting, temperatures of materials and concrete should be measured. If the predicted placing temperature or actual measured concrete temperature exceed the planned temperature, the construction plan shall be modified and appropriate construction methods selected based on measured temperatures of materials and concrete.

13.7 Curing

Curing shall be started immediately after placing concrete, so that the concrete surface can be protected from drying. Appropriate measures shall be taken to protect the concrete against direct sunlight and wind so that cracks due to rapid drying can be avoided.

[Commentary] The surface of concrete placed under hot weather dries up quickly when exposed directly to sunlight or wind so that the concrete becomes difficult to finish and the potential for crack formation increases. Therefore, the placed concrete should be cured as soon as possible so that the surface does not dry out. Moist curing period shall be decided in accordance with the provision stipulated in Table 8.2.1. In the case that wooden formwork is used, they shall be kept in a saturated condition during the curing period since this formwork is likely to dry out.

Moreover, the exposed concrete surface should also be kept in saturated conditions during the curing period after formwork is removed. Especially in the case of high temperature or low humidity, cracking is likely to occur due to rapid drying. Therefore, measures such as sprinkling or covering should be conducted in order to prevent the surface from drying. For structures with wide surface area like slabs, where sprinkling or covering is difficult, membrane curing may be applied in accordance with regulations stipulated in Section 8. The membrane curing agent should be of the type which absorbs only little thermal energy from direct sunlight.

If cracking due to the rapid drying of the surface is recognized while concrete has not hardened after placing, re-vibrating or tamping should be conducted to eliminate cracking.

CHAPTER 14 MASS CONCRETE

14.1 General

(1) In cases where thermal stress due to heat generated by the hydration of cement is problematic, the concrete is regarded as mass concrete and measures to be taken shall be carefully determined.

(2) For mass concrete, verification concerning thermal stress and thermal cracking due to heat generated by the hydration of cement shall be performed in advance in accordance with the Design: General Requirements (Chapter 12, Verification Related to Initial Cracking) of this Specification.

(3) It shall be ascertained prior to the commencement of construction that the conditions assumed in the Design section of this Specification agree with the actual construction conditions. If the conditions assumed in the Design section do not agree with the actual construction conditions, verification concerning thermal stress and thermal cracking due to heat generated by the hydration of cement shall be performed prior to the commencement of construction on the basis of the actual construction conditions.

(4) Prior to mass concrete construction, appropriate plans for concrete temperature control, transportation, placement, curing, etc., shall be made so that the effects of thermal crack control measures determined in advance can be achieved.

[Commentary] (1)Together with recent developments in advanced construction methods, there have been increasing demands for the construction of large-sized concrete structures. It has been frequently observed that thermal stress, which develops due to temperature variation during cement hydration process, causes thermal cracking of large-sized concrete structure. These problems were once considered peculiar to concrete dams or concrete structures with especially large-sized members. However, harmful cracks are often recognized even in relatively small-sized structures, depending on cement materials used and construction conditions. Therefore, concrete structures which face above-mentioned problem of thermal stress due to heat of hydration shall be dealt with as mass concrete and, consequently, special considerations are necessary.

Though it cannot be absolutely determined due to the fluctuation of the type of structure, materials used and construction conditions, the size of the member regarded as mass concrete is roughly considered to be not less than 80-100cm in thickness for wide slabs, or to be not less than 50cm for walls restrained at the lower end. For concrete with rich mix proportion as in the case of prestressed concrete structures, thin members may also be included in the scope of this chapter, depending on the restraining conditions. Dam concrete is not stipulated in this chapter but in the Standard Specifications: Dam Concrete.

(2) The crack controlling measures, such as crack prevention or restriction of crack position and width, should be taken at each stage of design, selection of materials, determination of mix proportions and construction. The method for evaluating the effectiveness of each crack controlling countermeasure, by quantitatively estimating the influence of these measures on the development of thermal crack at various stages, has been almost established from recent researches The verification for thermal crack in the construction of mass concrete should be carried out in advance by following Chapter 4, which stipulates the verification methods for thermal stress and thermal crack caused by

heat of hydration. In mass concrete, where large amount of concrete is used continuously, in order to satisfy the desired concrete quality, it is especially important that all processes of production, supply, transportation and compaction of concrete are controlled completely based on the construction plans.

During the construction of mass concrete structures, concrete may be delivered form several ready-mixed concrete plants. As a general rule, cement and chemical admixture produced by the same manufacturer, coarse and fine aggregates produced from the same region should be used when possible. When materials differ for each ready mixed-concrete plant, the trial mixing should be carried out in advance in order to confirm the safeness of mixing before construction. When using chemical admixture, great attention is required because incompatibility between chemical admixtures may be observed.

(3) Chapter 12 of the Design section of this Specification requires as a general rule that verification be performed concerning initial cracking. The same chapter also requires that a limit for crack width be set if cracking is to be prevented or permitted. Although the Design section assumes construction conditions for the purposes of design studies, actual construction conditions such as weather conditions (e.g., air temperature, wind) may change considerably. Prior to the commencement of construction, therefore, it must be checked whether the pre-assumed conditions agree with the actual construction conditions. If the pre-assumed conditions have turned out to differ from the actual construction conditions and the study results based on the Design section need to be modified, studies must be conducted again before starting construction by the method specified in the Design section of this Specification on the basis of the actual construction conditions.

(4) In controlling thermal cracking during mass concrete construction, various measures for preventing cracking, controlling the position, interval and width of cracks shall be carried out at construction stage in order to satisfy the required function and performance of the structure.

In order to control thermal cracking, not only the selection of cement type, materials, admixtures, mix proportions as well as the adjustment of concrete placing temperature, but also the selection of formwork dimension, lift height, joint position, placing time interval, material and fabrication of formwork as well as curing method should be considered thoroughly from production to construction stages. Depending on the structure type, controlling the crack position by crack-inducing joints may be effective in some cases. Regarding these measures in making concrete and construction for controlling and preventing cracking, construction of mass concrete should, in general, be carried out in accordance with Standard Specification: Design in which the requirements on material, mix proportion, production and construction method are described in details based on prior examination related to thermal cracking.

Other methods for controlling or preventing thermal cracking such as using pipe cooling for dam concrete or large bridge pier, using expansive concrete or arranging reinforcing bars for crack control can be adopted. However, since these methods lead to cost rise, their technical and economical efficiencies should be valuated.

14.2 Materials

(1) As a general rule, cement and admixtures used in mass concrete should be ones specified in the design.

(2) If cement or admixtures mentioned in Item (1) are to be used, verification concerning thermal stress and thermal cracking due to heat generated by the hydration of cement shall be performed.

[Commentary] As a general rule, cement and admixtures used in mass concrete must be selected after verification concerning thermal stress and thermal cracking due to heat generated by the hydration of cement.

This Specification requires that cement be selected on the basis of verification concerning thermal stress and thermal cracking. Since, however, actual construction conditions cannot always be predicted at the design stage, there may be cases where prior to the commencement of construction, cement and other materials are reconsidered and selected again through similar verification.

In the case of mass concrete, the quality of cement greatly affects the strength of concrete, heat generated by hydration, etc. When selecting cement to be used in mass concrete, therefore, it is necessary to thoroughly study the characteristics of different types of cement and select cement appropriately so that concrete of the required quality can be obtained. In general, it is desirable that low-heat cement such as moderate-heat portland cement, low-heat portland cement, blast furnace slag cement and fly ash cement be used. When selecting cement, it should be kept in mind that the generation of heat by blast furnace slag cement tends to be accelerated as temperature rises.

In cases where blended cement made by mixing portland cement with relatively large quantities of admixtures such as ground granulated blast-furnace slag and fly ash is used, the quality and properties of such blended cement often vary considerably among manufacturers. When using such cement, therefore, it is necessary to fully identify its quality and properties in advance by, for example, conducting tests. In general, in the case of cement whose heat generation is suppressed, the degree of long-term strength increase is relatively high, compared with normal portland cement. When using such cement, therefore, it is good practice to check the stresses that occur in the member during the period until the specified strength is reached and use a relatively old age (around 91 days) as a reference age at which the specified strength is determined.

Admixtures commonly used for mass concrete include mineral admixtures such as fly ash and ground granulated blast-furnace slag and chemical admixtures such as air-entraining agents, water-reducing agents, air-entraining water-reducing agents and air-entraining high-range water-reducing agents. The use of expansive admixtures has been increased in recent projects. The use of high-quality fly ash brings about a number of beneficial effects such as improving the workability of concrete, reducing the water content, increasing old-age strength development and reducing temperature rise due to the heat of hydration of concrete. Fly ash, therefore, is advantageous for the purpose of controlling the occurrence of cracking due to thermal stress. Furthermore, appropriate use of fine-grained blast-furnace slag powder makes it possible not only to increase the long-term strength of concrete but also to slow down the generation of heat due to hydration.

Appropriate use of air-entraining agents, water-reducing agents, air-entraining water-reducing agents or air-entraining high-range water-reducing agents makes it possible to improve the workability of concrete, reduce the water content and thereby reduce the cement content. By using these chemical admixtures, the amount of rise in concrete temperature can be reduced.

If a large volume of mass concrete is to be placed, it is recommended that retarder type water-reducing agents or air-entraining water-reducing agents be used to lower the rate of generation of the heat of hydration and prevent the occurrence of cold joints. In such cases, however, setting may be retarded considerably depending on such factors as the combination with mineral admixtures to be used and air temperature during construction. It is therefore important to check in advance on the degree of retardation of concrete setting and the influence on strength development characteristics by means of tests, etc.

14.3 Mix Proportions

(1) As a basic rule, the cement content of mass concrete should be as specified at the design stage.

(2) If it is not possible to achieve the required workability, strength, durability, watertightness, cracking resistance or steel protection performance with the cement content specified at the design stage or if the type of cement or admixture to be used has been changed, verification concerning thermal stress and thermal cracking shall be conducted again, and the cement content determined accordingly.

[Commentary] The rate of heat generation of concrete is roughly proportional to the cement content, and, in general, concrete temperature increases or decreases by about 1°C for every 10 kg/m^3 of increase in the cement content. A substantial increase in the cement content determined as a result of verification concerning thermal stress and thermal cracking must be avoided. If, however, it is difficult to achieve the required workability, strength, durability, watertightness, cracking resistance or steel protection performance with the cement content specified at the design stage, it may be necessary to reconsider the cement content. If the type of cement or admixture to be used is changed, it is necessary to perform verification concerning thermal stress and thermal cracking again and determine a cement content (or a binder content if non-cement binder is used) that does not cause any problem associated with thermal cracking.

14.4 Production

Mass concrete shall be produced, taking into consideration such factors as concrete transportation distance, transportation methods, placing methods, weather conditions and other conditions, so that the placing temperature does not exceed a specified limit.

[Commentary] Lowering the concrete placing temperature is effective in thermal stress and thermal cracking because doing so reduces the difference between the temperature in the member and the temperature outside the member and lowers the highest temperature in the member. One method of lowering the placing temperature is precooling, in which ingredients such as water and aggregate are cooled in advance when concrete is produced. The effect of the temperature of each material on the as-mixed temperature of concrete is as follows: a change of ±2°C in aggregate temperature resulting in a change of ±1°C in as-mixed temperature, a change of ±4°C in water temperature resulting in a change of ±1°C, and a change of ±8°C in cement temperature resulting in a change of ±1°C.

Precooling methods include a method that uses cold water, a method that uses flake ice or small ice fragments independently or in combination as part of mixing water, a method that uses cooled aggregate and a method that cools materials or concrete by using liquid nitrogen. If small ice fragments are used as part of mixing water, it must be ascertained before the placement of concrete that the ice has completely melted. If liquid nitrogen is used for cooling, care needs to be taken to ensure safety, particularly in the control of the concentration of oxygen at and around the place where liquid nitrogen is used.

Even if the temperature of concrete at the time of production is lowered, concrete temperature may rise during transportation so that the placing temperature becomes higher than expected at the planning stage. It is important, therefore, to determine the temperature of concrete at the time of production, taking into account likely amount of rise in concrete temperature due to such factors as transportation distance, transportation methods and weather conditions.

14.5 Construction

14.5.1 Partitioning into blocks, lift height and joints

In placing mass concrete, size of blocks, height of lift, the location and structure of joints, and interval between successive castings, should be decided based on the results of thermal verification.

[Commentary] In mass concrete, large volume of concrete is placed in many blocks which are separated by joins. The location and structural details of joints as well as the size of blocks (dimensions of horizontal and vertical partitioning) need to be determined with comprehensive consideration of heat dissipation and restraining conditions, as well as various construction conditions, one of which is concrete placing capacity each time. When mass concrete is placed into blocks partitioned vertically or into lifts divided horizontally, stresses will develop with the variation of temperature in concrete structure because the newly-placed concrete is restrained by the previously-placed one.

These stresses grow larger when the differences in the effective Young's modulus as well as in the temperature between new and old concretes increase. Therefore, concrete placing time interval should be kept as short as possible. However, where concrete is placed lift by lift on such bodies as rock beds which provide significant restraint, too short placing intervals may result in high temperature in mass concrete and, consequently, high potential of crack development. As a result, the placing interval at the construction site shall be determined with due consideration, together with other measures, to deal with the development of thermal stress.

14.5.2 Placing

The placing temperature of mass concrete shall not exceed the planned temperature. During placing process, the temperature of concrete shall be measured, The thermal history of placed concrete shall be monitored, and the plan for construction may be changed accordingly, if necessary.

[Commentary] The verification method for placing temperature of mass concrete is included in the “verification for thermal crack”. One must keep in mind that the assumed conditions at design stage of thermal characteristic of materials and environmental conditions may differ from those at construction stage. When actual placing temperature exceeds the assumed placing temperature of mass concrete, the prevention of thermal cracking as well as the control of crack width may become difficult. As a result, the desired function and performance may not be satisfied. Therefore, concrete temperature and temperature rise of placed concrete should be confirmed at the time of construction. The construction plan should be modified if the actual condition is too much different from the assumed one. Especially, when placing concrete under the scorching sun, special cares on the management of materials, concrete production, transportation, placing, etc. shall be applied to make sure that the actual placing temperature will not exceed the planned one. Since the exothermic properties of portland blast furnace slag cement is accelerated if temperature is high, the placing temperature should be as low as possible in order to control the temperature rise.

14.5.3 Curing

In curing mass concrete, appropriate care shall be taken to control concrete temperature, so that thermal cracks can be controlled as per plan.

[Commentary] In the curing of mass concrete, adequate measures for thermal crack control based on the results of the verification and curing methods specified in the construction plans need to be taken additionally with the conditions required for the curing of normal concrete. Specifically, it is necessary to apply appropriate measures to cool down the concrete temperature as close to the ambient air temperature as possible, to keep the temperature difference between the interior and exterior of the concrete member as low as possible and to maintain the temperature drop rate of the whole member at acceptable level . If necessary, such measures as thermal insulation and protection of the concrete surface with adiabatic materials (styrol or sheet) should be implemented. The sprinkle of more water that necessary may lead to the formation of cracking by the decrease in the surface temperature of conceret..

The pipe cooling is used in order to reduce maximum internal temperature of young concrete and overall temperature of members to average temperature of concrete structure. Pipe cooling is carried out by pumping chilled water or natural river water through the pipes previously placed in concrete. In pipe cooling practice, thin-walled steel pipes of external diameter of approximately 25mm are usually used. Factors such as the space between pipes, water flow, and length of a coil as well as cooling-off duration should be determined to obtain the required effect. The temperature of cooling water also should be determined by considering placing time intervals, construction period, thickness of members, etc. If the temperature of cooling water is too low, temperature difference within a member or between members may cause crack initiation. Therefore, sufficient caution needs to be taken. Temperature difference between the circumference of cooling pipe and cooling water should be maintained less than 20°C. In pipe cooling practice, air can be used in stead of water.

Mass concrete using moderate-heat portland cement, low-heat portland cement and blast furnace slag cement requires sufficient curing with thermal insulation to obtain sufficient strength.

14.5.4 Formwork

The material and structure of formwork for mass concrete, and the timing of formwork removal shall be appropriately decided so that the thermal cracking can be effectively controlled.

[Commentary] Concerning formworks for mass concrete, the material and structural details are recommended to be selected with consideration to the control of concrete temperature for the purpose of thermal crack control.

To minimize the temperature rise, formworks which have high heat dissipation may be used. However, in the case of mass concrete, control range of temperature rise is restricted and ambient temperature may drop drastically after placing, the use of exoteric metal formwork may cause large temperature differences between internal part of concrete and its surface. Therefore, sometimes the use of insulated formworks is effective. When insulated formworks are used, the retaining duration is prolonged, in principle, compared with the conventional formworks, and the thermal insulation of the concrete surface is recommended to be continued after formwork removal by such measures as covering the concrete with plastic sheets so as to protect the concrete surface from rapid cooling.

14.5.5 Crack-inducing joints

In cases when crack-inducing joints are provided to control the position of thermal cracks, the structural details and positions of these joints shall be determined as specified in the design documents.

[Commentary] In general, it is difficult to control the thermal cracking occurring in massive wall-type structures by taking measures from material or mix design aspect. In such cases, there is method in which reduced sections are provided at a certain spacing intervals on the longitudinal direction of the structure, to induce cracking at these sections, to prevent cracking at other portions, and to easily take care of the cracked sections. Details should be in accordance with Section 9.9 and the Design section 14.8 Crack-inducing joints.

CHAPTER 15 QUALITY CONTROL

15.1 General

(1) For the execution of concreting work, quality control shall be performed appropriately in all aspects of the work including concrete materials, reinforcing materials, equipment, concrete production methods, construction methods and the concrete structure until completion in order to construct a concrete structure with the required quality economically.

(2) Quality control is a series of voluntary activities of the Contractor, and the Contractor shall develop plans for methods that the Contractor can expect to be effective and carry them out appropriately.

(3) Records of quality control shall be kept for a certain period of time even after the delivery of the constructed structure so that they can be used for the quality assurance of the constructed structure and quality control for future construction work.

[Commentary] (1) Progress control, quality control, cost control and safety control are important in concreting work. Of these, quality control is a series of effective and organized activities performed at all stages of construction work in order to economically construct a concrete structure that matches its purpose of use. Quality control needs to be performed appropriately in all aspects of the work including concrete materials, reinforcing materials, equipment, concrete production methods, construction methods and the concrete structure until completion. Quality control in production and construction may be referred to as production control and construction control, respectively.

(2) A concrete structure can be made to rationally meet the owner's requirements if constructed under appropriate quality control. Because the owner receives a structure that has been constructed under the quality control of the Contractor and has passed inspection, inspection may be simplified by performing appropriate quality control.

Quality control should be performed so that the quality should be stayed in a stable condition. Warning in all stage of construction work should be found as soon as possible and make an action for it. It is important to establish the system contains PDCA cycle (Plan-Do-Check-Action). When drawing up a quality control plan, it is important to identify a person responsible for each process and construct an organizational system for quickly responding to an abnormality.

Since quality control is a series of voluntary activities performed by the Contractor, the Contractor can perform only activities that the Contractor deems necessary. If the Contractor's inspection covers all items and frequency of the inspection conducted by the owner, the measurements conducted by the Contractor are deemed to be equivalent to the measurements conducted by the owner. It is possible, therefore, to make passing the owner's inspection easier by checking, in advance, the design drawings and specifications and inspection criteria (inspection plan) shown by the owner and reflect them in the quality control plan. Hence, if tests are conducted as part of the quality control activities associated with production and construction, it is good practice to use methods that permit objective evaluation and that are easy to understand to the owner and methods specified for inspection purposes. For general tests, refer to the test methods specified in JIS, JSCE or other standards. It is difficult, however, to make a comprehensive judgment solely on the basis of quantifiable data such as measurement results obtained by means of tests and inspection devices specified in JIS or other standards. It is also important, therefore, to deploy experienced specialists and make judgments based on visual inspections.

(3) Quality control records are documents certifying that the required quality has been achieved, and are also invaluable data that can be used to improve quality and prevent problems in future projects. The Contractor, therefore, needs to store records for a certain period of time. For further information on record keeping, refer to Chapter 17.

15.2 Quality Control of Concrete Materials and Reinforcing Materials

In the quality control of concrete materials and reinforcing materials, materials shall be managed so that they meet their respective quality requirements and stay in a stable condition as much as possible.

[Commentary] In order to construct a concrete structure of the required quality economically, it is required, needless to say, that the quality of concrete materials, namely, cement, water, aggregate and admixtures, and reinforcing materials meet the specified requirements. In addition, it is desirable that variations in the quality of those materials be small. The state of storage of concrete materials and reinforcing materials should be controlled appropriately so that their quality does not change. The state of control should also be checked periodically.

Although the quality of admixture such as superplasticizer and quick setting admixture or reinforcing materials, which is used at construction site, depends on the conditions of construction site, the quality control at construction site is important. For the quality of aggregate, when the Contractor produces concrete, the Contractor shall tests related to the quality control of aggregate, and shall keep the storage conditions. Grading of aggregate and percentage of surface moisture may be used as an index in quality control of aggregate, for instance.

15.3 Quality Control in Concrete Production

In the quality control in the production of concrete, concrete production equipment and production processes shall be controlled appropriately so that concrete of the required quality can be produced stably and smoothly.

[Commentary] In the production of concrete, the storage facilities, measuring equipment and mixers must be stored appropriately during the production period so that the requirements specified in Section 5.2 are met. In order to continue to produce concrete of stable quality, it is good practice to measure the surface moisture content of aggregate with moisture meters on a continual basis and, if a considerable change or any abnormality in the property of concrete has been observed, take aggregate samples and compare surface moisture contents. Because it is necessary to ascertain that measurement errors are small enough to stay within an allowable range, if an automatic batching recorder (recorder–printer) is available, records from the recorder should be used to check whether measured values are stable. In mixing control, changes in the quality of concrete can be identified by observing the state of mixing of concrete on the monitor screen and checking the mixer load current.

The success or failure of quality control can be evaluated by checking, for example, the operation and cleaning status of production equipment, equipment deterioration and damage, and the properties of concrete during and after mixing. In many cases, evaluation can be made by visual observation or by listening to the sound of machines in operation.

Test results such as compressive strength, slump and air content of concrete can be recognized by quality chart. Obtained data is plotted in the chart with mean value, upper and lower control lines for quality control. The range of the control line should be defined appropriately. When the result out of the range is observed, it should be investigated whether the reason of the change causes the change of quality permanently, and a provision for it should be conducted. The control limit line shall be changed based on the quality control data during the construction period. A histogram is useful to represent the distribution of quality, and ratio of passed/false and margin for quality can be assessed by the histogram with criteria. The shape of histogram indicates warning in construction process (quality of the used materials, production of concrete and testing).

15.4 Quality Control of Concrete

The quality of fresh concrete and hardened concrete shall be controlled so that concrete of stable quality can be obtained.

[Commentary] The quality of concrete in a structure is greatly affected by the quality of the concrete used. When controlling the quality of concrete, therefore, it is important to accumulate quality control data and analyze data on a daily basis so that the relationship of the quality of concrete with the production of concrete materials and concrete can be quantified. The quality control should be conducted at appropriate period and frequency, refer to inspection standard Chapter 5 in this specification.

(a)Confirmation of mix proportions The mix proportions indicated in the mix plan do not necessarily agree with the mix proportions of the concrete actually produced. It is recommended, therefore, that production-related records such as the printed records be checked for comparison with the actual mix proportions.

(b)Quality control of fresh concrete If concrete is not homogeneous and does not have workability suitable for the types of work to be done such as transportation, placement and compaction, poor placeability or defects might result. The workability of fresh concrete can be judged to some extent by observing the state of concrete during unloading and placement even if tests are not conducted frequently. If quality fluctuates considerably, tests should be conducted on an as-needed basis to identify the causes of problems and take early corrective measures. It is also desirable that the frequency of quality control checks be increased until quality becomes stable.

i) Slump: Slump test is conducted to ensure the workability of concrete as well as homogeneity of concrete. It is necessary to check the production of concrete with given materials, the particle size distribution of aggregates, surface moisture content of aggregate and so on when the change of slump is acknowledged. Slump cone test can also provide an indicator of the quality of fresh concrete. Since slump will change wit time after the finish of mixing it is necessary to take into account the difference in time in which slump test and actual placement of fresh concrete are conducted.

ii) Air content: Change in air content results in the change of workability, strength and durability. In order to ensure air content in fresh concrete air content test is conducted. Since change in the air content results in the change in the slump the cause should be clarified and in case to take countermeasures surface moisture and particle size distribution of aggregates, temperature of fresh concrete and change in the air content are taken into account.

iii) Temperature of concrete: Temperature of concrete have influences on slump, air content, thermal temperature due to hydration, development of strength and properties of the hardened concrete. Therefore it is an important item for the quality control for the construction of mass concrete, cold weather concrete and hot weather concrete. Besides it is necessary to check the temperature of concrete during the curing.

(c)Quality control of hardened concrete Because the time required to get results of concrete strength tests conducted to test the quality of hardened concrete is long, those tests are usually not suitable for use in quality control. It is more rational, therefore, to spend effort in the quality control of materials and production. When rarely produced concrete is used or during a certain period of time after production is started or during a period when air temperature changes considerably, it is good practice to check on changes in compressive strength.

15.5 Quality Control during Construction

In the quality control during construction, it should be checked whether each type of construction work in progress such as the work related to concrete, reinforcement, and formwork and falsework agrees with the plan, and, if necessary, the methods being used should be changed to more effective methods so that concreting work can be carried out smoothly.

[Commentary] At the construction stage, it is important to check whether each type of construction work in progress such as the work related to concrete, reinforcement, and formwork and falsework agrees with the plan so as to carry out concreting work smoothly, attain the required quality and complete the work by the planned date. It is often not possible to proceed with the work as planned because of, for example, the changing quality of concrete, changing environmental conditions, differences in the experience of workers and differences in the performance of equipment. It is desirable that the Contractor carefully observe the state of construction work and, if improvement needs to be made, give the workers appropriate instructions as to specific methods to be used for further improvement of the methods used.

(a) Quality control in preparation Since weather during construction is always in a state of change, it is important to check on weather forecasts in advance and make preparation such as rescheduling the work to be done on the day or during the coming week or taking rain protection measures. Adequate preparation for each type of work minimizes problems encountered during construction.

(b) Quality control in concreting work If the methods used for transportation, placement, compaction, finishing and curing are not appropriate, it is difficult to construct a concrete structure of the required quality. It is important, therefore, to fully understand the points to remember described in Chapters 7, 8, 9, 12, 13 and 14 and check whether the methods described there are appropriate on the basis of the construction plan and the quality control plan. In the quality control for each type of work, the basic rule is to control the facilities and equipment used, staffing and construction methods. Prior to the placement of concrete, it must be carefully ascertained that the reinforcement and formwork and falsework have been placed and constructed as planned.

i) Transportation to the site: Transportation time of agitator truck should be checked to keep the given time until the finish of the placement of concrete so that placing concrete can be continued. The number of agitator truck based on the amount of placing concrete and its placing rate should be determined and transportation plan for these agitator trucks should be prepared before the actual construction. Schedules of managing transportation should be prepared in which planed and actual time for shipping, arrival, finishing of discharge and tests, estimated time interval, the numbering of agitator trucks, the amount of loading and accumulation, either quality control or inspection of acceptance are indicated. In addition it is a good practice to make close contact with a person in charge of quality control at the factories and at the placing site. These practices make it easy in placing concrete continuously.

ii) Transportation within the site: It is necessary to manage types of transportation equipments needed, its form and capacity, arrangement of personnel and method of transportation according to the prepared plan within the site. Concrete pump is usually used for the transportation within the site and concrete pumping works will be left the management to the specialist. However it is important that person in charge of quality control should advice properly the method of pumping by considering quality of concrete, transportation using agitator trucks, compaction, pressure to the formwork.

iii) Placement and compaction: In placing and compacting concrete the order of the placement, the placement rate and its height, interval of layered concrete, the position of joints, the height of compacting and method of compaction are needed to be checked. Proper countermeasures should be taken when actual workability is reduced though periods of time for the placement is within the allowable time. It is necessary to point out compaction time and its interval since the effectiveness of compacting with vibration may be different by the conditions of concrete and reinforcement arrangement.

iv) Finishing: In finishing concrete the number of finishing actions, the period and the methods of the finishing are managed if they follow to the initial planning. The appropriate period of the finishing may be varied depending on the weather conditions and the ability of workers. When the finishing time of placing concrete is delayed the finishing actions may be carried out during night. Subsidence cracks and separation occur by finishing with bleeding water. It is necessary to manage the schedule of the completion of finishing and its methods.

v) Curing: Equipments, workers arrangement and methods need to be checked if they follow to the initial planning. For wet curing a person in charge of quality control must understand the procedures of the curing to avoid improper curing. Inadequate wet curing may result from improper curing with sprinkling water, sheet and mat at locations of the projection of reinforcements. With inadequate wet curing the quality of concrete is reduced as compared with that of water-cured concretes. For strength and durability of structure the quality control of curing is important.

(c) Steel works: Followings are important notices for steel works. They also can be applied to the quality control for other types of reinforcement.

i) Drawing of bar arrangement: Types, diameter and length of steel, cover and space, bending shape and the position of anchor and joint are checked if they follow to the drawing. It is necessary to check if supportive and temporal bars are needed, there are positions at which bar is not arranged in accordance with the drawing and there are mistakes in the drawing

ii) Planning: A standard procedure for the planning of bar and personnel (for considering ability) arrangement, storage site within construction site and selection of equipments for bending bars is prepared. By considering load on the spacer necessary spaces of bar arrangement need to be secured.

iii) Acceptance and storage: Types, diameter, length and the number of bars needed are recognized. It is checked if the length is enough for the transportation and the no-use during processing is reduced. By ensuring if transported steels are ordered ones at acceptance the they are storage so as to prevent corrosion and dirt.

iv) Processing: Drawing of processing, the content of standard procedure and the specification of a slice processing machine (same as the radius of bending bar) are ensured. Types and the numbers of bars after the processing and the accuracy in the processing are needed to be checked and the controlling within own target values reduces the risk of failure in inspecti,

v) Fabrication: Spacer, band wires, space of formwork, given position and the interval of center, effective depth, cover, anchor length, position of bending, position, length and methods of joint, end treatment for compressive steel and weathering are checked. These checks must be completed before the placement of concrete. Allowable error in the target of control which is determined based on the types and importance of structures is set up with own values more severe than those employed at inspection so that the risk for failure in inspection is reduced. Re-fabrication of steel requires a great deal of labor and hence it is advisable to ensure each steps in fabrication to avoid mistakes. When time is elapsed after fabrication corrosion, contacting mud and oil and the displacement of bar arrangement take place. It is advisable to clean steel and ensure the accuracy of fabrication before the placement of concrete.

(d) Formwork and shoring: Followings are important notices for formwork and shoring.

i) Calculation and control: Sufficient strength and safety against expected load are required for formwork and shoring. A person in charge of quality control ensures the results of calculation of formwork and shoring. Attention is paid for the expectation of load since lateral pressure and external load that is beyond initial expectation may occur. By considering the minimum slump at the placement of concrete and the change of slump with time target slump is determined at the discharge of fresh concrete in this specification. Increase in the lateral pressure due to larger slump than the minimum slump specified must be taken into account. It is safe to consider the change in the rate of placing and temperature of concrete.

ii) Drawing and construction; Construction is ensured if it follows to the drawing and procedures. Construction accuracy for formwork and shoring is determined so as to obtain a given position, shape and size of structure. It is noticed that the accumulated error associated with each works must be still within the allowable error. Before re-use of formwork and shoring it is checked if the degradation is not influential to concrete and separation agents are removed. When these care are not properly taken into account surface concrete contacted with the formwork is affected. Corrosion of steel bars used as a fasten material and improper welding wires may result in the failure of formwork. These must be paid attention not to occur.

iii) Control in use: During placing concrete the leakage of pastes and mortar from the gap, widening, movement, slant and subsidence of formwork and shoring, softening in joints floating cylindrical mould need to be checked to prevent accident and take any actions if taking place. Workers in charge of not only concrete works but also formwork and shoring works are placed during placing concrete. Communication with a person in charge of quality control for concrete works should be made to ensure the use of concrete with expected slump, the rate of placement and temperature which are assumed in calculation for the formwork and shoring.

iv) Removal time: By considering temperature, conditions of structures and the formation of thermal cracks the formwork and shoring are removed. Strength development is slow in low temperature and displacement and cracks may occur when bottom plate formworks used in decks are removed.

15.6 Quality Control of Concrete Structures

Until a concrete structure is taken over by the Owner, the structure shall be kept under control so that a concrete structure of the required quality can be delivered to the owner.

[Commentary] Passing the owner's inspection of a concrete structure can be made easier by checking, during construction, on the state of concrete surfaces, the positions and dimensions of concrete members, the quality of the concrete in the structure, and concrete cover. For example, cracking might be caused by long-term temperature changes, drying shrinkage or changes in the state of stress in the course of construction even if there was no visible crack immediately after the completion of the structure. A concrete structure may also be affected by environmental factors such as natural phenomena including typhoons and earthquakes, the deformation of the surrounding ground, and vibration caused by transportation facilities. It is therefore advisable to periodically observe the concrete structure, the protection works around the structure, etc., to check whether there is no abnormality during construction and after the completion of the structure until the completion of delivery to the owner. If any abnormality has been discovered, quality control personnel need to report it to the quality control manager or the responsible engineer and take appropriate corrective measures.

CHAPTER 16 INSPECTION CONDUCTED BY CONTRACTOR

16.1 General

(1) The Contractor shall conduct inspections for acceptance of materials and inspections of concrete production facilities at each stage of construction in accordance with the construction plan and have the inspection results confirmed by the owner.

(2) Standard inspections to be conducted by the Contractor shall be inspections for acceptance of concrete materials, inspections of concrete production facilities, inspections for acceptance of concrete and reinforcing materials.

(3) As a general rule, inspection shall be conducted in accordance with predetermined criteria by using a method based on testing or measurement that permits objective evaluation. With respect to inspection methods and evaluation criteria, refer to the Construction: Inspection Standards of this Specification.

(4) No item that has failed to pass an inspection shall be received.

[Commentary] (1) and (2) Main inspections conducted by the Contractor are inspections for acceptance of materials for concrete production, inspections for acceptance of structural reinforcing materials and inspections of concrete production facilities. The results of inspections conducted by the Contractor must be documented and kept in storage and, on an as-needed basis, be reported to and confirmed by the owner. It is good practice for the Contractor, therefore, to incorporate the plans for inspections to be conducted by the Contractor on its own responsibility into the construction plan.

From the viewpoint of quality control to be performed by the Contractor, the inspections for acceptance of materials are essential for successful execution of concreting work of the required quality. Usually, therefore, inspections to be conducted by the Contractor are included in the tasks specified in the construction plan drawn up with the approval of the owner of the structure.

Even in an inspection conducted by the Contractor, a final decision may be made by the owner of the structure depending on the technical level, reliability, etc., of the inspection. It is therefore necessary to clarify the inspection system in advance through consultation with the owner of the structure.

(3) An inspection is done by comparing the results of a necessary measurement or test with predetermined criteria. Tests must be conducted by using a method that permits objective evaluation. As a general rule, methods specified in the Japanese Industrial Standards, JSCE standards, etc.

(4) Basically, an inspection is conducted to determine whether something is acceptable. As a general rule, therefore, an item that has failed to pass an inspection must be rejected.

CHAPTER 17 CONSTRUCTION RECORDS

The constructor shall record the schedule of concreting work, the state of production and construction, curing methods, weather and atmospheric temperature on the date on which construction work is performed, quality control and inspection results, etc., during construction and deliver the construction records thus prepared to the Owner of the structure.

[Commentary] Construction records provide basic information for the maintenance of the structure. Construction records, therefore, are also necessary for the progress of technology. Records should cover the following:

a) Records related to the quality of concrete: mix proportions, materials, quality control and inspection results, the name of the ready-mixed concrete plant, etc.

b) Records related to concreting work: quantities of concrete to be placed, methods, date, placing time, air temperature, humidity, pump type, pumping distance, pipe diameter, pumping company, personnel and organizational system, curing methods and periods, etc.

c) Material inspection results: results of concrete receiving inspections (e.g., slump, air content, specimen strength, chloride ion content), results of reinforcing bar receiving inspections

d) Other information: changes related to the quality of concrete, construction, etc.

Inspection Standards

CHAPTER 1 GENERAL

1.1 General

(1) The Owner shall assume the responsibility for inspecting the completed structure for acceptance.

(2) These Specifications present the standards for inspections that are conducted in each phase of concrete work during the construction of a new ordinary civil engineering structure and at the completion of the structure.

(3) In cases when experiments are carried out, the adapted methods should be those that enable an objective evaluation. In principle, methods adapted by JIS or JSCE Standards should be carried out.

(4) In cases inspection results indicate that the required performance criteria are not satisfied, appropriate countermeasures shall be taken.

[Commentary] (1) and (2) Inspections are conducted by the Owner of the project to determine whether the produced and constructed concrete, member and structure meet the designated performance requirements or not and whether the completed structure is acceptable or not. Various inspections are required in each phase of concrete production and structural construction. It is not effective or practical for the Owner to perform all the inspection work. It is stipulated that the Owner should assume the responsibility for conducting inspections to explicitly define the responsibility of the Owner of the structure. In some cases, the Owner carries out actual inspection work including measurements and testing in each phase. In other cases, the Contractor carries out measurements and testing and transfers the responsibility for inspections to the Owner by having the Owner verify inspection results. For the inspections conducted by the Contractor, refer to "Materials and Construction: Construction Standards".

If the ultimate goal of constructing a structure is to ensure the achievement of its performance requirements, it is ideal to inspect the performance of the completed structure firsthand. At present, however, only limited items can be inspected in a completed structure such as the surface condition of concrete and the locations and dimensions of members. Whether the performance requirements of the structure are met or not should therefore be verified by preparing an effective, economical and systematic inspection plan, consulting the design drawings and construction plans, and conducting appropriate inspections in each phase of construction in accordance with the plans. Most of the inspection standards described in this chapter are intended for application to ordinary work and incorporation into contract documents.

(3) Since the method of inspection varies depending on the type of the structure, materials, construction methods, etc., the inspection items, test methods and frequencies should be examined and planned beforehand. Objective testing methods and decision criteria should be used for inspections. To that end, tests shall be conducted using the methods that are in compliance with the Japan Industrial Standards or the standards of the Japan Society for Civil Engineers. The methods for inspections should generally be specified in contract documents.

The reliability of the inspection, which comprises visual observation and testing, as well as cost and time required, should also be examined beforehand. In the case of inspection of reinforcing bar arrangement for instance, it is currently more reasonable in terms of cost and reliability to give observation before concrete placing than to conduct nondestructive inspection after the construction of the structure, though technically feasible. Judgment criteria also significantly depend on the accuracy and reliability of testing. Since any current inspection method can be not infallible, it is not reasonable for the cost of inspection to select the nearly infallible inspection method.

(4) Inspection is basically carried out to judge whether or not the product is acceptable. It follows that, if the product is judged unacceptable, it should as a rule be rejected. However, in contrast to the case of mass-produced goods, rejection is not the best solution in most cases in consideration of the complicated processes, long construction period and social effects of delayed completion. It is more realistic to ensure the specified performance of the structure by taking appropriate remedial measures. A wide variety of remedial measures may be possible. Whereas corrective work in an intermediate stage may be sufficient in some cases, correction or strengthening in the final stage may be required in other cases. When any of these measures cannot ensure the specified performance, demolition and reconstruction are inevitable.

1.2 Definitions of Terms

The following definitions of terms are used in these Inspection Standards.

Inspection: Act of determining whether the quality meets the decision criteria or not.

Quality control: Effective and systematic technical activities performed in all construction phases for ensuring quality in order to construct concrete structures economically that achieve the requirements for their intended use.

[Commentary] Inspection As described in Section 1.2 of "Materials and Construction: Construction Standards", the items to be inspected include the qualities of materials, concrete, construction and completed structure. The qualities of materials and products are generally inspected by the purchaser and the Owner of the structure verifies the inspection results in writing. Inspections of construction work and the completed structure are generally conducted by the Owner of the structure.

Quality control Quality is controlled during the production of materials, during construction and for a structure or members. Quality control is voluntarily executed to construct the structure that is complied with the requested quality by the Contractor of construction work. The Contractor shall apply the needed quality control on their own judgments and shall execute the economical and reasonable quality control.

CHAPTER 2　INSPECTION PLAN

(1) Inspection plans shall be prepared in accordance with the design drawings and the specifications to specify the selected inspection items, testing and inspection methods, timing and frequency of testing and inspections, decision criteria in testing and inspections, required human resources to be assigned and other matters.

(2) Inspection shall be planned in consideration of the importance of the structure, type and scale of construction, construction period, reliability of the materials and construction methods, experience of the engineers, time of construction, effects on subsequent processes, efficiency, etc.

(3) The plan for inspection shall be established for all stages including concrete production and completed concrete structure. In the case of standard construction, inspections shown in Table 2.1 should be applied.

Table 2.1　Inspection requirement systems for insurance of structural performance

Items for Inspection \ Reference		Inspection of constituent materials of concrete (for acceptance)	Inspection of production	Inspection of concrete at time of delivery at site	Inspection of concrete at time of delivery at site	Inspection during execution			Inspection of structures			
						concreting	reinforcement	formwork and shoring	Surface texture position, shape and dimension of concrete members	position, shape and dimension of concrete members	concrete properties in structure	cover
		CH3	CH4	CH5	CH6	CH7 7.2	CH7 7.3	CH7 7.4	CH8 8.2	CH8 8.3	CH8 8.4	CH8 8.5
Production	Concrete materials	○										
Production	Manufacturing facilities and process		○									
Production	Transportation to the construction site			○								
Ready-mixed concrete				○							(△)	
Reinforcement					○							
Construction	Transportation within site					○			○		(△)	
Construction	Placement (or casting)					○			○		(△)	
Construction	Compaction					○			○		(△)	
Construction	Surface finish								○			

construction	Curing					○					(△)	
	Joints					○			○			
	Reinforcement						○					(○)
	Formwork and shoring							○		○		(○)

Explanatory notes

○ : possible (able to verify)

(○) : possible as required

(△) : possible as required (able to inspect the limited part of performance)

(4) The inspection plan should be flexible enough to cope with normal anticipated variations. However, in cases when the changes are beyond the anticipation, the inspection plan should be appropriately modified.

[Commentary] (1) and (2) The ultimate objective of inspections is to verify that the structure is designed in accordance with the design drawings so as to achieve the designated performance requirements. Though formulating an inspection plan is essentially an action to determine the items presented in Clause (1), the inspection systems to achieve the goal are not single but numerous. When determining the inspection system, the items given in Clause (2) should be considered.

The standard inspection presented in Section 3 and subsequent sections may be reasonably applied to common construction on a small scale. In the case of a large-scale and/or long-term project, or project involving special materials and/or methods, however, formulation of its own inspection system could be more reasonable.

Inspection is an act of ensuring the reliability of the structure. Varying the inspection method according to the reliability of the construction method is important. For the methods that are likely to involve human errors, the frequency of inspections should be increased. For the methods involving few errors in the process of construction, the frequency of inspections may be reduced. It may be reasonable for instance, even in a newly introduced method, to carry out inspection at short intervals in the beginning and progressively reduce the frequency of inspection when the same process is repeated, though such practice may be incompatible with the current system of agreement. When a new method is adopted for multiple projects, it may be reasonable to formulate a strict inspection system in the first project to which the method is introduced for the first time and reduce the frequency of inspection as the field experience accumulates. It is also worthwhile to consider simplifying the inspection for those who have received ISO 9000 series or other certifications or those who have remarkable track records. For instance, the inspection frequencies for ready-mixed concrete producers could be reduced for not only JIS accredited producers but also recipients of the compliance certificate by the National Quality Control Committee of the Ready-mixed Concrete Producers; and the inspection frequencies could also be reduced for pressure welders having an “excellence” certificate by the Japan Pressure welding Society in the recommendation system for excellent pressure welders.

It is also worthwhile to consider changing the inspection method according to the importance of the structure or members. For instance, the current JIS A 5308 “Ready-mixed Concrete” requires the same acceptance tests for both concrete for prestressed concrete elements and concrete for leveling concrete, but the former should normally be subjected to a closer inspection than the latter, while the inspection for the latter may be simplified compared with that for structural members.

From the viewpoint of the reliability of materials, inspection methods are sometimes employed that take the state of quality management in the production phase into consideration. For instance, whereas ready-mixed concrete is basically inspected by testing, inspection of reinforcing bar consists only of control of the mill sheet, as it is produced with little scatter of qualities and the qualities scarcely change after production.

In cases where quality management is considered inadequate in the field, conducting inspection without notification is worth considering in order to increase inspection efficiency. Inspection without notification, if conducted properly, may serve as an incentive for quality improvement.

It should be noted that introduction or improvement of an inspection method can produce a decisive effect on the inspection system. The restrictions of the chloride content in sea sand, for instance, used to be ineffective without a suitable inspection method when they were established but later became very effective after the development of a practical method of measuring chloride content in concrete. This indicates the importance of the improvement in the inspection equipment, the hardware. When a new inspection technology is developed, the inspection system should be actively reviewed.

(3) As shown in Table 2.1, materials are inspected for acceptance and production facilities are inspected in the phase of concrete production. In the construction phase, concrete and reinforcement are inspected for acceptance and concrete work, reinforcement work, form work and support work are inspected. For a completed structure, surface conditions, locations and dimensions of concrete members, concrete in the structure and concrete cover are inspected. Defects can be detected in the construction phase by inspections of surface conditions, locations and dimensions of members, concrete in the structure and concrete cover.

(4) A review of the inspection plan becomes necessary when the construction plan is modified.

CHAPTER 3 INSPECTION FOR ACCEPTANCE OF CONSTITUENT MATERIALS OF CONCRETE

3.1 General

(1) The party accepting concrete materials such as cement, water, aggregate and admixtures shall inspect the materials responsibly to verify whether they meet the designated quality requirements or not. The Owner of the structure shall verify the inspection results. Cement and admixtures may be inspected by confirming the lists of test records prepared by the production plants.

(2) If the quality of materials is determined to be inadequate in inspections, the materials shall be replaced or other measures shall be taken.

[Commentary] (1) It is important that cement, mixing water, aggregate and admixtures shall have the qualities prescribed in mix proportioning process to manufacture the requisite performance. The party producing concrete shall assume the responsibility for testing concrete materials to verify their quality when they are accepted. When producing concrete using the production facilities installed at the site as in dam or tunnel construction, the contractor shall assume the responsibility for testing materials to verify their quality. The Owner of the structure shall finally verify the results of inspections of concrete materials conducted by the contractor, fulfilling the responsibility of the accepting party.

(2) When the inspection results for the quality of materials were judged not to be conform to the requirement, if that cause can improved by engineer, such as the grading of aggregate or chloride ion content of sand, it may continue to use the material in condition of the improvement of that quality. But, if dealing with that come is not possible by engineer, such as the density or water absorption of aggregate, the measures such as the change of that material must be executed.

In cases where unacceptable materials have been used, whether the concrete using the materials achieves the designated performance requirements or not should be verified and appropriate measures should be taken based on the results.

3.2 Cement

Inspection of cement should be carried out in accordance with Table 3.2.1 as a standard.

Table 3.2.1 Inspection of cement

Type	Item	Testing or Inspection method	Period/Frequency	Criteria for judgment
Cements specified in JIS specification	Items specified in JIS for the different types of cement	Conformation of test results provided by manufacturer or in accordance with JIS R 5201	-Prior to construction work -At least once a month during construction work -After the cement has been stored for a long time	Complying with relevant JIS specification
Cements not specified in JIS specifications	Items arranged for achievement of usual purpose	Conformation of test results provided by manufacturer or referring to JIS R 5201		Complying with specifications arranged for achievement of usual purpose

[Commentary] Cements not specified in JIS have generally the unique properties, and are used for special purpose. For these cements, it is needed that quality items and specifications shall be arranged adequately for achievement of usual purpose and judgment must be led under these items and specifications.

3.3 Mixing Water

Inspection of mixing water should be carried out in accordance with Table 3.3.1 as a standard.

Table 3.3.1 Inspection of mixing water

Type	Item	Testing method/ Inspection method	Period/Frequency	Criteria for judgment
Service water (drinkable water)	-	Confirmation of the document about service water	Prior to the construction work	Shall be service water (drinkable)
Service water (not drinkable water)	Items specified in JSCE-B101or items specified in JIS A 5308 appendix 3	in accordance with JSCE-B101or JIS A 5308 appendix 3	-Prior to construction work -At least once a year during construction work -In case the water quality changes	Complying with JSCE-B101or JIS A 5308 appendix 3
Recovered water	Items specified in JIS A 5308 appendix 3	Referring to JIS A 5308 appendix 3	-Prior to construction work -At least once a year during construction work -In case the water quality changes	Complying with JIS A 5308 appendix 3

[Commentary] When drinkable service water is used for mixing water, this should be documented without requiring a special inspection test.

When drinkable service water is not used for mixing water, it shall be confirmed by inspection test in accordance with JSCE-B 101 “Quality Specifications of Mixing Water of Concrete” or JIS A 5308 appendix 3 “Mixing Water for Ready-mixed Concrete”, as standard. On JSCE-B 101, the following items, quantity of suspended solids, quantity of dissolvable evaporating remainders, chloride ion content, hydrogen ion content, strength ratio of mortars and increment of air content were specified, and on JIS A 5308 appendix 3, the follow items, quantity of suspended solids, quantity of dissolvable evaporating remainders, chloride ion content, difference of setting time of mortars, strength ratio of mortars and increment of air content were specified. Then the specification items for hydrogen ion content and difference of setting time of mortars are different in these specifications, respectively. When drinkable service water is not used for mixing water, inspection test shall be executed by either method in consideration of general use, as standard, so that the concrete would be satisfied the prescribed performance.

When recovered water is used, the quality must be confirmed in accordance with JIS A 5308 appendix 3 “Mixing Water for Ready-mixed Concrete” once in a year by the approximate test of JIS A 5308 appendix 3.

3.4 Aggregates

(1) Inspection of fine aggregate should be carried out in accordance with Table 3.4.1 as a standard.

Table 3.4.1 Inspection of fine aggregate

Type	Item	Testing method/ Inspection method	Period/Frequency	Criteria for judgment
Sand	Oven-dry density	Method in JIS A 1109	-Prior to construction work -At least once a month [1] during construction work -Incase the source of the sand is changed	Complying with specifications of Section 3.4.1 in "Materials and Construction: Construction Standards"
	Water absorption	Method in JIS A 1109		
	Grading	Method in JIS A 1102		
	Clay lumps	Approximate method in JIS A 1137		
	Loss in washing test	Method in JIS A 1103		
	Chloride ion content	Method in JSCE-C 502 or Method in JSCE-C 503		
	Organic impurities	Method in JIS A 1105	-Prior to construction work -At least once a year during construction work -In case the source of the sand is changed	
	Chemical soundness (alkali-silicate reactivity)	Method in JIS A 1145 Method in JIS A 1146	-Prior to construction work -At least once every 6 months during construction work -Incase the source of the sand is changed.	
	Soundness (Freeze-Thaw resistance)	Method in JIS A 1122	-Prior to construction work -At least once a year during construction work -Incase the source of the sand is changed.	
Crushed sand	Items specified in JIS A 5005	Method in JIS A 5005	-Prior to construction work -At least once a month [2] during construction work -Incase the source of the sand is changed	Complying with JIS A 5005

Blast-furnace slag fine aggregate	Items specified in JIS A 5011-1	Method in JIS A 5011-1	-Prior to construction work -At least once a month [3] during construction work -Incase the source of the sand is changed	Complying with JIS A 5011-1
Ferro-nickel slag fine aggregate	Items specified in JIS A 5011-2	Method in JIS A 5011-2		Complying with JIS A 5011-2
Copper slag fine aggregate	Items specified in JIS A 5011-3	Method in JIS A 5011-3		Complying with JIS A 5011-3
Electric furnace oxidizing slag fine aggregate	Items specified in JIS A 5011-4	Method in JIS A 5011-4		Complying with JIS A 5011-4
Recycled fine aggregate H	Items specified in JIS A 5021	Method in JIS A 5021		Complying with JIS A 5021

1) In case of hill sand, loss in washing test shall be tested at least once a week.

In case of sea sand or blended sand of sea sand and others, chloride ion content shall be tested once in a week at least

2) Alkali-silicate reactivity shall be tested once in 6 months at least, soundness shall be tested once in a year at least

3)For ferro-nickel slag fine aggregate, copper slag fine aggregate, electric furnace oxidizaing slag fine aggregate and recycled fine aggregate H, alkali-silicate reactivity shall be tested at least once every 6 months

(2) Inspection of coarse aggregate should be carried out in accordance with Table 3.4.2 as a standard.

Table 3.4.2 Inspection of coarse aggregate

Type	Item	Testing method/ Inspection method	Period/Number	Criteria for judgment
Gravel	Oven-dry density	Method in JIS A 1110	-Prior to construction work -At least once a month during construction work -Incase the source of the sand is changed	Complying with the specifications of Section 3.4.2 in "Materials and Construction: Construction Standards"
	Water absorption	Method in JIS A 1110		
	Grading	Method in JIS A 1102		
	Clay lumps	Approximate method in JIS A 1137		
	Loss in washing test	Method in JIS A 1103		

	Chemical soundness (alkali-silicate reactivity)	Method in JIS A 1145 Method in JIS A 1146	-Prior to construction work -At least once every 6 months during construction work -Incase the source of the sand is changed	
	Soundness (Freezing-Thawing resistance)	Method in JIS A 1122	-Prior to construction work -At least once a year during construction work -In case the source of the sand is changed	
Crushed stone	Items specified in JIS A 5005	Method in JIS A 5005	-Prior to construction work -At least once a month 1) during construction work -Incase the source of the sand is changed	Complying with JIS A 5005
Blast-furnace slag coarse aggregate	Items specified in JIS A 5011-1	Method in JIS A 5011-1	-Prior to construction work -At least once a month2) during construction work -Incase the source of the sand is changed	Complying with JIS A 5011-1
Electric furnace oxidizing slag fine aggregate	Items specified in JIS A 5011-4	Method in JIS A 5011-4		Complying with JIS A 5011-4
Recycled fine aggregate H	Items specified in JIS A 5021	Method in JIS A 5021		Complying with JIS A 5021

1) Alkali-silicate reactivity shall be tested at least once every 6 months, percentage of abrasion and soundness shall be tested at least once a year

2) For electric furnace oxidizaing slag fine aggregate, alkali-silicate reactivity shall be tested at least once every 6 months

[Commentary] Items of inspection test and methods shall be decided from character of construction work and/or experiences for same kinds of works. As concrete consists of large amount of aggregates, to ensure the durability of concrete, the following tests shall be carried out: namely density, water absorption, grading, deleterious substance content, soundness, chloride ion content and alkali-aggregate reactivity.

Test period and frequency of aggregates must be decided based on the tendency of alteration of the grading and moisture content. The inspection tests should be performed at least twice a day in the beginning of construction work. It may be decreased the frequency of test based on the judgment from the appropriate storage and treatment, and small variation of the grading and moisture content of aggregates.

When the sea sand is used, frequency of tests for chloride ion content, grading and moisture content must be increased compared to the other kind of aggregate. And in case the large content of shells in sea sand adversary affect the quality of concrete, the quantity of shells must be examined.

When the source of product is changed, it is necessary to confirm the qualities by inspection test. As the considerable variations of quality shall be occurred in case the source of product would be same but position in the source different, a special care must be taken for the alteration of out-looks of aggregates on receiving of materials.

3.5 Admixtures

(1) Inspection of mineral admixtures should be carried out in accordance with Table 3.5.1 as a standard.

Table 3.5.1 Inspection of mineral admixtures

Type	Item	Testing method/ Inspection method	Period/Frequency	Criteria for judgment
Fly ash	Items specified in JIS A 6201	Conformation of test results provided by manufacturer or in accordance with JIS A 6201	-Prior to construction work -At least once a month during construction work - In long term storage case	Complying with JIS A 6201
Expansive admixture for concrete	Items specified in JIS A 6202	Conformation of test results provided by manufacturer or in accordance with JIS A 6202		Complying with JIS A 6202
Ground granulated blast-furnace slag	Items specified in JIS A 6206	Conformation of test results provided by manufacturer or in accordance with JIS A 6206		Complying with JIS A 6206
Silica fume	Items specified in JIS A 6207	Conformation of test results provided by manufacturer or in accordance with JIS A 6207		Complying with JIS A 6207
Other than those listed mineral admixture	Required items	Conformation of test results provided by manufacturer or in accordance with required method		Complying with specifications arranged for achievement of usual purpose

(2) Inspection of chemical admixtures should be carried out in accordance with Table 3.5.2 as a standard.

Table 3.5.2 Inspection of chemical admixtures

Type	Item	Testing method/ Inspection method	Period/Number	Criteria for judgment
Air-entraining agent, Water-reducing agent, Air-entraining and High -range water-reducing agent, Fluidity agent, Superplasticizer, Rapid hardened agent	Items specified in JIS A 6204	Conformation of test results provided by manufacturer or in accordance with JIS A 6204	-Prior to construction work -At least once every 3 months during construction work - In long term storage case	Complying with JIS A 6204
Antiwashout agent	Items specified in JSCE-D 104	Conformation of test results provided by manufacturer or in accordance with JSCE-D 104		Complying with JSCE-D 104
Corrosion inhibitor for reinforcing bar in concrete	Items specified in JIS A 6205	Conformation of test results provided by manufacturer or in accordance with JIS A 6205		Complying with JIS A 6205
Other than those listed chemical admixture	Required items	Conformation of test results provided by manufacturer or in accordance with required method		Complying with specifications arranged for achievement of usual purpose

[Commentary] On the acceptance inspections of admixture, it shall be confirmed that brand and kind would be proper materials by carrying out control of the acceptance document and/or the label expression by visual observations. Inspection tests may be generally substituted for follow method, certification of conformity to the specification on the mill sheet expressed the test results by public testing organization or by product company for respective specification items. Inspection tests should be carried out when needed.

CHAPTER 4 INSPECTION OF CONCRETE PRODUCTION FACILITIES

(1) The party accepting concrete shall assume the responsibility for inspecting concrete production facilities. The Owner of the structure shall verify the inspection results.

(2) Inspection of concrete production facilities should be carried out in accordance with Table 4.1 as a standard.

Table 4.1 Inspection of concrete production facilities

Type		Item	Testing method/ Inspection method	Period/Frequency	Criteria for judgment
Material storage facilities		Required items	-Confirmation by visual observations -Confirmation of the structural figures of storage facilities -Measurement of temperature and humidity	-Prior to the construction work -Anytime during construction work	Complying with the specifications of Section 5.2.1 in "Materials and Construction: Construction Standards"
Batching facilities	Weighing machine	Accuracy of batching (static loading)	Measurement of error between the load and indicated value using weights or an electrical testing apparatus	-Prior to the construction work, -At least once every 6 months during construction work	Shall be weighing within permissible limit specified in low
	Weighing control equipment	Accuracy of batching (dynamic loading)	Measurement of error between set up value and counting value		Shall be weighing within prescribed permissible limit
Mixer	Bach mixer	Performance of mixing	Method in JIS A 1119	-Prior to the construction work, -At least once a year during construction work	Complying with JIS A 1119
	Continuous mixer	Performance of mixing	Method specified in JSCE-I 501 and JSCE-I 502		Complying with JSCE-I 501 and JSCE-I 502

[Commentary] (1) Verifying the performance of concrete production facilities such as material storages, measurement facilities and mixers at the start of or during construction is required for producing concrete with designated performance economically. In order to produce concrete with designated performance, the accepting party shall assume the responsibility for verifying that the concrete production facilities meet the performance requirements specified in Section 5.2 of "Materials and Construction: Construction Standards". The owner of the structure shall verify the inspection results.

(2) The weighing of materials is controlled by a weighing control system. The variance between the designated and actual weights shall be measured to verify that the precision of weighing is within the specified range. For inspecting the weighing meters, static loading tests shall be conducted using a weighing meter or electric detector to verify that the weighing meter can detect loads as precisely as designated.

CHAPTER 5 INSPECTION FOR ACCEPTANCE OF READY MIXED CONCRETE

(1) The accepting party shall assume the responsibility for conducting acceptance tests for ready mixed concrete. The Owner of the structure shall verify the inspection results.

(2) Acceptance tests for ready mixed concrete shall be conducted at the time of unloading.

(3) Inspections should be conducted in accordance with Table 5.1 as a standard.

(4) Professional engineers of the accepting party shall visually verify that concrete achieves a high level of workability at the time of unloading. No concrete with poor workability shall be placed.

(5) Water content of unit volume of fresh concrete should be inspected after the consultation between the accepting and producing parties concerning the inspection method and decision criteria.

(6) Mix proportions should be inspected by verifying that each material is produced at the designated proportion based on the printed weighing records. For inspection, water content per unit volume of concrete should be obtained by calculation using the printed weighing records for water and the calibrated volume of aggregate surface water.

(7) Water-cement ratio should be obtained from the printed weighing records of cement content per unit volume of concrete, and the water content per unit volume of concrete that is calculated based on the printed weighing record of water and the calibrated volume of aggregate surface water. Alkali-aggregate reaction should be verified based on the concrete mix proportion list.

(8) Strength shall be inspected in compressive strength tests. If the test result is unacceptable, the strength of concrete in the structure shall be examined.

(9) Shrinkage strain should be verified as required for important structures.

(10) When applying a fluidity agent to concrete, the slump and volume of air should be measured before and after the application at a rate of once per 50 m^3.

(11) Concrete determined to be inappropriate as a result of inspections shall not be used.

Table 5.1 Acceptance inspection of concrete

<table>
<tr><th colspan="2">Item</th><th>Testing method/
Inspection method</th><th>Period/Frequency</th><th>Criteria for judgment</th></tr>
<tr><td colspan="2">Condition of fresh concrete</td><td>Confirmation by visual observations of engineer in charge or appropriate engineer</td><td>-When unloading
-Anytime as required</td><td>Shall have the suitable workability and minimum variation in quality</td></tr>
<tr><td colspan="2">Slump</td><td>Method in JIS A 1101</td><td rowspan="6">When unloading, once in a day or once every 20~150m^3, depending upon the importance of structure and the scale of the construction work, and in the event of any appreciable change in the quality on unloading</td><td>Allowable error:
±1.5cm in the case of slump higher than 5cm and less than 8cm
±2.5cm in the case of slump 8cm to 18 cm</td></tr>
<tr><td colspan="2">Air content</td><td>Method in JIS A 1116
Method in JIS A 1118
Method in JIS A 1128</td><td>Allowable error:±1.5%</td></tr>
<tr><td colspan="2">Unit weight of water of fresh concrete</td><td>By tests on the unit weight of fresh concrete</td><td>Shall be in permissible limit</td></tr>
<tr><td colspan="2">Temperature of concrete</td><td>By temperature measure</td><td>Shall be conform to the prescribed conditions</td></tr>
<tr><td colspan="2">Bulk density</td><td>Method in JIS A 1116</td><td>Shall be conform to the prescribed conditions</td></tr>
<tr><td colspan="2">Chloride ion content</td><td>Method in JIS 1144 or Recognized method by reliable testing organization</td><td>When unloading,
In the case of sea sand twice a day, the other case once in a week</td><td>Shall not exceed 0.3kg/m^3 in principle</td></tr>
<tr><td colspan="2">Preventive of alkali-aggregate reaction</td><td>Confirmation of mix proportion report</td><td>Prior to the construction work and in which the material or mix proportion changes</td><td>Shall be confirmed the preventive</td></tr>
<tr><td rowspan="3">Mix proport-ion</td><td>Unit water content</td><td>Confirmation of the count surface moisture of aggregates and printed record for weighing measurements of water</td><td rowspan="2">-When unloading
-Twice in before noon and afternoon, respectively</td><td rowspan="3">Shall be in permissible limit</td></tr>
<tr><td>Unit cement content</td><td>Confirmation of printed record for weighing measurements of water</td></tr>
<tr><td>Water to cement ratio</td><td>Confirmation of the count surface moisture of aggregates and printed records for weighing measurements of cement and water</td><td>Prior to the construction work and in which the material or mix proportion changes</td></tr>
</table>

	Unit content of other materi-als	Confirmation of printed record for weighing measurements of concrete materials	-When unloading - Twice in before noon and afternoon, respectively	
Compressive strength (at 28-day age, in general)		Method in JIS A 1108	When unloading, once a day or once every 20~150m^3, depending upon the importance of structure and the scale of the construction work	The probability for compressive strength to be lower than characteristic compressive strength of concrete is less than 5% (Estimated using production risk)

[Commentary] (1) and (2) In order to verify whether the concrete delivered to the site meets the designated performance requirements or not, the party accepting ready mixed concrete shall assume the responsibility for conducting inspections. The Contractor shall basically assume the responsibility for conducting acceptance tests for ready mixed concrete at the time of unloading because the Contractor generally purchases ready mixed concrete.

(3) The Contractor shall verify responsibly that fresh concrete meets the designated construction performance requirements. The Owner of the structure should inspect the parameters related to performance after concrete hardens such as the amount of chloride ions, measures to control alkali-aggregate reaction, volume of air, water-cement ratio and strength. The Owner of the structure shall assume the ultimate responsibility for these parameters.

Slump: Slump tests are widely employed for evaluating the consistency of concrete. The plasticity of concrete can also be determined to some extent by slump tests. Not only the values obtained in slump tests should be used but also the shape and homogeneity of concrete should carefully be observed after the tests to determine workability. For the allowable margin of error for special concrete with a slump lower than 3 cm or higher than 18 cm, refer to relevant standards.

Air content: The volume of air entrained in AE concrete may sometimes vary greatly with changes in aggregate grading, temperature or other parameter even where concrete of the same mix proportions is produced using the materials in one and the same lot. The changes in volume of air entrained have great impact on workability, strength and durability of concrete. It should therefore be verified by testing that the designated volume of air is entrained at the time of acceptance.

Temperature of concrete: The temperature of concrete greatly affects the quality of fresh concrete, rise of concrete temperature due to the heat of cement hydration and characteristics of strength development. This parameter is an important determinant of concrete quality during the construction of mass concrete and during the concreting in cold or hot weather.

The temperature of fresh concrete should be measured in accordance with JIS A 1156 Method of Measuring the Temperature of Fresh Concrete.

Mass of unit volume: Inspecting the mass of unit volume is essential to the verification of whether or not the mass of unit volume in an actual structure is appropriate as compared with the mass of unit volume specified in the design of the structure. The inspection is particularly important in the case of light-weight aggregate concrete because substantial changes in mass of unit volume determine the quality of the structure.

Chloride ion content: Chloride ion concentration greatly affects the resistance to steel corrosion. In cases where a large number of chloride ions are highly likely to intrude into concrete as in cases where sea sand is used, the frequency of testing shall be increased.

As a method of inspecting chloride ion concentration in fresh concrete, JIS A 1144 Method of Inspecting Chloride Ion Concentration of Water in Fresh Concrete is available.

(4) Concrete needs to be homogeneous and sufficiently workable for transport, placement and compaction. Whether fresh concrete is sufficiently workable or not may be visually determined to some extent. Then, an engineer of the accepting party shall visually verify the state of concrete for any defects at the time of unloading or placement at the site. No concrete determined to be insufficiently workable should be placed. In order to enhance the reliability and precision of visual inspections, engineers with adequate knowledge and experience concerning concrete should conduct inspections. Visual inspections shall be conducted by professional engineers of the accepting party such as chief concrete engineers and concrete engineers. If questions are expected to arise during determination, the producing and accepting parties should consult with each other in advance and define appropriate decision criteria with mutual consent.

(5) For estimating the water content per unit volume of fresh concrete, such methods have been developed as the heating and drying method (drier method, microwave heating method, etc.), drying under reduced pressure method, air meter method and capacitive method. At present, however, the precision of measurement is limited. In testing, therefore, water content per unit volume of fresh concrete should be inspected exclusively to remove concrete containing excessive volume of water. The precision of testing and the method of calibration vary from method to method. Inspections should therefore be conducted after prior mutual consultations between the accepting and producing parties concerning the method or decision criteria to be applied.

(6) and (7) In cases where the condition of concrete production has been inspected and the qualities of concrete materials have been inspected for acceptance, concrete mix proportions may be verified based on the printed records of measurements. Unit quantity of water shall in principle be obtained through calculation using the measurements in respective batches and the percentage of aggregate surface water.

Water-cement ratio (water-binder ratio) is an important factor affecting strength and coefficient of carbonation velocity, coefficient of chloride ion diffusion, resistance to frost damage, resistance to chemical intrusion and permeability coefficient, which determine the durability of concrete. Inspecting water-cement ration (water-binder ratio) is therefore important. Water-cement ration (water-binder ratio) shall in principle be obtained by calculation using the printed records of measurements for cement (binder) and the unit quantity of water obtained from the percentage of aggregate surface water and the printed records of unit quantity of water.

When accepting concrete from a ready mixed concrete production plant with no equipment for printing measurement records, verification may be made by an appropriate method through the consultation with the producing party. Whether corrective measures are taken or not to control alkali-aggregate reaction shall be verified using the lists of mix proportions.

(8) In cases where highly reliable production facilities and production and quality management systems are in place, concrete strength may be inspected before concrete placement by verifying the qualities of concrete materials and mix proportions. In cases where production facilities or production management systems are not reliable or where the conditions of concrete production are unknown or concrete is not produced as specified, however, no concrete strength can be verified in

mix proportion inspections. Then, verification shall be made by strength tests after concrete placement. At present, JIS A 5308 Ready Mixed Concrete stipulates that strength tests should be conducted.

(9) Shrinkage strain should be measured in accordance with JIS A 1129 Methods of Test for Length Change of Mortar and Concrete. It should be verified that the measurement does no exceed a shrinkage strain of 1000 micro meter. The standard value is the shrinkage where concrete is placed under dry conditions for six months after wet curing for seven days. When applying ordinary ready mixed concrete with a proven track record to a structure, inspections by shrinkage tests may be eliminated.

(10) Even if the slump and air content of base concrete before a fluidity agent is within the allowable limit, slump and air content of the fluidity concrete may show considerable fraction for determined fluidity agent dosage. Therefore frequency of inspection test shall be increased compared to the case of ordinary concrete and these tests shall be performed to the both of the base concrete and the fluidity concrete.

For the slump of the both of the base concrete and the fluidity concrete, test shall be performed in high frequency from prior to the placing works to the period confirming the stabilized qualities on manufacturing, after that test may be performed in every $50m^3$ s. And visual inspection shall be conducted for each agitator tracks to monitor the properness of workability of fluidity concrete.

(11) It is no doubt that the concrete judged not to be in conformity with requirements on the results of acceptance inspection must not be placed. If the concrete was already placed into the structure, the inspection as the structural concrete must be performed. That inspection shall be executed on Section 8.4.

CHAPTER 6 ACCEPTANCE INSPECTION FOR REINFORCEMENT

(1) The accepting party shall assume the responsibility for verifying before construction that the reinforcement delivered to the site meets the quality requirements specified in design. The Owner shall verify the inspection results.

(2) Inspection of qualities of reinforcement should be carried out in accordance with Table 6.1 as a standard.

Table 6.1 Inspection of qualities of reinforcement

Type	Item	Testing method/ Inspection method	Period/ Frequency	Criteria for judgment
Steel bars for concrete reinforcement	Items specified in JIS G 3112	Confirmation of test results provided by manufacturer or in accordance with JIS G 3112	At delivery	Complying with JIS G 3112
Re-rolled steel bars for concrete reinforcement	Items specified in JIS G 3117	Confirmation of test results provided by manufacturer or in accordance with JIS G 3117		Complying with JIS G 3117
Reinforcing bars not conforming to the requirements of JIS G 3112 and JIS G 3117	Required items	Confirmation of test results provided by manufacturer or referring to JIS G 3112		Complying with specifications arranged for achievement of usual purpose
Epoxy-coated reinforcing bars	Items specified in JSCE-E102	Confirmation of test results provided by manufacturer or in accordance with JSCE-E102		Complying with JSCE E-102
Threaded rugged reinforcing bars with large diameter	Items specified in JSCE-E121	Confirmation of test results provided by manufacturer or in accordance with JSCE-E121		Complying with JSCE E-121
Prestressing wire Prestressing strands	Items specified in JIS G 3536	Confirmation of test results provided by manufacturer or in accordance with JIS G 3536		Complying with JIS G 3536
Prestressing bars	Items specified in JIS G 3109 or JIS G 3137	Confirmation of test results provided by manufacturer or in accordance with JIS G 3109 or JIS G 3137		Complying with JIS G 3109 or JIS G 3137
Prestressing steel not conforming to the requirements of JIS G 3536, JIS G 3109 and JIS G 3137	Required items	Confirmation of test results provided by manufacturer or in accordance with JIS G 3536,JIS G 3109 or JIS G 3137		Complying with specifications arranged for achievement of usual purpose

Rolled steels for general structures	Items specified in JIS G 3101	Confirmation of test results provided by manufacturer or in accordance with JIS G 3101		Complying with JIS G 3101
Rolled steels for welded structures	Items specified in JIS G 3106	Confirmation of test results provided by manufacturer or in accordance with JIS G 3106		Complying with JIS G 3106
Rolled steels for building structures	Items specified in JIS G 3136	Confirmation of test results provided by manufacturer or in accordance with JIS G 3136		S Complying with JIS G 3136
Steels for structures not conforming to the require-ments of JIS G 3101, JIS G 3106 and JIS G 3136	Required items	Confirmation of test results provided by manufacturer or referring to JIS G 3101,JIS G 3106 or JIS G 3136		Complying with specifications arranged for achievement of usual purpose

[Commentary] It is only right and proper that reinforcement shall process the required quality as specified for the design of the structure. Inspection to ensure the quality of reinforcement should be performed on prior the placing works in advance. The Contractor shall assume the responsibility for conducting acceptance tests for reinforcement. The Owner shall verify the results of inspections conducted by the Contractor.

The shipment of the reinforcement is generally made to the field directly from factories in the form of bundle with the manufacture’s certified mill sheet where the name (or abbreviation) of the manufacture, the name and type of reinforcement are legibly identified.

General inspection shall be performed by confirming that the description and kind shall be adapted to the prescribed reinforcement by visual observations, and that material properties, shape, size and weight of reinforcement shall conform to the specifications prescribed by JIS G 3112 or JIS G 3117 respectively by examination on mill sheet from product company. In this case, outlooks of reinforcement shall be examined and the measured the diameter shall be measured of reinforcing bars by calipers, etc.

When the reinforcements except for reinforcing bars are accepted, the same method for reinforcing bars shall be approximately taken. When epoxy-coated reinforcing bars or galvanized reinforcing bars are accepted, it is important to confirm that the coating or galvanizing parts have no defects. For other types of steel than reinforcing bars, inspections may be conducted as for reinforcing bars

CHAPTER 7 INSPECTIONS OF CONSTRUCTION

7.1 General

The Owner of the structure shall assume the responsibility for inspecting construction in accordance with the inspection plan.

[Commentary] The Contractor shall manage quality in each construction phase. The Owner of the structure shall assume the responsibility for inspection construction. Verifying the quality of a completed concrete structure is generally difficult in numerous cases. Construction shall therefore be inspected before concrete placement or during concrete construction as a standard practice.

7.2 Inspection of Concreting

(1) Inspection for transportation should be carried out in accordance with Table 7.2.1 as a standard.

Table 7.2.1 Inspection for transportation

Item	Testing method/ Inspection method	Period/Frequency	Criteria for judgment
Equipment and labor required for transportation	Confirmation by visual observations	Prior to the placing work and during transportation	Shall conform to the construction plan
Method of transportation	Confirmation by visual observations		Shall conform to the construction plan
Quantity of transportation	Confirmation of the quantity of concrete		Shall be prescribed quantity
Transporting time	Confirmation of the time of shipment and arrival on site		Complying with Section 7.3 in "Construction: Construction Standards" based on the placing hours

(2) In the inspection of pumping, it should be verified as a standard practice that the maximum pumping load on the pump during pumping is equal to or less than 80% of the maximum theoretical pumping pressure of the concrete pump.

(3) Inspection of placing should be carried out in accordance with Table 7.2.2 as a standard.

Table 7.2.2 Inspection of casting

Item	Testing method/ Inspection method	Period/Frequency	Criteria for judgment
Equipment and labor required for placement	Confirmation by visual observations	Prior to the placing work and during placement	Shall conform to the construction plan
Method of placement	Confirmation by visual observations		Shall conform to the construction plan
Quantity of placement	Confirmation of quantity from shape and size of placing zone		Shall be prescribed quantity

(4) Inspection of curing should be carried out in accordance with Table 7.2.3 as a standard.

Table 7.2.3 Inspection of curing

Item	Testing method/ Inspection method	Period/Frequency	Criteria for judgment
Equipment and labor required for curing	Confirmation by the visual observation	During curing	Shall conform to the construction plan
Method of curing	Confirmation by visual observations		Shall conform to the construction plan
Period of curing	Confirmation of curing days and curing time		Shall be conform to the prescribed conditions

(5) In cases when inspection for transportation, placing or curing of concrete before construction shows non-compliance with the required standards, appropriate measures, such as improvements of equipment, labor arrangement or improvements of construction method should be taken, so that required objectives are achieved. In cases when concrete has already been placed, it shall be determined whether the concrete within the structure meets the required purposes, and appropriate countermeasures should be taken as needed.

(6) In cases when it is required to determine the adequacy of curing, timing of formwork removal, introduction of prestress, or the load applicability at early stage, it is desirable that tests for strength are carried out using specimens cured under conditions as close as possible to the concrete at site.

(7) In the case of cold weather concreting, inspection should be carried out in accordance with Table 7.2.4, besides the provisions of (1) to (6). The timing for termination of curing, or formwork removal and shoring dismantlement, should be determined on the basis of strength of specimens cured under conditions as close as possible to the concrete at site, or on the basis of strength estimated using the records of temperature of

concrete.

Table 7.2.4 Inspection of cold weather concreting

Item	Testing method/ Inspection method	Period/Frequency	Criteria for judgment
Circumferential temperature	Measurement of temperature	Prior to the construction work and during construction work	Refer to Section 12.1 in "Materials and Construction: Construction Standards" based on mean daily atmospheric temperature
Concrete temperature at placing			Be within the limits of provided planning temperature, planning temperature range shall comply with Section 12.5 in "Materials and Construction: Construction Standards"
Concrete temperature on curing or circumferential temperature under the heat curing			Be within the limits of provided planning temperature, planning temperature range shall comply with Section 12.6 in "Materials and Construction: Construction Standards"

(8) Inspection of hot weather concreting should be carried out in accordance with Clauses (1)-(6) and Table 7.2.5.

Table 7.2.5 Inspection of hot weather concreting

Item	Testing method/ Inspection method	Period/Frequency	Criteria for judgment
Circumferential temperature	Measurement of temperature	Prior to the construction work and during construction work	Refer to Section 13.1in " Materials and Construction: Construction Standards" based on mean daily atmospheric temperature
Concrete temperature at placing		During construction work	Be within the limits of provided planning temperature, planning temperature range shall comply with Section 13.6 in " Materials and Construction: Construction Standards" For mass concrete, refer to Section 14.5.2 in " Materials and Construction: Construction Standards"
Transporting time	Confirmation of transporting time	Prior to the construction work and during construction work	The time from the start of mixing to the completion of the placing shall not exceed 1.5 hours and within the limits of provided planning temperature

(9) Inspection of mass concrete should be carried out in accordance with Clauses

(1)-(6) and Table 7.2.6.

Table 7.2.6 Inspection of mass concrete

Item	Testing method/ Inspection method	Period/Frequency	Criteria for judgment
Concrete temperature on placing	Measurement of temperature	During the construction works	Shall comply with the requirements of provided plan
Concrete temperature on curing or circumferential temperature under the temperature-controlled curing			

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[Commentary] (1), (2) and (3) In the inspections of concrete transport and placement, the types, models, capacities and quantities of transport and placement facilities, human resources assigned, transport channels to the site, methods of transport at the site, sections of concrete placement, locations of construction joints, and order and speed of placement shall be verified for compliance with the construction plan.

It shall be verified that the pumping equipment has sufficient pumping capacity for the concrete and piping conditions.

Sufficiency of the quantity of transportation and quantity of placement shall be controlled on the period of transporting and placing respectively. Required volume for practical placing is generally about 2% larger than the design volume as the reasons of counting error of materials, variation of density of aggregates, variation of air content, loss on unloading from agitator track, bleeding after placing and deforming of the form.

Transporting time means the period from the start of mixing to completion of placing. The variation of transporting time shall lead the change of workability and other properties due to the change of air content and the loss of slump. If the transporting time shall become extremely long, it would be difficult to construct in proper condition. Then the transporting time must not be longer than the specified period.

(4) In the inspection of curing equipments, labor arrangement for curing and curing method, it shall be confirm that the moist curing, temperature-controlled curing and protection from harmful effects would be executed according to the description of the construction planning documents. The curing period (curing days or hours) is specified on Sections 8.2, 8.3 and 8.4 in "Materials and Construction: Construction Standard" for moist curing, temperature-controlled curing and protection from harmful effects, respectively. These specifications are determined from the consideration for curing method, kind of structure, location, weather conditions, kind of cement type used, etc. In the inspection of curing period, execution of the curing under the prescribed

condition would be conformed.

(5) In cases where concrete is found to be unacceptable as a result of inspections of transport, placement and curing, the facilities and construction plan are considered unsatisfactory. Then, facilities should be improved and the construction plan should be reviewed as required. In cases where the structure has been completed, it should be verified that the structure meets the designated performance requirements. Inspections should be conducted during construction and improvement should be made immediately. Measures as preventive as possible should be taken.

(6) In order to estimate the adequacy of curing, appropriate time for form removal and prestressing or to ensure safety of the structure under working condition, real concrete strength in the structure must be estimated in some cases. For this purpose, the concrete test specimens shall be cured under conditions as close to the field conditions as possible. In cold weather concrete works, above-mentioned specification is extremely important.

(7) As specified on Section 12.1 in "Materials and Construction: Construction Standard", if mean daily temperature is 4˚C or below during construction, construction practice as cold weather concreting shall be required.

The times of the curing termination, form removal and shoring dismantlement shall be decided by using the strength of specimens cured under similar conditions to in-place concrete, or using the records of concrete temperature whose relationship between the concrete temperature and compressive strength has been obtained by advance tests. It is desirable that curing conditions for field-curing specimens are the same as those for real concrete structure, but the same temperature conditions cannot be realized by simply putting the specimens at the same place as the structure. Therefore, it is recommended to measure the temperature of the field-cured specimens, and to investigate the temperature difference between the specimen and structure.

When the temperature of the structure is measured, concrete strength can be estimated from integrated temperature, or maturity. The maturity is generally expressed by the follow equation.

$$M=\sum(\theta+A)\Delta t \qquad \text{(C7.2.1)}$$

where, M : integrated temperature, or maturity, in [(degree C.) x(day)] or [(degree C.) x(hour)]

θ: concrete temperature during Δt, in [degree C.]

A : constant, generally 10 [degree C.] is used,

Δt : time, in [day] or[hour].

The relationship between maturity M and concrete strength varies depending on several factors, such as the materials used, the mix proportions and the degree of drying or moisture condition. Therefore, it is recommended that the relationship is confirmed by advance tests.

(8) Concrete considered as hot weather concreting is prescribed in Section 13.1 in "Materials and Construction: Construction Standard".

(9) Concrete considered as mass concreting is prescribed in Section 14.1 in "Materials and Construction: Construction Standard".

The principle of reliable thermal cracking control in mass concrete is to evaluate the temperature or thermal stress of structures in advance. However, in actual practice, due to the complicated influence of many uncertain factors at the construction stages, the behavior of the structure may often differ from the prediction no matter how detailed tests or advanced analysis are conducted at planning stage. Therefore, in mass concreting it is necessary to measure concrete temperatures of the structures continuously from the time of placing to the time when the temperature of the concrete becomes nearly equal to atmospheric temperature, and to examine whether the temperature change is kept within a range predicted in advance.

When the measured temperature at each portion of the concrete after placement largely differs from the predicted value, the measures such as curing method and placing interval shall be reexamined, and care shall be taken for the succeeding concreting.

7.3 Inspection of Reinforcement

7.3.1 Inspection of fabrication and assembly of reinforcing bars

(1) Inspection of fabrication and assembly of reinforcing bars should be carried out in accordance with Table 7.3.1.

(2) When the inspection results reveal that fabrication and assembly of reinforcing bars is not in conformity with the requirement, the works for fabrication and assembly of reinforcing bars shall be modified.

Table 7.3.1 Inspection of fabrication and assembly of reinforcing bars

Item	Testing method/ Inspection method	Period/Frequency	Criteria for judgment
Kinds, diameter and quantity of reinforcing bars	- Confirmation of test results provided by manufacture, - Confirmation by visual observations, - Measurement of diameter	Completion of cutting and bending	Shall conform to the requirements of design document
Prepared dimensions of reinforcing bars	Measurement by scale, etc.	Completion of cutting and bending	Shall be within prescribed permissible limit
Kinds, placement and quantity of spacers	Confirmation by visual observations	Completion of assembly of reinforcing bars, and when concrete is not placed immediately right after completion of assembly of reinforcing bars	For deck, beam etc., Min. 4 spacers/m^2 For column, Min. 2 spacers/m^2
Fixing method of arranged reinforcing bars	Confirmation by visual observations	Completion of assembly of reinforcing bars, and when concrete is not placed immediately right after completion of assembly of reinforcing bars	Shall be sufficiently secured against displacement and movement of reinforcing bars caused by concrete placing
Arrangeme-nt of assembled reinforcing bars: Arrangemen t and length of joint and anchorage	Measurement by scale and confirmation by visual observations	Completion of assembly of reinforcing bars, and when concrete is not placed immediately right after completion of assembly of reinforcing bars	Shall conform to the requirements of design document
Arrangeme-nt of assembled reinforcing bars: Concrete cover		Completion of assembly of reinforcing bars, and when concrete is not placed immediately right after completion of assembly of reinforcing bars	More than designed cover according to verification of durability

	Effective depth			Allowable error: Smaller value±3% of design dimension or±30mm (as standard)
	Spacing between center of reinforcing bars			Allowable error: ±20mm (as standard)

[Commentary] (1) After the completion of bar placing and before the placement of concrete, the number and size of the bars should be inspected together with the location of bends, location and length of joints, spacing of bars, and bar support in the form in order to whether those items are satisfied with the required accuracy in design documents. The allowable error of criteria for judgment shall be decided under the consideration with kind and importance of the structure. The prescribed allowable errors for general concrete structure with columns, beams and walls are expressed in Table 7.3.1.

It is advisable to make as many inspections as possible during placing of reinforcing bars to avoid errors and to prevent the re-placement of bars that may require further time and cost. Following a long interval from the completion of bar placement to concrete placement, the inspection and cleaning of bars shall be undertaken to ensure that the bar positions are correct and any mud, oil or other materials which have been deposited are removed. Concrete should therefore be placed quickly after the cleaning and inspection at the end of the assembly of reinforcement.

As the allowable error of prepared dimension of reinforcing bars affects directly to the allowable error of location of assembled reinforcing bars, it shall be decided based on the kind and importance of the structures, member sizes, and directions of such tolerances. An example for general case is shown in Table C7.3.1.

The allowable error for the arrangement of the assembled reinforcing bars shall be ranged from □5 to □20mm. However, the least cover must be kept at every location containing the joint parts.

The relationship between the concrete cover specified in the design drawing and that specified in durability check shall be verified, and decision criteria should be determined using the following equation(C7.3.1).

$$C_m > C_d \qquad \text{(C7.3.1)}$$

where, Cm: measured concrete cover, and

Cd: concrete cover specified in durability check, which is expressed by the following equation.

$$C_d = C - \Delta C_e \qquad \text{(C 7.3.2)}$$

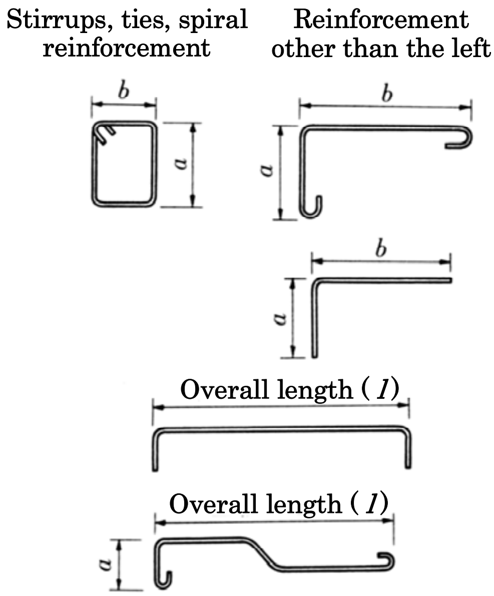
where, C: concrete cover shown in the design drawing

ΔCe: construction error assumed in design.

If the spacers installed properly are larger than the concrete cover specified in durability check, it may be determined that the designated concrete cover is available.

Table C7.3.1 Allowable error of prepared dimensions of reinforcing bars

Type of reinforcing bars		Sign (on light side figure)	Allowable error (mm)
Stirrup, hoop reinforcement, helical reinforcement		a, b	±5
Other types of reinforcing bars	Round bars of 28mm or below diameters, deformed bars 25mm or below diameters	a, b	±15
	Round bars of 32mm or below diameters/ deformed bars 29mm to 32mm diameters	a, b	±20
Total length after completion of cutting and bending		L	±20



(2) When the inspection results were judged that preparation and assembly of reinforcing bars was not in conformity with the requirement, it shall be modified properly. For the bended reinforcing bars, re-bending shall not be undertaken in principle due to the fact that it may harm the quality of the bars.

7.3.2 Inspection of joint of reinforcing bars

(1) When connecting reinforcing bars using gas welded joint, welded joint, mechanical joint etc. as the joint of reinforcing bars, the strength of joint shall be examined before using.

(2) Inspection of joint of reinforcing bars should be carried out in accordance with Table 7.3.2. as a standard. The detailes should be referred to the Guidelines of Anchorage and Joint for Reinforcing Bars.

Table 7.3.2 Inspection of joint of reinforcing bars

Type	Item	Testing method/ Inspection method	Period/Number	Criteria for judgment
Lap joint	Location	Measurement by scale and confirmation by visual observations	Completion of assembly of reinforcing bars	Complying with the requirements of design document
	Joint length			
Gas pressure welding joint	Location	Confirmation by visual observations, and measurement by scale and calipers carried as required	On all joints	Complying with the requirements of design document
	Outlook inspection			Complying with "Standard Qualification Procedure for Gas Pressure Welding Technique" published by "Japan Pressure Welding Society", Refer to Guidelines of Anchorage and Joint for Reinforcing Bars
	Super sonic flow detecting test[2]	Method specified in JIS Z 3062	Sampling [1]	
Butt arc-welded joints	Measureme-nt, Outlook inspection	Measurement by scale and confirmation by visual observations	On all joints	Complying with the requirements of design document, Be without surface defect
	Detailed outlook inspection	Measurement by calipers and other appropriate apparatus	More than 5%	Eccentricity: Not more than one-tenth of bar diameter Slope of joint parts:Not more than one-tenth of measured length For detail, refer to Guidelines of Anchorage and Joint for Reinforcing Bars

	Super sonic flow detecting test	Method specified in JIS Z 3062	Sampling rate: more than 20% and more than 30 samples	For detail, refer to Guidelines of Anchorage and Joint for Reinforcing Bars
Mechanical joint	Inspection test shall be executed on the consideration with the types of joint method For detail, refer to Guidelines of Anchorage and Joint for Reinforcing Bars			

1) One inspection lot is assumed to be pressure welding parts that the same working party constructed on the same day, and the standard of the lot size is about 200 samples. In the case of manual gas pressure welding, all SD490 bars shall be inspected. Sampling inspections shall be conducted at 30 locations per inspection lot for other types of bars. In the case of automatic gas pressure welding, sampling inspections shall be conducted at ten locations per inspection lot.

2) Inspections may be eliminated in the case of the hot punching method.

(3) When the inspection results for joints were judged not to satisfy the requirement, appropriate countermeasures shall be taken.

[Commentary] (1) and (2) Various joints have been developed for reinforcing bars to facilitate the construction of joints. Inspections shall be conducted to verify that all joints for reinforcing bars meet the designated performance requirements. Gas welded joints include manually gas welded joints, automatically gas welded joints and hot punching gas welded joints. Welded joints include butt arc-welded joints, butt arc stud welded joints, butt resistance welded joints and flare welded joints. Mechanical joints include crimped-sleeve joints, crimped-sleeve threaded joints, threaded deformed bar joints, mortar grouted joints, friction welded and threaded joints, wedged joints and combination joints. The performance of welded, mechanical and other types of joints varies according to the type of joint, materials used, skill of engineer performing jointing and method of jointing.

For details, refer to the Guidelines of Anchorage and Joint for Reinforcing Bars. Gas welded joints may be inspected in accordance with the Standard Specifications for Gas Welding of Reinforcing Bars prepared by the Japan Reinforcing Bar Joints Institute.

In generals, an inspection test for gas pressure welding joint is approximately executed according to the “Standard Qualification Procedure for Gas Pressure Welding Technique” published by “Japan Pressure Welding Society”.

(3) When the judgment does not comply with the specifications, the measures shall be performed according to the recommendations of “Standard Qualification Procedure for Gas Pressure Welding Technique”.

7.4 Inspection of Formwork and Shoring

(1) Inspection of formwork and shoring should be carried out in accordance with Table 7.4.1 as a standard.

Table 7.4.1 Inspection of formwork and shoring

Item	Testing method/ Inspection method	Period/Frequency	Criteria for judgment
Materials of form and shoring and kinds, material, shape and size of form tie	Confirmation by visual observations	Prior to construction of form and shoring	Shall conform to provided qualities and sizes
Placement of shoring	Confirmation by visual observations and measurement by scale	Completion of construction of shoring	The concrete members shall comply with the specifications on Sections 8.2 and 8.3 as hardened concrete members
Position and quantity of form tie	Confirmation by visual observations and measurement by scale	Prior to placing of concrete	
Shape and size, position of form	Measurement by scale	Prior to placing of concrete and during of placement	
Clear distance between form and reinforcing bar placed near side of form	Measurement by scale		Complying with the specifications for cover on Section 7.3.1

(2) When the inspection for formwork and shoring shows unsatisfactory results, appropriate countermeasures shall be taken.

[Commentary] If the structure is inspected upon completion, inspecting the formwork or supports may not be necessary. Defective formwork may, however, frequently cause problems during construction or after the hardening of concrete. Then, formwork and supports shall be inspected.

(1) Formwork and shoring must provide the sufficient strength and safety against the most unfavorable combination of actual loads prior to and during placing of concrete. Thus, inspections for those kinds of loads should be performed according to Table 7.4.1 not to cause such unusual matters as expansion of forms, leakage of mortar, sliding, leaning, settlement, looseness of connections, etc., and the configuration and dimensions of structures or members, and safety of construction must be ensure additionally.

Construction accuracy of formwork and shoring shall guaranty the required position, shape and dimension of the structure. Even if individual errors may be generally acceptable, the cumulative effects of these errors may have an adverse affect on the structures. Thus, it must ensure that the cumulative error does not exceed the prescribed allowable error.

CHAPTER 8 INSPECTION OF CONCRETE STRUCTURE

8.1 General

(1) The Owner shall inspect the surface condition and locations and dimensions of members of concrete structures.

(2) Concrete cover shall be inspected by nondestructive testing in accordance with Section 8.5 for key structures, slabs that are likely to have inadequate concrete cover and members that are highly likely to be subjected to chloride attack or carbonation under severe conditions.

(3) In cases where it is doubtful whether the structural performance requirements are achieved because of trouble during construction, structural performance shall be inspected as required.

(4) In cases where the structure is found to be unacceptable, or where detailed inspections become necessary based on the results of inspections including nondestructive tests, the safety and serviceability of the structure shall be verified by loading tests in accordance with Section 8.6.

[Commentary] (1) Concrete structures should be constructed as initially planned as possible within the allowable range if they are to meet the designated performance requirements. For verification, the Owner of the structure who accepts it should assume the responsibility for conducting inspections for verifying whether the surface condition is satisfactory or not and whether the location, shape and dimensions of the structure are within the allowable range or not.

Concrete structures like pile foundations constructed underground and high bridge piers for which no inspections are possible after the removal of formwork can be inspected only during construction or at the completion of part of the work.

For structures constructed under severe conditions, items for detailed inspections should be specified considering subsequent maintenance, and not only the appearance should be inspected by visual observation or measurement of dimensions but also nondestructive testing should be conducted for inspecting the quality of concrete and condition of reinforcement.

(2) In order for the structure to meet the performance requirements, the concrete cover as designed should be made available. For slabs in which concrete cover is likely to be insufficient or for members that are expected to cause damage to third parties in the case of spalling, nondestructive testing should be conducted for inspecting the concrete cover. For members that are likely to be subjected to steel corrosion due to chloride attack or carbonation, nondestructive testing should be conducted also for inspecting the concrete cover.

(3) Problems expected during construction include the frost damage to the concrete of the structure, poor concrete strength as determined based on the results of concrete acceptance tests and suspicion about structural safety for some well-founded reasons. In these cases, inspections should be conducted to verify that the designated performance requirements are achieved.

8.2. Inspection of Surface Texture

(1) Inspection of surface texture should be carried out in accordance with Table 8.2.1. Inspection shall be performed before any surface treatment.

Table 8.2.1 Inspection of surface texture

Item	Inspection method	Criteria for judgment
Situation of exposed concrete surface	Confirmation by visual observations	Shall be flat and shall not be recognizable defects such as from honeycombs, ridges, air bubbles and etc. Shall not be shown the insufficient cover and shall have a normal surface
Crack	Measurement by scale	Shall be within the permissible limit to satisfy of the requirement as the structure
Joints	Confirmation by visual observations and measurement by scale	Shall ensure the mutually tight bond between lower and upper layers

(2) When the defects are recognized during the inspection, the following counter-measures shall be conducted as required.

(a) Defects on a concrete surface such as abrupt bulges and ridges shall be removed to flatten the surface. Other surface imperfections such as honeycombs and fractured portions shall be removed and repaired appropriately.

(b) If initial cracks larger than allowed occur, the structure shall be repaired properly.

(3) In the case of mass concrete, besides inspection carried out as stipulated in Clauses (1) and (2) above, the inspection of thermal crack shall be conducted by visual observations after formwork removal. The timing of inspection of thermal cracks shall be decided taking into account temperature change in the structure. When the inspection points out the harmful cracks, adequate countermeasures shall be taken. When repair is necessary, appropriate materials and methods shall be selected so as to satisfy the requirement of the structure.

[Commentary] (1) and (2) Inspection of surface texture shall be performed prior to the undertaking of measures such as repair or refinishing. It is important to inspect the surface just after removal of formwork and curing. The visual inspection for surface defects such as cold joints, honeycombs, ridges, abrupt bulges, bubbles and different tone of colors will be conducted by visual observation shall be performed. Also, the location where the reinforcing bars have been visibly exposed or where the shapes of the reinforcing bars are clearly recognized due to insufficient concrete cover even before the reinforcing bars have not been exposed. Prior to repair, the examination on the service environment, location and status of defects shall be performed. Repair should be applied while implementing adequate quality management programs so as to eliminate the need of re-repair in the maintenance phase, by selecting concrete, mortar or polymer cementitious mortar with appropriate mix proportions considering the environment, location and size.

Initial cracks are ascribable to thermal stress due to the heating of concrete, drying shrinkage or loading. Although some cracks have little influence on the structure, other types of cracks may be hazardous to the structure. Therefore, allowable criteria of judgment shall be prescribed properly depending on the degree of necessity. The allowable crack width shall be determined in accordance with Section 8.3.2 of the Standard Specifications for Design and Construction of Concrete Structures: Design. The threshold crack width for steel corrosion specified in Table 8.3.2 shall be applied. In addition, it may refer to the “Limits of crack width concerning with requirement of repair” on “Recommendation for Repair and Reinforcement of Cracking in Concrete” that is published by Japan Concrete Institutes.

At the joints between placed layers, the uniformity of the existing concrete and newly placing concrete shall be inspected by visual observations. When the performance of joints between the both concretes is considered insufficient from the inspection results, it should be repaired by the effective method for repairing for cracks.

Works shall be conducted in accordance with the “Recommendation for Repair and Reinforcement of Cracking in Concrete” published by Japan Concrete Institute.

(3) Concrete to be regarded as mass concrete is outlined in the commentary of Section 14.1 in “Materials and Construction: Construction Standard”.

For mass concrete, the investigation with special caution shall be made in addition to the ordinary inspection of general structures due to the possible development of the thermal cracking which may impair the required quality or function of the structure. Period of inspection for thermal cracking shall be decided in connection with the alteration of the temperature in the structure, such as after the removal of forms, when the temperature of the concrete becomes nearly equal to that of the atmosphere and when the average temperature of the member becomes the lowest during the winter.

Materials used for crack repairs and their application methods are very diverse. Filling, grout injection and surface treatment with resins are generally adopted. Epoxy resins are frequently used for repairing cracks. The physical properties, applicable temperature, usable life, cohesion and use condition vary even for one and the same type of resin. In the related field, developments have been made both for materials and methods. Decision should be made based on the latest data. For structures that function properly only by cutting water leakage, cutting off water may replace repair.

8.3. Inspections of Locations and Dimensions of Concrete Members

(1) The locations and dimensions of concrete members should be inspected in accordance with Table 8.3.1 as a standard practice.

Table 8.3.1 Inspection of location, shape and dimension of concrete members

Item	Inspection method	Criteria for judgment
Plane position	Measurement by scale, transit, level and etc.	Allowable error: 30mm (as standard)
Height in design		Allowable error: 50mm (as standard)
Section size		Allowable error: 0~+50mm of designed length (as standard)

(2) When the inspection results reveal that the criteria of judgment are not satisfied, the countermeasures such as chipping, reconstruction and additional casting of concrete shall be taken.

[Commentary] (1) Inspection of location, shape and dimension of concrete members shall be in conformity with the prescribed accuracy based on the design documents. Allowable errors shall be decided considering the type and importance of the structure. The decision criteria in Table 8.3.1 present the standard tolerance for concrete structures constructed under ordinary structural and construction conditions. Tolerances for sectional area or length may vary according to the type of the member, e.g. columns, beams or walls.

8.4 Inspection of Concrete Properties in Structure

(1) Inspection of concrete in the structure shall be carried out, in the case the concrete is judged unacceptable during the acceptance inspection or in the inspection during construction, or when these inspections are not properly carried out. The following inspections shall be applied:

(a) Tests on the specimens taken upon delivery and subjected to the same conditions as the structure.

(b) Tests on the specimens taken from the structure.

(c) Nondestructive tests will be applied on the concrete in structures.

(2) In case the inspection evokes suspicion on the performance of the structure, tests shall be conducted to comprehensively judge the structural performance from various aspects, combining nondestructive tests, tests on drilled cores or sawed beams and loading tests on the structure. The loading test for confirming safety and serviceability of

the structure shall be conducted in accordance with Section 8.6. In case the structure does not conform with the performance requirements, appropriate countermeasures shall be taken, including removal of defective concrete, re-placing of concrete and strengthening of the structure.

[Commentary] (1) A simple and reliable test method for concrete in the structure is yet to be established. Judging from the field experience, the required performance of concrete in the structure can be assured by carrying out an acceptance inspection as specified in Chapter 5 and inspection during concreting as specified in Section 7.2 and ensuring conformity. Accordingly, omission of the inspection of concrete in the structure is permitted, provided that the acceptance inspection of the as-delivered concrete and placement-related inspection regarding transportation, depositing and curing is duly carried out and that the concrete is judged acceptable.

However, achievement of the required performance cannot be assured when concrete judged unacceptable by the acceptance inspection has already been placed in the structure or when the inspection of concreting work cannot be duly carried out. In such a case, concrete in the structure should be inspected as required.

Three methods are generally practiced for confirming the quality of concrete in the structure as given in the items (a), (b) and (c). Concrete structures are generally designed based on the compressive strength of concrete. Identifying concrete strength is therefore extremely important. In addition to the inspections described in Chapter 5 and Section 7.2, nondestructive tests such as Shmidt hammer tests (JSCE-G 504) should be conducted for inspection. The decision criteria should be determined fully considering the variations of test results. Decision should be made comprehensively by integrating the results of inspections described in Chapter 5 and Section 7.2.

(2) This is a requirement for confirmation of the performance of a structure when the inspection evokes suspicion about the development of the required performance of the concrete in the structure, such as concrete damage due to freezing, etc. In such a case, detailed quality tests should be conducted on concrete in the structure to examine if the structure can achieve the required purposes.

Test methods include nondestructive tests such as Shmidt hammer tests (JSCE-G 504) and ultrasonic testing, tests using concrete specimens (cores or beams) cut from the structure, in-situ tests for surface air permeability, tests for estimating concrete mix proportions and loading tests. The qualities of concrete in the structure may not be accurately judged by a single test method. Multiple tests should be combined to make a comprehensive judgment.

When the test results indicate that the performance requirements of the structure are not fulfilled, appropriate measures should be taken including strengthening of the structure, instead of removal of defective concrete and re-placing of the part.

8.5 Inspection of the Cover

(1) For structures or members for which inspections of concrete cover are found necessary after the hardening of concrete, the availability of designated concrete cover should be verified by nondestructive testing.

(2) Concrete cover should be inspected by nondestructive tests based on the decision criteria shown in Table 7.3.1.

(3) If the concrete cover is found unacceptable as a result of inspections, comparison shall be made among such methods as the chipping and re-construction of concrete and the application of protective measures like the coating of concrete surface. Then, appropriate measures should be taken to ensure the protection of steel.

[Commentary] (1) and (2) Though the cover is investigated at the time of the inspection of fabricated reinforcement, the cover can change depending on the degree of security of the formwork, reinforcement and spacers. The concrete cover of a completed structure should be measured by such nondestructive testing methods as electromagnetic induction, electromagnetic wave reflection and radiography. For important structures, members that are frequently likely to be subjected to steel corrosion under severe conditions and members that greatly affect third parties in particular, the concrete cover should be measured by nondestructive tests.

The criteria for estimating the concrete cover by nondestructive tests may be the same as shown in Table 7.3.1. When applying the criteria, the precision of the measurement equipment should also be considered. The precision should generally be approximately 5 mm. The measurement error due to the precision of equipment is assumed to be a risk in inspection when measuring the concrete cover.

Sampling inspections are generally conducted. Cross sections should be specified for measurement at certain intervals along the length of the structure or each time the cross section varies. Measurements should be taken at one point at the least in each element in the measurement cross section. Measurements should be made for a length of one meter or more transverse to the outermost reinforcement of each element.

For structures in which concrete cover is found insufficient as a result of sampling inspections, detailed investigations should separately be conducted.

(3) Insufficient cover reduces the performance of concrete to protect steel reinforcement. This requirement was established to ensure the performance.

8.6 Loading Test of Member and Structure

(1) In cases where a structure is considered unacceptable in inspections conducted before the completion of the structure, or where verification of structural performance is considered necessary because of well-founded suspicion about the performance of the structure, the performance of the structure should be verified.

(2) When confirming the safety and serviceability of the structure or members by the loading tests, the method of loading test shall be determined in order to certainly examine the required performance. Special care shall be taken when determining timing and methods of loading, the magnitude of the load, etc, so as not to exert harmful influence on the structure or members.

(3) It shall be ensured that the amount of deflection and strain during and after the loading test are not unusual in comparison with the values estimated in the original design.

(4) Appropriate countermeasures such as strengthening the structure or members

shall be taken in case that the safety and serviceability of the structure or members are probably insufficient based on results of loading test.

[Commentary] (1), (2) and (3) When the confirmation by loading tests shall be performed, it shall be considered the conforming tests for the performance of elements such as members and loading tests of structure. In the application of the test results, special attention needs to focus on that fact that the performance assessed in loading tests is generally limited to the part of elastic behavior.

The loading tests specified in this section shall be conducted by a responsible engineer who recognizes the need of the tests to verify the safety, serviceability or other parameters of the structure in cases where concrete strength is considered to be poor based on the results of concrete acceptance tests or concrete inspections during construction or where there is well-founded suspicion about the safety and serviceability of the structure during construction. The testing period shall be determined so that the loading tests could be performed after sufficient concrete strength is attained so that introduction of weak spots on the structure due to the early application of load can be avoided.

In case a new concept, a new construction method or a special material is adopted during the construction of structures, the loading test method shall be required as prescribed in the construction specifications concerned.

Behaviors applied to the structure or on the members by loading tests therein were varied depending upon the magnitude and type of the load, therefore it is important to select an appropriate method of testing so that it can be judged whether the structure or members of the structure have the strength and performance prescribed in the design or not. Loading tests may generally be done by the static load application, but the rate of application and the magnitude of a load shall be selected so as not to create weak spots by an expensive load.

To examine the behavior of members and structures, measurement of deformation in the whole structure, deflection of respective members, and the strain of the respective parts is required. The position for monitoring and the loading method of those examinations shall be properly selected based on the purpose of the test, the method of analysis and the degree of importance of the structure.

In the static loading tests, it shall be required to take care not to be affected by vibration, impact or other dynamic movement. The measurement errors that are largely affected by atmospheric temperature change during the test shall be kept as small as possible or an adjustment of the errors in the test results shall be prepared in advance.

Cracking that may exert harmful effects on the strength and durability of the structure, notably large residual deformations or other defects in the structure must be carefully observed not only during but also after the test. In addition, the propriety of the testing method shall be confirmed together with the performance of the structure. For the confirmation of the dynamic properties of a structure, such as natural frequency, a vibration loading test should be performed.

CHAPTER 9 RECORDS

9.1 General

(1) The results of inspections of concrete structures shall be organized and stored as inspection records.

(2) If repair, renovation or other corrective measures are taken based on the results of inspections, the reasons, repaired locations and range and materials used shall also be recorded.

[Commentary] (1) The results of inspections conducted before the structure is put into service serve as the initial values in inspections in the maintenance of the structure. The performance requirements for concrete structures in such terms as durability, safety, serviceability and restorability should be met throughout the design useful life. The inspection results for concrete structures are important data for identifying the initial conditions of the structure for maintenance, preparing inspection and investigation plans and analyzing the progress of the alteration and their causes. Inspection results shall therefore be kept with the construction records received from the contractor. These records should in principle be retained as long as maintenance is continued.

When maintaining a structure, not only the construction records received from the contractor but also (i) results of crack investigations upon completion of the structure, (ii) results of inspections of concrete cover, (iii) investigation results at the time of inspection of concrete during construction e.g. results of concrete strength tests based on rebound, (iv) results of inspection of completed part of the structure and (v) results of inspections of initial defects and past repair shall be recorded. In relation to crack investigations, recording crack widths, lengths and locations even where the width is within the allowable range may sometimes be useful during maintenance (Records in Chapter 12 of Part I Maintenance). The minimum number of records should be stored to ensure the use and organization of records.

9.2 Identifiers of Structures

Identifiers should be attached to structures in which such information is described as the name of the structure, load, design and construction organizations, date of commencement of construction, date of completion, and persons responsible for design, material supply, construction and construction control.

[Commentary] Specifying the names of chief design engineer and persons responsible for construction and construction management is explicitly defining the positions of respective engineers and paying tribute to the engineers engaged in the construction work. This is expected to contribute to the improvement of the durability of the structure and is also important to maintenance.

Special Concrete

CHAPTER 1 GENERAL

1.1 Scope

"Materials and Construction: Special Concrete" covers standards concerning the matters required for producing or constructing concrete structures that involve special materials, functions, construction methods, construction environment, structural formats and production methods.

[Commentary] In order to enable concrete structures to meet the designated performance requirements, it is sometimes necessary to use concrete that involves special materials, functions, construction methods, structural formats and production methods or to construct concrete under a special construction environment.

"Materials and Construction: Special Concrete" presents standards concerning the matters required for producing or constructing special concrete. Concrete that uses special materials and provides special functions includes expansive cement concrete, lightweight aggregate concrete, concrete using continuous fiber reinforcing materials, short fiber reinforced concrete and high strength concrete. Concrete that is constructed by a special method includes high fluidity concrete, shotcrete and prepacked concrete. Concrete that is constructed under a special environment includes underwater concrete and offshore concrete. Concrete that is of special structural format or is produced by a special method includes prestressed concrete, steel-concrete composite structures and industrial products.

There may be cases where special concrete is actually constructed or applied under different conditions from those described in this chapter. Then, special concrete shall be constructed in accordance with "Materials and Construction: General" or "Materials and Construction: Construction Standards". In cases where the stipulations in "Materials and Construction: Special Concrete" are inadequate or where applying the stipulations is not necessarily appropriate, special concrete should be constructed so as to be fit for the actual conditions fully considering the stipulations of "Materials and Construction: Special Concrete". For the special materials, methods and types of construction not sufficiently stipulated in this Specification, the following guidelines and manuals prepared by the Japan Society for Civil Engineers should be consulted.

“Recommendation for Design and Construction of Steel Fiber Reinforced Concrete”, 1983.

“Manual of Design and Construction for Lightweight Aggregate Concrete Structures”, 1985 (In Japanese)

“Recommended Practice for Concrete Made by Continuous mixer”, 1986 (In Japanese)

“Recommendations for Design and Construction of Structures by Prestressed Concrete Panel Composite Slab Method”, 1987

“Recommendations for Design and Construction of Prestressed Concrete”, 1991 (In Japanese)

“Recommendations for Design and Construction of Anti-washout Underwater Concrete”, 1991

“Design Code for Steel-concrete Sandwiches Structures”, 1992

“Recommended Practice for Concrete Containing Air-entraining and High-range Water-reducing

Agents – Recommendations for construction of high fluidity concrete", 1993

"Recommended Practice for Expansive Concrete", 1993

"Recommendations for Design and Construction of Concrete Structures Using Silica Fume in Concrete -Draft-", 1995

"Recommendations for Design and Construction of Concrete Structures Using Continuous Fiber Reinforcing Materials", 1995

"Recommendation for Design and Construction of Composite Structure", 1997 (In Japanese)

"Recommendation for Construction of High Fluidity Concrete", 1998 (In Japanese)

"Recommendation for Design of Pillar Member using Reinforced Concrete strengthened with Steel Fiber", 1999

"Recommendation for Concrete Pumping", 2000 (In Japanese)

"Recommendation for construction of tunnel concrete", 2000

"Recommendation for Design and Construction of Electro-chemical Protection against Corrosion", 2001

"Recommendation for Design and Construction of structure using self-compacting, high-strength and durable concrete", 2001

"Guidelines for Design and Construction of Concrete Using High Strength Fly Ash As Artificial Aggregate (draft)", 2001

"Present and Problems Concerning the Leaching of Micro-components from Concrete", 2003

"Guidelines for Design and Construction of Reinforced Concrete Using Epoxy Resin Coated Reinforcing Bars (revised edition)", 2003

"Guidelines for Design and Construction of Ultra High Strength Fiber Reinforced Concrete (draft)", 2004

"Guidelines for Design and Construction for Surface Protection Methods (draft)", 2005

"Guidelines for Shotcrete (draft): Tunnels", 2005

"Guidelines for Shotcrete (draft): Slopes", 2005

"Guidelines for Design and Construction of High Performance Fiber Reinforced Cement Composite Materials (draft)", 2007

Constructing the special concrete discussed in "Materials and Construction: Special Concrete" frequently requires professional skills. It is stipulated that special concrete should be constructed under the guidance of professional engineers with adequate knowledge and experience concerning the specific types of special concrete. The acceptance tests for the special concrete discussed in "Materials and Construction: Special Concrete" shall be conducted either by the Contractor or the Owner according to the type of concrete. When the acceptance tests for special concrete are conducted by the Contractor, the Owner needs to verify the results of inspection. The responsibilities of the Contractor and the Owner should therefore be defined explicitly.

1.2 Definitions

The terms used in Standard Specifications for Concrete Structures "Materials and Construction: Special Concrete" are defined as follows:

Expansive concrete - A type of concrete to which an expansive admixture has been added as a mineral admixture.

Expansive admixture - An admixture that is mixed with cement and water to generate ettringite or calcium hydroxide for causing concrete to expand.

Chemical prestress - Compressive stress that is applied to concrete when the expansion of expansive concrete is restrained by such objects as reinforcing bars.

Chemical prestrain - Initial strain that is applied to the restraining objects when the expansion of expansive concrete is restrained by such objects as reinforcing bars.

Shrinkage-compensating concrete - Expansive concrete with expansion capacity to offset or reduce tensile stress caused by the drying shrinkage using chemical prestress.

Chemical prestressing concrete - Expansive concrete with expansion capacity sufficient to leave chemical prestress even in case of drying shrinkage.

Shrinkage-compensated concrete - Reinforced concrete to which chemical prestress is applied to offset or reduce the tensile stress caused by drying shrinkage, mainly by using shrinkage-compensating concrete and restraining the expansion of concrete with reinforcing bars or other materials.

Chemical prestressed concrete - Reinforced concrete to which high expansion capacity is provided, mainly by using chemical prestressing concrete so that the chemical prestress that is introduced into concrete by restraining expansion and the chemical prestrain that is introduced to reinforcing bars may remain even where the chemical prestress and prestrain are partly eliminated by drying shrinkage

Lightweight aggregate - A kind of aggregate whose density is lighter than that of normal rock, used for reducing concrete weight or for the purpose of thermal insulation, etc.

Lightweight aggregate concrete - Concrete with specific gravity lower than that of normal concrete, produced using lightweight aggregate.

Surface-dry state of lightweight aggregate - The state of lightweight aggregate in which only water on the exposed surfaces is removed from its wet state.

Specific gravity of surface-dry lightweight aggregate - The density of a lightweight aggregate particle in a surface-dry state.

Prewetting - The work of soaking aggregates before using it.

Continuous fiber reinforcing material - Concrete-reinforcing materials made of continuous fibers bound together by adhesive. They can be unidirectional reinforcing materials,

round-up or wove continuous fibers.

Continuous fiber tendon - Continuous fiber reinforcing material used for applying prestress on concrete.

Continuous fiber - Continuous fiber for reinforcing the concrete such as carbon fiber, aramid fiber and glass fiber.

Fiber binder - Binder that solidifies fibers. Plastics such as epoxy resins and vinyl ester resins.

Short fiber reinforced concrete - Steel fiber reinforced concrete or synthetic fiber reinforced concrete.

Steel fiber reinforced concrete - Concrete made by mixing steel fiber into concrete, mainly to improve its toughness and abrasion resistance.

Synthetic fiber reinforced concrete - Concrete mixed with synthetic fibers mainly to enhance the effectiveness for preventing explosive fracture or spalling.

Short fiber content - Volume percentage of short fibers per cubic meter of short fiber reinforced concrete (%).

Steel fiber content - The volume percentage of total volume of steel fiber present in one cubic meter of steel fiber reinforced concrete.

Tension softening curve - The curve expressing the relationship between tensile stress and crack width.

Explosive fracture - Delamination or spalling of concrete surface when the concrete is subjected to fire.

Unit volume of dry-rodded coarse aggregate - The bulk volume of coarse aggregate to produce one cubic meter of concrete. It is obtained by dividing the unit weight of coarse aggregate into its weight per unit bulk volume (bulk density).

High fluidity concrete - Concrete with greatly enhanced flowability but still possesses high resistance to segregation.

Self-Compactability - The property of fresh concrete to uniformly fill all corners of formworks by its own weight without the need of external compaction.

Segregation resistance - The property of fresh concrete that enables to maintain its uniform distribution, i.e. avoiding the segregation, of constituent materials under gravity or application of external forces.

Flowability - The property expressing the level to which fresh concrete moves under gravity or application of external force.

Passability for narrowed area - The ability of fresh concrete to pass through narrowed gap(s) between reinforcing bars and fill up space by its own gravity without the risk of

segregation.

Viscosity agent - A type of admixture that increases viscosity and segregation resistance. Some of them have the ability to reduce the variations in quality of fresh concrete.

Unit absolute volume of coarse aggregate - The value is obtained by dividing the unit content of coarse aggregate by its density in saturated surface-dry state. Notation: m^3/m^3.

Shotcrete - Concrete conveyed by compressed air (using pump or compressor) through the conveying hose and sprayed from the nozzle at the end of the hose onto the target surface.

Lining concrete - Cast-in-place concrete inside the shotcrete sprayed in a tunnel constructed by the drill-and-blast method. Concrete is generally unreinforced. Where the lining is subjected to earth pressure or asymmetric pressure, however, reinforcing bars are used for reinforcement.

Wet spraying: Spraying of concrete mixed with all the materials using compressed air.

Dry spraying - Spraying of dry-mixed materials by pumping them using compressed air and adding designated amounts of water at and before the spray nozzle.

Set-accelerating agent - The chemical admixture added to shotcrete in order to shorten the setting time and increase the early strength of shotcrete.

Percentage of rebound - Percentage of the mass of concrete that rebounds without being attached to the surface in the total mass of concrete sprayed.

Dust concentration - Mass of solid fine particles that rebound or fly from nozzles and float in the air during spraying, expressed in milligrams per cubic meter of air.

Prepacked concrete - A kind of concrete produced by packing coarse aggregate particles of a specified grading into formwork and grouting mortar between the voids of the prepacked aggregates.

Grouting mortar - A mixture of cement, fly ash or other mineral admixtures, sand, chemical admixture, and water; used for injection into pre packed concrete, etc.

Minimum size of coarse aggregate - The size of coarse aggregate specified by the nominal size of the largest of all the sieves on which at least 95 % (by weight) of the aggregate is retained.

Underwater concrete - Any concrete used for construction under normal water, slurry or sea-water.

Stabilizer - Liquid used mainly for preventing the collapse of tunnel walls. Composed mainly of water and also of bentonite and polymer.

Anti-washout underwater concrete - Underwater concrete with segregation resistance enhanced by using anti-washout admixture.

Underwater washout resistance - The ability of preventing segregation under the washout

action of water.

Test piece made in water - The test piece made by dropping anti-washout underwater concrete into the mold placed underwater as specified by JIS A 1132.

Test piece made in air - The test piece made by filling anti-washout underwater concrete into the mold in air as specified by JIS A 1132.

Strength ratio of underwater concrete to normal concrete - The ratio of compressive strength of the test piece made in water to the test piece made in air at the same age.

Prestressed concrete - A type of reinforced concrete prestressed by means of prestressing the steel etc.

Prestressing Steel - High strength steel used to prestress concrete.

Prestress - Stress introduced in concrete before application of service loads to reduce tensile stresses induced in concrete by loads.

Tendon - A prestressing bar or strand.

Duct - Space created through the concrete of a posttensioned prestressed concrete member for enclosing a tendon.

Sheath - A case that forms a duct.

Anchorage fixture - A fixture for anchoring the ends of a tendon to concrete for transmitting prestress to the member.

Connection fixture - A fixture for connecting one tendon to another.

Pretensioning - Placing concrete while tendons are provided with tension, and transmitting the tension provided to tendons to concrete through the bond of the tendons and concrete after the hardening of concrete, to apply prestress.

Posttensioning - Providing tension to tendons after the hardening of concrete and applying prestress by anchoring the ends of tendons to concrete.

Grout for prestressed concrete - A mixture of cement, water and admixtures to fill the gap between the duct and tendon after prestressing in posttensioning.

Internal prestressing method - Method of prestressing using tendons placed in the concrete member.

External prestressing method - Method of prestressing using tendons placed outside the concrete member.

Deviation fixture - A fixture used for maintaining or deviating the position of tendon in the external prestressing method.

Deviation zone - A zone where the deviation fixture is fixed to the concrete member and a component of the tension generated by deviating the tendon is transmitted to the member.

Concrete product - Precast concrete products manufactured in succession in controlled factories.

Moist curing - A method of curing where concrete is kept in a moist condition for a certain period of time after placing.

Insulated curing - A method of curing where the necessary temperature is maintained by utilizing the heat of hydration of cement and preventing escape of heat to the utmost, by covering the surface of concrete with highly insulating materials

Accelerated curing - A curing method used to accelerate the hardening process and strength development of concrete.

Steam curing - An accelerated method of curing concrete in water vapor at high temperature

Steam curing at atmospheric pressure - Steam curing at atmospheric pressures.

Autoclave curing - A method of curing in a steam boiler (autoclave) at high temperature and high pressure.

Centrifugal compaction - Compaction of concrete by centrifugal force using a formwork revolving at an extremely high speed.

Casting - Production of factory products by placing concrete into a form and applying compaction to the placed concrete.

Instant demolding - Removal of a part or all of the formworks for concrete with an extremely stiff consistency immediately after placing and compacting using strong vibration or pressure.

Hot concrete – A concrete product of which temperature is over 40°C. immediately after the completion of mixing.

[Commentary] Lightweight aggregate: Lightweight aggregate is classified into artificial lightweight aggregate, natural lightweight aggregate and by-product lightweight aggregate. In this specification, only structural lightweight aggregate which is consistent in quality and can be used for making lightweight concrete is dealt with.

Surface-dry state of lightweight aggregate: For ordinary aggregates, such as river sand, river gravel and crushed stone, the saturated surface-dry state is defined as one of the standard states of their moisture content to be considered in expressing specified mix and other matters. In the case of lightweight aggregate, however, it is almost impossible to obtain its saturated surface-dry state, because lightweight aggregate generally absorbs much water and it takes a long time to saturate the insides of aggregate particles. Accordingly, in the case of lightweight aggregate, the state in which only the parts near the surfaces are nearly saturated with water and there is no water on the surface even if the insides of aggregate particles are not saturated is defined as surface-dry state. For practical purposes, this state is treated as the state to which saturated surface-dry state of ordinary aggregate corresponds. Therefore, the surface-dry state of lightweight aggregate is not a constant one, and it shall be noted that specific gravity in a surface-dry state varies depending on the degree of water saturation.

Prewetting: Aggregates in dry state absorb water of concrete during mixing and transporting. In order to minimize the degree of water absorption, it is necessary to conduct the work of soaking aggregate in water before using it. This operation is called prewetting.

Continuous fiber reinforcing material: Continuous fiber reinforcing material is the generic name of a material made of continuous fibers tied together by fiber binder for use as reinforcing material in concrete instead of steel bar or prestressing tendon. Continuous fibers like carbon fiber, Aramid fiber, glass fiber, or Vinylon fiber, etc, and binders like epoxy resin, vinyl ester resin, etc are usually used.

Steel fiber content: The reason for expressing the content of steel fiber in the unit of volume percentage of steel fiber in one cubic meter of concrete is that the volume, not the weight, of steel fiber in the matrix is the most directly influencing factor of the strength and deformation in steel fiber composite material.

Tension softening curve: It is believed that at the crack tip, there is a so-called fracture process zone governed by on the formation and the development of micro-crack (Fig. C1.2.1). Fracture process zone is classified into micro-cracking zone with many micro-cracks such as peeling-off of mortar at the surface of aggregate and the bridging zone with aggregates or steel fibers lying across the crack. Tension softening curve shows the relationship between tensile stress transferred in fracture process zone at the crack tip and the crack width.

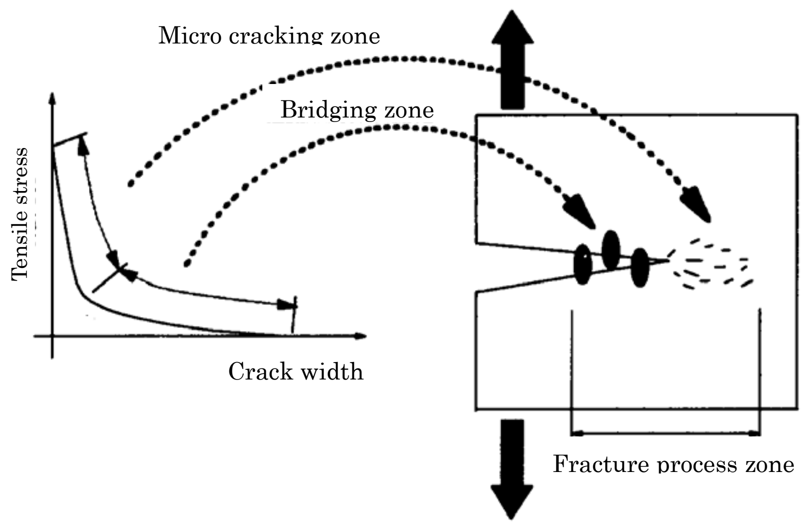


Fig. C1.2.1 Fracture process zone

High fluidity concrete: The definition of high fluidity concrete is in fact the definition used by Japan Concrete Institute or Architectural Institute of Japan. However, high fluidity concrete in this specification indicates the one with self-compactability.

Passability for narrowed area: The ability of fresh concrete which passes and fill into narrowed areas, such as the space between reinforcing bars, by its own weight without the need of external compaction. Passability can be approximately measured by U-shape filling test, box filling test or funnel flow test.

Absolute volume of dry-rodded coarse aggregate per unit volume of concrete and Bulk volume of coarse aggregate per unit volume of concrete: These values must be considered during mix design because they affect the self-compactability of high fluidity concrete or passability. Generally, as absolute volume of dry-rodded coarse aggregate per unit volume and bulk volume of coarse aggregate per unit volume of concrete become small, the Young's modulus of high fluidity concrete becomes lower, therefore, appropriate value must be determined. The weight of coarse aggregate per unit volume of concrete depends on density of coarse aggregate even if absolute volume of dry-rodded coarse aggregate per unit volume is the same.

Prepacked concrete: Coarse aggregate of a specific grading means the one which contains a little amount of particles passing the 15 mm sieve. Special mortar means mortar which possesses such properties as high flowability, little segregation, small shrinkage and expansibility.

Minimum size of coarse aggregate: The terms “minimum size of coarse aggregate” doesn’t mean the minimum size of the smallest particle. The definition was given based on the reason that it is not practical and improper to determine the actual minimum size by measuring the individual minimum size of particles, since coarse aggregate contains particles with various shapes. This term is used only in the case of pre-packed concrete.

Concrete product: Some example of concrete products are Hume pipes, piles, blocks, railroad sleepers, shield segments and precast composite slabs. They are mass-produced in succession in factories for different applications. Concrete members produced in factories are usually called factory product, precast product, concrete product, cement product, or prefabricated product. In this Specification, however, the term "concrete product" is used.

Moist curing: It is to ensure the necessary amount of water for the hydration of cement in concrete since it is not sufficient just by preventing the evaporation of water from the placed concrete. This curing method is also effective in preventing cracking due to drying shrinkage during initial hardening stage.

Temperature controlled curing: This curing method is to control the temperature in each part of the concrete to facilitate the normal hardening process and to avoid the cracking after hardening as well as and the development of excessive internal stress. In utilizing this curing method, it is necessary to take into account both the size of members and the effect of construction condition.

Accelerated curing: There are some curing methods to accelerate the hardening rate of concrete, such as steam curing, autoclave curing, hot water curing, electrical curing, infrared curing, and high frequency curing. However, in general, steam curing is widely used.

Steam curing: Steam curing is usually conducted at a higher temperature than 35°C. Such curing as that to maintain the temperature of concrete at a lower temperature than 35°C is not included here.

Centrifugal compaction: Centrifugal compaction is used for the placing of concrete products of hollow cylinders such as poles, piles, pipes and so on. The effect of centrifugal compaction is related to the magnitude of force originated by the revolution of formworks. The acceleration of centrifuge usually adopted is 20-40G.

Casting: In the production of concrete products, the process of placing concrete into a formwork and, then, providing compaction to the placed concrete is called casting, while stripping formworks is called demolding.

Hot concrete: Hot concrete of a temperature of 40 to 60°C is used to place in a formwork and remove the form in a short time after hot curing.

CHAPTER 2 EXPANSIVE CONCRETE

2.1 General

2.1.1 Scope

This chapter specifies standards on essential matters particularly needed for achieving required qualities and performances of expansive concrete. 'Expansive concretes' referred to in this chapter are shrinkage compensating concrete and concrete for chemical prestressing.

[Commentary] Expansive concrete is a general term for a type of concrete which consists of expansive admixture mixed together with cement, water, fine aggregate, coarse aggregate and other admixtures and which possesses volume expansion even after the start of hardening. There are various types of expansive concrete with different qualities depending on materials and mix proportions. In a case when expansive concretes are classified based on the expansive extent, they are roughly divided into shrinkage compensating concrete and concrete for chemical prestressing. And when reinforced concretes using expansive concretes are functionally classified, they are roughly divided into shrinkage compensated concrete and chemically prestressed concrete.

By restraining the expansion of expansive concrete with objects such as reinforcing bars, compressive chemical prestress will be induced in concrete, while in the objects, tensile chemical prestrain will be induced. Shrinkage compensated concrete is reinforced concrete imparted with a small chemical prestress at such a level to offset or reduce tensile stress occurring due to drying shrinkage or other causes. Chemically prestressed concrete is reinforced concrete imparted with a large chemical prestress by the addition of a large amount of expansive admixture compared with that in shrinkage compensated concrete, so that chemical prestress will remain even when drying shrinkage has been offset. As a result, it is possible to demonstrate the effectiveness of chemical prestress and chemical prestrain in the design of members and structures by utilizing chemically prestressed concrete.

Even when the expansive concrete having same expansive property is used for reinforced concrete, as shown in Table C2.1.1, it is possible to functionally classify that concrete as either shrinkage compensated concrete or chemically prestressed concrete, depending on the degree of restraint induced by objects such as reinforcing bars. Therefore, expansive concretes are roughly divided into shrinkage compensating concrete and chemical prestressing concrete based on the expansive capacity, which is totally different from the classification based on function.

In chemical prestressing concrete, the strength loss due to expansive action will not occur if proper restraining objects are provided. However, if the provision of restraining objects is improper, the strength loss will occur. In contrast, for shrinkage compensating concrete, expansive admixture is used in such an amount that the obtained concrete strength is almost equal to that of concrete with the same water-binder ratio and without expansive admixture in mix proportion.

Expansive concrete (mortar) has been applied mainly as cast-in-place concrete using shrinkage-compensating concrete, concrete products using shrinkage-compensating concrete or chemical prestressing concrete, various fill concrete and mortar for filling the voids in inverse lining or below the bridge bearing. Chemical prestressing concrete is also used for cast-in-place concrete.

Table C2.1.1 Classification of expansive concrete

Type	Function
Shrinkage compensating concrete	Shrinkage compensating concrete
Chemical prestressing concrete	Chemically prestressed concrete

2.1.2 General

When using expansive concrete, materials, mix proportions, production methods, quality management methods and construction methods shall be determined so as to produce designated quality.

[Commentary] The expansivity of expansive concrete varies according to the type of the expansive admixture or cement used, amount of expansive admixture per unit volume of concrete, age, method of curing, environment of the structure and dimensions of member cross section. The performance requirements for expansive concrete vary according to whether shrinkage-compensating or chemical prestressing concrete is used. The materials, mix proportions, production method and quality management method should therefore be determined so as to produce designated expansivity. When applying expansive concrete, it should be managed in the phases of mix proportions design, production and construction under the guidance of professional engineers who understand the characteristics of the concrete and have learned the use techniques and have adequate knowledge and experience.

2.2 Quality of Expansive Concrete

2.2.1 General

Expansive concrete shall meet performance requirements in terms of workability, strength, expansivity, durability, water tightness and steel protection. Variations of quality shall be minimized.

[Commentary] Expansive concrete as well as ordinary concrete should have designated workability and expansivity with minimum variations. Variations of expansivity may prevent shrinkage compensation or application of chemical prestress from producing an intended effect, or lead to strength reduction due to excessive expansion. The quality of expansive concrete should therefore be fully managed.

2.2.2 Expansivity

(1) The expansivity of expansive concrete shall be expressed in rate of expansion obtained in accordance with JIS A 6202. The test value at an age of seven days shown in Attachment 2 (Reference) should be used as a standard value.

(2) The standard range of expansion coefficient of expansive concrete is shown below.

- Expansion ratio of shrinkage compensating concrete: between 150×10^{-6} and 250×10^{-6}

- Expansion ratio of chemical prestressing concrete: between 200×10^{-6} and 700×10^{-6}

For chemical prestressing concrete used for concrete products, the upper limit of expansion coefficient may be set at 1000 x 10^{-6}.

[Commentary] (1) The coefficient of expansion of expansive concrete varies according not only to the concrete mix proportions, curing method and age but also to test conditions such as the dimensions of specimens and restraining conditions. The coefficient of expansion of expansive concrete shall therefore be expressed in the rate of uniaxially restrained expansion obtained in accordance with Attachment 2 (Reference) "Restrained Expansion of Expansive Concrete and Shrinkage Test Method" in JIS A 6202 "Expansive Additive for Concrete". In the method, specimens are used that have a rate of uniaxially retrained reinforcement of 0.95% provided by using restraining fixtures (namely, restraining end plates and restraining bars (prestressing steel)). It should be noted that the reinforcement rate is lower and the expansion rate is higher in ordinary concrete than when the above method is employed even where the same expansive concrete is used. The rate of expansion and the velocity of expansion vary according to the type of expansive admixture, quantity of expansive admixture per unit volume of concrete, curing temperature and the degree of wetting and drying. If a test is conducted in accordance with Attachment 1 (Regulations) "Method for Testing the Expansion of Expansive Admixtures by Mortar", expansion is completed at an age of seven days. The rate of expansion is therefore expressed in uniaxially restrained expansion rate at an age of seven days also in the testing of expansion by concrete as a standard practice.

(2) Expansive concrete is roughly classified by major use into shrinkage-compensating concrete or chemical prestressing concrete. The standard range of expansion rate is shown for each type of concrete. The range of expansion rate is the same for shrinkage-compensating concrete and chemical prestressing concrete in the range between 200 x 10^{-6} and 250 x 10^{-6}. The user may select an appropriate type considering the use of expansive concrete.

When applying an expansive admixture to shrinkage-compensating concrete with a water-binder ratio of 30% or lower such as high strength concrete and high-fluidity concrete, expansion may be controlled at an early age because of the lack of water required for the hydration of the expansive admixture and abnormal expansion occurs after the elapse of some time. When using an expansive admixture for concrete with a low water-binder ratio, therefore, it is necessary to verify in advance the type and quantity per unit volume of concrete of the expansive admixture, curing method and age at which expansivity should be determined by testing, in order to prevent abnormal expansion.

In chemical prestressing concrete, inappropriate arrangement of reinforcing bars or steel pipes for restraining expansion not only prevents the development of effective chemical prestress but also deteriorates the quality of expansive concrete as described above. The area and arrangement of reinforcing bars when using chemical prestressing concrete should be determined considering the expansivity of concrete, type of structure, characteristics of loads, dimensions of members and construction method. Highly unbalanced arrangement of reinforcing bars in the cross section creates sections with extremely high expansivity where concrete quality is deteriorated. Full attention should therefore be paid to the area and arrangement of reinforcing bars. In ordinary reinforced concrete structures, the area and arrangement of reinforcing bars should be determined so that the maximum expansivity in member cross section may be held to approximately 1000×10^{-6} or less during and at the completion of construction. The possibility that reinforcement yields or fractures, exhibiting brittle failure, when flexural cracks occur due to the increase of moment that induces flexural cracks owing to chemical prestress is greater than in ordinary reinforced concrete. In order to prevent brittle failure even at a strain of reinforcement of approximately 700×10^{-6}, the tension reinforcement ratio in rod members of rectangular cross section should be set at 0.25% or higher. In the case of a T-shaped cross section, longitudinal reinforcement should be arranged in 0.35% or more of the effective cross-sectional area of concrete.

For chemical prestressing concrete used for factory products, it was made permissible for the upper limit of expansion rate to be 1000×10^{-6}, which is higher than the 700×10^{-6} rate for cast-in-place concrete because the control of expansion rate and of reinforcing bars arrangement, etc. of factory products are superior compared with cast-in-place concrete.

2.2.3 Strength

(1) The compressive strength of expansive concrete should be the compressive strength at the age of 28 days

(2) The compressive strength of shrinkage compensating concrete shall be determined in accordance with JIS A 1108 and JIS A 1132.

(3) The compressive strength of chemical prestressing concrete should be determined in accordance with Appendix 3 of JIS A 6202.

[Commentary] (1) and (2) The compressive strength of expansive concrete shall be the compressive strength at the age of 28 days as for ordinary concrete. For shrinkage-compensating concrete, compressive strength and strength development identified in JIS (Japan Industrial Standards)-designated testing are similar to those for concrete with no cement replaced with expansive admixtures, so compressive strength shall be obtained in the same tests as those for ordinary concrete.

(3) Chemical prestressing concrete has higher expansivity than shrinkage-compensating concrete. There are therefore cases where the compressive strength obtained in accordance with JIS

A 1108 "Method of Test for Compressive Strength of Concrete" and JIS A 1132 "Method of Making and Curing Concrete Specimens" is greatly reduced due to excessive free expansion. Thus, use condition may be much different from actual conditions. Then, it becomes necessary to obtain compressive strength using specimens that are left in the formwork up to the start of compressive strength tests in accordance with Attachment 3 (Reference) "Method for Testing Compressive Strength by Curing Expansive Concrete Under Restrained Condition" to JIS A 6202.

2.3 Materials

2.3.1 Cement

Cements that comply with JIS R 5210, JIS R 521 1, JIS R 5212, and JIS R 5213 should be used.

[Commentary] Cements generally used for expansive concrete are ordinary Portland cement, moderate heat Portland cement, high-early-strength Portland cement, fly ash cement type B and blastfurnace slag cement type B. As long as these types of cements have been used, no abnormal expansion characteristics have been recognized. Then, it has been verified that the type of cement has little effect on expansivity. When using low-heat Portland cement or blended cement containing three cementitious materials with high content of blast furnace slag or fly ash, expansion sometimes occurs early or expansivity increases as setting of concrete or development of strength varies. These cements should therefore be used only after the achievement of designated performance requirements is verified by conducting tests or based on the records of use.

2.3.2 Expansive admixture

(1) The expansive admixture that complies with JIS A 6202 should be used.

(2) When using other expansive admixtures than those described in (1) above, their quality shall be verified and the method of use should be fully examined.

(3) Expansive admixtures shall be stored so as to maintain their quality.

[Commentary] (1) Expansive admixtures used for expansive concrete are divided into two major types according mainly to chemical composition: calcium sulfo-aluminate type (CSA type) and calcareous type (CaO type). In shrinkage-compensating concrete using these types of admixtures, the quantity of expansive admixture per unit volume of concrete has conventionally been set at 30 kg/m^3 as a standard. In recent years, calcium sulfo-aluminate/calcareous composite expansive admixtures and expansive admixtures with high content of calcareous components and low ratio of additives have been put to practical use, and the standard quantity of expansive admixture per unit volume of concrete has been set at 20 kg/m^3 in numerous applications. It has been reported that expansive admixtures with a low ratio of additives produce similar expansivity as in the past even at 20 kg/m^3. JIS A 6202 has, however, been established for expansive admixtures that are used at 30 kg/m3, the amount used for conventional shrinkage-compensating concrete. It was then stipulated that a quantity of expansive admixture of 20 kg/m^3 per unit volume of concrete may be used as a standard when conducting tests in accordance with JIS A 6202 for expansive admixtures with a low ratio of additives. It was also stipulated that either conventional expansive admixtures or expansive admixtures with a low ratio of additives should meet the quality requirements for expansive admixtures specified in JIS A 6202.

(2) As other expansive admixtures than those described in (1) above, expansive admixtures for mass concrete (also referred to as hydration heat control type) for reducing cracks due to thermal stress, and high-early-strength expansive admixtures for concrete products have been put to practical use. These admixtures are sometimes mixed with additives for controlling the heat of hydration or developing strength early. Then, the requirements for ignition loss stipulated in JIS A 6202 may sometimes not be met. This is because in the tests of ignition loss, the additives mentioned above are detected while ignition loss provides guidelines for determining the weathering of expansive admixtures. These expansive admixtures should therefore be used only after verifying other quality parameters than ignition loss that are specified in JIS A 6202 and verifying that the quality requirements for expansive concrete are met based on the existing records or by conducting tests.

(3) Since expansive admixtures contain large amount of free calcium oxide, it can be more easily weathered compared with cement. If expansive admixture is weathered by atmospheric moisture or carbon dioxide, its expansive property is reduced and, consequently, the required performance of expansive concrete may not be obtained. Therefore, the following points should be considered when storing expansive admixtures:

1) The expansive admixture shall generally be stored in a silo having humidity-proof structure exclusively used for expansive admixture in such a way that it will not become mixed with cement and other materials.

2) Bagged expansive admixture shall be stored in such a manner that it will not be in direct contact with the floor inside the storeroom, and arranged in a convenient order for hauling out and inspection.

3) Bags of expansive admixture shall be opened just before using, and admixture bags broken during storage shall not be used.

4) If the storage period is relatively long, tests shall be performed before using, to confirm all the required properties

2.4 Mix Proportion

2.4.1 General

When designing expansive concrete mix proportions, the quantity of water per unit volume of concrete should be minimized while ensuring the achievement of performance requirements in terms of strength, expansivity, durability, resistance to cracking, watertightness and steel protection, and providing appropriate workability.

[Commentary] It is extremely important to minimize the quantity of water per unit volume of expansive concrete as long as the designated performance requirements are met as for ordinary concrete.

2.4.2 Quantity of expansive admixture per unit volume of concrete

The quantity of expansive admixture per unit volume of expansive concrete should be determined through testing so as to provide the designated expansivity. For shrinkage-compensating concrete, the quantity of expansive admixture may generally be determined based on reliable documents.

[Commentary] The effectiveness of the shrinkage compensation and chemical prestressing of expansive concrete in a structure is higher with larger expansion rate. However, when the expansion rate is too high, the compressive strength of concrete is lower compared with non-expansive concrete of the same mix proportions. Therefore, it is important to find an appropriate range of expansion rate within that the strength declination does not occur.

When air content and slump are constant, the expansion rate of expansive concrete is mostly decided by the unit expansive admixture content regardless the water-cement ratio and the unit cement content. Therefore, in order to experimentally determine a unit expansive admixture content, concrete with a properly selected mix proportions and three different expansive admixture contents is tested in accordance with the Appendix 2 "Testing Method for Restrained Expansion and Shrinkage of Expansive Concrete" in JIS A 6202. Basing on the experimental results, the unit expansive admixture content corresponding to the desired concrete expansion rate will be selected.

In addition, expansive admixture content for shrinkage compensating concrete can also be determined based on available data of reliable sources. Table C2.4.1 shows the types of expansive admixtures and standard quantities per unit volume of concrete for shrinkage-compensating and chemical prestressing concrete.

Table C2.4.1 Types of expansive admixtures and standard quantities of expansive admixtures per unit volume of concrete

<table>
<tr><th>Type of expansive concrete</th><th colspan="2">Type of expansive admixture</th><th>Standard quantity of expansive admixture per unit volume of concrete (kg/m3)</th></tr>
<tr><td rowspan="4">Shrinkage-compensating concrete</td><td rowspan="2">For ordinary concrete</td><td>Conventional type</td><td>30</td></tr>
<tr><td>Low ratio of additives</td><td>20</td></tr>
<tr><td rowspan="2">For mass concrete</td><td>Conventional type</td><td>30</td></tr>
<tr><td>Low ratio of additives</td><td>20</td></tr>
<tr><td rowspan="2">Chemical prestressing concrete</td><td colspan="2">For ordinary concrete</td><td>35～50</td></tr>
<tr><td colspan="2">For concrete products</td><td>30～60</td></tr>
</table>

2.4.3 Quantity of cement per unit volume of concrete

The standard quantity of cement per unit volume of expansive concrete should be 260 kg/m3 or larger.

[Commentary] The strength and rate of expansion of expansive concrete are determined by the quantities of cement and expansive admixture, which are components of expansive concrete, per unit volume of concrete. The quantity of expansive admixture required to obtain the designated rate of expansion is generally determined based on the assumption of a constant quantity of binders (cement and expansive admixture) per unit volume of concrete identified by replacing the expansive admixture with cement in numerous cases. Then, increasing the quantity of expansive admixture per unit volume of concrete to obtain higher rate of expansion is likely to increase the ratio of the unit quantity of expansive admixture to the unit quantity of cement and deteriorate the strength and durability of concrete. These phenomena are found in concrete with a small quantity of binder per unit volume. Then, the standard minimum quantity of cement per unit volume of concrete shall be set at 260 kg/m^3.

2.4.4 Presentation of mix proportion

As a general rule, mix proportions should be presented as shown in Table 2.4.1.

Table 2.4.1 Representation of mix proportion

<table>
<tr><td rowspan="3">Maximum size of coarse aggeregate (mm)</td><td rowspan="3">Slump (cm)</td><td rowspan="3">Air content (%)</td><td rowspan="3">Water-to-binder ratio W/(C+F) (%)</td><td rowspan="3">Volume of sand s/a (%)</td><td colspan="8">Unit content (kg/m^3)</td></tr>
<tr><td rowspan="2">Water W</td><td rowspan="2">Cement C</td><td colspan="2">Admixtures F</td><td rowspan="2">Fine aggregate S</td><td colspan="2">Coarse Aggregate G</td><td rowspan="2">Chemical admixture</td></tr>
<tr><td>Expansive agent E</td><td>Other admixtures F’</td><td>mm - mm</td><td>mm - mm</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

A unit for amount of chemical admixture that should not be diluted and dissolved is ml/m^3 or g/m^3.

[Commentary] Water-cement ratio is regarded as water-binder ratio and unit quantities are presented for expansive admixture *E* and other admixture *F'* in accordance with Table 4.4.1 Method of expression of mix proportions in Section 4.7 of "Material and Construction: Construction Standards".

2.5 Production and Construction

2.5.1 Mixing

(1) For mixing, mixers with the designated mixing capability should be used as a

standard practice.

(2) Method for putting expansive admixtures into the mixer and mixing time should be determined by testing so that concrete may meet the designated quality requirements as a standard practice. The method and mixing time may be determined based on reliable documents or records whenever available.

[Commentary] (1) If mixing of expansive admixtures is insufficient although admixtures are accurately measured and input, expansive admixtures may sometimes be distributed unevenly in concrete and form masses or are provided in excessive quantities in some sections. Then, the strength of concrete may be reduced after hardening or expansion failure may occur locally. For mixing, therefore, the mixers specified in Section 5.2.3 of "Material and Construction: Construction Standards" should be used as a standard practice so that expansive admixtures or other concrete materials may be distributed fully evenly.

(2) Expansive admixtures should be mixed only after appropriate input procedure and mixing time are determined through testing so that expansive admixtures may be mixed in concrete fully evenly.

Generally, expansive admixture should be charged in at the same time with cement. If expansive admixture is charged in the mixer to the mixture either together with other materials or separately, the confirmation on whether it is thoroughly mixed or not shall be carried out in advance by experiments.

If expansive admixtures adhere to the inlet, inner wall of the mixer or mixing blades and form masses when expansive concrete is continuously mixed, the mixing of masses or fragments into concrete is likely to cause local expansion failure as in the cases described above. Masses of expansive admixtures should be removed immediately after they are formed. The location and procedure of input should be reviewed to prevent masses of admixture from forming.

2.5.2 Curing

(1) Expansive concrete should be maintained in a moist condition at all times for at least 5 days after placement

(2) In cases when steam curing or other accelerated curing methods are used, a test should be carried out to ensure in advance that the required quality can be obtained through the considering curing method.

[Commentary] (1) The purpose of expansive concrete is to compensate shrinkage, reduce crack generation due to shrinkage and introduce chemical prestress in order to improve mechanical propertied of concrete structure. For expansive concrete, the moist curing at the early stages is very important, not only for the strength development but also to obtain the required expansion. Therefore, if there is a possibility of formworks being dried due to small thickness or high temperature, formworks should be sprinkled with water and maintained in a moist condition. When formworks are removed within 5 days after placing concrete, exposed surfaces should be maintained in a moist condition. Expansive concrete generally ceases expanding at an age of approximately five days at normal temperatures. Expansive concrete shall therefore be kept constantly wet for at least five days after placement as a standard practice. If the shoring is removed within five days of placement, wet curing is required such as spraying water on the exposed surface or laying curing membrane over the concrete.

(2) If special curing methods, such as steam curing, insulated curing or heating, are applied, it is important to confirm in advance by experiments that the required properties of concrete will be satisfied.

2.6 Inspections

2.6.1 Expansive admixture acceptance tests

Conducting acceptance tests for expansive admixtures shall be the responsibility of the accepting party. Inspections should be conducted in accordance with Table 2.6.1.

Table 2.6.1 Expansive admixture acceptance tests

Type	Item	Testing methods/ Inspection method	Period/Frequency	Criteria for judgment
Expansive admixture	Quality	Verification based on the test records prepared by the manufacturer or by the method specified in JIS A 6202	At the delivery of materials	Compliance with JIS A 6202 (or through consultation with the Owner)

[Commentary] The party accepting expansive admixtures in the acceptance tests means the manufacturer of expansive admixtures. The results of inspections shall be confirmed by the Owner of the structure. Expansive admixtures may be inspected by verifying the test records prepared by the manufacturer. For expansive admixtures not meeting the quality criteria of JIS A 6202 such as expansive admixtures for mass concrete and high-early-strength expansive admixtures described in Section 2.3.2 (2), decision criteria should be defined through mutual consultations with the Owner.

2.6.2 Concrete acceptance tests

Conducting acceptance tests for expansive concrete shall be the responsibility of the accepting party. Inspections should be conducted in accordance with Table 2.6.2.

Table 2.6.2 Acceptance tests for expansive concrete

Type	Item	Testing methods/ Inspection method	Period/Frequency	Criteria for judgment
Shrinkage compensating concrete	Expansion	Confirmation of used expansive admixture content	When unloading, for all batches	Within ±3% of expansive admixture content stipulated in the Specification
	Strength	Testing method in JIS A 1108 and JIS A 1132	Determined by considering the importance and the scale of structure	It shall be made possible to estimate that the probability of the strength of expansive concrete decreasing below the design strength is 5% or lower based on the producer's risk ratio.
Chemical prestressing concrete	Expansion	Testing method in reference No. 2 of JIS A 6202	When unloading, once a day or once every 20-150m^3, depending upon the importance of structure and the scale of the construction work	Within ±15% of expansion ratio as prescribed
	Strength	Testing method in reference No. 3 in JIS A 6202	Determined by considering the importance and the scale of structure	It shall be made possible to estimate that the probability of the strength of expansive concrete decreasing below the design strength is 5% or lower based on the producer's risk ratio.

[Commentary] The party accepting expansive concrete in the acceptance tests means the Owner of the structure. There are, however, cases in which the Contractor of expansive concrete conducts tests and the Owner confirms the results. In the design of mix proportions of expansive concrete, it has been verified that the rate of expansion of expansive concrete is nearly proportional to the quantity of expansive admixture per unit volume of concrete. Therefore, the inspection of the expansion for shrinkage compensating concrete can be replaced by confirming the expansive admixture content in the mix proportion record when concrete is unloaded at construction site.

The meaning of "when unloading, for all batches" in Table 2.6.2 is that the confirmation must be made if the fluctuation of the expansive admixture content in all mixing batches is within ±3% of the content stipulated in specified mix proportion when concrete is unloaded from agitator trucks to the site.

For chemical prestressing concrete, the required expansion ratio is substantially larger and the lack of expansion also causes more negative effect on the structure compared with shrinkage compensating concrete. Therefore, the inspection of expansion must be carried out by expansion tests. Regarding the inspection of concrete strength, tests on compressive strength should be carried out by compression test considering characteristics of expansive concrete.

Other concrete inspections shall be conducted in accordance with Chapter 16 of "Materials and Construction: Construction Standards" and "Materials and Construction: Inspection Standards".

CHAPTER 3 LIGHTWEIGHT AGGREGATE CONCRETE

3.1 General

3.1.1 Scope

This chapter specifies standards on essential matters particularly required for the construction of lightweight aggregate concrete.

[Commentary] Over 40 years have passed since lightweight aggregate concrete was first used for civil structures in Japan. Consequently, the reliability to its durability is gradually increasing with increase of the experiences related to the design and construction. At present, it is possible to handle lightweight aggregate concrete in almost the same manner as normal aggregate concrete, except for items that require special attention. This chapter focuses on the matters required. For matters not referred to in this chapter, lightweight aggregate concrete shall be handled as if it were concrete using ordinary aggregate.

In this chapter, it is noted that concrete with artificial lightweight aggregate is simply called as lightweight aggregate concrete and artificial lightweight aggregate is also called as lightweight aggregate.

For the construction of lightweight aggregate concrete, “Manual of Design and Construction for Lightweight Aggregate Concrete” and “Recommendation on Design and Construction of Concrete Using High Strength Lightweight Aggregate Made of Fly Ash” published by JSCE are referred.

3.1.2 General

When constructing lightweight aggregate concrete, the qualities of lightweight aggregate and of lightweight aggregate concrete shall be fully examined so as to meet the designated performance requirements.

[Commentary] The basic matters to be considered when using lightweight aggregate concrete are described in detail in 3.2 Quality of Lightweight Aggregate and 3.3 Quality of Lightweight Aggregate Concrete. These sections should be consulted during construction.

3.2 Quality of Lightweight Aggregate

(1) Lightweight aggregate should comply with the aggregate classified in category 3 and 4 for concrete compressive strength specified in the JIS A 5002.

(2) In principle, when using lightweight aggregate concrete for structures subjected to freezing and thawing action, the freeze-thaw resistance of the concrete using that lightweight aggregate should be confirmed based on past experiences and records. However, it may be sufficient to confirm the freeze-thaw resistance of aggregate by referring to the result of freezing and thawing test on concrete carried out in accordance

with JIS A 1148.

(3) Whether alkali-silica reaction of lightweight aggregate occurs or not shall be verified based on the use records or in the concrete prism test.

[Commentary] (1) Because different types of lightweight aggregate are characterized by different properties, not all types of lightweight aggregate are necessarily suitable for the use in civil structures. Therefore, in this standard specification, lightweight aggregates made of expanded shale, expanded clay, pearl stone, fly ash, etc. that can be used for the concrete with adequate lightweight and strength are specified. These lightweight aggregates used as fine and coarse one are classified in the level 3 and 4 concerning compressive strength of concrete specified in JIS A 5002 “Structural Lightweight Aggregate for Concrete”.

They are generally clean, hard and properly distributed in the particle size and less scattered in the quality because of manufacturing in factories. However poor manufacturing processes and quality control will result in producing low quality aggregates and hence inadequate properties of concrete. Therefore, good quality products shall be selected for the use of lightweight aggregate. In addition, the properties of fresh and hardened lightweight aggregate concrete, such as workability, strength, durability, may be adversely affected because of lower strength characteristics and higher water absorption of the lightweight aggregate compared with the natural aggregates or the normal aggregates. Therefore it is important to acknowledge the properties of lightweight aggregate.

High-strength and low-water-absorption lightweight aggregates have recently been developed by improving the materials used and the methods of production. High strength lightweight aggregate made of fly ash (HFA) is an example. These aggregates, with no continuous air voids, have low water absorption and high strength. The lightweight aggregate concrete using these lightweight aggregate has much better basic quality in such terms as the ease of construction, strength and durability than conventional lightweight aggregate concrete and compares favorably with ordinary aggregate concrete. Table C3.2.1 compares the absolute dry density (standards) of aggregates. The absolute dry density of lightweight aggregates actually put to use varies greatly from 0.75 g/cm3 to 2.0 g/cm3. The characteristics of lightweight aggregates also vary accordingly. For constructing lightweight aggregate concrete structures that meet performance requirements, therefore, aggregates should be selected that are fit for the use, and construction should be carried out considering the quality of aggregates.

Table C3.2.1 Comparison of absolute dry density (standards) of aggregate

Aggregate		Absolute dry density (g/cm^3)
JIS A 5005 Crushed stone for concrete		Over 2.5
JIS A 5002 Class H, Lightweight aggregates for structural concrete	Coarse aggregate	Over 1.5 and below 2.0
	Fine aggregate	Over 1.8 and below 2.3
JIS A 5002 Class M, Lightweight aggregates for structural concrete	Coarse aggregate	Over 1.0 and below 1.5
	Fine aggregate	Over 1.3 and below 2.8
JIS A 5002 Class L, Lightweight aggregates for structural concrete	Coarse aggregate	Below 1.0
	Fine aggregate	Below 1.3
High strength aggregate of fly ash (HFA)		Not more than 2.0

(2) JIS A1122 “Test Method for the Stability of Aggregate Using Sodium Sulfate” is employed to test the performance of aggregate under weathering actions such as freezing and thawing action. However, in general, lightweight aggregate is hardly tested for its performance against frost damage by this method. The internal factor that affects the resistance of lightweight aggregate concrete

against frost damage is the relationship between pore structures of the lightweight aggregate and those of interfaced mortar. Therefore the performance against frost damage of lightweight aggregate itself is not specified but is to be investigated as lightweight aggregate concrete on the basis of past records. In addition, the freeze-thaw resistance of lightweight aggregate may be investigated by using the result of the freezing and thawing test according to JIS A 1148 “Test Method of Freezing and Thawing for Concrete”.

In case where the concrete with lightweight aggregate of high water absorption ratio is transported using a concrete pump, large amount of pre-wetting is necessary to prevent the blockade. However, Concrete that uses adequately pre-wetted low water absorption lightweight aggregate is poorly resistant to freezing and thawing action and should not be used in structures that are subjected to freezing and thawing.

Conventional lightweight aggregates have continuous pore spaces and hence need to be used under high water content by pre-wetting. On the other hand, nowadays, the lightweight aggregate with the water absorption lower than 5% is being used. The low water absorption type of lightweight aggregates has isolated pore spaces in the pore structure. Their use with carefully designed mixture proportions enables to transport the concrete using a concrete pump without large amount of water brought into concrete. It also turns out to increase the freeze-thaw resistance.

(3) When a glass phase is formed on the surface of the shell of aggregate in the course of burning of lightweight aggregate, alkali-silica reaction is likely to occur in the concrete using the lightweight aggregate. For using the aggregate, therefore, whether alkali-silica reaction of the concrete to be produced occurs or not should be verified in advance.

The reactivity of lightweight aggregate to alkali-silica reaction should be determined based on the use records. If use records are unavailable or unknown, verification should be made by conducting tests.

Using crushed lightweight aggregate in testing creates a condition different from that in concrete. JIS A 1145 "Method for testing alkali-silica reactivity of aggregate (chemical method)" therefore stipulates that no chemical methods should be applied to lightweight aggregate. JIS A 1146 "Method for testing alkali-silica reactivity of aggregate (mortar-bar method)" uses crushed aggregate with the grading of fine aggregate. Crushed and non-crushed lightweight aggregates are of highly different physical and chemical nature. Neither chemical nor mortar-bar method can determine the alkali-silica reactivity of lightweight aggregate itself. The alkali-silica reactivity of lightweight aggregate needs to be evaluated in tests using concrete using the aggregate. Concrete bar methods using concrete include the promotion of alkali-silica reaction by adding alkali inside the concrete (e.g. JCI method (JCI AAR-3) and Canadian method) and the promotion of alkali-silica reaction by supplying alkali (NaOH, NaCl, etc.) from outside (e.g. ASTM method and Danish method). A test method fit for the specific use should be selected.

3.3　Quality of Lightweight Aggregate Concrete

(1) Lightweight aggregate concrete shall be of homogeneous quality, fit for work and sufficiently workable to enable tight placement in the formwork. After hardening, lightweight aggregate concrete shall have the designated strength, durability and water tightness.

(2) When concrete pumps are used for transport at the site, lightweight aggregate concrete shall have adequate pumpability.

(3) Bulk density of lightweight aggregate concrete shall be appropriately specified and fall in the range of the bulk density determined in structure design. Lightweight aggregate concrete are classified into two types – lightweight aggregate concrete Type I and lightweight aggregate concrete Type II. Table 3.3.1 gives the standard range of the bulk density of the two types, respectively.

Table 3.3.1 Range of bulk density and combination of aggregate

Type of lightweight aggregate concrete	Range of bulk density (kg/m^3)	Aggregate used	
		Coarse aggregate	Fine aggregate
Type I	1,600～2,100	Either lightweight aggregate or partially normal aggregate	Normal aggregate
Type II	1,200～1,700	Either lightweight aggregate or partially normal aggregate	Either lightweight aggregate or partially normal aggregate

[Commentary] (1) The quality of lightweight aggregate concrete in such terms as strength, mass of unit volume, durability and water tightness should reach the designated level specified in the design of members and be able to facilitate construction. The quality varies greatly according to the type and combination of aggregates, and concrete mix proportions, so full examination should be made.

Lightweight aggregate concrete shall be classified into type I or II according to the combination of aggregates (Table 3.3.1). For making an effective use of light weight of lightweight aggregate concrete, using lightweight fine and coarse aggregates can reduce the mass of unit volume of lightweight aggregate concrete to approximately 1,200 kg/m^3. In cases where increasing the strength and durability is required, lightweight aggregates may partly be replaced with ordinary aggregates. Some of the coarse aggregates may be replaced with ordinary aggregates or some of the coarse and fine aggregates may be replaced with ordinary aggregates (Table 3.3.1). Table C3.3.1 roughly shows the range of masses of unit volume of concrete using various types of aggregates (using ordinary Portland cement and with a water-cement ratio of 40 to 60%). The mass of unit volume of concrete made of high strength lightweight aggregate made of fly ash (HFA) is slightly larger than that of lightweight aggregate concrete type I but is smaller than that of ordinary aggregate concrete by approximately 10%.

Table C3.3.1 Bulk density of concrete

Aggregate		Bulk density of concrete (kg/m^3)
Coarse aggregate	Fine aggregate	
Crushed stone	Pit sand	2,200～2,400
HFA	Pit sand	2,000～2,100
Lightweight aggregate	Pit sand	1,900～2,100

(i) Fresh properties : The construction of lightweight aggregate concrete, unlike the construction of ordinary aggregate concrete, generally involves the pre-wetting of aggregate and requires construction as air-entrained concrete. In the case of pumping, high performance air-entraining agents should be used. The properties of air-entraining agents need to be evaluated by testing before construction.

(ii) Strength : Lightweight aggregate concrete provides similar compressive strength to that of ordinary aggregate concrete. Other types of strength than compressive strength can be estimated based on the compressive strength. Aggregates, however, have strength limits. It should therefore be noted that the limit of compressive strength of generally used lightweight aggregate concrete is approximately 60 N/mm^2 and that the tensile and shear strengths (approximately 60 to 80% of those of ordinary aggregate concrete) and Young's modulus (approximately 40 to 80% of that of ordinary aggregate concrete) are much smaller than those of ordinary aggregate concrete. Lightweight aggregate concrete is easy to crumble due to high local impact. In sections that are likely to be subjected to impact, therefore, arranging additional reinforcement or making a relatively large chamfer by cutting off the corner of the member is required. In the points where extremely large impact is expected to act, no lightweight aggregate concrete should be used.

For some of the high-strength, low-water-absorption lightweight aggregates that have recently been developed, the above description may not be applicable because there may be a linear relationship between compressive strength and water-cement ratio as long as the water-cement ratio is less than approximately 25% (compressive strength is approximately 70 to 80 N/mm^2).

(iii) Resistance to freezing and thawing action : Lightweight aggregate concrete generally exhibits lower performance against freezing and thawing action because of larger water absorption of the lightweight aggregate. On the other hand, sufficient performance against freezing-thawing action can be generally given in the lightweight aggregate concrete, when using the lightweight aggregates whose adequate freeze-thaw resistance has been proved by the past experiences or freezing and thawing tests and the concrete being an air entrained one of which water to cement ratio is smaller than that described in Section 3.4.3(2). Increasing air content slightly, using lightweight aggregate under a dry condition as long as reliable construction management is possible, and replacing part or all of the coarse aggregates with ordinary aggregates are effective for increasing the durability of lightweight aggregate concrete. It should, however, be noted that concrete using lightweight aggregates that are considerably pre-wetted to prevent pump clogging suffer the reduction of resistance to freezing and thawing action. Concrete using high strength, low-water-absorption aggregates contains little water owing to low absorption and provides for pumping without increasing pre-wetting. The concrete therefore has similar resistance to freezing and thawing action as ordinary aggregate concrete with the same water-cement ratio and air content.

The freezing and thawing test that is generally employed in Japan is either the one conducted under submerged in water conditions, provided in JIS A 1148 “Freezing and Thawing Test for Concrete, Method A”. In the case when the frost resistance of lightweight aggregate concrete is tested using this method, the concrete with the pre-wetted lightweight aggregate, having 25 to 30% of the water content, normally shows significantly lower performance as compared with normal weight concrete that is used for the same mixture proportioning. However it is not always true that the result of the freezing and thawing test can accurately represent the actual performance of lightweight aggregate concrete structures. This is because the test conditions such as the speed of a freezing and thawing cycle, the minimum temperature, the number of cycles given continuously and the degree of the saturation and dryness in specimens are much more severe than those actually encountered under service conditions.

Considering above reasons it is practically impossible to predict the service life period of lightweight aggregate concrete structures and to judge if lightweight aggregate concrete is to be used based on the results obtained only from the freezing and thawing test under submergence in water like JIS A 1148, Method A. Therefore other test methods, such as JIS A1148, Method B for the freezing and thawing test under an air condition, may be used for the verification to account for the weather and other environmental conditions of concrete structures and members under consideration. In addition, when past records and practices under similar conditions are available they can be regarded as important such that the properties of lightweight aggregate used and the entrained air content may be used to verify the frost resistance of concrete under consideration.

(iv) Water tightness : The water tightness of lightweight aggregate concrete, if the concrete causes little bleeding and is homogeneous, is the same as that of ordinary aggregate concrete. Air-entrained concrete with a water-cement ratio shown in Section 3.4.3 (3) using aggregates for which water tightness has been confirmed based on the past examples and by conducting permeability tests for the concrete may have practical water tightness.

(2) For the transportation of lightweight aggregate concrete using a concrete pump the workability is significantly reduced due to the absorption of water into the lightweight aggregate by the pumping pressure and its reduction is followed by the blockage of the concrete inside the pump. These are different from the cases with normal weight concrete. To avoid this, the maximum pumping load (P_{max}) on a concrete pump is generally ensured to be less than 80% of the maximum theoretical discharging pressure of the pump described in Section 7.3.2 of "Construction: Construction Standards" by properly specifying the absorption of aggregate, the water content of aggregate, the workability of concrete and the types of concrete pump considering the properties of lightweight aggregate. In addition, it may be referred to the past similar construction records and experimental data.

Lightweight aggregate concrete with a slump of 18 cm or higher and with mix proportions leading to low cohesiveness provides an excellent pumpability. Standard pressure loss in pipe during the pumping of lightweight aggregate concrete required for calculating P_{max} is shown in Fig. C3.3.1 for reference.

For pumping lightweight aggregate concrete, pre-wetted lightweight aggregates are used and high performance water reducers are used to increase the slump of concrete during transportation. Lightweight aggregates with low water absorption that have recently been developed for higher durability may not cause pumpability to be deteriorated even when used without increasing the level of pre-wetting.

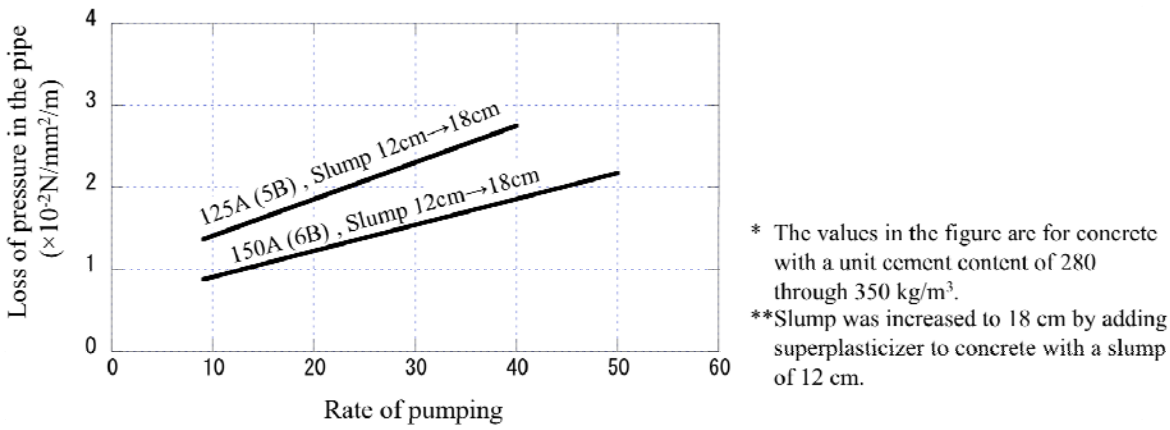


Fig. C3.3.1 Standard values of the loss in pressure of lightweight aggregate concrete

(3) Since the purpose of the use of lightweight aggregate concrete is to reduce the dead weight of the structure, the bulk density should be specified as the required performance. Type and bulk density of lightweight aggregate concrete shall be established considering the size and shape of structure and member, types of structure, construction method, environmental conditions and the purpose of structure.

In general, if actual bulk density is larger than that specified at design, the results become improper due to increase of weight of structures. However, it may not be always safe even when the actual bulk density is smaller than the specified value. In this way the verification is to be made.

3.4 Mix proportions

3.4.1 General

Lightweight aggregate concrete should be used as air-entrained concrete. Unit water content should be minimized by conducting testing as long as the designated strength, unit mass of volume, resistance to freezing and thawing action, water tightness, resistance to cracking and workability sufficient for work are available.

[Commentary] Lightweight aggregates have varying grain size, density, water absorption and strength according to the type. Mix proportions should therefore be determined after verifying whether the specific lightweight aggregate produces concrete of designated quality or not in testing. In the case of lightweight aggregate concrete as in the case of ordinary aggregate concrete, using concrete with a high unit water content is likely to increase unit cement content, resulting in cost increase, and cause aggregate segregation and cracking. Thus, producing flawless concrete may be difficult.

For certain types of lightweight aggregates, the unit water content required for obtaining workability as designated is higher than for ordinary aggregates and the resistance to freezing and thawing action may sometimes be reduced. Then, unit water content should be reduced using water reducers, air-entraining agents, high performance water reducers, etc. Using these agents may also improve the resistance of lightweight aggregate concrete to freezing and thawing action. Thus, lightweight aggregate concrete shall in principle be used as air-entrained concrete as well as ordinary aggregate concrete.

3.4.2 Mass of unit volume

In order to achieve the mass of unit volume of lightweight aggregate concrete as specified in design, lightweight aggregates shall be properly combined with ordinary aggregates.

[Commentary] The objective of using lightweight aggregate concrete is to obtain the benefit of weight reduction. Mix proportions should therefore be determined in design to achieve the designated mass of unit volume of concrete. The most important factor that determines the mass of unit volume of concrete is density. The type and combination of aggregates should be specified properly based on the concrete quality shown in Section 3.3. Combining aggregates is naturally important to the satisfaction of performance requirements for concrete in such terms as strength and durability. The ordinary aggregates used for lightweight aggregate concrete should in principle satisfy the stipulations in Section 3.4 of "materials and Construction: Construction Standards".

3.4.3 Water-cement ratio

(1) When determining the water-cement ratio based on the compressive strength of concrete, the procedure shall conform to Section 4.4.3 of "Materials and Construction: Construction Standards".

(2) When determining the water-cement ratio based on the resistance of concrete to freezing and thawing action, the ratio should be 5% lower than that used in ordinary aggregate.

(3) When determining the water-cement ratio based on the water tightness of concrete, the ratio should be 55% or lower.

[Commentary] (2) In relation to the actual resistance of lightweight aggregate concrete to freezing and thawing action, no report has been made on the deterioration of resistance of lightweight aggregate concrete to freezing and thawing action which has been in service for more than 15 years in cold areas in Japan. According to the results of tests for freezing and thawing resistance of concrete under severe conditions in laboratory, however, lightweight aggregate concrete has been found slightly less resistant to freezing than ordinary aggregate concrete. The maximum water-cement ratio shall therefore be set 5% lower than that given ratios in Table C5.2.11 of “Design: Main Text”, Standard Specifications for concrete Structures to ensure safety. The water-cement ratio is obtained in cases where concrete is properly placed, compacted and cured. In cases where no adequate curing is expected, a value lower than that shown in the table should be specified.

The water-cement ratio determined by durability in cases where lightweight aggregate concrete is used for offshore structures may be equivalent to that for ordinary aggregate concrete in cases where the temperature rarely falls below zero and no concrete is saturated with water. For structures that are saturated with water because of severe meteorological conditions, water-cement ratio should be determined based on the comprehensive consideration of materials used, construction conditions, measures to enhance durability and the importance of the structure. In the field, water-cement ratio should be set at a value 2 to 3% lower than designated considering the change in water content of aggregate and errors in material measurement.

(3) Water tightness of lightweight aggregate concrete may be assumed to be the same as that of ordinary aggregate concrete and is specified according to Section 2.6 of "Materials and Construction: Construction Standards".

3.4.4 Slump

(1) Slump of concrete shall be set at the minimum level possible as long as the concrete is fit for work.

(2) Slump of concrete should conform to Section 4.4.2 of "Materials and Construction: Construction Standards".

(3) When pumping lightweight aggregate concrete, slump before pumping should be set at 18 cm as a standard practice.

[Commentary] (2) Lightweight aggregate concrete tends to exhibit lower slump than that of normal weight concrete having the same consistency due to the smaller mass per unit volume. Therefore, specified slump for lightweight aggregate concrete may have the same or lower value than that of normal weight concrete.

(3) In case where lightweight aggregate concrete is transported by a concrete pump or placed into the dense space of large amount of reinforcements either superplasticized concrete or self-compacting concrete is employed so that the quality of concrete can be maintained and sufficient construction work can be executed. Water reducers with a rate of water reduction exceeding approximately 15%, higher than the rate for conventionally adopted water reducers, have recently been used for pumping lightweight aggregate concrete. Then, reduction of slump with time or due to transportation should properly be estimated based on the construction records or construction tests under similar conditions. In order to obtain high-fluidity concrete, segregation of lightweight aggregate should be carefully examined. For construction, refer to Chapter 7 High-fluidity Concrete.

3.4.5 Air content

(1) Taking into consideration the freeze-thaw resistance, workability, etc. the air content after mixing should be 1% higher than that of normal aggregate concrete as standard.

(2) Test of air content should be carried out in accordance with JIS A 1118. When measuring air content for the purpose of quality management or using low-water-absorption lightweight aggregates, tests may be conducted in accordance with JIS A 1128. When calculating the air content, the correction factor to account for the water absorption of lightweight aggregate should be accurately understood and used.

[Commentary] (1) The freeze-thaw resistance of lightweight aggregate concrete under severe weather and water saturated conditions is considered in some case to be lower than that of normal weight concrete. Therefore, the air content needs to be increased to overcome this.

(2) In order to prevent the measured value from being inaccurate due to the pressurized water absorption, test method for air content should be followed such as the volumetric method provide in JIS A1118 as the standard method.

The volumetric method generally requires considerable time and may sometimes not be fit for tests for quality management. Then it has been stipulated that the "method of test for air content of fresh concrete by pressure method" (JIS A 1128) may be adopted. When adopting the method, the aggregate correction factor for the absorption of lightweight aggregate should be measured accurately and the measurement should be corrected. Whenever using lightweight aggregates shipped at different dates or whenever the water content of lightweight aggregate varies considerably while the same lightweight aggregate is used continuously, the aggregate correction factor should be measured.

3.4.6 Presentation of mix proportion

As a general rule, mix proportions should be presented as shown in Table 3.4.1.

Table 3.4.1 Representation of mix proportion

Maximum size of coarse aggregate (mm)	Mass per unit volume (kg/m^3)	Slump (cm)	Air (%)	Water-cement ratio1) *W/C* (%)	Sand-Aggregate ratio *s/a* (%)	Unit content (kg/m^3)							
						Water W	Cement1) C	Admix-ture2),3) F	Normal fine aggregate4),5) S_1	Light-weight Fine aggregate4),5) S_2	Normal coarse aggregate4),5) G_1	Light-weight coarse aggregate4),5) G_2	Chemical admix-ture6) A

Note 1) When mineral admixtures with pozzolanic reactivity or latent hydraulicity are used, the term "water-binder ratio" should be used instead of "water-cement ratio".
2) As an indicator of resistance to material segregation, the unit amount of fine powder should be presented as a combined total for cement and admixtures.
3) When several materials of the same category are used, they should be detailed separately.
4) Fine and coarse aggregates should be presented in separate columns for lightweight and ordinary aggregates.
5) Quantity of lightweight aggregate per unit volume of concrete should be presented as the mass in an over-dry condition.
6) Quantity of ordinary aggregate per unit volume of concrete should be presented as the mass in a surface-dry condition.

[Commentary] The mass of lightweight aggregate varies greatly according to the moisture state of aggregate. In the mix proportions, therefore, the mass in an over-dry condition should be presented unlike for ordinary aggregate. When both lightweight and ordinary aggregates are used simultaneously, quantities of respective types of aggregates per unit volume of concrete should be presented. Types of structures, characteristic compressive strength, mix proportioning strength, the mass per unit volume used in design, types of cement, fine and coarse aggregates, types of chemical admixtures is also desirable to be described in the table of the specified mix proportion.

In batching, when lightweight aggregate is used under dry condition, corrections related to the effective water absorption should be conducted. Also, when lightweight aggregate is used under the surface water content, the amount of pre-wetting should be concerned and corrections related to the surface water content should be conducted.

In a format of field mix proportion, shown in Table 3.4.1, not only the bulk density but also the water absorptions, surface water contents of both fine and coarse aggregates and mix proportioning strength are preferably to be provided.

3.5 Production and Construction

3.5.1 Selection of plant

For producing lightweight aggregate concrete, a plant producing JIS-authorized lightweight concrete products that has been officially authorized, or a plant with equivalent production facilities and management systems should be selected considering the time required for transport to the site, concrete shipping capacity and quality management capability.

[Commentary] Ready mixed concrete plants have varying production facilities, production technology and quality management capability. Lightweight aggregate concrete should be purchased from a plant that manufactures JIS-authorized lightweight concrete products and conducts inspections in conformity with the uniform inspection standards established by the *Namakon* (ready mixed concrete) Quality Control Inspector Conference of Japan, and has been officially authorized.

In cases where no plants produce JIS-authorized products that can be transported to the construction site within the designated time, a production plant should be selected for which it has been verified in testing that it can steadily supply concrete of designated quality, considering the production facilities, quality management systems and expertise concerning lightweight concrete.

3.5.2 Transportation and storage of lightweight aggregates

(1) Coarse and fine lightweight aggregates shall be transported and stored separately.

(2) Lightweight aggregate shall be handled taking care to avoid crushing, separation of particles of different sizes, and being mixed with normal aggregate, dirt and foreign matters.

[Commentary] To produce a uniform quality of concrete the grading of aggregate must be constant. For this reason coarse and fine aggregates need to be transported and stored separately so that aggregates of different sizes do not mix. When transporting lightweight aggregate to the construction site, it is necessary to use a rubber-tire vehicle as the aggregate will be broken if other types of transportation, such as caterpillar bulldozer, excavator, etc. are used. The mix of broken aggregates results in non-uniform quality concrete and the required strength will not be obtained.

Lightweight aggregates are often stored in open-air but when stored in conical heaps large grains and small grains tend to become separated from each other. Therefore, it is suggested that aggregates should be stored in cylindrical silos or be enclosed in by walls in order to keep their level horizontally.

When a belt conveyer is used to convey lightweight aggregates, the care needs to be exercised not to make the inclination too steep and to clean the conveyer after conveying river sand to prevent the river sand from mixing with the lightweight aggregates.

3.5.3 Control of moisture content of lightweight aggregate

(1) Moisture content in lightweight aggregate shall be maintained at a pre-determined level.

(2) Moisture content of lightweight aggregate in case of pre-wetting shall be determined considering the possibility of pumping transportation, conditions of pumping, freeze-thaw resistance, etc.

[Commentary] (1) As the lightweight aggregate tends to absorb water more easily than ordinary aggregate, the concrete quality tends to vary during mixing, transportation and placing. Therefore, it is better to use them in a thoroughly wet condition. The presoaking of lightweight aggregate needs to be enough when pumping lightweight aggregate concrete. However, when concrete pump is not used for the transportation of the lightweight aggregate concrete, only controlling the moisture content in such a way that it hardly varies at the departure from a production factory is necessary. Lightweight aggregate that is largely presoaked at a production factory is used to prevent the water absorption during pumping. In these cases it is important to control the moisture content during the storage of the aggregates by providing a water spraying device such as a sprinkler, so that the lightweight aggregate does not become dry in the concrete plant.

It is possible for lightweight aggregate with lower water absorption capacity to be used under dry condition since the change of the properties during the mixing, transporting and placing is small and also the water absorption due to pressure is small as well. In these cases the moisture content of the lightweight aggregate that is stored under dry condition may be controlled so as to be constant.

Unless the moisture content of lightweight aggregate is uniform, the control of weighing mixing water becomes difficult. Therefore the moisture content must be controlled so as to maintain a uniform value not only in presoaking the aggregates but also in storage. The place of storage must be such that the aggregates are protected from rain and sunshine and well-drained. Also the volume of a storage facility shall be sufficient to store an enough amount of aggregates for one day consumption.

(2) Generally the use of lightweight aggregates containing excessive water will adversely affect the quality of the concrete by increasing the density or by reducing the freeze and thaw resistance. As adequate pre-wetting is required when pumping lightweight aggregate concrete, the resistance of lightweight aggregate concrete to freezing and thawing action is generally reduced. When constructing lightweight aggregate concrete that is subjected to alternative freezing and thawing in cases where the absorption of aggregate is not an issue in a series of work from concrete mixing to placement, reducing the water content of lightweight aggregate and constructing concrete using buckets should be considered.

3.5.4 Mixing

(1) The sequence of charging materials into the mixer shall be determined considering efficiency of mixing and water absorption by aggregate during mixing, so as to ensure that the lightweight aggregate concrete meets the required performance.

(2) The duration of mixing should, in principle, be determined through tests.

[Commentary] (1) The sequence of introducing lightweight aggregate concrete materials into the mixer has a large effect on the mixing efficiency, degree of water absorption of aggregates in the mixer and the like.

When using dry lightweight aggregate with high water absorption capacity, the materials in the mixer absorb a considerable amount of water causing variation in the quality of concrete such as slump or strength. Therefore, the care must be exercised in their use.

(2) As the mixing efficiency of lightweight aggregate concrete differs greatly depending on the type of aggregate, the consistency of the concrete, the type of mixer, the capacity of the mixer and the like, the required mixing time is specified and determined, mainly by tests such as JIS A1119 “Method of Test for Variability of Constituents in Freshly Mixed Concrete” and JIS A 8603 “Concrete Mixer”. The standard mixing time will be not less than one minute in the case of the forced mixing type mixer, and not less than two minutes in the case of the tilting type mixer, after all materials have been introduced into the mixer.

When a gravity type mixer is used, the mixing of lightweight aggregate concrete becomes ineffective compared with ordinary concrete, depending on the type of mixer. Therefore the minimum mixing time may be extended when tests are not performed. When the type of mixer and its method of use are adequate and the mixing performance can be confirmed by tests, the mixing time will be the same as in the case of ordinary concrete. In the case of using a small tilting type mixer at the construction site, because concrete may adhere to the inner wall of the mixer lowering the mixing efficiency, it is suggested that the sequence of introducing materials and mixing time should be determined by tests. If reliable documents or records are available, they may be consulted.

For the use of a continuous mixer, see Comments of Sections 5.2.3 and 5.4 of "Materials and Construction: Construction Standards"

3.5.5 Transportation within the construction site

(1) When lightweight aggregate concrete is transported using concrete pumps, it should be superplasticized concrete or concrete using high-range water reducing AE agents as standard.

(2) For the use of lightweight aggregate having larger water absorption, the water content of the aggregate should be reduced and buckets should be used for transporting the concrete to ensure the frost resistance.

[Commentary] (1) It is possible to transport lightweight aggregate concrete by a concrete pump when the concrete of the slump ranging from 8 to 12 cm is superplasticized so that the slump is increased to about 18 cm. Lightweight aggregate concrete in which high-range water reducing AE agent is added at the mixing may be also used for pumping. However, the use of lightweight aggregate with insufficient pre-wetting may cause blockage in the conveying pipe because of increasing frictional resistance of concrete in the pipe due to the large amount of water absorption by the aggregate under high pressure. Self-compacting concrete may be used with careful attention to the mixture proportion so that it does not cause the segregation of lightweight aggregate. In this case, refer to Chapter 7 High-fluidity Concrete.

There remain air voids in lightweight aggregate not absorbing water after pre-wetting. When pumping concrete, slump should be set slightly high and discharge should be reduced to prevent pressure in the pipe from increasing.

In case when a concrete pump is used for the transportation of lightweight aggregate concrete, the JSCE Recommendation “Recommended Practice for Concrete with High Range Water Reducer with AE Effect”, “Specification for Self-Compacting Concrete” and “Specification for Construction using Concrete Pump” may be referred to.

(2) Lightweight aggregate concrete with pre-wetted aggregates shows less frost resistance. In cases where there is no problem on the absorption of aggregates during mixing and placement for the construction with lightweight aggregate concrete subject to freeze thaw cycles, the water content of the aggregate should be reduced and buckets may be used for transporting the concrete to ensure the frost resistance.

3.5.6 Placing and compaction

(1) Concrete shall be placed taking into account the floating-up of lightweight aggregate and using methods that ensure the least segregation.

(2) When internal vibrator for lightweight aggregate concrete is used, an appropriate method shall be selected with due consideration of the thickness of each compacted layer, duration of vibration, spacing interval between vibrated points, etc.

[Commentary] (1) Segregation of lightweight aggregate concrete occurs because the coarse aggregate tend to float and mortar tends to sediment, which is the reverse tendency to that of normal weight concrete.

(2) When consolidating lightweight aggregate concrete using an internal vibrator, the effective consolidation range is smaller than that for normal weight concrete and tendency of the concrete to extend to the corners of the formwork and around the reinforcing bars by dead weight is weak. Therefore concrete shall be consolidated thoroughly by making the insertion intervals of the vibrator shorter and the duration of vibration slightly longer. However care must be exercised during vibration or the coarse aggregate may tend to float.

3.5.7 Surface finishing

When finishing the surface of concrete, floated coarse aggregates shall be pushed back into concrete.

[Commentary] As there may be cases where the lightweight coarse aggregates float to the surface, becoming the subject of deterioration due to weather conditions and mechanical action, concrete should generally be finished in such a way that floated coarse aggregates are pushed back into the mortar. In this case, the care must be exercised not to increase the bleeding significantly as a result of excessive finish operations. To finish the surface smoothly, it is suggested that refinishing should be performed after an adequate time has elapsed. When lightweight aggregate concrete is used in a floor slab, micro cracking tends to occur in a tortoise-shell pattern 30 minutes to 1 hour after finishing. Therefore, it is necessary to remove such micro cracks by lightly striking using a tamper and the like about 1 hour after the initial surface finishing. When excess bleeding water is generated after placing concrete in winter, it is recommended to remove the bleeding water properly and the surface should be finished in such a way as mentioned above.

3.6 Inspection

3.6.1 Inspection for acceptance of lightweight aggregate

The accepting party shall be held responsible for conducting acceptance tests for lightweight aggregates. The tests should be carried out in accordance with Table 3.6.1.

Table 3.6.1 Inspection for lightweight aggregate

Item	Testing method/Inspection method	Period/Frequency	Criteria for judgment
Items related to quality in JIS A 5002	Confirmation based on test results provided by manufacturer, or in accordance with JIS A 5002	Before the start of construction and once a month during construction	Compliance with JIS A 5002
Moisture content	In accordance with JIS A1134 and JIS A 1135	At least once a day	Falling within the range given in construction plan

[Commentary] The accepting party conducting acceptance tests for lightweight aggregates is the producer of lightweight aggregate concrete. The results of acceptance tests shall be confirmed by the Owner of the structure.

It is important to exercise proper quality control for lightweight aggregate to ensure that lightweight aggregate concrete which meets required properties is manufactured and constructed. Lightweight aggregate that is prescribed in this chapter complies with the JIS A5002: “Lightweight Aggregate for Concrete for Structural Use”. Quality control for the lightweight aggregate shall be exercised for the items prescribed in JIS A5002. Since artificial lightweight aggregate for concrete for structural use is normally controlled better than natural aggregate the data sheet of test results submitted by a production company may be used for the quality control like cement.

The water content of lightweight aggregate used for concrete plays an important role not only for the production of consistent quality of concrete but also for the transportation, such as pumping, and the placing. Care should be exercised in the case of pre-wetting because water content is likely to vary. Then the quality control for the water content becomes important during the production of concrete. The test for the water content shall be carried out once per day or more similar to the number of the test for the surface saturation of aggregate. It is difficult to specify an uniform standard judgment for test results on water content. However, the standard of water content can be specified by considering conditions for transporting concrete and consistent quality. It can be controlled within the range of ±2% for example, based on the standard value.

3.6.2 Inspection for acceptance of lightweight aggregate concrete

(1) The accepting party shall be held responsible for conducting acceptance tests for lightweight aggregate concrete. It should be verified by tests that concrete has the designated mass of unit volume when it is unloaded.

(2) Test for mass of unit volume of concrete should be carried out in accordance with JIS A 1116.

(3) Mass of unit volume of concrete shall be within the range specified at the design stage. In addition, the difference between the bulk density obtained by test and the one calculated from specified mix proportion shall be less than 50kg/m^3.

[Commentary] The accepting party conducting acceptance tests for lightweight aggregate concrete is the Owner of the structure. There may be cases, however, where the Contractor constructing lightweight aggregate concrete has conducted tests and the Owner has verified the test results.

The mass of unit volume of lightweight aggregate concrete does not vary greatly according to the degree of drying. The mass shall therefore be measured for fresh concrete to ensure safety. The density of fresh concrete is influenced by the variation of water content in the lightweight aggregate. Accordingly for the inspection of the density, a provision on the difference between the result obtained from the field inspection and the calculation one based on the specified mixture proportion is introduced, in addition to that the result of the inspection should fall within the range used at the design stage.

The mass of unit weight of lightweight aggregate concrete should be calculated using the following equation.

$$U_w = G_0(1+a_g/100) + S_0(1+a_s/100) + G' + S' + C + W \quad (\text{kg/m}^3) \qquad \text{(C 3.6.1)}$$

where

U_w : bulk density of fresh concrete based on specified mix proportion (kg/m^3)

G_0 : mass of coarse lightweight aggregate (oven dry state) in mix proportion (kg/m^3)

S_0 : mass of fine lightweight aggregate (oven dry state) in mix proportion (kg/m^3)

G' : mass of coarse normal aggregate (saturated surface-dry state) in mix proportion (kg/m^3)

S' : mass of fine normal aggregate (saturated surface-dry state) in mix proportion (kg/m^3)

C : cement content in mix proportion (kg/m^3)

W : water content in mix proportion (kg/m^3)

a_g : moisture content of coarse lightweight aggregate to be used (%)

a_s : moisture content of fine lightweight aggregate to be used (%)

Inspections for other parameters than the mass of unit volume of lightweight aggregate concrete should be conducted in accordance with Chapter 16 of "Materials and Construction: Construction Standards" and "Materials and Construction: Inspection Standards".

CHAPTER 4 CONCRETE USING CONTINUOUS FIBER REINFORCING MATERIALS (CFRM)

4.1 General

4.1.1 Scope

(1) This chapter specifies standards on essential matters particularly required for the construction of concrete using continuous fiber reinforcing materials (here-in-after called as "CFRM").

(2) In the case of prestressed concrete using CFRM as tendons, Chapter 12 shall be referred, whenever required.

[Commentary] (1) This chapter presents the matters required for construction when applying concrete using CFRM to a new structure. For continuous fiber reinforcing materials, continuous fibers are hardened with a binder into a bar shape as a substitute for reinforcing iron bar, into a bar or stranded shape as a substitute for prestressing steel member, and into a sheet shape. The latter is not discussed in this chapter because it is used mainly for repair or retrofit. The concrete using CFRM presented in this chapter is either of reinforced concrete structure in which CFRM, bar-shaped continuous fiber consolidated with binders, are used in place of steel bars (CFRM reinforcements) or with steel bars; or of prestressed concrete structure in which CFRM are used as tendons (CFRM tendons) in place of or with prestressing steel.

Five types of fiber are used for CFRM: carbon fiber, aramid fiber, glass fiber, vinylon fiber and combination thereof. They come in five shapes: rod, strand, braid, grid or rectangle. For the fiber binder (matrix), epoxy or vinyl ester type is used.

For members made of concrete using CFRM, the examination of corrosion of CFRM reinforcements due to environmental action such as carbonation and chloride chloride induced deterioration can be eliminated because CFRM are generally highly resistant to corrosion. Continuous fiber reinforcing materials (CFRM) are non-magnetic and fit for concrete structures or members that need to be non-magnetic. What is not mentioned in this chapter shall be prescribed in "Draft of Design and Execution Guide for Structure Made with Concrete Using Continuous Fiber Reinforcing Materials".

(2) Prestressed concrete with CFRM should be referred regarding exactly the same items as the ordinary prestressed concrete of PC grout, for example. Therefore, see Chapter 12, "Prestressed Concrete" for details.

4.1.2 General

When constructing concrete CFRM, methods for storing and assembling CFRM and for constructing concrete shall be determined under the guidance of professional engineers to meet the designated performance requirements.

[Commentary] Generally, CFRM are subject to surface damage because fiber resin is generally a synthetic resin. A deep scratch of the materials by a sharp edge of steel member will reduce its load performance remarkably. Especially if CFRM are used as tendons, a careless error at construction is greatly anticipated to result in a serious accident. In addition, CFRM may lose their quality if left in a high temperature, ultraviolet ray, or chemical environment. Various matters should be considered when constructing concrete using CFRM. When constructing concrete using CFRM, therefore, methods should be established for storing and assembling CFRM and for placing and curing concrete using CFRM under the guidance of professional engineers with sufficient knowledge and experience so that concrete using CFRM may meet the designated performance requirements.

4.2 Materials

4.2.1 Continuous fiber reinforcing materials (CFRM)

CFRM should comply with the provisions stated in JSCE-E 131 as a standard.

[Commentary] JSCE-E 131 "Specific Properties for Continuous Fiber Rods" specifies the properties of five types of fibers, namely carbon fiber, alamid fiber, glass fiber, vinylon fiber and the mixed fiber. It contains mechanical properties, nominal diameter and the maximum dimension for fiber types, namely rods, strands, lattices and rectangular shapes. These specifications may be used as the properties. Due to the fact that the types of fibers and the volume ratio of its amount contained control the mechanical properties of continuous fiber rods, the assured tensile strength, Young's coefficient, elongation, relaxation and so on are specified according to an combination of rod types and fibers used. Similarly nominal diameters and the maximum dimension are specified for each combination.

The JSCE standards specify seven methods for verifying the performance of CFRM in addition to these standards. The performance of CFRM should be verified by any of the methods according to the purpose.

4.2.2 Reinforcing steel bars

(1) Reinforcing steel bars that are used with CFRM shall be fit for the intended purpose of CFRM.

(2) In cases when CFRM are used to enhance the corrosion resistance in a concrete structure, the reinforcing steel bars used in conjunction should be epoxy coated reinforcing bars that conform to Clause 3.6.1(4) of "Materials and Construction: Construction Standards".

(3) In cases when ordinary reinforcing steel bars not specially treated for enhanced corrosion resistance are used, they should conform to Clause 3.6.1(1) of "Materials and Construction: Construction Standards".

[Commentary] (1) CFRM are corrosion-resistant and non-magnetic and used mainly for the structures and member that need to have such characteristics. CFRM may be used also because of such characteristics as lightweight, high strength and low elastic modulus. Therefore, reinforcing bars used in conjunction with CFRM must be selected in accordance with the intended purpose. It should be noted in this connection that non-magnetic reinforcing bars have also been developed in recent years.

(2) Considering the characteristics, CFRM are generally applied to structures in saline and other severe environments. From the viewpoint of corrosion resistance, reinforcing bars for use in conjunction with CFRM should be epoxy coated reinforcing bars that conform to Clause 3.6.1(4) of "Materials and Construction: Construction Standards".

(3) For ordinary reinforcing bars of no corrosion resistance, ones conforming to JIS G 3112 "Steel Bars for Concrete Reinforcement", which is described in Clause 3.6.1(1) of "Materials and Construction: Construction Standards", shall be basically used.

In recent years, stainless-steel and corrosion-proof reinforcing bars have been developed. When using these reinforcing bars, including non-magnetic reinforcing bars it is necessary to confirm the performance conforming to the above JIS standard.

4.2.3 Anchorages and couplers

(1) It shall be ensured that structure and strength of anchorages and couplers is such that they do not fail below the required capacity or undergo excessive deformation.

(2) It should be ensured that the performance of anchorages and couplers complies with JSCE-E 537.

(3) When selecting the material for the anchorages and couplers, it shall be ensured that they conform to the required performance.

[Commentary] (1) Anchorage or couplers shall be of a structural and strength corresponding to or superior to the anchoring or coupling system using CFRM, allowing for safety during prestressing work, prevent excessive set in anchorage etc. In this case, the guaranteed capacity of the anchorages or couplers and that of the tendons are treated separately. Because, the tensile strength of CFRM is evaluated totally, including the influence of anchorages, but the anchoring device itself cannot exhibit the tensile strength of CFRM completely in many cases. This tendency is more remarkable in multi-cables. “Anchoring or coupling system” here refer respectively to systems configured with CFRM and anchorages, and CFRM and couplers.

(2) It is recommended to verify the performance of anchorages or couplers by “Test Method for Performance of Anchorages and Couplers in Prestressed Concrete Using Continuous Fiber Reinforcing Materials” in JSCE-E 537. However, this test is intended for new types or types for which adequate test data is not available; testing may be omitted for quality-assured types whose test data is given in the appendix of the “Recommendation for Design and Construction of Concrete Structures Using Continuous Fiber Reinforcing Materials".

(3) “Materials used for anchorages and couplers” refers to synthetic resins, anchoring expansion agents, grouts, anchor bars etc. These materials are used for anchoring and coupling that are most important for prestressed concrete structures. Therefore, the materials must be confirmed to be stable in quality and excellent in durability.

4.3 Construction

4.3.1 Handling and storage of materials

(1) CFRM should be handled carefully. For example, they should be applied with

protection to prevent damage to their surface.

(2) In cases when CFRM are stored outdoors, placing them directly on the ground should be avoided, and they shall be suitably covered. Even in cases when CFRM are stored indoors, placing them directly on the floor should be avoided and, if required, they shall be suitably covered. In any case, they shall be stored in a manner that they are protected against environmental factors such as high temperature, ultraviolet rays, chemicals etc, which could impair the CFRM, and also protected against being damaged or deformed.

[Commentary] (1) CFRM is likely to be subjected to deep scars when a sharp edge tool or an acute part of steel touches their surface. CFRM should therefore be handled carefully during their transport and storage, and assembly of steel bars and placement of concrete by taking such measures as protection. CFRM using glass fibers in particular should be handled carefully because alkali intrusion through the scars on the surface is likely to deteriorate durability.

(2) Placing CFRM directly on the ground or on a concrete floor should be avoided, even in a warehouse because they may be damaged or lose their quality. Placing CFRM in a high temperature, ultraviolet ray, or chemical environment should be also avoided, because their quality may deteriorate. In both cases, CFRM must be stored in a state free of harmful environmental conditions.

CFRM that are shipped in the form of coils should be stored in coils with an increased diameter or linearly to prevent twists when CFRM are uncoiled.

4.3.2 Shaping, assembly and placing in position of CFRM tendons, CFRM reinforcements etc.

4.3.2.1 Shaping and assembly of CFRM tendons

(1) CFRM tendons shall be shaped and assembled in a manner that results in the shape and dimensions specified in the design, without damaging the material. CFRM tendons found to be damaged at the surface, bent, affected by exposure to high temperatures or stored outdoors for long periods, shall not be used.

(2) CFRM tendons should not be bent to shape.

(3) CFRM tendons expected to develop bond shall be cleaned of any oil, fat or foreign matter, which may impair the bond before assembly.

[Commentary] (1) CFRM must to be processed correctly in order to achieve the designed shapes and dimensions without damaging the materials. These tendons must be cut, processed for anchoring, or attached to anchorages by appropriate methods prescribed for each CFRM. For cutting CFRM, it is preferable to use an efficient high-speed rotary grinder which does not damage the material.

CFRM tendons which are bent or scratched on the surface must not be used because their tensile strength is greatly anticipated to be reduced. In addition, CFRM tendons which have been subjected to high temperature must not be used because the thermal deterioration of the resin may lower their performance as the binder and reduce the tensile strength of tendons. Under direct sunlight, some kinds of CFRM tendons may be deteriorated by ultraviolet rays, therefore CFRM tendons that have been stored outdoors for long periods should not be used.

(2) In general, thermosetting resins are used as binding materials for CFRM tendons. Since it is rather difficult to form such a material by bending on site in terms of both technically and quality, the bend forming of CFRM is basically avoided. If bend forming is not avoidable, however, factory processing that does not impair the materials is permitted. Since the tensile strength of CFRM tendons may be reduced under the influence of bend forming and internal bending radius, it is necessary to check whether the tensile strength satisfy the strength required in design by an appropriate test method that reproduces the actual state of use.

(3) Grease, paint, dirt, and other foreign substances may disturb to develop bond between concrete or PC grout and CFRM tendons and cause tendon slippage. Therefore, CFRM tendons must be used after full surface cleaning.

4.3.2.2 Shaping and assembly of CFRM reinforcement

(1) CFRM reinforcements shall be shaped and assembled in a manner that results in the shape and dimensions specified in the design, without damaging the material. CFRM reinforcements found to be damaged at the surface, bent except shaping, affected by exposure to high temperatures or stored outdoors for long periods, shall not be used.

(2) CFRM reinforcement should be bent to shape in the factory.

(3) In cases when the inside radius for bending CFRM reinforcement is not specified in the designs, the inside radius and method of bending shall be determined in a manner that ensures that the tensile strength of the bent-to-shape CFRM is not below the value considered in the design.

(4) CFRM reinforcement shall be cleaned of any oil, fat or foreign matter, which may impair the bond before assembly.

(5) CFRM reinforcements shall be placed accurately and adequately supported without damaging the material to ensure that no displacement or deformation is caused by concrete casting. The CFRM reinforcement shall be fixed using a method that does not damage the CFRM or harm its durability.

[Commentary] (1) CFRM reinforcement must be handled in the same way as CFRM tendons, according to the comment of Clause 4.3.2.1 (1).

(2) For the reason given in Clause 4.3.2.1 (2), the bend forming of CFRM reinforcement into stirrups or spirals is basically done at the factory. Certain types of CFRM reinforcement can be formed by bending and thermosetting on site or by heating on site using thermoplastic resins, however, the tensile strength of the bend-formed section of CFRM reinforcement bent in these ways should be confirmed by an appropriate test method.

(3) Bend to shaped section of CFRM reinforcement is known to reduce the tensile strength to a degree depending on the type of continuous fiber, the reinforcement manufacturing method of the reinforcement, and the inside radius of bending. Therefore, the inside radius of bending and bend

forming method should be determined after the decrease in tensile strength is confirmed by testing. It is preferable to maximize the inside radius of bending.

4.3.2.3 Making ducts other than sheaths

When making ducts other than sheaths, the material and method used shall not adversely affect the CFRM tendons, CFRM reinforcement and concrete.

[Commentary] A duct is used to reserve space for tendon placement and to insulate tendons from concrete. The duct material must be selected after it is verified not to corrode the CFRM tendon or CFRM reinforcement or to decompose the concrete. The forming shall not cause racking in the concrete, increase the friction remarkably at prestressting, or damage the CFRM tendons.

4.3.2.4 Placing sheaths and CFRM tendons

(1) Damaged sheaths or sheaths having corrosion inside shall not used.

(2) Sheaths and CFRM tendons should be placed accurately and adequately supported without damaging the material, to ensure that no displacement or deformation is caused by concrete casting.

(3) CFRM tendons shall be placed within the sheath without being tangled.

(4) In cases when pre-tensioned CFRM tendons are used, the CFRM shall be handled in a manner that does not cause damage at edges of contact.

(5) CFRM tendons and sheaths should be inspected after they are placed. In cases when inadequacies such as damage or an error in placing, etc. are found, required corrective action and changes shall be undertaken.

(6) Allowable error during placement of CFRM tendons should be determined to be within a range that does not adversely affect the concrete member, considering its size.

[Commentary] (1) Steel sheaths having corrosion inside shall not be used because this may increase the friction at prestressing, damage the CFRM tendons, or disturb to develop bond. Before use, the external surface of a sheath shall be made free of oils, loose rust, and other foreign substances that may disturb adhesion.

To prevent the damage of CFRM tendons in a sheath, a plastic sheath may be used after its performance is fully verified.

(2) Sheaths and CFRM tendons shall be held securely at comparatively short intervals with appropriate supports not damaging concrete members so that the concrete weights at concrete placing or vibrations by vibrator will not misalign the positions. The support intervals shall be determined appropriately by considering the types and rigidities of CFRM tendon and sheath and also the coefficient of friction. Since CFRM tendons have lower density than steel members, they should be fixed with respect to ascending force also at concrete placing.

(4) Pretension may break a continuous-fiber tendon placed through an arrangement hole of an end frame if the tendon is damaged by contact with the arrangement hole at tensioning or concrete

compaction. Therefore, it is preferable to prevent the CFRM tendon from direct contact with the frame by using a cushioning material at the arrangement hole of the edge frame for CFRM tendon.

(5) Error in placing or damage during the placement of sheaths or CFRM tendons shall be corrected not only during the placement. The sheaths and CFRM tendons shall be inspected carefully also during concrete placing after the placement and corrected if necessary.

(6) The allowable error during placing of sheaths and CFRM tendons differ depending on the member dimensions and tendon placement method. As a rule, it is preferable to keep the centroid deviation within 5 mm if the cross-sectional dimension of the member is less than 1 m and within 10 mm besides less than 1/200 of the member dimension if the cross-sectional dimension of the member is 1 m or more. Deviation over 10 mm shall be corrected in any case.

4.3.3 Placement of concrete

(1) Concrete shall be placed and compacted taking care that the placement of CFRM, reinforcing steel bars, anchorages, sheaths etc., is not disturbed, and no damage occurs to the CFRM.

(2) In cases when steam curing is carried out, the tensile force and temperature of curing, etc. shall be determined considering the thermal behavior of the CFRM, anchorages, couplers etc.

[Commentary] (1) Concrete placing must be done with care because it may disturb not only the placement of CFRM, reinforcing bars, and frames but also the placement of anchors and sheaths for prestressed concrete. It should also be noted that CFRM migrate easily due to ascending forces because they are more lightweight and less rigid. In case that the placement of CFRM, reinforcing bars, anchors, and sheaths is disturbed, an iron worker should be present even during concrete placing.

CFRM may be damaged by direct contact with an internal vibrator. To prevent this damage, an internal vibrator with urethane or a similar cushioning material is preferable.

(2) The coefficient of thermal expansion in the axial direction of a CFRM differs depending on the fiber type. All fibers except glass fiber show very different coefficients from that of concrete. The coefficient of carbon fiber is almost 0 but the coefficient of Aramid fiber indicates an opposite property to concrete. For steam curing of a pretension member using a tendon, the initial tension must be determined by considering the temperature history. Temperature correction is necessary even for the post-tension method, in cases when the hydration heat of a concrete is remaining. This regulation was prescribed because some CFRM and their anchors, couplers, and sheaths are subject to quality changes of materials at steam curing temperature. The increase in relaxation and the decrease in adhesion strength must be noted for CFRM especially at high temperature. For steam curing, heating shall be started three hours or more after concrete placing and the temperature rise shall generally be 15°C or less per hour. The temperature during curing shall be 65°C or less and shall not adversely affect the quality of CFRM and their anchors and couplers.

4.3.4 Prestressing

(1) The required tensile force in CFRM, method of prestressing, preventative measure against emergency situations during prestressing, calibration of tensioning equipment,

required compressive strength of concrete for prestressing and control of prestressing, should be determined as per relevant methods.

(2) The coefficient of friction and apparent modulus of elasticity of CFRM for control of prestressing should be determined by testing at site.

(3) The coefficient of friction of tensioning apparatus and anchorage should be determined by testing.

(4) Prestressing tendons shall be tensioned and anchored in a manner that each of the CFRM is tensioned to the required level.

[Commentary] Tension shall be as prescribed in Section 12.6.4. When using a process prescribed in the data section of "Draft of Design and Execution Guide for Structure Made with Concrete Using Continuous Fiber Reinforcing Materials", the control method prescribed for the process must be used.

(1) Since a CFRM tendon shows more elongation than a PC steel member to the same tension force, it may be necessary to reposition the jack or use a jack with a longer stroke.

(2) The coefficient of friction and the apparent Young's modulus must be measured at the initiation of works and again if the trouble found during control. Tension had better be controlled with the measured coefficient of friction μ. The allowable standard limit of μ given in Table C13.7.1 is for PC steel member. For CFRM tendon, it is necessary to determine the allowable standard limit of μ in the same way as for PC steel member.

(4) A CFRM tendon shows a linear stress-strain curve with no yielding and its ultimate strain is smaller than that of a PC steel member. Since a CFRM tendon has a property of great strength decrease by bending, tensioning of CFRM tendons and anchoring to the anchorage must be carried out carefully to avoid brittle failure. The tensioning section lengths of CFRM tendons should be made uniform from the beginning and the elongation of each CFRM tendon at tensioning must be controlled more strictly than when a tension is given to a PC steel member. At the tensioning of a CFRM tendon, the tension should be increased not quickly but gradually. When a CFRM tendon is fixed on an anchor, slippage may become greater than for a PC steel member. Because of small tensile rigidity, however, the decrease of tendon tensile force attributable to slippage at anchorage generally becomes small.

4.4 Inspection

4.4.1 Inspection for acceptance of materials

(1) The accepting party shall be held responsible for conducting acceptance tests for CFRM. The tests should be in accordance with Table 4.4.1.

Table 4.4.1 Inspection for acceptance of CFRM

Item	Testing method/Inspection method	Period/Frequency	Criteria for judgment
Quality item of JSCE-E 131	Verification based on the test records prepared by the manufacturer, or test using a method specified in JSCE-E 531, 533, 534	On acceptance	Shall confirm to JSCE-E 131

(2) Conducting acceptance tests for anchorages and couplers for continuous fiber reinforcing materials (CFRM) tendons shall be the responsibility of the accepting party. Inspections should be conducted for the anchorage or coupler in combination with the CFRM tendon in accordance with Table 4.4.2. Note that the inspection may be avoided for materials of the quality assured.

Table 4.4.2 Inspection for acceptance of anchorage or coupler

Item	Testing method/ Inspection method	Period/Frequency	Criteria for judgment
Tensile strength (or Tensile load)	Verification based on the test records prepared by the manufacturer, or test using a method specified in JSCE-E 537	On acceptance (Inspections may be eliminated for those of guaranteed quality and with good track records.)	Anchorage or coupler should confirm to standards to achieve the designated objective.
Anchorages and couplers			
Fatigue strength	Verification based on the test records prepared by the manufacturer, or testing of a system incorporating the anchorage or coupler using a method specified in JSCE-E 535		
Relaxation value	Verification based on the test records prepared by the manufacturer, or testing of a system incorporating the anchorage or coupler using a method specified in JSCE-E 534		

[Commentary] The accepting party held responsible for conducting acceptance tests means the Owner. Generally, however, the Contractor constructing concrete using CFRM conducts tests and the Owner confirms the test results.

(1) In terms of mechanical properties, durability, and handling method, CFRM generally differ greatly from steel members. This must be kept in mind for appropriate inspection. The performance requirements and inspection details for reinforced or prestressed concrete using CFRM are similar to those using ordinary reinforcing materials. Acceptance tests shall therefore be conducted in accordance with "Construction: Construction Standards".

(2) The mechanical properties of the CFRM tendon are greatly affected by the performance of anchorages and couplers. Whether the type is single or multiple, the general system performance tends to be lower than that of the CFRM tendon itself. When using CFRM tendons, therefore, the entire system, including anchorages and couplers shall be tested with respect to items that seemingly affect the CFRM tendons to verify the performance.

The shape, performance, and state of use of anchorages or couplers differ greatly depending on the model of anchorages or couplers and the type of CFRM tendon. Therefore, it is necessary to determine an appropriate test that can reproduce the state of use and the tensile force effecting state. This test shall verify that the anchorages and couplers have structures and strengths not to be fractured or remarkably deformed under each proof tensile load or less and that they have the prescribed fixing efficiency and coupling efficiency for CFRM tendon. Depending on the type of anchorages and couplers, it is also important to check that set loss due to tendon slippage is within allowable limits; furthermore, given that continuous fiber reinforced concrete structures are often located in extreme environments, any steel anchorages and couplers must be confirmed to be sufficiently durable.

This test may be omitted if the CFRM tendon has verified quality and the anchorages and couplers are given in the data section of "Draft of design and execution guide for structure made with concrete using continuous fiber reinforcing materials" exclusively for the CFRM tendon and have assured quality and history of use.

4.4.2 Inspection for protection of CFRM

(1) The accepting party shall be held responsible for conducting inspection for protection of CFRM. The tests should be in accordance with Table 4.4.3 as a standard.

(2) In cases when from the results of the inspection, protection to the CFRM is determined to be inadequate, the method of protection shall be appropriately modified.

Table 4.4.3 Inspection for protection of CFRM

Item	Method for testing and inspection	Period/Frequency	Criteria for judgment
Method of storage	Visual observation	At the time of acceptance	As per the document giving details of the construction plan
Method of transportation		At the time of transportation	
Method of fixing		Prior to placing concrete	
Method of concrete placing		During concrete placing	

[Commentary] At each stage of work, CFRM shall be inspected to verify that they are protected from damage as prescribed in the construction plan.

Inspection of concrete must refer to Chapter 16 in "Materials and Construction: Construction Standard" and "Inspection Standard".

CHAPTER 5 SHORT FIBER REINFORCED CONCRETE

5.1 General

5.1.1 Scope

This chapter presents standards for necessary matters concerning the quality and construction of short fiber reinforced concrete. The short fibers to be discussed in this chapter are steel fibers and synthetic fibers.

[Commentary] Short fiber reinforced concrete is a composite material with tensile strength, flexural strength, cracking resistance, ductility, shear strength and impact resistance enhanced by uniformly distributing discontinuous short fibers in concrete. Fibers used for short fiber reinforced concrete include metal fibers such as steel and stainless fibers, inorganic fibers such as glass, carbon and ceramic fibers, and synthetic fibers such as aramid, nylon, polyvinyl alcohol(PVA), polyethylene and polypropylene. This chapter discusses steel and synthetic fibers as they have good track records. When using carbon and other fibers, this chapter should be consulted while considering the characteristics and track records of respective fibers.

Steel fiber reinforced concrete has been applied not only in non-structural members but also in structural members of various structures because it provides greatly improved mechanical properties. Steel fiber reinforced concrete is highly resistant to crack opening. Using steel fiber reinforced concrete for unreinforced concrete reduces crack width and enhances fatigue strength. As the content of steel fibers increases, therefore, the thickness of pavement or tunnel lining can be reduced. Resistance to freezing and thawing action and durability can also be improved. Using steel fiber reinforced concrete for reinforced concrete increases the shear strength of members. Steel fiber reinforced concrete is therefore effective for structures that require particularly high shear strength. High toughness against compression during compressive failure and against bending during flexural failure means high resistance to impact or explosive loads.

The above characteristics of steel fiber reinforced concrete are determined by the shape, dimensions, content, orientation and dispersion of steel fibers in concrete, and by the quality of concrete. The quality of steel fiber should be verified in testing before use. Steel fibers with a length of 20 to 60 mm, diameter of 0.3 to 0.9 mm and aspect ratio (diameter-length ratio) of 30 to 100 are generally used. The percentage of steel fiber in concrete ranges from 0.5 to 2.0%, which is equivalent to a unit quantity of approximately 40 to 160 kg/m^3. When constructing steel fiber reinforced concrete, the "Recommendations for Design and Construction of Steel Fiber Reinforced Concrete (draft)" and "Recommendations for Design of Steel Fiber Reinforced Concrete Column Members (draft)" should be consulted. For shotcrete using steel fibers, refer to Chapter 8 Shotcrete, "Recommendations for Design and Construction of Steel Fiber Reinforced Concrete (draft)" and "Recommendations for Construction of Steel Fiber Reinforced Shotcrete (draft)".

Ultra high strength fiber reinforced concrete has recently been put to practical use that has a characteristic value of compressive strength of 150 N/mm^2 or higher owing to the use of extremely fine powder like silica fume and has high cracking strength and tensile strength with the mixing of steel fiber of approximately 2%. Steel fibers with a length of 10 to 20 mm and a diameter of 0.1 to 0.25 mm, unlike the conventional steel fibers, are now being used. For super high strength fiber reinforced concrete, refer to the "Recommendations for Design and Construction of Ultra High Strength Fiber Reinforced Concrete Structures (draft)".

Synthetic fibers are generally inferior to steel fibers in terms of mechanical reinforcement. The former are, however, difficult to corrode and can be easily shaped during manufacturing. They have a low density and can be deformed easily, facilitating construction. Short fiber reinforced concrete using synthetic fibers as that using steel fibers sees its toughness against bending and other mechanical properties enhanced with the increase of the percentage of short fibers. In tunnel lining concrete, synthetic fibers with a length similar to that of ordinary steel fibers are used as well as steel fibers. Recently, small quantities of synthetic fibers are mixed to reduce plastic shrinkage, prevent cracking due to drying shrinkage and concrete spalling and prevent explosion during fire rather than to improve mechanical characteristics in numerous cases. For these applications, synthetic fibers with a length of 10 to 20 mm and a diameter of 0.02 to 0.3 mm are frequently used. The length is shorter and the diameter is smaller than steel fibers. Synthetic fibers come in a large number of types with the aspect ratio between 40 and 700. The percentage of short fibers in concrete varies with the objective of use. The percentage is 0.04 to 0.1% for preventing concrete from spalling from viaducts, 0.2 to 0.3% for preventing the explosion of high strength concrete or more than 0.3% for controlling the cracking of tunnel lining concrete. Synthetic fibers have a low density. The quantity used per unit volume of concrete is 0.3 to 5 kg/m^3. The characteristics of short fiber reinforced concrete vary according to the shape, dimension and percentage of synthetic fiber. The quality and effect of the synthetic fiber to be used should be verified in testing before used.

Mixing approximately 2% of high strength synthetic fiber such as polyvinyl alcohol fiber (PVA) and high strength polyethylene fiber enables the production of short fiber reinforced mortar with high mechanical properties, which is proposed as ductile material with multiple fine and high density cracks. When using ductile materials, refer to the "Recommendations for Design and Construction of High Performance Fiber Reinforced Cement Composites with Multiple Fine Cracks (HPFRCC) (draft)".

5.1.2 General

When using short fiber reinforced concrete, materials of proven quality shall be employed, mix proportions shall be determined to meet the designated performance requirements and the concrete shall be manufactured and constructed properly. Inspections shall be conducted as required in each phase.

[Commentary] To obtain the designated quality of short fiber reinforced concrete, short fibers should in principle be dispersed evenly. Quality is greatly influenced by the length, shape and percentage of short fiber, maximum size of coarse aggregate, water-cement ratio, percentage of fine aggregate, mixing method, compaction method and other factors. These parameters shall therefore be fully examined before construction.

5.2 Quality of Short Fiber Reinforced Concrete

5.2.1 General

Short fiber reinforced concrete shall have the designated strength, toughness, durability, cracking resistance and workability and be of uniform quality.

[Commentary] In cases where short fibers are not uniformly distributed or oriented in a specific direction, the designated strength or toughness may not be achieved. Tensile strength, flexural strength, shear strength and toughness increase nearly in proportion to the percentage of short fibers in concrete. Compressive strength, however, does not change greatly. Steel fiber reinforced concrete and short fiber reinforced concrete with a relatively large quantity of synthetic fibers gradually fail while maintaining a certain level of ductility even after cracking occurs. The brittleness of concrete is improved considerably and the toughness is increased greatly.

In cases where steel reinforced concrete is used in reinforced concrete structures, cracking seldom occurs and electrical resistance varies. It has been reported that the corrosion of reinforcement is controlled even under severe conditions as in marine environments.

5.2.2 Strength properties

5.2.2.1 Compressive strength

Compressive strength of short fiber reinforced concrete shall be determined in accordance with JIS A 1108.

[Commentary] The compressive strength of concrete increases marginally due to addition of short fibers to the concrete. The compressive strength shall be specified in a manner similar to normal concrete. The probability of not attaining design characteristic compressive strength should be less than 5%, when tests are carried out in accordance with JIS A 1108 “Method of Test for Compressive Strength of Concrete”. It is noted that the coefficient of variation of compressive strength of short fiber reinforced concrete may be equal to that of normal concrete.

5.2.2.2 Tensile strength

Tensile strength of short fiber reinforced concrete shall be determined in accordance with JIS A 1113 or by the direct tension tests using concrete specimens.

[Commentary] Though it is desirable that the tensile strength be determined by direct tension tests, an accurate test method using a general-purpose test apparatus is not yet to be established. Thus, the tensile strength of short fiber reinforced concrete shall normally be determined using JIS A 1113 “Method of test for splitting tensile strength of concrete.” In this case, the strength at the first crack may be taken as the tensile strength. The tensile strength should be specified in a manner that the probability of failure at a value lower than the characteristic value of tensile strength is less than 5%.

5.2.2.3 Flexural strength

Flexural strength of short fiber reinforced concrete should consider its size effect as a standard.

[Commentary] Due to the significant size dependence, it is difficult to think of flexural strength as an index for characterization of material properties of short fiber reinforced concrete. However, on the basis of the full-scale testing, the experimental value can be taken as the characteristic value for the actual structure. In general, flexural strength is generally determined in accordance with JSCE-G 552 “Test Method for Flexural Strength and Flexural Toughness of Steel Fiber Reinforced Concrete”.

5.2.3 Deformation characteristics

5.2.3.1 Deformation characteristics under compression

(1) The stress-strain curve of short fiber reinforced concrete should be determined by a method in accordance with JSCE-G 502 as a standard.

(2) The stress-strain curve of short fiber reinforced concrete may be assumed using reliable data.

[Commentary] As in the case of normal concrete, the stress-strain curve of short fiber reinforced concrete also varies widely depending on the type and age of concrete, state of stress of concrete, and rate and path of loading. However, the inclusion of fibers scarcely affects the compressive strength and the deformation characteristics in compression, as long as the applied load is less than the compressive strength. Accordingly, this specification allows use of provisions of JIS A 1149 “Test Method for Static Modulus of Elasticity of Concrete” for determination of the stress-strain curve and the deformation properties of short fiber reinforced concrete in compression.

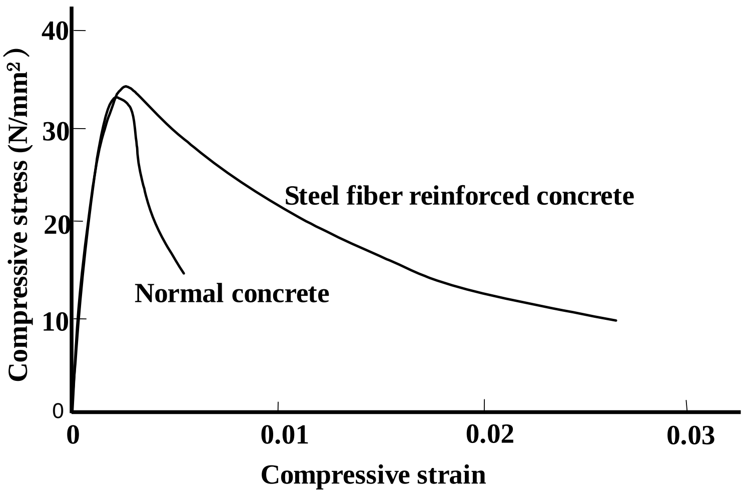


Fig. C5.2.1 Example of compression test results

The inclusion of short fibers is however known to improve the deformation characteristics of concrete after the peak load as shown in Fig.C5.2.1. In the case of synthetic fiber, improvement of deformation characteristic depends on fiber content significantly, and much fiber content improves the deformation characteristics of concrete after the peak load.

When a high accuracy is required in calculation of stresses, etc., a stress-strain curve representing the actual conditions should be used. In such cases, compression-softening should be taken into consideration.

5.2.3.2 Tension softening properties

(1) Tension softening properties of short fiber reinforced concrete should be determined by the results of the direct tension tests or flexure tests using test specimens.

(2) The tension softening curve of short fiber reinforced concrete may be specified using a linear or any other suitable model based on reliable data.

[Commentary] (1) Since short fibers transfer stress after cracking, the effect of short fiber reinforced concrete on the tensile fracture property remarkably appears in the tension softening curve, which shows the relationship between tensile stress and crack width. In case when the tension-softening property of short fiber reinforced concrete needs to be specified, for example in the case of columns, it may be specified using a tension-softening curve. Though direct tensile test can be carried out to determine the tension softening curve, it shall be required to have a highly rigid testing machine completed with precise displacement control. In certain cases, it may be impossible to apply as method of verification for short fiber reinforced concrete. The tension softening curve may be calculated from flexural test results, while recommending determination of the curve based on tests under direct tension. Several methods of estimating a tension softening curve on the basis of the flexure test results have been proposed. Appendix 1 of "Design Recommendations for Concrete Columns Reinforced with Steel Bars and Fibers" gives a brief outline of such method, and Test Method 2 "Recommendations for Design and Construction of High Performance Fiber Reinforced Cement Composites with Multiple Fine Cracks (HPFRCC) (draft)" provides an example of the direct tensile test. It may be noted that, in principle, only machine with displacement control should be used for direct tensile test and flexure test.

(2) The tension softening curve of short fiber reinforced concrete generally shows a reduction in stress immediately after cracking. As the softening behavior after cracking has been known to depend on the type, shape, and content of short fibers, the tension softening curve of short fiber reinforced concrete may be specified using a linear or any other suitable model, depending upon the application. A tension softening curve obtained from direct tension tests can be divided into two zones as shown in Fig. C5.2.2 – one is the region immediately after cracking, where the stress abruptly decreases, and, the other is the region where the stress decreases slowly as the crack-width increases. The area under the tension softening curve, i.e., fracture energy G_F, represents the resistance of concrete to cracking.

A typical tension softening curve is shown in Fig. C5.2.3. This curve is quoted from "Design Recommendations for Concrete Columns Reinforced with Steel Bars and Steel Fibers" and may be used as a reference.

For short fiber reinforced concrete with synthetic fiber, fiber content significantly depends on the application, tension softening properties of concrete is dramatically improved with increasing of fiber content.

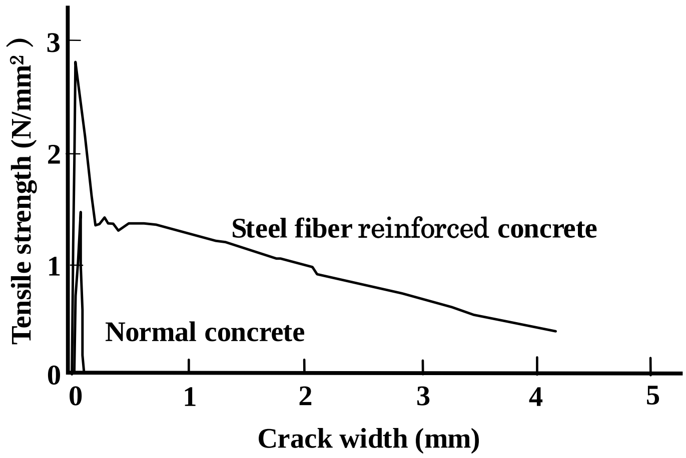


Fig. C5.2.2　A typical tension softening curve

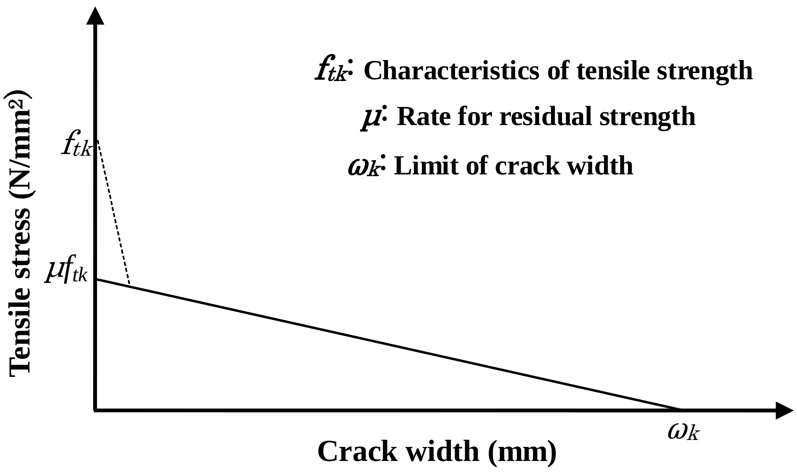


Fig. C5.2.3　A typical specified tension softening curve

5.2.3.3　Flexural toughness

In cases when the performance of short fiber reinforced concrete in terms of flexural toughness is specified on the basis of field experience without using a tension softening curve, indices as the coefficient of flexural ductility determined from test values in accordance with JSCE-G 552, the load-deflection curve and load-crack width curve obtained from flexural test of concrete specimens, may be used.

[Commentary]　In the past, short fiber reinforced concrete has been used in applications such as tunnel lining, paving, slope protection, and repair and reinforcement without carrying out calculations for stress or numerical analysis. In these cases, flexural toughness may be adequately specified on the basis of field experience or shall be specified by the coefficient of flexural ductility based on values determined through tests carried out in accordance with JSCE-G 552 “Test Method for Flexural Strength and Flexural Toughness of Steel Fiber Reinforced Concrete”. Also, it may be specified by the post-cracking period in the load-deflection curve or the load-crack width curve, obtained from flexural testing of concrete specimens.

The scale effect between the actual structure and specimens should be adequately considered, as the results of flexural toughness can vary widely, depending on the size of the specimen.

5.2.4 Prevention of explosion

When using short fibers to prevent explosion during a fire, the types and quantities of synthetic fibers to be used should be verified by an appropriate method as a standard practice. The percentage of short fibers to be mixed for preventing explosion may be determined according to the type of synthetic fiber to be used based on reliable data.

[Commentary] In concrete with a low water-cement ratio such as high strength concrete and high fluidity concrete, vapor pressure sometimes increases in concrete during a fire and surface concrete is exploded. Mixing synthetic fibers, however, provides a route for vapor to pass during a fire while synthetic fibers are burned and is effective for preventing explosion. Polypropylene short fibers are fully effective for preventing explosion in a range of fiber content (volume percentage) between 0.165 to 0.33% (a range of quantity mixed between 1.5 to 3.0 kg/m^3). Mixing of synthetic fibers has little influence on the strength or durability of concrete. Short fiber reinforced concrete with explosion prevention capacity has frequently been used in columns of high rises with a design strength of 80 N/mm^2 or higher. Use is also being considered in tunnels with an ordinary strength that are subjected to a fire under severe conditions.

Polypropylene is frequently used, and polyacetal and polyvinyl alcohol (PVA) are also adopted. Effectiveness for preventing explosion varies because fusion point varies according to the type of synthetic fiber. The larger quantity, the smaller diameter and the longer length of the fiber give the more effective for preventing explosion. Melting point and burning temperature are different for polypropylene and polyacetal. Synthetic fibers provide adequate explosion prevention capacity at a mixing percentage by volume of 0.2 to 0.3%. It should, however, be notes that some of the synthetic fibers are likely to emit toxic gas when they are burned.

When using a synthetic fiber for which no data is available on the standard percentage for mixing to provide explosion prevention capacity, the quantity of the synthetic fiber effective for preventing explosion should be verified for the specific type of synthetic fiber in appropriate heating tests while varying the percentage of the synthetic fiber to be mixed. The heating temperature should be specified considering the RABT curve (ZTV Tunnel Curve) for testing tunnel fire specified in recommendations concerning highway tunnel facilities and operation in Germany, or the RWS tunnel curve of the Ministry of Transport, Public Works and Water Management of the Netherlands.

5.2.5 Prevention of spalling

When using short fibers to prevent concrete from spalling from the structure, the types and quantities of short fibers to be used should be verified by an appropriate method as a standard practice. The standard percentage of short fibers to be mixed for preventing concrete spalling may be determined according to the type of short fiber to be used based on reliable data.

[Commentary] Concrete spalling from concrete viaducts is likely to cause damage to third parties. When using short fiber reinforced concrete to prevent spalling, small quantities of synthetic fibers with a percentage of 0.04 to 0.1% are applied. Synthetic fibers are used on the slabs and beams at upper and middle levels of concrete viaducts, and on curbs and railings where concrete is cast in-situ.

In order to determine the quantity of short fiber effective for preventing concrete spalling for the specific type to be used, the effectiveness should be verified in tests in which damage is caused by hammering to induce concrete spalling. Fig. C 5.2.4 shows an example of method for verifying the effectiveness of short fibers for preventing concrete spalling. In the tests using the method, an expansive agent is injected into holes at the positions of reinforcement in the specimen, expansion pressure is used to cause cracking and the spalling of concrete cover is induced by hammering in order to simulate concrete spalling due to the corrosion of reinforcement. The ratio between the frequency of hammering until spalling occurred in the case with short fibers and the frequency in the case with no short fibers (hammering frequency ratio) is obtained while varying the quantity of short fibers mixed to evaluate the effectiveness of short fibers for preventing spalling. The short fiber mixing ratio at a hammering frequency ratio of approximately eight was regarded as a guideline for the standard quantity of short fibers to be mixed. In order to prevent the expansive agent injected into the holes at the positions of reinforcement from expanding excessively and exploding, the designated quantities of expansive agent should be used by the designated method.

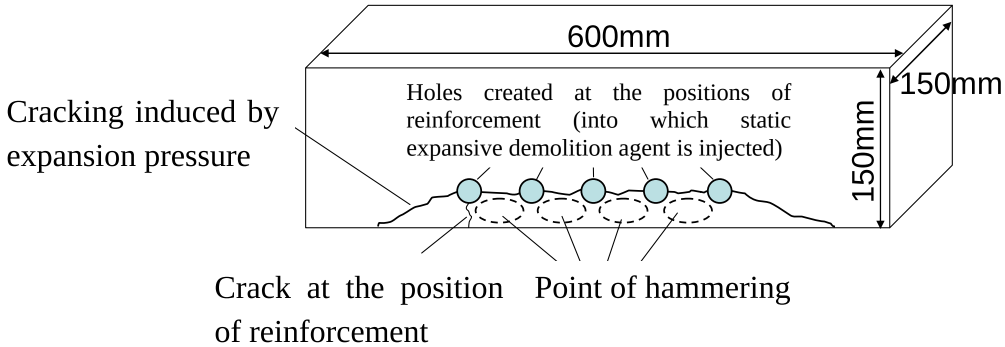


Fig. C5.2.4 Test for verifying the effectiveness for preventing concrete spalling

5.2.6 Other performance

In cases where performance other than strength and deformation characteristics are especially required, these shall be appropriately confirmed on the basis of tests using scaled specimens and models, testing of conventional specimens, or analysis.

[Commentary] Performance of short fiber reinforced concrete other than strength and deformation characteristics include abrasion and impact resistance. However, enough relevant data is not available from past research work and no standard test or method of analysis is currently available to determine these properties. Therefore, in case when these properties are specified, they should be appropriately evaluated.

5.3 Short fibers

5.3.1 Steel fibers

(1) Steel fibers used should comply with JSCE-E 101 as a standard.

(2) When steel fibers other than those specified in (1) above are used, the quality shall be appropriately confirmed and the application shall be thoroughly investigated.

[Commentary] The reinforcing effect of short fibers increases as the fiber length increases. A fiber length of at least 1.5 times the maximum aggregate size is recommended considering the ease of fiber dispersion. While a fiber length of 30mm or more is generally recommended for short fiber reinforced concrete, the fiber length for shotcrete should be selected considering the fact that short fibers are more workable but less effective in reinforcing concrete.

Short fibers of 20mm or less, which permit easy spraying, are used for shotcrete, while longer fibers of about 60mm with a high reinforcing effect are used for slabs. Therefore, JSCE-E 101 “Quality Specifications for Steel Fibers for Concrete” requires the nominal length and aspect ratio of short fibers to be between 20 and 60mm and between 30 and 80, respectively. When the fiber that is no specified in JSCE-E 101 is used, quality of the used fiber and usage of the fiber shall be well investigated referring to JSCE-E 101.

5.3.2 Synthetic fibers

Synthetic fibers shall have proved quality so that the short fiber reinforced concrete using the synthetic fibers meets the designated performance requirements.

[Commentary] Synthetic fibers are less effective for mechanical reinforcement than steel fibers. The former, however, have several benefits. For example, they are free from corrosion, the thickness and surface shape of the fiber can be treated relatively freely according to the objective and they have a low density and are easily deformed, so they are easy to construct. Synthetic fibers are used for varieties of purposes including the control of cracking due to plastic shrinkage or drying shrinkage, prevention of spalling, improvement of toughness against bending and prevention of explosion during a fire. Examples of physical properties of typical synthetic fibers are listed in Table. C5.2.4. Most of the organic fibers used for short fiber reinforced concrete are synthetic fibers. For producing high strength short fiber reinforced concrete using synthetic fibers, polyvinyl alcohol (PVA) fibers and high strength polyethylene fibers are used.

Table. C5.2.4 Examples of physical properties of synthetic fibers

Type	Tensile strength (N/mm^2)	Modulus of elasticity in tension (kN/mm^2)	Density (g/cm^3)	Heat resistance	
				Softening point (℃)	Melting point (℃)
Polyethylene fiber	200	2.5	0.94～0.96	100～115	125～135
Polypropylene fiber	300～980	3～10	0.91	140～160	165～173
Polyvinyl Alcohol fiber	800～1500	20～40	1.26～1.30	220～230	Not explicitly known

When using synthetic fibers to reinforce concrete, the bond between hardened cement and fiber is important. If the bond is extremely lower than the limit elasticity stress of the fiber, fibers start ejecting from the hardened cement as soon as cracking occurs. Then, reinforcement is insufficient. Polyvinyl alcohol fiber is highly hydrophilic because the material contains hydroxyl, and provides a high bond strength. Polypropylene fiber and polyethylene fiber have a low bond strength with hardened cement. For these types of fibers, the bond is improved by using fibers of a special shape or treating the surface.

The chemical properties of synthetic fiber varies according to the type. The deterioration of synthetic fibers due to alkali reaction induced by cement has a great impact on the durability of short fiber reinforced concrete. A method has therefore been proposed for verifying the deterioration of flexural strength and toughness by dipping a specimen of short fiber reinforced concrete using synthetic fiber in hot alkali water.

In short fiber reinforced concrete using synthetic fibers, the larger the quantity of short fibers mixed and the shorter the diameter of the short fiber, the greater the performance but the lower the workability. At the same percentage of short fibers mixed in concrete, slump is lower for longer fibers and for thinner fibers.

5.4 Mix proportions

(1) Short fiber reinforced concrete shall be appropriately proportioned in a manner that it meets the requirements for design concrete.

(2) The shape, size and content of short fibers should be determined considering the required strength and deformation characteristics of the short fiber reinforced concrete.

(3) Short fiber reinforced concrete shall be proportioned in a manner that the water content is kept to a minimum, while meeting the required performance.

(4) The shape, size and content of short fibers shall be clearly indicated in the mixture proportions.

[Commentary] (1) Short fiber reinforced concrete shall have the required strength and deformation properties, durability, and capability to protect the reinforcing bars, while having workability for proper placing.

Fibers in short fiber reinforced concrete should, in principle, be uniformly dispersed to achieve the required qualities or performance, which are strongly affected by the length, shape, and content of short fibers, maximum size of aggregate, water-cement ratio, sand-aggregate ratio, and methods of mixing and consolidation. Especially, a very high fiber content needs a high unit water content and sand-aggregate ratio, which could induce bleeding and segregation, and hamper mixing, transportation, placing, and consolidation. Such issues should, therefore, be thoroughly looked into before start of operations such as production and placement/application.

Whereas the flexural strength and toughness of short fiber reinforced concrete increase as the fiber content increases, the compressive and tensile strengths do not change much with the fiber content.

(2) The compressive strength of short fiber reinforced concrete is determined primarily by the water-cement ratio, as in the case of normal concrete, and not by the fiber content, though an increase in the fiber content may increase the flexural and bond strengths, and toughness. Further, this increase, particularly in the case of toughness, depends on the shape and size of fibers. Thus, in this section the compressive strength shall be considered on the basis of the water-cement ratio, as in the case of normal concrete, and the shape, size, and content of short fibers for short fiber reinforced concrete shall be determined taking the required flexural or bond strength and deformation properties into consideration. However, it has been found that the fiber content should be up to 0.5 to 2% by volume of concrete to be adequately mixed using normal mixing methods.

It also is noted that the fiber content, raw material, method of production, surface treatment, and shape of short fibers for concrete columns should be selected in accordance with “Design Recommendations for Concrete Columns Reinforced with Steel Bars and Steel fibers”. In cases when the fibers used do not conform to these requirements, it should be ensured that the tension softening properties of the resulting short fiber meet the specified requirements.

The deformation properties of short fiber reinforced concrete are also affected by the maximum size of aggregate. Thus, the short fibers used short fiber reinforced concrete should be sufficiently long compared to the maximum aggregate size in order to satisfy the desired deformation properties. Therefore, the length of short fibers should be specified to be at least 1.5 times the maximum aggregate size. In the case of short fiber reinforced mortar, maximum aggregate size of fine aggregate should be considered. The short fiber with the length of 12mm or less can be, therefore, used in the application to prevent spalling or explosion of concrete.

(3) In addition to compressive strength but also deformability is an important performance item for short fiber reinforced concrete. It is therefore necessary, that the proportioning of short fiber reinforced concrete be carried out in a manner that the resulting concrete satisfies the deformability requirements also.

The unit water content required for short fiber reinforced concrete linearly increases as the fiber content increases, and for each fiber percent by volume of concrete, an increment of as much as 20 kg/m^3 may sometimes be required. It is therefore essential to minimize the unit water content of short fiber reinforced concrete within the range that produces concrete satisfying the quality requirements. From this point of view, that use of admixtures such as air-entraining and water-reducing admixtures, high-range water reducing AE admixtures is recommended. In the case of short fiber reinforced concrete, in order to maintain the workability, the sand-aggregate ratio may need to be substantially increased as the aspect ratio of the fibers increases (see “Recommendations for Design and Construction of Steel Fiber Reinforced Concrete Structures”).

5.5 Production and Placement/Application

5.5.1 Fiber addition and mixing

(1) In principle, a revolving-blade mixer should be used.

(2) Short fibers shall be added to concrete in the mixer in a manner that ensures their uniform dispersion in the concrete.

(3) Short fiber reinforced concrete shall be thoroughly mixed in order that the required qualities can be obtained.

(4) In principle, the mixing time should be determined by relavant tests.

(5) In cases when short fibers are added to concrete in an agitating truck, the concrete shall be mixed at high speed, and shall be confirmed that the quality requirements are met.

[Commentary] (1) Since short fiber reinforced concrete is a composite material, in which short fibers are uniformly dispersed and formed a homogenous composite material, it is important that fibers are thoroughly mixed with the concrete. As concrete including short fibers may require greater energy for mixing, than concrete without fibers, the present specification recommends use of a revolving-blade mixer as a standard mixer instead of a gravity mixer. It is noted that the mixing load of short fiber concrete using the revolving-blade mixer may require between 2 to 4 times the energy required in the case of normal concrete.

(2) Dispersing short fibers uniformly in concrete without forming fiber balls is of paramount importance for obtaining short fiber reinforced concrete having the required properties. The method of adding fibers to the concrete including selection of fiber type and the points and sequence of fiber addition is therefore a critical factor requiring utmost care for producing short fiber reinforced concrete having the desired properties. When the fiber having the length over 40mm is used, mix proportions, mixing and transportation should be confirmed to meet the required performance, such as mechanical properties. When a fiber-ball is found in the mixed concrete, the concrete shall not be used in a concrete structure.

(3) In order to obtain short fiber reinforced concrete having the required qualities, it is necessary that fibers should be uniformly dispersed in the concrete, which should form a homogenous composite material. Therefore, the method of charging short fibers into the mixer and mixing so that the short fibers can be dispersed uniformly should be established.

For adding normal steel fibers, devices such as dispersing dispensers may be used. In the case of flat fibers and fibers bundled with water-soluble adhesive, addition may be made at a time without forming fiber-balls.

(4) As the mixing time to be necessary for adequate dispersion of added fibers varies depending on the type and content of fibers, it is recommended that, in principle, the mixing time for short fiber reinforced concrete shall be determined using test mixes and confirming that the properties of the concrete obtained meet the specifications. Mixing time can be also determined through the reliable data or track records.

(5) In general, the high speed mixing in cases when short fibers are added to concrete in an

agitating truck is conducted. Although synthetic fibers of 0.1% or less in volume are used for prevention of spalling, adequate fiber is put in the agitating track. High speed mixing using an agitating truck shall be adopted for 2-4 min. to obtain well dispersion of fiber itself. In the case of synthetic fibers, high speed mixing, however, increases air content of concrete.

In cases when steel fibers are added to the concrete in an agitating truck, the qualities of the resulting concrete are affected by the method of addition and mixing time. The method of addition and the mixing time should therefore be appropriately specified to ensure that the resulting short fiber reinforced concrete meets the specifications.

5.5.2 Transportation

When using concrete pump for transportation, the pumping loads are greater than those for normal concrete. This shall be appropriately considered when making the selection of the type of pump, etc.

[Commentary] When concrete pumps are used to transport short fiber reinforced concrete, they should have a sufficiently large capacity, as losses in internal pressure may be larger than those for normal concrete. Also, the piping layout should be such that an increase in the pumping loads is avoided. Further, since flexible pipe sections are particularly vulnerable to abrasion, their material, diameter, and pipe thickness should be appropriately selected according to the placing conditions.

5.6 Inspection

5.6.1 Inspection for acceptance of short fibers

Inspection for acceptance of short fibers shall be conducted under the responsibility of acceptance side. The inspection should be carried out in accordance with Table 5.6.1.

Table 5.6.1 Inspection of short fibers

Type	Item	Testing method /inspection method	Period/Frequency	Criteria for judgment
Steel fiber	Quality	Data sheet of the tests provided by manufacturer	Prior to construction, during construction, and when the type of fiber is altered	Conformance to JSCE-E 101
Synthetic fiber	Quality	Data sheet of the tests provided by manufacturer	Prior to construction, during construction, and when the type of fiber is altered	Conformance to quality control level of manufacturer

[Commentary] Acceptance side of short fiber means manufacturer of short fiber reinforced concrete, and the inspection results shall be confirmed by the Owner of the concrete structure. In the cases of fibers not conforming to JSCE-E 101 “Specification for Steel Fiber for Concrete”, inspection should be carried out by the same test and inspection methods as conforming fibers and be judged in accordance with JSCE-E 101. Criteria for the judgment should be verified through the various tests of short fiber reinforced concrete. Although a standard or specification for a synthetic fiber is not established, the criteria for the judgment should be specified conforming to quality control level of manufacturer.

5.6.2 Inspection for acceptance of concrete at delivery

Inspection for acceptance of short fiber reinforced concrete shall be conducted under the responsibility of the acceptance side. The inspection should be carried out in accordance with Table 5.6.2 as standard.

Table 5.6.2 Inspection for acceptance of concrete

Item	Testing method/ Inspection method	Period/Frequency	Criteria of judgment
Steel fiber content by volume (when deformation properties are specified as performance requirements)	In accordance with JSCE-F 554	- When unloading - Once in a day or once every 20-150 m^3, depending upon the importance of structure and the scale of the construction work	Within the specified range of fiber content by volume
	In accordance with JSCE-F 555 (Shotcrete)		
Steel fiber content by weight (when only strength properties are specified as performance requirements)	Mass of fiber added to concrete	- At the time of unloading - All batches	Within the specified range of fiber content by weight
Synthetic fiber content	Mass of fiber added to concrete, or number of bags	- At the time of unloading - All batches	More than the specified fiber content

[Commentary] The acceptance side of short fiber reinforced concrete means the Owner of the concrete structure. Occasionally, constructer of the short fiber reinforced concrete tests and the Owner of concrete structure confirms the test results.

As in the case of compressive strength of normal concrete, it is difficult to directly inspect for the strength and deformability of the short fiber reinforced concrete at the time of delivery. Nevertheless, these properties significantly depend on the materials used and their proportions and their relationships have been confirmed in the verification stage. At this stage, therefore, it is considered enough to ensure that the materials and their proportions used in the concrete conform to the original specifications.

In cases when steel fiber is used, as part of the inspection for acceptance of short fiber reinforced concrete for which the deformability is specified as one of the performance requirements, direct measurement of short fiber content in samples taken from as-delivered concrete shall be carried out in accordance with JSCE-F 554 “Test Method for Content of Steel Fiber in Steel Fiber

Reinforced Concrete" or JSCE-F 555 "Test Method for Content of Steel Fiber in Sprayed Steel Fiber Reinforced Concrete."

As far as the inspection for acceptance of short fiber reinforced concrete for which performance requirements are specified only in terms of strength, only a measurement of the mass of added short fibers may be carried out. The fiber content may be measured on the basis of the number of bags of short fibers added to the concrete at the time of mixing from the charging hole. Fractions of a bag must be measured by mass.

In cases when synthetic fiber is used, fiber content in concrete shall be inspected through the measurement of fiber weight. When the fiber is added into concrete at agitating truck, the fiber content may be measured on the basis of the number of bags of short fibers added to the concrete.

Regarding the allowable range on fiber content for the criteria of the inspection, not only allowable value of variation for each measurement but also averaged values of several measurements can be used. For example, a change of ±20% for median can be used as the criteria for each measurement, and the criteria that the mean value of three measurements should be more than 95% of median can be also used.

For short fiber reinforced concrete, inspection of acceptance, which is similar to that of normal concrete, is required. Although the slump and air content of concrete before and after adding of fiber might be changed, the occasion for the inspection should be decided consulting with the Owner of a structure.

The inspection except for the above shall be carried out in accordance with this specification (Materials and Construction, Construction Standards Chapter16 and Inspection Standards).

CHAPTER 6 HIGH-STRENGTH CONCRETE

6.1 General

6.1.1 Scope

This chapter specifies requirements particularly for construction of high-strength concrete with characteristic compressive strength of 60 N/mm^2 to 100 N/mm^2.

[Commentary] For structures such as prestressed concrete bridges, tanks and diaphragm walls, and for industrial products such as poling boards, precast prestressed concrete beams and prestressed concrete piles, concrete with strength higher than that of ordinary concrete is used. It is recently possible to manufacture high-strength concrete with a compressive strength of 200 N/mm^2 or higher, or a design strength of 150 N/mm^2. High-strength concrete with a design strength of 100 N/mm2 or higher can be manufactured only at a limited number of plants. Special considerations are required throughout the production, construction and quality management phases. Then, this chapter discusses high-strength concrete with a design strength of 60 to 100 N/mm^2 and describes the matters required in the construction of the concrete. When using concrete with a design strength of more than 100 N/mm^2 or less than 60 N/mm^2, this chapter may also be consulted because they are similar to those types of concrete discussed in this chapter at a certain design safety factor specified in the design of mix proportions.

In general, one basic way to achieve high strength for concrete is to keep the water to cement ratio as low as possible in the range to achieve the required performance of concrete. In recent years, the development of high-range water reducuing AE (air-entrainig) agents or high-range water reducing agents has made it possible to produce high-strength concrete with a characteristic compressive strength of around 60 N/mm^2 with relative ease by lowering the water-cement ratio to about 30%, while retaining required workability. In cases where a design strength of 80 to 100 N/mm^2 is required, producing concrete of the designated quality simply by reducing the water-cement ratio is difficult. In numerous cases, therefore, various types of cements or admixtures are used or compressive strength is determined for an age older than 28 days. When purchasing high-strength concrete as ready mixed concrete, the difference in description between Chapter 6 Ready Mixed Concrete of "Construction: Construction Standards", JIS A 5308 Ready Mixed Concrete and this chapter should be considered.

When providing self-compactibility to high-strength concrete, Chapter 7 High Fluidity Concrete or the "Recommendations for Design and Construction of Self-compactible, High-strength, High-durability Concrete Structures (draft)" should be consulted. When using organic short fibers to enhance resistance to explosion during a fire, Chapter 5 Short Fiber Reinforced Concrete should be consulted. Chapter 10 Underwater Concrete, Chapter 12 Prestressed Concrete, Chapter 14 Industrial Products and other chapters should be consulted according to the use of high-strength concrete to understand the characteristics of respective types of concrete and to verify strength enhancement and construction considerations.

Ultra high strength fiber reinforced concrete has recently been developed with a design strength of 150 N/mm^2 or higher and with great toughness owing to the use of short fibers. Concrete using high strength lightweight aggregate made of fly ash (HFA aggregate) also enables the design and construction of concrete with a design strength of up to 80 N/mm^2. For using these types of concrete, refer to the "Recommendations for Design and Construction of Ultra High Strength Fiber Reinforced Concrete (draft)" and "Recommendations for Design and Construction of Concrete Using HFA Aggregate".

6.1.2 General

When constructing high-strength concrete, methods for selecting materials, determining mix proportions, production and quality management shall be selected properly under the guidance of professional engineers with adequate knowledge and experience concerning high-strength concrete so as to meet the designated performance requirements.

[Commentary] Numerous plants have never produced high-strength concrete. In the early stages of construction planning, therefore, the facilities of plants, quality of aggregate and other materials and production management capacity should be investigated, plants should be selected fit for producing high-strength concrete and appropriate mix proportions should be determined based on the results of trial mixing. Construction should be carried out more carefully than for ordinary concrete in the transport, placement, compaction, finishing, curing and formwork design phases. In order to ensure that the designated quality of high-strength concrete is obtained, the methods for selecting the high-strength concrete materials, determining mix proportions, production and quality management should be fully examined and construction should be carried out according to carefully prepared plans under the guidance of professional engineers with adequate knowledge and experience concerning high-strength concrete.

6.2 Quality of High-Strength Concrete

High-strength concrete shall meet the designated performance requirements in terms of strength, durability, resistance to cracking, watertightness and fire resistance, have workability fit for work and be of highly homogeneous quality.

[Commentary] The quality of high-strength concrete is different from that of ordinary concrete in some respects. The quality characteristics of high-strength concrete are described below.

(i) Strength: High-strength concrete achieves high strength by reducing the water-binder ratio. The compressive strength of concrete in the structure may, however, sometimes be lower than the compressive strength of the specimen because of the initial high temperature hysteresis caused by the heat of hydration since the unit binder content is high.

(ii) Durability: High-strength concrete is highly resistant to the progress of carbonation and chloride intrusion because it is of a more compact structure than ordinary concrete. With the increase of unit binder content for enhancing strength, however, the total alkali content of concrete increases. Then, non-reactive aggregates for alkali-silica reaction should be used. In order to ensure resistance to freezing and thawing action, setting and controlling air content properly is important even in high-strength concrete.

(iii) Resistance to cracking: High-strength concrete provides superior protection for steel. The performance of steel may, however, be deteriorated due to cracking caused by the heat of hydration of the binder because the unit binder content is higher in high-strength concrete than in ordinary concrete. It is important to make stress analysis of volumetric changes due to both temperature distribution and autogenous shrinkage, and to take appropriate measures to prevent damaging cracking.

(iv) Watertightness: High-strength concrete is of such a compact structure that it is highly watertight. It should, however, be noted that unless appropriate measures are taken against cracking, water permeates the cracks and the designated watertightness may not be obtained.

(v) Fire resistance: High-strength concrete is of a compact structure. If concrete surface is heated considerably during a fire, therefore, the lower the water-binder ratio, the more likely is explosion to occur and the greater the degree of damage. When using high-strength concrete in structures that need to be fire-resistant, measures should be taken to prevent explosion. Explosion is generally prevented by mixing organic fibers in concrete, preventing the splashing of fragments by explosion using steel plates or controlling temperature rise by applying fire-proof coating. A method should be adopted for which effectiveness has been fully verified.

(vi) Workability: High-strength concrete is highly cohesive, increasing the resistance in the pipe during pumping and making vibratory compaction less effective. Efficiency of concrete placement in the formwork may sometimes be reduced. High fluidity concrete should therefore be used to ensure the designated workability.

6.3 Materials

6.3.1 Cement and admixture

(1) Cement and admixture should comply with the requirements of JIS.

(2) When using cement or admixture not conforming to JIS, whether the designated quality requirements are met or not shall be verified based on reliable documents or by conducting tests.

[Commentary] (1) In high-strength concrete with a design strength of 80 N/mm^2 or higher, low- or moderate-heat Portland cement conforming to JIS R 5210 is frequently used. Reducing the water-cement ratio is insufficient for ensuing the designated strength. Silica fume conforming to JIS A 6207 is generally used as an admixture. Also used are ground granulated blast-furnace slag, fly ash and expansive additive conforming to JIS A 6206, 6201 and 6202, respectively.

(2) In high-strength concrete, binders such as ground granulated blast-furnace slag, gypsum-type admixtures and ettringite-type admixtures are used in place of cement. Cements premixed with silica fume have been adopted in an increasing number of cases in view of the complexity of management and varying quality of silica fume composed of ultra-fine particles. When using cements or admixtures not conforming to JIS, whether the designated quality requirements are met or not should be verified based on reliable documents or by conducting tests.

6.3.2 Aggregate

(1) Aggregate should be used that meets the quality requirements described in Chapter 3 of "Construction: Construction Standards" and enables high-strength concrete to obtain the designated strength.

(2) Aggregate that has been determined to be harmless in relation to alkali-silica reaction by testing specified by JIS A 1145 or 1146 should be used.

[Commentary] (1) Attributes such as the strength, which describe the quality of high-strength concrete may vary considerably with the type of aggregate used. The reason for this is that as the strength of the cement matrix approaches the strength of the aggregate, the compressive strength of the concrete is greatly affected by the aggregate strength. Selecting aggregates to be used in high-strength concrete, therefore, is a very important task, and the use of hard aggregates such as crushed hard sandstone is desirable. In some regions, however, acquiring excellent aggregate is difficult. It should be verified in preliminary testing that the designated compressive strength can be provided.

(2) In high-strength concrete, unit cement content is high and the total alkali content of concrete is also high. Aggregates inducing no alkali-silica reaction shall be used in high-strength concrete. Local availability of aggregate should be identified in the planning phase and methods for acquiring aggregates causing no alkali-silica reaction should be examined.

6.3.3 Chemical admixture

(1) Chemical admixure should be air-entraining and high-range water reducing agents or high-range water reducing agents that conform to JIS A 6204.

(2) When using admixtures not conforming to JIS, whether the concrete meeting the designated performance requirements can be obtained or not shall be verified based on reliable document or by conducting tests.

[Commentary] (1) In high-strength concrete, the water-binder ratio should be set at a level lower than in ordinary concrete. Setting the unit water content greatly influences the unit binder content. For improving concrete workability and preventing cracking due to the hydration of the binder, admixtures highly effective for reducing water and maintaining slump are required. When producing high-strength concrete, therefore, high performance air-entraining and water-reducing agents or high performance water reducing agents that conform with JIS A 6204 Chemical Admixtures for Concrete shall be used as a standard practice.

(2) High-strength concrete is subjected to greater autogenous shrinkage than ordinary concrete. Expansive additives or shrinkage reducing agents are sometimes used to control cracking. When using admixtures for which quality requirements have not been specified in JIS such as shrinkage reducing agents, it should be verified that quality is improved as intended or the admixture is compatible with other materials

6.4 Mix Proportion

6.4.1 Strength

In cases where the compressive strength of concrete in the structure is likely to be reduced below the compressive strength of the specimen as the concrete is subjected to high temperature hysteresis in the initial stages, the mix proportions of high-strength concrete should be determined considering the effect of the reduction of compressive strength as a standard practice.

[Commentary] High-strength concrete, with a high unit binder content, is subjected to high temperature hysteresis in the initial stages if it is placed in a member of large cross section. The compressive strength of concrete in the structure may sometimes be reduced below the compressive strength of the specimen used for management. If the temperature of concrete exceeds approximately 50°C due to heating, the effects should be considered in numerous cases. Testing methods include using the compressive strength of a core sample collected from a specimen of simulated member, and using the compressive strength of a cylindrical specimen cured in a tank to which temperature hysteresis equivalent to that of the member or in a device in which temperature hysteresis can be followed.

No strength reduction has been reported in cases where cement with a low calorific value e.g. low-heat portland cement was used or where mixing temperature was held low by pre-cleaning or other means. In structures using cements that have a low-calorific value or in which strength develops slowly, therefore, temperature rise due to heating should be minimized by taking measures such as increasing the age as a basis for compressive strength above 28 days.

6.4.2 Slump or slump flow

The workability of high-strength concrete should be specified based on the slump or slump flow according to the properties or construction method of concrete. At the time of concrete placement, slump should be 18 to 21 cm, or slump flow should be 50 to 65 cm.

[Commentary] High-strength concrete is highly cohesive and should be provided with greater fluidity than ordinary concrete. A criterion fit for evaluating the workability of high fluidity concrete is slump flow. In order to ensure the designated workability, slump is set to be 18 to 21 cm for high-strength concrete with a design strength of approximately 60 N/mm^2, and slump flow is set to be 50 to 65 cm for high-strength concrete with a greater strength in numerous cases. For the high-strength concrete discussed in this chapter, slump at the time of placement is set to be 18 to 21 cm, or slump flow is set to be 50 to 65 cm as a standard practice. A standard for judgement, as to whether slump or slump flow tests should be used for workability evaluation may be as follows; using slump for concrete with a slump of 21 cm or less, and using slump flow for concrete with a slump of 24 cm or more. Slump and slump flow should be specified properly considering the compactibility and fluidity at the time of placement and changes in these parameters in production through placement. Having the same slump flow as high-strength concrete does not always ensure self-compactibility. If self-compactibility is required, mix proportions should be determined in accordance with Chapter 7 High Fluidity Concrete. For industrial products, slump may be specified regardless of the value shown here. Slump may be reduced as long as compaction is possible.

6.4.3 Air content

For high-strength concrete that needs to be resistant to freezing and thawing action, the standard air content should be set as shown below.

For characteristic compressive strength of 60 N/mm^2	4.0%
For characteristic compressive strength of 80 N/mm^2	3.5%
For characteristic compressive strength of 100 N/mm^2	3.0%

[Commentary] In cases where high-strength concrete needs to be resistant to freezing and thawing action, the designated water content should be achieved. Air content greatly influences concrete strength. Air content should therefore be minimized as long as the designated resistance to freezing and thawing action can be obtained. Generally, the greater the concrete strength, the more resistant to freezing and thawing action. Standard air content is shown here according to the design strength.

6.4.4 Water-binder ratio

Water-binder ratio shall be determined so as to obtain the designated strength.

[Commentary] For high-strength concrete, various admixtures are used in addition to cement such as silica fume and ground granulated blastfurnace slag. Water-binder ratio rather than water-cement ratio is therefore discussed here. More factors affect the compressive strength of high-strength concrete than that of ordinary concrete. In cases where the aggregate has a low strength, no linear relationship may be established between water-binder ratio and compressive strength. Preliminary verification should be made in testing.

The type, air content and base materials of the binder vary according to the construction project. Presenting a water-binder ratio corresponding to the design strength is therefore difficult. According to the past construction records, the water-binder ratio is approximately 30 to 35% at a design strength of 60 N/mm^2, and approximately 25 to 30% at a design strength of 80 N/mm^2. At a design strength of 100 N/mm^2, 7 to 15% of silica fume is used and the water-binder ratio is frequently set at 18 to 22%.

6.4.5 Water content

The standard water content shall be less than 175 kg/m^3. Water content shall be minimized by conducting testing as long as the designated performance requirements can be met.

[Commentary] The increase of unit quantity of binder is closely related to the occurrence of cracking due to cement hydration and to the increase of the total alkali content of concrete. Water content should therefore be minimized to prevent the unit quantity of binder from increasing. Excessively reducing water content, however, may lead to the deterioration of workability or to the delay of setting due to the increase of chemical admixtures used. Therefore, the standard water content shall be less than 175 kg/m3. Water content should be minimized by conducting testing as long as the designated performance requirements can be met.

6.4.6 Unit content of coarse aggregate

The unit content of coarse aggregate should be as high as possible to the extent that the required workability is achieved.

[Commentary] In high-strength concrete, the greater the unit quantity of coarse aggregate, the better the quality of hardened concrete as long as the designated workability is obtained. An optimum unit quantity of coarse aggregate should be obtained so that workability may be achieved in a wide range between a slump of 18 cm or more and a slump flow of 65 cm for high-strength concrete. Guidelines for the absolute volume of coarse aggregate in a unit volume of concrete in cases where coarse aggregates with a maximum size of 20 mm are used are listed in Table C6.4.1. When self-compactibility is required, refer to the absolute volume of coarse aggregate in a unit volume of concrete shown in Chapter 7 High Fluidity Concrete.

Table C6.4.1 The range of unit bulk volume of coarse aggregate (for the case of the maximum size of aggregate being 20mm)

Slump or slump flow	Unit bulk volume of coarse aggregate (m^3/m^3)
18 to 21 cm of slump	from 0.40 to 0.34
50 to 65cm of slump flow	form 0.36 to 0.31

6.5 Production

6.5.1 Selection of plants

For producing high-strength concrete, a plant that has been officially authorized, or a plant with equivalent production facilities and management systems shall be selected considering the time required for transport to the site, concrete shipping capacity and quality management capability.

[Commentary] Producing high-strength concrete requires high-level management. A plan that has been officially authorized or a plant with equivalent production facilities and management systems shall be selected. Some of the officially authorized plants, however, may not have produced high-strength concrete. A plant should therefore be selected considering the type and quality of materials that can be used, quantities of storage facilities and conditions of materials stored, mixing performance of mixers, time required for transport to the site, quality management capability and other factors.

The quality of high-strength concrete is likely to be influenced by the grading of aggregates and change in surface moisture. Plants should therefore be equipped with such facilities as storages with high drainage capacity divided according to the grading of aggregates and devices capable of automatically measuring surface moisture. Plants should preferably be selected where the load currents in the mixer while mixing can be verified or automatic measurements can be output.

6.5.2 Mixing

(1) Batch-type forced-action mixers should be used in principle for mixing high-strength concrete.

(2) The method for mixing high-strength concrete shall be determined based on the records or by conducting testing so that the designated quality may be obtained.

[Commentary] (1) High-strength concrete is highly cohesive and places heavier burdens on the mixer than ordinary concrete. High-strength concrete therefore shall be produced in principle using batch-type forced-action mixers with high mixing capacity.

(2) Mixing high-strength concrete tends to require longer time than mixing ordinary concrete because dispersing materials uniformly such as fine grained silica fume, high performance air-entraining and water-reducing agents and high performance water reducing agents is required. Mixing time varies according to the mix proportions of high-strength concrete, performance of the mixer and quantity of concrete to be mixed in each batch. The lower the water-binder ratio, the longer the mixing time tends to be. At a water-binder ratio of more than 20%, the mixing time may exceed 180 seconds. The dispersion of high performance air-entraining and water-reducing agents and high performance water reducing agents is determined by the quality of materials used, order of material input and mixing capacity of the mixer. For mixing high-strength concrete, therefore, selecting an appropriate method to ensure the designated quality is important.

6.5.3 Production control

The production of high-strength concrete shall be managed so that the designated performance can be obtained steadily.

[Commentary] The workability and compressive strength of high-strength concrete are likely to be influenced by the grading of aggregates and change in surface moisture. In cases where the surface moisture of aggregates is expected to vary greatly, it should be measured frequently and the accuracy of moisture correction should be increased to secure the designated water content. Variations in material quality or concrete temperature may cause the water reduction capacity of high performance air-entraining and water-reducing agents and high performance water reducing agents to vary. If the load currents in the mixer during mixing vary greatly, fresh concrete should be tested promptly and measures should be taken to reduce the variation of concrete quality.

6.6 Construction

6.6.1 Transportation within construction site

(1) Transport facilities are specified in Chapter 7 of "Materials and Construction: Construction Standards" and should be selected considering the properties and change in quality of high-strength concrete.

(2) Concrete pumps with adequate pumpability should be selected.

(3) When pumping concrete under a condition under which no pumping has been done, the type and pumping rate of the concrete pump and the diameter of pumping pipe should be determined based on the results of full-scale pumpability tests simulating actual pumping work.

[Commentary] (1) Concrete pumps are frequently used for transporting high-strength concrete at the site as well as ordinary concrete. High-strength concrete is, however, so cohesive that the resistance in the pipe is increased. Pumping at the required rate for the required length may therefore be difficult, or the quality of concrete is substantially changed during pumping. Then, high-strength concrete may be transported using buckets. When concrete is transported in buckets, the rate of placement may be lower than in the case where concrete pumps are used, and concrete may not be placed continuously. Care should therefore be exercised concerning the daily quantity of concrete to be placed, division of places for concrete placement, allowable time lag between two placing lifts and post-placement curing. It should also be noted that placing high-strength concrete using buckets with no agitation capacity for a long time induces surface stiffness and thereby deteriorates the quality of high-strength concrete. Thus, appropriate facilities should be selected for the transport of high-strength concrete at the site fully considering the deterioration of workability during transport by pumping or other means and the change in quality of high-strength concrete during transport.

(2) and (3) High-strength concrete is highly cohesive, so pumping load is higher for high-strength concrete than for ordinary concrete. The higher the pumping rate, the more serious the problem. The pressure loss in the pipe for one meter of horizontal pipe for high-strength concrete may sometimes exceeds the level five times as large as the standard value for ordinary concrete shown in Fig. C 7.3.1 in Chapter 7 of "Materials and Construction: Construction Standards". After pumping, the slump or slump flow and air content may be changed greatly in some cases. The pressure loss in the pipe and quality change for high-strength concrete vary considerably according to the mix proportions or pumping condition. They cannot be presented quantitatively. When pumping high-strength concrete under a unprecedented condition, therefore, the type and pumping ratio of the concrete pump and the diameter of the pipe shall be determined properly by conducting full-scale pumping tests simulating actual pumping work, as a standard practice. Conducting pumping tests under actual pumping conditions before the start of construction work is, however, difficult. Tests may be eliminated if reliable data is available. After the start of construction work, work should be carried out while confirming the oil pressure gauge readings or the state of concrete discharged at the outlet as required.

6.6.2 Placement and compaction

(1) The time from the mixing to the end of placement of high-strength concrete should be set to be two hours or less in cases where it has been verified that the quality of high-strength concrete remains unchanged when outdoor temperature exceeds 25°C.

(2) The method of placement, compaction time, interval of vibrator insertion and other parameters shall be determined after preliminary verification by testing.

[Commentary] (1) If appropriate quantities of appropriate types of high performance air-entraining and water-reducing agents or high performance water-reducing agents are used, slump or slump flow of high-strength concrete varies little with time. Using high performance air-entraining and water-reducing agents or high performance water-reducing agents helps delay the setting of concrete. If the surface of placed concrete is kept sufficiently wet, integrity may be ensured even where the time lag between two placing lifts is long. Then, the time from mixing to the end of placement may be set to be longer than 1.5 hours stipulated in 7.2 in Chapter 7 of "Materials and Construction: Construction Standards" as long as it does not exceeds two hours in cases where it has been verified that outdoor temperature increase above 25°C would have no adverse effects on the quality of high-strength concrete.

(2) High-strength concrete is so cohesive that vibrators have difficulty in transmitting vibration through the concrete and are not fully effective for compacting concrete. It is therefore necessary to verify in advance the time required for compaction and the interval of vibrator insertion. In numerous cases, high-strength concrete is designed to have higher slump or slump flow than ordinary concrete (6.4.2). It should therefore be noted that high-strength concrete may flow excessively toward lower sections affecting the scheduled progress of placement or compaction or that finishing the surface of freshly placed concrete may become difficult.

6.6.3 Finishing and curing

High-strength concrete shall be finished and cured by such a method that prevents the drying of concrete surface at the end of placement and provides the designated dimensions, surface condition and quality.

[Commentary] In high-strength concrete, bleeding rarely occurs and concrete surface dries right after the placement and stiffness occurs. Setting is delayed and surface finishing may sometimes become difficult. In high fluidity high-strength concrete that is managed based on slump flow, highly cohesive paste adheres to the trowel, pulling the surface. Smoothing the surface may sometimes be difficult. In these cases, an appropriate amount of water should be sprayed over the surface using atomizers during finishing. Drying of concrete surface may sometimes shorten the allowable time lag between two placing lifts or cause plastic shrinkage cracks. In order to protect concrete surface from direct radiation or wind, concrete surface should be covered with membranes or curing mat immediately after placement and water should be sprinkled on the surface or concrete should be cured using membranes. Liquid membrane-forming compounds for curing are applied either during or at the end of finishing. The quantity to be applied and the timing of application vary according to the type of the compound. When using compounds, the method of application and the effects of compounds should be verified in advance based on reliable documents or by conducting tests.

In high-strength concrete, binders such as moderate- and low-heat Portland cements, silica fume and ground granulated blast-furnace slag are frequently used. No standard period of wet curing has, however, been specified for these binders in Table 8.2.1 in "Materials and Construction: Construction Standards" . The period of wet curing should therefore be determined according to the type of the binder, combinations of binders or design strength of the binder. High-strength concrete has a low water-binder ratio. The compressive strength of concrete at an early age when forms can be removed (Table C 11.8.1 in Materials and Construction: Construction Standards) can sometimes be obtained. At the age, however, the temperature of members is extremely high. If forms are removed at an inappropriate time or if concrete is cured improperly after the removal of forms, cracking is likely to occur. The method of curing or the timing of form removal shall therefore be determined based on reliable documents or by conducting tests considering the period of wet curing required to ensure the designated strength and durability and the change in thermal stress at the end of curing.

6.6.4 Formwork

The lateral pressure of high-strength concrete on the formwork should, in general, be treated as hydrostatic.

[Commentary] High-strength concrete is designed to have workability in the range between a standard slump of 18 cm and a slump flow of 65 cm. The lateral pressure acting on formwork is nearly fluid pressure. Setting takes a long time and the lateral pressure acting on the formwork is reduced slowly. Formwork shall therefore be designed on the assumption of fluid pressure. In cases where sufficient management is possible, however, by adjusting the rate of placement or measuring lateral pressure by pressure gauges, pressure lower than fluid pressure may be assumed when designing formwork.

6.7 Inspection

The accepting party shall be held responsible for conducting acceptance tests for high-strength concrete in accordance with Table 6.7.1.

Table 6.7.1 Inspection for acceptance of high-strength concrete

Item	Testing method /Inspection method	Period/Frequency	Criteria for judgment
Slump or slump flow	In accordance with JIS A 1102 or JIS A1150	When accepting, once a day or once every 20~150m^3, depending upon the importance of structure and the scale of the construction work	Slump: Specified value ±2.5cm (when specified value is 18cm) Specified value ±2.0cm (when specified value is greater than 18cm and smaller than 21cm) Slump flow: Specified value±7.5cm

[Commentary] The accepting party conducting acceptance tests for high-strengh concrete is the Owner of the structure. There may be cases, however, where the Contractor constructing high-strength concrete has conducted tests and the Owner has verified the test results.

It should be noted that the compressive strength of high-strength concrete is more likely to be affected by the smoothness of the surface of the loading test specimen subjected to loading and the stiffness of the loading test apparatus than ordinary concrete. There is a risk of fragments of the specimen splashing at the time of compressive failure. Tests should therefore be conducted after taking measures to prevent fragments from splashing.

The decision criterion for slump flow has been specified at plus or minus 7.5 cm as compared with the set value. In cases where slump flow exceeds 70 cm in testing, the segregation of aggregates may occur at certain mix proportions. The setting and the range for management should therefore be determined after verifying no occurrence of segregation.

Inspections of concrete other than those listed in Table 6.7.1 shall be conducted in accordance with Chapter 16 of "Materials and Construction: Construction Standards" and "Materials and Construction: Inspection Standards".

CHAPTER 7 HIGH-FLUIDITY CONCRETE

7.1 General

7.1.1 Scope

This chapter specifies standards on essential matters particularly required for the construction of high-fluidity concrete.

[Commentary] High-fluidity concrete refers to a concrete with greatly enhanced flowability while retaining high resistance to segregation. The performance evaluation method of fresh high-fluidity concrete widely differs depending on whether vibration is given to the concrete during placing. This chapter is applicable to high-fluidity concrete having self-compactability with which concrete can be placed in every corner of formwork without causing segregation even without vibration. For this reason, concrete with relatively high fluidity but with no needs of self compatibility to which vibrations are applied to help compaction is not discussed in this chapter.

High-fluidity concrete not only increases the reliability of structures from the viewpoint of quality or durability but also permits energy/labor-saving at construction sites and rationalization of construction. In pre-cast product plants as well, high-fluidity concrete is highly effective in reducing noise as it requires no vibration. One of the major characteristics is the properties of fresh concrete that are greatly different from those for ordinary concrete. To use the characteristics, production of concrete is important and numerous points should be considered. This chapter specifies matters that require attention to ensure its performance in selecting materials, proportioning, producing, and placing.

For matters not described in this chapter, refer to the "Construction Guidelines for High Fluidity Concrete". For high strength concrete using high fluidity concrete and industrial products using high fluidity concrete, refer to Chapter 6 High Strength Concrete and Chapter 14 Industrial Products, respectively.

7.1.2 General

When constructing high-fluidity concrete, methods for selecting materials, determining mix proportions, production and quality management shall be selected properly under the guidance of professional engineers with adequate knowledge and experience concerning high-fluidity concrete so as to meet the designated self-compactability.

[Commentary] Various types of materials are used for high fluidity concrete. Mix proportions can be determined freely. High fluidity concrete has unique characteristics as compared with ordinary concrete. For example, the quality of high fluidity concrete is determined by the effects of change in surface moisture of aggregate. High fluidity concrete should therefore be produced and constructed by understanding its characteristics, learning the methods for using it, determining the materials to be used, mix proportions, production method and quality management method and fully identifying the properties of high fluidity concrete so that the designated self-compactibility may be achieved steadily under the guidance of professional engineers with adequate experience.

7.2 Quality of High-Fluidity Concrete

7.2.1 General

High-fluidity concrete shall meet the designated performance requirements in terms of strength, durability, resistance to cracking and self-compactability, and shall be of highly homogeneous quality.

[Commentary] One of the major characteristics of high fluidity concrete is self-compactability. Reduction of self-compactability due to the heterogeneous nature of fresh concrete leads directly to such problems as pipe clogging during pumping, fall from a large height or material segregation during long-distance flow, poor injection in densely arranged reinforcement and honeycombing on the surface of formwork. Care should therefore be exercised especially as to the quality of fresh concrete as compared with the case for ordinary concrete.

7.2.2 Self-compactability

(1) For high-fluidity concrete, the level of self-compactability should be determined considering the shape, dimensions and bar arrangement for the structure in which concrete is placed.

(2) The level of self-compactability shall be appropriately determined for the concrete just before placing in the formwork.

(3) Three ranks of self-compactability are defined as follows:

Rank 1: Self-compactability for high-fluidity concrete placed into members or segments having complicated shapes and/or small cross-sectional areas with a minimum clearance of 35 to 60 mm between reinforcing bars.

Rank 2: Self-compactability for high-fluidity concrete placed into reinforced concrete structures or members with a minimum clearance of 60 to 200 mm between reinforcing bars.

Rank 3: Self-compactability for high-fluidity concrete placed into structures having large cross-sectional areas, with little or no reinforcement, such as structures where the minimum clearance between reinforcing bars exceeds 200 mm or plain concrete structures.

(4) It is advisable to select the Rank 2 level of self-compactability as a standard for normal reinforced concrete structures or members.

[Commentary] (1) and (2) The level of self-compactability should be determined for concrete right before placement in the formwork considering the shape, dimensions and bar arrangement for the structure in which concrete is placed. Construction conditions such as the height of fall, distance of flow and the height of a lift should be determined according to the specified level of self-compactability for reflection in the construction plan.

(3) and (4) Ranks 1 to 3 are defined as the levels of self-compactability of concrete. These ranks are set based on the dimensions and reinforcement arrangement of the structures or members. Rank 2 is defined as the capability of concrete with which it can be self-compacted through a minimum bar clearance of 60 to 200 mm. This normally corresponds to the steel content of 350 to 100 kg/m^3. Rank 1 is a level on which concrete meets severer requirements than for Rank 2, representing the minimum cover depth and clearance specified in the Clause 13.3 of Standard Specifications for

Concrete Structures "Design: Main". Rank 3 is a level on which concrete meets easier conditions than Rank 2, requiring the self-compactability demonstrated where the minimum bar clearance is more than 200 mm and maximum steel content is less than 100 kg/m^3. In normal concrete structures and members, the minimum bar clearance is 60 to 200 mm and the steel content is roughly 100 to 200 kg/m^3. Therefore, a self-compactability level of Rank 2 is selected as a standard for ordinary reinforced concrete structures and members. In cases where high-fluidity concrete is applied for filling narrow space like concrete joined under existing concrete members or for filling steel shells of a steel-concrete composite structure, Rank 1 or 2 self-compactability high-fluidity concrete should be used regardless of bar arrangement. High-fluidity concrete in respective ranks corresponds to high-fluidity concrete with performance represented by a filling height of more than 300 mm (restriction R1, restriction R2 and with no restrictions) in U- or box-shaped container (Fig. C7.2.1) in tests using a filling tester specified in JSCEF-F511 "Void Passing Tests Using High-fluidity Concrete Filling Tester (draft)" (Table C7.2.1).

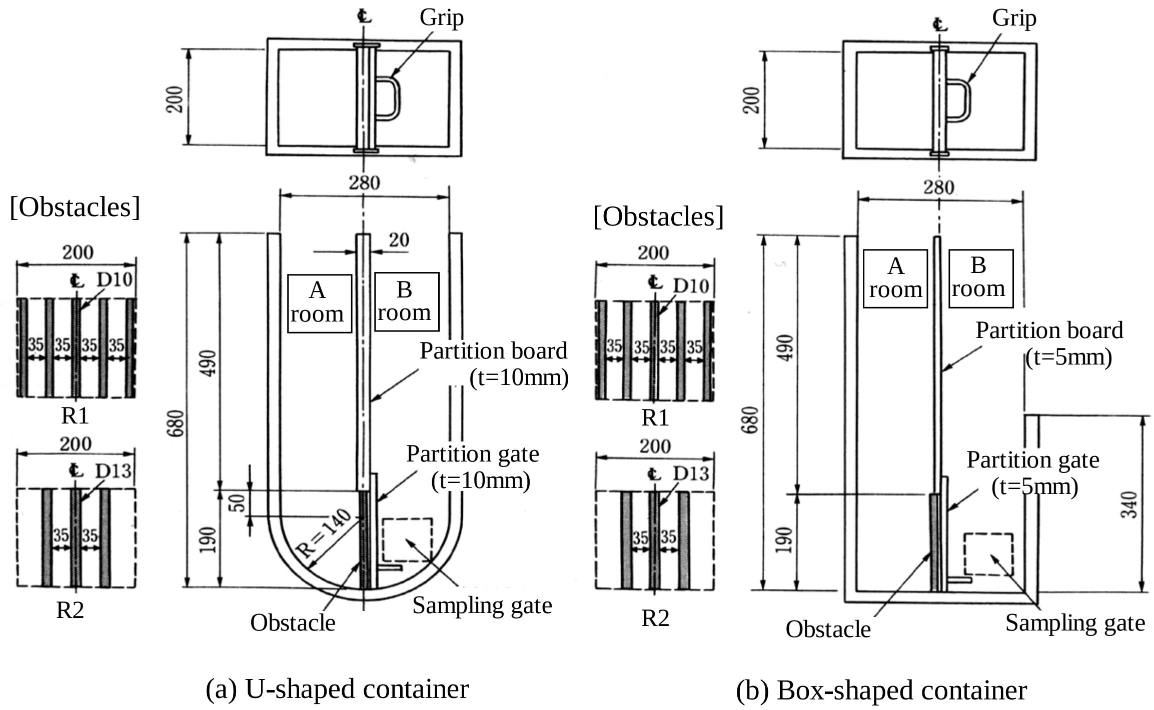


Fig. C7.2.1 Shapes and dimensions of apparatuses for self-compactability test

Table C7.2.1 Rank of self-compctability of high-fluidity concrete

Rank of self-compactability		1	2	3
Condition	Minimum bar clearance (mm)	35～60	60～200	over 200
	Steel content (kg/m^3)	over 350	100～350	under 100
Filling height in a U- or box-shaped container* (mm)		over 300 (restriction R1)	over 300 (restriction R2)	over 300 (without restriction)

* Filling height specified in JSCEF-F511 "Void Passing Tests Using High-fluidity Concrete Filling Tester (draft)"

7.3 Materials

(1) Materials used in high-fluidity concrete should be those of which quality has been confirmed to JIS or the JSCE standards.

(2) In the case of using materials having qualities not specified in the standards of JIS or the JSCE standards, the fulfillment of both the self-compactability of the fresh concrete made using them and the properties of the hardened one shall be confirmed by reliable documents or by conducting tests.

[Commentary] (2) The self-compactability of concrete made using materials not covered by the JSCE Standard Specification or those that will be newly developed can be used after verifying self-compactability of concrete. In this case as well, it should be confirmed that such concrete satisfies the quality requirements for hardened concrete specified in the JSCE Standard Specification by reliable documents or by conducting tests.

Amongst the materials not specified by JIS or the JSCE standards, limestone powder, crush stone powder and viscosity agent are examples of materials for high-fluidity concrete for which sufficient field experience has already been acquired. When increasing the amount of powder to enhance the resistance to material segregation, increasing the binder as powder is likely to promote heating or shrinkage. Limestone powder and crushed stone powder are therefore used as powder with poor or no reactivity. Viscosity agents are classified into two types: one used simply to introduce segregation resistance to fresh concrete, and another used both for imparting segregation resistance and for reducing the influence of fluctuation of the material qualities on the performance of concrete. On the other hand, some of the viscosity agent may interact with other chemical admixtures, producing adverse effects on each other’s performance each other. Therefore, these should be used after checking the performance, with due attention to their combinations.

7.4 Mix proportion

7.4.1 Selection of types of high-fluidity concrete

When designing mix proportions for high-fluidity concrete, an appropriate type of high-fluidity concrete should be selected from among powder type, viscosity agent type and combination type considering the type of the structure, structural conditions, construction conditions, types of materials available and restrictions at concrete production plants.

[Commentary] High-fluidity concrete is classified into three types: powder type, viscosity agent type or combination type based on the type and quantity of the material used. In powder-type high-fluidity concrete, the resistance to material segregation is generally enhanced by increasing the amount of powder without using viscosity agents. In viscosity-agent-type high-fluidity concrete, resistance to material segregation is increased using viscosity agents. Viscosity agent and powder types can be clearly classified according to whether viscosity agents are used or not. Combination-type high-fluidity concrete uses viscosity agents like viscosity-agent-type high-fluidity concrete. In the combination type, resistance to material segregation is provided basically by increasing the unit amount of powder as in powder-type high-fluidity concrete and self-compactability is provided by considerably enhancing fluidity using high performance air-entraining and water-reducing agents or high performance water reducing agents. In combination-type high-fluidity concrete unlike in powder or viscosity agent types, viscosity agents are used not only to provide slight resistance to material segregation but also to produce and construct steady and self-compactible high-fluidity concrete relatively easily by minimizing the variations of fresh concrete properties due to variations of quality and condition of materials.

What type of fluidity concrete is appropriate varies according to the conditions unique to each structure such as the type of the structure, structural condition, construction condition, types of materials available and restrictions at concrete production plants. An appropriate type of high-fluidity concrete should be selected considering the following points.

(i) In cases of severe structural conditions or inappropriate grading or grain size of coarse aggregate, using powder- or combination-type fluidity concrete should be considered with a view to reducing the quantity of aggregate.

(ii) In cases where thermal stress or autogenous shrinkage is an issue as in mass concrete, selecting a viscosity agent type with relatively low unit binder content for reducing the amount of binder or reducing the heat of hydration in powder or combination type by adjusting the types and combinations of powder should be considered. In cases where varieties of types of admixtures are required and only a few cement silos are available on a standby basis, using premixed powder such as blended cement containing three cementitious materials should be considered.

(iii) In cases where high strength is required, powder- or combination-type high-fluidity concrete is applicable as a relatively low water-binder ratio can be specified. Conversely, in cases where high strength is not required or is structurally detrimental, selecting the viscosity agent type with a relatively high water-binder ratio or preventing strength from increasing excessively by adjusting the type and combination of powder in powder- or combination-type high-fluidity concrete should be considered.

(iv) In cases where steadily securing self-compactability by minimizing the variations of fresh concrete properties is required while fine aggregate grading and surface moisture vary in a wide range, using the combination type should be considered.

(v) In cases where aggregates contain few fine particles, using the powder or combination type to increase the amount of powder should be considered. In cases where aggregates contain numerous fine particles, using the viscosity agent type should be considered.

7.4.2 Mix design

The mix proportions of high-fluidity concrete should be determined so that the concrete may have the designated fluidity, resistance to material segregation and self-compactability according to the structural condition of the structure, construction condition and environmental condition, and that the designated performance requirements may be achieved in such terms as strength and durability.

[Commentary] In high-fluidity concrete, resistance to material segregation and fluidity, which are mutually conflicting performance requirements for fresh concrete, are achieved by combining different types and quantities of materials. Various materials and mix proportion design methods are therefore used. Various mix proportions can achieve the same performance goal. This is a great difference from the conventional concept of concrete mix proportions.

In the design of mix proportions of high-fluidity concrete, the maximum size of coarse aggregate and absolute coarse aggregate content are first determined to ensure the designated self-compatibility and excellent passage through voids after the type of high-fluidity concrete is selected. Next, water content, water-powder ratio and unit amount of powder required for ensuring the designated self-compactability are determined. Then, water-binder ratio and unit binder content are specified to achieve the performance requirements in such terms as strength and durability. Air content, unit content of fine aggregate and quantities of admixtures used are also determined. Whether or not the fresh concrete to be obtained is provided with the designated fluidity, resistance to material segregation and self-compactability is then verified.

The goals to be achieved at respective ranks of self-compactability in evaluation tests for powder-, viscosity-agent- and combination-type high-fluidity concrete during the design of mix proportions are shown in Tables C7.4.1 through C7.4.3. For the resistance to material segregation, any one of the parameters listed in the table should be satisfied. For the general procedure of mix proportions design for each type of high-fluidity concrete, refer to the mix proportions design manual in the "Guidelines for Construction of High-fluidity Concrete". In the powder- or combination-type high-fluidity concrete, the unit amount of powder is generally large. In cases of a large amount of cement, the total alkali content increases and there is a concern about alkali-aggregate reaction. For mix proportion design considerations in such a case, refer to Chapter 6 "High Strength Concrete."

Table C7.4.1 Self-compactability ranks of powder-type high-fluidity concrete and targets to be achieved in evaluation tests

Rank of self-compactability		1	2	3
Absolute volume of coarse aggregate content (m^3/m^3)		0.28～0.30	0.30～0.33	0.32～0.35
Fluidity	Slump flow (cm)	60～70	60～70	50～65
Resistance to segregation	Funnel flow time of V_{75} funnel or O funnel (s)	9～20	7～13	4～11
	50 cm flow time (s)	5～20	3～15	3～15

Table C7.4.2 Self-compactability ranks of viscosity-agent-type high-fluidity concrete and targets to be achieved in evaluation tests

Rank of self-compactability			1	2	3
Absolute volume of coarse aggregate content (m^3/m^3)			0.28～0.31	0.30～0.33	0.30～0.36
Fluidity	Slump flow (cm)		55～70	55～70	50～65
Resistance to segregation	Funnel flow time (s)	V_{75} funnel or O funnel	10～20	7～20	7～20
		S_{100} funnel*	4～8	3～8	3～8
	50 cm flow time (s)		5～25	3～15	3～15

* Reference "Flow test method using S funnel" in "Guidelines for construction of high-fluidity concrete"

Table C7.4.3 Self-compactability ranks of combination-type high-fluidity concrete and targets to be achieved in evaluation tests

Rank of self-compactability		1	2	3
Absolute volume of coarse aggregate content (m^3/m^3)		0.28～0.30	0.30～0.33	0.30～0.35
Fluidity	Slump flow (cm)	65～75	60～70	50～65
Resistance to segregation	Funnel flow time of V_{75} funnel or O funnel (s)	10～25	7～20	7～20
	50 cm flow time (s)	5～20	3～15	3～15

7.4.3 Representation of mix proportion

As a general rule, mix proportions should be presented as shown in Table 7.4.1.

Table 7.4.1 Representation of mix proportion

Maximum size of coarse aggregate (mm)	Rank of self-compact-ability	Water to binder ratio (%)	Water to powder ratio by volume (%)	Air content (%)	Unit volume of coarse aggre-gate (m^3/m^3)	Unit weight (kg/m^3)							
						Water W	Cement C	Admix-ture F	Fine aggre-gate S	Coarse aggre-gate G	Chemical admixture		
											Super-plasti-cizer	Viscosity agent	Others

Notes 1) When more than one material of the same kind is used, each shall be indicated in a separate box.
2) Shown in the columns for self-compactability ranks are the types of obstacles in void passage tests using filling equipment.
3) The dosage of an air-entraining and high-range water-reducing admixture shall be expressed in kg/m^3 and shall be included in the unit water content.
4) The dosage of other chemical admixtures sham be expressed in ml/m^3 or g/m^3 and shall be indicated undiluted and undissolved.
5) The viscosity agent content shall be expressed in kg/m^3.

[Commentary] The mixture proportions shall be expressed as the content of each material in terms of mass per cubic meter of concrete. It should be noted that the water-powder ratio by volume and unit volume of coarse aggregate which affects passability through narrowed area should be indicated in the format, in addition to the water-binder ratio, as the volume of powder strongly affects the deformability and segregation resistance of high-fluidity concrete.

It is desirable that the format include the type of structure, type of high-fluidity concrete, characteristic compressive strength, age at which the characteristic strength is assured, type of cement, type and physical properties of mineral admixtures, type and physical properties of coarse and fine aggregates and type of chemical admixtures. It is also desirable that it includes the structural conditions of the structure like reinforcement conditions, as well as the construction conditions, such as the transportation time, construction methods and seasonal conditions. The inclusion of the slump flow, flow time to 50 cm and funnel efflux time in the data sheet is recommended because these are useful for the control of self-compactability.

7.5 Production

7.5.1 Selection of plants

For producing high-fluidity concrete, a plant that has been officially authorized, or a plant with equivalent production facilities and management systems shall be selected considering the time required for transport to the site, concrete shipping capacity and quality management capability.

[Commentary] Plants should be selected considering the production management capability, availability of engineers with adequate knowledge about high-fluidity concrete and other factors.

The quality of high-fluidity concrete is easily affected by changes in the surface moisture and grain size distribution for aggregate. Plants should therefore be selected that use storage and management methods for minimizing the changes. Plants should also be equipped with equipment for monitoring the mixer loads during concrete mixing and facilities for outputting measurement records.

7.5.2 Storage of aggregates

Aggregates should be stored so as to minimize the change in surface moisture.

[Commentary] High-fluidity concrete is generally more susceptible to fluctuation in unit water content than normal concrete. For this reason, in order to produce high-fluidity concrete having stable qualities, it is necessary to control the fluctuation of the surface moisture of aggregate, particularly fine aggregate by the following methods.

(i) The storage facility is covered with a roof to prevent aggregates from being weathered.

(ii) When piling aggregates in open yards for storage, the aggregates are covered with curing membranes to protect them from weathering or solar radiation.

(iii) When the surface moisture of fine aggregate is high, the surface moisture tends to be heterogeneous even where the aggregate is stored in facilities with a roof. Surface moisture should be held to 5% or less. For coarse aggregates, surface moisture of 1% or less is desirable. To that end, aggregates should be retained in storages several days ahead of placement and surface moisture of aggregates should be reduced throughout the storage facilities.

(iv) Adequate quantities of aggregates should be stored to prevent aggregates in another lot from being used in a round of construction.

(v) In cases where aggregates in another lot need to be used frequently because large quantities are placed at once, systems that mechanically maintain surface moisture at a certain level such as by using centrifugal forced dewatering equipment should be used.

7.5.3 Mixing

(1) Batch-type forced-action mixers should be used for mixing high-strength concrete.

(2) The high-fluidity concrete mixing method should be determined based on the existing records or by conducting tests.

(3) The batch of high-fluidity concrete should be determined considering the type of high-fluidity concrete, mixing capacity of the mixer, transport volume and rate of shipment. The standard batch should be 80 to 90% of the maximum capacity of the mixer.

(4) The high-fluidity concrete mixing time for each batch should be determined considering the type of high-fluidity concrete, mixing capacity of the mixer and other factors. The standard mixing time should be 90 seconds or more in the case where a revolving-paddle mixer is adopted.

(5) It shall be verified by mixing using an actual mixer at the plant that high-fluidity concrete meets the designated performance requirements for fresh concrete.

[Commentary] (1) High-fluidity concrete has a lower yield value and higher plastic viscosity than ordinary concrete. Batch-type revolving-paddle mixers with high mixing capacity shall be used in principle for producing concrete. Horizontal biaxial revolving-paddle mixers should generally be used that can reduce mixing time and takes a short time for discharging.

(2) Materials are input to the mixer in a similar sequence to that for ordinary concrete in numerous cases. In high-fluidity concrete, however, the mixing load is larger than in ordinary concrete. Excessively large loads are imposed at the time of input of coarse aggregates. The mixer may discontinue operating or is enforced to cease. Care should therefore be exercised. The effectiveness of high performance air-entraining and water-reducing agents or high performance water reducing agents for dispersion is affected by the type of powder used, quality of aggregates, order of material input and capacity of the mixer. Then, a high performance mixer should be used, and the material input order, mixing volume and mixing time should be determined properly based on the existing records or by conducting tests so that the mixed concrete may meet the designated performance requirements.

(3) In high-fluidity concrete, the load on the mixer tends to increase during mixing. The batch is therefore frequently reduced to obtain adequate mixing capacity. In existing records, the batch is set to be 80 to 90% of the maximum capacity of the mixer in numerous cases.

(4) In high-fluidity concrete, unit amount of powder is increased or thickening agents are used to enhance resistance to material segregation. High-fluidity concrete therefore tends to be more cohesive and require more mixing time for obtaining the designated quality than ordinary concrete. The mixing time required for obtaining the designated quality uniformly varies according to the mixing capacity of the mixer and the batch. An appropriate mixing time should be verified by conducting tests. In existing records of construction, the mixing time in the case where a revolving-paddle mixer is used is set to be 90 to 150 seconds in numerous cases. The mixing time for revolving-paddle mixers should therefore be set to be 90 seconds or longer as a standard practice.

(5) The properties of fresh high-fluidity concrete produced in the plant to be used for actual construction may frequently differ from those of high-fluidity concrete proportioned in advance in laboratories. This results from different mixing efficiency of the mixer. In such a case the proportions are normally corrected by adjusting the dosage of high-range water reducing AE agent. The manual for production and construction in the “Recommendation for Construction of

High-fluidity Concrete" may be instructive in understanding details of such adjustment.

7.5.4 Quality control during production

(1) The frequency of measurement of surface moisture should be increased as required to accelerate the correction of surface moisture of aggregate.

(2) The quality of fresh concrete is likely to vary at the start of production. Tests should be conducted frequently for quality control until stable quality is obtained.

[Commentary] (1) In high-fluidity concrete, the properties of fresh concrete are vulnerable to the effects of change in aggregate surface moisture. In the first several batches, the surface moisture is high even in an aggregate storage covered with a roof. Measurements should therefore be taken the required number of times until the value of surface moisture is stabilized and equipment should be adopted that provides for prompt correction of measurements.

(2) The surface moisture of aggregate is likely to vary right after the start of production, so the quality of fresh concrete is also likely to vary. The frequency of quality management tests should be increased until the quality is stabilized for reflection in production management. For high-fluidity concrete, quality management tests should be conducted in terms of fluidity, resistance to material segregation and self-compactability in addition to the verification of power consumption by the mixer during mixing and the quality verification tests of fresh concrete as practiced for ordinary concrete, so as to obtain the designated properties. Generally, fluidity is controlled by conducting slump flow tests and resistance to material segregation is controlled based on the 50 cm flow time and the funnel flow time. Self-compactability should be controlled by conducting tests for passability through narrowed area using a filling tester as required.

7.6 Construction

7.6.1 Transporting and placing

(1) When using concrete pumps for transport at the site, the pump diameter, piping route and pipe length should be determined considering the quality of concrete, pump type, pumping condition, ease of work and safety. The types and quantities of pumps should be determined considering the quality of concrete, pump diameter, pumping distance, pumping load and pumping rate. Pumping condition should be determined based on the test results or records.

(2) The placing rate of high-fluidity concrete should be adequately established according to the mixture proportions, shapes and dimensions of members and reinforcement arrangement conditions on the basis of test results and field experience.

(3) The maximum permissible drop height and flow distance of high-fluidity concrete should be determined in advance considering the mix proportions, structural conditions and construction conditions.

(4) The designated quality needs to be maintained during the work from the production of high-fluidity concrete to the end of placement.

[Commentary] (1), (2) and (3) When high-fluidity concrete is conveyed by pumping, an increase in the pumping rate tends to lead to a greater pressure loss than normal concrete. Fig. C7.6.1 shows an example of relationship between the pumping rate and the pressure loss in the pipe. The relationship varies greatly according to the quantity of powder. The larger the quantity of powder, the greater the pressure loss in the pipe. Also, pumping generally tends to reduce the slump flow of high-fluidity concrete.

When no test results are available, the following pumping conditions should be applied as a standard: The length of the pipeline should not be more than 300 m with 4- or 5-inch pipes; the free drop height of concrete should be around 5 m or less; and the maximum lateral flow distance should be 8 to15 m or less.

Excessively quick placing of high-fluidity concrete can entrap air or cause defective filling in certain structures. It is, therefore, necessary to establish the placing rate adequately according to the mixture proportions, shapes and dimensions of members and reinforcement arrangement based on test results and field experience. The rate of placement is generally lower than for ordinary concrete in numerous cases. In approximately 50% of cases, the rate of placement has been 10 to 40 m^3/hr. The mean rate is approximately 30 m^3/hr. When placing concrete in closed space, an appropriate concrete flow slope, rate of placement and locations of air vents should be determined to prevent incomplete filling. Though high-fluidity concrete is proportioned to provide high flowability and resistance to segregation, segregation can occur when it is dropped or flowed for an excessively long distance. The maximum permissible drop height and flow distance should, therefore, be established in advance in consideration of the mix proportions and structural and construction conditions.

In structures in which air voids are aesthetically detrimental, lightly striking the surface of formwork may be necessary. It has, however, been known that lightly striking the surface may remove or embed air voids. Great care should therefore be exercised when striking the surface of formwork. The effects of striking should be confirmed in advance.

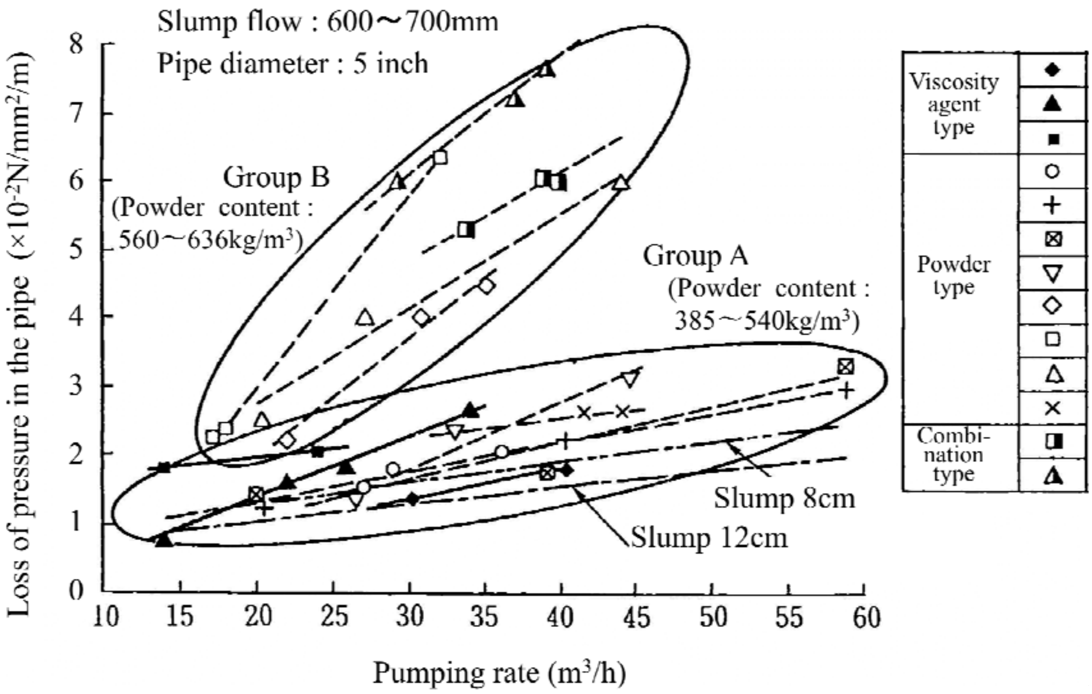


Fig. C7.6.1 Example of pressure loss in pipe under pumping of high-fluidity concrete

(4) It is functionally important that high-fluidity concrete maintains the designated self-compactability until the end of placement. Placement in densely arranged reinforcement or filling in narrow space may take longer time than for ordinary concrete in numerous cases. With the recent enhancement of high performance air-entraining and water-reducing agents, the quality of fresh concrete can now be maintained for a long time. It is necessary to use appropriate admixtures that enable the maintenance of fresh concrete quality and to select mix proportions that provide for the provision of designated self-compactability in the production phase through the end of placement.

7.6.2 Finishing and curing

Until the time of surface finishing, measures to prevent drying of the concrete surface shall be taken. Also, care should be exercised not to miss the time to take such measures.

[Commentary] Finishing work is difficult to perform on high-fluidity concrete, due to its high viscosity and little amount of bleeding water. It is, therefore, necessary to take measures to prevent surface drying until the time of finishing, and care should be exercised not to miss the time for taking such measures.

7.6.3 Construction joints

Treatment at construction joints of high-fluidity concrete may be simplified if it can be ensured that the required performance can still be achieved.

[Commentary] The small amount of bleeding water of high-fluidity concrete forms less laitance on the construction joint surfaces than normal concrete. For this reason, simplified treatment of construction joint surfaces is permitted, provided the required performance of the joint surface is confirmed.

7.6.4 Formwork

(1) The lateral pressure of high-fluidity concrete on the formwork should, in general, be treated as hydrostatic.

(2) When placing high-fluidity concrete into closed spaces, vent holes shall be provided at appropriate positions in the top forms.

(3) In the case when the presence of surface voids impairs the aesthetics of the structures, care shall be exercised in selecting the sheathing materials and type of form removers.

[Commentary] (1) The lateral pressure of high-fluidity concrete placed in formwork acts similarly to liquid pressure on the formwork, due to its high flowability. In addition, the longer setting time of high-fluidity concrete than that of normal concrete generally tends to retain the high lateral pressure for a longer time. Therefore, the lateral pressure of high-fluidity concrete on the formwork should be designed as liquid pressure.

(2) Air in closed spaces should be allowed to escape out of the forms as concrete is filled in them. To this end, vent holes should be provided at appropriate positions in consideration of the placing method and shapes and dimensions of the portions to be placed.

(3) High-fluidity concrete can leave many voids on the formed surfaces. For structures on which such voids will damage their aesthetic appearance, the sheathing materials and type of form removers should be selected with care, as these can affect the state of air-voids being left on formed surfaces.

7.7 Inspection

The accepting party shall assume the responsibility for conducting acceptance tests of high-fluidity concrete. Self-compactability should be inspected before concrete placement as a standard practice (Table 7.7.1).

Table 7.7.1 Inspection of self-compactability

Ranks of self-compactability	Testing method/ Inspection method	Period/Frequency	Criteria for judgment
Rank1 to 3	In accordance with JSCE-F511	At least once for each 50 m^3	Filling height is not less than 300 mm

[Commentary] The accepting party conducting acceptance tests for high-fluidity concrete is the Owner of the structure. There may be cases, however, where the Contractor constructing high-fluidity concrete has conducted tests and the Owner has verified the test results. The performance of concrete produced and transported for actual construction can differ from that of designed concrete. It is, therefore, important to conduct inspection before placing, even if the concrete has been verified at the construction planning stage. It is particularly important to examine before placing that produced and transported concrete attains the established self-compactability for ensuring reliability of the structure. Since the changes in the temperature and transportation time during the construction can alter the self-compactability from the designed level, it has to be confirmed by a suitable method by the time the placing begins.

The inspection is generally carried out at the point of unloading after production/transportation. In this case, it should be confirmed that the changes in the self-compactability due to conveyance within the site, such as pumping after unloading, are sufficiently small. Furthermore, the time after production and before shipping may be specified for inspection, if it is also confirmed that the transportation after production causes only marginal changes in the self-compactability.

Self-compactability inspection is required as a rule by the test for passability through narrowed areas with a filling tester.In the test for passability through narrowed areas using a filling tester, the obstacle conditions corresponding to the established self-compactability rank should be used. An inspection frequency of at least once for each 50 m^3 was adopted referring to the frequency of inspection specified for superplasticized concrete.

A simple alternative test method may be applied in place of the inspection testing, if the possible factors for quality fluctuation of concrete during production are identified and if such a simple test method can be established with clear criteria corresponding with the criteria for rejection in the inspection by passability test using a filling tester. In cases where quality change is ascribable to the changes in moisture and quantities of high performance air-entraining and water-reducing agents and the changes can be corrected sequentially based on the verification of the measurements at the time of production based on records, evaluation may be conducted based both on the slump flow and 50 cm flow time and funnel flow time. In this case, it is necessary to establish judgment criteria corresponding to rejection by the test for passability through narrowed areas using a filling tester or 100% testing with passability test equipment.

The best means of inspecting self-compactability is the implementation of 100% testing with passability test using void passage equipment. If 100% testing with passability test using void passage equipment installed between the truck agitator and pump is possible, it may be conducted. For the methods of testing, refer to the production and construction manual described in the "Guidelines for Construction of High-fluidity Concrete".

When a concrete is rejected by inspection because of insufficient flowability, the concrete may be added with a high-range water-reducing AE agent at a dosage in a predetermined range for re-inspection. When rejected because of segregation, the concrete must not be used. In any case, the causes for rejection must be identified for adequate and prompt remedial measures to improve subsequent production.

Other concrete inspections than those described here shall be conducted in accordance with Chapter 16 of "Materials and Construction: Construction Standards" and "Materials and Construction: Inspection Standards".

CHAPTER 8　SHOTCRETE

8.1　General

8.1.1　Scope

This chapter presents the standards concerning shotcrete used for the construction of tunnels and slopes.

[Commentary] Shotcrete is classified into three major types: tunnel shotcrete used as the primary tunnel lining, slope shotcrete used to protect slopes from weathering and erosion, and repair or retrofit shotcrete for repairing or retrofitting concrete structures. Repair or retrofit shotcrete is not discussed in this chapter because materials and mix proportions for this type of shotcrete are greatly different from those for tunnel and slope shotcrete in certain members and under certain construction conditions and because few records or reliable data is available. This chapter is applicable to tunnel shotcrete (study structures include inclined and vertical shafts and large-cavity structures) and slope shotcrete. The shotcrete for repairing or retrofitting concrete structures should be constructed under the guidance of professional engineers with adequate knowledge and experience in accordance with the "Guidelines for Shotcrete (draft): Repair and Retrofit".

Tunnel shotcrete as well as the rock bolts and steel supports is a major component of support system, a standard system for a mountain tunnel. Tunnel shotcrete provides excellent adhesion to the soils excavated earlier and develops the designated early strength right after shotcreting, and is expected to be effective for preventing soil spalling or reinforcing the soil, preventing weathering, applying internal pressure to the soil and distributing external forces.

Slope shotcrete is used for shotcreting for preventing the weathering of exposed rock surface, slope erosion and water seepage in the soil and for constructing shotcrete cribbing for preventing small-scale or thin surface collapses.

Shotcrete offers numerous benefits. Factors related to the shotcreting method, however, greatly affect the quality of shotcrete and the accumulation of dust has serious impact on the environment and on the health and safety of workers. For dust, the Labor Standards Bureau of the Ministry of Health, Labor and Welfare presented the "Guidelines Concerning the Dust Control during the Construction of Tunnels and Other Structures" in December 2000. Reducing dust is an important issue in shotcreting. With the increase of tunnel cross section, demand has been increasing for mechanical performance enhancement such as higher strength and tougher shotcrete. To meet the demand, efforts have been made to improve the quality, ease of work, cost performance, safety and work environment through the development of such admixtures as silica fume and fine limestone powder, dust reducing agents, acid set accelerators for liquid, such admixtures as set accelerators for slurried powder and shotcrete machines using rotational or centrifugal force instead of compressed air.

For matters not described in this chapter, refer to the "Standard Specifications for Tunnels: Mountain Tunnel Construction Methods". Related guidelines should also be consulted such as "Part 2 Shotcrete in Mountain Tunnels" of the "Tunnel Concrete Construction Guidelines (draft)", "Shotcrete Guidelines (draft): Tunnels", "Shotcrete Guidelines (draft): Slopes", "Highway Earthworks Series – Manual for Slope Protection" of the Japan Road Association (March 1999) and the "Design and Construction Guidelines for Slope Cribs" of the Japan Slope Protection Association (revised in March 2003).

8.1.2 General

When constructing shotcrete, the materials, mix proportions, shotcreting type, shotcrete machine and facilities and construction method should be determined under the guidance of professional engineers with adequate knowledge and experience so that the designated performance requirements may be met.

[Commentary] Tunnel and slope shotcrete has both benefits and drawbacks as described below. The materials, mix proportions, shotcreting type, shotcrete machine and construction method should be determined under the guidance of professional engineers with skills required for the construction of shotcrete so that the shotcrete may meet the designated performance requirements.

Shotcreting is classified into wet or dry shotcreting. In wet shotcreting, concrete is mixed in a mixer and is pumped using compressed air as in the production of ordinary concrete. Then, set accelerators are applied at the nozzle as required and the concrete is sprayed. In dry shotcreting, set accelerators are applied to dry mixed cement and aggregate and the mixture is pumped using compressed air. Pressure water is added to the mixture at the nozzle before the concrete is sprayed.

Examples of dry and wet shotcreting systems are shown in Exp. Fig. 8.1.1. In cases where the cross section of excavation is small and the tunnel has a great length, the dry shotcreting system is adopted because a small shotcrete machine can pump materials over a long distance. In tunnels of large cross section like highway or railway tunnels, the wet shotcreting system is used in numerous cases.

For tunnel shotcrete, the wet shotcreting system has recently been adopted in numerous cases in order to improve the work environment and reduce the loss of materials. Also for slope shotcrete, use of the wet shotcreting system is moving into the mainstream.

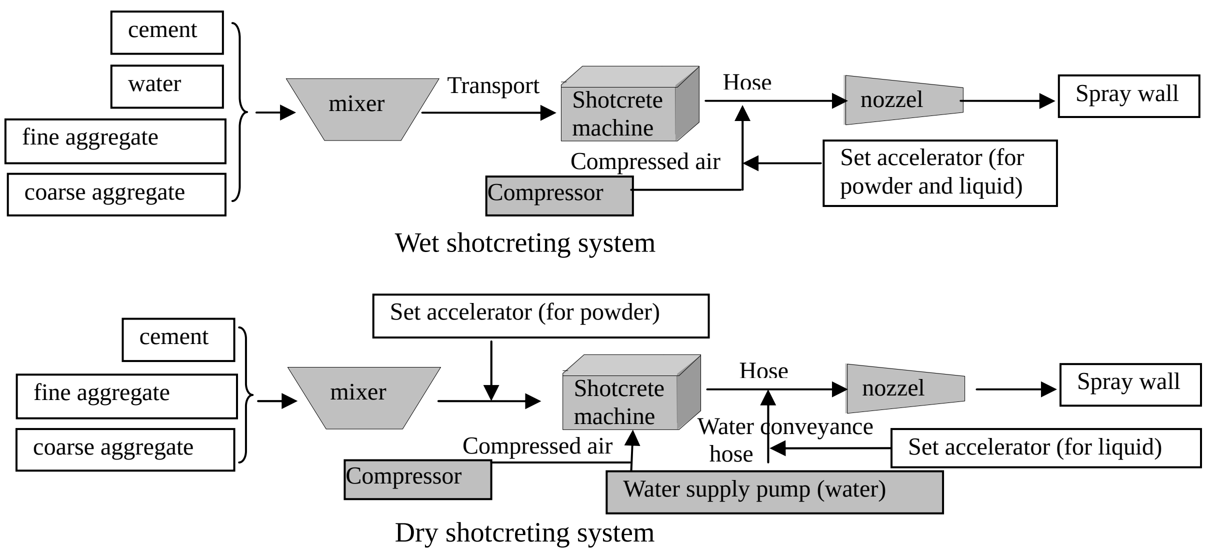


Fig. C8.1.1 Examples of shotcreting systems

8.2 Quality of Concrete

8.2.1 General

Shotcrete shall have mechanical properties, provide workability during shotcreting and

be able to control the dust concentration and percentage of rebound as designated, and should be of homogeneous nature. Slope shotcrete shall be sufficiently durable as designated.

[Commentary] For shotcrete, the 28-day strength shall be specified as the design strength as in ordinary concrete. Tunnel shotcrete needs to meet the mechanical property requirements including the early strength up to an age of 24 hours to ensure early stabilization of the tunnel and surrounding ground during tunnel construction. When determining the performance requirements for shotcreting, workability should be designated to reduce quality variations, and the percentage of rebound and dust concentration should be minimized to improve the construction environment. Slope shotcrete should keep the third party free from adverse effects of delamination or spalling, keep aesthetic and landscape performance within the allowable range, and be sufficiently durable to control the expansion of reinforcement due to corrosion caused by carbonation or chloride attack and the cracking due to freezing and thawing action or alkali-silica reaction.

8.2.2 Mechanical properties of concrete

(1) The mechanical properties of tunnel shotcrete should be expressed by the 28-day compressive strength and the 24-hour strength as a standard practice.

(2) Compressive strength tests for tunnel shotcrete at an age of 28 days should be conducted in accordance with JIS A 1107 using core samples produced as stipulated in JSCE-F 561 and 553. The early strength should be tested in accordance with JSCE-G 561 or 562.

(3) The mechanical properties of slope shotcrete should be expressed by the 28-day compressive strength.

(4) Compressive strength tests for slope shotcrete at an age of 28 days should be conducted in accordance with JIS A 1107 using core samples produced as stipulated in JSCE-F 561 and 553.

(5) Other mechanical properties than compressive strength shall be determined as required. Tests should be conducted after identifying the quality standards and test method.

[Commentary] (1) : The strength of tunnel shotcrete as a mechanical property requirement varies according to the use of the tunnel, e.g. railway, highway or water conveyance channel, and the structural condition including the cross section and geological condition. The 28-day design strength obtained based on the design of the tunnel supports is generally set to be approximately 18 N/mm2 in numerous cases. Tunnel shotcrete should be applied immediately following the excavation to retain the earth. The designated strength therefore should be secured at an early age so as to prevent the attached concrete from spalling due to its own weight and to provide resistance to vibrations induced by blasting. As the strength at an early age, a 24-hour compressive strength of 5 or 8 N/mm2 is frequently specified.

(2): The 28-day strength of tunnel shotcrete shall be tested as a standard practice by testing core samples produced by shotcreting in accordance with JIS A 1107 "Method of Collection of Core Samples from Concrete and Method of Test for Compressive Strength". Test samples are produced in accordance with JSCE-F 561 "Production of Samples for Compressive Strength Test of Shotcrete (Mortar)". For steel fiber reinforced shotcrete, refer to JSCE-F 553 "Production of Samples for Strength and Toughness Tests of Steel Fiber Reinforced Shotcrete". Samples of tunnel shotcrete are produced by shotcreting. Voids or cavities in the sample reduce the compressive strength. At the time of testing, therefore, the method of shotcreting and the condition of the shotcrete machine should be determined by verifying the continuity of spray walls for the sample, monitoring the voids or cavities and measuring the apparent concentration (mass of unit volume) of the sample. In the wet shotcreting system, the compressive strength of concrete before the application of set accelerators may sometimes be tested by JIS A 1108 "Method of Test for Compressive Strength of Concrete" to estimate the design strength of concrete.

The early strength up to an age of 24 hours after the start of shotcreting is low. It is therefore difficult to measure strength by processing and shaping the sample and subjecting it to a direct compressive test as for ordinary concrete. As a standard practice, therefore, a guideline shall be obtained for early strength by measuring the pullout resistance by JSCE-G 561 "Method of Early Strength of Shotcrete by Pullout Method", or tests shall be conducted by JSCE-G 562 "Method of Test of Early Compressive Strength of Shotcrete in Beams".

(3) and (4): The 28-day strength of slope shotcrete shall be tested by a method similar to that for testing the 28-day compressive strength of tunnel shotcrete described in (1) above. The design strength is generally set to be 15 N/mm2 in numerous cases, but is sometimes set to be 18 or 21 N/mm2.

(5): Other mechanical properties of shotcrete include flexural strength and flexural toughness in cases where short fibers are mixed. Flexural strength should be tested by JIS A 1106 "Method of Test for Flexural Strength of Concrete". Flexural toughness should be tested by JSCE-G 552 "Method of Test for Flexural Strength and Toughness of Steel Fiber Reinforced Concrete" using the samples produced in accordance with JSCE-F 553.

8.3 Materials

8.3.1 Cement

(1) Ordinary Portland cement complying with JIS R 5210 should be used as a standard practice.

(2) Other types of cements than that mentioned in (1) above shall be used only after verifying that the shotcrete meets the designated quality requirements.

[Commentary] (1) and (2): For shotcrete, ordinary Portland cement is generally used. In cases where the shotcrete is exposed to a sulfate environment (e.g. in hot spring areas) or to an environment affected by salt as in an ocean, Portland blastfurnace cement type B is used. It should be noted that when using Portland blastfurnace cement, applying acid set accelerators containing aluminum salts may sometimes cause the components of blastfurnace slag and acid set accelerator to react to each other to form hydrogen sulfide gas. In cases where high early strength is required as in slope shotcrete construction in cold areas or in placing concrete in arch and then in sidewalls during tunnel excavation, high early strength Portland cement is used.

8.3.2 Aggregate

For shotcrete, aggregates inducing no alkali-silica reaction should be used as a standard practice.

[Commentary] Shotcrete has higher cement content than ordinary concrete. Set accelerators for tunnel shotcrete contain alkali components in numerous cases. The total alkali content of concrete generally exceeds 3.0 kg/m3. For shotcrete, aggregates shall be used as a standard practice that are determined to induce no alkali-silica reaction by conducting tests using JIS A 1145 "Method of Test for Alkali-silica Reaction of Aggregate (chemical method)" or JIS A 1146 "Method of Test for Alkali-silica Reaction of Aggregate (mortar bar method)".

In cases where aggregates inducing no alkali-silica reaction are unavailable, blended Portland cement should be used that is effective for controlling alkali-silica reaction, and acid set accelerators with a low alkali content should be adopted.

8.3.3 Set accelerator

Set accelerators used for shotcrete shall comply with JSCE-D 102.

[Commentary] Set accelerators promote the hydration of cement and accelerate the setting (hardening) of concrete. Set accelerators prevent sprayed concrete from sagging or falling due to its weight, secure the designated thickness of shotcrete, reduce rebound and enhance early strength of concrete; and thereby provide sufficient strength to resist ground deformation and vibrations caused by blasting. These are the reasons for generally adopting set accelerators for tunnel shotcrete. At the same time, however, set accelerators are likely to deteriorate the long-term strength of concrete or cause damage to the health of workers as part of the dust. Set accelerator of guaranteed quality should therefore be used. Set accelerators that comply with JSCE-D 102 "Quality Standards for Set Accelerators for Shotcrete (draft)" should be used.

Major set accelerators currently used for tunnel shotcrete are listed in Table C8.3.1 with their shape and components. Cement mineral set accelerators promote the hydration of cement, and is therefore effective for setting and developing early strength. Acid set accelerators are slightly less effective for developing early strength but effective for reducing dust concentration or rebound. They are therefore used also as a measure for controlling total alkali content in cases where aggregate that is unavailable for inducing no alkali-silica reaction is used. Appropriate set accelerators should be selected considering the use, materials, mix proportions, construction method and other factors because they have varying characteristics although they comply with JISCE-D 102.

Methods have recently been reported for reducing the dust concentration in cases where powder set accelerators are used, using slurries produced by mixing powder set accelerators with water; or for enhancing early strength using both powder and liquid set accelerators.

For slope shotcrete, set accelerators are also used in some cases to prevent the sagging of concrete or help develop early strength in the shotcreting on sharp slopes. Then, appropriate type and quantity of set accelerator should be determined fully considering such conditions as the condition of construction site, method of construction and temperature.

Table C8.3.1 Classifications of set accelerators used for tunnel shotcrete

Shape	Type	Components
Powder	Cement mineral	Calcium aluminate cement
		Calcium sulfoaluminate
Liquid	Acid	Water-soluble aluminum salt (alkali-free)
	Alkaline	Inorganic salt and aluminate

8.3.4 Admixtures and short fibers

(1) Standard admixtures used for shotcrete should comply with JIS A 6201, 6206 or 6207.

(2) Standard fine limestone powder should comply with JCI-SLP "Quality Standards for Fine Limestone Powder for Concrete (draft)".

(3) Standard steel fibers should comply with JSCE-E 101. Other types of short fibers shall be used only after verifying that the designated quality requirements are met for the shotcrete.

(4) Standard chemical admixtures should comply with JIS A 6204.

(5) Other types of admixtures shall be used only after verifying that the designated quality requirements are met for the shotcrete.

[Commentary] (1): For shotcrete, JIS-complying fly ash, ground granulated blastfurnace slag and silica fume are used. It has been verified that these admixtures not only enhance the mechanical properties of concrete but also improve concrete resistance to material segregation, enhance the ease of work in such terms as concrete pumpability and reduce the dust concentration and rebound. When using admixtures, it should be verified in advance by conducting testing that the designated quality requirements are met for the concrete..

(2) Shotcrete using fine limestone powder as well as that using admixtures has been determined to improve the ease of construction and work and reduce the dust concentration and rebound. Fine limestone powder is sometimes used with other types of admixtures. When using fine limestone powder, it should be verified in advance by conducting testing that the designated quality requirements are met for the concrete.

(3): Shotcrete using steel fibers is used in sections subjected to structurally high stress such as tunnel portals, intersections of tunnels and enlarged sections; or in sections under poor geological conditions that are subjected to great earth pressure such as fault fracture zones and expansive ground, mainly for improving toughness. Increasing the flexural strength, tensile strength, shear strength and flexural toughness of shotcrete is expected to reduce shotcrete thickness and prevent shotcrete from spalling. In cases where steel fibers are used in shotcrete, however, steel fibers may be deformed during mixing or shotcreting. In some cases, the designated mechanical properties and toughness may not be available for shotcrete even if the designated percentage of steel fibers is attained. Steel fibers should therefore be of a shape that prevents deformation during mixing or shotcreting and causes no clogging of the hose. Steel fibers used in shotcrete should generally comply with JSCE-E 101 "Quality Standards for Steel Fiber Products for Concrete" and have a length of approximately 30 mm and have both ends treated.

When using steel fibers in shotcrete, the pumping load of concrete, quantity of steel fibers in the material that rebounds, orientation and deformation of steel fibers in concrete and wear of shotcrete machine or auxiliary equipment should be fully considered. For the mix proportions and methods of production and construction of shotcrete using steel fibers, refer to "Design and Construction Guidelines for Steel Fiber Reinforced Concrete (draft)".

Other synthetic fibers than steel fibers such as vinylon and polypropylene fibers are used in some cases. When using these types of fibers, it should be verified in advance by conducting testing that the designated quality requirements are met for the shotcrete based on Chapter 5 Short Fiber Reinforced Concrete as for steel fibers.

(4): Chemical admixtures for concrete has been used in an increasing number of cases to reduce the water content of shotcrete, improve resistance to material segregation and obtain designated workability. For slope shotcrete in particular, the designated resistance to freezing and thawing action is frequently demanded. It is therefore necessary to use air-entraining agents, air-entraining water-reducing agents and high performance air-entraining water-reducing agents. The effectiveness of these admixtures, however, varies according to the quality, mix proportions and construction method of cement and aggregate. The effectiveness should therefore be verified in advance by conducting tests. When using a chemical admixture, appropriate type and quantity should be determined after verifying that the designated quality requirements may be met for the shotcrete.

(5): Other admixtures used in shotcrete include thickening agents and retarding agents. Thickening agents are frequently used mainly to reduce dust and are generally referred to as dust reducing agents. Thickening agents are used also to prevent material segregation during pumping and to reduce rebound. Retarding agents may sometimes be used to delay the setting of concrete when the duration from the start of mixing to the end of shotcreting (placement) is expected to exceed the duration stipulated in Section 7.2 of "Construction: Construction Standards" in cases of transport of ready-mixed concrete from the plant to the site or of intensive nighttime shotcreting. If these admixtures are used in large quantities, the designated quality may be adversely affected by the reduction of early strength and design strength. Appropriate type and quantity should be determined only after verifying that the designated quality requirements can be met for the shotcrete.

8.4 Mix Proportions

(1) When determining the mix proportions, the following parameters shall be determined so that the designated quality requirements may be met for the shotcrete.

(a) Maximum size of coarse aggregate

(b) Percentage of fine aggregate

(c) Water-cement ratio, unit cement content and water content

(d) Type and unit quantity of admixture

(e) Type and quantity of set accelerator

(2) Mix proportions should be determined by conducting testing before the start of construction work based on reliable data.

[Commentary] (1): The workability of wet-type tunnel shotcrete is frequently controlled in a slump range between 8 and 14 cm. For the workability of slope shotcrete, flow value is set to be approximately 120 mm as stipulated in JIS R 5201 "Physical Test Method for Cement" in numerous cases. In the dry system, materials are mixed with water at the nozzle. The surface moisture of fine aggregate is mainly used as a parameter for controlling the ease of work.

For shotcrete, mix proportions should be determined for respective shotcrete type by selecting the maximum size of coarse aggregate, percentage of fine aggregate, water-cement ratio, unit cement content and unit water content, type and unit quantity of admixture and type and quantity of set accelerator, based on the reliable data and construction records so that the designated performance requirements may be met in such terms as quality of the sprayed concrete, cost performance and ease of shotcreting work.

When determining the mix proportions of shotcrete, the following parameters should be considered to meet performance requirements for shotcreting work.

(i) Freedom from clogging or pulsation during pumping

(ii) Low rebound ratio and dust concentration

(iii) Nonoccurrence of delamination, spalling and surface sagging of sprayed concrete

(a) Maximum size of coarse aggregate: Increasing the maximum size of coarse aggregate reduces the unit water content and unit cement content, and is beneficial from a viewpoint of durability and cost performance. In shotcrete, however, the rebound of aggregate increases and the content of aggregate in the sprayed concrete is reduced. Clogging and pulsation are also likely to occur during pumping. These are the reasons for specifying the maximum size of coarse aggregate at 10 to 15 mm in most of the cases either in tunnel or slope shotcrete.

(b) Percentage of fine aggregate: In shotcrete, the higher the percentage of fine aggregate, the lower the rebound ratio and the higher the water content. On the other hand, the lower the percentage of fine aggregate, the smaller the resistance to material segregation resulting in a higher rebound ratio, and the more frequently the clogging of the hose occurs. These are the reasons for using fine aggregates in tunnel shotcrete in a range between 55 to 70% in numerous cases. For slope shotcrete, there are cases of a range between 70 to 100%. In numerous cases, mortar is used without using any coarse aggregate. When using short fibers, a large percentage of fine aggregate should be selected as for ordinary concrete.

(c) Water-cement ratio, unit cement content and water content: The water-cement ratio of tunnel shotcrete is generally approximately 50 to 60% for the wet system, or 45 to 55% for the dry system. The standard water-cement ratio for slope shotcrete should be 60% or lower. In the wet system, the ratio is frequently set to be approximately 55 to 60%. In the wet system, unit water content tends to be higher than in the dry system because the designated slump is secured while not affecting concrete transport and pumping. In the dry system, the water-cement ratio is controlled by adjusting the amount of water added at the nozzle according to the surface moisture of the fine aggregate used. It is therefore important to control the amount of water at the nozzle using a flow meter considering the surface moisture of fine aggregate and the performance requirements for shotcreting.

The unit cement content of tunnel shotcrete is set to be 360 kg/m3 at a design strength of approximately 18 N/mm2 in most cases. Generally, the lower the unit cement content, the higher the rebound ratio. The higher the unit cement content, the more likely is pulsation to occur during pumping, resulting in smaller pumpability. If aggregates with low solid volume percentage are used, the unit water content increases and problems are likely to occur such as clogging during pumping and sagging during shotcreting. Measures may be sometimes required like increasing the unit cement content or increasing unit powder content by applying admixtures. In tunnel shotcrete with a design strength of approximately 36 N/mm2, the unit cement content is increased nearly to 450 kg/m3 and the unit water content is reduced by using chemical admixtures. In slope shotcrete, the unit cement content should be set to be 400 kg/m3 or higher to ensure shotcreting work.

(d) Type and unit quantity of admixture: In shotcrete, admixtures are used to make high strength concrete, enhance concrete resistance to material segregation and reduce rebound ratio and dust concentration (Section 8.3.4). Excessively large quantities of admixtures, however, may place large burden on pumpability or ease of shotcreting work. When using admixtures, therefore, the unit volume of admixture should be verified in advance by conducting tests considering the type of set accelerator used so that the designated requirements for shotcrete quality and shotcreting work may be met.

(e) Type and quantity of set accelerator: The quantity of set accelerator used in tunnel shotcrete is five to 10% of the unit cement content in most of the cases. The quantity of set accelerator varies according to the type of accelerator, and is affected by various parameters such as the material, mix proportions, slump and temperature at the end of mixing of shotcrete; conditions of the sprayed surface such as the temperature and seepage in the tunnel; method of injection of set accelerator into the nozzle and the method of shotcreting.

When spraying slope shotcrete, set accelerator is used to reduce rebound and to secure shotcrete thickness early on sharp slopes or under overhangs. Then, set accelerator is likely to deteriorate resistance to freezing and thawing action. Careful attention should therefore be paid to the type and quantity of set accelerator.

The type and quantity of set accelerator should therefore be determined based on reliable data or construction records, or by conducting preliminary tests so that designated quality requirements may be met for the shotcrete. The quantity of set accelerator is generally not included in volume calculation for mix proportions.

(2): The quality and ease of work of concrete vary according to the component of the mix. Mix proportions therefore shall be determined after conducting tests before the start of construction work.

8.5 Production

8.5.1 General

When producing shotcrete, facilities for storing, measuring and mixing the materials and shotcrete machines shall be selected so as to meet quality requirements for the shotcrete.

[Commentary] For producing shotcrete, facilities meeting designated performance requirements should be used. In this section, the process of shotcrete production is assumed to end at the point where set accelerator and water are added at the nozzle. Necessary matters concerning the production facilities and shotcrete machines are described in this section.

8.5.2 Production facilities

(1) For measuring the volume of materials, equipment with designated measurement accuracy should be used as a standard practice.

(2) For mixing, mixers with designated mixing capacity should be used as a standard practice. The method for inputting materials and mixing time should be determined so that the designated quality requirements are satisfied.

[Commentary] (1): In the dry shotcreting system, continuous mixers are sometimes used that measure the volume of materials for producing concrete. When using continuous mixers, the measuring equipment for respective materials should be inspected using the materials to be used in the work before the start of construction work. Measuring the volume of materials generally results in a larger margin of error in measurement than measuring the mass of materials. Equipment should therefore be adjusted to maximize the accuracy of measurement of materials and to hold the margin of measurement error below the allowable level.

In cases where measuring the mass is difficult when measuring the volume of water to be added in the dry shotcreting system or when measuring the quantity of chemical admixtures applied in the wet shotcreting system, flow meters or other equipment should be used for measurement. When using a small quantity of admixtures like dust reducing agents, it should be verified in advance that the margin of measurement error is below the allowable level by calibrating the equipment for applying admixtures. The margin of measurement error should be held below the level specified in Section 5.3 of "Construction: Construction Standards". When using equipment for measuring the volume like continuous mixers, the "Guidelines for Construction of Concrete Mixed in Place Using Continuous Mixers (draft)" should be consulted for reference.

(2): For mixing, appropriate material input procedure and mixing time should be specified so that concrete materials may be mixed uniformly. For mixing, mixers shall be used as a standard practice that have capacity as stipulated in Section 5.2.3 of "Construction: Construction Standards". If no designated quality requirements are met, appropriate measures should be taken like increasing the mixing time.

8.5.3 Shotcrete machine and accessory equipment

(1) Shotcrete machines shall be able to uniformly and continuously pump and spray concrete of designated quality.

(2) Accessory equipment shall be able to help shotcrete machines meet the designated performance requirements.

[Commentary] (1): Shotcrete machines need to be able to uniformly and continuously transport materials so that the designated quality of concrete and work efficiency may be secured. When constructing shotcrete, the nozzle is either remote-operated by an automatic shotcrete machine or operated manually. In cases where a wide work area is available and no scaffolding is required, automatic shotcrete machines are generally adopted. In a tunnel cross section of 30 m2 or less or when spraying concrete on a slope, concrete is sprayed manually in numerous cases.

Shotcrete machines have been put to practical use in numerous types and have varying capacity. Shotcrete machines should be selected based on the existing records. It should be verified by conducting preliminary tests that the designated quality requirements are met for the concrete. Using compressed air for transporting materials or for spraying concrete may cause the pressure to rise temporarily due to clogging with materials or for other reasons. It should be made sure that adequate strength is available at the points of hose connection and attachment. Shotcrete machines, without the capacity for pumping materials uniformly and continuously, may fail to provide designated quality and excellent finished surface and deteriorate work efficiency. For remote-operating the nozzle, automatic shotcrete machines are required that can maintain appropriate distance and angle between the shotcrete surface and nozzle and enable the shotcrete to meet the designated quality requirements. Pumping distance for slope shotcrete in particular is affected by the area where shotcreting work takes place. If the pumping distance or vertical height is increased, pumping becomes difficult and concrete quality is likely to become heterogeneous. A hose length of 100 m or a height of 45 m is therefore specified as a standard.

(2): Accessory equipment to be used with shotcrete machines include compressors and equipment for applying water and admixtures including set accelerators. Compressors should be provided with adequate capacity considering the piping resistance and leakage because insufficient volume or pressure of compressed air may cause clogging or production of non-uniform shotcrete. Then, no designated quality requirements are met.

If no appropriate equipment is used for applying water and admixtures including set accelerators, application may not be stable causing rebound and generating dust. Then, no designated quality may be obtained. Methods of adjustment to secure the designated quantities should be verified in advance by conducting material pumping tests. Compressed air used for pumping contains moisture. When using powder set accelerators, therefore, the moisture in compressed air should be removed using a drier.

When storing powder set accelerators in the tunnel, moisture should be removed because humidity is high in the tunnel and set accelerators are likely to be weathered. When storing liquid set accelerators outside the tunnel, dissolved components may sometimes precipitate when the temperature of liquid set accelerators lowers. These points should be taken into consideration for selecting appropriate storage methods and installing appropriate facilities.

8.6 Construction

8.6.1 General

An appropriate construction plan shall be prepared concerning the transport and application of shotcrete to ensure the safety of shotcreting workers.

[Commentary] Tunnel or slope shotcrete is applied in closed work space, on sharp slopes or at high altitudes. Work space is frequently limited. There are risks of rock falls from the rock mass or earth and of collapse. In order to ensure that the designated quality requirements are met for shotcrete under such a work environment, safety measures should be taken thoroughly by providing protective appliances to workers or other means and a good construction plan should be prepared concerning the specific spraying work.

8.6.2 Preliminary treatment of shotcrete surface

(1) Loose rocks expected to fall during shotcreting shall be removed carefully.

(2) Any seepage on shotcrete surface shall be drained properly to prevent shotcreting work or sprayed concrete from being adversely affected.

[Commentary] (1): Loose rocks that are expected to fall, if any, should be removed carefully in advance to ensure the safety of shotcreting work and the bond between the earth and shotcrete.

When spraying concrete on the slope, steel wire mesh is installed to control or disperse the cracks on the earth or rock and to prevent the delamination and falling of mortar to be sprayed. In cases where wire mesh needs to be installed at a certain distance from the earth, welded wire mesh with a steel diameter of 2 mm and a mesh size of 50 mm is adopted. One or two anchor pins with a diameter of 13 to 16 mm and a length of 200 to 400 mm are generally arranged per cubic meter.

(2): Seepage on the shotcrete surface not only deteriorates the bond between the shotcrete and surface but also causes the water to enter the concrete, degrading concrete quality, washes away concrete before hardening or causes water pressure to act behind the hardened concrete, inducing cracking or delamination.

In cases of large quantities of seepage in the tunnel, drainage pipes or filters should be installed. In cases of small quantities of seepage, concrete is sprayed after changing the mix proportions such as increasing the cement or set accelerator content or reducing the water content as long as the ease of shotcreting work can be ensured. For controlling seepage on the slope, 20- to 30-cm square geomembranes or drainage mattresses are installed at intervals of one meter or longer, or other measures are taken. In ordinary wire netting works, drainage pipes are installed.

For seepage control measures, refer to Section 6.4.3 of II Shotcrete in Mountain Tunnels of the "Tunnel Concrete Construction Guidelines (draft)", Section 7.7.1 of "Shotcrete Guidelines (draft): Tunnels" and Section 7.2 of "Shotcrete Guidelines (draft): Slopes".

8.6.3 Shotcreting work

(1) Shotcreting should be carried out under the guidance of professional engineers with adequate knowledge and experience concerning shotcrete.

(2) In the wet shotcreting system, shotcreting shall be completed as soon as possible after the unloading of shotcrete.

(3) The nozzle and shotcrete surface shall be positioned at right angles inasmuch as possible and appropriate shotcreting distance and pressure should be maintained.

(4) Concrete shall be sprayed so as to minimize the rebound and dust concentration.

(5) Concrete shall be sprayed for an appropriate thickness so as to prevent delamination, spalling or sagging of concrete. Concrete shall be sprayed the required number of times until the designated thickness is reached.

(6) When spraying concrete in areas where steel supports are installed, concrete shall be sprayed so as to leave no gap between the earth and the steel supports to ensure the bond.

(7) When spraying concrete, care shall be exercised to prevent rebound materials from being embedded in the concrete layer.

[Commentary] (1): The quality of shotcrete is greatly affected by the shotcreting method and the skill of nozzle operator. The shotcreting method should therefore be selected under the guidance of professional engineers with adequate shotcrete knowledge and experience, and nozzle operators well versed in spray nozzle handling should carry out the work.

Shotcreting on the slope is subjected to the effects of weather or temperature. Then, the quality of shotcrete is somewhat affected. In cases where no appropriate curing is expected to be possible in such a case where temperature may falls close to the freezing point after shotcreting, no shotcreting work should be carried out.

(3): The greatest bond can be achieved between the shotcrete and shotcrete surface in cases where the materials are sprayed from the nozzle at an appropriate rate at right angles to the shotcrete surface. Shotcreting should therefore be carried out while maintaining the appropriate shotcreting distance and pressure so that the nozzle may be positioned at right angles to the shotcrete surface inasmuch as possible.

(4): The rebound and the generation of dust during shotcreting may be reduced by selecting the shotcrete method described in (3) above. The rebound and dust increase unless set accelerators or concrete is supplied steadily at the start of shotcreting. In order to carry out shotcreting steadily as early as possible, therefore, equipment for applying set accelerators or other admixtures and concrete pumps should be adjusted.

(5): The allowable shotcrete thickness varies according to the position of the shotcrete surface, whether the surface is wet or dry, shotcrete material, type and quantity of set accelerator, shotcrete system and skill of nozzle operator. The shotcrete thickness per round of work should be specified so as to prevent the delamination, spalling or sagging of sprayed materials. Concrete should be sprayed only after the layer of concrete sprayed earlier hardens sufficiently to hold the next layer of concrete.

(6): In cases where the shotcrete thickness is smaller than the thickness of steel supports, securing the continuity of supports and wall surface may become difficult. Concrete should therefore be sprayed as shown in Exp. Fig. 8.6.1 (a). is of concern.

The grid opening should be large enough to allow shotcrete to readily fill the spaces behind the grid. It is normally 100 by 100 mm or 150 by 150 mm, with the wire diameter being 3.2 to 6.0 mm. A grid size of 10 by 10 mm has been used for a tunnel in soil ground to prevent soil outflow due to shotcreting.

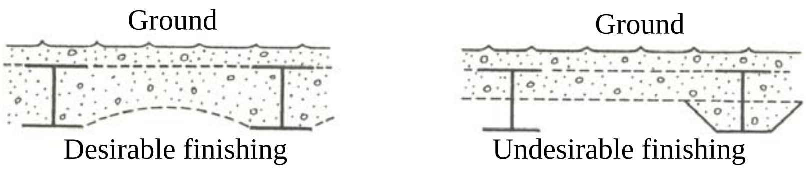


Fig. C8.6.1 finishing of shotcrete

(7): In swelling or weak ground, shotcrete is sometimes used for closing the invert early. Then, concrete is sprayed downward rather than horizontally. Rebound concrete is likely to be embedded as it is, creating voids. Shotcrete with voids sees its strength deteriorated. Care should therefore be exercised during shotcreting not to embed rebound materials.

8.6.4 Dust control measures

(1) The rebound ratio and dust concentration during shotcreting shall be minimized.

(2) In cases where the rebound ratio and dust concentration are likely to be at detrimental levels, appropriate corrective measures shall be taken.

[Commentary] (1) and (2): Dusts are produced during tunneling by excavation, machine operation or shotcreting. This chapter discusses the rebound and dusts produced during the spraying of tunnel concrete.

The dusts produced during shotcreting or rebound materials contain highly alkaline cement or set accelerators. Shotcreting workers should therefore use appropriate protective appliances (e.g. hard hats, goggles, dust masks, protective gloves, safety coats and safety boots) for their health and safety.

Even with the installation of blowers for injecting indoor or outdoor air in close space like a tunnel, completely removing dusts is difficult. While spraying concrete, the dust concentration should be measured by digital dust meters or high-volume suppliers, and dust control measures should be taken as required.

Methods for controlling dusts produced during shotcreting are described below.

(i) Measures taken at the source of dust

(a) Selecting shotcreting methods that minimize dust production (e.g. reviewing shotcreting distance or pumping pressure, adopting the wet shotcreting system, and employing shotcreting using rotational or centrifugal force)

(b) Selecting materials that minimize dust production (e.g. using dust reducing admixtures, or liquid or powder set accelerators in the form of slurry; and using such admixtures as silica fume and fine limestone powder)

(ii) Measures to control the dusts produced

(a) Discharging or diluting dusts by air conditioning

(b) Installing dust collectors

For controlling the dusts that are produced during tunnel excavation, refer to the "Guidelines Concerning Dust Control during Tunnel Construction" prepared by the Labor Standards Office of the Ministry of Labor of Japan in December 2000..

8.6.5 Concrete protection

In cases where the shotcrete is exposed under severe conditions, appropriate concrete protection measures shall be taken.

[Commentary] In the tunnel, temperature is stable and humidity is high except in sections near the tunnel portals. Shotcrete is in contact with the soil and drastic drying hardly occurs. Tunnel shotcrete is covered with geomembranes or lining concrete and is not exposed for a long time. At present, sprayed concrete is not generally cured. In cases where a dry condition is created rapidly after the construction of shotcrete or no lining concrete is constructed, appropriate concrete protection work should be done such as the application of curing admixtures to prevent drying and the atomization.

For slope shotcrete, wet curing and heat curing are required. Slope shotcrete is applied over a wide area in numerous cases. Shotcreting should therefore be carried out at an appropriate time so as to eliminate the need of special curing.

8.7 Inspections

8.7.1 Acceptance tests for concrete materials

The accepting party shall be held responsible for conducting acceptance tests for admixtures used in the shotcrete. Acceptance tests should be conducted in accordance with Table 8.7.1 as a standard practice.

Table 8.7.1 Admixture Acceptance Tests

Type	Item	Test or inspection method	Timing and frequency	Decision criteria
Set accelerator	Quality	Verification based on the test records prepared by the manufacturer or using a method specified in JSCE-D 102	At the time of delivery of materials	Conformity with JSCE-D 102
Dust reducer	Quality	Verification based on the test records prepared by the manufacturer	At the time of delivery of materials	Conformity with the values specified in the test records or the specified range

[Commentary] Major admixtures used for shotcrete are set accelerators and dust reducers. In the acceptance tests of these admixtures, their conformity is determined at the time of delivery based on the test records prepared by the manufacturer in most cases. Table 8.7.1 shall be used as standards. In cases where these admixtures are stored for a long time or some defects are detected during the inspection of concrete work, specified admixtures are inspected at the instruction of the accepting party. The inspection results are verified by the Owner.

For admixtures for which no standards have been established like JIS such as dust reducers, their quality should be verified in advance and the decision criteria that should be adopted in acceptance tests should be determined based on the test records provided by the manufacturer.

For maintaining and managing the quality of shotcrete properly, Material Safety Data Sheet (MSDS) should be consulted that presents storage methods for respective components or compositions of materials.eting. Shooting methods using pumps should conform to the “Recommendations for Pumping of Concrete”.

8.7.2 Concrete acceptance tests

(1) The accepting party shall be held responsible for conducting acceptance tests for concrete in the wet shotcreting system. Acceptance tests should be conducted in accordance with Table 8.7.2 as a standard practice.

(2) Acceptance tests for concrete in the dry shotcreting system may be replaced with inspections based on the material measurements.

Table 8.7.2 Acceptance tests for shotcrete

Item	Test or inspection method	Timing and frequency	Decision criteria
Workability of concrete in the wet shotcreting system	Method specified in JIS A 1101	Before the start of shotcreting and at the designated frequency during construction	Should be within the designated range of slump
	JIS R 5201 flow test	10) Before the start of shotcreting and at the designated frequency during construction	Should be within the designated range of flow value
Measurements of concrete materials in the dry shotcreting system	Method specified in JIS R 5308 or JSCE-I 501	Before the start of shotcreting and at the designated frequency during construction	Should be within the designated range of measurement
Compressive strength of concrete in the wet shotcreting system	Method specified in JIS A 1108	Before the start of shotcreting	Compressive strength should be higher than designated (for reference value)

[Commentary] The accepting party in shotcrete acceptance tests means the Owner of the project. The Contractor for shotcreting, however, usually conducts tests and the Owner verifies the test results.

Acceptance tests for shotcrete should be conducted for the items listed in Table 8.7.2 as the tests for ordinary concrete.

Concrete in the dry shotcreting system, unlike ordinary concrete, cannot be inspected based on the properties of fresh concrete including slump. Acceptance tests for concrete in the dry shotcreting system may be replaced with the tests based on the measurements of materials obtained by measurement equipment used in concrete mixing.

8.7.3 Inspection of concrete work

The Owner shall be held responsible for inspecting shotcreting work. Inspections for shotcrete used for tunnels and slopes should be conducted in accordance with Tables 8.7.3 and 8.7.4, respectively as a standard practice.

Table 8.7.3 Inspections of tunnel shotcrete work

Type	Item	Test or inspection method	Timing and frequency	Decision criteria
Inspection of shotcreting work	Rebound ratio	Method specified in JSCE-F 563	Before the start of shotcreting and at the designated frequency during construction	Rebound ratio should be below the designated level.
	Dust concentration	Method specified in JSCE-F 564	Before the start of shotcreting and at the designated frequency during construction	Dust concentration should be below the designated level.
	Compressive strength of shotcrete	Method specified in JIS A 1107 or 1108	Before the start of construction and whenever the designated mixing condition is changed during construction	A five-percent or lower probability of compressive strength falling below the design strength can be estimated from an appropriate producer's risk ratio.
	Early strength of shotcrete	Method specified in JSCE-G 561 (pull-out tests) or JSCE-G 562 (beam)	Before the start of construction and whenever the designated mixing condition is changed during construction	Early strength should exceed the designated level.
Inspection of shotcrete thickness	Shotcrete thickness	Visual inspection, use of measurement pins, inspection by drilling, etc.	At the designated frequency during construction and at the end of construction	Shotcrete thickness should exceed the design thickness.
	Deformation of shotcrete	Visual inspection or based on records	At the designated frequency during construction and at the end of construction	Shotcrete should be free from damaging deformation or cracking.
Inspection of condition in the tunnel	Dust concentration in the case of ventilation in the tunnel	Refer to the method described in the Explanation in Section 8.6.4	At a point where the excavated length exceeds 50 m, and at the designated frequency in subsequent construction	3 mg/m3 or less

Table 8.7.4 Inspections of tunnel shotcrete work

Type	Item	Test or inspection method	Timing and frequency	Decision criteria
Inspection of shotcreting work	Compressive strength of shotcrete	Method specified in JIS A 1107 or 1108	At the designated frequency during construction and at the end of construction	A five-percent or lower probability of compressive strength falling below the design strength can be estimated from an appropriate

				producer's risk ratio.
Inspection of shotcrete thickness	Shotcrete thickness	Use of measurement pins, inspection by drilling, etc.	At the designated frequency during construction and at the end of construction	- 1 cm at a design shotcrete thickness of less than 5 cm. -2 cm at a designated shotcrete thickness of 5 cm or more. The minimum shotcrete thickness in cases of rough shotcrete surface should be 50 or higher percentage of design shotcrete thickness. The mean thickness should be larger than the design thickness.
	Deformation of shotcrete	Visual inspection or based on records	At the designated frequency during construction and at the end of construction	Shotcrete should be free from damaging deformation or cracking.
Inspection of the size and position of shotcrete cribwork	Sectional size of crib	Measurement using a scale	At the designated frequency during construction and at the end of construction	Height: -3 cm. Width: -3 cm.
	Center to center distance between vertical and horizontal cribs			26) Center to center distance between vertical and horizontal cribs: ± 10 cm

[Commentary] In the inspection of shotcrete, one of concrete work inspections, rebound ratio, dust concentration, early strength and compressive strength, four performance parameters related to shotcreting, are inspected. Early strength and compressive strength are investigated in daily inspections. Rebound ratio and dust concentration are investigated as required.

Methods for investigating rebound ratio for tunnel shotcrete are affected by the condition of soil excavation, shotcreting method and skills of workers. Investigation accuracy is not sufficiently reliable. Investigations themselves require much effort. Rebound ratio shall therefore be investigated as required. Rebound in the tunnel is frequently inspected near the point of excavation. Inspections should be conducted while ensuring safety in the work environment considering the stability of soil or excavated face and the strength development of tunnel shotcrete. In cases where good track records on the past shotcreting are recognized based on the mix proportions of tunnel shotcrete, inspections of rebound ratio may be replaced with inspections of dust concentration and visual examinations. Inspection timing and frequency of tunnel shotcrete strength and decision criteria are listed in Table C8.7.1.

Table C8.7.1 Examples of timing and frequency of strength inspections and decision criteria

Timing and frequency	Decision criteria
Once per a tunnel length of 20 m or 40 m	28-day compressive strength should be 18 N/mm2 or higher.
Once each time tunnel is excavated for 50 m	28-day compressive strength should be 18 N/mm2 or higher, or 36 N/mm2.
Once each time tunnel is excavated for 25 m	One-day compressive strength should be 5 N/mm2 or higher, or 8 N/mm2.
Once per tunnel length of 20 m in the initial stages of excavation (approximately 200 m from the start of excavation). Subsequently, once in 50 m.	One-day compressive strength should be higher than 5 N/mm2. 28-day compressive strength should be higher than 18 N/mm2.

Slope shotcrete may sometimes have different compressive strengths in trial mixing and during actual construction owing to the difference in spraying or curing condition. The mean 28-day compressive strength should therefore be set to be 25 N/mm2 or higher. Parameters for each inspection items of slope shotcrete are frequently inspected each time 50 to 100 m3 of the volume is handled or at least once during construction work.

For direct measurement of shotcrete thickness, measurement pins are installed, measurement pins are inserted into the shotcrete layer while the shotcrete is sill soft, or measurement holes are drilled after shotcreting. Tunnel shotcrete is generally sprayed on the surface of steel supports that are erected right after excavation (Fig. C8.6.1). It may be inspected visually that shotcrete is sprayed on the surface of steel supports for a thickness larger than the designated thickness. The construction of shotcrete should be visually inspected daily or regularly for cracking, leakage, deformation, etc. and records should be kept. Examples of the timing and frequency of shotcrete thickness inspections and decision criteria are listed in Table C8.7.2. For shotcrete inspections, measurement holes of a diameter of 32 mm or longer are drilled mainly using electric augers in numerous cases. The timing and frequency of inspections should be determined to the specifications established by the receiving party. Shotcrete thickness should be evaluated based on the soil excavation condition.

Table C8.7.2 Examples of timing and frequency of shotcrete thickness and decision criteria

Testing or inspection method	Timing and frequency	Decision criteria
-Drilling holes of a diameter of 32 mm or longer with electric augers or other devices -Installing measurement pins (nail wire or round steel bars) at post-shotcreting measurement points and spraying concrete while displaying shotcrete thickness	-Measurement points are set in a cross section each time an advance is made for 40 m, and measurements are taken at five points in the crown and one each on either sidewall at the least. -Measurement points are set in a cross section within a length of 20 m or less, and measurements are taken at five points in the crown and one each on either sidewall at the least.	-Thickness should be larger than design thickness. In special areas such as the ends or injections in an excellent rock mass, the minimum thickness should be 1/3 of design thickness. -In cases where the design thickness is the minimum thickness, measurement should be equal to or larger than design thickness. In cases where the design thickness is the mean thickness, the mean thickness measurement should be equal to or larger than design thickness.

The tunnel environment for tunnel shotcrete is determined not only by the temperature and humidity during work but also by the dust that affects workers' health. The latter parameter is therefore also inspected to determine the environment in the tunnel. This parameter is defined as "dust concentration while a tunnel ventilation system is in operation" to distinguish it from shotcrete dust.

CHAPTER 9 PRE-PLACED AGGREGATE CONCRETE

9.1 General

9.1.1 Scope

This chapter presents the standards for the matters required for the construction of pre-placed concrete.

[Commentary] Pre-placed aggregate concrete or Prepacked conceret is concrete made by filling forms with coarse aggregate of selected grading and by grouting the voids of the aggregate with a specially prepared mortar under sufficient pressure. Special mortar means high fluidity grouting mortar that hardly causes material segregation and has adequate expansibility.

Pre-placed aggregate concrete is used for grouting, repair and retrofit, as a shield against radioactivity, as unreinforced offshore concrete and for other purposes. Pre-placed aggregate concrete is applied to wide varieties of structures of varying type, importance and scale.

High strength pre-placed aggregate concrete has been put to practical use that can produce a 91-day compressive strength of 40 to 60 N/mm^2 by using high performance water reducing agents. Mortar injected into high strength pre-placed aggregate concrete has higher compactibility than ordinary pre-placed aggregate concrete but requires special construction methods because of its high viscosity. This chapter presents the construction standards for ordinary pre-placed aggregate concrete and also for high strength pre-placed aggregate concrete.

9.1.2 General

(1) In order to construct pre-placed aggregate concrete structures of the designated quality, the place of construction, meteorological condition and construction method shall be examined under the guidance of professional engineers with adequate knowledge and experience.

(2) Pre-placed aggregate concrete construction methods shall be selected properly depending on ordinary concrete or high strength concrete.

[Commentary] (1) Pre-placed aggregate concrete differs considerably depending on whether the concrete is ordinary, large scale or high strength. In ordinary pre-placed aggregate concrete, the construction method which uses the close spacing of injection pipes has been adopted to obtain better quality concrete. Contrary to this, in construction of large-quantity pre-placed aggregate concrete where construction efficiency is essential, the close spacing of injection pipes may not only reduce concreting efficiency but also make it difficult to provide a proper capacity mortar plant due to the huge number of injecting pipes required. In this sense, a method which allows increased spacing of the injecting pipes by using larger size coarse aggregate with a rich mix proportion has been applied. In pre-placed aggregate concrete work where hi-strength is required, a high-range water-reducing agent is used as the chemical admixture to produce a grout mortar of low water-cementitious material ratio and high efficiency in intruding into the voids of coarse aggregate.

Thus, in pre-placed aggregate concrete, the most adequate materials and construction methods including chemical admixtures, mix proportion of grout mortar, gradation of coarse aggregate, spacing of injecting pipes, and construction equipment shall be selected depending on the structures.

(2) Pre-placed aggregate concrete construction methods vary greatly according to whether ordinary or high strength concrete is required.

For high strength pre-placed concrete, a grout mortar of low water-cementitious material ratio should be used. Grouting mortar can be injected smoothly into the voids between coarse aggregates despite its high viscosity by mixing admixtures composed of high performance water reducing agents and various types of additives.

9.2 Quality of Pre-Placed Aggregate Concrete

9.2.1 Quality of concrete

(1) Pre-placed aggregate concrete shall have the designated strength, durability and crack resistance and be of homogeneous quality.

(2) The 91- or 28-day compressive strength should be adopted as the standard strength of pre-placed aggregate concrete according to the construction condition or use.

(3) The compressive strength test of pre-placed aggregate concrete shall be conducted following JSCE-G 522.

[Commentary] (2) Due incorporation of mineral admixtures such as fly ash in many cases, pre-placed aggregate concrete cannot be expected to have sufficient compressive strength in early stages. However, if adequate curing is allowed, the compressive strength will continue to increase, and after approximately 13 weeks of aging, the long-term strength will be equivalent to or higher than that of concrete composed of ordinary portland cement only. For concrete which develops its strength slowly like the above mentioned, Concrete strength should be evaluated at old age.

Pre-placed aggregate concrete is especially adaptable to such applications as underwater concrete, concrete to be injected into voids, and filling concrete. In these cases, most curing conditions will be satisfactory, and only after a considerably long period the concrete structure will be subjected to design load. Therefore, it is reasonable to apply 91-day compressive strength as the characteristic compressive strength when pre-placed aggregate concrete is used for such structure.

However, when pre-placed aggregate concrete be used for general structures where the proper curing over a long period cannot be expected or structures on which the design load may act within 91-days after concreting, the application of 28-day compressive strength is advisable. In the above sense, the characteristic compressive strength of pre-placed aggregate concrete shall be determined based on either the 28-day or 91-day test specimen cured under the standard condition, depending upon the intended use of the concrete.

(3) Since the strength of pre-placed aggregate concrete made by grouting expansive mortar which contains aluminum powder is considerably affected by the degree of restraint of mortar expansion and the amount of bleeding water squeezed out, its compressive strength shall be tested according to JSCE-G 522 “Test Method for Compressive Strength of Pre-placed Aggregate Concrete”.

9.2.2 Quality of grouting mortar

Grouting mortar shall be able to produce concrete that hardly causes material segregation and has the designated fluidity, strength, durability and crack resistance.

[Commentary] Grouting mortar needs to have the following characteristics to produce pre-placed aggregate concrete of the designated quality.

(i) In the fresh state, grouting mortar needs to facilitate pumping and injection, to have high fluidity and pumpability to enable the filling of the voids between coarse aggregates and to maintain the aforementioned characteristics until the end of injection.

(ii) While it is injected into the voids between coarse aggregates, mortar should seldom cause material segregation and induce little bleeding and expand adequately during the period between injection and hardening.

(iii) After it hardens, mortar should have the compressive strength required to produce concrete of the designated quality, have bond with coarse aggregate and have sufficient durability and crack resistance.

9.3 Mix design

9.3.1 Materials

(1) The cementitious material shall be used either an appropriate mixture of ordinary portland cement meeting the requirements of JIS R 5210 and fly ash meeting the requirements of JIS A 6201, or, fly ash cement meeting the requirements of JIS R 5213.

(2) When cementitious materials other than those given in (1) above are used, it shall be ensured through tests that pre-placed aggregate concrete meeting quality of requirements, can be obtained.

(3) Appropriate admixtures shall be used considering the fluidity and resistance to material segregation of grouting mortar.

(4) Fine aggregate with an adequate grading shall be used considering the fluidity and pumpability of grouting mortar.

(5) Minimum size of coarse aggregate shall be more than 15 mm.

(6) The maximum size of coarse aggregate should not be more than 1/4 the minimum thickness of the member. Further, in the case of reinforced concrete, the maximum size of the coarse aggregate should not exceed 1/2 the clearance between the reinforcing bars.

[Commentary] (1) For the binder of the grout mortar used for pre-placed aggregate concrete, a mixture of ordinary portland cement and mineral admixture such as fly ash are used as cementitious material to improve fluidity, resistance against chemical intrusion, and to control hydration heat, ordinary Portland cement with fly ash, or fly ash cement conforming to JIS R 5213 are generally used.

(2) If high-early strength portland cement instead of ordinary portland cement, portland blast-furnace slag cement or low-heat portland is used, it must be ascertained before use by testing that the required quality of pre-placed aggregate concrete obtainable.

(3) Chemical admixtures to be used in the grout mortar of pre-placed aggregate concrete shall promote the fluidity, prevent segregation, retard setting, and give expansibility to the mortar.

Pre-blended chemical admixtures for pre-placed aggregate concrete containing the optimum amount of water-reducing agent, gas generating agent, viscosity agent, and set-retarding agent required for furnishing these properties to the grout mortar, are available commercially. Therefore, for general use pre-placed aggregate concrete, this pre-blended type of chemical admixture is recommended.

The gas generating agent contained in this type of chemical admixtures is generally scaly aluminum powder equivalent to JIS K 5906 “aluminum powder for paints” type 2. The expansibility by the aluminum powder is subtly altered by the quality of the aluminum powder, the quality of cement, the temperature, the mix proportion, the mixing time, the pressure after grouting, etc. At 10 to 20 C, many of previous experience indicate that the weight ratio of aluminum powder to cementitious material Al/(C+F) is generally from 0.010 to 0.015 %. Under the conditions with the construction of special attention needed the amount of aluminum powder is increased or decreased so as to satisfy the expansion with the standard values given in Section 9.3.2.

If pre-blended chemical admixtures for pre-placed aggregate concrete are not used, a mixture of water-reducing agent conforming to the provisions of JIS A 6204, aluminum powder and other agents shall be used.

Grouting mortar tends to lose fluidity at high temperatures. Retarders and thickening agents should therefore be used simultaneously to maintain fluidity.

Grout mortar with a low water-cement ratio tends to rapidly lose its fluidity under high temperatures. To preserve the fluidity, use of a set-retarding agent and water retentive agent may be effective. However, prior to using a water retentive agent, it shall be carefully examined since this agent may seriously affect the properties of concrete, especially the strength.

(4) To improve the fluidity and the resistance against segregation of the grout mortar, a finer fine aggregate than for conventional concrete shall be used.

If the water-cementitious materials ratio is the same, a fine aggregate with greater F.M. allows less cementitious material and water needed to obtain an equivalent fluidity. However, an excessive F.M. will make grout mortar segregate and block pumps or delivery pipes. Furthermore, defective filling of the voids of the aggregate by grout mortar may result. If F.M. is too low, an excessive unit content of cementitious materials and water will be necessary to obtain the required fluidity. The maximum size of fine aggregate shall thus be 2.5 mm and F.M. shall be between 1.4 and 2.2. The standard grading of fine aggregate is shown in Table C9.3.1.

Table C9.3.1 Standard grading of fine aggregate

Nominal sieve (mm)	Percentage of mass passing through sieve
2.5	100
1.2	90-100
0.6	60-80
0.3	20-50
0.15	5-30

The grout mortar for high-strength pre-placed aggregate concrete is normally used where high-quality pre-placed aggregate concrete with a low water-cementitious materials ratio and a lesser water content than grout mortar for normal pre-placed aggregate concrete is required. Therefore, great care must be exercised in controlling the materials. Furthermore, particular attention should be paid to the surface moisture content in the fine aggregate since it may considerably affect the fluidity of grout mortar and the compressive strength of pre-placed aggregate concrete. The fineness modulus of fine aggregate should be between 1.8 and 2.2 to minimize the cementitious material content within the limit for obtaining the required fluidity.

(5) As minimum size of coarse aggregate is larger, it will be easier for the grout mortar to flow into and fill out voids. Therefore, the minimum size coarse aggregate selected should be the largest possible in a practically permissible range. If small size particles are abundantly contained in coarse aggregate, sufficient grouting may not be possible due to the extremely reduced void space of the

aggregate. The lower limit of the minimum size of coarse aggregate has therefore been specified as 15 mm.

(6) The maximum size of coarse aggregate is generally two or four times the minimum size. A smaller difference between the maximum size and the minimum size of coarse aggregate will not impede the grouting. However, the grout mortar needed will be increased with the decreased solid volume percentage. Therefore, an appropriate grading shall be selected.

The volume of the void of coarse aggregate varies according to the grading of the aggregate and the shape of particles. In general, it ranges from 40 to 48 %. The apparent void ratio tends to increase when the shape of particles is plate type and to decrease when the shape of particles is spherical type.

9.3.2 Mix proportion of grouting mortar

The mix proportions of grouting mortar shall be determined so as to meet the following conditions.

(1) The flowability shall be determined using the flow time in accordance with JSCE-F 521. The standard flow time should be taken to be between 16 and 20 seconds. For high-strength pre-placed aggregate concrete, the standard flow time should be between 25 and 50 seconds.

(2) The amount of bleeding at three hours after the start of the experiment shall not exceed 3% when tested according to JSCE-F 522. For high-strength pre-placed aggregate concrete, this amount shall not exceed 1%.

(3) The amount of expansion at three hours after the start of the experiment should, in general, be between 5 and 10% when tested according to JSCE-F 522. For high-strength grouting mortar, this amount should be between 2 and 5%.

(4) Required compressive strength shall be obtained when tested according to JSCE-G 521.

[Commentary] In order to obtain grouting mortar of the designated quality, construction conditions should be fully identified, appropriate materials should be selected and mix proportions of grouting mortar should be determined so that the mortar may meet conditions (1) through (4) described in Section 9.3.2.

(1) The flow time specified in this section is only a general standard. Mortar with flow time out of the specified range may be injected in some cases. However, The flow time of low flowability mortar will be more significantly influenced by variations in the water content. If the target flow time exceeds 20 seconds, mortar injection may be impended by slight measuring errors, the variation in the fine aggregate surface moisture content, elapsed time, temperature rise during mortar delivery and so on. On the other hand, a mortar with a flow time of less than 16 seconds will have large possibility of segregation. Therefore, the standard flow time may be taken to be between 16 and 20 seconds.

If the flow time of mortar for high strength pre-placed aggregate concrete, which is tested according to JSCE-F 521, is not more than 25 seconds, segregation of mortar tends to occur and if the flow time exceeds 50 seconds, penetration into voids to the bulk of coarse aggregate is decreased. The standardized flow time of grout mortar is, therefore, 25 to 50 seconds. However, a grout mortar with a flow time of approximately 20 seconds may be used when it can be proved that appreciable segregation does not occur.

(2) Bleeding of the mortar is not only caused by the water ascension resulting from the settling of solid particles as generally seen in conventional concrete, but also includes water displacement in

the course of generating hydrogen bubbles. This may interrupt the bond between grout mortar and coarse aggregate or reduce the strength of the upper portion of the concrete and increase laitance, and therefore, it should be minimized. The bleeding limit of 3% specified here has been determined by examining past construction records.

The bleeding ratio of the mortar for grouting for high-strength pre-placed aggregate concrete using a high range water-reducing agent is usually very small, less than 1 % for a water-binder ratio of less than 40 %.

(3) The purpose of making the mortar for grouting expansive is to increase the bond strength between coarse aggregate and mortar and to prevent spaces between those coarse aggregates and the mortar by allowing the mortar to expand while it is settling and shrinkage due to the bleeding. Therefore, the expansion shall be higher than the bleeding. If possible, the expansion more than twice the bleeding is recommendable. However, an excessively high expansion is also undesirable since it results in increased voids in the mortar.The expansion of the mortar actually injected into the voids of the coarse aggregate may differ from that obtained from tests. However, satisfactory results have generally been obtained, as long as the expansion according to the JSCE-F 522is within 5 to 10 %.

The expansion can be adjusted by the aluminum powder content and will fluctuate according to the properties of the cement, type and content of admixture, temperature of mortar, acting pressure, etc. Moreover, the expansion process may be considerably different even though the expansion at three hours after starting the test is same. The targeted expansion should be determined by considering the actual working conditions after examining the time change of the expansion of the sampled mortar.

Considering that the expansion will be much lower in cold weather and considerably higher with more rapid expansion in hot weather, it is necessary to determine the proper expansion by adjusting the aluminum powder content. In deep sea construction, the adjusted value of the expansion under the atmospheric pressure should be estimated by applying Boyle’s law, and an adequate amount of aluminum powder should be added to obtain the optimum value of the expansion of such pressurized mortar. In such cases, however, rapid expansion may occur, so it is important to shorten the time required from the mixing till mortar injection and to provide proper measures to prevent excessive expansion of the mortar before the completion of the injection by minimizing the temperature rise.

A lower expansion ratio of mortar can be accepted for grouting for high-strength pre-placed aggregate concrete due to its small bleeding. In cases where the expansibility of grouting mortar for high strength concrete is 0.5 to 1.0%, the compressive strength of concrete reaches the maximum value. Compressive strength is affected little until the expansibility reaches approximately 5%.To increase the freeze-thaw resistance, the expansion ratio of the mortar for grouting for high-strength pre-placed aggregate concrete shall be not less than 2 %. Therefore, the expansion ratio of the mortar for grouting for high-strength pre-placed aggregate concrete is specified as 2 to 5 %.

(4) The compressive strength of grouting mortar must satisfy the required strength, and shall be tested according to JSCE-G 521 “Test Method for Compressive Strength of Grouting Mortar of Pre-placed Aggregate Concrete”. When mix proportion of pre-placed aggregate concrete is decided, the compressive strength should be obtained according to JSCE-G 522 “Test Method for Compressive Strength of Pre-placed Aggregate Concrete.” As a rule of thumb, however, the compressive strength may be estimated as 70-80 % of that of grouting mortar.

9.3.3 Representation of mix proportion

Mix proportions of pre-placed aggregate concrete shall be given in the format given in Table 9.3.2.

Table 9.3.2 Representation of mix proportion

Coarse aggregate			Mortar used for grouting									
Minimum size (mm)	Maximum size (mm)	Void content (%)	Range to time of flow	Water binder ratio W/(C+F) (%)	Admixture substitution ratio F/(C+F) (%)	Sand binder ratio S/(S+F) (%)	Unit content (kg/m^3)					
							W	C	F (*)	S	Chemical admixture (**)	Aluminum powder (***)

Note (*): F is shown administers
(**): A unit for amount of chemical admixture that should not be diluted and dissolved is ml or g.
(***): A unit for amount of Aluminium powder is g. It is differently displayed with the chemical admixture for pre-placed aggregate concrete

[Commentary] The description of the type of structure, characteristic compressive strength, mix proportioning strength, the type of cement, F.M. of the fine aggregate, type of coarse aggregate, the type of admixture, etc. should be written in addition to the table of the mix proportion.

9.4 Production and Placing

9.4.1 Production and placing of grout mortar

9.4.1.1 Production plant

(1) Production plant of grout mortar shall have the material supply system, a weighing system and mixer which possess specified performance so that mortar having required performances can be obtained.

(2) Mortar mixers shall be capable of producing a mortar of the required performance

[Commentary] (1) The performance of grout mortar and the quality of pre-placed aggregate concrete are greatly influenced by the production plant. Control of each equipment which constitutes production plant needs to be performed appropriately.

The quality of grout mortar varies noticeably according to the materials used, the mortar production facilities and, in particular according to the performance of the mixer and mixing temperature. Therefore, prior to starting construction, the quality of grouting mortar should be verified before construction by mixing on a trial basis under the conditions similar to actual conditions. An example of arrangement of construction facilities in the phase of grouting mortar production through the construction phase is shown in Fig. C9.4.1.

Since the grout mortar for high strength pre-placed aggregate concrete has larger mass of unit volume and higher plastic viscosity than grout mortar for normal pre-placed aggregate concrete, the energy required for mixing is about 1.5 times that for normal pre-placed aggregate concrete. It should, therefore, be mixed using a mixer with high mixing efficiency.

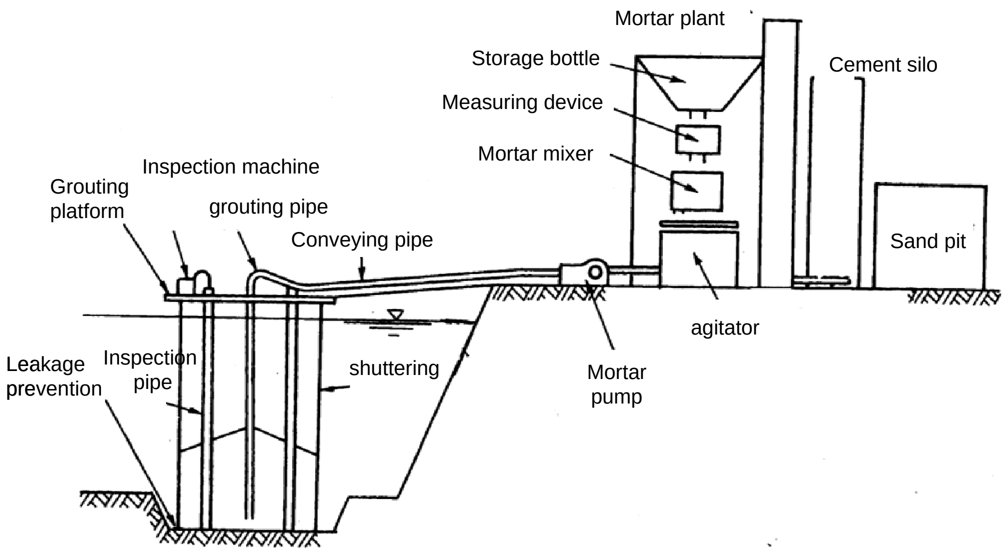


Fig.C9.4.1 Example of arrangement of construction equipments in grouting of mortar

(2) The capacity of a grout mortar mixer per drum is normally 0.2 to 1.5 m^3, and mixers having a single drum, double drums, or triple drums are commonly employed. The order of charging materials into the mixer is water, admixtures, fly ash, cement and fine aggregate. The mixer should be designed to mix the materials uniformly and to disperse the cement and admixtures efficiently.

If the mixer has a low mixing capacity, the working efficiency will be decreased as mixing time is prolonged to obtain the required fluidity of the grout mortar. High-speed mixing provides higher mixing efficiency but due care should be taken with high-speed mixing as it increases temperature of the grout mortar, resulting in an earlier gas generating of the aluminum powder and decreased fluidity of grout mortar.

A mixer having a paddle rotation speed of 125 to 500 r.p.m. is commonly employed and the mixer should be able to produce grout mortar having the required fluidity and quality within 2 to 5 minutes.

9.4.1.2 Mixing

(1) The time of charging materials and the mixing time shall be controlled to carry out within given time.

(2) Agitators shall be capable of stirring the mortar for grouting slowly in a manner that the mortar retains the required properties till the completion of grouting.

[Commentary] (1) The time of charging materials into the mixer and mixing time shall be controlled to minimize the range of variations because these variations are major cause of variation of fluidity of grout mortar.

Since high-speed mixing for a long time will increase the temperature of the grout mortar and decrease the fluidity of the grout mortar, due care shall be taken when grouting in hot weather or when grouting for a long period. Because of this, the grout mortar should be delivered to a grout agitator tank immediately after mixing.

(2) Agitators store the mixed grouting mortar and stir it at low speed to prevent material segregation and the change in fluidity. Agitators enable continuous supply of grouting mortar to pumps.

If the capacity of the grout agitator tank is excessive, the quality of the grout mortar will be adversely affected by prolonged storage, and too small a capacity of the grout agitator tank will make the use of the grout agitator tank meaningless. The suitable grout agitator tank capacity should thus be determined by considering the required hourly rate of mixing quantity and the capacity of the grouting pump to be used. A grout agitator tank having a capacity of three to five times that of the mixer is commonly employed.

9.4.2 Construction and control

9.4.2.1 Shuttering

(1) Shuttering shall be designed to sufficiently resist the lateral pressures of pre-placed aggregate concrete and any other external forces during construction.

(2) Leakage of mortar for grouting through joints in the shuttering and the interface between the foundation and the shuttering shall not be allowed to occur.

[Commentary] (1) Wood forms have been commonly employed in the repairing and strengthening of existing concrete structures using pre-placed aggregate concrete. Steel forms, on the other hand, have been commonly employed in under-seawater construction, construction of important structures and for the formwork subjected to high lateral pressure of pre-placed aggregate concrete during execution of work.

Formwork for pre-placed aggregate concrete greatly differs from those for conventionally placed concrete such that greater care is needed to prevent grout mortar leakage in the forms, the form must be prefabricated on the shore for under-seawater construction, and coarse aggregate is pre-placed into the forms before the mortar is grouted into the voids of the coarse aggregate. Therefore, the forms shall be designed to be strong and rigid enough to prevent harmful deformation and breakage.

In under-seawater construction, it is especially important to seize accurately, in the design stage of the formworks, impact loads during installation of the forms, water pressure caused by variations of tidal level.

1) Influence for the impact during coarse aggregate placement

Estimation of impact loads during coarse aggregate placement and lateral pressure of pre-placed aggregate concrete should be calculated as follows:

Pressure during coarse aggregate placement:

$$p = (1+i)\cdot W_{wa} h_a$$

Where,

p: pressure acting upon forms during coarse aggregate placement (kN/m^2)

i : impact coefficient during coarse aggregate placement 0.6 to 0.7

h_a: depth of coarse aggregate

W_{wa}: unit weight of coarse aggregate (kN/m^3). In general, W_{wa}=10*W_a

where, in air: $W_a = \frac{100-V}{100}\rho_a$

in water: $W_a = \frac{100-V}{100}(\rho_a - 1)$

V: percentage of voids of coarse aggregate, commonly 40 to 48%

ρ_a: density of coarse aggregate (t/m^3)

2) Lateral pressure of pre-placed aggregate concrete

The lateral pressure of pre-placed aggregate concrete depends on the mix proportion of the grout mortar, temperature of the grout mortar, rising rate of the grout mortar surface, height of placement, percentage of voids of the coarse aggregate mass and stiffness of the formwork. In general, the maximum lateral pressure of pre-placed aggregate concrete may be considered as the sum of coarse aggregate pressure and mortar pressure, and should be calculated as follows:

$$P_{\max} = K_a \cdot W_{wa} \cdot h_a + 2 \cdot W_{wm} \cdot R_t \cdot V/100$$

The term "2R_t" is the depth of grout mortar while the influence of setting of grout mortar is negligible.

Where,

P_{max}: maximum lateral pressure of pre-placed aggregate concrete (kN/m^2)

K_a: coefficient of lateral pressure of coarse aggregate, commonly K_a=1

W_{wm}: unit weight of mortar (t/m^3), W_{wm}=10·W_m, which is W_{wm}-10 in water

R: rising rate of mortar surface level (m/h)

T: time of initial setting of mortar (h)

(2) As grout mortar has high fluidity and a long setting time, mortar leakage can readily occur from small openings between the foundation and forms and from joints of the forms. Therefore, the forms for pre-placed aggregate concrete should be sufficiently tight to prevent mortar leakage.

Mortar leakage from the mortar-foundation interface is prevented by caulking the gaps with bagged sand, bagged concrete, or soil cement or by placing cloth sheets in front of the forms or putting special sponges at the bottom of forms prior to forms installation. The surface of the foundation contacting with the forms should be finished as flat as possible, the gap between the bottom edge of the form and foundation should be eliminated by sealing it with highly viscous cement or other means. As for the prevention of mortar leakage from the joints of forms, several methods are commonly used such as tightening forms after putting cloth and/or sponges in the interfaces of the form joints, spreading sealing materials on the inside surface of forms and caulking the joints of forms with gum tape.

9.4.2.2 Charging coarse aggregate

(1) When any damage to embedded items such as injection pipes and sounding wells is anticipated in charging coarse aggregate, they shall be suitably protected.

(2) Coarse aggregate charged within the shuttering shall be kept clean till grouting is carried out.

(3) The coarse aggregate shall be so charged as to obtain a uniform distribution and to prevent the coarse aggregate from breaking.

[Commentary] (1) In cases where the injection height is low, injection pipes are erected after the input of coarse aggregate. However, generally, embedded items such as injection pipes and sounding wells are commonly installed prior to the placing of coarse aggregate. These shall be adequately protected by caps on the top of the pipes and by tightly securing the pipes to the forms so that they do not suffer breakage, bending and movement due to the falling impact of the falling coarse aggregate during placing operation. If the coarse aggregate particle size is small and the grouting depth is shallow, injection pipes may be installed after placing coarse aggregate.

(2) If the coarse aggregate is contaminated with mud or other materials the bonding of the mortar to the aggregate may be impeded and the grout mortar may not penetrate completely into the voids of the coarse aggregate. Therefore, mud and contaminations on the coarse aggregate surface should be eliminated by screening and washing.

The coarse aggregate should be screened and washed again before being placed in the forms considering that it will have collected mud and contaminants during transportation and handling even though it was clean originally. In the under-seawater construction, marine life such as seaweed and shells, and others may grow on the surface of the coarse aggregate after it is placed. Therefore, the mortar should be grouted as soon as possible after placing coarse aggregate. The fine materials which settle or are deposited on the surface of the foundation should be removed by using an air-lift pump or suction pump, and due care shall be taken to prevent the contamination of the coarse aggregate surface by suspended fine materials during placing.

(3) Coarse aggregate is commonly discharged directly into the forms from a grab-bucket mounted on bottom-door-type barges or from a grab bucket mounted on hopper barges when the forms are underwater. When the tops of the forms are above water, the coarse aggregate is commonly placed using a hopper temporarily installed on the forms with a belt conveyor. In this case, if the coarse aggregate is discharged from one fixed place, the uniform grain size distribution of the aggregate throughout the forms will not be expected resulting in non-uniform penetration of the mortar. Therefore, coarse aggregate should be placed so as to give uniform distribution throughout the form by shifting the hopper gate. If aggregate breaks due to excessive impact during the placement, rock fragments will get mixed with the coarse aggregate, with the result that grout mortar will not penetrate completely into the voids of the aggregate. As abovementioned, it is necessary to have a low free falling height from the hopper gate and/or to flood the forms with water to absorb the impact of aggregate during the placement.

9.4.2.3 Grouting equipment and injection pipes

(1) A sufficient amount of equipment of the proper capacity for mortar grouting shall be provided considering the constructing conditions and construction methods.

(2) Injection pipes shall have structures in which the injecting work can carry out reliably and smoothly. The inside diameter of the pipes should be the same or less than that of the delivery pipes.

(3) In general, the horizontal spacing of vertical injection pipes should be approximately 2 meters.

(4) In general, the horizontal and vertical spacing for horizontal injection pipes shall be approximately 2 and 1.5 meters respectively. In principle, horizontal injection pipes shall have valves to prevent backflow.

[Commentary] (1) Mortar grouting shall be planned adequately with regard to the supply of materials, the capacity of the mortar plant, the distance from the mortar plant to the injection points, the capacity of the grout pump, and the number of pumps to be used considering the grouting quantities, the working time, site conditions and others so that mortar grouting can be continuous and smooth. When the grouting operation may need a considerably long time, it is desirable to provide standby pumps for any unforeseen line blockage or other breakdown.

(2) Grout mortar injection should proceed as a smooth process in which the height of the lower end of the injection pipes may be adjusted and the injection pipes may be withdrawn due to any temporary shutdown in the injection operation. The lower end of the injection pipes should be kept approximately 5 cm above the bottom of the aggregate, the end should be cut slant, or there should be a chair made of reinforcing steel bars which is provided under the lower end of the injection pipes so that plugging and excessive free falling underwater can be prevented at the start of injecton.

Steel pipes of 25 to 60 mm inside diameter are normally used as injection pipes. The inside diameter of injection pipes should be the same as delivery pipes. Should injecton pipes of smaller inside diameter than that of delivery pipes be used, the injection pipe should be connected to the delivery pipes through tapered jointing pipes to prevent any segregation of mortar due to the sudden increase of pressure in the pipe.

(3) and (4) Spacing of injection pipes should be determined properly so as to minimize the segregation of the mortar to be injected into the voids of the coarse aggregate, and to obtain the required quality of pre-placed aggregate concrete considering the minimum size of coarse aggregate, grouting rate of mortar and other factors. Large distance between injection pipes will cause segregation of mortar while penetrating into the aggregate mass and many decrease concrete strength.

9.4.2.4 Pumping

(1) Mortar pumps shall have sufficient pumping capacity. They shall be suitable for injecting mortar continuously and preventing air intrusion.

(2) Delivery pipes shall be suitable for delivering grout mortar smoothly.

[Commentary] (1) In determining the type of grout mortar pump to be used, carefully consideration shall be made of the job conditions such as coarse aggregate size, the area to be grouted, and the inside diameter of the injection and delivery pipes. For example, if a high-capacity grout mortar pump is used with a small particle coarse aggregate, the grout mortar flow gradient becomes large and the segregation of grout mortar will be accelerated. A pump having a discharge capacity from 100 to 150 liter per minutes has commonly been employed.

An approximately 5mm sieve screen and a hopper having a suitable size should be provided between the mixer and the pump to prevent the intrusion of foreign materials and air into the grout mortar pump.

(2) A delivery pipe is used to carry the grout mortar discharged from the grout mortar pump to the injection pipes. The delivery pipe shall be selected and arranged with due care because the plugging of delivery pipes will cause delays in the grouting operation, decrease of working efficiency and deterioration of the quality of pre-placed aggregate concrete.

The pumping pressure of the grout mortar pump is mostly due to the resistance in the delivery pipe. The resistance in the delivery pipe varies according to the diameter of the delivery pipe, the grout velocity inside the pipe, fluidity of the mortar, the shape of joints used, and the material of the delivery pipe. Therefore, the following measures shall be taken so that pressure head loss will be minimized:

a) The length of the pipe line between the grout pump and injection points be kept to the practical minimum.

b) A relay grout agitator tank and relay pump, if the delivery pipe length exceeds 100 meters, be provided.

c) Sharp bends and sudden changes in the sectional area of the delivery pipe line be avoided.

d) Watertight joints which can be removed easily be provided to prevent blockage at the pipe joints resulting from the dehydration of the grout mortar caused by the pressure during pumping.

e) The inside diameter of the delivery pipes is normally the same as the outlet inside diameter of the pumps. However, the inside diameter of delivery pipes shall be so determined that the average flow rate of mortar (pumping rate/cross sectional area of delivery pipe) is between 0.5 to 2 m/s. Because the solid particles will settle due to the segregation of the grout mortar where the grout mortar flow rate inside the pipe is too low, and the pressure head loss is too high when the flow rate is too high.

A delivery manifold system may be used when the grout mortar is delivered through plural delivery pipe lines using one pump. However, if such plural delivery pipe lines are operated at the same time, an uniform flow rate of grout mortar will not be expected. Therefore, the grout mortar should be delivered from one pipe to another pipe in series using a manifold system. Due care shall be taken to prevent the plugging of delivery pipes which may be caused by intermittent mortar delivery when the delivery interval to each delivery pipe is prolonged.

9.4.2.5 Grouting

(1) The grouting mortar shall be injected continuously until the mortar surface has reached the elevation designated in the design or construction plan.

(2) Injection of the grouting mortar shall be started from the lowest point and be carried out in heading for the upper area. The rising rate of the mortar surface should be about 0.3 to 2.0 m/hr.

(3) In principle, mortar shall be injected while the vertical injection pipes are salvaged. The tip of pipe shall be kept the condition inserted in the mortar, 0.5 to 2.0 meters below the mortar surface.

(4) To inspect the rising of mortar, a monitoring system shall be provided to measure the mortar surface level.

[Commentary] Prior to grouting, the grouting pipe line should be inspected for foreign materials, the grout pump and pipe line should be washed out by passing water through them, then cement paste should be injected to lubricate the inside surface of the pipe line and to insert the lower end of the injection pipes in the placed cement paste. This prior cement paste injection is especially important for underwater construction. Since without this operation, the lower end of the injection pipes are not in the grout mortar, and the grout mortar fall freely into the water, and may experience the segregation of mortar, and the possible blockage of pipes as well as voids of coarse aggregate, causing serious weakness in the concrete. The quality and quantity of the cement paste should be determined that the subsequent injected grout mortar does not serve a weak point, in consideration with the type and capacity of the pump, scale of the structure and so on.

(1) Construction joint, made due to the interruption of grouting which will cause a serious weakness in the pre-placed aggregate concrete shall be avoided unless indicated in the design or working plan. If the grouting is interrupted through unavoidable circumstances such as the temporary shutdown of the grouting equipment or sudden changes in weather conditions which results in the provision of a construction joint, particular attention shall be paid according to Section 9.4.2.6.

When the grouting operation is interrupted for not more than about 2 to 3 hours and the grout mortar has not yet set retaining sufficient fluidity, the mortar injection may be resumed without special measures. However, if the injection pipes have been withdrawn, the lower end of the injection pipes should be inserted a sufficient depth below the grouted surface and rich cement paste should be injected prior to resuming grout mortar injection. In other cases, it is quite risky to resume injection of grout mortar without taking proper measures.

The quality of the mortar near the grout surface tends to be considerably lower than that of the mortar inside due to adverse effects such as dilution with water and fall of the expansion restraint of mortar and other factors. The deteriorated part of the mortar should be eliminated by re-injecting rich mortar with shorter injection pipes. Alternatively, grout mortar shall be injected 50 cm above the design level then the excess portion be removed after hardening.

(2) Fundamentally, grout injection shall be started at the lowest point, then grout mortar should be gradually injected to the higher points and be prevented from falling freely in the water so that it can fill all the voids of the coarse aggregate completely.

The grout mortar should be injected as slowly as possible. If the grout mortar is injected rapidly, the elimination of water and air bubbles in the coarse aggregate will become difficult, and in underwater construction, the grout mortar will be diluted with water and considerable laitance will develop. Therefore, injection rates which will depend on the fluidity of grout mortar, the grouting area and the grouting depth should be so determined that the rising rate of the grout mortar is approximately 0.3 to 2.0 m/hr.

The grout should be brought up in a horizontal layer by moving the injection points. For the above purpose, a constant discharge rate of grout mortar shall be maintained and grout mortar shall be delivered to the injection pipes in sequence at adequate regular intervals. However, when the grouting area is relatively small, the mortar may be injected into the entire area at the same time with all injection pipes being connected to the pump.

When the grouting depth is relatively shallow and the grouting area is relatively wide, the grout mortar may be injected from a row of injection pipes provided at one end of the forms over the entire width of the forms at the same time by advancing injection points from one end to the other end by changing the valves.

(3) Mortar should be injected by a vertical pipe withdrawing the injection pipes in sequence, but when the grouting depth is relatively shallow, grout mortar may be injected without withdrawing the injection pipe. When the grouting depth is relatively deep and withdrawing the injection pipe is difficult, grout mortar may be injected through closely arranged injection pipes, or double injection pipes with punched pipes adopted as external pipes should be used (Fig. C9.4.2) so that they can be withdrawn readily from the injected mortar.

In either case, the lower end of the injection pipe shall always be inserted below the grout surface to prevent segregation of the mortar during the operation. Due care shall also be taken if the embedded injection pipes are relatively deep, since there may be difficulty in injecting grout mortar due to the setting of grout mortar around the lower end of the injection pipe. The proper inserted depth of the injection pipe, which may depend on the grout mortar injection rate, shall be maintained 0.5 to 2.0 meters below the grout surface.

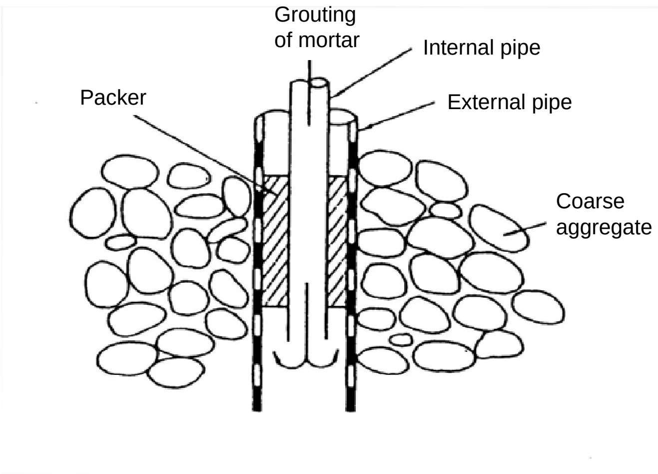


Fig.C9.4.2 Double injection pipes

(4) There are several methods of measuring the flow conditions and the rising surface level of the grout mortar within the aggregate mass. A suitable method shall be employed considering job conditions.

The measurements are commonly conducted by means of a sounding well which consists of 38 to 65mm diameter steel pipes provided with slots at frequent intervals so that the grout surface level is the same inside and outside the pipes. The sounding well is set up in the same manner as the injection pipe. And the measuring will be made using the sounding line equipped with a float and weight or with electronic sensors. Also used is an ultrasonic sensor mounted on the top of the sounding well to automatically measure the location of the grout mortar surface in the sounding well.

The ratio of the number of sounding well to that of injection pipes usually ranges from 1 : 1 to 1 : 2 depending on the importance of the structure. Another method of measuring the grout mortar surface level is conducted using an electrical detector installed in the voids of the aggregate mass prior to mortar grouting. This method can estimate the location of the grout mortar surface by the variations of the electric current and resistance.

When grouting is being made in dry areas, a measuring method using small holes made in the forms a regular intervals beforehand, is normally adopted by which the mortar surface position can be known by the grout mortar seepage through the small holes. These methods enable the location and slope of the grout surface to be known at all times with reasonable accuracy. The lower end of the injection pipe shall be adjusted and the injection point shall be moved accordingly.

The flow gradient of grout mortar surface should be maintained at not more than 1 : 3.

9.4.2.6 Construction joints

(1) In principle, horizontal construction joints shall not be made in underwater construction.

(2) At horizontal construction joints in construction in the air, new concrete shall be carefully placed in an appropriate manner after removing the surface laitance of the previously placed pre-placed aggregate concrete.

[Commentary] (1) In pre-placed aggregate concrete construction, grout should be injected continuously, and horizontal construction joints shall be avoided unless indicated in the working plan because the joint may seriously weaken the surface due to the difficulty in removing laitance in the joint. When the horizontal construction joint is made due to unforeseen circumstances, the surface should be prepared for the succeeding lift by removing loose aggregate and all laitance. The joint shall then be provided with a dowel or groove, or steels shall be inserted to reinforce the joint. The work should then be resumed after the grout mortar hardens.

(2) The laitance of the placed concrete surface should be removed thoroughly by means of an air-jet or water-jet, and in cases that the quality of the concrete or mortar in the surface layer is judged to have deteriorated, those portions shall be removed using a concrete breaker or other equipment. Water containing fine solids suspension formed by the debris of removed laitance and concrete shall be discharged.

In placing the succeeding lift, rich cement paste shall be injected prior to the start of grouting mortar to prevent segregation by the free fall of grout mortar through the water.

9.4.2.7 Construction in cold weather

In the case of construction in cold weather, freezing of aggregates and the mortar for grouting shall be prevented. Appropriate insulation and heat shall be carried out to prevent delay of expansion of the mortar.

[Commentary] When injection work is conducted in cold weather, due care shall be taken to prevent excessively low temperature of the materials. The extremely lowered temperatures of mortar at night will cause a considerable decrease in its expansion ratio and delay the setting time of the grout mortar. The aggregate shall be stored with cover sheets and protected from snow during transportation and handling to prevent it from freezing. The mixing water may be preheated to raise the temperature of grout mortar, however the temperature of water shall be less than approximately 40˚C to prevent the rapid setting of grout mortar.

The early strength of the grout mortar using fly ash, portland blast-furnace slag cement or fly ash cement is usually lower than that made using ordinary portland cement alone, and so the mix proportion shall be determined in advance using trial batch. When necessary, mortar with small water to cement ratio should be used.

9.4.2.8 Construction in hot weather

In the case of construction in hot weather, temperature increase, early expansion and decrease in flowability of the grouting mortar shall be prevented, and appropriate measures for materials and construction methods shall be taken.

[Commentary] When the temperature of the mixed up grout mortar exceeds 25˚C, the fluidity of grout mortar tends to decrease rapidly, the flow gradient may become steeper, expansion may occur too early and the expansion ratio may be excessively high. As a result, the injection pipes and delivery pipes may get readily plugged, the grout mortar may undergo excessive segregation and quality of concrete may deteriorate. Therefore, when grouting in hot weather, the temperature of mixed up grout mortar shall be reduced as much as possible by keeping the cement temperature as low as possible and pre-cooling the water and the fine aggregate. During injection, great care shall be taken to prevent the early expansion and decrease in fluidity of the grout mortar by minimizing the storage time in the grout agitator tank, injecting it soon after mixing, lowering the temperature of the delivery pipe, retarding setting time, improving fluidity, strictly controlling fluidity and flow gradient of the grout mortar and preventing the interruption on injection.

9.5 Inspection

9.5.1 Material acceptance tests

The receiving party shall be responsible for conducting acceptance tests for grouting mortar materials. Acceptance tests should be conducted in accordance with Table 9.5.1.

Table 9.5.1 Inspection of materials for grouting mortar

Type	Item	Testing method/ Inspection method	Period/Frequency	Criteria for judgment
Aluminum powder	Quality	Conformation of test results provided by manufacturer or in accordance with JIS K 5906	-Prior to construction work -Once a month during construction work	Complying with JIS K5906
	Expansion ratio of mortar	Method in JSCE-F 522		Complying with the specifications of Section 9.3.2
Chemical admixture for pre-placed aggregate concrete	Performance of mortar	Method in JSCE-F 522	-Prior to construction work -Once a month during construction work	Complying with the specifications of Section 9.3.2
Coarse aggregate	Minimum size of coarse aggregate	Mehotd in JIS A 1102	-Prior to construction work -When material is changed	Larger than 15mm

[Commentary] The accepting party that conducts acceptance tests for grouting mortar materials is the producer or contractor. The producer or contractor shall conduct acceptance tests and the Owner shall verify the test results.

Specifications for aluminum powder and pre-blended chemical admixture for pre-placed aggregate concrete have not been defined. Therefore, mortar using these materials should be tested to check that the materials can give the required performance to the pre-placed aggregate concrete.

9.5.2 Acceptance test of pre-placed aggregate concrete and mortar for grouting

The receiving party shall be responsible for conducting acceptance tests for concrete and grouting mortar. Acceptance tests should be conducted in accordance with Table 9.5.2.

Table 9.5.2 Acceptance test of concrete and grouting mortar

<table>
<tr><th>Performance</th><th>Item</th><th>Testing method/ Inspection method</th><th>Period/Frequency</th><th>Criteria for judgment</th></tr>
<tr><td>Inspection of concrete</td><td>Compressive strength</td><td>Method in JSCE-G 522</td><td rowspan="6">Once each time 20 to 150 m3 of mortar is applied according to the importance of the structure and the scale of the construction project</td><td>It can be estimated at appropriate producer's risk that the probability of failing to provide the design strength is 5% or less.</td></tr>
<tr><td rowspan="5">Inspection of grouting mortar</td><td>Temperature of grouting mortar</td><td>bar thermometer etc.</td><td>Shall conform to the requirements of construction plan</td></tr>
<tr><td>Compressive strength</td><td>Method in JSCE-G 521</td><td>It can be estimated at appropriate producer's risk that the probability of failing to provide the design strength is 5% or less.</td></tr>
<tr><td>Flowability (flow time)</td><td>Method in JSCE-F 521</td><td>Within the standard value in 9.3.2</td></tr>
<tr><td>Resistance to segregation (bleeding ratio)</td><td rowspan="2">Method in JSCE-F 522</td><td>Satisfying the specified value in 9.3.2</td></tr>
<tr><td>Expansion (expansion ratio)</td><td>Within the standard value in 9.3.2</td></tr>
</table>

[Commentary] The receiving party that conducts acceptance tests for pre-placed aggregate concrete and grouting mortar is the Owner. There are, however, cases where the Contractor that produces pre-placed aggregate concrete conducts acceptance tests for pre-placed aggregate concrete and the Owner verifies the test results.

The quality of grouting mortar greatly affects the quality of pre-placed aggregate concrete. In order to produce pre-placed aggregate concrete of the designated quality, therefore, grouting mortar also needs to be of the designated quality. The temperature, fluidity, resistance to material segregation and expansibility of grouting mortar should be inspected.

Fluidity shall be inspected by conducting fluidity tests focused on flow time, and resistance to material segregation shall be inspected by conducting bleeding tests as a standard practice. In cases where other parameters need to be inspected than fluidity, resistance to material segregation and expansibility, appropriate inspection methods should be selected.

For other types of concrete inspections than those described above, refer to Chapter 16 of "Materials and Construction: Construction Standards" and "Materials and Construction: Inspection Standards".

CHAPTER 10 UNDERWATER CONCRETE

10.1 General

10.1.1 Scope

(1) This chapter presents the standards for matters required during the construction of ordinary underwater concrete, anti-washout underwater concrete and underwater concrete used for cast-in-place piles or diaphragm walls.

(2) In cases when preplaced aggregate concrete is used under water, Chapter 9 shall apply.

[Commentary] (1) Ordinary underwater concrete and anti-washout underwater concrete are constructed over a relatively wide area in the ocean or in other underwater areas. Ordinary underwater concrete is used mostly for unreinforced concrete. Anti-washout underwater concrete with increased resistance to washout is used for unreinforced or reinforced concrete. Underwater concrete is also used for cast-in-place piles or diaphragm walls that involve the construction of reinforced or steel framed reinforced concrete in water or in stabilizing fluid.

The type and construction method vary according to the type of underwater concrete. Ordinary underwater concrete, anti-washout underwater concrete and underwater concrete used for cast-in-place piles or diaphragm walls are discussed in Sections 10.2, 10.3 and 10.4, respectively.

10.1.2 General

Performance varies according to the type of underwater concrete. When constructing underwater concrete, therefore, appropriate materials, mix proportions, methods of placement and construction machinery shall be selected under the guidance of professional engineers with adequate knowledge and experience concerning underwater concrete to minimize material segregation.

[Commentary] There is no proper method to confirm the uniformity of placed concrete, the reliability of a construction joint for normal underwater concrete in a wide area. Considerations are therefore required for such measures as the enhancement of strength requirements to a level higher than during the construction in the air. The quality of underwater concrete is determined by the quality of construction in particular. An appropriate construction method that minimizes material segregation should therefore be selected.

Anti-washout underwater concrete may be of much higher quality than ordinary underwater concrete if appropriate materials, mix proportions and construction methods are selected. Another benefit is a small amount of leaching of suspended solids into surrounding water during construction. Anti-washout underwater concrete has therefore been frequently adopted for constructing high quality underwater concrete structures or in cases where preventing water pollution is required. The properties of fresh concrete are, however, much different in anti-washout underwater concrete from those of ordinary underwater concrete, and more considerations are required in construction. These points should be taken into consideration when constructing anti-washout underwater concrete. For the matters not mentioned in 10.3 concerning anti-washout underwater concrete, refer to the "Design and Construction Guidelines for Anti-washout

Underwater Concrete (draft)".

Underwater concrete used for cast-in-place piles or diaphragm walls is also used for such structures as earth retaining walls and wall members of main structures. Reliable construction requires high-level construction management including the management of construction accuracy, stabilizing fluids and concrete quality.

When using underwater concrete in the ocean, attention should also be paid to durability. The stipulations described in Chapter 11 "Offshore Concrete" should be honored.

In order to use an underwater concrete method that prevents material segregation by blocking the contact of concrete and water through the improvement of construction equipment, the method should be fully examined considering the field conditions and adequate construction management should be performed so as to achieve the designated quality of concrete.

Performance varies greatly according to the type of underwater concrete. Each type of underwater concrete should therefore be constructed under the guidance of professional engineers with adequate knowledge and experience concerning the type.

10.2 Ordinary Underwater Concrete

10.2.1 Mix proportions

(1) Standard slump values at the time of placement are listed in Table 10.2.1.

Table 10.2.1 Slump of underwater concrete

Construction method	Range of slump (cm)
Tremie pipes or concrete pumps	13～18
Bottom discharge buckets or bags	10～15

(2) The standard strength should be determined on the assumption that the strength during underwater construction is 0.6 to 0.8 time the strength of a standard specimen.

(3) The standard water-cement ratio should be set at 50% or lower.

(4) The standard unit cement content should be set at 370 kg/m^3 or higher.

[Commentary] (1) Underwater concrete cannot be compacted and so requires an appropriate amount of fluidity. The standard slump at the time of placement has been specified as shown in Table 10.2.1 according to the construction method. For underwater concrete, highly cohesive mix proportions are required so as to minimize material segregation. To that end, using appropriate admixtures and increasing the percentage of fine aggregate to an appropriate level are required. The standard percentage of fine aggregate should be set at 40 to 45% in cases where gravel is used for coarse aggregate and should be increased 3 to 5% in cases where crushed stone is used.

(2), (3) and (4) Existing survey results show that the compressive strength of underwater concrete placed by tremie may sometimes be reduced to approximately 60% of compressive strength of a standard specimen if the distance of flow from the tremie exceeds 3 m. This suggests that concrete is likely to be subjected to washout in the vicinity during underwater placement and have its strength reduced.

In order to minimize strength reduction and resultant concrete quality deterioration and to ensure the ease of construction, rich mixes are desirable for underwater concrete. The standard maximum water-cement ratio and minimum unit cement content have been set at 50% and 370 kg/m^3, respectively.

When using fly ash meeting the requirements in JIS A 6201 "Fly ash for concrete" or granulated blast-furnace slag meeting the requirements in JIS A 6206 "Granulated blast-furnace slag for concrete", the fly ash or blast-furnace slag may be regarded as part of the unit cement content.

10.2.2 Placement

10.2.2.1 General

(1) Concrete shall be placed in static water.

(2) Concrete shall not be made to fall in water.

(3) Concrete shall be placed continuously until it reaches the designated height or water surface while keeping the surface as horizontal as possible.

(4) Concrete shall not be stirred during the placement.

(5) Flow of water shall be prevented until the concrete hardens.

(6) Surface laitance shall be removed at the end of placement of a lift before starting the placement of another lift.

(7) Concrete should be placed in general using tremie or concrete pumps.

[Commentary] (1) Underwater concrete should be placed while building an appropriate temporary enclosure to control the flow of water to prevent water contamination due to the washout of cement and the formation of laitance. Even if no complete enclosure can be built, concrete should be placed while the flow velocity is 5 cm/sec or lower.

(2) Letting concrete fall in water causes material segregation and washout of cement. Concrete is likely to fall in water in cases where construction tools are handled improperly. The handling procedure should be thoroughly examined and preventive measures should be taken.

(3) Before resuming the placement of concrete after suspension, laitance should be removed as per stipulation (6). Removing laitance is very demanding. The placement of concrete should therefore not be suspended until the designated height or water surface is reached unless suspension is inevitable.

In the case of a continuous lift of several meters, placement in short time may sometimes cause the form to swell due to the lateral pressure acting on the form and the mortar to leak. Due attention should therefore be paid to the strength and assembly of the form.

(4) In order to minimize concrete material segregation at the contact with water, the tip of the tremie or pump should be fixed during placement.

(7) Tremie or concrete pumps are fit for the construction of underwater concrete while preventing cement washout. No bottom discharge buckets or bags should be used except for structures that are not so important because they cannot enable continuous concrete placement and

the quality of concrete placed is not sufficiently reliable.

10.2.2.2 Placement using tremie pipes

(1) Tremie pipes shall be watertight and be sufficiently large to enable the free fall of concrete.

(2) The area where concrete is placed by a single tremie pipe should be determined so as not to deteriorate the quality of concrete.

(3) The tip of the tremie pipe shall be placed in the concrete already placed during concrete placement.

(4) The tremie must not be moved laterally during concrete placement.

(5) The handling of the tremie from the start to the end of concrete placement shall be studied in detail in advance, and measures shall be taken to prevent material segregation in the concrete being placed.

(6) When using a special tremie pipe, its applicability and use shall be examined carefully.

[Commentary] An example of underwater concrete placement by a tremie is shown in Fig. C10.2.1.

(1) In actual concrete placement by a tremie, 25-cm-inner-diameter tremie pipes are frequently adopted where water depth is 3 m or less, or 30- to 50-cm diameter tremie pipes are used where water depth is 5 m or more. The inner diameter of tremie pipe should be approximately eight times the maximum size of coarse aggregate

(2) Letting the concrete that flows out at the bottom end of the tremie flow in the water for a long time deteriorates concrete quality. The area where concrete can be placed by a single tremie pipe is generally limited to approximately 30 m2. In an example, concrete was placed in an area of approximately 60 m^2 for an unreinforced concrete structure of simple shape with large height and area.

(3), (4) and (5) Dropping concrete in the water causes considerable material segregation. The contact of water and concrete should therefore be prevented by using a tremie pipe with a cap at the tip or inserting a plunger at the start of concrete placement. In order to prevent water from entering the tremie pipe during concrete placement, the bottom end of the tremie should be embedded in the concrete already placed.

(6) A special tremie is equipped with a flexible hose in the pipe section to leave no concrete in the pipe using the pressure balance with the water outside the pipe. Another special tremie has a remote-controlled valve and a concrete surface sensor at the tip. These tremies eliminate the need of insertion of their bottom end into the concrete already placed and therefore can place concrete in a wider area than by ordinary tremies. When using a special tremie, its applicability under the construction conditions should be verified and the method of its use should be fully examined

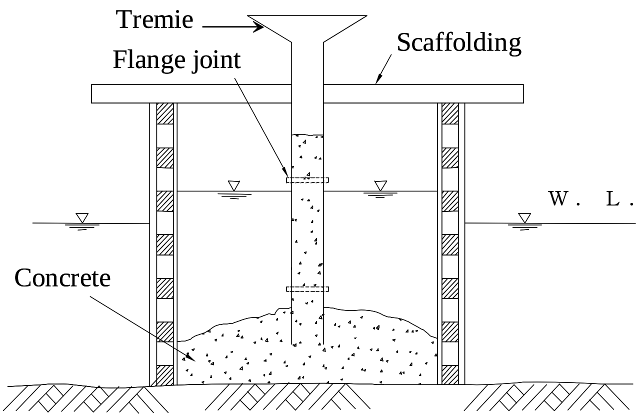


Fig. C10.2.1 Placement of underwater concrete by a tremie

10.2.2.3 Placement by pumping

(1) Concrete pump piping shall be watertight.

(2) Concrete shall be placed by the method described in Section 10.2.2.2.

[Commentary] (1) Underwater concrete is pumped to a lower area, so negative pressures are frequently created. Then, the water in the vicinity penetrates the concrete and concrete quality is deteriorated unless the piping is watertight.

(2) In actual construction, pipes of 10- to 15-cm diameter, three to four times the maximum size of coarse aggregate, are used in numerous cases. The area in which concrete can be placed by a single pipe is approximately 5 m^2.

The contact between water and concrete in the pipe should be prevented by inserting a sponge ball at the start of concrete placement, and the pipe should be filled with water and the tip of the pipe should be embedded into the concrete already place to a depth of 30 to 50 cm during placement, to prevent the deterioration of concrete quality. When moving the pipe, it should be equipped with a check valve at the tip to prevent the reverse flow of water into the pipe or the underwater drop of concrete in the pipe.

In the case where the pumping pressure is high, the tip of the pipe should be provided with adequate mass or fixed so as to prevent concrete from being stirred owing to the shaking of the pipe tip.

A method involves concrete placement by placing the tip of the concrete pump in the tremie (or steel casing) installed at the point of placement. The tremie prevents the tip of the pumping pipe from shaking. If the tip of the tremie is inserted into the concrete already paced, the tremie also prevents material segregation due to concrete fall in the pipe or reverse water flow in the pumping pipe.

A report has been made on a number of quality tests of underwater concrete placed by inserting the tip of the concrete pump into a steel casing. The concrete was placed in an area of approximately 38 m^2 per casing and the flow distance in the water was less than 5 m. The test results show that the core samples collected from the underwater concrete structure had strength with a small amounts of variations and had designated resistance to freezing at a unit cement content of 340 kg/m^3, water-cement ratio of 50% and a percentage of fine aggregate of 43% or higher. In cases where the mix proportions and construction conditions are clearly known and the guarantee of quality has been verified as in the above case, the unit cement content may be reduced to some extent despite the stipulations in Section 10.2.1.

10.2.2.4 Placement using bottom discharge buckets or bags

(1) Bottom discharge buckets and bags shall be designed to open easily when discharging concrete as their bottom reaches the concrete placement surface.

(2) Bottom discharge buckets and bags shall be slowly lowered in the water during concrete placement. After the discharging of concrete, bottom discharge buckets and bags shall be raised gradually until they are fully away from the concrete surface.

[Commentary] Numerous types of membrane are used for bottom discharge bags. Placing underwater concrete using bottom discharge buckets or bags causes the concrete to be piled and results in insufficient filling of the form. When adopting these means, therefore, water depth should be measured and the concrete should be placed at low points on the top surface of concrete.

The use of the underwater concrete placed by the above method should be selected considering the fact that concrete may not be uniform in different buckets or bags.

10.3 Anti-Washout Underwater Concrete

10.3.1 Materials

(1) The anti-washout admixture for underwater concrete shall conform to JSCE-D 104.

(2) High performance water reducers, plasticizers, high performance air-entraining water reducers, water reducers, air-entraining water reducers and other admixtures shall comply with JIS A 6204 and should not have adverse effects when used in combination with anti-washout admixtures.

(3) Aggregate that has been found safe in alkali-silica reaction tests shall be used.

[Commentary] (1) Underwater concrete, at the time of placement, should have designated anti-washout capacity and fluidity sufficient to enable construction without compaction. Hardened concrete should have designated strength, durability and crack resistance. In order to provide anti-washout underwater concrete with these properties, anti-washout admixtures with designated capacity should be used.

There are many types of chemical admixtures available to enhance the resistance to segregation underwater. Then, the quality and performance of these admixtures vary in wide range. Therefore, chemical admixtures for enhancing the resistance to segregation used in the construction shall conform to JSCE-D 104 “Quality Specifications for Anti-washout Admixtures for Underwater Concrete”.

(2) The amount of water content of anti-washout underwater concrete to obtain the required flowability is more than that of normal underwater concrete because of the increasing viscosity effect of the admixture. However, in order to avoid the excessive increasing of water content,

high-range water-reducing agent conformed to JSCE-D 101 “Quality Standards for Superplasticizers for Concrete” or water-reducing agent conformed to JIS A 6204 shall be used at the proper amount. It is known that some combinations with these agents and the chemical admixtures for the resistance to segregation underwater may have a negative influence on the performance each other. Therefore, it is necessary that the combination with admixtures is examined thoroughly and the performance is confirmed before use.

(3) If antiwahsout underwater concrete is used in the sea, alkali metal is supplied by the seawater in addition to alkali contained in concrete. Both fine and coarse aggregates that have been found safe in alkali-silica reaction testing should therefore be used to ensure safety.

10.3.2 Mix proportions

(1) The mix proportions shall be determined by test so that the requirements of strength, resistance to segregation under water, flowability, etc. are satisfied.

(2) The target strength of anti-washout underwater concrete shall be determined considering the design strength and variation of concrete quality.

(3) Strength shall be determined based on the 28-day compressive strength of a specimen prepared in the water in accordance with JSCE-F 504.

(4) The underwater segregation resistance of anti-washout underwater concrete shall be determined based on the degree of underwater segregation or ratio between strengths in the water and in the air.

(5) The fluidity of anti-washout underwater concrete shall be represented by slump flow. Slump flow tests should be conducted in accordance with JIS A 1150.

(6) The air content of anti-washout underwater concrete should not be more than 4% as a standard.

(7) The maximum size of coarse aggregate should not exceed 40mm, and also not exceed 1/5 of the least dimension of a member, nor 1/2 of the minimum spacing of reinforcing bars.

[Commentary] (1) Anti-washout underwater concrete is used for various structural construction from small-scale consolidation of rubble mounds to large-scale bridge pier construction, and comes in a wide variety of types such as unreinforced concrete, reinforced concrete and steel framed reinforced concrete. The mix proportions of anti-washout underwater concrete should therefore be determined by conducting tests fully considering the construction conditions such as the underwater flow distance, degree of water pollution prevention and underwater drop height, and the structural conditions such as the clearance of reinforcing bars so as to achieve designated strength, underwater resistance to segregation, fluidity and durability.

(2) and (3) The 28-day compressive strength of a core sample of anti-washout underwater concrete placed at an underwater drop height of 50 cm or lower and an underwater flow distance of 5 m or less is equal to or higher than the compressive strength of a specimen created underwater at the same age. Concrete strength shall therefore be determined based on the 28-day compressive strength of a specimen created in accordance with JSCE-F 504 "Method of preparing underwater specimens for testing the compressive strength of anti-washout underwater concrete (draft)".

The target strength of anti-washout underwater concrete should be obtained by multiplying the design strength by a premium coefficient obtained in accordance with Section 4.4.3 (2) in "Materials and Construction : Construction Standards" according to the coefficient of variance of concrete compressive strength estimated at the site.

Anti-washout underwater concrete has chloride intrusion resistance and resistance to corrosion due to various types of salt similar to those for ordinary concrete. When applying anti-washout underwater concrete in the ocean, therefore, Section 11.3 should be consulted. Then, the water-cement ratio should be determined based on the results of check of chloride intrusion resistance. When determining the water-cement ratio considering the effect of corrosion on reinforcing bars and chemical action on concrete, the standard maximum ratio should be determined as shown in Table C.10.3.1

Table C.10.3.1 Maximum water-cement ratio of concrete determined from durability (%)

Environment \ Type of concrete	Unreinforced concrete	Reinforced concrete
In fresh water	65	55
In seawater	60	50

(4) As for the degree of underwater segregation, tests should be conducted by Attachment 2 "Method for testing underwater segregation in anti-washout underwater concrete (draft)" to JSCE-D 104 "Quality standards for anti-washout admixtures for concrete", and the suspended solids and potential of hydrogen may be set to be 50 mg/l or lower and 12.0 or lower, respectively. The ratio between strengths in the water and in the air may be set to be 0.8 or higher where relatively high resistance to underwater segregation is required as in reinforced concrete, or 0.7 or higher under normal conditions.

(5) The values of slump flow representing the fluidity of anti-washout underwater concrete are listed in Table C.10.3.2 under various construction conditions. The slump flow is measured five minutes after the slump cone is lifted in the test conducted in accordance with JIS A 1150 "Concrete slump flow test (draft)".

Table C.10.3.2 Slump flow of anti-washout underwater concrete

Construction condition	Range of slump flow (cm)
In cases where fluidity needs to be minimized as in the consolidation of plastering on the surface of a steep slope (1:1.5 to 1:2) or in the construction of thin slabs on a slope (up to 1:8)	35 - 40
In cases where concrete is placed in an area of simple shape	40 - 50
Under normal conditions and in cases where concrete is placed in standard reinforced concrete structures	45 - 55
In cases where concrete is placed in an area of complicated shape and in cases where high fluidity is required	55 - 60

(6) In the case of excessive amounts of air, not only compressive strength is reduced but also

raising of air foam in the concrete during concrete flow causes water pollution and quality variations.

(7) Underwater concrete cannot be compacted in most cases. In order to increase concrete compactibility, therefore, more strict conditions have been specified for anti-washout underwater concrete concerning the minimum spacing of reinforcing bars than for ordinary concrete. In actual construction, the maximum size of coarse aggregate is mostly 20 mm or 25 mm because increasing the size of coarse aggregate is not expected to greatly reduce unit water content or unit cement content and because the segregation of coarse aggregate is more likely to occur as the size increases.

10.3.3 Mixing

(1) For anti-washout underwater concrete, cement, aggregate and anti-washout admixtures should be dry mixed preliminarily and then all the materials shall be mixed. Authorized plants equipped with manufacturing facilities should be used in general.

(2) Forced-action batch mixers should be used in general.

(3) The standard batch should be 80% of nominal mixer capacity or less.

(4) The mixing time should be determined by conducting tests.

[Commentary] (1) For producing homogeneous anti-washout underwater concrete by mixing, cement, aggregate and anti-washout admixtures should be dry mixed in a plant and then water and designated admixtures should be mixed. The standard dry mixing time may be set at 20 to 30 seconds. When mixing anti-washout underwater concrete at a ready mixed concrete plant, the slump flow, compressive strength of a specimen created underwater, ratio between strengths in the air and in the water, and the type and quantity of anti-washout admixtures should be determined in addition to ordinary parameters through consultation with the manufacturer.

(2) Forced-action batch mixers with performance specified in Section 5.2.3 of "Materials and Construction: Construction Standards" should be used in principle because adequate capacity of mixing anti-washout underwater concrete is required. When using tilting mixers, care should be exercised because concrete may sometimes adhere to the inner wall of the drum resulting in inadequate mixing.

In small-scale construction work, anti-washout underwater concrete may sometimes be mixed by agitation in a truck agitator to which anti-washout admixtures are input. Then, the availability of concrete of designated quality owing to adequate mixing should be verified before using the concrete.

(3) Anti-washout underwater concrete places heavier burden on mixers than ordinary concrete. A batch should therefore be 80% of nominal mixer capacity or less so as to obtain concrete of designated quality.

(4) Mixing time should be determined in accordance with the stipulations of JIS A 1119 "Methods of testing the differences in mortar and in fine aggregate in the concrete mixed using a mixer". Mixing time should be determined only after conducting mixing tests to verify whether the concrete is of designated quality or not. The mixing time for forced-action mixers is generally 90 to 180 seconds.

10.3.4 Placement

(1) Concrete should be placed in static water at an underwater height of fall of 50 cm or less as a standard practice.

(2) Concrete shall be placed either using tremies or concrete pumps. Care shall be taken not to deteriorate the quality of anti-washout underwater concrete.

(3) The standard underwater flow distance should be 5 m or shorter.

[Commentary] (1) Placing anti-washout underwater concrete in water flowing at low speed or dropping concrete in water is likely to make reliable concrete. Methods should, however, be avoided that may deteriorate quality for no reason. Static water means the water with a flow velocity of 5 cm/sec or lower.

(2) The tip of the tremie or concrete pump should be kept embedded into the concrete already placed during concrete placement for the same reason as described above. When suspending concrete placement or moving the pipe tip of the tremie or concrete pump, reverse water flow should be prevented.

When pumping anti-washout underwater concrete, the pump pressure is two to three times that for ordinary concrete and the rate of pumping 1/2 to 1/3 of that for ordinary concrete. Care should therefore be taken when developing a construction plan.

Buckets may sometimes be used for placing anti-washout underwater concrete with low slump flow in relatively small-scale construction or on slope ways. Placement using buckets results in discontinuous placement. Care should be taken to prevent water from entering the gap from the previously placed lift.

(3) Anti-washout underwater concrete has higher fluidity than ordinary concrete and causes little quality deterioration due to flow. The area to be covered by a tremie or a fixed pump pipe may be increased over that for ordinary underwater concrete. The underwater flow distance should, however, be held to 5 m or less because letting concrete flow excessively induces quality deterioration and heterogeneity. In cases where the underwater flow distance needs to be longer than 5 m, the achievement of concrete of designated quality should be verified by testing or based on the existing construction records.

10.3.5 Protection of concrete surface

Since anti-washout underwater concrete requires a long setting time, the concrete shall be protected from surface scour by flowing water or waves before concrete hardens after placement.

[Commentary] Anti-washout underwater concrete has adequate resistance to underwater segregation. If subjected to direct effect of flowing water or waves, however, cement may flow out or concrete surface may be scoured. Then, protective measures should be taken by covering the concrete surface with membrane or installing a form to the height required to prevent the flowing water or waves from directly affecting the concrete surface.

10.4 Underwater Concrete Used for Cast-In-Place Piles or Diaphragm Walls

10.4.1 Mix proportions

(1) For underwater concrete used for cast-in-place piles or diaphragm walls, strength shall be determined considering the strength reduction during construction.

(2) The standard maximum size of coarse aggregate should be specified at 1/2 or less of the spacing of reinforcing bars and 25 mm or less.

(3) The standard slump should be 18 to 21 cm. Slump flow shall be set in a range between 50 to 70 cm in cases where the design strength *f'ck* exceeds 50 N/mm^2 because especially high fluidity is required.

(4) The standard water-cement ratio should not exceed 55%.

(5) The standard unit cement content should be 350 kg/m^3 or higher.

[Commentary] (1) For underwater concrete used for cast-in-place piles or diaphragm walls, the strength during underwater construction shall be set at approximately 0.8 time that during air construction and the strength during construction in stabilizing fluid shall be set approximately 0.7 time that during air construction based on the past records.

(2) In underwater concrete, the larger the coarse aggregate, the more likely is material segregation to occur. If the reinforcing bars are arranged at small spacing, concrete is unlikely to flow outside the pre-assembled reinforcing bars, resulting in inadequate filling or segregation is likely to occur in the concrete outside the pre-assembled reinforcing bars due to the fall of concrete. The standard maximum size of coarse aggregate has been set to be 1/2 or less of the spacing of reinforcing bars and 25 mm or less. In cases of large wall thickness and pile diameter, and large spacing of reinforcing bars, the maximum size of coarse aggregate may be set at 40 mm or less on condition that concrete mix proportions and slump are fully examined.

When using lapped joints or bundled bars, concrete is not likely to fill neatly. Attention should therefore be paid not to reduce the spacing of reinforcing bars excessively.

(3) Underwater concrete used for cast-in-place piles or diaphragm walls is generally placed in water using tremies, so the concrete should be highly fluid. In the case of low fluidity, concrete is placed in a mound with the tremie at the midpoint, slimes composed of debris and cuttings are formed at the joints, and concrete is locally deteriorated or voids are created as the slime or stabilizing fluid is entrained. In the case of a small spacing of reinforcing bars, concrete may not fill completely. It should be noted that segregation is likely to occur when the slump exceeds 21 cm and that fluidity is reduced at a slump of 18 cm or less.

Diaphragm walls with a design strength of 50 N/mm^2 or greater have recently been constructed. Then, the spacing of reinforcing bars is reduced as the amount of reinforcement increases. In order to obtain high concrete compactibility, concrete should be provided with high fluidity. Fluidity may be required in numerous cases that should be managed in terms of slump flow not slump. High fluidity is generally achieved by adding high performance air-entraining water reducers. Adding an excessively large amount of high performance air-entraining water reducers, however, may cause material segregation or extraordinarily delay setting. When using concrete with a design strength of 50 N/mm^2 or greater, the range of fluidity that provides adequate quality should be verified in advance in testing and proper construction management should be exercised.

For underwater concrete used for diaphragm walls with a design strength of 50 N/mm^2 or greater, rich concrete mix is used. Low-heat cement is therefore generally used to prevent the occurrence of thermal cracking. Low-heat cement comes in various types. Moderate heat Portland cement, low-heat Portland cement, blast-furnace slag cement type B with a ground granulated blast-furnace slag content of 50% or higher, ordinary Portland cement or multicomponent cement, which is moderate heat Portland cement with one or two types of admixtures, is frequently adopted.

In order to prevent thermal cracking, 91-day design strength is generally adopted and unit cement content is reduced in numerous cases.

(4) and (5) The design strength varies for underwater concrete used for cast-in-place piles or diaphragm walls according to the use. The design strength is generally set at 24 to 30 N/mm^2 in numerous cases. Mix proportions may be specified to achieve the design strength even at a water-cement ratio of approximately 60% and a unit cement content of approximately 300 kg/m^3. The water-cement ratio and unit cement content have been specified as described above because a certain amount of viscosity is required to prevent segregation in water and because strength reduction needs to be considered due to the entraining of slime or mixing of stabilizing fluid.

When using diaphragm walls only as temporary structures, water-cement ratio may be set at 300 kg/m^3 or higher. When using fly ash complying with JIS A 6201 or ground granulated blast-furnace slag complying with JIS A 6202, the fly ash or the ground granulated blast-furnace slag may be regarded as part of the unit cement content.

10.4.2 Pre-assembled reinforcement

(1) Pre-assembled reinforcement shall be sufficiently hard to prevent damaging deformation during storage, transport or erection.

(2) Sufficient concrete cover shall be provided.

(3) Spacers of appropriate shape shall be arranged properly so as to secure covering as per design documents.

(4) Pre-assembled reinforcement shall be erected as early as possible after the completion of excavation. Reinforcement shall be kept in position and vertical to prevent bending, buckling, omission and contact with the wall of the drill-hole during erection.

[Commentary] (1) The deformation of pre-assembled reinforcement (also referred to as the cage of reinforcement) causes the reduction of concrete cover, collapse of the wall of the drill-hole, impossibility of erection of reinforcement and simultaneous rising of pre-assembled reinforcement in the case of pile construction using casing. Pre-assembled reinforcement should therefore be assembled properly to form the designated shape at the designated size, and should be made sufficiently hard so as to prevent damaging deformation during lifting, transport or erection.

Pre-assembled reinforcement may be reinforced by reinforcing the steel wire hanger clamping fixture or reinforcing for protection from twisting or crushing of pre-assembled reinforcement. For reinforcement work, large-diameter erection bars or steel plates with designated dimensions should be used. In rectangular pre-assembled reinforcement as for diaphragm walls, reinforcing bars should be arranged externally in a diagonal grid pattern. Then, reinforcing bars should be arranged so as not to prevent the insertion of the tremie. When stacking previously arranged reinforcement for storage or transport, deformation should be prevented by taking measures such as inserting temporary supports in the pre-assembled reinforcement.

When producing pre-assembled reinforcement, vertical and horizontal reinforcements may be welded rather than bundled to enhance the ease of construction as long as designated conditions are met.

(2) No underwater concrete used for cast-in-place piles or diaphragm walls can be compacted. Concrete may not fill completely in cases where the clearance between the drill-hole wall and reinforcement is small. For underwater concrete, constructed in water or stabilizing fluid, the result of construction can hardly be determined. Considering these points, concrete cover should be set at 10 cm or more. Concrete cover may, however, be set at 8 cm or more for temporary walls or water cutoff walls. Concrete cover here means the distance from the outer edge of hoop to the outer edge of the design cross section of a pile or wall.

(3) Pre-assembled reinforcement should be applied with spacers and designated concrete cover should be secured. Spacers should be of a shape that prevents the removal or scraping of the drill-hole wall when inserted into the pre-assembled reinforcement.

Spacers should be arranged at vertical intervals of 3 to 5 cm and in four to six locations at the same depth, and should be attached to the main reinforcement. The projection height of spacers and the clearance from the drill-hole wall and from the inner surface of casing should be determined considering the accuracy of excavation of drill-hole wall surface and the prevention of simultaneous rising of pre-assembled reinforcement at the time of extraction of casing. Spacers should be shaped so as to prevent the formation of slime.

(4) Pre-assembled reinforcement should be erected as early as possible after the completion of excavation because the drill-hole wall is likely to collapse and slime is likely to settle.

Pre-assembled reinforcement should be lifted and erected so as not to induce deformation detrimental to the pre-assembled reinforcement itself. For piles using no casing, due care should be taken not to cause the shaking or inclination of pre-assembled reinforcement to induce the collapse of drill-hole walls. Pre-assembled reinforcement should be erected moderately at the predetermined position while keeping the reinforcement vertical and preventing lateral shaking. Pre-assembled reinforcement is generally erected by lifting reinforcing bars at the top edge of pre-assembled reinforcement or steel plates using steel hangers in numerous cases.

In cases where no pre-assembled reinforcement can be inserted smoothly during erection, the pre-assembled reinforcement should be lifted, causes should be identified and corrective measures should be taken.

10.4.3 Placement

(1) Slime shall be completely removed before concrete placement.

(2) Concrete shall be placed using tremies.

(3) Concrete shall be placed to a height 50 cm or more above the design surface, and shall be removed after hardening.

(4) Due consideration shall be given when disposing of the used stabilizing fluid.

[Commentary] (1) Placing concrete while slime is deposited at the bottom of the drill-hole has adverse effects such as the deterioration of the end bearing capacity of the pile and the deterioration of concrete quality due to the entrainment of slime. It should therefore be ensured that slime be removed. Slime should be removed twice: at the end of excavation and right before concrete placement. Removal may take place once at an appropriate time for some methods or under certain conditions.

(2) Underwater concrete used for cast-in-place piles or diaphragm walls should be placed using tremies to ensure construction because concrete placement generally takes place in stabilizing fluid, concrete is placed to a great height, construction is carried out over a wide area and high quality concrete is required.

The inner diameter of tremie should be approximately eight times the maximum size of coarse aggregate. In cases of a maximum size of coarse aggregate of 25 mm, therefore, tremies 20 to 25 cm in pipe diameter should be used.

If the tremie is embedded to an extremely small depth during concrete placement, concrete may rise through the tremie and segregation may occur, or the top end of the tremie may be raised above the concrete surface. The tremie should therefore be embedded to a depth of 2 m at the minimum in the concrete during concrete placement. The depth of embedment may, however, be set at 2 m or less in cases where the concrete surface can be verified easily when placement is expected to be completed soon.

Embedding the tremie to an extraordinary depth is likely to cause concrete to flow poorly, induce inadequate filling, make the lifting of the tremie difficult, increase the height of lifting of the tremie, and cause the concrete to fall drastically in the tremie leading to segregation. The depth of embedment should therefore be set at approximately 9 m at the maximum or at 6 m under normal conditions.

When constructing diaphragm walls, concrete flows a longer distance than when constructing cast-in-place piles. An excessively long flow distance from the tremie results in segregation. Tremies should therefore be installed at intervals of less than 3 m longitudinally, and should be placed even at ends or in corners.

Placing concrete extremely slowly causes the deterioration of concrete quality due to the entrainment of stabilizing fluid. Extremely high speed of placement on the other hand deforms connection steel plates at joints or causes concrete inflow into joints in the case of primary elements of diaphragm walls. Concrete is generally placed at a rate of 4 to 9 m/hr for primary elements or 8 to 10 m/hr for secondary elements in most cases.

When placing concrete using multiple tremies, concrete should be placed so that concrete surfaces may rise simultaneously to minimize the difference in concrete height.

(3) Quality is deteriorated on the top surface of concrete due to the mixing of the stabilizing fluid and slime and bleeding-induced laitance during concrete placement. Concrete should therefore be placed more than 50 cm above the design surface. The extra height of placement for diaphragm walls used for temporary walls or cutoff walls may be set to be 50 cm or less if adequate examination is made.

(4) Mishandling of used stabilizing fluid is likely to cause the clogging of drain pipes in the vicinity of the site or pollute surrounding roads. Considerable attention should be paid to the disposal of used stabilizing fluid by preparing disposal facilities such as settling tanks and vacuum vehicles. The drainage and environmental standards concerning the construction work in question should be fully investigated in advance and disposal plans should be developed accordingly.

10.5 Inspections

(1) The accepting party shall conduct acceptance tests for ordinary underwater concrete. The tests and inspections should be in accordance with Table 10.5.1.

Table 10.5.1 Acceptance tests for ordinary underwater concrete

Item	Testing or inspection method	Timing and frequency	Decision criteria
Compressive strength	Method shown in JIS A 1108	At the time of unloading, daily or once in 20 to 150 m^3 according to the importance of the structure or the scale of work.	It can be estimated at appropriate producer's risk that the probability of failing to provide the design strength considering the allowance during underwater construction is 5% or less.
Water-cement ratio	Obtained from automatic measurements of cement, aggregate surface water ratio and water content.	At the start of construction work, and when materials or mix proportions vary.	50% or less
Unit cement content	Automatic measurements	Same as above.	370 kg/m^3 or higher
Slump	Method shown in JIS A 1102	At the time of unloading, daily or once in 20 to 150 m^3 according to the importance of the structure or the scale of work.	Value shown in Table 10.2.1

(2) The accepting party shall conduct acceptance tests for anti-washout underwater concrete. The tests and inspections should be in accordance with Table 10.5.2.

Table 10.5.2 Acceptance tests for anti-washout underwater concrete

Item	Testing or inspection method	Timing and frequency	Decision criteria
Compressive strength of specimen made in the water	Method shown in JSCE-F504	At the time of unloading, daily or once in 20 to 150 m^3 according to the importance of the structure or the scale of work.	It can be estimated at appropriate producer's risk that the probability of failing to provide the design strength is 5% or less.
Maximum size of coarse aggregate	Mix proportions testing	At the start of construction work, and when materials or mix proportions vary.	40 mm or less. Not exceeding 1/5 or the minimum size of the member and 1/2 of the spacing of reinforcing bars
Degree of underwater segregation	Method shown in JSCE-D104	Same as above	Suspended solids should not exceed 50 mg/l. Potential of hydrogen should not exceed 12.0.

Ratio between strengths in the water and in the air	Method shown in JSCE-F504	Same as above	For ordinary concrete, 0.7 or higher. For reinforced concrete, 0.8 or higher.
Slump flow	Method shown in JIS A 1150	At the time of unloading, daily or once in 20 to 150 m^3 according to the importance of the structure or the scale of work	Designated value plus or minus 3 cm

(3) The accepting party shall conduct acceptance tests for underwater concrete used for cast-in-place piles or diaphragm walls. The tests and inspections should be in accordance with Table 10.5.3.

Table 10.5.3 Acceptance tests for underwater concrete used for cast-in-place piles or diaphragm walls

Item	Testing or inspection method	Timing and frequency	Decision criteria
Compressive strength	Method shown in JIS A 1108	At the time of unloading, daily or once in 20 to 150 m^3 according to the importance of the structure or the scale of work.	It can be estimated at appropriate producer's risk that the probability of failing to provide the design strength considering the allowance during underwater construction is 5% or less.
Maximum size of coarse aggregate	Mix proportions testing	At the start of construction work, and when materials or mix proportions vary.	25 mm or less. Not exceeding 1/2 of the spacing of reinforcing bars
Water-cement ratio	Obtained from automatic measurements of cement, aggregate surface water ratio and water content.	Same as above	55% or less
Unit cement content	Automatic measurements	Same as above.	350 kg/m^3 or higher
Slump or slump flow	Method shown in JIS A 1102 or 1150	At the time of unloading, daily or once in 20 to 150 m^3 according to the importance of the structure or the scale of work.	Value in the construction plan. Slump in cases with no specifications: 18 to 21 cm. Specified slump flow plus or minus 5 cm.

[Commentary] The accepting party conducting underwater concrete acceptance tests means the Owner. There may, however, be cases in which the Contractor conducts acceptance tests for underwater concrete and the Owner verifies test results.

The segregation resistance underwater is affected by the variation of materials and mix proportion on producing and by the little difference on producing conditions. Therefore, the inspection of the resistance to segregation underwater for normal underwater concrete and underwater concrete for cast-in place piles or diaphragm walls is specified to be carried out by confirming the mix proportion and the type of used materials. Moreover the inspection of the resistance to segregation underwater for anti-washout underwater concrete is specified to be carried out by tests of level of segregation resistance underwater and ratio of strength underwater to in air and so on.

For inspections of other concrete than described here, refer to Chapter 16 of "Materials and Construction: Construction Standards" and "Materials and Construction: Inspection Standards".

CHAPTER 11 CONCRETE FOR MARINE STRUCTURE

11.1 General

11.1.1 Scope

(1) This chapter presents the standards for matters required during the construction of concrete marine structures.

(2) When constructing underwater concrete structures, Chapters 9 and 10 shall also be consulted.

[Commentary] (1) In this chapter, ports, seashores and sea are collectively referred to as oceans. Not only the concrete used for the structures that are located in tidal areas or below the sea level and are subjected direct to the action of seawater but also the concrete used for the structures that are constructed on land or above the sea level and are subjected to the actions of waves, seawater or splash are regarded as concrete for marine structures. The marine structures discussed in this chapter include small members installed on the seashore, large marine floating structures and large or deep-sea marine structures. Structures using concrete for marine structures in parts of or throughout the structure are referred to as marine concrete structures. Marine concrete structures include breakwaters, moorings, revetments, marine bridges, offshore terminals, docks, submarine tunnels, offshore airports, offshore power plants and offshore cities. For these structures, members are produced as precast concrete members and assembled at the site in numerous cases. Then, concrete is of uniform quality.

This chapter describes the construction of concrete for marine structures and the construction work for marine concrete structures. Marine concrete structures come in wide varieties of types. Establishing stipulations covering all of the types is extremely difficult. When constructing a specific structure, therefore, it is necessary to fully understand the performance requirements for the structure, and apply the stipulations in this chapter considering the service life, functions, effects of failure or damage on the functions, difficulty of repair or retrofit, uncertainties including natural conditions, and construction conditions. The "Corrosion Protection Guidelines for Marine Concrete Structures (draft)" prepared by the Japan Concrete Institute or other documents may be consulted as required.

11.1.2 General

(1) Measures shall be taken to prevent the quality degradation of marine concrete structures during their service life due to concrete deterioration or steel corrosion.

(2) Concrete for marine structures shall be constructed fully considering the construction conditions, environmental conditions and the effects of sailing ships.

(3) When constructing concrete for marine structures, due care shall be exercised for environmental protection to prevent the pollution of the marine environment or the adverse effect on the ecosystem.

[Commentary] (1) Marine concrete structures are more vulnerable to chloride intrusion than ordinary structure on land. Once the corrosion of the steel in concrete due to chloride intrusion becomes outstanding, completely restoring the functions of the structure by repair or retrofit is difficult. In marine concrete structures, therefore, due attention should be paid to the durability of concrete and the corrosion protection of steel in concrete. The corrosion of steel in concrete can generally be prevented by producing compact concrete, increasing the concrete cover, preventing cracks due to thermal stress or drying shrinkage or adopting appropriate materials and construction method. In important structures or structures for which repair is difficult, more active corrosion protection measures may be required using steel corrosion protection methods with good track records such as using epoxy resin coated reinforcement, coating concrete surface and providing cathode protection. For these corrective measures, refer to the "Construction and Design Guidelines for Reinforced Concrete Using Epoxy Resin Coated Reinforcement (revised edition)", "Construction and Design Guidelines for Electrochemical Corrosion Protection Methods (draft)", "Construction and Design Guidelines for Surface Protection Methods (draft)", "Manuals for Respective Methods" and the "Corrosion Protection Guidelines for Marine Concrete Structures (draft)" prepared by the Japan Concrete Institute.

(2) When constructing concrete for marine structures, sea breezes, waves and tidal currents should be taken into consideration. The effects on the passage of ships or on the fishing grounds in the vicinity, and the adverse effects of passing ships at night or in heavy weather should be examined in advance, and adequate corrective measures should be prepared.

Concrete for marine structures is constructed under more severe conditions and greater performance requirements are required than for ordinary concrete on land. Concrete placement at an offshore site should be avoided wherever possible. Precast members produced at land or marine yards under better construction conditions should be used. Precast members should be installed at an offshore site in accordance with Section 11.6.

(3) When constructing cast-in-place concrete for marine structures, measures should be taken to prevent the contamination of sea water. While concrete for marine structures is being constructed or is in service, the environment should be protected and the surrounding environment should be kept free from any adverse effects. For these matters, refer to "Present conditions and problems concerning the leaching of minute components of concrete" or other works.

11.2 Materials

Materials used for marine concrete structures shall not impair the durability of concrete

[Commentary] Concrete for marine structures is subject to gradual damage due to damaging actions such as the physical and chemical actions of sea water, meteorological actions, and impact or friction caused by waves or drifting solids. Chloride ion intrusion into the concrete is highly likely to corrode internal steel. In order to ensure the durability of concrete and the protection of steel under the above conditions, materials resistant to the action of sea water should be used for producing concrete for marine structures, and construction should be carried out carefully. In cases where concrete alone cannot fully meet the above performance requirements under certain marine environments, concrete surface should be coated to provide adequate protection in the marine environment, or epoxy resin coated reinforcement or other types of reinforcement should be used that are unlikely to be corroded.

Cement: Highly resistant to the action of sea water are blastfurnace slag cement and fly ash cement. For the concrete for marine structures, Portland cement with a low content of C3A is highly resistant to sea water, to sulfate in particular. Care should, however, be exercised from a viewpoint of steel corrosion. Sulfate-resistant Portland cement, moderate heat Portland cement and low heat Portland cement have a low content of C3A. Concrete using these types of cement has a low capacity of immobilizing chloride ions. Then, chloride ion intrusion into concrete is likely to be accelerated. These types of cement have a lower capacity of immobilizing chloride ions than ordinary Portland cement. When using these types of cement, therefore, the water-cement ratio should be reduced to produce the concrete of low permeability. Blast furnace slag cement on the other hand has a high capacity of immobilizing chloride ions and is highly resistant to sea water, so it is considerably effective for preventing steel corrosion. Ordinary blast furnace slag cement type B may have a high early age strength at certain levels of slag content and fineness, and the adiabatic temperature of concrete sometimes rises higher than in ordinary Portland cement. Cracking due to thermal stress has been reported at certain member dimensions or under certain restraining or environmental conditions. Some variations of blast furnace slag cement type B are of low-heat type. When using the type of cement, the heating conditions should be verified and a longer design age should be specified.

Moderate- and low-heat Portland cements or fly ash cement produces low heat of hydration and may be adopted to control thermal cracking. The concrete using these types of cement, however, has a low early age strength. When using these types of cement, therefore, special attention should be paid to early age wet curing to develop an appropriate level of strength. Early age wet curing is also important to blast furnace slag cement.

Aggregate: Materials that crumble easily, have joints, have low strength, have high absorption and swell are unfit for aggregate because they are not sufficiently durable. Sea water may sometimes accelerate alkali-aggregate reaction. The reactivity of aggregate should therefore be fully examined.

Admixtures: Admixtures complying with JIS A 6201 "Fly ash for use in concrete", JIS A 6202 "Expansive additive for concrete", JIS A 6206 "Ground granulated blastfurnace slag for concrete" and JIS A 6207 "Silica fume for concrete" should be adopted as a standard practice. Replacing cement with an appropriate amount of ground granulated blast furnace slag or fly ash produces watertight concrete highly resistant to the chemical actions of sea water. These admixtures are said to control chloride ion intrusion into or movement in concrete. The effectiveness of these admixtures, however, varies according to their physical and chemical properties, the ratio of cement replacement and the curing conditions of the concrete using these admixtures. Their effectiveness should be verified by testing before using them, or appropriate methods of their use should be determined based on the past examples of their use. Using silica fume properly is also said to improve the resistance of concrete to sea water or the capacity of concrete for controlling chloride intrusion. When using silica fume, however, the performance of concrete using silica fume should be verified in advance by conducting tests. For the use of expansive additives, refer to Chapter 2 Expansive Concrete.

Chemical admixtures: Using chemical admixtures complying with JIS A 6204 "Chemical admixtures for concrete" such as air-entraining agents, water reducers, air-entraining water reducers, high performance air-entraining water reducers, high performance water reducers and superplasticizers improves concrete workability, resulting in the production of highly durable watertight concrete. These chemical admixtures provide high resistance to heavy meteorological actions, and are fit for use in concrete for marine structures.

Anticorrosives: Anticorrosives that have been applied to concrete surface coating or lining include organic materials such as epoxy, urethane and polyester resins; and materials mainly composed of polymer cement mixed with SBR (styrene-butadiene rubber), acrylic and ethylene-vinyl acetate copolymer. Some materials have not yet proved effective in actual structures over a long time. Quality varies greatly for one and the same material according to the construction condition. When selecting anticorrosives, therefore, tests should be conducted or selection should be made based on the past examples of construction. For selecting or using surface protection methods using surface lining materials, refer to the "Design and Construction Guidelines for Surface Protection Methods (draft)" and "Manuals for Respective Methods". There may be cases where embedded forms using polymer-impregnated concrete, cement concrete with synthetic resin impregnated into the voids, are used as anticorrosives.

Steel: When using epoxy resin coated reinforcement, the "Design and Construction Guidelines for Reinforced Concrete Using Epoxy Resin Coated Reinforcement (revised edition)" should be consulted.

Corrosion of steel greatly deteriorates fatigue strength. In cases where steel is subjected to cyclic loading, special care should be exercised to prevent steel corrosion. In cases where high tension steel like prestressing steel is subjected to stress exceeding 60% of tensile strength, the steel is likely to suffer stress corrosion. Construction should therefore be conducted carefully.

Continuous fiber reinforcing materials have recently been used as non-corrosive reinforcing materials. When using continuous fiber reinforcing materials, Chapter 4 Concrete Using Continuous Fiber Reinforcing Materials should be consulted.

11.3 Mix proportions

(1) For concrete for marine structures, the water-cement ratio shall be determined so as to meet the designated performance requirements.

(2) Unit cement content shall be determined so as to meet the designated performance requirements considering the sectional area, importance and environmental conditions of the structure.

(3) The standard air content of concrete for marine structures should be set as shown in Table 11.3.1.

Table 11.3.1 Standard air contents of concrete for marine structures (%)

Classifications of environmental conditions		Maximum size coarse aggregate (mm)	
		20 or 25	40
Freezing and thawing actions	(a) Offshore air	5.0	4.5
	(b) Splash zone	6.0	5.5

[Commentary] (1) On the offshore, reinforced concrete and prestressed concrete members are likely to be subjected to various actions such as freezing and thawing actions and chemical actions of various types of salt contained in sea water. Material deterioration and steel corrosion are likely to occur with the elapse of time. In order to provide adequate resistance to these severe actions, water-cement ratio, unit cement content and air content should be determined so as to meet the designated performance requirements.

The splash zone in particular is between the mean low water level and the sum of mean high water level and wave height, and is subjected to tidal actions and alternate wetting and drying by the splash of waves. Thus, the zone is under the most severe condition from a viewpoint of durability. Concrete is therefore likely to be subjected to internal steel corrosion, freezing and thawing actions, chemical intrusion and other types of damage. In the offshore air above the splash zone, sea breezes are constantly active and the splash of waves sometimes affects the environment. The condition is second severest following the splash zone. In the sea at depths below the mean high water level, sea water applies chemical and frictional actions but internal steel corrosion is more moderate than in the splash zone or in the offshore air. It should be assumed that the structures subjected to severe actions of sea breezes are under the similar conditions to those in the offshore air. When constructing concrete under unfavorable conditions affected by sea water or tidal actions, the water-cement ratio of the concrete should be reduced below that at ordinary construction sites.

Table C11.3.1 shows standard maximum water-cement ratios of air-entraining concrete that are determined from durability. The water-cement ratio should be set below the values listed in the table. The water-cement ratio should also be lower than the design ratio determined based on the results of check of resistance to chloride ion intrusion considering the concrete cover.

(2) Increasing the unit cement content produces homogeneous compact concrete, and increases resistance to chemical intrusion of various types of salt contained in sea water and to internal steel corrosion. The unit cement content determined from the durability of reinforced concrete for marine structures should be higher than the values listed in Table C11.3.2. Water-cement ratio should be determined as per (1) above. The unit water content should be 175 kg/m3 or lower to ensure durability. The unit cement content determined accordingly should be higher than the values shown in Table C11.3.2. The unit water content is not expected to be lower than the values in view of the upper limits of the water-cement ratio determined to ensure resistance to chloride ion intrusion and of the unit water content. Admixtures complying with JIS A 6201 "Fly ash for use in concrete", JIS A 6206 "Ground granulated blastfurnace slag for concrete" and JIS A 6207 "Silica fume for concrete" may be regarded as part of cement.

With excessive increase of the unit cement content, concrete cracking becomes more likely to occur due to drying shrinkage in small cross section or due to thermal stress ascribable to the heat of hydration in large cross section. In cases where no performance requirements are determined to be met in thermal cracking check, corrective measures should be taken including the replacement of materials through the use of blended cement, low heat cement or admixtures. Early age cracking accelerates chloride ion intrusion into concrete and steel corrosion. Care should therefore be exercised to prevent thermal cracking and autogeneous shrinkage cracking.

(3) Standard air content of concrete for marine structures should be set as shown in Table 11.3.1. Concrete for marine structures is subjected to the actions of chlorides contained in sea water and sees its resistance to freezing and thawing actions deteriorated. In the splash zone, therefore, the air content of fresh concrete should be set as shown in Table 11.3.1 (b) using chemical admixtures. For members that are frequently subjected to the effects of meltwater in the offshore air, air content shown in Table 11.3.1 (b) should be used.

Structures are free from freezing and thawing actions if they are constantly in the sea or temperature rarely falls below zero.

Table C11.3.1 Maximum water-cement ratios determined from durability(%)

		Construction conditions	
		Ordinary construction	Concrete products, or the quality equal to or higher than concrete products
Environmental classifications	Offshore air	45	50
	Splash zone	45	45
	Undersea	50	50

Note: If verified based on research results, the value specified in Table C11.3.1 plus 5 to 10 may be specified as the maximum water-cement ratio.

Table C11.3.2 Minimum cement content of concrete determined to ensure durability (kg/m^3)

		Maximum size coarse aggregate (mm)	
		20 or 25	40
Environmental classifications	Offshore air, Splash zone	330	300
	Undersea	300	280

11.4 Construction

(1) When constructing concrete marine structures, care shall be exercised especially during transport, placement, compaction and curing.

(2) Construction joints shall be avoided wherever possible. In cases where construction joints are inevitable, Chapter 9 of "Materials and Construction: Construction Standards" shall be honored and appropriate measures shall be taken to prevent adverse effects on durability.

(3) Concrete shall be protected from sea water until it reaches an age of five days.

(4) An appropriate gap shall be provided between the steel and formwork to secure designated concrete cover.

[Commentary] (1) Even under severe conditions as in the marine environment, structures for which proper construction management is exercised keep functioning as designated over a long period of time. It has, however, been verified that a slight defect greatly reduces structural durability under severe conditions. Poor construction results in the acceleration of structural deterioration in the poorly constructed sections. Careful process control should therefore be exercised throughout the process from transport to placement, compaction and curing.

(2) In ordinary structures, avoiding constructing joints is important. In marine structures in particular, construction joints should be avoided because deterioration frequently starts at the joints. Construction should be planned so as to make no construction joints in the low water section between a point 60 cm above the high water level and another point 60 cm below the low water

level. In the case of a great tidal range and a lift of a large depth or in the case where the formation of construction joints is inevitable, Chapter 9 of "Materials and Construction: Construction Standards" should be strictly adhered to.

(3) If concrete that hardens only incompletely is inundated in sea water, mortar washout and other damage are likely to occur. Concrete should therefore be protected from direct contact with sea water until it completely hardens and certain levels of strength and watertightness are achieved. Approximately five days are required for ordinary Portland cement to achieve the goal. The period should be increased for blended cement like blast furnace slag cement above the period for ordinary concrete to achieve the designated levels of strength and watertightness.

(4) Repairing marine concrete structures is difficult in numerous cases. An appropriate method should be employed to provide designated concrete cover to prevent internal steel corrosion. Mortar or concrete spacers with performance equivalent to or higher than that of mainframe concrete should be used where the spacers are in contact with the formwork.

11.5 Concrete Surface Protection

In sections subjected to abrasion or impact, concrete surface shall be protected using appropriate materials or concrete cover, or sectional area shall be increased.

[Commentary] In structures subjected to flowing water containing sand particles, waves containing gravel or the impact of ships, the areas to which abrasion, impact or other severe actions are applied should be provided with surface protection using appropriate materials such as rubber fenders, wood, excellent stones, steel and high polymetric materials, concrete cover or sectional area should be increased. Special care should be exercised in the prestressing steel anchorage zones because they may be detrimental to durability.

11.6 Installation of Precast Concrete Members

(1) When constructing precast concrete members, measures shall be taken to safely transport and tow the members to the site of installation so as to prevent durability defects.

(2) When installing precast concrete members, the soil in which the members are installed and the method of installation shall be selected so as to achieve the designated accuracy.

(3) Appropriate methods meeting the designated requirements for load bearing capacity and durability shall be used for connecting precast members to each other or connecting precast members to other members..

[Commentary] (1) When transporting or towing precast members constructed on land or offshore for installation at designated locations, meteorological, oceanographic, marine and other conditions should be investigated in advance and allowance should be provided for construction machinery to ensure safe construction. Considering in advance the emergency escape methods or shelters is very important to the safety of construction. Verifying whether the loads acting on the precast concrete members during the transport or towing is estimated or not in the design phase is important in order to keep the members safe against the loads and prevent them from damage due to the loads.

(2) The soil in which precast members are installed should have designated load bearing

capacity and be sufficiently flat. To that end, the soil is frequently improved by replacement, rubble beds are leveled or underwater concrete is constructed. For installing precast members at the designated locations, a less tight schedule should be developed, fully capable construction machinery and skilled divers should be made available and work should be performed under excellent conditions.

(3) Connecting precast members is more difficult in offshore construction than in construction on land. The connections are likely to become weak points of the structure. The structural format should therefore be selected so as to minimize offshore connecting work, or connection methods should be selected that facilitate offshore construction work and ensure load transmission. Synthetic resins used for adhesion include epoxy resins for hardening by wetting. Synthetic resins of known composition and with verified performance and environmental safety should be used. Waterproofing work should be applied as required. Efforts should also be made to prevent chloride ions or water from permeating the connections.

11.7 Inspections

Concrete for marine structures shall be inspected for cracking responsibly by the Owner. If the inspection results suggest the possibility of durability deterioration, appropriate measures shall be taken.

[Commentary] In concrete for marine structures, outstanding surface cracking and early age defects accelerate the intrusion of chloride ions and the corrosion of steel in concrete. If cracks are detected in inspections that are expected to be detrimental to use and deteriorate durability, appropriate corrective measures should be taken. For other matters, refer to "Materials and Construction: Inspection Standards".

CHAPTER 12 PRESTRESSED CONCRETE

12.1 General

12.1.1 Scope

This chapter describes standards on essential matters particularly needed for construction of prestressed concrete with prestressing steel.

[Commentary] (1) Although various kinds of prestressing methods have already been developed, this chapter only covers the methods where the prestressing force is introduced to the concrete members as a reaction force by a tensile force which is mechanically applied to tendons placed inside or outside of the concrete. Prestressing methods are classified into two categories; the post-tensioning system and the pretensioning system, depending upon whether the tensile force is applied before or after placing the concrete. The post-tensioning system is again divided into two groups; the bonded method where the tendons and the concrete members are bonded together as one element, and unbonded method where they are not. In the pretensioning system, the tendons and the concrete are directly bonded and the prestressing is introduced due to the bond stress between concrete and tendon. The pretensioning system is mainly used for concrete products. The internal cable method where the tendons are placed inside of the concrete has mainly been used up to now, however, recently, the external cable method where the tendons are placed outside of the concrete has often been used as it reduces the cross section area of the concrete members and makes maintenance easy.

This chapter refers to the case where prestressing steel is used as tendons. In case where continuous fiber reinforcements are used for prestressing tendon, execution should follow 'Chapter 4, Continuous fiber reinforced concrete'.

The items that are not covered in this chapter should follow the “Recommendations for Design and Construction of Prestressed Concrete Structures”.

12.1.2 General

(1) During the construction of prestressed concrete structures, work shall be carried out carefully in accordance with the sequence specified in design documents. The effect of accuracy in construction on the safety of the structure during different stages of the work shall also be considered.

(2) Construction of prestressed concrete structures shall be managed at the presence at the site of professional engineers with adequate knowledge and experience concerning prestressed concrete.

[Commentary] (1) In the construction of prestressed concrete structures, stresses occurring in the member vary extremely depending on the construction method or sequence, and sometimes stresses may reach critical levels. Therefore, it is particularly important to perform the work carefully in accordance with the design documents.

When making a plan for prestressed concrete construction work, items peculiar to prestressed concrete should be included in addition to the items for general concrete construction work. Construction work should be planed to be executed smoothly taking account of safety, economy and influence on environment.

1. Prestressing steel shall be placed with proper method in the location as specified in the design documents without any impairment on the quality of the material. Location accuracy shall be determined by taking account of dimensions of the structure to keep the quality of the structure as specified in the design documents.

2. Anchorages and couplers shall be assembled in the accurate shape and dimensions as specified in the design documents, and shall be properly installed in the location and direction specified in the design.

3. Prestressing shall be planed so that the required tension force is applied to each of the constituent prestressing steel of the prestressing tendons.

4. Grouting shall be performed as earlier as possible after prestressing. The plan for grouting shall be determined taking account of selection of materials, mix proportion and injection method so as to satisfy the required performance of grout.

(2) In prestressed concrete work, construction accuracy greatly affects the safety of the structures. Accordingly, it is necessary to understand the extent of its influence when executing the construction work. In turn, when construction errors occur, proper correction can be taken if the engineer has full knowledge of the influence on the safety. Therefore, in the construction of prestressed concrete structures, it is desirable that the engineer with full knowledge; e.g. Prestressed Concrete Engineer authorized by Japan Prestressed Concrete Engineering Association, must station the construction site and supervise the construction works.

12.2 Quality of Concrete

12.2.1 Required compressive strength of concrete at the time of prestressing

(1) The strength shall be set so as to prevent any defects due to tensioning.

(2) The strength should be more than 1.7 times the maximum compressive stress occurring in concrete just after prestressing. In the case of the pretensioning system, the compressive strength of concrete shall not be less than 30N/mm^2.

(3) The strength around the anchorages shall be more than the strength required to resist anchoring forces.

[Commentary] (1) and (2) The required compressive strength of concrete at prestressing of tendons must be on the conservative side with a certain factor of safety against the maximum compressive stress that may occur just after prestressing. This maximum compressive stress will be reduced later by the relaxation of tendons, the creep and drying shrinkage of concrete and the permanent loads, so that the safety factor considered above can be smaller than that against the design loads. However, if the given stresses become too large compared with the compressive strength of the concrete, the creep of concrete exceeds the range in which the creep is in proportion with the applied stress. Therefore, in this standard the required compressive strength must not be less than 1.7 times the maximum compressive stress occurring just after prestressing. However, it is recommended that the safety factor for the required compressive strength must be increased for the members which have relatively large dead load, because the stresses larger than calculated in the design may occur depending upon the support conditions.

When a structure is designed using the creep coefficient shown in Table C5.2.7 and C5.2.8 of the Standard Specifications for Concrete Structures "Design" and constructed without applying any special curing methods such as the elevated-temperature accelerated curing, the time for prestressing the concrete must be determined not only by the condition of the compressive strength but also by the condition on the concrete age that shall be not less than the one corresponding to the creep coefficient used in the design. In addition, when the creep coefficient specified in Clause 5.2.9 (2) of the Standard Specification "Design" is applied, the required conditions for prestressing must be determined to meet the conditions considered in the design.

The reason for specifying the compressive strength not less than 30 N/mm^2 at the transfer of prestresses in the pretensioning system is not only to take into account the safety factor against the actual maximum compressive stress but also to ensure the sufficient bond strength between the tendons and concrete. In addition, when large bending moments or shear forces are expected to act in a short member or near an end of a member, the required compressive strength at transfer of prestresses should be not less than 35 N/mm^2.

(3) Safety of concrete around the anchorages must be examined considering the bearing stresses of concrete in contact with the anchorages and the design bearing strength of concrete prescribed in Clause 5.2.1(4) of the Standard Specification "Design". The anchorage and anchoring method vary depending upon the kind of the prestressing system, so that the required concrete strength around the anchorages at prestressing of tendons should be determined in advance by tests corresponding to the anchorage and anchoring method applied.

12.2.2 Required workability of concrete

(1) Workability should be determined so as to ensure the placement of concrete around the tendons, sheaths, reinforcement and anchorages.

(2) For standard slump, Section 4.4.2 of "Materials and Construction: Construction Standards" should be referred.

[Commentary] Tendons, sheaths, reinforcement and anchorages are frequently arranged in a complex manner in a prestressed concrete member which is thinner than a reinforced concrete member. The concrete near the anchorage is subjected to considerably large local forces. It is therefore important to ensure that appropriate fluidity is provided so that concrete may be adequately placed in the vicinity of anchorages to create dense concrete.

The minimum slump during concrete placement in prestressed concrete members is shown in Table 4.4.6 of "Materials and Construction: Construction Standards". The slump has been calculated from the relationship between the area of reinforcement and the slump obtained based on the results of investigations of approximately 600 prestressed bridge superstructures.

12.3 Required performance of grout

12.3.1 General requirements

Grout shall completely cover the tendons to prevent corrosion and fill all voids in the ducts to properly bond the tendons and concrete.

[Commentary] There are two aims for grout applying for internal cable method; one is to prevent the tendons from corrosion, the other is to bond the tendons and concrete together as one element.

If the grouting is not perfect, it is expected that corrosion of the tendons induce concentrated cracks, and in the worst case, sudden deterioration of the load-carrying capacity would occur. The qualities of the grout greatly affect the durability of the prestressed concrete members. Therefore, the grout shall be filled in the ducts so that the two aims mentioned above are achieved.

Particularly in a severe environment, multi layer protection; e.g. waterproofing of anchorages, waterproofing of the joints, post-waterproofing of the grout hose and using high density polyethylene sheath in an area where measures against salt damages are needed, in addition to filling grout in the ducts, is recommended in order to protect the tendons from corrosion. In the areas where measures are required to prevent chloride intrusion, protection should be provided by multiple measures including the adoption of plastic instead of steel sheaths.

12.3.2 Consistency

(1) Consistency, which includes flowability, segregation resistance and volumetric changes, shall be determined considering the length and shape of ducts, changes in climate and weather conditions, type of prestressing steel and the proportion of the sectional area of the prestressing steel to that of the duct.

(2) In cases where standard structural and construction conditions are selected, the fluidity, resistance to material segregation and rate of volumetric change of the grout for prestressed concrete may be specified in the following range. Resistance to material segregation may be specified based on the bleeding rate. In daily construction management, water-cement ratio that is obtained from the mass of unit volume may be used instead of bleeding rate and rate of volumetric change.

(a) As a standard for fluidity, the flow time obtained in fluidity tests (JSCE-F 531) should be within the range identified in full-scale tests or based on the past records.

(b) The bleeding rate obtained in bleeding tests (vertical pipe method) (JHS 420-2004) should be 0.3% or lower and be 0.0% in 24 hours.

(c) The rate of volumetric change obtained in the tests of volumetric change (vertical pipe method) (JHS 420-2004) should be between -0.5% and 0.5%.

[Commentary] <u>(1)</u> The characteristics of flowability of grout in ducts vary from not only the viscosity and the flow properties but also the area and size of the space through which grout flows, the gradient of the ducts in the flow direction, the shape of ducts, the shape of tendons and the pressure of grout injection. Also, the length of ducts and the thermal change may affect the characteristics of flowability. It is difficult to control consistency of the grout only with the characteristics of the grout.

It is needed to specify the space ratio in ducts and location of the inlets, outlets and vents for grout, considering the length and the shape of ducts adequately, taking into account the influence on the members, as well as to select a mix proportion of grout with flowability, in order to fully ensure the filling performance of the grout in the ducts. Also, it is important to choose suitable materials for the grout to meet the construction and the weather conditions during grout injection.

In cases such as the injection of grout with low viscosity in ducts arranged in a curved shape, grout does not flow through the full section of the duct but along the lower side of the duct towards the down slope of the duct, and the grout is filled up from the bottom portion of the duct as the grout is injected. As a result, some air may be trapped in the duct and remains at the upper portion of the duct as a void. The lower the viscosity of grout become, the bigger would be the space in the duct and the lower the flow rate become, the higher would be the rate of probability of occurrence of the air void. (see Fig. C12.3.1)

In order to achieve 'full section flow' where grout flows through the full section of the duct, viscous plasticity and flow rate shall be determined adequately considering the area of space and inclination of the duct.

When the "full section flow" is not adopted, arrangement of the inlets, vents and outlets and the flow rate shall be determined adequately understanding the occurrence mechanism of the air void. Recently, the grout with super low viscosity has been developed, and an increasing number of construction methods using no full face placement system have been adopted. The grout with low viscosity has advantages in terms of controlling the injection pressure and to shorten the injection time when the length of the duct is relatively long.

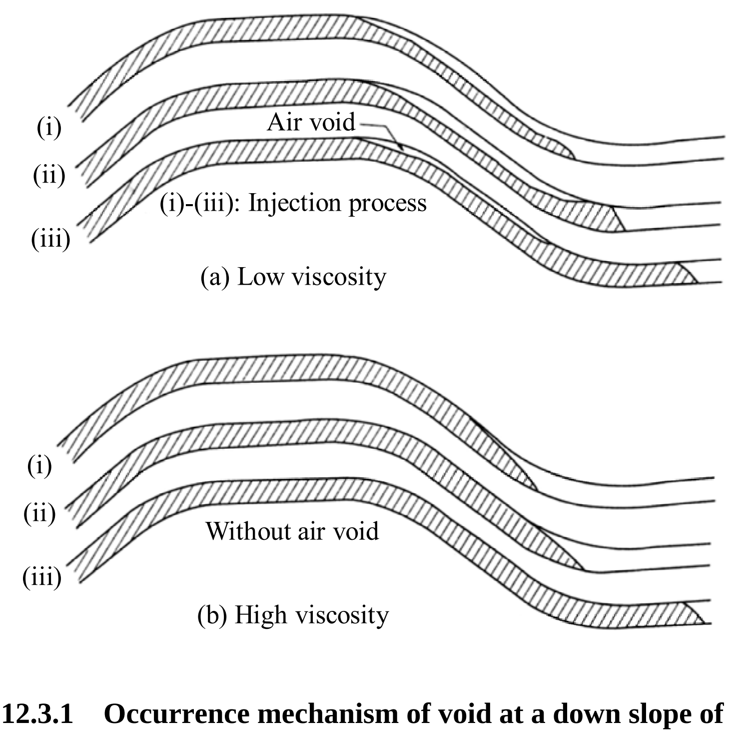


Fig. C12.3.1 Occurrence mechanism of void at a down slope of duct

As described above, whether grout for prestressed concrete is adequately injected into the duct or not is comprehensively determined by numerous factors such as the structural design, quality of the grout and construction method. Excellent pumpability may not always be ensured even if respective parameters are specified separately. Then, full-scale tests should be conducted under the structural and construction conditions similar to those for the actual structure, or examples of similar past construction that produced no damaging residual air should be used for reference to specify the materials and quality of grout for prestressed concrete, construction method, management method and other parameters.

If the cables are of a shape different from that in past full-scale tests, other full-scale tests are required. It should therefore be verified based on the design drawings in the first place whether the shape of the cables is in the range identified in the past full-scale tests. The type of fluidity of grout admixtures selected and the rate of injection determine the position of the air outlet. The type of fluidity of grout admixtures should be selected by fully examining the construction condition in the planning phase. The positions of injection inlet, air outlet and discharge outlet are determined according to the type of fluidity. Unless the positions can be determined, they should be confirmed by conducting full-scale tests. For construction, the grout admixtures should be selected according to the type of fluidity specified, and the mix proportions providing the designated quality should be determined by mixing on a trial basis. A flowchart in the planning through construction phases for grout for prestressed concrete is shown in Fig. C12.3.2.

Production of no residual air damaging in construction is generally verified by confirming that the grout injected and confined in grout hoses at air outlets and discharge outlets has not gone away by hardening, or by using sensors to confirm injection. If the results of verification is determined to be similar to the excellent results obtained in the past tests, the past results may be used.

An example of cable arrangement for which designated pumpability has been confirmed in past full-scale tests is shown in Table C12.3.1. For details, refer to the "Design and Construction Guidelines for Grout for Prestressed Concrete" of the Japan Prestressed Concrete Engineering Association and the "Construction Manual for Grout for Prestressed Concrete and Pregrouted Prestressing Steel (revised edition) 2006" of the Japan Prestressed Concrete Contractors Association.

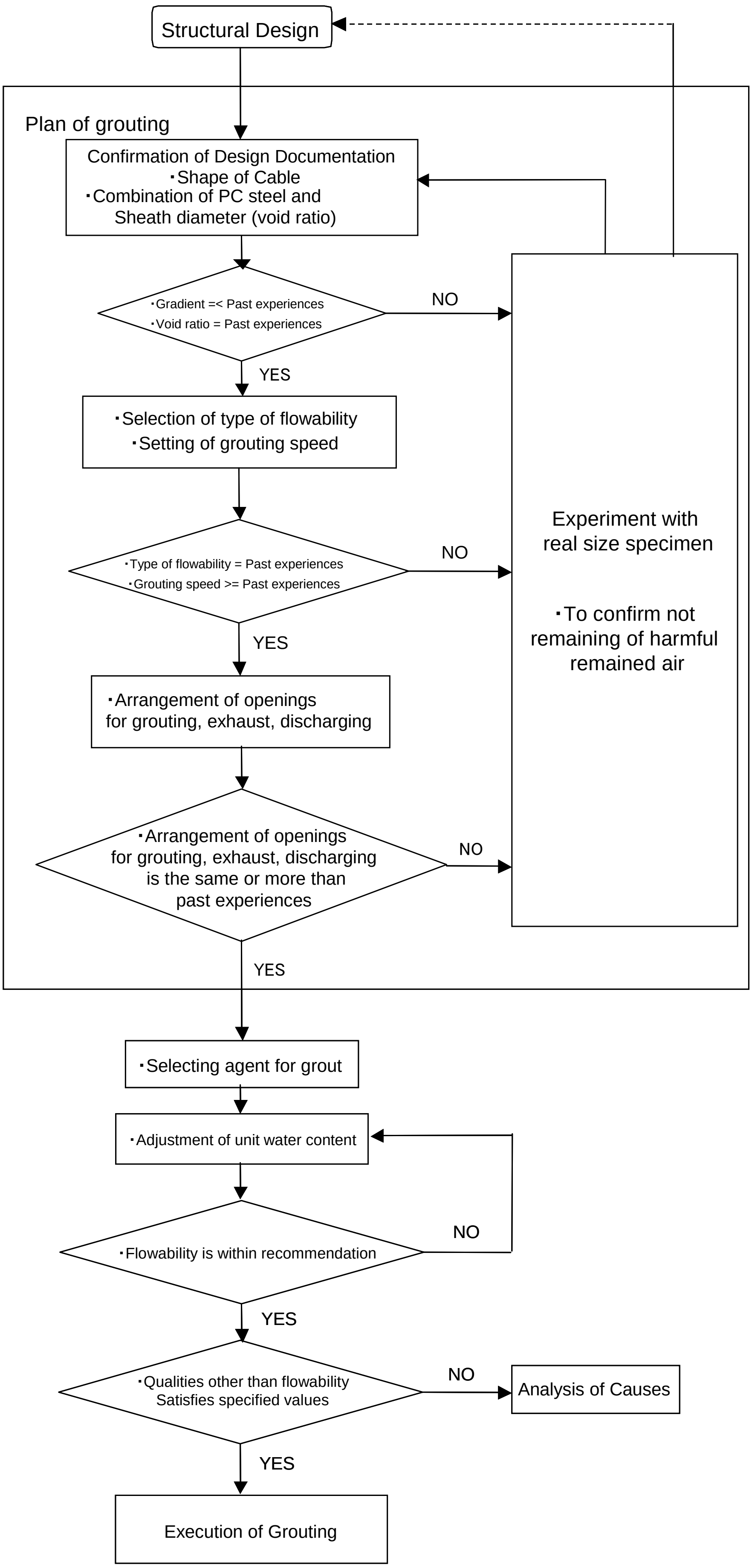


Fig.C12.3.2 Flow of planning and execution of grouting

Table C12.3.1 Examples of cable arrangement for which designated pumpability has been verified based on the results of past full-scale tests

direction of cable	tendon	Inner diameter of sheath (mm)	Void ratio (%)	Maximum descending gradient of cable (°)
Direction of axis of bridge	12S12.7	63.5	63	9
		65	64	15
		70	69	15
	12S15.2	75	62	15
		80	67	5
normal direction to axis of bridge	1S21.8	35	67	0
	1B26	35	45	0
	1B32	39.3	34	12
		41	39	12
Vertical direction	1B32	50	59	-
	1B40	50	36	-

(2) Filling conditions have been examined by the injection test using full scale specimens with specified range of flowability, bleeding ratio and expansion ratio of the grout. The filling performance of the grout can be controlled with the flowability, bleeding rate and expansion ratio of the grout. In cases where it has been verified that the bleeding rate and the rate of volumetric change are in the designated range at designated mix proportions, using the water-cement ratio that is obtained from the mass of unit volume instead of bleeding rate and rate of volumetric change in daily management is recommended. Efficiency is the reason for the recommendation because the process enables immediate check for calculation errors for materials and quality verification before injection.

(a) Fluidity should be controlled so that the flow time of grout for prestressed concrete during construction may be within the range of flow time that is obtained by full-scale tests or based on the past records. The position of the air outlet is determined by the range of flow time. The position should therefore be specified that is fit for the range of flow time.

JP funnel flow time is classified into three major types according to the type of grout admixture: more than 14 seconds for highly viscous type, 6 to 14 seconds for low viscous type and less than 6 seconds for ultra-low viscous type. One of these types should be selected.

(b) For the bleeding rate for grout for prestressed concrete, the rate specified in JSCE-F 532 "Bleeding Rate of Grout for Prestressed Concrete and Expansibility Test Method (polyethylene bag method)" has been adopted. It has, however, recently been confirmed that bleeding and settlement are more outstanding in tests using one- to 1.5-m long vertical pipes at the center of which prestressing strands are installed. This is because the prestressing strands, working like the wick of an oil lamp, cause the bleeding water to be concentrated at the top of the pipe. As a more strict test method than conventional methods, JHS 420-2004 "Method for Testing Bleeding Rate and Rate of Volumetric Change of Grout for Prestressed Concrete (vertical pipe method)" shall be adopted.

(c) The rate of volumetric change is determined on the assumption of use of non-bleeding-type grout admixtures. The standard rate of volumetric change has been set to be in a range between -0.5% and 0.5% in view of the margin of error. JHS 420-2004 shall be adopted also for the rate of volumetric change as a more strict test method.

It has been stipulated that in daily construction management, the water-cement ratio that is obtained from the mass of unit volume may be used instead of the bleeding rate and the rate of volumetric change. Whether the bleeding rate and the rate of volumetric change are in the designated range or not is verified indirectly by confirming whether the water-cement ratio that is calculated from the mass of unit volume of mixed grout for prestressed concrete is in the recommended range of water-cement ratio (range in which the manufacturer has confirmed that the designated bleeding rate and the rate of volumetric change are achieved, and the range recommended by the manufacturer including the margin of error). It is also verified that there are no calculation errors for materials and that materials are mixed at the designate water-cement ratio.

The water-cement ratio that is calculated from the mass of unit volume of mixed grout for prestressed concrete should be the recommended water-cement ratio specified for each grout admixture product plus or minus 1.5% and should be in the serviceable range (marginal range in which the manufacturer has confirmed that the designated bleeding rate and rate of volumetric change can be achieved). This is because a largest margin of error of approximately 15% has been confirmed due to the mixing of air for the water-cement ratio in cases where cement, water and admixtures were accurately measured, and because exceeding the serviceable range is not allowed even where the margin of error is taken into consideration. If the test results are in the designated range, therefore, injecting mixed grout is allowed.

12.3.3 Bond strength between concrete and tendons

(1) The bond strength to ensure monolithic behavior of concrete and tendons shall be determined in an appropriate manner considering the type and shape of ducts, as well as the type of tendons.

(2) In general, the bond strength between concrete and tendons may be determined using the compressive strength at the age of 28 days. Compressive strength should be determined in accordance with JSCE-G 531. The standard value should be taken as 30N/mm^2 or more.

[Commentary] (2) The Standard Specification for Concrete Structures, “Part 2: Materials and Construction” (1996) specified a uniform compressive strength of grout of 20N/mm^2. This provision is a carryover from the "formwork method" provisions in the Guidelines for Grout for Prestressed Concrete, a document attached to the revision of the “Recommendation for Design and Construction of Prestressed Concrete Structures” published by JSCE in 1961. In the “formwork method,” the strength of expansive grout that is formed and weighted down is determined. Considering the fact that the grout strength thus determined is lower than the strength of sheathed grout, relatively low levels of strength were specified. The rationale for that provision was as follows:

1) At the time the provision was adopted, expansive grout containing aluminum powder was the most widely used type of grout.

2) Obviously the strength of grout that is allowed to expand freely is considerably lower than the strength of grout confined in a sheath. It is not easy, however, to reproduce the degree of grout confinement used to prepare test specimens.

3) Strength is also influenced by the degree to which water is allowed to flow out of grout. It is also very difficult, however, to reproduce the degree to which water is allowed to flow out of sheathed grout.

The conditions under which the above provision was adopted 30 years ago have changed dramatically now. Today, non-bleeding type chemical admixtures are used, and non-expansive grout is used in most projects. The new provisions of this specification have been adopted in view of the fact that the required performance of grout is to protect tendons from corrosion and to achieve structural integrity of structural concrete and tendons and act as integral part of the concrete.

Although the relationship of bond strength needed to achieve structural integrity with compressive strength has not yet been elucidated, the compressive strength of concrete for internal cable method should be 30 N/mm^2 or more, by referring to standards in other countries.

12.3.4 Corrosion resistance of steel

(1) The designated performance requirements for structures shall not be deteriorated due to steel corrosion caused by corrosive materials contained in grout for prestressed concrete.

(2) Resistance to steel corrosion shall generally be determined based on the total chloride ion content in grout during mixing. The total ion content shall be less than 0.08% of the mass of cement.

[Commentary] (1) The mechanism of electrochemical corrosion of tendons is the same as the corrosion mechanism of reinforcing bars. Because of the service conditions, the tensile strength of tendons is higher than that of reinforcing bars, and tendons are always subjected to tensile stresses equal to nearly 60% of the normal tensile strength. Breaking of tendons could, therefore, result from a decrease in cross sectional area due to corrosion, strength reduction due to pitting corrosion, or delayed failure such as stress corrosion cracking and hydrogen embrittlement.

In general, stress corrosion cracking of a material results from the simultaneous action of tensile stress and a chemical component such as chlorides, nitrates, carbonates or liquid ammonia. Hydrogen embrittlement is a phenomenon that occurs under stress because of hydrogen dissolved in a solid material during the manufacturing process or due to steel corrosion. These phenomena progress with time and eventually cause a brittle failure.

As a matter of fact, it is difficult to quantitatively describe environments conducive to delayed failure. At least it can be said, however, that in order for prestressing tendons to break in stress corrosion or hydrogen embrittlement tests, it is necessary to conduct tests under considerably stringent, accelerated conditions. Therefore, as long as grouting is performed adequately by using standard procedures, the possibility of delayed failure should be very low. Since delayed failure often causes internal cracks that are difficult to detect and causes extensive failure of tendons, it must be kept in mind that delayed failure not only could impair the required performance of the structure but also is very dangerous.

(2) In some countries, the use of nitrates and thiocyanates as grout ingredients is prohibited. In Japan, under the present conditions the possibility that grout contains chemical components that

could cause delayed failure such as stress corrosion cracking and hydrogen embrittlement is low. For this reason, on condition that Material Safety Data Sheet (MSDS) for grout admixtures should be consulted to verify that no chemical components are contained that cause delayed failure, only the chloride ion content at the time of mixing is specified in order to achieve the required level of corrosion resistance of steel on condition that the steel manufacturers' certificates should be checked in advance.

As the total chloride ion content during mixing, 0.3 kg/m3, the same as in concrete, has been adopted. This is because the chloride ion contained during the mixing of grout for prestressed concrete is mostly supplied from the cement and because there were no operation problems as long as the limit chloride ion content was less than 0.02%. In 2003, however, JIS R 5210 concerning Portland cement was revised and the limit chloride ion content of ordinary Portland cement was increased to 0.035%. In grout for prestressed concrete using a unit cement content of approximately 1300 kg/m3, the total chloride ion content exceeded 0.3 kg/m3 causing some problems.

Steel corrosion in NaCl-NaOH solutions is determined by the ratio between the molar concentration of chloride ion and that of hydroxide ion (OH-) ([CL-]/[OH-]). The limit [CL-]/[OH-] for corrosion in hardened cement has been reported to be higher than that in solutions in numerous researches.

The chloride ion in hardened cement is classified into free chloride ion dissolved in pore water or chloride ion immobilized in hydrate. Only the free chloride ion is involved in steel corrosion. Cement hydrates immobilize chloride ion. Then, the free chloride ion concentration decreases as the unit cement content increases while the chloride ion content per unit volume remains constant.

In western countries, the same percentage of cement mass is used both in concrete and grout for prestressed concrete as the limit of chloride ion content during mixing. In the United States (American Concrete Institute), the limit chloride ion content has been set at 0.06% or lower of cement mass for free chloride ion in pore water, and at 0.08% or lower of cement mass for total chloride ion content. In Europe (EN), the limit is set at 0.10% or lower of cement mass for total chloride ion content.

The Japan Prestressed Concrete Engineering Association conducted tests concerning the limit state for the occurrence of steel corrosion based on the chloride ion content in grout for prestressed concrete for preparing the "Design and Construction Guidelines for Grout for Prestressed Concrete". In the tests, changes in self-potential and polarization resistance with time were measured under wet conditions at eight different levels of chloride ion in the grout for prestressed concrete in the range between 0.02% of cement mass (0.3 kg/m3) and 2.4% of cement mass (31.3 kg/m3), and a bridge girder in service for a long time was dismantled and investigated. As a result, it was reported that the chloride ion in the limit state for the occurrence of steel corrosion in the grout for prestressed concrete accounted for approximately 0.3% of cement mass (3.9 kg/m3) and that similar results were obtained in tests in which steel was subjected to stress. A bridge girder that had been in service for 17 years was removed due to chloride intrusion and dismantled for investigation. As a result, it was confirmed that the rate of mass reduction increased rapidly due to steel corrosion when the chloride ion in the grout for prestressed concrete around the prestressing steel exceeded 0.4% of cement mass (5.2 kg/m3) and that small amounts of corrosion occurred at a cement mass of 0.08% or lower. The "Design and Construction Guidelines", based on the above results and on the specifications in the West, stipulate that the chloride ion contained in the grout for prestressed concrete should be 0.08% or less of cement mass. The limit value of chloride ion has therefore been revised from 0.3 kg/m3 to 0.08% or less of cement mass.

While checking on the possibility of the corrosion of tendons due to intrusion of chloride ions, it is advisable to consider the thickness of cover over ducts because tendons are often in contact with ducts.

12.4 Material

12.4.1 Prestressing steel

(1) Prestressing steel wire and prestressing steel strands that conform to JIS G 3536 should be deemed to be standard.

(2) Prestressing steel bars that conform to JIS G 3109 or JIS G 3137 should be deemed to be standard.

(3) If prestressing steel that is not mentioned in Item (1) or (2) is to be used, tests shall be conducted to verify that the design values are met and determine the method of using the prestressing steel.

(4) When subjecting prestressing steel to re-processing or thermal treatment for anchorage, connection, assembly or arrangement, it shall be verified by testing that the quality of prestressing steel is not deteriorated due to such treatment.

[Commentary] Refer to "Materials and Construction: Construction Standards" 3.6.2.

12.4.2 Anchorages, couplers, and deviators

(1) Structure and strength of anchorages and couplers shall be such that breakage and excessive deformation is avoided before the applied tensile load reaches the value as may be specified for anchoring or coupling prestressing steels.

(2) The performance of anchorages and couplers should be determined in accordance with JSCE-E 503 as standard.

(3) Deviators used for external cable structures shall have sufficient strength to resist active deviation forces of the cable and shall conform to a shape that does not damage the tendons.

[Commentary] (1) Tendon anchorages used in the post-tensioning method can be classified as follows:

(a) Those that anchor prestressing steel wires, prestressing steel strands, or parallel prestressing steel bar groups or prestressing steel bars by using the wedge action in the radial direction or the circumferential direction

(b) Those that anchor prestressing steel wires or prestressing steel bars by cutting threads on their ends and installing nuts

(c) Those that anchor prestressing steel wires or prestressing steel bars by fabricating a head at the wire or bar end

(d) Those that anchor multi-layered prestressing steel strands by securing the strand end into a steel socket with a low-melting point alloy poured into the socket

(e) Those that anchor prestressing steel strands or multi-layered prestressing steel strands by press-fitting a sleeve onto the strand end (by, for example, cold drawing) and using the bearing pressure of the strand-end of the sleeve or cutting threads on the outside of the sleeve and installing a nut

(f) Those that anchor prestressing steel wires or prestressing steel strands by bending them in a wavy pattern or in loops and embedding them directly in concrete so as to use the bond with the concrete or the bearing pressure of the concrete

(g) Those that anchor prestressing tendons by anchoring them, by some means, to an anchor head, tensioning them through pull rods and grouting the space behind the anchor head so that the tendons are anchored by bearing pressure and bond after the grout hardens

Couplers include ordinary couplers that connect together untensioned tendons and anchoring couplers that connect tensioned tendons to untensioned tendons.

Depending on anchorage or coupler location or in cases where prestressing tendons are bonded for use, it may not be necessary for anchorages or couplers to be capable of withstanding the full tensile load capacity of the tendons. However, in order to ensure safety in tensioning work and prevent increases in anchorage settings, this specification requires the structure and strength of anchorages and couplers to be able to withstand the full specified tensile load capacity of the tendons.

Even if anchorages or couplers are capable of withstanding the full tensile load capacity of prestressing tendons under static loads, the fatigue strength of anchorages or couplers is often lower than that of the tendons. If variable stresses due to normal variable loads are large relative to the fatigue limit of anchorages or couplers, they need to be located in a cross section where bending moment is small or in an area close to the neutral axis of a cross section where variable stresses are small.

(2) It is usually very difficult to check by calculation whether or not an anchorage or coupler satisfies the requirement of Clause (1) above. It is therefore a good practice to conduct a test in accordance with JSCE-E 503 “Method of Performance Test of Anchorages and Couplers for Prestressed Concrete Construction”. Such a test, however, does not need to be conducted if the quality of anchorages or couplers is guaranteed by their manufacture on the basis of sufficient test data. It is advisable to refer to the “Recommendations for Design and Construction of Prestressed Concrete Structures” while selecting anchorages or couplers. However, when using a new type of anchorages or couplers or when sufficient test data are not available, it is necessary to conduct tests on a sufficient number of test specimens in order to ensure safety.

The number of anchorage sets needed and the amount of play in couplers vary with the type of anchorage or coupler. These requirements, therefore, must be determined by studying existing test data and, if necessary, conducting tests for verification.

(3) Deviators must be strong enough against deviation forces of tendons and must be capable of mitigating stress concentration due to acting forces and adequately transferring acting forces to structural members. The inside surfaces of deviators must be smooth because projecting parts or steps on the inside surfaces of deviators could damage tendons or tendon sheaths. If a tendon is sharply bent on an edge of a deviator or in contact with only an edge of a deviator, durability of tendons could be adversely affected because of fretting. In cases, therefore, where a bent steel pipe is used as a deviator, it is, therefore, necessary to enlarge both ends of the pipe so that the tendons and sheath do not come into contact with an edge of the deviator.

12.4.3 Sheaths

(1) Sheaths used shall be such that they are not deformed during handling and casting of concrete, and also be capable of preventing any leaking-in of cement paste through laps or joints.

(2) The shape and size of sheaths should be determined considering the procedures to insert the prestressing steel, consistency of grout, the requirement of sufficient bond strength and its friction against prestressing steels.

(3) In cases when high level of durability particularly against chloride induced corrosion is required, plastic sheath should be used.

[Commentary] (1) Sheath is used as materials to form ducts for the prestressing steel. The duct may otherwise be made in a way that rubber pipes or steel pipes are used instead of sheaths and after concreting they are removed at an appropriate time before the concrete is hardened.

Sheath should be selected confirming that it will not easily deform or crush and that it will not let the cement paste leak into it, since otherwise the friction during tensioning will remarkably increase.

(2) The shape and the size of the sheath should fulfill the required function. The diameter of the sheath is determined depending on easiness of inserting the prestressing steel or easiness of filling the grout. As the latter is the most essential for the durability of the prestressed concrete structures, it should be fully taken into account when determining the size of the sheath.

For the structures requiring the bond after tensioning, steel sheath is usually used. Ribbed or corrugated sheaths are relatively stiff against the deformation during handling and effective for the bond between the concrete and the grout.

For the un-bonded construction requiring no bonds, steel or plastic sheath is used.

(3) In cases where durability is required including chloride intrusion control, high cut-off capacity against chloride ion, water and air as well as ordinary requirements for sheaths is highly important to the protection of prestressing steel from corrosion. Plastic sheaths shall therefore be adopted in principle because they have proved to be effective for meeting the requirements.

Plastic sheaths are made of polyethylene or polypropylene. Polyethylene is available at high, intermediate or low density.As a polyethylene sheath to be used for the prestressed concrete structures, hard high-density polyethylene sheath should be used since it meets the requirement of the strength, abrasion resistance and so on. Care must be taken, however, to avoid deformation of the connections or the fittings due to steam curing or so, as the polyethylene sheath may easily deform under high temperature.

12.4.4 Grout for prestressed concrete

(1) In general, the cement used for grouting should comply with JIS R 5210.

(2) Water used for grouting shall not contain harmful amounts of substances, which may adversely affect the grout or the prestressing tendons.

(3) Use of admixtures in grouts as well as the quality and method of application of these admixtures shall be appropriately examined beforehand.

(4) Admixtures used in grouts should be of a non-bleeding type to avoid bleeding.

[Commentary] (3)and(4) Grout used for prestressed concrete is required to maintain the required levels of flowability and filling ability during grouting and to develop sufficient bond strength between the tendons and sheath after hardening so as to achieve watertightness and protect the tendons.

Common practice today is to use high-range water reducing agent as dispersing agents to achieve an adequate level of flowability and viscosity-modifying agents for bleeding control. Admixtures capable of performing these functions are called non-bleeding type admixtures and are available as either high-viscosity types or low-viscosity types for the use in grouting methods and under different grouting conditions. This specification thus requires the use of non-bleeding type chemical admixtures because they make it possible to achieve the desired level of flowability and their bleeding control effect is relatively unaffected by other conditions.

Since it takes some time to completely dissolve viscosity-modifying agents in water, it is important to use them after mixing them with water thoroughly and uniformly.

12.4.5 Auxiliary materials for injecting grout for prestressed concrete

(1) Grout caps shall be able to prevent any air from being left inside, be resistant to injection pressure and provide air tightness at joints with the anchorage fixture.

(2) Grout hoses shall be semi-transparent and form the injection inlet, air outlet and discharge outlet. The hose cross section should be held at the time of assembly or concrete placement. Grout hoses shall have adequate strength against injection pressure.

[Commentary] (1) Grout caps should have an appropriate injection inlet or discharge outlet and air outlet so as to leave no air inside. The grout cap on the injection side is subjected to extremely high grout injection pressure. Grout caps therefore should have adequate strength to prevent deformation or breakup and should be able to structurally prevent grout for prestressed concrete from leaking through the joint with the anchorage fixture. Grout caps should be of a structure that enables the verification of grout filling. In cases where durability is required in particular as for controlling chloride intrusion, plastic grout caps should be adopted.

(2) Grout hoses should be semi-transparent so that the filling of grout may be verified. The diameter should be at an appropriate level to prevent injection pressure from rising extremely. Grout hoses should have adequate strength to prevent bending and provide resistance to the impact of concrete placement or injection pressure. At the end of injection, the end of the grout hose needs to be closed to prevent grout leakage or air inflow. Hoses therefore should be made of materials that can ensure

air tightness. Tetron blade hoses of an inner diameter of 19 mm or larger should be used for multiple strands. Tetron blade hoses of an inner diameter of 15 mm or longer should be used for single strands or prestressing bars.

12.4.6 Protecting duct

Protecting ducts for external cable structures shall be selected considering their ability to protect tendons, and function as a duct for grouting anti-corrosive materials, specified strength/durability, and their erosion resistance performance.

[Commentary] Since protection tubes are placed outside the concrete and in many cases the environmental conditions to them are more severe than those for the sheath inside the concrete, materials for the protection tubes should be so selected as to secure the easiness of maintenance and the durability against corrosion. Furthermore they should have enough strength against the injection pressure of the filling material or the contact pressure at the bent.

12.4.7 Coating material for unbonded tendons

Coating material for unbonded tendons shall not cause corrosion of the tendons or deterioration of concrete, and shall not cause bond stresses between the tendons and the concrete while prestressing.

[Commentary] The reason for the use of coating materials for the un-bonded tendons is that it is required to coat and protect the prestressing steel in the prestessed concrete preventing from rusting but not necessarily required to develop the bond between the prestressing steel and the surrounding concrete. In the following cases it is required to break the bond between the prestressing steel and the surrounding concrete partly or entirely.

(a) where in the pre-tensioned prestressed concrete members excessive tensioning is to be decreased in the particular area,

(b) where in the post-tensioned prestressed concrete members un-bonded system is adopted to minimize the construction eliminating sheathing or grouting,

(c) where in the post-tensioned prestressed concrete members stress concentration in the prestressing steel induced around the cracks during earthquake,

For such un-bonding, asphalt emulsion, cut-back asphalt, grease, wax, epoxy or other plastics are reported to have been used. It is required for them not to crack, become brittle, liquefy, but to be chemically stable, water-tight, and not to cause chemical change harmful to the concrete or the prestressing steel. Since contamination of other places with or mixing in the concrete of the coating materials of the prestressing steel not only cause harmful effects on the surrounding but also damage the coating materials themselves, it is required to take measures such as protecting the surface with tapes or others, or hardening the surface of the coating materials themselves.

12.4.8 Material for jointing precast concrete members

Concrete, mortar and adhesives used for jointing precast concrete members shall have the required strength and watertightness, and shall comply with the on-site work conditions of jointing.

[Commentary] For the prestressed concrete structures to be unified by jointing precast members and tensioning them, concrete, mortar or adhesives are usually used as jointing materials.

Kinds or qualities of materials used for jointing are determined depending in many cases on the kinds of the structures or the details of the joint and sometimes on the working conditions. It should be paid attention that the jointing materials with inadequate kinds or quality may lower the strength of the joint or the water-tightness and shorten the life of the entire structure.

As a rule, epoxy resin adhesives to be used for jointing precast members should meet the requirement of JSCE-H 101 "Specification for Epoxy Resin Adhesive in Precast Concrete (for Bridge Girders)". Epoxy resin adhesives have usually been mixing types of two liquids, a main and a hardening liquid but recently one liquid, moisture-hardening types which harden with moisture contained in the atmosphere or in the concrete. Despite a difference of applicable period and hardening period between two types, performances of hardened epoxy resin are nearly the same, quality standard for one liquid, moisture-hardening type epoxy resin can be based on JSCE-H 101 " Specification for Epoxy Resin Adhesive in Precast Concrete (for Bridge Girders)".

12.4.9 Storage of materials

(1) Prestressing steel shall not be placed on the ground but shall be stored in warehouses by supporting it at appropriate intervals, or shall be properly covered when placed outdoors. The objective is to prevent the attachment of toxic oil, salt and dust and damaging corrosion, flaws and deformation.

(2) Anchorages and couplers shall be stored in a warehouse and protected from corrosion. No oil or dust shall be allowed to adhere to the surface that comes in contact with concrete.

(3) Deviating devices, sheaths and protecting tubes shall be stored in a warehouse, or when stored out-doors, shall be properly covered to protect them against corrosion, harmful scarring and deformation, and against adhesion of harmful oil, salt or dust.

(4) Adhesives shall be stored in a manner that any segregation of materials, deterioration in quality is prevented and no impurities get mixed. Materials stored over a prolonged period shall be tested before use to check the quality.

[Commentary] (1) See "Materials and Construction: Construction Standards" 3.7.5(2).

(2) As the anchorages and the couplers are essential materials in the prestressed concrete, it has been specified that they should be stored in a warehouse.

Rusting screws may bring about the declined strength of the screws, the difficulty of assembling anchorages and couplers and the difficulty of tensioning. Therefore, the screws must be prevented from rusting by coating oils or so. The parts of contact of anchorages and couplers with the concrete must be prevented from contamination with oil, dust or dirt to secure the bond strength.

In cases where combined action of sleeve and wedge is required as for wedge-type anchorage fixtures, special care should be exercised to prevent the combined action from being deteriorated due to corrosion or damage during storage.

(3) When deviators, sheaths and protection tubes are contaminated with dust, damaged or deformed, tensioning will be hindered and in the bonded construction oil, dust or dirt will harm the bond. Therefore, storage must be done so as to prevent these harmful effects preferably stored in a warehouse. Even in short period of storage outside they should at least be covered to prevent harmful effects.

(4) As adhesives may deteriorate in quality when exposed to temperature higher than 30℃ such as that in summer season, they should be stored inside a cool and dark place in a lidded can which has to be opened just before the use of the adhesives.

Furthermore, as passing longer period than six months after production may cause segregation of the materials or mixing rust of the can, storage period should not be too long.

12.5 Proportioning of grout mix

(1) In the design of mix proportions of grout for prestressed concrete, grout admixtures shall be selected considering the construction condition so that the designated quality may be achieved.

(2) Mix proportions of grout for prestressed concrete shall be planned considering the environmental and meteorological conditions for the selected grout admixtures so that the designated quality and specified fluidity may be achieved, and the performance shall be verified by trial mixing.

(3) The water to cement ratio of the grout should not be more than 45%.

(4) Mix proportions of grout for prestressed concrete shall be adjusted during construction as required.

[Commentary] (1) In the design of mix proportions of grout for prestressed concrete, grout admixtures should first be selected so as to meet the requirements in Section 12.3.

(2) Grout for prestressed concrete on the market has its unique properties, which should be taken into consideration when determining appropriate mix proportions. The properties of grout for prestressed concrete are affected by the environmental and meteorological conditions at the time of construction. The temperature of mixed concrete in particular affects the fluidity and the duration of service of grout for prestressed concrete. The temperature of mixed concrete should be predicted during construction and mix proportions should be determined so that the design fluidity can be achieved. The designated quality and fluidity should be verified for the planned mix proportions by trial mixing.

(3) The standard water-cement ratio should be set to be 45% or less, and should be minimized as long as the designated fluidity can be obtained. Care must be taken, however, not to make it lower than necessary in cases, for example, where the duct is long, the void ratio of the duct is small, grout temperature could become high or the grout is apt to lose water. Use of water reducing retarders is very effective in lowering the water to cement ratio without compromising the

flowability of grout.

(4) Mix proportions for grout for prestressed concrete are determined based on the environmental and construction conditions during construction. In actual construction, however, conditions may be sometimes different from those assumed. Mix proportions should be adjusted properly in cases where the designated fluidity or performance cannot be achieved before grout injection or in cases where no designated performance is expected to be achieved after grout injection.

12.6 Execution

12.6.1 Installation of tendons

12.6.1.1 Cutting, bending and placing of prestressing steel

(1) Prestressing steel shall be fabricated and placed in the accurate shape and dimensions as specified in the design documents without impairing the quality of the material. Prestressing steel, which has been excessively bent, affected by extreme heating and/or exposed to high temperatures, shall not be used.

(2) All loose rust, oil and other harmful substances, which may impair the bond of the prestressing steel used for the pretensioning or the bonded post-tensioning system, shall be removed before use.

[Commentary] (1) Prestressing steel should be fabricated in a way to keep the accurate shape and dimensions and not to damage the quality of the material. For this purpose the bending of the prestressing steel should always be carried out mechanically in the cold working to achieve the smooth curve. Fixing to the anchorages or fabricating for the anchoring should be carried out in accordance with the specified methods, referring to the "Recommendation for Design and Construction of Prestressed Concrete Structures, JSCE" and so on. Excessively bent prestressing steel should not be used since its straightening back will damage its material quality. Prestressing steel exposed to spark due to arc-welding or rapidly cooled after heated with high temperature should never be used, since its material quality has been changed to brittle. When arc-welding nearby the prestressing steel is inevitable, it should not be allowed to let the arc-electrode contact the prestressing steel and an earth wire should never be taken from either the prestressing steel or the arranged reinforcing bars.

Mechanical method is recommended in case of cutting the end of the prestressing steel after tensioning, but when inevitably cutting by heat such as fusing, it should be carried out confirming that its effect will not reach the anchorage. Screws of the prestressing bar in the coupler should not be cut by heat, since their quality may be damaged by heat.

(2) When fixing the prestressing steel to the anchorage, the surface of the prestressing steel near the anchorage should be cleaned with particular care since oil or surfaced rust may often cause slipping of the tensioning steel.

12.6.1.2 Installation of sheaths, protecting tubes and tendons

(1) Sheaths shall be appropriately installed in position and orientation without being damaged. Sheaths shall be rigidly supported using spacers or steel frames so as to prevent any disturbance or deformation during concrete casting. The joints of sheaths shall be securely sealed to prevent the penetration of cement paste when casting of concrete.

(2) Tendons shall be installed in sheaths without any entanglement.

(3) Unbonded tendons shall be carefully installed without inflicting any damage to the coating.

(4) Inspection shall be carried out after installation of sheaths and tendons, and corrective actions shall be taken in case any damage, etc. is found.

(5) Tolerances for installation of tendons in the formwork shall be determined so that the concrete members are not adversely affected considering factors such as the size of the members, etc.

[Commentary] (1) Prescribed tensioning of the prestressing steel can still fail to give the prescribed prestress if the position of the prestressing steel is inaccurate. Therefore the prestressing steel should be accurately positioned. During concrete placement, since incomplete sheath joints, joints with the anchorages and prestressing steel joints will occur the same defects as described in the commentary of Clause 13.6.2 (1), leaking of the cement paste into the sheath should be prevented by lengthening the lap length, taping around the joints or so. The prestressing steel and the sheaths should be firmly fixed using appropriate supports at shorter intervals so as not to shift the position because of the weight of the concrete or the strong vibration of the vibrator during concrete placement. The interval of such supports should be determined according to the kinds of the prestressing steel and the sheath.

(2) When accommodating several prestressing wires or strands in a sheath, care must be taken not to tangle the prestressing wires or strands using anti-tangling devices or so, since tangling of them will not only increase the friction during tensioning but also can cause uneven stresses in them.

(3) Prestressing steel used for the un-bonded construction is usually coated. Since exfoliation of the coating not only cause the difficulty of the tensioning but also eliminate the effect of corrosion protection, care should be taken when installing the un-bonded prestressing tendons and in case of exfoliation it should be repaired.

(4) Shift of the position of the prestressing steel or damage of the sheath caused during arranging the prestressing steel should be repaired either during arranging or after arranging, with careful inspection to find any shift or damage, before concrete placement.

(5) Tolerance of the position varies depending on the size of the members or on the way of arrangement of the prestressing steel. For the prestressing steel, the sheath and the protection tube tolerance should be not more than 5mm in case of not more than 1m of the distance between the center of the prestressing tendon and the extreme fiber of the member, and not more than 1/200 of the size of the member or 10mm whichever is the less in case of not less than 1m.

12.6.1.3 Formation of ducts

The material and the method for forming the ducts shall not adversely affect the prestressing tendons and concrete in cases when sheaths are not used.

[Commentary] Although the duct is prepared in order to insulate prestressing tendon with concrete, while securing the space for arranging prestressing tendon, the material used for the formation shall be investigated the character and confirmed that prestressing tendon does not corrode or concrete does not deteriorate. Moreover, the method to form duct shall not be such to make concrete produce a crack, or not to increase friction remarkably during prestressing. In case of producing bond later, as concrete and prestressing tendon shall act uniformly, its bond between concrete and grout shall be large and sufficient. In case of forming the duct without using sheath, generally the following methods are applied.

(i) The method to form duct by covering prestressing tendon with insulating material such as asphalt, a polymer material and oil, and embedding into concrete: In this case, the insulating material which can achieve insulation between concrete and prestressing tendon completely and does not produce big friction shall be chosen. Moreover, covering shall be done with the manner such that material does not exfoliate at the time during handling and placing of concrete. This method is used for the case not to produce bond between duct and concrete.

(ii) The method to form a duct by embedding mold etc. into concrete (a steel pipe, steel bar, plastic pipe, wood stick, rubber hose, etc.), and pulling out this before hardening of concrete: In this case, the mold etc. shall not deform easily at the time of placing concrete. Moreover, in case of producing bond later, the material used for it shall be such that it does not leave anything what injures bond into duct.

(iii) The method to drill to the hardened concrete and form a duct: The method to drill shall be to secure the position of duct correctly and not to produce big friction between prestressing tendon and concrete. Moreover, foreign substances such as powder by drill which serves as a fricative basis or injures bond shall be removed before inserting prestressing tendon.

12.6.1.4 Assembly and installation of anchorages, couplers and deviating devices

(1) Anchorages and couplers shall be assembled in the accurate shape and dimensions as specified in the design documents, and shall be appropriately installed at the location and in the direction specified in design.

(2) The bearing surface of the anchorage shall be perpendicular to the tendons.

(3) In cases when tendons are coupled, sufficient space shall be provided in the duct on the pulling side of the coupler to permit movement of the coupler when tensioning the tendons.

(4) An inspection shall be carried out after installation of the anchorages, couplers and deviation devices, and damaged hardware shall be replaced or repaired. Any disturbance error in the position of the hardware shall also be corrected.

[Commentary] (1) and (4) As the large scale force are applied to the anchorage and the connection implement by prestressing, it is important to assemble correctly as plan and to arrange to accomplish the right transfer of stress and accident prevention.

(2) If the prestressing tendon is not installed perpendicular to the bearing plate, at the time when prestressing tendon is tensioned or it is anchored, prestressing tendon fractures may occur or there is a possibility that anchoring prestressing tendon may become impossible due to the occurrence of local bending stress. Therefore, it is preferable to assemble them so that the anchor and prestressing tendon may become perpendicular correctly, and to maintain the straight line part of suitable length in the prestressing tendon near anchorage.

(3) In the case that the prestressing tendon coupling is done, it is necessary to calculate beforehand the amount of movements of the coupler by giving tension force to prestressing tendon and to provide space, which is generous enough to this at a tension side. Moreover, it is required to confirm the position of a joint after the assembly of a coupler.

12.6.1.5 Arrangement of openings for grouting, exhaust and discharging

(1) Openings for grouting, exhaust and discharging shall be appropriately installed in terms of their location and orientation.

(2) Grout caps should be used for anchorage fixtures.

(3) Hoses used for grouting, exhaust and discharging openings shall not be concentrated in regions at the rear of anchorages.

(4) In cases when the ducts are very long or large-sized ducts are used, extra inlets in the middle should preferably be provided.

(5) Hoses for grouting shall be securely installed in a manner that during the concrete casting, they do not become detached or bend.

[Commentary] (1) The positions of injection holes, vent, and outlet shall be planned and arranged by considering the cable form or the grouting direction. The direction of a grout injection hole is made into the direction according to the grouting position, and a vent and an outlet shall be attached on the upper side of the duct. An outlet shall be prepared in consideration of the generating mechanism of the remaining air depending on the viscosity of grouting etc.

(2) As the rising of an air bubble is influenced by a height difference near anchorage used as a grout injection part and a discharge part and it is easy to become an air void, an anchorage end cap shall be used to avoid it. An anchorage end cap used for grout is preferable to have the characteristics of the non-iron and the structure where grout filling can be easily checked. A grout hose need to be held vertically about 1.0m above from the girder surface. This is for replacing the air bubble etc. and grout, which exist inside duct.

(3) Distribution of the grout hoses is needed in order to avoid a risk of air void concentrating until grout injection is done, becoming a cross-sectional deficit and becoming lack of bearing capacity against the prestressing force in the case that intensive arrangement of the grout hose is carried out at the back side of anchorage.

(4) In cables used for such as a continuation girder, if a cable length is long, it is possible that grout injection pressure becomes high and pouring speed becomes slow, and it tends to be the cause

of trouble generation. In the case that cable length exceeds about 50m; it is preferable to prepare injection holes also in the middle of over cable length to inject by the step-by-step formula (a system which injection is gradually done by the use of the outlets which the outflow was checked as a injection hole).

(5) To prevent the connection part of a grout hose from separating during the casting concrete or to prevent grout hose bend deformation, it shall be connected each other using a strong attachment band. Moreover, the middle support to the concrete side of a grout hose is strongly attached to reinforcing bars etc. by the steel wire etc.

12.6.2 Formwork and shoring

(1) Formwork and shoring shall be designed so as not to obstruct deformation of concrete members on account of prestressing. Formwork that may obstruct deformation of concrete members during prestressing, should be removed before prestressing, unless the removal adversely affects the concrete members. However, formwork and shoring, which are provided for the reaction forces of gravity loads after prestressing, shall not be removed.

(2) Formwork shall be adequately cambered considering deformations in concrete members during and after prestressing so that the members will be in the required shape and configuration upon completion.

[Commentary] (1) In case of the prestressing, it is preferable to remove some forms before prestressing, and it is also preferable to consider as the structure, which can remove a part of sole plate of formwork so that a concrete member can contract freely. As the deformation of the member while prestressing, the reaction force acting on a form will change a lot with places. Therefore, the portion which receives self-weight and other loads for the first time after prestressing, unless after giving the prestress to bear those loads at least, removal of the formwork and shoring shall not be performed.

Shoring shall be arranged so that the concrete member's stability is maintained as the assumption in design calculation after prestressing. If lifting of shoring is large, it is also required to take the measures which sink timbering simultaneously with prestressing.

12.6.3 Casting and compaction of concrete

During casting and compaction of concrete, great care shall be taken to avoid any disturbance to reinforcing bars, anchorages, couplers and sheaths, and ensure that voids surrounding reinforcing and tensioning materials are removed by compaction.

[Commentary] In a prestressed concrete structure, as an arrangement of prestressing tendons and reinforcing bars is complicated, it is necessary to pay careful attention in casting and compaction of concrete.

12.6.4 Prestressing

12.6.4.1 General requirements

(1) Prestressing tendons shall be tensioned in a manner that imparts the required tensile force to each of the constituent prestressing steel tendons or strands.

(2) In cases when the tendons are tensioned sequentially, care shall be taken to ensure that the concrete is not subject to harmful stresses at any stage.

(3) In cases when a particular tensioning apparatus is specified for a specific pre-stressing method, such a specific apparatus shall be used. When no specific tensioning apparatus and load-measuring device are specified, a tensioning apparatus that is capable of giving the required tensile force accurately shall be used.

(4) Special care shall be taken to avoid accidents during prestressing.

[Commentary] (1) and (2) In the case that multi-strand prestressing tendons are simultaneously tensioned as one bundle of cable, it is needed to maintain the length of each strand so that equal tension force is given to each strand prior to the beginning of stressing operation. Moreover, there shall be no slip at the anchor of prestressing tendon.

The following specific points should be taken into consideration.

(i) Since there is a possibility that slips may occur in wedge type anchorages during prestressing, each prestressing tendon shall be marked to control the existence of such slips.

(ii) In pretensioning system, in the case when the prestresing is done in a manner such that several prestressing tendons are beforehand anchored to the anchorage abutment, and the tension force is going to be given simultaneously to all prestressing tendons by the anchored abutment to be moved, the preliminary tensioning pulling and arrangement of each prestressing tendons by suitable force is required in order to eliminate the differences of the tendon lengths due to the slack of each prestressing tendon before fixing.

(iii) In post-tensioning system, in the case when several to about ten prestressing tendons are made into a bunch and prestressing is done simultaneously, it is important to arrange the lengths of the prestressing tendons before prestressing.

In measurement of elongation of prestressing tendon, a measuring point shall be prepared after giving suitable tension force for prestressing tendon so that the slack of prestressing tendon or the slack of a connection implement may not be included in measured value.

(iv) Tension force value given to prestressing tendon shall be predetermined in consideration of the slip of the anchoring equipment, and the influence of high temperature during accelerated curing etc. in the case of pre-tensioning system. Anchorage equipment shall be loosened gradually so that each prestressing tendon enables to be loosened uniformly to give prestress.

In the case when each prestressing tendon is tensioned separately and anchored by using the wedge type anchorage, a certain amount of set loss will occur at the anchorage. Although the amount of reduction of the tension stress due to the amount of set loss can be disregarded to some extent in such case when the length of tendon is comparatively long, it is not ignorable in the case such that moving bench system with the use of comparatively short length tendon is used, or in the case that the anchorage system with a large amount of set loss is used.

To arrange the prestressing tendon on a polygonal line, there are methods to give predetermined tension force by carrying out whether prestressing tendon being raised or lowered at the position of bending point after arranging prestressing tendon in the shape of a straight line beforehand and to tension from the end of prestressing tendon after arranging prestressing tendon on a polygonal line. By arrangement of these prestressing tendon and the order of tensioning, as the states of the friction loss between support equipment and prestressing tendon differ, a proper investigation of the relation between the order of tensioning and friction loss in prestressing tendon shall be carried out beforehand.

In the case when the loss of tension force takes place due to such a cause, the amount of reduction shall be calculated beforehand by calculation or survey, and tensioning of prestressing tendon shall be done so that the predetermined tension force may be given in consideration of these losses.

Since there is a possibility of giving a shock to concrete and spoiling bond between prestressing tendon and concrete if the anchoring equipment of prestressing tendon is loosened rapidly during prestressing, loosening of anchoring equipment shall be carried out gradually.

In addition, if tension force of each prestressing tendon does not loosen uniformly simultaneously at the same time, unexpected bending moment may arise and it may have a detrimental influence on concrete member and anchoring equipment. Moreover, in the case when the concrete member is manufactured with the method that a part of prestressing tendon is arranged being bent up and vertical reaction force raised by the tension force of prestressing tendon is transferred to the manufacture bench, generally, support equipment at the bending up point must be loosened prior to the loosening of the anchoring equipment. However, in such a case that the vertical reaction force of a bending up point is large compared with the mass of concrete member, as it may have a detrimental influence on concrete by loosing the support equipment previously, prestressing shall be carried out after confirming that the order of loosening will not have any detrimental influence on the concrete member.

In addition, if it is made to cool completely after the rapid curing with high temperature is performed before prestressing, as there is also a possibility that the prestressing tendons exposed between concrete members may fracture, it is preferable to give prestress to members before a temperature falls.

(v) Tension force given to prestressing tendon shall be determined in accordance with the design value in consideration of friction loss, deformation of anchorage or a slip in case of post-tensioning system. In the case that the prestressing tendon is tensioned one by one, it shall be done not to cause detrimental stress to concrete in each stage. Moreover, tension force given to each prestressing tendon shall be determined so that tension force of prestressing tendon may become equal respectively in consideration of elastic deformation of concrete in this case.

Tension force of prestressing tendon decreases as it becomes farer from the tensioning end due to the friction between prestressing tendon and duct. Therefore, if tension force given to the tensioning end is not enlarged considering this friction loss, it becomes impossible to give predetermined tension force to prestressing tendon in a design section.

As the actual quantity of the friction loss may differ from that assumed in the design, tension force given to prestressing tendon end shall be defined based on the friction value measured by the test in on-situ construction.

In the case that the prestressing tendon is anchored to concrete with an anchorage, that has a set, the amount of permissible set loss should be decided beforehand. If this amount of permissible set loss is exceeded at the anchorage, it is necessary to redo prestressing.

In the case that the prestressing tendons are tensioned one by one every single or every several groups and anchored, only a part of prestressing tendon is tensioned before all prestressing tendons are stressed to the required tension force and anchored. Due to this reason, depending on the position and size of the prestressing tendons, the torsional moment, bending moment in transverse direction and stress detrimental to a part of member may arise due to statically indeterminate force in a statically indeterminate structure. Therefore, the order of tensioning of prestressing tendons, method and value of tension force shall be determined considering these effects so that detrimental stress shall not arise on concrete in each stage.

In post-tensioning system, the elongation of prestressing tendon is generally calculated by measuring the extract length of the prestressing tendon from a concrete member with deduction of elastic deformation of concrete. When all the prestressing tendons are tensioned simultaneously, the amount of elastic deformation of concrete shall not be disregarded. In the case that tensioning is done for each group of prestressing tendons, as the amount of elastic deformation of the concrete is mostly in inverse proportion to the number of groups divided, if there are many groups, it does not interfere even if extract quantity of the prestressing tendon is considered to be the elongation to full length as it is. However, the original tension forces of the prestressing tendons tensioned previously generally decrease due to the elastic deformation of the concrete occurred by the prestressing tendon which is subsequently tensioned. Therefore, according to the method shown in the commentary (1) (i) of Section 15.3 of the Standard Specifications for Concrete Structures “Design”, tension forces given to each prestressing tendon shall be adjusted considering the reduction of the average tension force of prestressing tendons.

For the calculation of prestressing tendon extract, the Young's modulus of the prestressing tendon examined on site shall be used. In the value of apparent Young's modulus, the above-mentioned prestressing tendon extracts and the influence by the difference of quantity and elongation, etc. should be included.

(3) Prestressing jack may be prescribed in the “Guideline of Design and Construction of Prestressed Concrete” for every type of prestressing tendon with specific prestressing method. In such a case, specific prestressing jack shall be used.

(4) During the stressing operation, prestressing tendon has possibilities of doing harm as a result of releasing tremendous stored energy rapidly if the breakage of prestressing tendon, anchorage or tensioning equipment occurs. It is preferable to place a protection board behind the tensioning equipment. Moreover, the workers engaged in prestressing work as well as neighboring workers must be careful enough about the harm prevention and must not stand behind the tensioning equipment or anchored equipment during stressing operation in any cases in order to prevent a worker's harm. In addition, it is also preferable to train skillful workers and the stressing operation shall always be carried out by these workers on the basis of the engineer presence that has sufficient knowledge such as prestressed concrete engineer authorized by the Japan Prestressed Concrete Engineering Association.

12.6.4.2 Calibration of tensioning equipments

Tensioning equipments shall be calibrated before use. The equipments shall be recalibrated periodically and the results shall be recorded. In cases when the tensioning equipments are subjected to an impact, while in use, recalibration shall be carried out.

[Commentary] Since load-measuring devices of tensioning apparatus may not show the actual tensile force due to the internal friction of the device or the friction between prestressing tendons and anchoring device, calibration must be carried out beforehand for these friction losses so that the tensile force applied to prestressing tendons can be correctly read from the load-measuring device.

The load-measuring devices of tensioning apparatus may often be incorrect so that periodical calibrations shall be carried out to check the function and precision.

The most precise range of the load-measuring device is different in accordance with the type and capacity. The type and capacity should be selected so that it can be constantly used in the range of highest precision.

Calibration of tensioning apparatus is one of the most important works for stressing operation, therefore, it is necessary to frequently carry out calibrations. Dual-pointer standard gauge or dynamometer for calibration shall be prepared at the work site. In general, tensile force should be directly checked by dynamometers. Nevertheless, such devices are mostly expensive and it may be acceptable to use dual-pointer standard gauges at the general work site. Attention must be paid, however, to the inability of knowing increase of internal friction losses due to mechanical failure of jack, though the calibration by standard gauge can show whether the pressure indication by the load-measuring device is correct or not.

12.6.4.3 Control of prestressing

(1) Prestressing shall be controlled so that the tensile force in each tendon is not less than the specified value, taking into account the deviations due to various reasons.

(2) The tensile force applied to the tendons shall be measured by the readings of the load as well as the elongation or extension of the tendons. Moreover, the linear relationship between the two shall be confirmed during the prestressing work. If the relationship is not linear, prestressing shall be carried out again. In case the anomaly still remains for the second time, work shall be suspended and the cause of the anomaly shall be determined.

(3) In cases when several tendons are placed in a concrete member and the tendons are grouped, tensioning of the tendons shall be controlled both as a group and individual tendon.

(4) In cases when the number of the tendons placed in a concrete member is extremely small, as in the case of concentrated cable system, special attention shall be paid to the control of prestressing.

(5) In principle, the friction coefficient and the apparent Young's modulus of a tendon should be determined through tests carried out at site.

[Commentary] This article provides the control of prestressing for main prestressing tendons. For the tendons with little change in angle and with a small length as in the case of transverse prestressing, applying all the conditions may not be appropriate. Then, the tendons should be managed under the conditions inasmuch as possible.

(1) In the case of prestressing tendons with friction, even when friction coefficient and apparent Young's modulus of a tendon are measured, the measured results can only show the average condition of prestressing tendons at the time. Accordingly, prestressing tendons are fairly different

for each other. Tension forces applied to prestressing tendons must be determined so as not be less than the design values considering these differences.

For this reason, it may be safe to stress the tendons with approximately 2-3% larger tensile force than the design values.

For controlling the prestressing in the case when several tendons are arrenged on a member, followings are convenient and widely used to determine the anchoring point of prestressing tendons;

The apparent Young's modulus are measured on considerable numbers of prestressing tendons and the average value Ep is calculated. Prestressing calculations are carried out for any more than two friction coefficient μ using Ep. Indications of load-measuring device and extraction amount of tendons for applying specified tensile force are calculated for each friction coefficient, and they are plotted in a diagram as Points A, B,…… When the apparent Young's modulus is correct, the line which connects Points A and B becomes the theoretical anchoring line to the corresponding friction coefficient (see Fig. C12.6.1).

In such a case, additionally, the relationship between the actual indication of load-measuring device and the extraction amount shall be plotted on the figure, and the friction coefficient μ corresponding to the intersection point of the line which connects Point A and B should be controlled within the tolerance of the friction coefficient calculated from the test. Although, the friction coefficient corresponding to the intersection point of the line which connects Point A and B may be a negative value, it does not mean that the actual friction coefficient becomes negative. Difference of the apparent Young's modulus may produce such value.

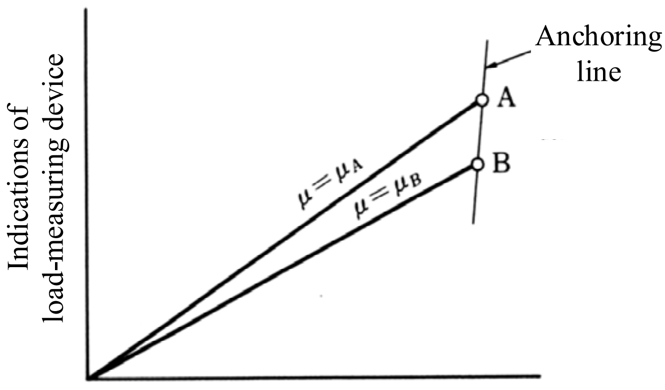


Fig. C12.6.1 Diagram for controlling the presterssing

(2) The relationship between the indication of load-measuring device and the extraction amount of prestressing tendon does not become linear when the measuring results are incorrectly read during prestressing, in cases of something wrong with the pointer of load-measuring device or any other abnormalities. In such cases, not only the reliability for the results of prestressing declines, but also it may cause a large error on the correction value of elongation or extraction amount, which gives adverse effects to the control of prestressing. For this reason, when the relation between the indication of load-measuring device and the extraction amount of prestressing tendon does not become linear, the work must be stopped to redo the prestressing.

(3) Considerable differences cannot be avoided for tensioning each prestressing tendon. Accordingly, even when there is a considerable error, it cannot be easily found on the control of

prestressing for each tendon. As a result, predetermined tensile force cannot be applied in some cases. For this reason, prestressing tendons should be grouped, and the average tensile force in each group should be calculated. Moreover, the influence of dispersion due to accidental errors should be minimized so that the causes of abnormality can be promptly and correctly found.

The following method is convenient when controlling prestressing by grouping tendons.

The relationship between the indication of load-measuring device and the extraction amount for each prestressing tendon is plotted on the figure, and the intersection point to the line which connects Points A and B (See Fig. C12.6.1) is obtained. The coefficients of frictions for the intersection points are calculated for each group and are adopted as statistics values. The average value of such the statistic ones is controlled so that it is within the tolerance, as shown in Table C12.6.1, against the friction coefficient value μ calculated through the measurement.

Table C12.6.1 Standard value of tolerance for friction coefficient

Number of prestressing tendons in the group	Tolerance of μ
1	±0.4
4	±0.2
6	±0.16
Above 10	±0.13

The tolerance is based on prestressing control data at many sites. Even in the normal control condition, approximately 5% of standard deviation is considered to be unavoidable in the relationship between the tensile force on the designed cross section estimated from the indication of load-measuring device when prestressing and the tensile force of the same cross section estimated from the extraction amount. Accordingly, the tolerance is calculated for μ value so that the 95% is within the tolerance under the normal controlled condition. Even in the normal condition, it may be deviated from the tolerance in a rate of once in 20 times.

When manufacturing very large numbers of prestressed concrete members, it is recommended to calculate the standard deviation of the differences based on the actual field results and determine the tolerance.

In group control of prestressing, deviation from the tolerance does not mean that specified tensile force is not be able to applied, but that designed prestress may not be applied with higher possibility when prestressing is continued under the condition out of the tolerance, and is to judge if prestressing condition is favorably maintained.

<u>(4)</u> In concentrated cable systems, accidental errors during prestressing are the errors of tensile force which will affect the safety of members. Accordingly, measures must be taken to reduce such accidental errors.

Consequently, the following measures must be taken:

(a) Continue the measurement of friction coefficient and apparent Young's modulus until stable measured value can be obtained sufficiently, and calculate the required tensile force using such the value.

(b) Repeat prestressing several times until the relationship between the elongation or extraction amount of prestressing tendons and the reading of load-measuring device is stabilized before anchoring.

(c) In the case of extremely long prestressing tendon, provide an observation window in the middle and check the traveling amount of prestressing tendon at the midpoint.

(5) The friction coefficient of tensioning apparatus and anchorage should be measured by tests, in principle. When there is enough test data on the prestressing method that has been widely used, friction coefficient may be estimated using such the results.

Friction coefficient between prestressing tendons and the duct largely affects on the tensile force. Moreover, it often changes even at the same site as time passes. Accordingly, measurements must be carried out not only when starting the construction but also during the construction.

Young's modulus of prestressing tendons is employed to calculate the tensile force from the extraction amount of prestressing tendons. Extraction amount of prestressing tendons relates to not only the elastic elongation of prestressing tendons but also the shortening of members. The apparent Young's modulus calculated from the extraction amount of prestressing tendons during prestressing usually becomes considerably lower than that indicated on the mill sheet of prestressing steel materials. Accordingly, the apparent Young's modulus calculated from the extraction amount must be used to calculate the tensile force for prestressing.

Since the apparent Young's modulus changes depending on the conditions of the site and the arrangement of tendons, it must be calculatedfor each layout of the tendon on the site. Generally, the apparent Young's modulus is approximately $1.81 \sim 1.96 \times 10^5$ N/mm^2 when the Young's modulus indicated on the mill sheet of prestressing steel materials is 2.01×10^5 N/mm^2. However, it may become smaller value in some special cases.

The apparent Young's modulus is able to be estimated to be 1.95×10^5 N/mm^2 when a small number of members in which prestressing wires are arranged with the normal layout, are prestressed. However, the suitability of this estimation shall be ensured on the prestressing control.

12.6.4.4 Protection of anchorages and end surfaces of members

(1) In the pre-tensioning system, tendons shall be cut evenly after prestressing at the ends of the members, and shall be protected from corrosion.

(2) In the post-tensioning system, the anchorages and the end surfaces of the members shall be protected from damage or corrosion.

[Commentary] (1) In general, prestressing tendons should be cut so as to be less than 5mm from the ends of members in length, even if not indicated on design document. As much as possible, a mechanical cutting method should be applied. Only when it is unavoidable, a gas cutting method can be applied. Then, the end surfaces of the members should be protected from corrosion by painting asphalt or coal tar, or wrapping with mortar.

(2) In many cases, as anchorages of the post-tensioning system are arranged at the surfaces of the members, they are easy to be suffered from external shocks and permeation of the rain water. In addition, the anchorages are always in the state on which high force acted after prestressing. Consequently, they should be sufficiently protected from damage by the shock from the exterior or corrosion due to the rain water.

Therefore, the anchorages should be placed in depressions which are completely filled with concrete or mortar subsequently. Construction joint should be cleaned up and chipped before casting the concrete or the mortar, for which the non-shrinkage types are used, at the depressions for the anchorages. Moreover, the waterproof processing should be carried out at the surface of joint.

When the anchorages are exposed to the weather for comparatively long time during construction, or when there are necessary to be exposed in atmosphere for re-prestressing, a corrosion inhibitor with high quality shall be painted on the anchorage surface and shall be easily re-painted.

12.6.5 Grouting

12.6.5.1 General requirements

(1) Grouting should be carried out as soon as possible after prestressing to protect the tendons against corrosion, in principle.

(2) When constructing grout for prestressed concrete, professional engineers with adequate knowledge about grout for prestressed concrete shall manage construction.

[Commentary] (1) If prestressing tendons without grouting are left as they are after prestressing, there are possibilities of breaking out of the tendon, incidence of an accident, or incidence of a member breakage due to an accident occurring on the anchorages of the prestressing tendon. Additionally, in a case when the prestressing tendons without grouting are left for a long period of time, the intruded rainwater may cause corrosion in the tendons. Therefore, grout should be injected as soon as possible after prestressing, and it is necessary to unify the tendons with the member so as to protect the tendons from corrosion.

(2) Developing construction plans and injecting grout for prestressed concrete after understanding the necessity, importance and filling mechanism of grout for prestressed concrete helps eliminate human errors or eliminates unnecessary tests or inspections. Professional engineers with adequate knowledge about grout for prestress concrete should therefore manage the construction of grout for prestressed concrete. Professional engineers here means the prestressing engineers authorized by the Japan Prestressed Concrete Engineering Association who have attended the training sessions on grout for prestressed concrete conducted by the Japan Prestressed Concrete Contractors Association.

12.6.5.2 Mixing and agitating

(1) The grout should be mixed using a grout mixer capable of mixing one batch of grout sufficiently within 5 minutes.

(2) The grout should be steadily agitated until grouting operation is finished.

[Commentary] (1) The grout mixer should have sufficient function which can disperse cement particle. The mixing procedure of grout materials is able to be determined so as to be suitable for the admixture to be used. However, followings must be avoided; these are, giving excessive load to a motor due to not enough mixing of cement and water, intruding excessive entrapped air into the grout during mixing, and obtaining not well mixed grout in a prescribed mixing time.

In case that the cement particles coagulate, the cement should let a 1.2mm-sieve pass before mixing.

Since the temperature of grout will rise and its flowability will decline in case when intense mixing continues for a long time, a special attention is required when mixing time is prolonged, or grouting is executed in a high temperature. In such a case, countermeasures to prevent rising temperature of grout, for example, using retarder or fly-ash, and mixing grout slowly, must be carried out.

(2) Because grout will cause a segregation of material and/or declination of flowability, grout must be agitated gradually during grout injection.

12.6.5.3 Grouting

(1) Prior to grouting, the duct shall be flushed with compressed air to confirm that there are no blockages and that the duct is air-tight.

(2) Just after mixing the grout, the grouting shall be carried out gradually with adequate pressure using a grout pump capable of injecting the grout without entrapping air in the process.

(3) The grout shall be screened through an appropriate sieve before pumping.

(4) The grouting shall be continued without an intermission until the grout with the same consistency comes out of the vent openings and free ends.

(5) While grouting, the injected volume of grout should be controlled using a flow meter.

[Commentary] (1) Before grouting, ducts shall be checked to be air-tight without any blockage. When blockages cannot be checked, and when there is a leakage from the duct, it is necessary to provide some suitable measure.

(2) In a case when grout is injected quickly, there is a possibility that the grout may not be sufficiently injected. Therefore, the injecting pressure should be maintained adequately during grouting. A power grout pump that can be equipped with a function of gradual injection is convenient, but also good as using a handy type pump that has same performance. Use of the pump that presses the grout directly with air is prohibited, because there is a risk of entrapping the air into the grout.

(3) Generally, 1.2mm sieve is used for screening the grout before pumping.

(4) Grouting has better to be injected toward the higher place from the lower place, in order to fill up a duct fully with the grout. In case when most of the portion of the duct is lower than the injection inlet, vent openings for the water drain as well as the grout discharge shall be provide as many as possible. When injection is performed downward in an inclined duct, grout flows along the bottom of the sheath and fills the duct up gradually from the lowest toward the top of the duct. So air voids tend to appear around the upper potion of the duct. And in case where a duct has convex portions, grout flows along the bottom of the sheath after passed the highest point, and air voids tend to appear near the highest point. Therefore, when there are convex portions in the middle of a duct, openings combined air vent with grout discharge shall be provided so as to eject the entrapped air considering above mentioned phenomenon.

The vent openings are closed after confirming the steady coming-out of the grout without dilution. It is required that injection is carried out using sufficient amount of grout without any hesitation to discharge the necessary amount of grout. Finally, backward flow of the grout should be avoided by closing all vent openings so that the pressure should be raised and maintained a little higher than that of injection, then the grouting should be terminated.

Care must be taken so that the pressure will not become excessively high during injection. For the high viscosity type of gout, it may be effective in control of injecting pressure that grout is injected after passing water in advance. In general, the injection pressure should be not more than 2 Mpa considering capacities of grouting hoses, joints and caps. Grouting hoses should be held vertically not less than 1 m in length from the surface of the girder in order to confirm that no air void is left in the sheath. In case when the grout level drops, counter measures, e.g. re-injection, have to be carried out.

(5) Grout flowmeter is available for the both types, a printer-type and a chart-type. The printer-type is a type that prints construction date, cable number, time, and amount of injected grout on a sheet. The chart-type records the amount of flow and pressure on a graph as well as prints them. The type of flowmeter shall be chosen so as to be suitable for the location of grouting and the amount of grout. In advance of injection, flowmeter must be calibrated.

12.6.5.4 Treatment of injection inlet, openings for air vent and grout discharge

The cut faces of the hoses used in injection inlet and openings for air vent and grout discharge, shall be appropriately treated and finished to achieve sufficient density of the surface to prevent water and any other harmful substance from penetration into the hose and become a cause for corrosion of sheaths or steels.

[Commentary] Since a coefficient of thermal expansion differs from that of concrete, there is a possibility that a gap is formed between concrete and the hose and it can be a water path in a long period. And also concerning the concrete cast in depressions, if its water-tightness is not maintained, water will penetrate into the joint, and there is a possibility of occurrence of cracks induced by freezing and thawing, consequently steel corrosion. Therefore, in principle, grouting hoses shall be cut 1cm or more in depth below concrete surface, and depressions after cutting the hoses shall be filled with epoxy resin. Especially in a cold district, since there is a possibility of permeation of calcium chloride scattered on the road for freezing prevention, care must be taken in the execution. Furthermore, waterproofing must be carried out for the road surface of bridge, which are directly influenced by rain water or de-icing agents.

12.6.5.5 Grouting in cold weather

When grouting is carried out during cold weather, the temperature around the ducts shall be maintained at not less than 5 °C before injection. The standard temperature of grout during injection should be between 10 and 25 °C. In principle, the temperature of the grout should be kept at not less than 5 °C for at least 5 days after completion of injection.

[Commentary] If grouting is performed in the cold season when the averaged temperature becomes 4 °C or less, the grout may freeze and may not have required intensity. Moreover, the frozen grout may expand and surrounding concrete may crack along with a duct. Therefore, it is required to carry out the grouting with careful attention to weather conditions.

From the results of previous experiments, it was found that the hydration reaction will progress, and grout with a required quality can be obtained under the following conditions: the temperature of the duct circumference when grouting is 5°C or more, the temperature when grouting is in the range of 10-25°C, and the temperature of grout is kept at 5°C or more over five days after grouting.

However, according to another report, when the unit water content is minimized by using a high-range water-reducing agent, the required strength can be obtained, without expansion by freezing, if it takes at least 10 hours for the grout temperature to reach -5 °C after injection with the same initial conditions, and if even after that the temperature is kept at -5 °C for two days off and on. Therefore, grouting can be carried out if weather conditions can be stabilized, and grouting can be completed when temperature in the daytime is 5°C or more, when the prediction of the lowest temperature several days after is possible, and the temperature of subsequent grout can be kept at 0 °C or more over five days. In this case, the temperature of the grout shall be recorded for 5 days after injection and it shall be confirmed that the temperature has stayed not below 0°C.

12.6.5.6 Grouting in hot weather

In cases when grouting is carried out during hot weather, appropriate measures shall be taken to prevent an unacceptable rise in the grout temperature and early hardening of grout.

[Commentary] Since a blockade will tend to take place by set that is too early if grouting is carried out in the hot season where the averaged temperature exceeds 25°C, consideration to material and construction must be adequately given for prevention of uncertain grouting.

In hot weather grouting, the temperature of grout for prestressed concrete should be minimized. It is important to finish grouting in a short period of time as much as possible.In order to lower the temperature of grout, it may be effective to reduce the water temperature by feeding ice into a water tank or using a water cooler.

12.6.6 Manufacture and construction of precast members

12.6.6.1 Manufacture

(1) The structure of the production platform shall be such that precast members obtained are accurate in shape and size. It shall be constructed considering deformation of the members and change in the reaction force due to prestressing.

(2) Precast members shall be carefully manufactured to ensure accurate jointing and assembly.

[Commentary] This paragraph covers precast members except factory products explained in Chapter 14. Regarding the other items not explained here, “Guideline of Design and Construction of Precast Concrete Block System (Draft)” published by Japan Prestressed Concrete Contractors Association and “Specification of Design and Construction of External Cable Structures and Precast Segmental Method (Draft)” published by Japan Prestressed Concrete Engineering Association can be referred.

(1) Generally, many precast members are manufactured using a few production platforms. Hence, in such cases, the structure of the production platform should be so as to avoid uneven settlement caused by casting concrete and the softening of the ground by due to curing water. The production platforms shall be designed and manufactured after surveying and investigating the topographic and geological features, and considering the vertical and horizontal loads act on the production platforms during manufacture.

Some prestressed members may be supported on the both sides of themselves due to warping induced by prestressing. Consequently, the production platforms shall be manufactured so that the harmful settlement and deformation may not occur by the load at both end supports of the members, and so as not to restrict the shortening of the member by the elastic deformation resulting from prestressing.

(2) In order to ensure monolithic behavior of precast members by prestressing, the members shall be such that the construction work for the joint portion can be performed properly, the prestressing tendons can be easily installed in the ducts and the shape and dimensions of the structure will be such as planned.

Therefore, in the manufacture of the precast members, the work shall be carefully performed, taking these matters well into consideration, so that the shape and dimensions of the members and joint surfaces can be accurately secured and the locations of the ducts can be arranged correctly.

When producing the members using an adhesive as a bonding material and in case of match casting members, in which the joint surface of a precast member is cast against the joint surface of the already-made unit, guide-keys (dowels, slots, etc.) shall be provided on both surfaces in advance so as to enable accurate and easy jointing of the two surfaces.

When detaching the members, it is advisable to separate them perpendicular to the joint surface. Cracking, breaking and lacking at the corner of concrete may occur at the joint surface if the members are lifted up parallel or diagonal to the joint surface. Consequently, the production platforms and the forms shall be manufactured with consideration of the above-mentioned matters. Release agents are generally applied on the joint surfaces to reduce the resistance of detaching. The release agent shall be effective in easy stripping and be thinner film as possible without bond strength loss and durability of adhesives.

It is difficult to adjust the direction of the jointed members during erection since the accuracy of erection of members produced with mach casting method is determined at manufacturing. Hence, if an erection error may be much larger than expected at the final stage, the error should be modified as soon as possible during construction.

When precast members are introduced prestress, deformations such as warping and shortening will occur, and further time-dependent deformation will take place due to creep and shrinkage of concrete. If these deformations are predicted to cause harmful effects on the shape and dimension of the structure, the members shall be manufactured in anticipation of such deformations.

12.6.6.2 Transportation

(1) Precast members shall be transported such that they are not damaged in any manner.

(2) When transporting precast members, they shall be supported at predetermined locations. In cases when support needs to be inevitably provided at other locations, it shall

be verified in advance that the members are not adversely affected.

[Commentary] (1) Since the loads acting upon the precast member vary according to the phases of the work depending on the methods of handling during transportation and erection, the members shall be handled in such a way as to avoid harmful effects on themselves. If the member is largely inclined from side to side during transportation, the dead load may cause the bending moment laterally and the tensile stress may occur on the side and at the top fiber. Generally, a member with a relatively narrow width, compared with the span between supports, tends to become unstable sidewise.

Hence, when a member with a narrow width and long span between the supports is to be transported or erected, sufficient safety shall be ensured in advance against the tensile stress and the lateral buckling caused by the effect of the lateral load. If the analysis shows that the safety of the member is comparatively small, the sufficient countermeasures as followings shall be taken. For instance, to arrange tensile reinforcements within a portion in tension, or to restrain the lateral deformation by installing temporary bracings on the side of the member, or to shorten a hanging up span, or to increase the degree of restriction against torsion at the ends of the member.

Thus, safety against cracking and lateral buckling shall be improved in advance, and furthermore, the members shall be handled carefully upon transportation and erection.

(2) Since, during transportation, the prestressed concrete members are in general subjected to the combined stresses only corresponding to the prestressing and the bending due to the dead load, the stress at the top fiber of the member is usually zero or nearly zero. Therefore, upon transportation, the member shall be supported at positions designated in the design drawings or design calculation documents, otherwise a large tensile stress may be induced at the top fiber of the member and may result in cracking when a bending moment acts on the member in a direction not originally considered.

If the member cannot be inevitably supported on the proper positions at the designated positions, and the cantilever portion of the member may be longer than expected, the negative bending moment by the dead load at the supports and the prestress may cause high tensile stress at the top fiber of the member. Hence, when the member is supported at the unexpected positions, it is necessary to ensure the safety by calculation in advance. Also, even if the position of the support is not prescribed, the safety of the handling method shall be ensured in advance.

12.6.6.3 Storage

(1) Supports shall be provided for precast members at prescribed locations during storage, and appropriate measures shall be taken to ensure that the members do not fall. In cases when members are stored in a pile, supporters shall be firmly placed at proper positions to prevent a collapse of the pile.

(2) When precast members are stored, appropriate measures shall be taken to prevent any ingress of water into ducts that may freeze or have an adverse effect such as corrosion of sheaths and couplers.

[Commentary] (1) During storage, precast members shall be firmly supported on the prescribed positions. Also, measures shall be taken to prevent the members from being inclined and fallen because of an uneven settlement of the ground or an earthquake.

In cases when the members are stored in a pile, the positions of supporters for each layer shall be carefully arranged to be in a vertical line. If not, the unexpected bending moment at designing may occur in the member below the supporters due to the weight of the members stacked above. Also if the dimensions or the quality of the supporters differs from that of designated, for instance, if the heights of the supports at two points are extremely different or if the supports are not of the required length, or if the strength of the supports is insufficient, not only may unexpected loads act upon the members but the members may be damaged by the collapse of the stack. Hence, sufficient attention shall be paid to the dimensions or strength of the supporters.

(2) Post-tensioned members without grout shall not be stored for a long time in cold weather, since the frozen water in the ducts may cause cracking of the members. If the storage in such condition is inevitable, appropriate measures such as drain-holes at the lower position of the ducts shall be provided to prevent any ingress of water. Also, as the prestressing tendons rust or corrode if they are left in the ducts for a long time without grouting, such a situation shall be avoided. If the storage in such condition is inevitable, sufficient preventive measures against rusting or corrosion of the tendons shall be taken.

12.6.6.4 Jointing

(1) Joint surface of precast members shall be maintained sound and clean by completely removing any harmful substances, such as loose particles of aggregate, poor-quality concrete, laitance, mud, and oil.

(2) At the time of jointing the members, they shall be so aligned with the ducts in terms of their position and shape that no gaps or twists are caused during jointing and prestressing.

(3) Jointed parts of ducts shall be appropriately treated to prevent concrete, mortar and bonding agents used for jointing, from flowing into the duct as well as to avoid conjunction with adjacent ducts.

(4) The structure and strength of shoring for jointing the members shall be such that it can withstand the loads applied during jointing and elastic deformations due to prestressing.

(5) Waterproofing shall be applied at all locations from where water or chloride ions could flow into a duct.

[Commentary] (1) Poor-quality concrete at joint surfaces brings a poor-quality joint for precast members even if a bonding material is of good quality.

Consequently, the joint surfaces of the members shall be carefully finished up. In case when loose particles of aggregate and poor-quality concrete remain on the joint surfaces, they shall be removed, and treatments shall be taken so that the joint surfaces are clean and sound. Laitance and release agent for a form may remain, and mud and oil may stick to the joint surfaces during transportation and storage even if the elaborate work is done. Thus, any substances, which harmfully affect the jointing, shall be removed with a wire blush and others in advance.

When concrete or mortar is used as a bonding material, the joint surface shall be kept wet before casting.

On the other hand, when using adhesives as a bonding material, the thickness of the joint is negligible thin after assembling members. Therefore, if there is a projection, such as a roll-up end of a sheath, on the joint surfaces, even if relative small, it may cause a harmful effect including stress concentration on them. Thus any projection on the joint surfaces shall be removed. Also, the joint surface shall be sufficiently kept dry before applying adhesives.

The most suitable manner shall be taken for the jointing of precast members, concerning the bonding material, in order to achieve the required quality such as strength, durability and water-tightness.

When the concrete or mortar is used as the bonding material, thickness of the joint is usually relatively thin, 10 to 500 mm, compared with the depth of the members. Hence, it is necessary to choose a mix proportion in order to obtain the most suitable flowability for each location and the required quality. Also, the concrete or mortar shall be sufficiently compacted by vibrators so that it will fill around the ducts and enter all the corners of the form. In this case, the joint portion shall be made firm enough to prevent the sheaths from being crushed or being out of place, or the cement paste from flowing into the sheaths.

If an adhesive is to be used as the bonding material, the work shall be performed with particular care to the following points as the nature of the material is quite different from that of the concrete or mortar.

(a) To choose an adhesive suitable for conditions of execution:

The characteristics of adhesives with same kind of resin are more or less different depending on the manufacturers, and a mix proportion and others. Hence, the adhesive that is most suitable for the conditions of execution such as temperature and working hours and that has required quality shall be chosen.

(b) To weigh and mix accurately:

The adhesive consists of two agents, the principal agent and the hardening agent. Accurate measurement of these two agents is required during execution in accordance with the specified mix-proportion.

In general, mechanical mixing is preferred to evenly mix the principal agent and the hardening agent although manual mixing may be allowed for a small quantity. If the amount of a batch is too large and is beyond a capacity of a container, the great heat is generated and the pot life is reduced. Thus, particular attention shall be paid on mixing by machines.

(c) To consider the weather condition such as temperature and rain during execution:

Excessive low temperature of concrete at the joint surface will cause a higher viscosity of adhesive, difficulties of the work and a slow hardening reaction. On the other hand, excessive high temperature will lead to a smaller viscosity, a flagging increase, a rapid progress of the hardening reaction and a short pot life. Therefore, it is recommended that the execution will be done when the concrete temperature is between 15 to 25 °. When the execution is done at the temperature other than these, the adhesive suitable for the temperature at use shall be chosen.

The adhesive wet with rain shall be removed from the surfaces.

(d) To be careful in the application of adhesives and attentive to the safety of work:

Adhesives shall be applied as thin as possible, with no missing areas, in even thickness, quickly and elaborately. Also, when jointing the members by compression, the appropriate treatment is needed in advance to prevent the adhesive from flowing into the ducts.

Some kinds of adhesives may have harmful effects on skin by direct touch. Thus, it is necessary to protect skin by wearing rubber gloves from being inflamed while working.

(e) To cure and protect members sufficiently after jointing in order to obtain the required quality:

After precast members are temporarily jointed during the pot life, moderate compressive stress shall be applied to the joint surfaces to prevent the generation of tensile stress until hardening of the adhesives. If the temperature of the joint surface after jointing is lower than expected, it will take a much time to harden the adhesive. Hence, the insulated curing by the appropriate method shall be taken to avoid it. Also, since rainwater may intrude if it rains immediately after the bonding, the jointed portion shall be protected with sufficient care, by covering it with sheets, for instance, to avoid adverse influences on the bonding effect.

(2) Members shall be carefully manufactured so as to have exact shapes, dimensions and locations of ducts and to adhere closely each other. When they are installed in the field, fine adjustments shall be enable so that the member sections and the ducts will fit precisely at the joint and the prestressing tendons can be easily inserted. If an adhesive is used as the bonding material in the cantilevering erection in which the members are jointed in succession as they are being prestressed, it is difficult to adjust the length or direction of the members at the joints as the thickness of the joints is negligibly thin. Hence the manufacture and installation of members, especially installation of the first member which is to be used as the basis, shall be done accurately with particular care. Also, in case when a large deviation in length or direction is predicted, a method of modifying them shall be planned in advance. Furthermore, members shall be securely held on shoring to avoid discordance or twisting during the jointing and prestressing.

(3) In case of jointing of ducts, it shall be required to prevent a bonding material from flowing into the ducts since the inflow has a harmful effect on insertion of tendon and injection of grout. It is necessary to confirm whether the inflow is in the duct or not after jointing. If any inflow is found, it shall be removed as soon as possible. Also, care must be taken that, if the spaces between adjacent ducts are not filled with bonding material, the grout may flow into the adjacent ducts.

(4) Temporary shoring for jointing operation shall withstand the dead load of the members, the mass of the erective machines and the elastic deformations due to prestressing.

Erection and prestressing sequences prescribed in the design drawings shall be followed strictly. Since these sequences are determined considering the stress condition of each member at each phase of work or the statically-indeterminate forces due to prestressing, the members being under construction may be damaged or the stress conditions specified for the structure may not appear if these sequences are unreasonably changed.

(5) The initial defects such as detachments and gaps can easily occur at a joint. Also, a joint can be a path of water or chloride ions in a long-term even if the elaborate work is done. Waterproofing shall be applied at the joint with couplings of ducts to prevent a tendon from corrosions. The same treatment shall be needed for bridge decks that are directly affected by rainwater and de-icing agents. It is desired that waterproofing is applied to the side and the bottom of bridge, although the chance of penetrations of water and chloride ions is rare except for in seashore area.

12.6.6.5 Erection

(1) Erection shall be carried out safely taking into account the characteristics of the members and the structure after examining the erection plan.

(2) In cases when an erection method different from that planned at the design stage is adopted, its safety shall be ensured by carrying out a prior examination of stresses and deformations expected during erection.

(3) Erection shall be carried out, whenever necessary, after safety is ensured through evaluation of stresses and deformations in each member.

[Commentary] In general, prestressed concrete members are given prestress corresponding to the dead load of the members. Therefore, if the state of the stresses due to the dead load differs greatly from that being designed because of the modification in the erection method or mishandling in the course of the erection work, the balance in stresses may be lost and the prestressed concrete members may have cracks, or may even break in some. Thus, it is essential to carry out the erection in compliance with the instructions shown in design documents. In case when the erection should be performed in a different way from that of the design documents, sufficient study shall be required on the state of stresses and deformations.

12.6.7 Construction of external cable structures

12.6.7.1 Handling of tendons

(1) Tendons shall be transported and stored so that no damaging deformation or other damage may be incurred.

(2) Tendons shall be placed in protective tubes so as not to be entangled.

(3) Coated tendons and cables to which anticorrosives have been applied shall be arranged so as not to damage the protective coating or anticorrosives.

(4) Protective tubes and tendons should be placed on appropriate supports under a condition close to the designated cable shape except at the deviator.

[Commentary] (1) Tendons should naturally be transported and stored considering the physical and chemical properties of coating materials and anticorrosives. In cases where tendons are stored in hot places, the resin coating the steel is likely to soften. In cold and humid conditions, condensation is likely to corrode the steel.

(2) When arranging tendons, freedom from entanglement of tendons near the anchorage fixture should be confirmed because the entanglement of tendons not only increases friction but also causes the cable to fracture near the anchorage fixture.

(3) The thickness of coating of tendons is determined to ensure anticorrosive performance. Unless the coating is arranged so as not to be subjected to damage, anticorrosive performance is not ensured. The same is true for cables coated with anticorrosives. Adequate care should therefore be exercised when arranging tendons. When inserting the steel, the exterior of the coating should be inspected for damage or peeling. Measures should also be taken to prevent damage to the coating in

the areas that are likely to interfere with the deviator. Even in the case where damage to the coating is detected, repair may be applied in the field if the repair can provide the designated anticorrosive performance.

(4) Arranging protective tubes and tendons in a shape greatly different from the designated cable shape may not only complicate subsequent handling but also increase the loss of tension. Protective tubes and tendons shall therefore be arranged in a shape as similar to the designated cable shape as possible.

12.6.7.2 Assembly and arrangement of anchorage zone

(1) Anchorage fixture in which tendons can be replaced shall be installed so that the positions of parts may be properly maintained.

(2) Protective caps shall be attached at the end of the anchorage fixture to protect the anchorage fixture and tendons from corrosion.

[Commentary] (1) In systems that adopt a double-tube structure near the anchorage zone and enable the replacement of tendons, a pre-assembled anchorage zone should be attached to the formwork so as to maintain the positions of parts as designated.

(2) External prestressing systems shall be covered with protection cap at the ends, and inside of the ducts shall be filled with corrosion inhibitor or be grouted in order to protect the external tendons and the anchorages from the corrosion. Protection cap should be waterproof and be rust prevention itself.

12.6.7.3 Assembly and installation of deviating devices

At the time of construction at the deviator, it shall be ensured that no tendons are broken locally due to an error of installation.

[Commentary] The arrangement form of an external cable is determined by the installation position of anchorage and a deviation device. For this reason, regardless of the arrangement position size of a deviation device, it shall be arranged with full care of the direction of a continuous deviation part and anchorage part.

As dense reinforcing bars arrangement is served at a deviation part, it is strictly needed to maintain the placing space of concrete and the fixing method of a deviation device.

12.6.7.4 Handling of protective tube

(1) During the transportation and storage of protective tubes, appropriate packing for the tubes shall be conducted considering the properties of materials of the tubes.

(2) When protective tubes are connected, jointed parts shall not be weak points.

(3) When protective tubes are arranged, required space between prestressing steels and protective tubes shall be kept.

[Commentary] (1) As protective tubes, polyethylene (PE), polyvinyl chloride (PVC), fiber reinforced plastic (FRP), polypropylene (PP) or steel tubes are used. Methods of handling protective tubes should be determined according to the characteristics of respective materials.

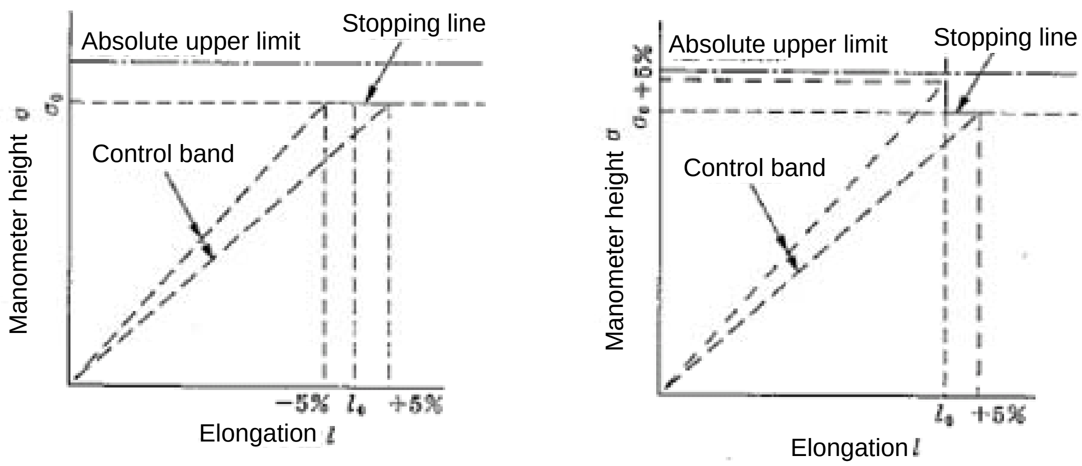
(2) For the joints of protective tubes, adhesion, welding, thermal shrinking, clamping or other method is adopted. Bonding methods should be selected so that joint zones may be fully resistant to the pressure of injection of anticorrosives and fully waterproof to protect tendons.

(3) Tendons and protective tubes should be arranged properly using internal spacers or racks so that anticorrosives may evenly wrap tendons.

12.6.7.5 Control of prestressing

Tension shall be controlled for each external cable to prevent the tension given to the external cable from decreasing below the designated level considering the characteristics of the external cable structure.

[Commentary] In the arrangement of external cables, changes in angle are generally smaller than for internal cables and the loss of tension due to friction is smaller. Methods of management using the coefficient of friction as parameters (12.6.4.3 Commentary) may sometimes be inappropriate. Then, the readings from load cells should be assumed at a certain level and the variation should be held to plus or minus 5% of a designated level (Fig. C12.6.2a). Another method involves holding the readings from load cells and variations to 0 to plus 5% of designated levels because a shortage of tension is of concern when the apparent coefficient of friction is expected to exceed the coefficient of friction assumed in design (Fig.C12.6.2b). In either case, no trial stressing is generally carried out on grounds of a small amount of friction loss, and the values shown in Fig. C15.3.2 in the "Standard Specifications for Concrete Structures: Design" may be used for calculating the tension. In cases where the total variation of cable angle exceeds 30 degrees according to the existing records, however, trial stressing should be done and tension should be managed using the coefficient of friction as a parameter.



a) ±5% control b) 0 - +5% control

Fig.C12.6.2 Example of controlling of prestressing

12.6.7.6 Injection of anticorrosives

(1) The injection of cement grout shall be planned and implemented as for the grout for prestressed concrete for internal cables.

(2) The injection of other materials shall be planned and implemented fully identifying their characteristics.

[Commentary] (2) Other materials include grease, wax and polyurethane. Soft materials in particular should be used fully considering the effects of their post-injection expansion or shrinkage due to thermal changes on protection tubes.

12.7 Inspection

12.7.1 Material acceptance tests

12.7.1.1 Prestressing steel

The accepting party shall assume the responsibility for prestressing steel acceptance tests. The tests should be carried out in accordance with Table 12.7.1 as a standard practice.

Table 12.7.1 Acceptance test of prestressing steel

Type	Item	Test or Inspection method	Timing and frequency	Criteria for judgment
Prestressing wires and strands	Quality items in JIS G 3536	Verification based on a list of test records prepared by the manufacturer or by a method specified in JIS G 3536	Upon delivery	Compliance with JIS G 3536
Prestressing bars	Quality items in JIS G 3109 or 3137	Verification based on a list of test records prepared by the manufacturer or by a method specified in JIS G 3109 or 3137	Upon delivery	Compliance with JIS G 3109 or 3137
Prestressing steel other than those specified in JIS G 3536, 3109 or 3137	Required items	Verification based on a list of test records prepared by the manufacturer or by a method specified in JIS G 3536, 3109 or 3137	Upon delivery	Compliance with specifications defined to achieve the designated goal

[Commentary] The accepting party conducting acceptance tests means the Owner. Generally, however, the prestressed concrete contractor conducts tests and the Owner verifies test results. This holds true also in the acceptance tests for anchorage and connection fixtures (12.7.1.2), sheaths (12.7.1.3) and for adhesives used for connecting precast members (12.7.1.4).

Prestressing steel is generally delivered in bunches of rolls. The certificate of inspection, symbol indicating the type, nomenclature and manufacturer (or logo) are indicated on the surface of the bunch. General acceptance tests involve the visual verification of the brand and type of prestressing steel and verification that the type, diameter, size and mass of the prestressing steel are in agreement with the specifications in JIS G 3536 "Prestressing wires and strands", 3109 "Prestressing bars" or 3137 "Small-diameter deformed prestressing bars" based on the lists of test records prepared by the manufacturer. At the same time, the diameter of the prestressing steel should be measured using calipers and the appearance should be inspected.

12.7.1.2 Anchorage and coupler

The accepting party shall assume the responsibility for anchorage and coupler acceptance tests. The tests should be carried out in accordance with Table 12.7.2 as a standard practice.

Table 12.7.2 Acceptance test of anchorage and coupler

Item	Method for test/inspection	Timing and frequency	Criteria for judgment
Performance items in JSCE-E 503	Verification based on a list of test records prepared by the manufacturer or by a method specified in JSCE-E 503	Upon delivery	Compliance with specifications in “Guideline of Design and Construction of Prestressed Concrete”

[Commentary] The shapes, performance and service conditions of anchorages and couplers vary widely depending on the type of anchorage or coupler. It is, therefore, necessary to determine test methods so that their service conditions and the way of tensile forces can be accurately reproduced.

For this reason, in cases where the performance of an anchorage or coupler is to be tested, it is common practice to test the combinations of anchorages and concrete or of anchorages or couplers and tendons.

Test results obtained must satisfy the conditions listed below.

(a) Test on combinations of anchorages and concrete:

Anchorages must be able to withstand 100% of the rated tensile strength of the tendons.

(b) Test on combinations of anchorages or couplers and tendons:

In the static tension tests that do not involve bonding, the anchoring efficiency of anchorages or the connection efficiency of couplers must be 95% or more of the rated tensile strength of tendons. In cases, however, where the anchoring efficiency or connection efficiency becomes lower than 95% because of a modification made to tendons but not lower than 90%, new standard values may be set.

The anchoring efficiency and connection efficiency here refer to the percentage of the maximum tensile load to the rated tensile strength of the tendons.

These tests of anchorages and couplers should be conducted in accordance with the test methods described in JSCE-E 503 “Method of Performance Test of Anchorages and Couplers for Prestressed Concrete Construction”.

Even in cases where neither anchorages nor couplers are used, but materials, such as reinforcing bars, concrete, grout and auxiliary materials, are used as integral parts of anchoring or connection systems, equal care must be taken in determining test methods.

Anchorages or couplers, which are used at the locations subjected to large variable stresses due to permanent variable loads, need to be tested for the fatigue strength under appropriate stress amplitude and cycling loading conditions. In cases where prestressing tendons are to be used without being bonded with concrete, the fatigue strength test is very important.

For the anchorages and couplers, that are covered by the "Recommendations for Design and Construction of Prestressed Concrete Structures (JSCE)" and that have proven performance, may be used without conducting this test.

Anchorages and couplers that have undergone corrosion of steel or have been fouled damaged or deformed while being stored at the construction site for a long period of time must be used only after their quality is verified through testing even if those anchorages and couplers were in good condition when they arrive at the construction site. Damaging steel corrosion here means the loss of cross section like pitting corrosion. Rust cannot be removed with sandpaper.

12.7.1.3 Sheaths

The accepting party shall assume the responsibility for sheath acceptance tests. The tests should be carried out in accordance with Table 12.7.3 as a standard practice.

Table 12.7.3 Acceptance test of Sheath

Item	Method for test/inspection	Timing and frequency	Criteria for judgment
Quality items regarding leakage of paste	Verification based on a list of test records prepared by the manufacturer or specified leakage test	Upon delivery	No leakage of paste in the specified method

[Commentary] Since sheaths are likely to be stepped on during pre-concreting work and susceptible to impact by vibrators or other equipment before the concrete placement, they shall be strong enough to withstand such physical interference. They shall also be rigid and strong enough to retain its shape against the pressure of placed concrete and be sealed sufficiently to prevent the inflow of cement paste in concrete.

In general, the following tests shall be performed to determine the quality of sheath:

(a) Inject cement paste with a water-cement ratio of 50% (Fig. C12.7.1) into sheath specimens produced in accordance with (i) to (ii) below, and leave for 30 minutes. Water leakage is allowed, but there shall be no leakage of cement paste through the sheath.

[Sheath specimen preparation procedures]

(i) Specimen for testing resistance to local external force

Place a sheath specimen of length four times its inner diameter with a round steel bar with a diameter 0.8 times that of the sheath inner diameter inserted onto a flat surface. Then, apply a short period loading to the sheath using a 9 mm diameter round steel bar weighing 1 kN placed at its center and perpendicular to its axis (see Fig. C12.7.2).

If the sheath is made of material that varies significantly in hardness depending on the temperature, this loading test shall be performed at -10℃, +20℃, and +50℃.

(ii) Specimen for testing resistance to uniform external force

Apply a force of $P=100\pi D^2$ (N) to a sheath specimen with an inner diameter of D (cm) and a length of 4D in the manner shown in Fig. C12.7.3 at the ambient temperature for 10 minutes.

(b) Inject cement paste with a water-cement ratio of 50% into a sheath specimen bent to a radius equal to 30 times the sheath inner diameter. There shall be no leakage of cement paste through the sheath (see Fig. C12.7.4).

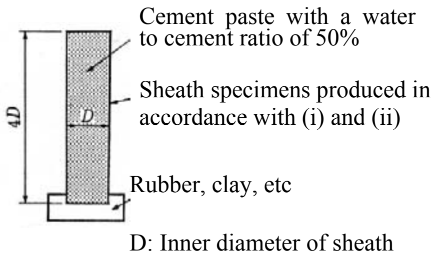


Fig. C12.7.1 Sheath test method (a)

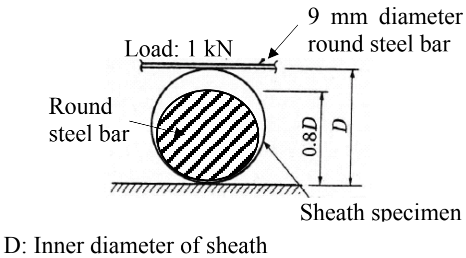


Fig. C12.7.2 Sheath specimen for testing resistance to local external force

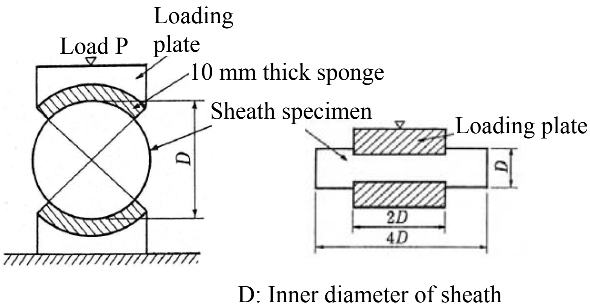


Fig. C12.7.3 Specimen for testing resistance to uniform external force

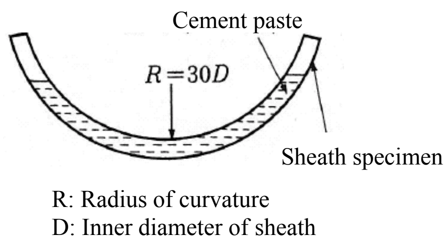


Fig. C12.7.4 Sheath test method (b)

The above tests may be omitted if the sheath has been tested and found suitable for its intended use by the manufacturer.

In order to ensure the correct injection of grout, the sheaths shall be inspected immediately prior to the use and concrete placement for defects such as corrosion, grime, scratches, and deformation. If any defects are found during this inspection, the sheaths shall be repaired or replaced. Damaging corrosion here means corrosion in which the coefficient of friction with the tendon seems to have varied greatly.

12.7.1.4 Adhesive agents for jointing precast members

The accepting party shall assume the responsibility for conducting acceptance tests for adhesive agents used for jointing precast members. The tests should be carried out in accordance with Table 12.7.4.

Table 12.7.4 Acceptance test of adhesive agents for jointing precast members

Item	Method for test/inspection	Timing and frequency	Criteria for judgment
Quality items in JSCE-H101	Verification based on a list of test records prepared by the manufacturer or JSCE-H101	Upon delivery Before the commencement of construction work	Compliance with JSCE-H101

[Commentary] Where an epoxy resin bonding agent is to be used for jointing precast members, it shall conform to JSCE-H 101 "Specification for Epoxy Resin Adhesive in Precast Concrete (for Bridge Girders)". If the bonding agent is used under special conditions or circumstances, it shall be tested as required for the properties such as tensile strength at high temperature, tensile strength when hardening in water, impact strength, compressive Young's modulus, thermal expansion coefficient, hardening shrinkage ratio, and water absorption coefficient. Degree of decrease in tensile strength at high temperature shall be tested, if usage is for structures and road surfaces with asphalt pavement subject to direct sunlight, because bonding agents tend to lose strength when exposed to high temperatures, even after hardening. If it is necessary to joint precast members while they are still wet, the bonding agent shall be tested in advance for any decrease in tensile strength when hardened in water.

It is also recommended to check in advance whether the form releasing agent used in the production of the precast members is compatible with the bonding agent and has no detrimental effect on the bond strength.

Tests on epoxy resin bonding agents may be difficult to perform on site, since they generally require special apparatus and measurement techniques. For this reason, some of the tests may be omitted if the review of the test data issued by the manufacturer reveals no problems, or if the bonding agent is used within a reasonably short period of time after delivery to the site, or if the major factors (e.g., construction period, construction conditions, and structure size) are comprehensively reviewed.

However, since properties of epoxy resin bonding agents such as workability before hardening are greatly affected by temperature, it is necessary to carry out a test to verify that the bonding agent is suitable for use under the prevailing temperature fluctuations. Tests shall also be performed if the bonding agent has been stored for a long period of time before use, since the properties of such materials may change with storage time.

12.7.2 Inspection of grout

12.7.2.1 Acceptance test of grout

The accepting party shall assume the responsibility for conducting acceptance tests for grout. The tests should be carried out in accordance with Table 12.7.5.

Table 12.7.5 Acceptance test of grout

Item	Method for test/inspection	Timing and frequency	Criteria for judgment
Flowability	JSCE-F 531	Prior to grouting and when variation in quality is found: once per day or more	Falling within the range specified in the construction plan
Bleeding Ratio	JSCE-F 532		Less than 0.3% 0.0% (24 hours later)
Volume change ratio	JHS 420	Prior to grouting and when variation in quality is found: once per day or more	-0.5% - +0.5%
Compressive Strength	JSCE-G 531	Prior to grouting and when variation in quality is found: once per day or more	$30N/mm^2$ or more at 28 days
Chloride Content	Using a reliable test method, and carried out by an organization of repute.		Should be 0.08% or less of cement weight

[Commentary] The accepting party conducting acceptance tests means the Owner. The prestressed concrete contractor, however, generally conducts tests and the Owner verifies test results.

Grout quality varies considerably depending on conditions such as the materials used, mixer capability and temperature. Prior to grouting, therefore, it is necessary to conduct tests on flowability, bleeding ratio, expansion ratio and compressive strength under conditions designed to reproduce the same as actual conditions as much as possible. Since the grout quality also varies slightly depending on the site conditions, sufficient testing is needed for management purposes.

In actual construction, at mix proportions at which it has been verified that the bleeding rate and the rate of volumetric change are in the designated range, the water-cement ratio that is obtained from the mass of unit volume and enables quick interpretation of results may be used for quality inspection instead of the bleeding rate and the rate of volumetric change generally inspected before injection on a daily basis. Then, specimens should be prepared in accordance with JSCE-F 506 "Method for preparing cylindrical specimens for compressive strength tests of mortar or cement paste", and the water-cement ratio estimated by measuring the mass should be plus or minus 1.5% of the recommended range for water-cement ratio specified for each admixture and be in the serviceable range.

The variance occurs between the estimated water-cement ratio obtained from the mass of unit volume and the specified water-cement ratio because of the variations of the mass of packed cement, mismeasurements or measurement errors, too much or too little mixing time and the mixing of air. In the preliminary mixing, the mass of packed cement should be measured, water should be measured to achieve the specified water-cement ratio, the air content of the grout for prestressed concrete mixed accurately should be measured and a reference value based on the air content should be specified. Measuring the mass of packed cement, water and air content in the field with a proper frequency is also effective for correcting errors. For details, refer to the "Design and Construction Guidelines for Grout for Prestressed Concrete" of the Japan Prestressed Concrete Engineering Association and the "Construction Manual for Grout for Prestressed Concrete and Pregrouted Prestressing Steel 2006 (revised edition)" of the Japan Prestressed Concrete Contractors Association.

In the inspection of chloride ion content, a testing method appreciated by a reliable organization and for which accuracy has been verified by the Japan Institute of Construction Engineering or an equivalent third-party organization should be adopted.

12.7.2.2 Inspection of grouting

(1) The Owner shall assume the responsibility for conducting inspection prior to grouting. The tests should be carried out in accordance with Table 12.7.6 shown below.

Table 12.7.6 Inspection prior to grouting

Item	Method for test/inspection	Timing and frequency	Criteria for judgment
Preparation of Materials	Visual inspection, Number of Cement Bags	Before and during execution	Compliance with the construction plan
Production Facility and Labor	Visual inspection		
Charging of materials			
Mixing Time	Stop watch	During execution	

(2) The Owner shall assume the responsibility for conducting inspection during grouting. The tests should be carried out in accordance with Table 12.7.7 shown below.

Table 12.7.7 Inspection of grouting process

Item	Method for test/inspection	Timing and frequency	Criteria for judgment
Facility and Labor	Visual inspection	Before and during execution	Compliance with the construction plan
Grouting Method			
Volume	Flow meter	Total volume	The amount applied is as predetermined

(3) The Owner shall assume the responsibility for conducting inspection after grouting, exhaust and discharge. The tests should be carried out in accordance with Table 12.7.8 shown below.

Table 12.7.8 Inspection after grouting

Item	Method for test/inspection	Timing and frequency	Criteria for judgment
Treatment of openings after Grouting/Exhaust/ Discharging	Visual inspection	Upon completion of grouting	Compliance with the construction plan

(4) In the case that the production or grouting process is found to be unacceptable during the inspection carried out prior to the commencement of construction, appropriate corrective measures, such as improvement in the systems, reassignment of labor, or changing the methods, should be taken to ensure that the predetermined requirements are met. In the case that the grouting has already been completed, other appropriate measures shall be taken to ensure that the predetermined requirements are met.

[Commentary] (4) Grouting inspection methods include the direct and nondestructive inspection methods. In the direct inspection method, the concrete cover is directly removed to inspect the grout in the sheath, hence, this is the most reliable method for inspection. However, since only one cross section of prestressing tendons can be observed in this method, in order to inspect the degree of completeness of continuous grouting, it is necessary to conduct inspection at two or more locations. In this case, care must be taken not to damage prestressing tendons when drilling holes.

Nondestructive inspection methods are inspection methods that do not damage the members. Nondestructive inspection methods that have been proposed include the following:

(i) X-ray inspection method

In the X-ray inspection method, images are taken by using the principle that when X-ray passes through a substance, the intensity of X-ray transmitted through the substance varies with such factors as the type and thickness of the substance. The methods of using X-ray film, such as a photosensitive recording medium (film method), the method of using an "imaging plate" (IP) and processing images on a computer (IP method), are already in use.

(ii) Sounding methods

In sounding methods, a concrete member, which is used for inspection, is impacted, or ultrasonic pulses are transmitted through the member, and then the response of the member is analyzed. Techniques using hammer impacts and ultrasonic pulses have been developed.

If a part of a member is found that there is some defect due to grout, regrouting shall be performed. Materials used for regrouting must meet the following requirements:

- High flowability and penetration
- High rust resistance
- Strength according to its design requirement
- High workability

For materials used for regrouting, the ability to penetrate fine spaces is important.

Materials used for regrouting should be cement materials (inorganic materials).

Cement materials include the following:

- Fine-grained cement
- Fine-grained cement + polymer
- Cement + calcium sulfoaluminate
- Cement + aluminum + sulfonate compounds

In general, the cement materials form an alkaline zone around prestressing tendons and suppress the progress of steel corrosion even if penetration is not complete.

No non-cementitious materials (organic materials) should be used for re-injection because the potential of hydrogen is low and the passive film on the steel surface is likely to be unstable in the case of incomplete filling and because there may occur a gap from the area where grout is applied for prestressed concrete in the vicinity.

12.7.3 Inspection of execution

12.7.3.1 Inspection of sheaths, protecting tubes and tendon arrangements

The Owner shall assume the responsibility for conducting inspection of sheaths, protecting tubes and tendon arrangements. The tests should be carried out in accordance with Table 12.7.9 shown below.

Table 12.7.9 Inspection of sheaths, protecting tubes and layout of tendons

Item	Testing method/ Inspection method	Period/ Frequency	Criteria for judgment
Type/Diameter/ Quantity	Visual inspection, measurement of diameter	After layout	Compliance with design documentation
Anchorage Method	Visual inspection	Before casting concrete	No potential deformation or disturbance during casting concrete
Layout	Visual inspection, measurement of location		Tolerance: As specified in design documentation. In cases when the distance between the center of the tendon and the edge of concrete is less than 1m, the tolerance shall be ±5mm, for 1 m or more 1/200 or less of the size of concrete or ±10mm whichever is smaller.

[Commentary] The purpose of the inspections is to ensure that the structure will satisfy the quality requirements. Since, in terms of structural safety, prestressing tendons are the most important component of prestressed concrete structures, they shall be carefully inspected. However, since prestressing tendons are inserted into ducts created in the concrete by embedding sheaths and protective conduits, the accuracy of tendon installation and the ability to induce the specified stress on the tendons are determined by the accuracy of sheath and conduit alignment. Furthermore, the structural integrity of the interface between tendons and concrete, and thus the long-term durability of the structure, is dependent on whether grout is properly injected into the sheaths and protective conduits. This means that the sheaths and protective conduits also indirectly play an important role in the safety of the structure, and the inspections shall be performed with the consideration of this crucial function.

In general, the most desirable approach to structure inspections is non-destructive inspection after completion. However, given the imperfect inspection techniques currently available, the only practical choice is to use the results of tests carried out before concrete placing to evaluate the characteristics of the completed structure. This approach is based on the assumption that the conditions prevailing, when the inspections are performed, remain unchanged after concreting. This means that it should be confirmed during the inspections that all components and materials will remain free from deformation and displacement, and they will maintain in the same condition even if subjected to disturbances during concrete placement.

Although it is desirable that a structure should follow the drawings as accurately as possible, discrepancies may arise due to various constraints and site conditions. To cope with this, certain alignment tolerances are usually incorporated into structure designs. If such tolerances (allowable tolerances) are specified in the drawings, the inspections must include the checks to determine whether the components and materials have been installed in such a manner that they are satisfied. When the alignment tolerances are not specified in the drawings, Table 12.7.9 should be followed.

12.7.3.2 Inspection of anchorage and coupler assembly and arrangement

(1) The Owner shall assume the responsibility for conducting inspection of anchorage and coupler assembly and arrangement. The tests should be carried out in accordance with Table 12.7.10 shown below.

(2) It shall be confirmed that the arrangement of the couplers is such that the concrete close to the perimeter is not adversely affected by the tension of tendons.

Table 12.7.10 Inspection of anchorage and coupler assembly and arrangement

Item	Testing method/ Inspection method	Period/ Frequency	Criteria for judgment
Type/Diameter / Quantity	Visual inspection, measurement of diameter	After layout	Compliance with Design Documentation
Anchorage Method	Visual Inspection	Prior to casting Concrete	No potential deformation or disturbance during casting concrete
Layout	Measurement using scales and visual inspection		Tolerance: As specified in design documentation or, if the distance between the center of a tendon and the edge of concrete is less than 1m, the tolerance shall be ±5mm, for 1 m or more, 1/200 or less of the size of concrete or ±10mm, whichever is smaller (standard)
Arrangement of Reinforcing Bars	Visual inspection	After layout	Compliance with design documentation

[Commentary] (1) If allowable tolerances for the installation of anchorage devices and couplers are not given on the drawings, in general, Table 12.7.10 should be followed.

Anchorage devices and couplers are usually tested for performance in combination with reinforcement bars under specified conditions. Therefore, the inspections shall determine whether the actual installation completely matches the conditions guaranteed by the test.

Even if anchorage devices are properly placed, they may not fulfill their specified function if the concrete surrounding the anchorage has defects. Therefore, the inspections shall determine not only whether the installation of the anchorage devices is correct, but also whether the reinforcement bars and other materials are arranged in such a way that the concrete surrounding the anchorage is prevented from any defects that may occur.

(2) In some designs, the couplers are free to move when prestress is applied to the tendons. With such designs, if movement is restricted, not only is application of the specified prestress inhibited, but there may also be adverse effects on the concrete surrounding the tendons. For this reason, the inspections shall determine whether the adequate space (duct) is provided to allow the movement of the couplers.

12.7.3.3 Inspection of opening layout for grouting, exhaust and discharging

The Owner shall assume the responsibility for conducting inspection of opening layout for grouting, exhaust and discharging. The tests should be carried out in accordance with Table 12.7.11 shown below.

Table 12.7.11 Inspection of opening layout for grouting, exhaust and discharging

Item	Testing method/ Inspection method	Period/Frequency	Criteria for judgment
Type/Diameter / Quantity	Visual inspection, measurement of diameter	After layout	Compliance with the construction plan
Anchoring Method	Visual inspection	Prior to casting concrete	No potential deformation or disturbance during casting concrete
Layout	Visual inspection		Compliance with the construction plan

[Commentary] The layout of prestressed concrete grout injection, air exhaust port, and grout discharge port plays a very important role in injecting grout into the ducts and allowing air bubbles to escape. The inspections shall determine whether the type, diameter, number, and location of grout hose to be used are in conformity with the work plan. The inspections shall include checking for vent looseness or damage, which may cause the vents to come away during concrete placement, and whether the vents will maintain functionality as grout injection, air exhaust port, and grout discharge port.

CHAPTER 13　STEEL-CONCRETE COMPOSITE STRUCTURES

13.1 General

13.1.1 Scope

This chapter presents the standards for filling concrete and for producing, transporting and erecting steel members that are required for meeting the construction and performance requirements for structures during the construction of steel framed reinforced concrete members, concrete-filled columns and sandwiched members, all of which are of steel-concrete composite structure.

[Commentary] This chapter refers to the construction described in Chapter 16 Steel-Concrete Composite Structure of the Standard Specification for Concrete Structures, "Design: Main Text". For matters concerning the filling of concrete, refer to the "Design and Construction Guidelines for Composite Structures (draft)" and "Performance Check Guidelines for Composite Structures (draft)". For matters concerning steel members, refer to the "Steel Structure Design Guidelines", "Standard Specifications for Steel-Concrete Composite Structures", "Specifications for Highway Bridges: Part II Steel Bridges" (Japan Road Association).

This Specification takes up:

Steel reinforced concrete member: A structure consisting of such steel frames as H beams, Warren truss members in reinforced concrete to resist external forces by frames and concrete. A structure with main bars and anti-shear reinforcing bars around steel frames is intended here. For construction-related matters not explained herein, refer to “Standard for Designing Railway Structures with Explanation - Composite Steel and Concrete Structures” (Railway Technical Research Institute).

Concrete-filled steel column: A structure consisting of a circular or square pipe filled with concrete. For construction-related matters not explained herein, refer to “Standard for Designing Railway Structures with Explanation - Composite Steel and Concrete Structures” (Railway Technical Research Institute).

Sandwich member: A structure consisting of two plates linked using steel reinforcements and filled with concrete. For construction-related matters not explained herein, refer to “Design Code for Steel-Concrete Sandwich Structures (Draft)”.

13.1.2 General

(1) When constructing steel-concrete composite structures, examinations should be made in advance of the production, transport and erection of steel members and of the filling of concrete, and adequate construction plans should be prepared.

(2) Steel-concrete composite structures should be constructed properly in accordance with the construction plans.

(3) Inspections should be conducted as required in respective construction phases for structures to meet the designated performance requirements.

[Commentary] (1) When constructing composite steel-concrete structures, general parameters and the materials and parts, production methods (original size, cutting and processing, welding), production process, temporary assembly, transport, erection and connection of steel members should be examined. For concrete, the filling capacity and construction methods should be examined.

13.2 Materials

13.2.1 Steel

(1)Qualities of steel used, such as steel plates, shape steel, steel pipes and re-bars should conform to the quality specifications provided in JIS or JSCE Standards, etc.

(2)Jointing materials such as welding materials, high-strength bolts, etc. should conform to JIS, etc.

[Commentary] For composite steel-concrete structures, materials of verified quality should be used.

The materials used for composite steel and concrete structures refer to concrete, steel reinforcements, and jointing materials.

(1) The standard materials of such structural steel as plates and shape steel conform to JIS G 3101 “Rolled Steels for General Structure”, JIS G 3106 “Rolled Steels for Welded Structure”, or JIS G 3136 “Rolled Steels for Building Structure”.

The standard pipes conform to JIS G 3444 “Carbon steel tubes for general structural purposes”, JIS G 3466 “Centrifugally Cast Steel Pipes for Welded Structure”, and JIS G 5012 “Carbon Steel Pipes for Ordinary Piping”.

The standard type of stud for shear connector conforms to JIS B 1198 “Headed Studs”.

Reinforcement complying with Section 3.6.1 of "Materials and Construction: Construction Standards" should be used as a standard practice. When welding the reinforcement to steel plates or steel sections for shear connectors, due care should be exercised to provide the quality of welding described in this chapter.

To enhance the composite action with concrete, such composite structural steel as checkered plates, ribbed pipes, and H-shape steel with indentations have been developed. Whether it is appropriate to use these steel may be judged by testing or from past data.

(2) The welding materials are prescribed in JIS Z 3211 “Covered Electrodes for Mild Steel”, JIS Z 3212 “Covered Electrodes for High Tensile Strength Steel”, JIS Z 3351 “Submerged Arc Welding Solid Wires for Carbon Steel and Low Alloy Steel”, and JIS Z 3352 “Submerged Arc Welding Fluxes for Carbon Steel and Low Alloy Steel” and the high-strength bolts are prescribed in JIS B 1186 “Sets of High Strength Hexagon Bolt, Hexagon Nut, and Plain Washers for Friction Grip Joints”. Torcia high-strength bolts now very popular are prescribed not in JIS, but in “Set of Torcia High-strength Bolt, Hexagon Nut, and Plain Washer for Friction Jointing” (Japan Road Association). Therefore, this standard may be used instead.

13.2.2 Concrete

(1) Concrete should have designated filling capacity so that concrete and steel are in monolithic form and meet the designated performance requirements.

(2) In cases where compaction is difficult between steel plates or verifying the inside is impossible as for sandwiched structures and concrete filled columns, self-compactible high fluidity concrete should be used as a standard practice.

[Commentary] (1) In composite steel-concrete structures, selecting concrete quality so as to ensure integrity between concrete and steel is important. The filling capacity of concrete should therefore be determined properly according to the structural format, dimensions and concrete construction method.

If the relationship between concrete compactability, flowability, and segregation resistance is clear, the concrete compactability can be represented by flowability and segregation resistance.

The concrete flowability is represented by a slump or slump flow. The segregation resistance is evaluated from that in a static state expressed by a bleeding rate and from that when the concrete moves. If highly flowable concrete is used, the segregation resistance when the concrete moves can be expressed with the flow arrival time and the efflux time.

The concrete compactability of a composite steel and concrete structure depends greatly on structural conditions (structural form, shape, and dimensions of a structure or member), concrete conditions (materials, mixing, consistency of fresh concrete, and bleeding characteristic), and construction conditions (concrete placement method). Composite steel and concrete structures must be filled with concrete in order to prevent detrimental voids (defective compacting) between the concrete and steel. However, voids tend to occur under the upper or lower flanges of a steel frame in steel reinforced concrete, under a diaphragm in a concrete-filled steel column, and under the upper plate of a sandwich structure. In order to eliminate these defects, concrete compactability must be set appropriately. Also, whether the required concrete compactability is achieved or not must be verified based on past data or by concrete compacting test and compactability analysis.

Even if concrete fills properly, bleeding occurs in ordinary concrete and a gap of a few millimeters may occur in places where bleeding water is retained. When using ordinary concrete, therefore, corrective construction measures should be taken by injecting shrinkage compensating mortar or equivalent paste in the gaps created by bleeding, or the structure should be designed to meet the designated performance requirements.

(2) In cases where compaction is difficult between steel plates or verifying the inside is impossible as for sandwiched structures and concrete filled columns, there is a concern that damaging voids (that cannot be filled completely) may remain between concrete and steel.

Self-compactible high fluidity concrete should be used. When using high fluidity concrete, refer to Chapter 7 High Fluidity Concrete.

However, if the space surrounded with steel plates is large enough for a worker to enter for concrete placement or if a work method to secure concrete compacting is established, the concrete compactability may be set in the same way as for ordinary reinforced concrete or steel reinforced concrete.

Even in cases where self-compactible high fluidity concrete is used, autogeneous shrinkage of concrete sometimes causes slight delaminations from steel in large cross section. The gaps created by delaminations are small, less than 1 mm. Considerations should be made in the design phase to ensure that the structure meets the designated performance requirements even in case of delaminations, or it should be verified in the design phase that delaminations have only limited effects. In cases where injection is required in small delaminations, injecting mortar is difficult. Shrinkage compensating paste should be used.

13.3 Production of Steel Members

13.3.1 Processing of steel

(1) In the processing of steel, the mechanical properties required in design or other performance requirements shall be satisfied. High strength bolt holes should be processed so that they may be of such a quality that the design joint strength may develop.

(2) For easy compacting, steel members shall have concrete placing holes and vent holes arranged appropriately.

(3) Before production starts, a full-size drawing or the equivalent shall be prepared to confirm the basic shape and the existence of obstacles in production.

(4) In the plank layout of main members, in principle, the main stress direction on each member shall in general coincide with rolling direction.

(5) For marking the lines on the steel plate, in principle, a chisel or a punch should not be used where a tensile stress is large or a repeated load is applied.

(6) In principle, main members shall be cut by automatic gas cutting. Each cut cross section, processed edge surface or chipped surface shall satisfy the prescribed quality.

(7) In cases when there is shoulder-down, warp or uneven at the cut line, it shall be finished flatly by edge polishing or grinder finishing.

(8) A drill or both a drill and a reamer should be used for boring holes of specified diameters in a main member. However, a punch may be used for boring holes in a board less than 12 mm thick for the secondary member.

In cases when boring bolt holes of specified diameters in a main member before tentatively assembled, in principle, template should generally be used except when an NC punching machine is used.

(9) The cold bending of a main member should be processed with due care regarding

the deterioration of toughness and cracking caused after the processing.

[Commentary] (2) When holes in steel members are made and followed by welding it is necessary to confirm that there is no structural problem.

(3) The design drawing also shall be checked to ensure that the concrete placing holes and the vent holes are arranged appropriately and that site welding is minimized. The basic shape before production and problems during production are checked by life-size fabrications on the floor or using numerical control (NC).

(4) In general, the mechanical properties of steel plates do not differ greatly between the rolling direction and the rolling perpendicular direction about the tensile strength and yield point. However, the elongation is smaller by 10 to 15％ and the squeeze smaller by 5 to 15％ in the direction perpendicular to rolling. Also, since the Charpy impact value in the direction perpendicular to rolling may be about half that in the rolling direction, the main stress direction and the rolling direction shall basically be matched for the plank layout of a main member.

(6) Plates are cut by gas cutting or shearing. To ensure high-quality cut sections, main members shall basically be cut by auto gas cutting. However, a filler, a tie-plate, a steel section, a gusset plate of 10 mm or less in thickness, and a stiffener may be cut by shearing.

(8) For the diameters, diameter tolerances, penetration ratios, and stopping ratios of bolt holes, "Standard for Civil Engineering Works" (Japan Railway Construction Public Corporation) and "Specifications for Highwaybridge with Explanation II - Steel Bridges" (Japan Road Association) shall be referred.

(9) Cold bending may lower the toughness of steel or cause them to crack. For the cold bending of main members, therefore, the internal diameter shall be basically 15 times the plate thickness or more to prevent great local strains. However, the internal diameter may be seven times or five times the plate thickness or more for steel reinforcements whose results of the Charpy impact test prescribed in JIS Z 2242 "Method of impact test for metallic materials" satisfy the conditions given in Table C13.3.1 below and chemical components do not contain nitrogen more than 0.006％. For cold bending in the rolling perpendicular direction, the Charpy absorbed energy value in the direction perpendicular to rolling applies.

Table C13.3.1 Tolerance of cold bending radius against Charpy absorbed energy

Charpy absorbed energy：J	Internal radius of cold bending
150 or more	Seven times the plate thickness or more
200 or more	Five times the plate thickness or more

The test temperature, the number of test samples, and the sampling position for the Charpy impact test conform to JIS G 3106 or JIS G 3114

13.3.2 Factory welding

(1) In order to satisfy the required joint performance, factory welding shall be done.

(2) For factory welding, the items shall be described in a work plan

(3) Factory welding must be done indoors or in a similar environment.

[Commentary] (1) This article gives the minimum necessary items, with respect to welding, that should be described in a construction plan and confirmed at execution. In general, welded joint performance is not only determined by the indication of a welding symbol but is also affected greatly by the metallurgical properties related to execution and the degree of existing defects. These items require due care at work. Verifying the following points is important to the satisfaction of designated joint performance requirements.

(a) Type and characteristics of a steel

(b) Welding method, open edge shape, and type and characteristics of a welding material

(c) Qualifications for welding engineers (refer to JIS Z3801 "Standard qualification procedure for manual welding technique" and JIS Z3841 "Standard qualification procedure for semi-automatic welding technique".

(d) Welding environment and facilities

(e) Shape of joint (groove), Processing of steel pieces to be joined, assembling accuracies

(f) the cleanness and Dry state of a section to be welded

(g) Drying condition of a welding material

(h) Welding conditions and order

(i) Other points to remember

(2) The following items should be described in construction plans concerning welding as a minimum.

1. Qualification of a welder
2. Welding test
3. Assembling method of work piece and accuracy in combination
4. Assembly welding (Temporary welding)
5. Cleaning and drying of member before welding
6. Selection and charge of welding materials
7. Preheating
8. General notes on welding work
9. Inspection of welding

10. Attachment of hangers and apparatus for erection

11. Defect repairing method

12. Strasin release method, etc.

13.3.3 Temporary assembly, assembly symbol and transportation

(1) For temporary assembly, appropriate supports should be set up to make each member free from stress.

(2) Before transportation, assembly symbols shall be marked on each member. If a member having 5 tons or more in weigh, its weight and center of gravity shall be marked.

(3) Members should be transported carefully not to damage them or to prevent salt adhesion on the way.

[Commentary] (1) The purpose of temporary assembly is to check the shape and dimensions of each produced member, the status of jointing between members, the assembled status, the welded status, and disturbances to site erection. If a method different from temporary assembly can ensure inspections of equivalent precision, temporary assembly may be performed partially or totally omitted.

As a rule, members shall be assembled temporarily with no stress in individual members. If the joints of temporary assembly can be reproduced at the erection site, the specified shape can be obtained. However, due to the specific requirements of certain erection methods, it may not be possible to support a member in a stress-free arrangement. In such a case, an appropriate temporary assembly method shall be selected in consideration of the design and the erection method.

(2) Assembly symbols, masses, and gravity centers are usually indicated by painting. Even if the unit mass is less than 5 tons, the mass and the center of gravity should be indicated in the case where the member is of a complicated shape.

(3) Care should be exercised not to damage members during loading, unloading and transport. Special care is required in particular in cases where field welding is involved or where chloride adhesion is expected during offshore or coastal transport.

13.4 Erection of Steel Members

13.4.1 Erection

Steel members shall be erected in accordance with the method and the procedure of construction determined in design. If an erection method different from that planned at the design stage is adopted, safety shall be insured by reexamining the stress and deformation to be expected during the erection.

[Commentary] For construction methods and procedures that differ from those originally prescribed, it is necessary to be considered safety before erection because stresses due to dead loads, such as those of steel reinforcements and pre-hardened concrete, may change drastically, causing such problems as concrete cracking and steel frame buckling or deformation.

13.4.2 Temporary placement and assembly of steel members

(1) In the case of temporary placement of steel members at the construction site, the members shall be placed to avoid contact with the ground. For long-term temporary storage, appropriate measures shall be taken to prevent contamination, damage, rusting, and deformation.

(2) Members shall be assembled according to the specified assembling order.

[Commentary] (1) Special care must be taken to prevent toppling because a temporary installation place may not always be topographically flat.

(2) When assembling members, adjust the positions of high-strength bolt holes by using temporary tightening bolts and drift pins, and then tighten the high-strength bolts. Since members may be damaged and slightly deformed during transportation, it is necessary to take great care not to produce root gaps between members.

13.4.3 Jointing using high-strength bolts

(1) Contact surfaces of the both work pieces to be jointed shall be treated to achieve a 0.4 or greater of slip factor except for bearing connection.

(2) Table 13.4.1 gives the standard values of the axial forces for bolt tightening.

Table 13.4.1 Axial force for bolt tightening

Nominal diameter of screw	Axial Force for Bolt Tightening (kN)	
	F8T	S10T, F10T
M 20	144	178
M 22	178	221
M 24	207	257

(3) Bolts shall be fastened as follows:

(a) For the full tightening of a Torcia type high-strength bolt, a dedicated tightening machine shall be used.

(b) For the tightening of a high-strength hexagonal bolt by the torque method, the tightening torque shall be adjusted to apply the axial force for bolt tightening equally to each bolt.

(c) In principle, the axial force should be applied to a high-strength hexagonal bolt by turning the nut.

(4) Bolts should be tightened sequentially beginning from the one at the center of a connection plate, then this procedure shall be repeated again. After initial tightening, in principle, bolts, nuts, and washers should be marked in order to find out easily the tightening errors and co-turning.

(5) In the case when both welding and high-strength bolt friction jointing are used together, in principle, a high-strength bolt should be tightened after welding is completed.

[Commentary] (1) In the design of friction jointing, the slip strength of a joint is calculated with the slip factor on the joint surface as 0.4. Therefore, a joint surface must be processed to make its slip factor 0.4 or more. The slip factor here means a kind of coefficient of friction but is adopted here because the term is used in previously published standard documents.

Up to the present, making a joint surface rough by removing black rind is known to produce 0.4 or greater slip factor. Even when this kind of processing is done at shop production, it is difficult to maintain this status until jointing at site. The joint surface is often rusty, greasy, or dusty. Therefore, it is important to clean the joint surface well immediately before jointing at site.

Bolt tightening must be made to connect members with connection plates.

(2) It is a standard to increase axial force for tightening bolt at execution by 10% from the design axial force when considering the dispersion of torque coefficient, the creep, the relaxation, and the dispersion of slip factor.

A Torcia high-strength bolt produces a tightening torque when an axial force twists and breaks the rupture groove at part of the bolt. This bolt is produced with a purpose to carry the axial force for tightening bolt. Therefore, setting the bolt itself will ensure a axial force equivalent to that for a high-strength hexagon bolt.

“Specifications for Highway Bridges, Part II Steel Bridges” (Japan Road Association) prescribes that the average axial force for tightening bolt of Torcia high-strength bolts at room temperature (10 to 30°C) shall be within the range in Table C13.4.1 below when five samples taken randomly from one production lot are tested.

Table C13.4.1　Average axial force for tightening bolt at room temperature (10 to 30°C)

Set	Screw nominal diameter	Average of axial forces for tightening bolt in a set from one production lot: kN
S10T	M 20	172～202
	M 22	212～249
	M 24	247～290

(3) A Torcia high-strength bolt has its pin tale cut by a certain tightening torque. For full tightening, a special tightening device for Torcia high-strength bolts is necessary.

High-strength hexagon bolts are jointed roughly by the torque method and the turning-nut method depending on the control of tightening bolt axial force. This article prescribes the torque method that is frequently used. In the torque method, a bolt is basically tightened by turning its nut, because the torque coefficient of a bolt set is specified for nut turning. If it is inevitable in a construction procedure to turn a bolt head, it is necessary to check the value again. Prior to execution, an appropriate tightening torque must be selected to reach the standard bolt axial force.

The bolt tightening machine and measuring instruments must be inspected at appropriate timings to check their precisions.

(4) If bolts at a joint are tightened from outer edge, the connection plate is lifted and does not connected tightly. To prevent this problem, the bolts shall be tightened from the center to the edge.

If each bolt is tightened with the required axial force, the first tightened bolt tends to become loose. As a rule, each bolt shall be tightened in two steps. For the initial tightening, about 60% of the axial force for tightening bolt given in Table 13.4.1 is recommended.

(5) As a rule, bolts shall be tightened after welding to reduce welding constraints and to prevent deformation by welding from lowering the slip strength. When tightening high strength bolts after welding, deformation due to welding should be prevented by temporarily tightening the bolts or attaching restraining materials during welding.

Also, for welding after the tightening of high-strength bolts, therefore, the influences of constraints must be considered.

13.4.4 Welding in construction site

(1) For the site welding, it is necessary in advance to examine the effects of shrinkage, deformation, constraints, and etc., which accompany the welding, on the overall and detail structures to be welded

(2) Notes on the site welding work should be the same as those given in Section 13.3.2.

[Commentary] Site welding described in this article means welding for site jointing during erection.

The checking items for execution of site welding are in accordance with Section 13.3.2. However, site welding generally requires stricter control than shop welding in factory because the groove accuracy, groove cleaning, drying, fluctuation of secondary current, and drying of welding materials are difficult to maintain in good condition, compared with shop welding in factory.

For site welding, the side welding method and measures against anticipated on-site deformation must be determined at the stage before factory production and must be reflected in factory production and site welding. The relationship between the bolt tightening method or bolt hole size and shrinkage, and how to create the designated shape of the welding plane at the end of the member should be considered in the phase of production in plant.

If weather conditions on the welding site are as listed below, welding shall be avoided to prevent welding defects, except when the working conditions for welding can be set with a windbreaker or a pre-heater.

1) Raining or case when rain is anticipated during execution

2) Immediately after raining

3) Strong wind

4) Temperature of 5°C or below

13.5 Concrete Construction

(1) Concrete shall be placed and compacted carefully to prevent imperfect filling between the concrete and steel.

(2) When using self-compactible high fluidity concrete in a bulkhead section, a closed space encircled by steel plates, the concrete should be placed continuously as a standard practice.

[Commentary] (1) Steel reinforced concrete tends to have voids under the upper or lower flanges of a steel member in a beam, at a joint between a column and a beam, and at a splice. To prevent these defects, make concrete overflow through the air vents at concrete placement and compacting to ensure full compacting and also take the measures such as followings.

(a) For a beam, place concrete from one side of the web of steel beam while ensuring full compaction. After checking the full compacting of concrete under the flange, start placing concrete on the other side.

(ii) In a column-beam connection, concrete placement should be suspended at the bottom of the beam, concrete should be fully compacted and additional concrete should be placed from two or more points on the side of the column. Then, concrete should be fully compacted.

In composite steel-concrete structures, steel arrangement and concrete-steel contact conditions are considerably different from those in ordinary concrete. The quality and filling method of concrete should be fully examined in the construction planning phase.

(2) In cases where compaction is difficult between steel plates or verifying the inside is impossible as for sandwiched structures and concrete filled columns, self-compactible high fluidity concrete should be used as a standard practice. Then, continuously placing concrete in a bulkhead section, a closed space, is important. Self-compactible high fluidity concrete is greatly different from ordinary concrete. In order to make best use of its characteristics, the rate and locations of placement should be selected properly.

13.6 Inspection

13.6.1 General

In order to verify that the completed structure meets the designated performance requirements, effective and economical inspection plans should be prepared and the accepting party should assume the responsibility for conducting necessary inspections in each construction phase.

[Commentary] Since the construction of a composite steel and concrete structure requires steel member production and erection as well as concrete works, it is important to plan appropriately the inspection including steel member production and erection.

13.6.2　Inspection for acceptance

13.6.2.1　Inspection for acceptance of steel

The accepting party shall assume the responsibility for conducting acceptance tests for steel. The tests should be carried out in accordance with Chapter 6 of "Construction: Inspection Standards". For the inspection of steel not mentioned in Chapter 6 of "Construction: Inspection Standards", Table 13.6.1 should be referred.

Table 13.6.1　Inspections for acceptance of steel pipes

Classification	Item	Testing method/ Inspection method	Period / Frequency	Criteria for judgment
Carbon steel pipe for general structures	Quality item in JIS G 3444	Manufacturer's test sheet or the method in JIS G 3444	At delivery	Compliance with JIS G 3444
Square steel pipe for general structures	Quality item in JIS G 3466	Manufacturer's test sheet or the method in JIS G 3466		Compliance with JIS G 3466
Centrifugal cast-steel pipe for welded structures	Quality item in JIS G 5201	Manufacturer's test sheet or the method in JIS G 5201		Compliance with JIS G 5201

[Commentary] The accepting party conducting acceptance tests for steel is the contractor of composite steel-concrete structures. The results of acceptance tests should be verified by the Owner.

13.6.2.2　Inspection for acceptance of jointing materials

The accepting party shall assume the responsibility for conducting acceptance tests for jointing materials. Inspection for acceptance of jointing materials should be carried out in accordance with Table 13.6.2.

Table 13.6.2 Inspections for acceptance of jointing materials

Classification	Item	Testing method/ Inspection method	Period / Frequency	Criteria for judgment
Covered electrode for mild steel	Quality item in JIS Z 3211	Manufacturer's test sheet or the method in JIS Z 3211	At delivery	Compliance with JIS Z 3211
Covered electrode for high-tension steel	Quality item in JIS Z 3212	Manufacturer's test sheet or the method in JIS Z 3212		Compliance with JIS Z 3212
Submerged-arc welding solid wire and flux for carbon steel and low-alloy steel	Quality item in JIS Z 3351 and JIS Z 3352	Manufacturer's test sheet or the method in JIS Z 3311 and JIS Z 3352		Compliance with JIS Z 3311 and JIS Z 3352
Torcia high-strength bolt	Necessary item	Manufacturer's test sheet or necessary method		Compliance with standards prescribed for achieving the purpose of use
High-strength hexagonal bolt	Quality item in JIS B 1186	Manufacturer's test sheet or the method in JIS B 1186		Compliance with JIS B 1186

[Commentary] The accepting party conducting acceptance tests for connection materials is the contractor of the composite steel-concrete structure. The results of acceptance tests should be verified by the Owner.

Welding materials and jointing materials such as high-strength bolts are usually inspected even at the manufacturing factory. Therefore, the material properties, strengths, shapes, dimensions, and others may be checked with inspection sheets submitted from the manufacturing factory. Torcia high-strength bolts are specified not in JIS, but in “Set of Torcia High-Strength Bolt, Hexagon Nut, and Plain Washer for Friction Jointing” (Japan Road Association). Therefore, this standard may be used instead.

Data for torque coefficient of high strength bolts are also submitted from the manufacturing factory. The data need to be checked because the storage conditions after shipping may change the torque coefficient from that at factory inspection.

13.6.2.3 Inspection for acceptance of concrete

The accepting party should assume the responsibility for conducting the acceptance tests for concrete.

[Commentary] When using ready-mixed concrete, refer to Chapter 5 of "Materials and Construction: Inspection Standards". The stipulations concerning the use of special concrete should be adhered to. In cases where concrete not mentioned in "Materials and Construction" is used or where the structure needs to meet special performance requirements, appropriate acceptance tests should be conducted considering the characteristics of concrete or the performance requirements for the structure.

13.6.3 Inspection for production of steel members

13.6.3.1 Inspection of welding

The Owner should assume the responsibility for inspecting welding by an appropriate method fit for the objective. External and internal flaws should be inspected in accordance with Tables 13.6.3 and 13.6.4, respectively.

Table 13.6.3 Inspection of external flaws

Item	Testing or inspection method	Timing	Decision criteria
Weld cracking	Visual inspection and magnetic particle inspection as required	At the time of production	No cracking is found
Appearance and shape of the bead	Visual inspection	At the time of production	As stipulated in the construction plan
Reinforcement and finishing of groove weld	Visual inspection	At the time of production	As stipulated in the construction plan

Table 13.6.4 Inspection of internal flaws

Item	Testing or inspection method	Timing	Decision criteria
Radiography	Method specified in JIS Z 3104	At the time of production	Less than specified size
Ultrasonic testing	Method specified in JIS Z 3060	At the time of production	Less than specified size

[Commentary] The welding quality is affected by joint type, material properties, plate thickness, welding conditions, precision of groove and assembly, cleanness of groove, control of preheating, postheating and inter-layer temperatures, and welding skill. Therefore, these conditions must be well considered at inspection. In the field, achieving the same level of welding quality as at the plant is difficult in numerous cases. Inspection methods are also restricted. Due care should therefore be exercised in field welding as compared with plant welding.

Welding is usually checked by visual inspection, radiographic testing, ultrasonic testing, magnetic particle testing and penetration testing. As a rule, the external flaws is to be visually inspected from end to end. In inspection, priority is given to undercuts, overlaps, cracks, pits, and bead irregularities. Cracks are mainly checked by visual inspection, but magnetic particle testing or penetration testing may be used as required.

Internal flaws during welding should be inspected by JIS Z 3104 "Methods of radiographic examination for welded joints in steel" and JIS Z 3060 "Methods for ultrasonic examination for welds of ferritic steel".

For details of welding quality control and inspection, refer to 17.4 Welding of the "Specifications for Highway Bridges: Part II Steel Bridges" prepared by the Japan Road Association. Decision criteria should be established based on the document.

Ultrasonic examination methods are generally used in the field for inspecting internal flaws during field welding because using radiation is difficult in the field. Flaws should be repaired carefully considering the effect of repair on the parent materials.

13.6.3.2 Inspection for tightening of high-strength bolt

The Owner should assume the responsibility for inspecting the tightening of high strength bolts in accordance with Table 13.6.5.

Table 13.6.5 Inspection of high strength bolt tightening

Item	Testing or inspection method	Timing	Decision criteria
Torque-shear high strength bolt	Cutting of pin-tail nut is verified for all samples. Visual inspections are conducted using markings.	At the time of production	Visual inspection
Hexagonal-headed high strength bolt	Testing using a torque trench Ten percent of bolts in a group are used as a standard practice.	At the time of production	Bolt tightening torque is plus or minus 10% of the torque specified at the time of calibration

[Commentary] A Torcia high-strength bolt can be confirmed to be tight if the pin tale is broken. Therefore, only the cutting pin tale as well as a co-turn with marking should be checked.

If abnormal tightening is detected in tightening test of a high-strength hexagonal bolt using an automatic recorder, the bolt may be found by referring the recording paper and the marking and be retightened.

When a torque wrench is used, a high-strength hexagon bolt must be checked immediately after tightening because the torque coefficient changes if the tightened bolt is left for a long time.

When welding follows the tightening of high strength bolts, the effects of restraining should be taken into consideration.

“Steel Highwayridge Construction Handbook” (Japan Road Association) may be referred to for the acceptance criteria and other details.

13.6.4 Inspection for filling condition of concrete

The Owner should assume the responsibility for verifying by an appropriate method that concrete fills so that the composite steel-concrete structure may meet the designated performance requirements.

[Commentary] In cases where directly verifying the compaction is difficult between steel plates, inspection should be made by a method the reliability of which has been verified. Inspection methods include infrared thermography, hammering tests, ultrasonic tests and application of radioisotope. Inspection should be conducted at the end of placement to verify concrete filling and after the hardening of concrete to verify the effects of bleeding and other phenomena.

Damaging voids (poorly filled areas) are likely to occur below the top and bottom flanges of steel members in steel framed reinforced concrete structures, below the diaphragm in concrete filled columns, and under the top steel plate in sandwiched structures. Careful inspections are therefore required.

In cases where air vents are installed in steel plates at appropriate locations, whether concrete fills completely or not can be determined by verifying concrete overflow through the air vents.

In cases where voids that are not allowed (poorly filled areas) are detected and shrinkage-compensating mortar or paste of equivalent performance is injected, care should be exercised not to deteriorate the performance of steel members due to punching or welding.

CHAPTER 14 FACTORY PRODUCTS

14.1 General

14.1.1 Scope

This chapter presents the standards required for production and construction of factory products.

[Commentary] This chapter provides the general performance requirements for factory products, including not only plain and reinforced factory products but also prestressed factory products, to be produced continuously in large quantities in a well-controlled plant. However, provisions of this chapter are not applicable to plants with insufficient control, or pre-cast units produced in a temporary yard near a construction site.

14.1.2 General

Factory products should be produced under the guidance of professional engineers with adequate knowledge about factory products, paying due attention to the materials, mix proportions, mixing, application of reinforcement, shaping and curing, with a view to meeting the designated quality requirements for the factory product.

[Commentary] Factory products have several characteristics. First, the materials, mix proportions, production facilities and construction can be managed easily. Second, factory products can be produced constantly by skilled workers. Third, production, transport and assembly of factory products can easily be mechanized to save manpower. Fourth, concrete can be placed at locations rarely affected by the weather where simple work is possible. Fifth, full-scale tests are stipulated in appendices to JIS documents and can be conducted for most of the factory products. Sixth, some factory products have very small cross section.

Since it is assumed that factory products are manufactured in highly controlled plants, restrictions on the maximum size of coarse aggregates and the minimum cover for steel may be relaxed as stated elsewhere.

Since early age strength, instant demolding ability, and, in some cases, high strength are required, stiff concrete with low W/C may be used in the manufacture of factory products. Compaction using strong vibration, centrifugal compaction, pressing compaction, instant demolding, accelerated curing and other special manufacturing techniques are normally used in producing large numbers of high quality factory products. However, when these special techniques are used, characteristic care shall be taken during manufacture, because the special techniques differ from those used when producing normal concrete.

Numerous factory products are transported to the construction site for assembly and connection. Then, the connection is likely to become vulnerable. Due care should therefore be exercised during transport and connection so as not to deteriorate the quality and performance of the product.

In manufacturing factory products with lightweight concrete, high strength concrete and self-compacting concrete, the following chapters should be referred to: Chapter 3 “Lightweight Aggregate Concrete”, Chapter 6 “High Strength Concrete” and Chapter 7 “High Fluidity Concrete”, respectively. Also, when using expansive admixture, continuous fiber reinforcing materials and steel fiber reinforcing materials for factory products, the following chapters should be referred to: Chapter 2 "Expansive Concrete", Chapter 4 "Continuous Fiber Reinforced Concrete" and Chapter 5 "Steel Fiber Reinforced Concrete", respectively. For prestressed concrete and composite steel-concrete structures, refer to Chapter 12 Prestressed Concrete and Chapter 13 Composite Steel-concrete Structures.

Chief concrete engineers and concrete engineers authorized by the Japan Concrete Institute; and civil engineering concrete block engineers, factory products production supervising engineers and other engineers authorized by factory production associations should permanently be present at factory products production plants.

14.2 Concrete Quality

14.2.1 General

Concrete used for factory products shall have the designated strength, durability, resistance to cracking and watertightness, and shall be of homogeneous quality.

[Commentary] In many cases, accelerated curing is used to make factory products, which can be demolded at an early age and transported within the factory or to the construction site. Also, factory products, such as concrete piles and sheet piles, may be subjected to impact loads or localized and concentrated loads under erection or construction. Further, some factory products may be located in severe environmental conditions such as marine or other corrosive environments. Thus, Concrete for factory products should have the strength, durability, resistance to cracking, watertightness and protection for steel fit for the type. In cases where concrete is used under special conditions, it should also meet other quality requirements. Appearance is also an essential quality factor for factory products, so it should present a designated appearance.

The total amount of chloride ion contained in concrete should be 0.30 kg/m^3 or less for prestressed and reinforced factory products as for ordinary concrete in order to prevent the corrosion of steel used in factory products. In cases where chloride ions have little effects on reinforced factory products used under normal conditions and unreinforced factory products with additional reinforcement, the upper limit of total chloride ion in concrete may be set at 0.6 kg/m^3 or less.

14.2.2 Strength of factory products

(1) The strength should be specified on the basis of the compressive strength determined using one of the following methods:

(a) In the case of general factory products, the value of the compressive strength at the age of 14 days.

(b) In cases when special accelerated curing such as autoclaving is used, the value of compressive strength at an appropriately lower age than 14 days.

(c) In cases when accelerated curing is not used, or in the case of relatively thick members, the value of compressive strength at the age of 28 days.

(2) Compressive strength tests for concrete used for factory products shall be

conducted as described below.

(a) Specimens should be made under the same compaction and curing conditions as those for factory products.

(b) Typical specimens should be 10 cm in diameter and 20 cm in height, and be cylindrical.

(c) Compressive strength should be specified as stipulated in JIS A 1108.

(3) In cases when factory products are manufactured in a manner similar to that of ordinary reinforced concrete members, or in cases when it is difficult to meet the provisions in Clause (2)(a) above, the strength of concrete in the products, shall be specified in terms of compressive strength tests carried out according to JIS A 1132 and JIS A 1108.

(4) Compressive strength at the stage of demolding, application of prestressing, or delivery, shall meet the required value determined for each stage of manufacture.

[Commentary] (1) Compressive strength is almost always required for evaluating the quality of factory products as well as for normal concrete. Because, as it is rare that tensile strength and bending strength, etc. are specified as a quality of the factory products, the compressive strength is specified as the representative property for the quality of factory products. In cases when the quality of factory products is specified on the basis of strength except for the compressive strength, the strength of the determined requirement shall be satisfied.

As various methods in curing factory products are used, with the progress in age, considerable differences appear in development of the strength. In general, the strength of the factory products develops rapidly in the early stage because the members of factory products are usually thinner, accelerated curing is more often used, and because the water-cement ratio is less than that used in the production of the conventional concrete. However, the rate of increase in the strength of factory products in the long-term is less than that of conventional concrete. Therefore, the strength of general factory products under atmospheric-pressure steam curing, shall be specified, while referring to results of experiments, on the basis of compressive strength at 14 days determined using (a).

As the strength of the factory products using a high-pressure steam curing method (autoclave curing method) can only be increased with time after the curing ends, the compressive strength should be determined using (b). The strength of factory products not using accelerated curing or factory products with comparatively thick section shall be specified, as well as the conventional reinforced concrete structures, on the basis of compressive strength at the age of 28 days determined using (c). In the above case, comparatively thick sections of factory products denote sections with thicnesses greater than 45 cm.

In cases where the factory product is shipped before it reaches a designated age through mutual consultation between the accepting party and the manufacturer, it should be verified at the time of shipment that the designated compressive strength is available.

Furthermore, in some types of factory products, the compressive strength can be specified at appropriate age that is less than 14 days or more or less than 28 days by using a combination of material used and the curing method.

(2) In the manufacturing of factory products, some factory products are compacted using centrifugal force, strong vibration and pressure. Further, steam curing is generally used for

accelerated curing. Therefore, it is not adequate that the compressive strength of the factory products in such manufacturing conditions is evaluated on the basis of the compressive strength of test specimens under standard curing. Thus, as it is necessary that, in order to appropriately evaluate the quality of factory products, test specimens and manufacturing conditions of the factory products are as equal as possible, the test specimens are determined as mentioned in Clause (a).

The maximum size of coarse aggregate used in factory products is smaller than that used in normal concrete, because the thickness of members in factory products is less than that of members in conventional reinforced concrete structures. Also, the usual strength test can easily be carried out using cylindrical specimens whose size is 10cm in diameter and 20cm in height. Further, cylindrical specimens whose size is 10 cm in diameter and 20 cm in height have been used in the compressive strength of factory products. Therefore, the test specimen in which the cylinder size is determined as mentioned in Clause (b). However, in cases when using coarse aggregates having a maximum size of 30 mm or more, it is necessary to use cylindrical test specimens of large type, at least 12.5 cm in diameter and 25 cm in height. Factory products compacted using centrifugal force should, in principle, be prepared according to the JIS A 1136 "Method of Test for Compressive Strength of Spun Concrete". In the case when cylindrical specimens whose size is 5 cm in diameter and 10 cm in height are used in factory products using mortar or when a test specimen of hexagonal cylinder, etc. which has no capping is used, the comparative test with cylindrical specimen as mentioned above needs to be sufficiently carried out, and these characteristics shall be understood when in use.

(3) It is proper that a compressive strength test is carried out in order to investigate the quality of factory products in accordance with the following standards; the JIS A 1132 "Method of Making and Curing Concrete Specimens" and the JIS A 1108 "Method of Test for Compressive Strength of Concrete". When the manufacturing method of factory products is similar to that of ordinary reinforced members, it is quite natural that compressive strength tests using standard test specimens can be the basis for determining the concrete strength of factory products without carrying out any special tests. When factory products require special compaction and curing methods, and the testing method for test specimens made in the same condition has not been prescribed, the compressive strength of standard test specimens can be utilized to determine the compressive strength of factory products. In this case, the relation between the compressive strength and the actual strength of factory products should be investigated sufficiently.

(4) In cases when the compressive strength used in factory products at the stage of demolding, application of prestressing, or delivery is determined, the determined strength shall be satisfied. In cases when the strength has not been determined even in the manufacturing process, it is important to satisfy the required value which the Engineers in charge of manufacturing indicate, if necessary.

14.3 Materials

14.3.1 Cement

Cement shall be selected properly so as to obtain factory products that meet the designated quality requirements.

[Commentary] For factory products, ordinary Portland cement is used in most cases. High early Portland cement is frequently used for prestressed factory products because it enables early development of high strength. It is also fit for factory products that need to be shipped quickly or for factory products that are produced during the cold period. In order to enhance the resistance to sea water and control thermal cracking in large factory products, blended cement such as blastfurnace slag cement and fly ash cement, and moderate heat cement are used. For these types of cement, adequate curing is required because the development of early age strength is generally delayed. When using cement for which no JIS stipulations are available such as white Portland cement for producing colored concrete, and ultra rapid hardening cement, its quality should be verified by testing.

The cement for factory products should be selected based on Section 3.2 of "Materials and Construction: Construction Standards" considering the characteristics of factory product production methods and the performance requirements for the product.

14.3.2 Fine and coarse aggregates

(1) Fine and coarse aggregates shall be appropriately selected, depending upon the type of products, method of manufacture, etc. in a manner in which the required quality is imparted to the factory product.

(2) Maximum size of coarse aggregates shall not be more than 40 mm and shall not exceed 2/5 of the minimum dimension of the product or 4/5 of the minimum clearance between reinforcing bars. However, in cases when conditions for sufficient compaction are confirmed, every aggregate can be used without any limitations.

(3) In the case of pre-stressed factory products, recycled aggregates shall not be used.

[Commentary] (1) Factory products need to have not only excellent quality and performance but also good appearance in numerous cases. The type and properties of the aggregate to be used should therefore be fully investigated by referring to Sections 3.4.1 and 3.4.2 of "Materials and Construction: Construction Standards". The grading of fine aggregate has great impact on the appearance. Appropriate mixes of large and small particles should therefore be used.

The concrete for factory products that require high strength is greatly affected not only by mixing, curing and other production conditions but also by the quality of aggregate. Selecting fine and coarse aggregates of excellent quality is especially important.

Use of crushed fine aggregates or fine aggregates made from granulated iron-blast-furnace slag has an advantage in terms of better control of deformation of factory products at the time of instant demolding. Also, use of lightweight aggregates leads to lighter factory products, which not only reduce the dead load of the structure, but also are advantageous from the point of view of transportation and erection. When using lightweight aggregates, refer to Section 3.2.

When using recycled aggregates, recycled concrete aggregate can be used for factory products only when it is confirmed through a careful survey of previous results that the required performance of factory products, such as compressive strength, drying shrinkage and durability, are not adversely affected.

(2) Generally, coarse aggregates having a maximum size of 20 or 25 mm may be used in factory products. For products with particularly smaller thicknesses, aggregates with a maximum size of 10 mm or 15 mm may be used. Further, in cases of factory products with a relatively large cross section, aggregates with a maximum size of 40 mm have been used and thus the maximum size of coarse aggregates that may be used has been kept at 40 mm.

It is probable that concrete will spread to the edge of the framework because (a) coarse aggregates used for factory products are controlled to keep a constant grading, (b) aggregates of excessively large particle size are seldom used, and (c) concrete can be sufficiently compacted.

Therefore, the maximum size of coarse aggregates is specified as 2/5 of the minimum thickness of factory products and 4/5 of the minimum clearance between reinforcing bars.

Since compactability can be checked by a test of real-size specimens (products), some factories especially manufacture factory products with a little thickness or densely reinforced bar arrangement without any limitation on aggregate size for reduction of the shrinkage or economical efficiency. In such cases, factory products can be manufactured without any limitations on aggregate size.

(3) It is known that drying shrinkage and creep in concrete using recycled aggregate are larger than those using normal aggregate, and in cases in which concrete is used in prestressed factory products, the loss of prestress become large. Especially, performance of such concrete in terms of its ability to protect the reinforcing bar is not clear yet. Thus, the use of recycled aggregate in prestressed factory products is not allowed.

14.3.3 Admixtures

Admixtures shall be used in factory products only after appropriately considering the peculiar mix proportion, compaction, accelerated curing, etc., and the effect on the quality of the product and improvement in the efficiency of production.

[Commentary] Chemical admixtures, such as air-entraining agents, water-reducing agents, air-entraining and water-reducing agents, high-range water-reducing agents, high-range water-reducing and air-entraining agents, and high viscosity agents are normally used during manufacture of factory products. In general, high-range water-reducing agents, or high-range water-reducing and air-entraining agents are used in cases when high strength concrete in products is required.

Mineral admixtures, such as expansion admixtures, admixtures for high strength concrete (mainly composed of anhydrous gypsum), ground granulated blast-furnace slag, fly ash and silica powder are normally used during manufacture of factory products. Recently, special factory products, made with high strength concrete or high durability concrete, which contain high-range water-reducing agents, or high-range air-entraining and water-reducing agents, and silica fume have been manufactured. Additionally, some mineral admixtures, which can be used to make factory products that can be demolded early and ensure rapid manufacturing, have been developed. Such mineral admixtures have enabled development of factory products that have an advantage from the view point of shortening the curing period and releasing formwork at earlier ages, especially during winter’s season.

Nowadays, texturized or colored factory products have been developed from the consideration that they harmonize with their environment better. Although there are many coloring agents, it should be ensured that the quality of factory products is not adversely affected.

14.3.4 Reinforcing steel

(1) Reinforcing steel, wires, and rebar used in factory products shall be complies with Sections 3.6.1 and 3.6.2 of "Materials and Construction: Construction Standards". If these materials are complied with one of the following standards, they can satisfy the required qualities.

Hard Drawn Steel Wires	**JIS G 3521**
Low Carbon Steel Wires	**JIS G 3532**
Low Carbon Steel Wires and Rods	**JIS G 3505**
High Carbon Steel Wires and Rods	**JIS G 3506**
Welded Steel Wire and Bar Fabrics	**JIS G 3551**

(2) Steel wires for pre-stressed factory products shall follow Sections 3.6.2 of "Materials and Construction: Construction Standards". If that material is complied with the following standard, it can satisfy the required qualities.

Hard Drawn Steel Wires for Pre-stressed Concrete JIS G 3538

(3) In cases when reinforcing steel other than Clauses (1) and (2) above is used, or in cases when the reinforcing steel is re-processed or heat-processed, the qualities of the material should be confirmed by the tests. Also, the appropriate strength, other design parameters, and the method of use shall be determined by other manners.

[Commentary] (1) and (2) Since the factory products are generally manufactured with thinner unit members, reinforcing steel with a size of 10 mm or smaller is often used. Also, low carbon steel wires and rods often are used for manufacturing factory products. In addition, many factory products are specified by JIS which allows the use of these steel materials.

According to Clause (1), reinforcing materials, which are not specified in either Sections 3.6.1 of "Construction: Construction Standards" or Sections 3.6.3 of "Construction: Construction Standards", shall be checked in terms of their strength, parameters for design, and application method with the consideration of the yield point and crack controlling properties for their kind or purpose of use.

(3) The application method of steel materials not explained in Clauses (1) and (2) above shall be determined after the confirmation of their qualities.

If the epoxy-coated reinforcing bar mentioned in Sections 3.6.1 of "Materials and Construction: Construction Standards", satisfy the certain quality, they do not need to undergo the confirming tests, since manuals or specifications for those materials have been published. However, their performance must be checked to satisfy requirements if those materials have the chance of undergoing a hot curing process or other special manufacturing process. When reinforcing steel is processed for thread rolling, bluing, and so on, the performance of reinforcing steel shall be specially checked so that the quality does not alternate.

Short fibers may be used for reinforcement of mortar such as alkali-resistant glass fibers, carbon fibers, polypropylene fibers, polyethylene fibers and vinylon fibers. Then, appropriate tests should be conducted considering the type of fiber and the product manufacturing method to verify that the factory product is of the designated quality. When using synthetic fibers, a variation of short organic fibers, refer to Chapter 5 Short Fiber Reinforced Concrete.

When replacing the reinforcement or prestressing steel of factory products with continuous fiber reinforcing materials made by converging carbon fibers, aramid fibers and other continuous fibers with resins, the continuous fiber reinforcing materials should comply with JSCE-E 131 "Quality Criteria for Continuous Fiber Reinforcing Materials (draft)". In cases of non-compliance, adequate tests should be conducted. When using continuous fiber reinforcing materials, refer to Chapter 4 Concrete Using Continuous Fiber Reinforcing Materials.

14.4 Mix Proportions

14.4.1 General

Mix proportions for factory products shall be determined appropriately considering the method of molding and curing in order that the products have the required strength, durability and water-tightness.

[Commentary] Properties of factory products such as strength, durability and water-tightness should be determined through tests carried out on actual factory products directly, or on concrete specimens produced under equivalent conditions. Thus, the mix proportions for factory products should be determined to satisfy the required conditions. When factory products will be located in environments with cyclic freezing and thawing, the performance of freeze-thaw resistance should be improved by using air-entrained concrete.

It is necessary to find the optimum condition by checking both the effect of mix proportions and the effect of accelerated curing in cases when mix proportions are determined by considering the required strength of concrete at the demolding stage or the required strength at the pre-stressing stage for factory products.

The concrete mix proportions for factory products should be able to provide the factory product with adequate compactibility, strength and durability and excellent concrete surface, and should be fit for the factory product shaping method.

For factory products with instant demolding, care shall be taken to select the unit water content, sand-aggregate ratio, and air content appropriately.

The required concrete strength should be determined considering the variation of concrete quality in factory products. For factory products, mix design is developed under more severe conditions than stipulated in Section 4.4.3 of "Materials and Construction: Construction Standards" to enhance quality. The compressive strength of concrete obtained in a round of test has been set to be 90% of design strength or greater, and the mean compressive strength obtained in three rounds of tests has been set to be greater than the design strength.

14.4.2 Workability

(1) Workability of concrete shall be determined taking into consideration the shape and size of the product, and the method of production.

(2) It should be verified that appropriate workability is achieved by conducting slump tests, slump flow tests or other appropriate tests.

[Commentary] (1) The method of production differs according to the type of product, because the variety of factory products abounds, and because the shape and size of products differ considerably. Therefore, the workability of concrete shall be appropriately required for the method of production in factory products. The shaping methods for factory products include vibratory compaction with a great force and centrifugal compaction. Due care should be exercised not to cause material segregation.

Although most factory products are manufactured using concrete with 5-10 cm slump, some products are manufactured using concrete with 15 cm slump. In cases when factory products are manufactured using self-compacting concrete, a test using slump flow may be applied to determine the workability of factory products.

(2) When using concrete with a slump of 2 cm or higher, workability can be controlled by conducting slump tests. When shaping stiff concrete with a slump of lower than 2 cm by instant stripping of forms, fresh concrete needs to be controlled by conducting other types of tests. The methods for measuring the workability of stiff concrete with a slump lighter than 2 cm include JSCE-F 508 "Method for testing the compactibility of extremely stiff consistency concrete (draft)", EN 12350-3 "Testing fresh concrete - Part 3: Vebe test" and EN 12350-4 "Testing fresh concrete - Part 4: Degree of compactibility". Concrete workability is generally determined by shaping factory products using compaction methods for actual factory products in numerous cases. Shaking table consistency test methods for pavement concrete is not fit for measuring the workability of extremely stiff consistency concrete because of extremely low amplitude and frequency.

14.5 Production

14.5.1 Factory production

(1) Concrete should be produced in accordance with Chapter 5 of "Materials and Construction: Construction Standards" as a standard practice.

(2) Ready-mixed concrete should be used in accordance with Chapter 6 of "Materials and Construction: Construction Standards" as a standard practice.

(3) Appropriate batch mixers shall be used to mix the concrete used in the products.

[Commentary] (1) and (2) For factory products, relatively stiff concrete with a slump of 5 to 10 cm is frequently used. Workability needs to be achieved that is fit for the shaping method. A test value of 14-day compressive strength is generally used. The premium coefficient in mix proportions is specified under more severe conditions than for ordinary concrete. When using ready-mixed concrete, an appropriate type of concrete fit for the factory product to be manufactured should be purchased through full consultation with the manufacturer of the ready-mix concrete.

(3) Stiff consistency concrete having a low water-cement ratio is generally used for factory products. For mixing such concrete, forced mixing type mixers are suitable. Care shall be taken when tilting mixers are used, as mortar may adhere to the inner mixer lining and the base of blades. This may adversely affect the uniformity of the concrete.

14.5.2 Assembly of reinforcement

(1) The reinforcement shall be assembled by tying annealed steel wire or appropriate clips at the important area in the intersections of reinforcing bars.

(2) In cases when spacers are used, the material and the method of use shall be selected taking into consideration the durability and appearance of the product.

(3) The stirrups, additional steel bars, etc. should, in principle, not be welded to prestressing tendons.

[Commentary] (1) In general, reinforcing bars of factory products are tied using annealed steel wire of 0.5 mm or larger in diameter, or adequate clips. Also, reinforcing bars of factory products to be manufactured in large quantities are mostly pre-assembled, and spot welding is commonly used for them. In all cases, reinforcing bars shall be carefully tied and assembled so as not to be deformed in the manufacturing process.

(2) Using spacers for fixing reinforcing steel into a position is effective, however, care must be exercised to prevent spacers from making weak points in the structure and to avoid deterioration of the durability of factory products due to the harmful effect of corrosion of the reinforcing steel. It is advisable to use spacers made of the same properties of concrete or mortar as the factory products. When using plastic or other types of spacers, the one with a minimum thermal expansion coefficient and of large cross section (opening ratio) that hardly causes lateral buckling of steel due to its weight should be selected. It should be verified before using a spacer that it has no adverse effects on the durability of factory products, based on the records of its use.

(3) Since pre-stressing steel generally contains a large amount of carbon, it is unsuitable for welding. Furthermore, since pre-stressing steel is always worked under high tension, a change in the mechanical properties or a reduction in the sectional area due to welding may cause serious accidents. Thus, the welding of pre-stressing steel is prohibited in principle. However, in the case of pre-stressed concrete piles and other products, spot welding of additional bars to heat-treated pre-stressing bars using the automatic machines, which contain a relatively low amount of carbon, is widely used. When the welding current and time are fully controlled, the reinforcing steel can be spot welded to the pre-stressing steel. In these cases, it is required that the mechanical properties of the tendons be checked to ascertain that they are not less than the design values.

14.5.3 Formwork

The formwork shall have a rigid structure, have an accurate shape and size, and be easy to assemble and remove.

[Commentary] During compacting, molds for factory products are subjected to strong vibration and high pressure. In addition, the molds are repeatedly used, and steam curing usually generates thermal stress in the molds. Accordingly, the molds must be strong and conveniently assembled and disassembled. Steel molds are usually used for concrete forms, and synthetic resin molds are also used. When using molds, sufficient consideration must be given to handling, cleaning, application of form releasing agents, maintenance, and so on.

For production of factory products with accurate dimensions, it is necessary that the tolerances for mold dimensions be less than that for the dimensions of factory products.

14.5.4 Molding

(1) Molding shall be appropriately done using mechanical compaction methods in

order to have factory products with the required quality.

(2) The surface of factory products shall be smoothly finished, taking their applications into consideration.

[Commentary] (1) Compaction methods generally used for factory products include vibration compaction, centrifugal compaction, pressing compaction, vacuum compaction and methods combining the above. Close relationships exist among the type of factory products, mix proportions, mixing and casting. Therefore, it is essential that a suitable mechanical compaction method relevant to the condition be adopted and that casting be performed with care.

Numerous houses have recently been built around plants, and the noise and vibration generated by the manufacture of factory products has been an issue. The working environment for plant employees has been another serious issue. For solving these problems, vibration-free shaping methods using high fluidity concrete with self compactibility or shaping methods that vibrate high fluidity concrete for supplementing concrete filling have been adopted for shaping factory products.

(2) In general, surface finishing is done after compaction by using finishing tools such as rulers, trowels and external vibrators with a bottom plate. Factory products that are compacted by the pressing compaction method are mechanically finished by means of the pressing plate which is attached to the top of the mold. In cases where factory products have an apparent limitation of size in their design specification, the surface finishing shall be done with those considerations.

In cases where the concrete surface is not specially finished, the exposed concrete surface shall be flat and dense. This is one of the most important points for improving the durability and water-tightness of factory products, as well as its external appearance. Therefore, it is necessary to compact concrete carefully with vibrating tables, form vibrators, rod type vibrators, and other equipment, taking care of the surface smoothness of the forms and the leakage of mortar from the joints between forms. Fine surface air voids created by entrained air are not detrimental to durability. Large air voids, however, may deteriorate durability. Large air voids that are likely to deteriorate durability should therefore be repaired during manufacturing regardless of whether the surface is exposed or not upon completion.

For special concrete surface finishing, water jetting, washing using a wire brush, shot blasting by throwing abrasive, using grinders and polishing using sharpening stone are available.

The proper finishing method should be selected in order to meet the requirements.

For example, the contact surface of the factory product members jointed to cast-in-place concrete members after their erection or assembly shall be scarred in order to obtain a good bond between the old and new concrete.

14.5.5 Curing

(1) The method and duration of curing of factory products shall be determined such that the required quality is met, taking into consideration the type and method of manufacture and use.

(2) No accelerated curing should cause concrete cracking, delamination or deformation, or should have damaging effects on the long age strength or durability.

(3) Temperature should be controlled during accelerated curing in accordance with Table 14.5.1.

Table 14.5.1 Temperature control during accelerated curing

Item	Check	Timing and frequency	Criteria for judgment
Temperature	Heat generation speed Cooling down speed Maximum temperature and its holding time	In cases where changes are made to production plans, materials or mix proportions	Compliance with the specification of designation

[Commentary] (1) Concrete shall be cured sufficiently after casting in order to avoid harmful effects on quality such as low temperatures, drying, sudden temperature variations, loads and impact. It is necessary that proper curing methods such as wet curing and insulated curing be applied for the specified period even after de-molding. When the hydration of cement is progressing and sufficient strength is obtained by using an accelerated curing method such as steam curing, a period of additional curing, such as wet or insulated curing, can be shortened or be omitted depending upon the type of factory product. In cases where adequate strength can be obtained and the designated performance requirements can be met for factory products owing to the progress of cement hydration as a result of steam curing or other types of accelerated curing, the period of subsequent wet curing or insulated curing may be reduced or such curing may be eliminated for certain types of factory products.

It is generally recommended that factory products be additionally cured wet after accelerated curing in order to continue the successive hydration of many un-hydrated cement particles in the hardened concrete after the application of steam curing, and to improve properties of the concrete such as strength, water-tightness and durability. It is necessary that factory products requiring specially high-strength, abrasion resistance, water-tightness, freezing-thawing resistance, or those that will be subjected to strong impact loads be cured wet until the required quality is obtained.

(2) Steam curing at atmospheric pressure is widely used to obtain high productivity. In cases using steam curing, improper operations such as an immediate supply of steam just following casting, rapid temperature rises, or curing at extremely high temperatures will undoubtedly have harmful effects on the factory products. Also, the concrete surface is apt to crack when the factory products are taken out from steam curing chambers at high temperature and rapidly cooled down. Therefore, there are many examples of steam curing applications stipulated as follows;

1) Steam curing shall be started when 2-3 hours or more have elapsed after mixing.

2) Factory products after demolding are put into stream curing rooms and the curing room temperature is raised uniformly.

3) The rate of temperature rise should be no more than 20°C per hour, and the maximum

temperature should be 65°C.

4) The temperature of the curing room shall be lowered slowly, and factory products should be removed from the room when the temperature difference between the curing room and the atmosphere has nearly disappeared.

In general, the elapsed time from mixing to the start of steam curing may be shortened if the water-cement ratio of the concrete is low. Conversely, if the water-cement ratio is high, it is necessary to lengthen the elapsed time.

Cases have been reported overseas in which deterioration occurred due to the delayed ettringite formation after hardening for factory products that were exposed to a cold wet environment after they were cured at high temperature in normal-pressure steam curing. Deterioration is said to be related to hot curing and alkali amount and likely to occur at 90°C or higher temperature. In Japan, deterioration due to delayed ettringite formation has not been outstanding because temperature is maintained at a relatively low level and the alkali content of cement is held low during the steam curing of factory products, but careful investigations will be required in the future. Concrete temperature rises above the curing temperature because of the heat of hydration. The difference between curing temperature and concrete temperature should also be considered.

In addition to the above method, autoclave curing and pressure curing are generally used as accelerated curing methods. Autoclave curing, used for the curing of PC pole or pile, is a curing method using a high pressure, 1N/mm^2, and 180°C vessel. Pressure curing is a method of curing concrete cast in a mold at a high-temperature of about 100°C under a pressure of 0.5-1.0 N/mm^2. Using these curing methods, sufficient strength can be obtained at an early age.

When the hot-concrete method is employed to shorten the pre-curing period or steam curing period after mixing, it is important to verify the properties of the concrete by testing the slump loss with the elapsed time after mixing. The long-term strength and other properties shall also be tested.

(3) The high productivity by the acceleration of curing and de-molding is the special requirement for the manufacture of factory products. However, rapid heat generation or cooling down causes porous and low durable factory products. Since The quality of concrete is frequently determined by the method, temperature and time of curing. For concrete used for factory products, temperature should be fully controlled in accelerated curing in particular.

14.5.6 De-molding and prestressing

(1) De-molding of factory products shall be done after achieving sufficient concrete strength for handling.

(2) Pre-stressing shall be carried out after confirming that the required strength has been reached

(3) In cases where instantly removing the form has no adverse effects on factory products, the form can be partly or completely removed before concrete hardens.

(4) The strength at the time of form removal or at the time of prestressing should be controlled in accordance with Table 14.5.2.

Table 14.5.2　Strength control at the time of form removal or prestressing

Item	Items to be verified	Timing or frequency	Standards
Strength at the time of form removal	In accordance with 14.2.2	In cases where changes are made to production plans, materials or mix proportions	Compliance with the conditions specified by JIS or in production plans
Strength at the time of prestressing			

[Commentary]　(1) The form should naturally be removed after the strength reaches the level at which the factory product can be handled without any problem. When storing factory products over a long period of time, the de-molding time of factory products shall be scheduled with a consideration not only of the concrete strength, but also of the properties of creep or drying shrinkage.

(2) For prestressed factory products, the form is partly removed right before prestressing in numerous cases. Then, the form should be removed only after verifying that the strength specified at the time of prestressing is achieved.

The time of pre-stressing of factory products shall be decided and referred to in Section 12.2.1.

(3) When shaping factory products by strong vibratory compaction or application of pressure using extremely stiff concrete, removing the form right after the shaping is not likely to adversely affect the transport, curing or other work. Concrete is also free from any damaging effect on its quality. For these factory products, the form may be removed immediately following the shaping even before concrete hardens.

(4) It should be verified that concrete strength at the time of form removal should be higher than the designated level so as not to adversely affect factory products in form removal or subsequent work. For prestressed factory products, it should be verified that the strength at the time of prestressing is higher than designated.

The checking of the relation between the quality of factory products and strength property by the compressive strength test at early age is useful for quality control in the manufacturing process of material, mixture proportion, curing, and so on.

14.6　Transportation and storage

(1) Transportation of factory products shall be undertaken, paying attention to safety. Also, factory products shall not be damaged during handling and transportation.

(2) In cases when factory products are stored, any extraordinary stress and plastic deformation shall be not caused in the factory products due to their own-weight or due to their stacking.

[Commentary]　Great care shall be taken during transporting of factory products. Since factory products are easily cracked and damaged during transporting, preventive measures should be done. Especially when long factory products such as bridge girders, poles, piles, and sheet piles are transported and stored, great care should be taken with respect to the suspension points and the method of support so as to avoid generating any large bending moment in these products. When stacking factory products for storage, stacking methods shall be determined by taking into account the strength and the dead load of the factory products, as well as the stacking conditions. When stacking bridge girders, preventive measures shall be taken to prevent tumbling down caused by earthquakes or by other unexpected loads.

Furthermore, since factory products are usually de-molded, transported and stored at an early age, they may be deformed by the harmful effects of drying shrinkage, creep, etc., due consideration shall be sufficiently given to support positions during transportation and storage.

However, when the safety of the members has been already checked, the required compressive strength can be lowered according to instructions from the Engineer in charge.

14.7 Erection and Jointing

Erection and jointing of factory products shall satisfy matters considered in the design stage.

[Commentary] Assembly and erection shall be fully planned. Since, in general, joints may become the weak points, assembly and erection, and jointing of factory products shall be performed in good conditions. When jointing piles and transversely fastening bridge girders, great care shall be taken regarding the relative positioning among members in order to satisfy the joint performance specified in the design stage.

When factory products are jointed to each other by using a bonding agent, the joints shall be tightly bonded. Care shall be taken regarding the mix proportions, mixing, the surface preparation, the workable time of the bonding agent, and the curing after bonding with the consideration of Section 12.4.8 and 12.6.6.

14.8 Inspections

14.8.1 Material acceptance tests

The accepting party shall be held responsible for conducting acceptance tests for concrete and reinforcing materials for factory products in accordance with Chapters 3 and 6 of "Construction: Inspection Standards".

[Commentary] The accepting party that conducts acceptance tests for the materials for factory products is the manufacturer of factory products. The inspection results should be verified by the Owner of the construction project.

In the acceptance tests for concrete and reinforcing materials for factory products, quality may be verified based on the test result checklist prepared by the manufacturer as for ordinary structures.

If no test result checklist prepared by the manufacturer is available at the time of acceptance tests for JIS-authorized steel, JIS-authorization mark should be verified at the time of delivery. At JIS-authorized plants, JIS Q 1012 "Conformity assessment - Conformity assessment for Japanese Industrial Standards - Guidance on a third-party certification system for precast factory products" should be adhered to.

14.8.2 Acceptance tests for factory products

(1) The accepting party shall assume the responsibility for conducting acceptance tests for factory products by appropriate methods to verify that the factory products meet the designated performance requirements.

(2) Appropriate methods, timing and frequency of inspection should be selected for respective inspection items considering the type and use of the product.

(3) Factory products shall not have harmful defects in service, such as cracks, flaws, warping, and twists. Dimensional tolerance shall be such that factory products satisfy the required performances specified in JIS or the production scheme.

(4) Factory products shall have the strengths required by the design.

(5) In cases when the strength of concrete can be substituted for the required strength of factory products, compressive strength of concrete shall be generally used. The inspection method to measure the compressive strength of concrete shall be carried out in accordance with JIS A 1108 or Section 14.2.2.

(6) For factory products in which the quality assurance of a JIS mark, etc. is shown, the mill sheet of the final inspection can be substituted for inspection by specific agreement between manufacturer and the accepting party.

(7) In cases when the products can not be accepted, appropriate countermeasures shall be implemented under the agreement between the manufacturer and the accepting party.

[Commentary] (1) The accepting party conducting acceptance tests generally means the Contractor. The Contractor usually conducts acceptance tests through mutual consultation between the Owner of the construction work and the Contractor, and the test results are verified by the Owner.

As a characteristic of acceptance tests of factory products, actual factory products can be sampled and tested. The inspection methods described in JIS A 5365 "Precast factory products - General rules for method of inspection" are total inspections, sampling inspections and inspections involving no testing based on the past records. Nondestructive and destructive inspections are also available.

Factory products come in varieties of types, are used for various purposes and have varying performance requirements. Uniformly determining the inspection method is therefore difficult. When inspecting factory products, the accepting party should select appropriate methods for respective inspection items through mutual consultation with the manufacturer.

For inspecting factory products, the kinds of inspection methods and proposal selection standards, specified in JIS A 5365 “Pre-cast Factory products - General Rules for Method of Inspection”, and the performance testing methods, specified in JIS A 5363 “Pre-cast Factory products - General Rules for Methods of Performance Test”, can be referred to.

(2) and (3) The inspection items for factory products include the appearance, shape, size, compressive strength, flexural strength, external pressure and internal pressure. The accepting party should properly select inspection items according to the quality requirements through mutual

consultation with the manufacturer.

An example of inspection items due to the kinds of factory production is shown in Table C14.8.1.

Table C14.8.1 An example of inspection items due to the kinds of factory production

Kinds of factory products	Inspection items
Concrete bricks	appearance, shape, size and compressive strength
Reinforced spun concrete pipe	appearance, shape, size, outer pressure strength for the outer pressure pipe, inner and outer pressure strength for the inner pressure pipe
Pre-stressed concrete pile	appearance, shape, size, flexural strength at the body, flexural strength, assembly of reinforcing steel

The timing and frequency of inspections should be determined by the accepting party based on the size of the lot for testing and the sampling method through mutual consultation with the manufacturer.

The factory products described in the appendices to JIS documents should be inspected using the testing and inspection methods specified in the appendices. The factory products not described in the appendices should be inspected using the methods specified in the production plans. In cases where no production plans have been prepared, factory products may be inspected based on the testing and inspection methods for similar JIS products stipulated in JIS A 5365, JIS A 5371 "Precast unreinforced factory products", JIS A 5372 "Precast reinforced factory products" and JIS A 5373 "Precast prestressed factory products".

When the test or inspection cannot be done using actual factory products, it is important that the test or inspection shall be done using a prepared specimen specified by the manufacturing scheme. In addition, the placement of reinforcing steel, the state of the dimensional tolerance, and the depth of cover concrete should be tested and inspected by using specimens after the strength tests. The freezing and thawing test shall be done, if necessary.

For the placement of reinforcing steel, inspection shall be done by the non-destructive testing method, a test using destructive specimens, or by measurements before concrete casting. When it is clear that the placement of reinforcing steel does not move by casting concrete, the measurements before concrete casting is better.

Dimensional tolerance strictly influences the assembling or jointing correction of factory products. For factory products (class I) shown in JIS-recommended specifications, allowable margin of error in size is presented in the corresponding standards.

The factory products not described by the JIS appendix must be followed by the specified allowance of dimensional tolerance described in the manufacturing scheme.

Cracked factory products influence the durability of themselves. And the flaws or un-uniformed color of factory products influence their aesthetics. Moreover, warping and twists of factory products cause low assembling accuracy and low performance. Therefore, factory products shall be free from these harmful defects in service. Pre-tensioning pre-stressed factory products, since they may become are possible to be warp, shall be inspected for harmful warping.

There is no uniformed testing method for the components, because the testing scale may become large and uneconomical compared to the testing method of the unit product. Therefore, the performance test results inspected at the verification stage are normally used instead of the actual test results, by explicit agreement between the manufacturer and the ordering agents.

Construction performance, such as transportation, assembling and jointing, is normally evaluated by the actual results of the appearance, shape, size and compressive strength of concrete. Factory products with special construction methods are inspected for accuracy at the temporary assembling stage.

(4) A test using actual factory products can show the performance requirement of flexural strength, shear strength, inner pressure strength, outer pressure strength, and so on. A proper specimen can be used for the testing of complex-shaped or large-sized products. In addition, the un-destroyed testing method using actual products can be done when considering production uniformity, testing cost or testing time.

(5) As the substitute parameter, compressive strength of concrete specimen can be used for the inspection, when factory products are difficult to test directly. Compressive strength of concrete is normally used for the substitute parameter. Therefore, this parameter was determined in this specification. Compressive strength should be determined considering the method for increasing the design strength as described in Explanation in Section 14.4.1.

In cases when other strength properties are specified for factory products, the proper test shall be done for their requirements. In this case, bar arrangement should also be inspected for reinforced factory products. Bar arrangement and wiring should also be inspected for prestressed factory products. For factory products for pavement, flexural strength of concrete is important and is adopted as an alternative characteristic.

(6) When the qualities of factory products are certified by a third party such as JIS, or when the factory products can be considered to have good performance, manufactured products can be thought of as having undergone well quality-controlled production. Therefore, for factory products, which are certified by JIS or another third party, the inspection can be done with a mill sheet of the final test made at the factory. The final test means the test which is done by the manufacturing companies for their quality insurance. Generally, the appearance, the shape and the size are basically checked in the final test. And the compressive strength, flexural strength, shear strength, outer pressure strength, inner pressure strength, cracking load, bending strength at the joints, assembly of reinforcing steel or thickness of cover concrete are optionally selected, if necessary.

(7) Sampling inspections are generally conducted at the time of acceptance of factory products. The decision criteria at the time of inspection and the methods for handling unacceptable products vary according to the type of product and inspection item. The inspected lots should therefore be handled properly through mutual consultation between the accepting party and the manufacturer.