

**Basis of Structural Design  
for Buildings and Public Works**

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**Ministry of Land, Infrastructure and Transport**



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## 1. General

### 1.1. Scope

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This “Basis of Structural Design for Buildings and Public Works” covers structures in general and provides the basic direction for establishing and revising technical standards related to structural design. In principle, this “Basis of Structural Design” requires explicit treatment of the fundamental performance requirements of structures, such as safety, and the factors affecting the performance of structures. The concept of reliability design shall be applied as a basis for verifying compliance to performance requirements.

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- (a) This “Basis of Structural Design” covers structures in general in both building and public works fields. The term “structure” is here defined as “organized construction works designed to provide intended functions while resisting actions.”
- (a) This “Basis of Structural Design” is a comprehensive framework, which covers both fields of buildings and public works, and shows the basic issues necessary to establish or revise the technical standard of design for each type of structure. In other words, it is equivalent to so-called “Code for Code Writers.” Some of the basic issues may not be necessary for a specific technical standard of a structure. This “Basis of Structural Design” leaves selection of the necessary issues to the code writers for an individual structure.
- (b) Whereas the design of a structure is a comprehensive work taking account of not only safety, serviceability and restorability but also landscape, impact on the environment, economic efficiency, etc., this code only covers “structural design” considering serviceability, safety, restorability, etc., as specified in Sec. 1.2.
- (c) The fundamental performance requirements of structures and the factors affecting the performance of structures are required to be treated in an explicit manner to ensure transparency and accountability of decision making about public structures in terms of structural design, as these have recently become increasingly in demand.
- (d) The requirement for “applying the concept of reliability design as a basis” is intended for “considering limit states and maintaining the probability of exceeding the limits within permissible target ranges during the design working life in consideration of uncertainty of the external actions and resistance of the structure”. Setting the basis of this “Basis of Structural Design” on reliability design ensures international validity of Japanese design standards. It also enables the results of studies worldwide to be incorporated in Japanese design standards. It is important to refer to reliable data in the process of setting the basis

on the reliability design concept. It is also important to accumulate such data and open it to the public for this purpose.

## 1.2. Basic requirements of design

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When designing a structure, the design working life of the structure should be specified, and the following fundamental performance requirements (1) to (3) should be ensured for the specified period.

- (1) Safety of human life in and around the structure is ensured against foreseeable actions (Safety).
  - (2) The functions of the structure are adequately ensured against foreseeable actions acting on structures (Serviceability).
  - (3) If required, continued use of the structure is feasible against foreseeable actions by restoration using technologies available within reasonable ranges of cost and time (Restorability).
- 

(a) When designing a structure, specifying a design working life is required.

(b)(1) and (2) above refer to fundamental performance requirements for safety and serviceability, respectively.

(c) The concept of safety is based on “human safety,” with the requirement being “safety of human life in and around the structure,” including prevention of collapse of constructed structures that are normally unmanned into the concept of safety.

(d)(3) above describes a fundamental performance requirement of “restorability” in addition to the other fundamental performance requirements, safety and serviceability.

The requirement for restorability is intended to control the level of damage, thereby enabling continued use of the structure by repairing damage to the structure from the foreseeable actions using appropriate techniques within reasonable cost and time.

In earthquake-prone Japan, designing public facilities that would restore their functions shortly after an earthquake to allow their continued use is an example of design taking account of restorability. Restorability as a fundamental performance requirement can also be recognized from the standpoint of avoiding the situation in which a great number of buildings are on the verge of collapse after an earthquake, requiring demolishing and rebuilding.

(e) It should be noted, though not specified as a requirement, there is a concept of requirement

for structural integrity, or ability of a structure not to be damaged to an extent disproportionate to the original cause, such as local failure producing a fatal effect on the entire structural system. This concept is included in ISO 2394 as a fundamental requirement. Such a concept should also be considered as a part of the fundamental safety and restorability requirements.

## 2. Limit states

### 2.1. General

Limit states to be verified shall be the ultimate limit states, serviceability limit states, and restorability limit states. The limit states shall be selected according to the purposes of the structure to be designed.

- (a) In some technical standards in the civil engineering field, fatigue limit states are paralleled with ultimate limit states and serviceability limit states. However, this code includes fatigue in the ultimate limit states and serviceability limit states, regarding it as a variety of action causing limit states (see Table 2-1).
- (b) When designing, engineers do not have to consider all of the above-mentioned limit states, but are required to select limit states according to the characteristics of each structure.

Table 2-1 Limit states

(a) Ultimate limit states (safety)	States beyond which the stability of the structure is no longer retained under structural failure or large deformation expected to result from foreseeable actions, threatening safety of human life in and around the structure	
	Limit states under specific design situation	Fatigue limit states (caused by fatigue damage due to repeated variable actions)
		Durability limit states (caused by damage due to the influence of environmental action)
		Fire resistance limit states (caused by damage due to fire)
(b) Serviceability limit states (serviceability)	States beyond which the functions of the structure no longer fulfill their purposes under expected responses to foreseeable actions	
	Limit states under specific design situation	Fatigue limit states (caused by fatigue damage due to repeated variable actions)
		Durability limit states (caused by damage due to the influence of environmental action)
		Fire resistance limit states (caused by damage due to fire)
(c) Restorability limit states (restorability)	States beyond which the structure can no longer be restored by repair using technologies available within reasonable ranges of cost and time	

- (c) The requirement for selection of limit states to be verified according to the purpose of the structure is intended for permitting changes of limit states to be verified depending on the type of structure as given in Table 2-2. For instance, the fatigue limit state can be a

predominant condition for bridges, whereas it is mostly of no concern for general buildings excepting vibration control members.

Table 2-2 Example of selecting limit states by structure type

		General buildings	Bridges	Debris barriers	Banking	...
Ultimate limit states						
Limit states under specific design situation	Fatigue limit states					
	Durability limit states					
	Fire resistance limit states					
Serviceability limit states						
Limit states under specific design situation	Fatigue limit states					
	Durability limit states					
	Fire resistance limit states					
Restorability limit states						

Note 1) “ ” denotes applicable limit states. “ ” denotes selectively applicable limit states.

Note 2) In this example, the serviceability limit states are not selected for debris barriers, as their intended function of retaining debris is fulfilled unless they turn over or collapse. However, such structures as slit dams for debris flow control may require consideration of abrasion.

Note 3) Limit states should be selected from among those given in the table according to the characteristics of the structure as the above-mentioned example of debris barriers.

#### Supplementary Note:

##### (1) Examples of limit states in Draft ISO

The latest draft of ISO DIS 19338: Performance and Assessment Requirements for Acceptance of National Standards on Structural Concrete (for vote between October 2001 and March 2002) proposed by ISO TC 71/SC 4 specify five types of limit state: ultimate limit state (structural safety), serviceability limit state, restorability limit state, durability limit state, fire resistance limit state, and fatigue.

Supplementary note: Examples of limit states specified in domestic technical standards – Part 1

	Japan Society of Civil Engineers		The Japanese Geotechnical Society	Architectural Institute of Japan	
	Standard Specifications for Concrete Structures (2002)	Recommendations for Design of Steel Structures (1997)	References by Research Committee for Limit State Design of Foundation Structures (1996)	Recommendations for Ductility Assurance Seismic Design of Reinforced Concrete Structures (Draft) (1999)	Recommendations for Limit State Design of Steel Structures (1998)
1. Ultimate limit states	States beyond which a structure or structural element is undergoes failure, toppling, buckling and/or major deformation, thereby losing stability and/or functions	States beyond which a structure or structural element undergoes failure or is subjected to major deformation or displacement, losing stability and/or functions.	Ex: States beyond which sectional failure of piles occurs.	Limit states within which safety of human life is ensured in consideration of uncertain factors, e.g., maximum possible ground motions in the region.	Limit states related to the structural safety of buildings. Limit states of the ultimate load-bearing capacity of steel structures should be considered.
1'. Ultimate limit states during an earthquake			States beyond which part of the superstructure and foundations undergoes rupture of critical sections, loss of stability, transformation into a mechanism, etc., during an earthquake of a level encountered once in the working life.	Safety – ultimate limit states Safety corresponds to ultimate limit states in the performance evaluation items for life protection. The design objectives will therefore be “no collapse” and “withstand vertical loads.” It corresponds to “severe damage” in terms of damage degree of structures and “on the verge of collapse” by P-δ deformation limits. For structural elements, it corresponds to the deformation limits of hinged elements and the limit states of causing brittleness failure of columns.	
2. Restorability limit states				Limit states of response specified to control damage during an earthquake  Restorability (reparability) – design limit states Restorability (reparability) is a performance evaluation item for controlling the damage level. The limit states corresponding to this are referred to as design limit states, damage control limit states, or reparability limit states. To be precise, this should be specified by quantifying the damage levels of structural materials and non-structural materials in consideration of the repair cost required after an earthquake, i.e., to make the repair financially feasible.	
3. Serviceability limit states	Limit states beyond which a structure or structural element is no longer durable or properly usable due to excessive cracking, displacement, deformation, and/or vibration.	Limit states beyond which a structure or structural element is no longer usable due to excessive deformation, displacement, and/or vibration.	Ex: Limit states beyond which cracking of piles exceeds the permissible value; limit states beyond which deleterious deformation occurs in the superstructure.	Limit states of response specified to permit continued use of a structure nearly unconditionally.	Limit states related to serviceability/habitability of buildings. Serviceability limit capacity and serviceability limit deformation of steel structures and limit states (permissible limits) regarding the floor vibration and rolling of building floors should be considered.
3'. Serviceability limit states during an earthquake			Limit states beyond which running safety of vehicles cannot be ensured during an earthquake encountered several times during the working life of the structure due to damage/displacement of members of the superstructure and foundations.	Serviceability – serviceability limit states Serviceability is an item of performance evaluation to ensure continued use of a structure. Serviceability limit states are design criteria imposed on structures to ensure serviceability, within which the structure is scarcely damaged after an earthquake and remains nearly unconditionally usable. For general structures, the requirements may include limiting the response within the elastic limits. Requirements regarding cracking are also essential for reinforced concrete structures.	
4. Fatigue limit states	Limit states beyond which a structure or structural element undergoes fatigue failure due to repeated action of variable loads.	Limit states beyond which a structure or structural element sustains fatigue damage due to repeated loading, losing its functions.			
Remark			Distinction of limit states during an earthquake from other limit states is required, but no definitions are provided.		

**Supplementary note: Examples of limit states specified in domestic technical standards – Part 2**

	Building Research Institute	Railway Bureau, MLIT (Formulated by Railway Technical Research Institute)		Ports and Harbors Bureau, MLIT (Published by Japan Port and Harbor Association)
	General Report on “Development of New Building Structure Systems” in MLIT’s General Technology Development Project (1998)	Design Standard for Railway Structures – Concrete Structures (1999)	Design Standard for Railway Structures – Foundation Structures and Earth Retaining Structures (2000)	Technical Standard for Port and Harbor Facilities (1999)
1. Ultimate limit states	(1) Safety - Purpose of performance requirements: Avoid risks to human life in and around the structure (life protection) - Contents of performance evaluation: Adequately prevent failure of structural frames, building members, equipment, fixtures, and ground to ensure safety	States beyond which a structure or structural element is fractured or inclined, involving buckling and/or major deformation, thereby losing stability and/or functions.	States beyond which foundations lose stability and/or functions, or their displacement exceeds the yield point, under loads, other than earthquake loads, that rarely act during the design working life.	States beyond which failure occurs under the maximum load.
1'. Ultimate limit states during an earthquake			States beyond which foundations sustain irreparable damage, losing stability and/or functions, due to a major earthquake that acts during the design working life.	
2. Restorability limit states	(2) Restorability - Purpose of performance requirements: Ensure ease of restoration from damage of buildings caused by external actions (property conservation) - Contents of performance evaluation: Adequately control deterioration and damage of structural frames, building members, equipment, fixtures, and ground (within specified ranges) to ensure building restorability			
3. Serviceability limit states	(3) Serviceability - Purpose of performance requirements: Ensure the functions and habitability of buildings (Functions/habitability assurance) - Contents of performance evaluation: Adequately eliminate functional damage and perceived malfunctions of structural frames, building members, equipment, fixtures, and ground to ensure serviceability	States beyond which a structure or structural element is no longer durable or properly usable due to excessive cracking, displacement, deformation, and/or vibration.	States beyond which foundations lose the required serviceability and/or durability, or exceed the limits within which the displacement is regarded as elastic, under loads that occasionally act during the design working life.	States beyond which relatively light inconvenience, such as excessive cracking, occurs due to loads of a scale that occasionally act during the design working life.
3'. Serviceability limit states during an earthquake			States beyond which foundations lose serviceability and/or durability, or their displacement exceeds the yield point, due to a medium-scale earthquake that acts during the design working life.	
3''. Long-term serviceability limit states			States beyond which foundations lose the required serviceability or durability under loads that act constantly or for a long time during the design working life.	
4. Fatigue limit states		Limit states beyond which a structure or structural element undergoes fatigue failure due to repeated action of variable loads.		States beyond which failure similar to that beyond the ultimate limit states occurs due to repeated loads that act during the design working life.
Remark				

## 2.2. Ultimate limit states

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Ultimate limit states shall refer to states beyond which the stability of a structure is no longer retained under structural failure or large deformation resulting from foreseeable actions, threatening the safety of human life in and around the structure.

They shall include limit states beyond which the stability of a structure is no longer retained, threatening the safety of human life in and around the structure, due to the following damage (limit states under specific design situations):

- Fatigue damage resulting from repeated loading of variable actions (Fatigue limit states)
  - Damage resulting from environmental actions (Durability limit states)
  - Damage resulting from fire (Fire resistance limit states)
- 

- (a) It is possible to separately specify limit states under a specific design situation for each cause of ultimate limit states, such as fatigue limit states, durability limit states, and fire resistance limit states. In this code, however, these are regarded as states composing ultimate limit states, since they represent varieties of actions causing ultimate limit states.
- (b) The reason why fatigue and other limit states are treated explicitly in this code as limit states under specific design situations is that fatigue failure can be a decisive condition for certain structures. Also, since limit states under a specific design situation are regarded as independent limit states in certain technical standards in Japan, consistency with such standards was taken into consideration.
- (c) As stated in 1.2 (Basic requirements of design), the concept of safety is based on safety of human life. Accordingly, ultimate limit states are specified as states beyond which safety of human life in and around the structures, including unmanned ones, is threatened.

### 2.3. Serviceability limit states

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Serviceability limit states shall refer to states beyond which the functions of the structure no longer fulfill their purposes under responses to foreseeable actions. They shall include the limit states beyond which serviceability of the structure is no longer retained due to the following damage (Limit states under specific design situation):

- Fatigue damage resulting from repeated loading of variable actions (Fatigue limit states)
  - Damage resulting from environmental actions (Durability limit states)
  - Damage resulting from fire (Fire resistance limit states)
- 

It is possible to separately specify limit states under a specific design situation for each cause of serviceability limit states, such as fatigue limit states, durability limit states, and fire resistance limit states. In this code, however, these are regarded as states composing serviceability limit states, since they represent varieties of actions causing serviceability limit states.

### 2.4. Restorability limit states

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Restorability limit states shall refer to states beyond which continued use of the structure by repair using technologies available within reasonable ranges of cost and time is no longer feasible under damage resulting from foreseeable actions.

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- (a) Restorability limit states are limit states regarded as being located between serviceability limit states and ultimate limit states (see Fig. 2-1).
- (b) Restorability limit states are intended to specify the conditions corresponding to function restoration emphasized in public works structures and the conditions for retention of property values emphasized in building structures. Conditions in which a structure is repaired to tentatively restore its functions in a short time (emergency restoration) for temporary use but is eventually reconstructed are not included in restorability limit states. Such restoration is regarded as temporary use of a structure in ultimate limit states or similar states.
- (c) “Technologies available within reasonable ranges of cost and time” were specified to limit the cost to a certain range, since any structure can be restored by applying new

technologies to be developed or by using unlimited money and time.

- (d) As shown in the example of selecting limit states in Table 2-2, limit states should be selected according to the characteristics of the relevant structure. For restorability, the main consideration may be, for the time being, verification of the design of structures for which rehabilitation or repair after an earthquake should be considered.
- (e) In both fields of building and civil engineering, the limit states that are currently recognized as requiring explicit treatment as restorability limit states are only those under seismic action. For instance, limit states for damage due to environmental action (durability) are currently not explicitly treated but included in the detailed structural specifications. For this reason, durability limit states are not specified as limit states under specific action in the category of restorability limit states in this code. However, explicit specifications for limit states regarding fatigue, durability, and fire resistance may proceed towards adoption as targets of the current detailed specifications in certain fields. In such a case, it is appropriate to include the framework of limit states under specific design situations in the restorability limit states.

Supplementary Note:

In the discussion of restorability limit states under seismic action, the following understandings in the building and civil engineering fields were presented:

Understanding in civil engineering field	<ul style="list-style-type: none"> <li>- The civil engineering field pays attention to the state in which the functions of public works structures (infrastructures) can be restored shortly after an earthquake to permit their continued use.</li> <li>- For instance, the JSCE Standard Specification for Concrete Structures requires that structures be restorable shortly after an earthquake with no need for strengthening.</li> </ul>
Understanding in building field	<ul style="list-style-type: none"> <li>- The building field pays attention to the state in which structures can be repaired with cost small enough to retain their values as assets.</li> <li>- Restorability limit states are significant to avoid the situation in which a great number of buildings are on the verge of collapse after an earthquake, requiring demolishing and rebuilding</li> <li>- In regard to restorability of damaged functions, non-structural members and finishing materials should be considered.</li> </ul>

## Definitions of limit states in ISO 2394

Limit states	ISO 2394
General	<p>The structural performance of a whole structure or part of it should generally be described with reference to a specified set of limit states which separate desired states of the structure from undesired states.</p> <p>The limit states are divided into the following two categories:</p> <ol style="list-style-type: none"> <li>a) ultimate limit states, which correspond to the maximum load-carrying capacity or, in some cases, to the maximum applicable strain or deformation;</li> <li>b) serviceability limit states, which concern the normal use.</li> </ol> <p>The effect of exceeding a limit state may be irreversible or reversible. In the irreversible case, the damage or malfunction associated with the limit state being exceeded will remain until the structure has been repaired. In the reversible case, the damage or malfunction will remain only as long as the cause of the limit state being exceeded is present. As soon as this cause ceases to act, a transition from the undesired state back to the desired state occurs.</p>
Ultimate limit states	<p>Ultimate limit states include:</p> <ol style="list-style-type: none"> <li>a) loss of equilibrium of the structure or of a part of the structure, considered as a rigid body (e.g. overturning);</li> <li>b) attainment of the maximum resistance capacity of sections, members or connections by rupture (in some cases affected by fatigue, corrosion, etc.) or excessive deformations;</li> <li>c) transformation of the structure or part of it into a mechanism;</li> <li>d) instability of the structure or part of it;</li> <li>e) sudden change of the assumed structural system to a new system (e.g. snap through).</li> </ol> <p>The effect of exceeding an ultimate state is almost always irreversible and the first time that this occurs it causes failure.</p>
Serviceability limit states	<p>Serviceability limit states include:</p> <ol style="list-style-type: none"> <li>a) local damage (including cracking) which may reduce the working life of the structure or affect the efficiency or appearance of structural or non-structural elements; repeated loading may affect the local damage, e.g. by fatigue;</li> <li>b) unacceptable deformations which affect the efficient use or appearance of structural or non-structural elements or the functioning of equipment;</li> <li>c) excessive vibrations which cause discomfort to people or affect non-structural elements or the functioning of equipment.</li> </ol> <p>In the cases of permanent local damage or permanent unacceptable deformations, exceeding a serviceability limit state is irreversible and the first time that this occurs it causes failure.</p> <p>In other cases, exceeding a serviceability limit state may be reversible and then failure occurs as follows:</p> <ol style="list-style-type: none"> <li>a) the first time the serviceability limit state is exceeded, if no excess is considered as acceptable;</li> <li>b) if the excess is acceptable but the time when the structure is in the undesired state is longer than specified;</li> <li>c) if the excess is acceptable but the number of times that the serviceability limit state is exceeded is larger than specified;</li> </ol>

	<p>d) if a combination of the above criteria or of some other relevant criteria occur.</p> <p>These cases may involve temporary local damage (e.g. temporarily wide cracks), temporary large deformations and vibrations.</p> <p>Design criteria for serviceability limit states are generally expressed in terms of limits for acceptable deformations, accelerations, crack widths, etc.</p>
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### 3. Actions

#### 3.1. Definitions

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Action shall refer to the following:

- An assembly of concentrated or distributed mechanical forces acting on a structure (Direct action).
- The cause of deformations imposed on the structure or constrained in it (Indirect action).
- The cause of deterioration of the materials of the structure (Environmental action).

Loads shall refer to action on the structure converted as required to an assembly of mechanical forces directly applied to the structure through a model for assessing the response characteristics of the structure to be used as input for static calculation of sectional forces, stress, and displacement for design purposes.

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- (a) In the present code, the terms “action” and “load” are clarified by the above definitions to provide common grounds for discussion across the fields. As defined above, the concept of action was adopted as the basis for common argument, since the “load” partially depends on the characteristics of the relevant structures when converting from action.
- (b) The history of design may have begun with the examination of how “weight (loading)” ought to be supported, and the technology may then have outgrown the concept of “weight.” The term (concept) “action” was therefore introduced to international standards, while many Japanese design technical standards have used the term “load” to represent a widened scope of the concept. At this moment, it is difficult to set a single boundary between these terms applicable to all fields. Counterforces and reactions are also treated differently in each field. Section 3.1 (Definitions) does not intend to provide a unified guideline for the boundaries but narrows the defined range of action, and Section 3.2 (Classification of actions) presents the classification of variability as a basis of introducing the concept of reliability design.
- (c) According to these definitions, actions can be input into a model for evaluating the response characteristics of structures either directly or after being converted into loads. For instance, loads are not employed when directly considering the actions of earthquake ground motions, wind, and waves on structures in a dynamic analysis or when considering displacements directly as actions for structures affected by ground subsidence.

Table 3-1 Difference between action and load

Action	Load
- Common to both building and civil engineering fields, due to being unconnected to the characteristics of structures (However, predominant action varies depending on characteristics).	- Basis of the design of structures; variable depending on the characteristics of structures. - May be simplified by modeling or for reasons of design calculation.

- (d) Indirect actions include expansion and contraction caused by temperature changes, prestress, and subsidence.
- (e) Environmental action is included in the actions to be considered for verifying serviceability and safety, though ISO 2394 treats them as “environmental influences” instead of environmental action.

Supplementary note

The definition of “action” differs from that of “action” in ISO 2394. Whereas this code includes the environmental influences in actions, ISO 2394 defines action as follows:

- An assembly of concentrated or distributed mechanical forces acting on a structure (direct action).
- The cause of deformations imposed on the structure or constrained in it (indirect action).

ISO 2394 also describes in the section of “Action models” that a basic action variable,  $F_0$ , is transformed to action,  $F$ , by variables and a function, which depend on the structural properties, as given below. According to ISO 2394, action (e.g., wind pressure) is derived from a basic action variable (e.g., wind velocity) and a variable necessary for transformation (e.g., a variable in the velocity-pressure relationship). However, the description does not clarify the relationship between “load (e.g., wind load) and action (e.g., wind pressure)” with confusion about the definitions and the use of the terms. The definition of “action” in this code provides a clearer relationship than that in ISO 2394. The same term “action” is adopted in this code despite the difference from ISO’s concept of the term, because it will help stimulating the discussion of the subject in the future.

$$F = \phi(F_0, \omega)$$

where  $F$  = action

$F_0$  = basic action variable

$\omega$  = a variable that transforms a basic action variable to action e.g. (variable for converting wind velocity into wind pressure)

### 3.2. Classification of actions

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Actions shall be classified into permanent action, variable action, and accidental action.

(1) Permanent action

Action that is likely to act continuously throughout the design working life and for which the variation in magnitude is small compared with the mean value; or for which the variation tends to be monotonic increases or decreases throughout the design working life of the structure until the action attains a certain limit value.

(2) Variable action

Action for which the variation in magnitude during the design working life is neither negligible in relation to the mean value nor monotonic.

(3) Accidental action

Action that is difficult to predict by probabilistic and statistical techniques but cannot be socially disregarded.

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(a) The difference between permanent and variable actions is the magnitude in variation of the action during the design working life. Accidental action is action whose frequency distribution of occurrence is difficult to predict or for which predicting or analyzing frequency distribution is meaningless. Representative examples are as follows:

Permanent action:	dead weight of structures, prestress, etc.
Variable action:	wind, snow, earthquake ground motion, etc.
Accidental action:	rock fall, collision, maximum ground motion, fault displacement, etc.

It should be noted that environmental action may be regarded in some cases as variable action, though it is generally designated as permanent action.

(b) Whereas the magnitude of action on most structures is selected in consideration of the frequency of occurrence over time, facilities against debris flow and refuge facilities are not designed by verifying safety against actions with a low possibility but designed to function against exceptional actions that should be socially prepared for (accidental actions). In other words, accidental actions should be considered on the basis of such a concept that they are risks to be socially addressed.

(c) Various arguments have been presented as to whether earthquake ground motions should be treated as variable action or accidental action. Since this code is based on the concept of reliability design, ground motions should be basically designated as variable action.

- (d) Such extraordinary ground motions may be treated as accidental actions that it is difficult to treat them probabilistically, while they are introduced as design ground motions in such countries as Japan and the United States where seismic engineering and seismic design technology have been well developed. ISO 3010 (Seismic action on structures) requires that seismic actions be treated as either variable or accidental actions.

### 3.3. Treatment of actions

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A structure shall be designed against actions for which consideration is deemed necessary either by social judgment or by judgment of the owner of the structure.

Variable actions that can be statistically assessed shall preferably be expressed using a specified reference period as return expectation values for this period, or as fractile for probability of non-exceedance during this period.

Though statistic assessment is inapplicable to accidental actions, explicit indication shall preferably be made by a method easily understandable.

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- (a) Each action is required to be considered in the design according to the necessity for social address and judgment of the owner. The reason for dependence on the social necessity and the judgment of the owner of the structure is that safety of structures involves social commitment even for private structures, such as residential structures in general.
- (b) Among the several methods available for expressing the characteristic values of variable actions, the expected values in terms of return period for a specified reference period or the probability of non-exceedance is preferably required.
- (c) The concept of reference periods for actions is a convenient technique for utilizing probability models obtained from data. For ultimate limit states, a relatively long reference period may be adopted in comparison with the design working life for estimating a large action that rarely occurs. On the other hand, a reference period corresponding to actions that occurs relatively frequently may be adopted for serviceability limit states. For instance, the magnitude of an action may be assessed in terms of the probability of non-exceedance for a reference period of 50 years to assume representative values when the span of accumulated data is no more than 40 years. As for the assessment of actions regarding serviceability limit states, a variable action with a probability of exceedance of 95% for a reference period of 1 year may be adopted for representative values. While this is a concept relative to the concept of design working life,

they should be appropriately related in order to carry out reasonable design.

Introduction of the method of partial factors is recommended later in this code in Chapter 5 (Method of performance verification) to ensure a certain level of reliability. By this method, representative or characteristic values defined for a certain reference period and multiplied further by load factors (possibly 1.0) are used for design. The meaning of the reference period and representative values may therefore vary depending on whether or not the method of partial factors is adopted.

ISO 3010 provides two examples of treating seismic action on structures in parallel in its Appendix A (Informative): one in which different reference periods are given to the ultimate limit states and serviceability limit states during an earthquake, while unifying the load factors, and the other in which the reference period is unified while the load factors are differentiated (see Tables 3-2 and 3-3). However, it should be noted that most seismic design codes in Japan and the United States assume the level of ground motions for verifying the ultimate limit states using the concept of the maximum ground motion instead of a variable action, which permits the expression of return period.

Table 3-2 Load factors and representative values for magnitudes of ground motion: Example 1

Limit states	Importance	Load factors	Representative value	Return period
Ultimate limit states	High	1.5 – 2.0	0.4	500 years
	Medium	1.0		
	Low	0.4 – 0.8		
Serviceability limit states	High	1.5 – 3.0	0.08	20 years
	Medium	1.0		
	Low	0.4 – 0.8		

Table 3-3 Loading coefficients and representative values for magnitudes of ground motion: Example 2

Limit states	Importance	Load factors	Representative value	Return period
Ultimate limit states	High	3.0 – 4.0	0.2	100 years
	Medium	2.0		
	Low	0.8 – 1.6		
Serviceability limit states	High	0.6 – 1.2	0.4	100 years
	Medium	0.4		
	Low	0.16 – 0.32		

(d) This code also provides later in Chapter 4 (Seismic design) a seismic performance matrix, in which the design ground motion level is basically required to be explicitly indicated based

on the probabilistic and statistical technique. The level of reliability of the eventually obtained level of the ground motion is required to be explicitly indicated in either case of adopting the method in which each ground motion level is directly set (only the characteristic values are given) or the method in which characteristic values obtained from the common reference period are multiplied by different load factors.

### 3.4. Load combination

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The basic rule of load combination shall be as follows:

In addition to the permanent load, the predominant load (variable load or accidental load) shall be assumed to take the maximum design value (fractile value, social target value, etc.). Other loads (variable loads or accidental loads) shall be set at the most probable values that are appropriate for combining with the predominant load.

In the case where the application of a load nullifies the effect of another load, load combination may not have to be considered.

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- (a) This section is titled “Load combination,” instead of “Action combination,” because combinations of loads or load effects converted from actions, rather than actions as they are, are considered in actual design practice. In most international standards, load combinations are discussed without clearly defining “loads” with respect to “action.” Meanwhile, in this code, environmental action is regarded parallel to direct and indirect actions. Actions should in some cases be regarded as combination of actions depending on the purposes, characteristics, and importance of structures, such as the effects of direct and indirect actions in a deterioration environment. Each of these should be verified by an appropriate method.
- (b) The load combination specified here is the basic rule and does not necessarily have to be applied to all structures. Since design in the building and civil engineering fields cover an extremely broad spectrum of structures, this rule does not always have to be observed in such design conditions as shown in table 3.4.

Table 3-4 Examples of exceptions to load combination rule

Structures for which serviceability limit state is considered for loads with low probability of exceedance	- Dams - Tide embankment
Structures for which serviceability limit state is considered for extremely rare accidental events	- Rock shed - Facilities against debris flow

- (c) The requirement “In the case where the application of a load nullifies the effect of another load, load combination may not have to be considered” applies to the case where, for instance, the loads do not have to be combined when stresses in a concrete structure due to temperature loads are released by cracking or yielding of the concrete during an earthquake.

Supplementary note

ISO 2394's definitions of terms related to action (loads)

a. Constituents of representative values

Representative values of an action	Characteristic value of an action
	Combination value
	Frequent value
	Quasi-permanent value

b. Definitions of terms

Term	Definition
action	<ol style="list-style-type: none"> <li>1) An assembly of concentrated or distributed mechanical forces acting on a structure (direct action).</li> <li>2) The cause of deformation imposed on the structure or constrained in it (indirect action).</li> </ol>
permanent action	<ol style="list-style-type: none"> <li>1) Action which is likely to act continuously throughout a given reference period and for which variations in magnitude with time are small compared with the mean value.</li> <li>2) Action whose variation is only in one sense and can lead to some limiting value.</li> </ol>
variable action	Action for which the variation in magnitude with time is neither negligible in relation to the mean value nor monotonic.
accidental action	Action that is unlikely to occur with a significant value on a given structure over a given reference period.
representative value of an action	A value used for the verification of a limit state. Note: Representative values consist of characteristic values, combination values, frequent values and quasi-permanent values, but may also consist of other values.
combination value	Value chosen, in so far as it can be fixed on statistical bases, so that the probability that the action effect values caused by the combination will be exceeded is approximately the same as when a single action is considered.
frequent value	Value determined, in so far as it can be fixed on statistical bases, so that: <ul style="list-style-type: none"> <li>- the total time, within a chosen period of time, during which it is exceeded is only a small given part of the chosen period of time; or</li> <li>- the frequency of its exceedance is limited to a given value.</li> </ul>
quasi-permanent value	Value determined, in so far as it can be fixed on statistical bases, so that the total time, within a chosen period of time, during which it is exceeded is of the magnitude of half the period.
reference period	A chosen period of time which is used as a basis for assessing values of variable actions, time-dependent material properties, etc.
design working life	Assumed period for which a structure or a structural element is to be used for its intended purpose without major repair being necessary.
Load combination	Set of design values used for the verification of the structural reliability for a limit state under the simultaneous influence of different actions.

## 4. Seismic design

### 4.1. Seismic performance

In seismic design, the specified seismic performance shall be explicitly indicated, and the ground motion level corresponding to the performance shall be specified.

One or more suitable seismic performance shall be selected from the limit states given in Chapter 2 according to the purposes of the structure to be designed. The earthquake ground motion level corresponding to these performance should be determined in the standard seismic performance matrix given in Table 1 in consideration of the characteristics of the structure including its importance.

The level of ground motion should be expressed as a result of assessment in terms of the frequency of events to be experienced during the design working life of the structure (treatment as variable actions). This does not apply to the case where the expression in terms of frequency of events to be experienced during the design working life is inappropriate (treatment as accidental actions).

Table 1 Standard matrix for seismic performance

Seismic performance		Functions to achieve the purposes of the structure are ensured (Serviceability limit states)	Continued use of the structure is feasible by restoration using technologies available within reasonable ranges of cost and time (Restorability limit states)	Stability of the structure is retained intact and safety of human life in and around the structure is ensured (Ultimate limit states)
Treatment as variable actions	Ground motion assessed as being experienceable several times during design working life of the structure			
	Ground motion assessed as being rarely experienceable during design working life of the structure			
	Ground motion assessed as being scarcely experienceable during design working life of the structure			
Treatment as accidental actions	Ground motion assessed as the maximum level ever experienceable by the structure			

- (a) From the standpoint of emphasizing the importance of seismic design in the design of structures in Japan and disseminating the seismic design technology accumulated in Japan, seismic design is treated as an independent chapter.
- (b) Table 1 provides a basic framework of ground motion levels and seismic performance permitting selection of a seismic performance matrix according to the characteristics of the structure to be designed (see supplementary note on page 22, 23).
- (c) The ground motion levels in Table 1 are basically required to be indicated by the frequency of variable actions that the structure to be designed is expected to experience during its working life. In the report on “Long-term evaluation of Nankai trough” by the Headquarters for Earthquake Research Promotion, however, the return period of a maximum level earthquake in the relevant area is assessed to be around 100 years. In such a case, it is inappropriate to express the ground motion level in terms of the frequency of occurrence during the design working life of the relevant structure. Attempts have also been made in recent years, particularly for important structures, to directly assess the ground motion levels to be considered by combining the theoretical ground motions representing the fracture processes of the hypocenter and various observation results. Accordingly, the box for “ground motion assessed as the maximum level ever experienceable by the structure” in Table 1 should be selected when it is appropriate to explicitly indicate the ground motion level by the concept of the maximum ground motion (treatment as an accidental action) instead of the concept of frequency (treatment as variable action).
- (d) When treating ground motion as accidental action as stated above, the reliability level should preferably be accountable with respect to the purpose of the structure, design working life, and other design conditions including other actions.
- (e) “Ground motions assessed as being scarcely experienceable during the design working life of the structure” and “ground motions assessed as the maximum level ever experienceable by the structure” in Table 1 may confuse the designer, as they both imply maximum levels of ground motions. However, these do not have to be simultaneously considered in most cases. Either can be selected depending on the purpose, importance, location, etc., of the structure. The three levels of ground motions regarded as variable actions are arranged in the table to indicate that the ground motions in a lower box are greater. However, “ground motions of the maximum level” assumed as accidental actions are difficult to link to one of the above-mentioned three levels, as it is difficult to treat in a probabilistic and statistical

manner and cannot necessarily be labeled as “rare” from certain aspects.

It should be noted that these two concepts lead to different calculation processes. Verification could be carried out by both processes when an exceptionally long design working life is assumed or when particularly careful design is required, such as the case of structure B in the supplementary note in page 23. However, such double-verification is not normally required.

- (f) The expression “ground motion assessed as being experienceable during the design working life of the structure” for ground motion levels includes the possibility of assessment by setting a ground motion level to be addressed by the design, estimating the return period of such a ground motion for comparison with the design working life, and judging as “extremely rarely experienceable during the design working life.” In other words, the ground motion levels to be addressed by the design should not necessarily be derived from the frequency of occurrence during the design working life (see 4.2 (Method of indicating ground motion levels)).
- (g) The specific magnitude of the ground motion assessed as “being scarcely or extremely rarely experienceable during the design working life of the relevant structure” can be varied depending on the design working life, importance, etc., of the structure. In other words, the definition of “scarcely” and “extremely rarely” are not fixed but should be clarified for individual structures.
- (h) “Ensuring the retention of the function to fulfill the purposes of the structure” is considered to be a standard requirement against a “ground motion assessed as being experienceable several times during the design working life of the structure.” However, alternative requirements may be possible in certain regions for a ground motion with the same frequency, such as “limiting the damage to a predetermined level (restorability limit state),” “preventing collapse (ultimate limit state),” and preventing fatalities due to damage to the structure (ultimate limit state).” Indicating the relevant ground motion level and seismic performance level on the basic matrix is useful in such a case as well.
- (i) Though three seismic performance levels are provided to represent the serviceability limit state, restorability limit state, and ultimate limit state, seismic performances more in detail may also be specified for certain structures.

#### Supplementary note 1

An image of different positions in the matrix for structures for different uses

Structure A

Seismic performance		Functions to achieve the purposes of the structure are ensured (Serviceability limit states)	Continued use of the structure is feasible by restoration using technologies available within reasonable ranges of cost and time (Restorability limit states)	Stability of the structure is retained intact and safety of human life in and around the structure is ensured (Ultimate limit states)
Ground motion level				
Treatment as variable actions	Ground motion assessed as being experienceable several times during design working life of the structure			
	Ground motion assessed as being rarely experienceable during design working life of the structure	√		
	Ground motion assessed as being scarcely experienceable during design working life of the structure			
Treatment as accidental actions	Ground motion assessed as the maximum level ever experienceable by the structure			√

Structure B

Seismic performance		Functions to achieve the purposes of the structure are ensured (Serviceability limit states)	Continued use of the structure is feasible by restoration using technologies available within reasonable ranges of cost and time (Restorability limit states)	Stability of the structure is retained intact and safety of human life in and around the structure is ensured (Ultimate limit states)
Ground motion level				
Treatment as variable actions	Ground motion assessed as being experienceable several times during design working life of the structure			
	Ground motion assessed as being rarely experienceable during design working life of the structure		√	
	Ground motion assessed as being scarcely experienceable during design working life of the structure			√
Treatment as accidental actions	Ground motion assessed as the maximum level ever experienceable by the structure			√

Supplementary note 2

Ground motion levels and seismic performance levels specified in various technical standards in Japan

(1) Ground motion levels

(a) JSCE Standard Specifications for Concrete Structures [Seismic Design] (1996)

Level	Description
Level 1 ground motion	Ground motions with a magnitude that would be encountered several times during the service life of structures
Level 2 ground motion	Ground motions with a magnitude that would be rarely encountered during the service life of structures

(b) Specification for Highway Bridges [Seismic Design] by the Japan Road Association (JRA) (March 2002)

Level	Description
Level 1 ground motion	Ground motion with a higher probability of occurrence during the service life of a bridge
Level 2 ground motion	Strong ground motions with a lower probability of occurrence during the service life of a bridge
	Type I: earthquakes occurring at tectonic plate boundaries and affecting large areas
	Type II: near-field inland earthquakes

(c) Enforcement Ordinance of Building Standard Act (April 2000)  
(Calculation of permissible stress, etc.)

Level	Description
Primary design level	Coefficient of shearing force: in principle 0.2 (Local factor: 0.7-1.0)
Secondary design level	Coefficient of shearing force: in principle 1.0 (Local factor: 0.7-1.0)

(Critical load-bearing capacity calculation)

Level	Description
Primary design level	Earthquakes that may be encountered once or more during the period when a building exists
Secondary design level	Earthquakes that may occur scarcely

(d) Guidelines for Ductility-based Seismic Design of Reinforced Concrete Structures by the Architectural Institute of Japan (AIJ) (August 1999)

Level	Description
Level 1	Moderate earthquakes that may occur several times during the service life
Level 2	Major earthquakes that may be encountered once in the service life
Level 3	Maximum possible ground motions (e.g., 1995 Hyogoken-Nanbu Earthquake and 1891 Nobi Earthquake due to inland active faults)

(e) AIJ Proposal for Improvement of Disaster Prevention Performance of Buildings and Cities (Third Proposal) (January 1998)

Level	Description
D	Ground motions that may be encountered several times during the service life
C	Ground motions regarded as intermediate between B and D
B	Ground motions that may be encountered once during the service life
A	Ground motions that may rarely be encountered during the service life
S	Ground motions that may scarcely encountered during the service life

(f) JSCE Proposal for Seismic Standards for Public Works (Third Proposal) (June 2000)

Level	Description
Level 1 ground motion	Ground motion that a structure is required to withstand without damage (Second Proposal)
Level 2 ground motion	Maximum ground motion conceivable for present and future at the site (Third Proposal)

(g) Basic Plan for Disaster Prevention by the Central Disaster Prevention Council (July 1995), Part 2 “Measures against Earthquakes”

Level	Description
General ground motion	Ordinary ground motion with a probability of occurrence of once or twice during the service life of a structure
Ground motion of a higher level	Ground motion of a higher level resulting from a great near-field or marine earthquake with a lower probability of occurrence

(h) Notification about the Details of the Technical Standard of Port Institutions (April 1999)

Level	Description
Level 1 ground motion	Ground motion with a higher probability of occurrence during the service life of a facility
Level 2 ground motion	Strong ground motions with a lower probability of occurrence during the service life of a facility

(2) Seismic performance

(a) JSCE Standard Specification for Concrete Structures [Seismic Design] (1996)

Seismic performance	Description
Seismic performance 1	Functions are retained intact requiring no repair after an earthquake.
Seismic performance 2	Functions are restorable in a short time requiring no strengthening after an earthquake.
Seismic performance 3	The entire system of the structure does no collapse during an earthquake

(b) JRA Specification for Highway Bridges, Part V “Seismic Design” (March 2002)

Seismic performance	Description
Seismic performance 1	Soundness as a bridge is not impaired by an earthquake
Seismic performance 2	Damage by an earthquake is limited and the functions as a bridge can be recovered promptly
Seismic performance 3	Damage by an earthquake is not fatal for the functions as a bridge

(c) Enforcement Ordinance of Building Standard Law (April 2000)

(Calculation of allowable stress, etc.)

Level	Description
Primary design level	Structural integrity is not damaged (within the allowable stress)
Secondary design level	Collapse of building is prevented to protect human life.

(Critical load-bearing capacity calculation)

Level	Description
Primary design level	Building superstructure is not damaged (damage limit displacement).
Secondary design level	Collapse of building superstructure is prevented to protect human life (safety limit displacement).

(d) AIJ Guidelines for Ductility-based Seismic Design of Reinforced Concrete Structures

(August 1999)

Seismic performance	Description
Level 1	Continued use is unconditionally possible.
Level 2	Damaged to a certain extent but the damage is controlled to a level below the planned damage limit.
Level 3	Safety of human life is ensured.

(e) AIJ Proposal for Improvement of Disaster Prevention Performance of Buildings and

Cities (Third Proposal) (January 1998)

Seismic performance	Description
1	No damage
2	Light damage
3	Moderate damage
4	Failure/collapse

Light damage: Lightly damaged but no injury or functional damage to the building.

Moderate damage: Significant damage to the building but scarcely involves casualties. The functions of the building may fail.

Failure/collapse: The damage may not be restorable. Casualties may be involved.

(f) JSCE Proposal for Seismic Standards for Public Works Structures (Third Proposal) (June

2000)

Seismic performance	Description
Level 1 ground motion	All structures are required in principle to sustain no damage. (Second Proposal)
Level 2 ground motion	Important structures and structures for which early restoration is necessary are required to be restorable in a relatively short time, even if they sustain damage or residual plastic deformation after an earthquake. Other structures are required in principle to prevent collapse of the entire system of structure, even if they are damaged to an unrestorable degree.

(g) Basic Plan for Disaster Prevention by the Central Disaster Prevention Council (July 1995), Part 2 “Measures against Earthquakes”

Seismic performance	Description
General ground motion	Freedom from severe obstruction to the functions is required as a basic objective.
Ground motion of a higher level	Freedom from severe impact on human life is required as a basic objective.

(h) Notification on the Details of the Technical Standard of Port Facilities (April 1999)

Seismic performance	Description
Seismic performance 1	Required stability of a facility is secured and its sound functions are retained intact.
Seismic performance 2	Suffered damage is slight, and its functions are promptly recoverable after an earthquake to retain the intended functions.

Supplementary note 3

Basic Plan for Disaster Prevention by the Central Disaster Prevention Council

The Basic Plan for Disaster Prevention formulated by the Central Disaster Prevention Council in July 1995, which provides the national policy and plan for earthquake disaster management, gives the concept for ensuring earthquake resistance of structures and facilities in its Article 1 of Part 2 “Countermeasures,” Chapter 1, Section 1 “Construction of Quake-resistant Country and Cities.” The entire text of the concept is given as follows:

<p><b>Concept for Ensuring Earthquake Resistance of Structures and Facilities</b></p> <p>When planning enhancement of the earthquake resistance of the country and cities, it is necessary to ensure earthquake resistance structures and facilities, such as buildings, public works structures, communication facilities, lifeline facilities, and facilities related to disaster</p>
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prevention. Though the method of seismic design of these structures may vary depending on their type and purpose, the basic concept should be as follows:

- Seismic design of structures and facilities should address both general ground motions that may be encountered once or twice during their service lives and ground motions of a higher level resulting from great near-field or submarine trench-type earthquakes with a lower probability of occurrence.
- Structures and facilities should be designed with the basic objective of preventing major disruption to the functions under general ground motions and grave impact on human life under ground motions of a higher level.
- Moreover, a greater margin of seismic performance should be provided against higher-level ground motions for important structures and facilities. Such structures and facilities include those whose functional disruption can be a significant obstacle to emergency operations or can have significant impact on economic activities over wide areas, such as regions and the entire country, and buildings accommodating many people.

It should be noted that ensuring earthquake resistance includes measures to ensure integrated system security, such as maintaining replaceability and providing backup systems, in addition to the above-mentioned seismic design of individual structures and facilities.

Supplementary note 4

Examples of seismic performance matrices

(1) Vision 2000, USA\*

Earthquake design level	Earthquake performance level			
	Fully operational	Operational	Life safe	Near collapse
Frequent (43 years)	●	○	○	○
Occasional (72 years)	■	●	○	○
Rare (475 years)	★	■	●	○
Very rare (970 years)		★	■	●

○: Unacceptable performance; ●: Basic objective; ■: Essential/hazardous objective; ★: Safety critical objective

\* Guidelines established by the Structural Engineers Association of California.

(2) Seismic design guidelines for port structures\*\*

Performance Grade	Design earthquake	
	Level 1	Level 2
Grade S	Degree I: Serviceable	Degree I: Serviceable
Grade A	Degree I: Serviceable	Degree II: Repairable
Grade B	Degree I: Serviceable	Degree III: Near collapse
Grade C	Degree II: Repairable	Degree IV: Collapse

Note “Grade S” denotes the highest importance. And “Grade C” denotes the lowest importance.

\*\* Guidelines established by the International Navigation Association.

## 4.2. Method of indicating ground motion levels

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The specified ground motion level should be explicitly indicated in terms of return period or probability of non-exceedance assumed in the design (treatment as variable action).

When treating ground motions as accidental actions, the level of reliability of the characteristic values finally adopted in the design shall be accountable.

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- (a) As stated in Chapter 3, ground motions are basically regarded as variable actions in this code, as it is based on the concept of reliability design. For this reason, the method of indicating ground motion levels employs in principle a probabilistic approach using such parameters as return periods. This is consistent with the probabilistic methods mostly employed for expressing other actions using return periods and other parameters.
- (b) It should be noted that the method specified in this section is the method of indicating the ground motions. The method of setting the ground motion does not necessarily have to be based on a probability approach. As stated above, an alternative method is also possible in which the ground motion level to be considered in the design is directly set by combining the theoretical ground motion representing the fracture processes at the hypocenter and various observation results.
- (c) When earthquake actions are regarded as accidental actions, it is impossible to assess them in terms of return period or probability of non-exceedance. Nevertheless, the level of reliability of the characteristic values of the ground motion finally adopted in the design should preferably be accountable.

## 5. Method of verifying performance

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Various formats have been proposed for verifying performance, among which no particular format is specified at the current stage. However, in consideration of future accumulation of data related to uncertain factors of various kinds, this code recommends that the verification method considering reliability, such as the method of partial factors, is incorporated in the technical standard related to design in an appropriate form.

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- (a) A growing trend is set towards reliability design, being led by ISO 2394. Transparency and accountability in regard to decision making have become increasingly required for public structures. In consideration of the aspect of ensuring transparency and accountability in structural design, it was decided that the method of partial factors be recommended here as one of effective methods. The method of partial factors referred to in this code is a method in which the scatter (distribution) of basic components of response values and limit values including load-bearing capacity and serviceability are considered to determine partial factors of design parameters in order to ensure targeted fundamental performance requirement with a certain reliability. The method of partial factors corresponds to so-called level I of reliability design, but applying level II or III is not restricted either.
- (b) Assuming a uniform safety factor for variable actions and permanent actions may not lead to the same levels of performance requirements between structures for which the variable actions have predominant effects and those for which permanent actions have predominant effects. These problems can be clarified by introducing the method of partial factors.
- (c) Various partial factors are conceivable depending on the properties of the structure to be designed. ISO 2394 provides the following factors as examples of partial factors:

ISO 2394

Load side	Load-bearing capacity side
$S_d = S(F_d, a_d, \theta_{sd})$ $F_d = \gamma_f \cdot F_r$ $a_d = a_{norm} \pm \Delta a$ $\theta_{sd} = \gamma_{sd}$	$R_d = R(f_d, a_d, \theta_{rd})$ $f_d = f_k / \gamma_m$ $a_d = a_{norm} \pm \Delta a$ $\theta_{rd} = 1/\gamma_{rd}$
$\gamma_f$ : load factor $\pm \Delta a$ : geometric scatter $\gamma_{sd}$ : model uncertainty factor of load effect	$\gamma_m$ : material factor $\pm \Delta a$ : geometric scatter $1/\gamma_{rd}$ : model uncertainty factor of load-bearing capacity
$(\gamma_n$ : importance factor of structure)	

## Annex1 Definitions

Some of the terms used in this Basis of Structural Design for Buildings and Public Works are defined as follows:

Term	Definition
fundamental performance requirement	In a wide sense, this term refers to a concept that includes structural and functional performance requirements necessary for the use of a structure without inconvenience, including such conditions as the landscape and environment. In this Basis of Structural Design for Buildings and Public Works, however, it refers to an essential performance required for the structure, for which verification is conducted in the structural design.
design working life	Assumed period for which a structure is to maintain the specified functions as a basis for design. During this period, the structure is required to be usable for its intended purpose by normal maintenance without major repair being necessary.
safety	Performance of a structure to protect human life in and around the structure from the assumed actions. Defined in relation to ultimate limit states.
serviceability	Performance of a structure to adequately function without inconvenience in service under the assumed actions. Defined in relation to serviceability limit states.
restorability	Performance of a structure by which continued use of the structure under the assumed actions is technically feasible by repair within reasonable cost. Defined in relation to restorability limit states.
limit states	States beyond which a structure no longer satisfies the design performance requirements.
ultimate limit states	Limit states beyond which stability of a structure is impaired due to failure, major deformation, or loss of equilibrium of forces of its structural members and safety of human life in and around the structure is no longer ensured.
serviceability limit states	Limit states in which the required serviceability of a structure is retained and its intended functions are ensured.
restorability limit states	Limit states in which continued use of a damaged structure is possible by repair with technologies available within reasonable cost and time.
limit states under specific design situation	Types of serviceability and ultimate limit states specifically designated by the process or action causing the limit states.
fatigue limit states	Limit states caused by fatigue damage due to repeated variable actions.
durability limit states	Limit states caused by damage due to the effect of environmental actions.
fire resistance limit states	Limit states caused by damage due to fire.
action	Generic term for “causes of mechanical forces acting on the structure,” “causes of deformation of the structure,” and “causes of deterioration of the materials of the structure (environmental action).”
load	Action converted to set of mechanical forces directly applied to the structure for use as input values in the static calculation using load models to determine the sectional forces, stress, and displacement for the purpose of design.

Term	Definition
permanent action	Action that is likely to act continuously throughout the design working life of a structure and for which variations in magnitude with time are small compared with the mean value; action whose variation is marginal and can lead to some limiting values; or action that is inclined to monotonic increase or reduction in a certain direction throughout the design working life.
variable action	Action whose variation in magnitude with time is neither negligible in relation to the mean value nor monotonic.
accidental action	Action that is unlikely to occur with a significant value on a given structure in the design working life; action whose occurrence is difficult to predict by statistical techniques but not socially negligible.
reference period	A chosen period of time used as a basis for probabilistically assessing values of variable actions, time-dependent material properties, etc., to specify representative values.
representative value of an action	A value specified for specific purposes, such as verification of a limit state. Note: Representative values may be used for verification as they are or by being further multiplied by a load factor, depending on the technique to be adopted in the performance verification. Note: Representative values consist of characteristic values, combination values, frequent values and quasi-permanent values, but may consist of other values.
characteristic value of an action	Principal representative value. Note: It is chosen on a statistical basis, so that it can be considered to have a specified probability of not being exceeded towards unfavorable values during a reference period, or on acquired experience, or on physical constraints.
load combination	Set of design values used for the verification of the structural reliability for a limit state under the simultaneous influence of different actions.
fractile value	A value of a random variable at which the cumulative probability of the observations of the variable is less than the value. The fractile is often given as a percentage.
seismic performance	Performance related to deformation, damage, etc. under seismic action.
verification	Set of activities performed to confirm whether or not a structure fulfills the fundamental performance requirements. Confirmation is generally made by comparing the response values to an action with the limit values of load-bearing resistance, serviceability, etc., but may also be made by the judgment of the designer based on field experience and test results.
method of partial factors	Calculation format in which allowance is made for the uncertainties and variabilities assigned to the basic variables by means of representative values, partial factors and, if relevant, additive quantities.

## Annex2 Summary of Discussion at Committee Meetings

It was decided at the committee meetings and secretarial meetings that the following items would be selected as “essential items,” for which matters common to building and civil engineering fields and matters common to various construction types, such as steel and concrete, would be brought up for discussion by the committee consisting of members representing various fields.

Essential items	Summary of discussion
Fundamental performance requirements	Determination of fundamental performance requirements for design
Limit states	The types of limit states to be covered
Actions (loads)	Determination of the basic manner in which actions (loads) are treated
Verification methods, e.g., method of partial factors	Concept of verification methods, such as the method of partial factors
Seismic design	Concept of seismic design on an international level

Meanwhile, international technical standards for structural design tend toward establishment of general technical standards common to most structures while formulating technical standards for each type of structure in regard to matters specific to the characteristics of the each type.

A typical example of such a trend is the Eurocode currently being formulated by the European Committee for Standardization (CEN), in which Eurocodes 0, 1, and 8 are common to all types of structure .

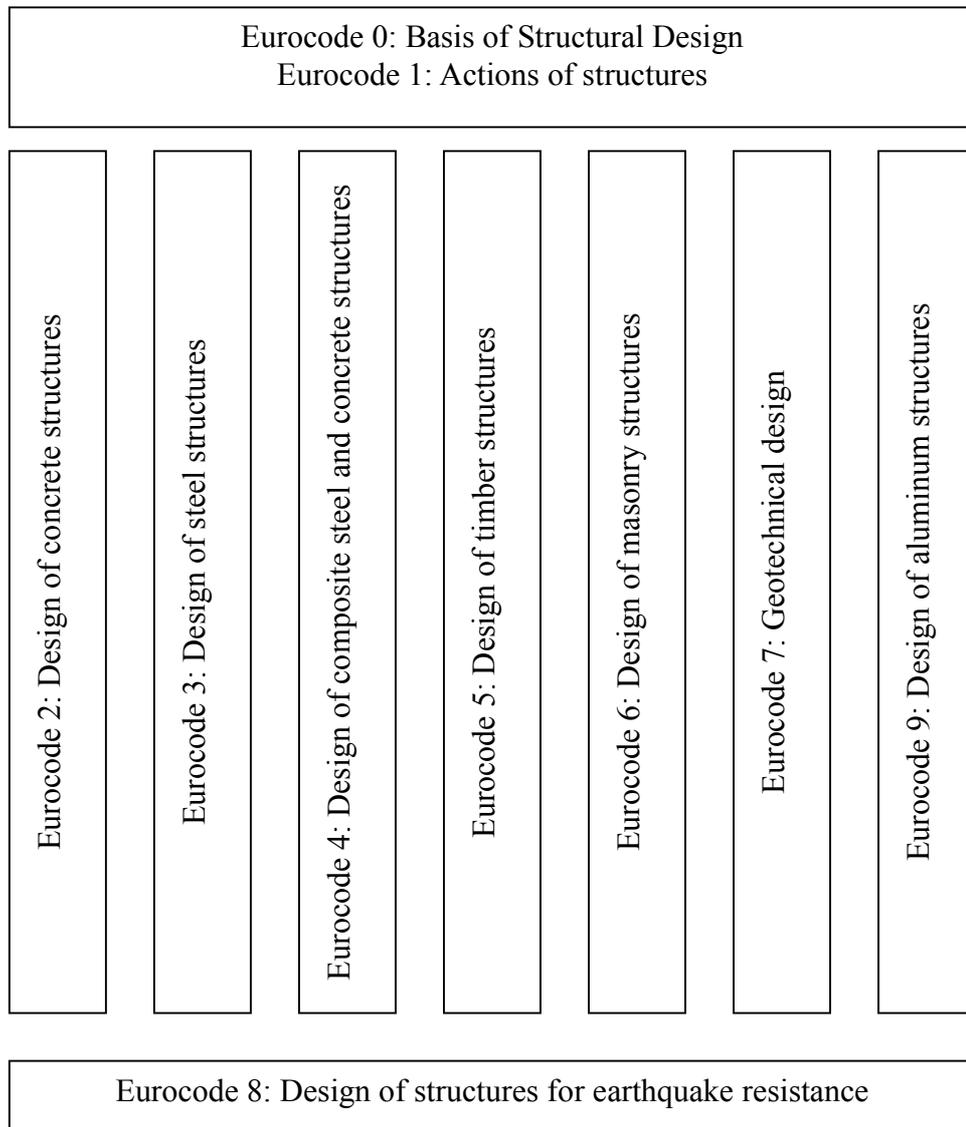


Fig. Entire system of Eurocode standards

In ISO, the general principles on reliability (ISO 2394) were formulated as a counterpart of Eurocode 0.

The arguments presented for the Basis of Structural Design for Buildings and Public Works are intended to make it serve as an intermediary between the current Japanese systems and international ones of technical standards.