JAPAN SOCIETY OF CIVIL ENGINEERS 1994 STUDY TOUR REPORT
-TRAVEL REPORT-

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(Recommended by the Canadian Society for Civil Engineering)

l. Introduction

In 1992, the Japan Society of Civil Engineers created a study tour grant program to promote exchanges and dialogue between civil engineers of Japan and other countries. In 1994, the JSCE offered one of these travel grants to the Canadian Society for Civil Engineering, and I have had the honour of being awarded this grant. This offered me a golden opportunity to learn the Japanese state-of-the-art and state-of-Practice on a few topics of great interest to me, namely the seismic-resistance assessment and retrofit of existing steel buildings and bridges, construction of new types of seismic-resistant steel structures, and the use of pultruded fibre-reinforced plastic structural shapes in buildings, bridges and other civil engineering structures.

The study tour took place from October 30th to November 12th 1994. Its itinerary had been designed to have a well balanced mix of visits to construction sites, and industry, governmental, and academic research facilities. All facilities visited were located in the Tokyo Metropolitan area.

The amount of information which was provided by the numerous civil engineers met is quite considerable, and this report can only provide a brief summary of the topics discussed and observations made. Nonetheless, although numerous omissions are necessary due to space constraints, it is hoped that this report will provide a useful overview of the Japanese expertise on the aforementioned topics, and encourage other non-Japanese civil engineers to establish professional contact (and in some cases, tasting friendships) with Japanese civil engineers.

2. Construction Site Visits

2.1 Tsurumi Bridge - Metropolitan Expressway Public Corporation

The Tsurumi bridge is a 3-span continuous 1020 m long cable-stayed bridge which is an important link of the new Tokyo Bay Ring Expressway project. It is planned that a second identical bridge will be constructed within a 50 m centre-to-centre distance from the first one. Therefore, subsequently to computer graphic simulations, single plane cable-stayed bridges were found to be more elegant.

With a main span of 510 m, the Tsurumi is not the longest cable-stayed bridge in the world, but undoubtedly the longest single plane one. A most interesting aspect of this bridge is its all steel construction. Even the elevated approaches and interchanges between the Yokohama Bay and the Tsurumi bridges are all steel. Consequently, some time was spent to discuss the design detailing requirements to achieve rigid connections between the columns, girders and foundations, and a visit of the interior of the towers and of the girders' underside was conducted to observe various other aspects of detailing. Obviously, a careful attention was paid to avoid fatigue problems, and effective drainage path were implemented to avoid water entrapment and rust problems.

Seismic and wind resistance were also important design considerations. In particular, vane-type dampers were introduced adjacent to the bearings on the main piers to attenuate the severity of longitudinal movements and cable tensions during earthquakes.

Another impressive feature of this bridge is the large number of maintenance vehicles (8), elevators (4) and gondolas (4) which have been constructed to provide long term maintenance of the steel towers and girders, and integrated to the structure without any negative impact on the aesthetic of the bridge. Some time was also spent looking at another very elegant all steel construction, the nearby Yokohama Bay bridge which won the prestigious JSCE Tanaka prize for bridge engineering in 1990.

2.2 Shimizu Corporation Construction Site

There has not been many seismic rehabilitation projects of historical buildings in Japan so far. This may be because there is apparently no government agency imposing stringent historic preservation requirements as is often the case in North America. The Yurakucho building, in Tokyo, is the largest seismic rehabilitation project of an historical Japanese building ever conducted.

This building, constructed more than 50 years ago, owns its historical value partly because it was the U.S. Army headquarters after the second world war. A visit of this project was therefore most interesting. A meeting was held with the Shimizu Corporation professionals in charge of this project prior to a tour of the construction site. The existing building frame consists of a composite steel frame, where all steel members were also "wrapped" into reinforced concrete, an archaic construction practice of the days when steel frame construction was very expensive in Japan. Particularly interesting in this project was the seismic rehabilitation criteria adopted, the addition of double shear-walls needed for proper anchoring to the existing members, and the design of innovative expansions joints to eliminate undesirable seismic structural response between the retrofitted existing building, preserved existing facades, and a new adjacent more flexible steel buildings.

During a visit of the Shimizu Corporation headquarters, a presentation was made of the planned Shimizu Super High-Rise (SSH), a 550 metres building which will be the tallest building in the world when constructed, its height being roughly equal to the CN tower in

Toronto.

All phases of the seismic and wind resistant design, foundation design, construction technology, fire-protection, functionality, and disaster prevention, incorporated the latest state-of-the-art techniques and technology. This promises to be a national landmark when completed.

2.3 Obayashi Corporation Construction Sites

Two important construction sites where large-scale steel structures are being constructed were visited. The Obayashi Corporation was involved in both projects and could provide valuable structural engineering explanations prior to the site visits.

The first project was the Tokyo International Forum centre, a 1.6 billion dollars (US) complex of convention and exhibit facilities, and large capacity auditoriums. The key feature of this project is undoubtedly its glass atrium, the largest ever constructed worldwide. Although of a relatively simple and elegant structural concept, the sheer size of the project makes every construction detail a complex challenge. For example, the very large thickness needed for some key connection components required the use of casted steel for these pieces. Moreover, the temporary support structures, approximately 50 metres tall, required more tons of steel than a comparable permanent buildings of the same high. Innovative structural solutions were also devised for earthquake and wind resistance. Finally, because very large size structural welds are needed by this project, a stringent quality control program is in place, which requires ultrasonic testing of all welds, and, for all thick welds, pre-heating of the base steel to 100°C.

The second project visited was the expansion of the Tokyo train station. More than 4000 trains and l.6 million passengers per day transit through the Tokyo train station, the third busiest in the world.

New train lines must be added (in anticipation of the 1998 winter Olympic) without disruption to this existing traffic. However, because no more ground space is available at that station, new elevated tracks and platforms must be added. This required very large space frames constructed of built-up box sections for beams and columns. As was apparently done on all construction sites in Tokyo, the beam-to-column connections consisted of beams bolted to stub-beams pre-welded to the columns. More labour is required for each connection (since both a welded joint and a bolted splice are executed), but this detailing eliminates the need for their site welding, with the added benefit of higher-quality shop-welding of these critical beam-to-column welds - not a bad idea in view of the reported performance of North-American type beam-to-column connections during the recent Northridge (Los Angeles) earthquake. Again, given the size of beams find columns used on this project, the construction details were impressive.

3. Private Research Institutes and Companies

3.1 Kajima Technical Research Institute

Kajima is one of Japan's three supercontractors (along with Shimizu and Obayashi) whose reputation is well known worldwide. This architects/engineers/contractors/developers firm employs more than 14,000 engineers and has developed its own research facilities, currently divided among the Kobori Research Complex, and the Kajima Technical Research Institute. The structural engineering and earthquake engineering research facilities are located at this latter Institute, with a staff of more than 320 research engineers. It is noteworthy that Kajima was the first Japanese company in this industry to establish a research institute, in 1949.

Kajima's experimental earthquake engineering research facilities are impressive. A 5m by 5 m shake table, capable of six degree-of-freedom excitations and able to support specimens of up to 30 tons, has an operating range of 0 to 60 Hz and up to 2g peak input accelerations. Not surprisingly, the massive foundation of the table is itself supported on a floating system to prevent propagation of vibrations to the laboratory and surrounding buildings during operation of the table. The scale of Kajima's adjacent large-size structural testing laboratory, which can be used for static, pseudodynamic, or fatigue tests, is equally impressive. An approximately 45 m by 20 m testing area, with a 2 m thick reaction floor, coupled with a 12 m high reaction wall, 16 m long and 3 m thick, make this laboratory a very powerful research facility. Other experimental capabilities include a rather unique 30 Mega-Newton fatigue testing machine to test the stay cables of cable-stayed bridges which can be inclined to 60-degrees to simulate realistic cable grouting conditions. Research engineers at Kajima have also installed a fully computerized pseudo-dynamic testing facility, thus implementing the latest earthquake engineering testing techniques which have actively been developed by Japanese earthquake engineering researchers. Kajima's engineers have also developed a six-actuator experimental set-up which allows significant reduction in the size of bridge column specimens needed for testing, while being able to fully reproduce the state of shear, axial, flexural and torsional efforts in the section of interest.

An important trust of Kajima's research in earthquake-resistant design has been the development of active and passive seismic-resistance systems, notably a new seismic and vibration isolation system, energy dissipating steel dampers, and computer controlled variable-stiffness buildings. All of these technologies have been implemented in actual buildings, or into some of the Kajima Research Institute's own buildings, which certainly gives an interesting marketing perspective to these new technologies.

In the field of advanced composite materials, Kajima has developed a new process which allows rods of carbon fibre reinforced plastic to harden when heated by the passing an electrical current through the material. Therefore, construction using these rods can be done using a soft material which can be easily handled and formed to its final shape prior to hardening.

3.2 Sumitomo Construction Company's Institute of Technology and Research

Engineers at the Sumitomo Institute of Technology and Research have invested a considerable earthquake engineering research efforts to develop, test, and implement a number of passive seismic resistance technologies. One very interesting approach has been the introduction of viscous damping devices in new buildings. One such device is an impressive high-damping wall, which essentially consist of having, at each floor, a large steel plate (connected to the above floor level) slide inside a steel-wall sleeve (connected to the floor below) filled with a highly viscous liquid. During an earthquake, the relative displacement of the floors is damped by the laminar flow of the viscous fluid between the steel plates. This effectively introduces a true velocity dependant damping mechanisms into the structure. Effective structural damping level of up to 30% of critical damping can be achieved. This technique has already been implemented in one building constructed in Japan. The effectiveness of this system has been demonstrated (luring this visit by performing shaking table tests of two multi-story model structures, with and without the wall-damping devices to allow comparison of the seismic performance, and visually illustrate the dynamic effectiveness of this damping device.

This research institute is also currently developing second generation base isolation devices, that is devices which can shift the fundamental vibration period of buildings up to much larger periods than currently possible using current base isolation products. A sliding device has already been developed and implemented into a five-story demonstration steel structure constructed on the Sumitomo Research Institute site. This structure is used to make an impressive demonstration of the effectiveness of base isolation. A dynamic shaker adjacent to the structure inputs a 0.003g sine wave excitation to the foundation of the building, at the resonance frequency of the steel model.

Standing at the fifth story, severe vibrations are felt (approximately o.o2g) when the base-isolation mechanism is restrained by a locking device implemented for demonstration purposes, but these become imperceptible vibrations when the base isolation mechanism is free to function as intended.

In-line with the Sumitomo's philosophy of passive earthquake resistance mechanisms using structural isolation and damping devices, research is underway to develop suspended buildings, floating structures, and damping pile-foundation devices. These appear to be promising technologies.

Involvement in the field of advanced composite materials has consisted largely of development of aramid fibre reinforced plastic rods for pre-stressed and post-stressed concrete structures. Beyond traditional testing of various specimens, it is noteworthy that a model bridge has been constructed and instrumented, and has been used for two years already by trucks accessing a Sumitomo's material storage yard. Performance has been excellent so far, and monitoring continues.

3.3 Japan Railways' Railway Technical Research Institute

Researcher from the Bridge Laboratory of Japan Railways' Railway Technical Research Institute were met to discuss the details of earthquake-resistant design criteria for railway bridge structures in Japan, and, in particular, the design requirements for steel railway bridges and the observed performance of railway bridges in past Japanese earthquakes. It was also learned that a new Limit States Design criteria for railway bridges has recently been completed and will soon to be adopted. Hopefully, an English version of this new code will be available in a the future for study by railway engineers and bridge designers worldwide.

3.4 Arisawa Company

A manufacturer of pultruded fibre reinforced plastic structural shapes was visited to discuss the use of these structural shapes in Japan. Discussions revealed that the difficulty in constructing high capacity and reliable connections is the major problem limiting the broader use of these shapes in structural engineering applications. As such, this is not much different than the situation in North America, although these shapes have found some use in non-seismic regions there.

4. Public Research Institutions

4.1 Public Works Research Institute - Ministry of Construction

The research facilities of the Public Works Research Institute (PWRI) of the Ministry of (instruction are located in the Tsukuba Science City. Numerous equipment are present there for earthquake engineering related testing, including a 30 mega-newton universal testing machine, four 2 m by 3 m single-degree-of-freedom shake tables, and one 6 m by 8 m two-degrees-of-freedom shake table.

The experimental investigation of multiple bridge pier out-of-phase excitation is possible using these multiple tables. Also, it was an interesting experience to stand on the large table while full time-scale and amplitude-scale seismic ground motion records were played back, and feel the very significant difference in "signature" of strong motions as recorded on rock and on soft soils from the same Japanese seismic event.

Finally, a considerable amount of time was spent discussing recent and on-going research on the seismic performance of steel bridge columns with Dr. K. Kawashin'1a, an internationally recognized expert on this field, and his research colleagues. It was also particularly valuable to be able to see up-close the various failure modes of numerous steel column specimens which had recently been statically and dynamically tested at the PWRI.

4.2 Building Research Institute - Ministry of Construction

The research facilities of the Building Research Institute (BRI) of the Ministry of Construction are also located in the Tsukuba Science City. The BRI houses the largest reaction wall in the world it is 25 metres tall, 20 metres wide and 6 metres thick. This facility has been used for the testing of numerous full-scale structures, up to a 7-story reinforced concrete frame building, a 7 story steel frame building, and a S-story reinforced masonry building. Many of these tests have also been conducted using the recently developed pseudo-dynamic testing method. Needless to say, testing at this scale is very labour and resource intensive, and, for that reason, a "normal"-scale testing laboratory is also located in an adjacent building. Of particular interest on the day of the visit was the testing of cylindrical steel columns filled with concrete (i.e. hybrid members) under pure compressive loading using a 2500 ton universal testing machine. A very interesting type of local buckling developed in these members at their ultimate failure load.

5. Academic Research Institutions

5.1 Institute of Industrial Science, University of Tokyo

A short visit was paid to the International Centre for Disaster-Mitigation Engineering of the University of Tokyo. While there, it was particularly interesting to learn that one of the research groups of the Institute of Industrial Science has constructed a based isolated observation tower, equipped with numerous instrumentation (including video recorders) to record during future earthquakes: (i) the performance of the tower itself with respect to the ground, and (ii) the seismic performance of four adjacent large scale weak multistory concrete and steel building specimens which are expected to be destroyed by a future large earthquake. Given Japan's history of seismicity, this "real-life" experiment should likely happen in a near future.

5.2 Earthquake Research Institute, University of Tokyo

A meeting was held with key researchers of the Earthquake Research Institute of the University of Tokyo. An overview of the activities of that Institute was presented by Dr. Higashihara and his colleagues.

The details of a dense array of strong motion recording instruments installed in the Ashigara Valley were discussed. Particularly interesting were the results of a blind ground motion prediction experiment conducted as an international cooperative effort. From the Ashigara Valley array of seismographs, pairs of weak and strong ground motions recorded at two observations sites were selected: one on a rock outcrop, the other on top of an alluvial deposit nearby.' Then, in a blind experiment, researchers worldwide were asked to predict the ground motion at the sedin'1ent site given only the weak and strong motion records for the station located on rock, and, of course, all available geotechnical data on the surrounding area. The results received from 44 participants differed greatly, with the predicted spectral values sometimes varying by two orders of magnitude.

Also discussed at length was the Modified Discrete Element Method (MDEM) developed at the University of Tokyo and which has found a broad range of possible applications so far. This method has been particularly useful to conceptually study the dynamic behavior of various geotechnical or structural engineering problems. Work is currently underway at the Earthquake Research Institute to apply the MDEM to study seismological geophysical phenomena.

6. Conclusions

A striking quality of Japanese civil engineering practice is the determination and confidence that the construction of large scale research facilities and a dedication to research will undeniably enhance the safety and reliability of their constructions, particularly regarding the threat posed by earthquakes, with definite positive benefits to the Japanese society. Moreover, it is particularly impressive that private construction companies do not hesitate to construct large scale test structures or even real demonstration buildings for testing new technologies. In fact, these demo-buildings implementing new design or devices are often own by these construction companies, which use them as full-scale marketing tools for these new technologies. Also key is the acceptance by owners that severe earthquakes will undoubtedly happen in a near future. This produces a profound incentive for the acceptance of advanced new technologies, with owners showing a willingness to pay a premium at the initial construction time if this may provide content protection and damage reduction during a future large earthquake.

This societal environment can partly explain why Japanese steel construction practice is somewhat unique, particularly regarding some most interesting differences in detailing philosophy, where the emphasis is often on quality and reliability. Similarly, Japanese research in earthquake-resistant steel constructions, and the broader field of earthquake engineering, overall showed constant initiative and ingenuity, both in curiosity-driven research and practical applications.

International exchanges such as those sponsored by the JSCE study tour grant are most valuable to provide civil engineers worldwide with a better understanding with this particular Japanese environment.

Entering the twenty-first century, it is hoped that such a climate of positive international exchanges, mutual understanding and cooperation will further develop.

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Sincerely, "arigato gozaimashita".

Mr. Kono (left, Executive Director of JSCE 1993- 97), Bruneau (right) Asst.Prof.