With Society, the Past, the Present and the Future of Our Bridge Technology and Development

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1. Introduction

From the postwar restoration until the period of rapid economic growth, freeway networks were constructed from the metropolitan area and major cities to various regions around the nation. Steel bridge technical development in this period contributed dramatically to numerous technical innovations including use of high-strength steel and its manufacturing technology, erection technology for cable structure and precision control system, and wind resistant and aseismic measures to solve problems of severe natural conditions. These technical developments provided the bases for construction of long-span bridges such as the Honshu-Shikoku Bridge. On the other hand, the destruction of a viaduct by the Great Hanshin Earthquake in 1995 was a lesson for recognizing the importance of safe distribution systems and utilities, and it shed light on the role of maintenance control and extension of life of bridges as an important subject for traffic management in the future. Further, as the capital investment is depressed today, there is an ever-greater demand for reduction of traffic jams and improvement of the road side environment from the viewpoint of recovery of urban function, and bridge technology is now beginning to change its direction.

The history of steel bridges of Mitsubishi Heavy Industries, Ltd. (MHI) starts with the history of construction of bridges in Japan, dating back to Kurogane Bridge (Nagasaki) in the early days of the Meiji era. The history of steel bridges of MHI is introduced in this paper, together with social needs and the present and future outlook of the technical development of steel bridges.

2. Development of bridges and history of MHI

Kurogane Bridge (**Fig.1**), the first iron bridge in Japan, was manufactured in 1868 by Nagasaki Seitetsusho, the former name of MHI. Until the end of World War II, MHI manufactured more than 10000 tons of bridges in overseas countries that included China, Korea and Taiwan. In 1920s, many bridges were constructed such as the Takamatsu Bridge, a bascule bridge, while in addition many job orders were received from the Ministry of Railways for utilizing MHI's welding technology in welding reinforcement of railroad bridges and test girders by full welding. After the war, the leading technologies in Europe and America were learned, and rational, economical bridge construction was studied. The unique achievements realized at that time included the Sakagoe Bridge of composite lattice girder (1955), the Iizuka Bridge using 50 kgf/mm^2 strength steel (1955), the box girder Yotsugi Bridge (1956), the Ikada Bridge using prestressed concrete in its main girder (1958), and the Kema Bridge of continuous composite girder (1959). In the Nagara River Bridge (1963), 60 kgf/mm^2 strength steel was used for the first time, and its steel specifications are inherited in SM570Q of JIS.

Arch bridges include the trussed Langer bridge and the Nielsen system bridge of high order statically intermediate structure with inclined hangers. The first examples in Japan are the Ao Bridge (1965) and the Aki Bridge (1967).

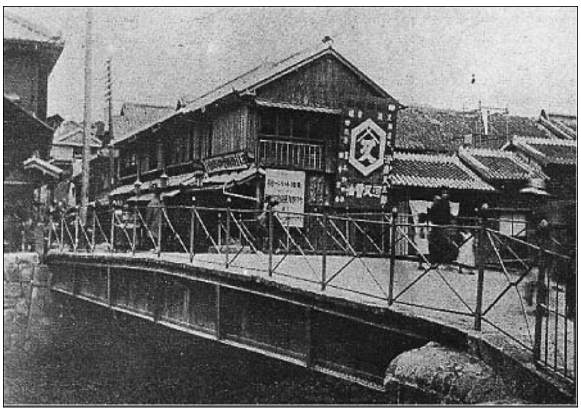

Fig. 1 Kurogane Bridge

Fig. 2 Minato Bridge

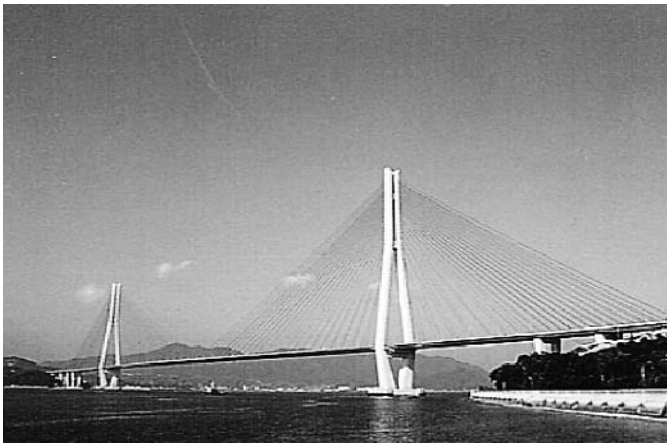

Fig. 4 Tatara Bridge

Fig. 3 Akashi Strait Bridge

Fig. 5 Kurushima Strait Bridge

Regarding truss bridges, MHI participated in the construction of the Minato Bridge (**Fig. 2**), the third biggest cantilever truss bridge in the world in 1973. This bridge was built by using 70 and 80 kgf/mm^2 strength steel massively for the first time in Japan.

In the latter half of the 1960s, Japan's first cable-stayed bridge was erected—the Maya Bridge (1966), and in the 1970s, MHI jointly constructed the multicable system Kamome Bridge. On the basis of MHI's leading and up-to-date structural design, analytical technology, wind-resistant design, and precision management technology, many cable-stayed bridges were built in quick succession.

MHI also participated in the construction of suspension bridges such as the Kanmon Bridge (1973) and Hirato Bridge (1977), and the Greater Naruto Bridge, North and South Bisan Seto Bridges, Honshu-Shikoku Bridge which had been thought to be a "Dream Bridge."

In this history, various technologies have been developed in order to construct more rational and longer steel bridges. In order to evaluate the stability against wind, a diffusion wind tunnel of the biggest scale in Japan was installed to test by using large models and a three-dimensional full-scale model, while to test the aseismic strength, a large-scale three-dimensional shaking table was built to reproduce three-dimensional behavior with high precision.

3. Era of longer bridges

These technologies nurtured for decades contributed greatly to the construction of the Honshu-Shikoku Bridge. MHI played a central role in the construction of the Akashi Strait Bridge (**Fig. 3**), the world's longest suspension bridge completed in 1998, the Tatara Bridge (**Fig. 4**), the world's longest cable-stayed bridge, and the Kurushima Strait Bridge (**Fig. 5**), the world's first three-bridge suspension bridge. These bridges were constructed between many islands in the beautiful Seto Inland Sea National Park. The bridge construction required technical developments taking account of natural conditions such as fog, tidal currents, strong winds and earthquakes, and the busy international navigation routes.

The Akashi Strait Bridge has an overall length of 3 911 m, with a center span of 1991 m, and the main tower stands 283 m high. The main tower was constructed by a climbing crane system in order to shorten the construction period. A damping device to prevent oscillation by wind was installed on the top of the crane, and both economy and safety requirements were satisfied. These

Fig. 6 Yume-Mai Bridge

technologies were applied to the Kurushima Strait Bridge and also to the Megami Bridge now under construction. For the stiffening girder, too, wind-resistant and aseismic measures are important matters: by development of a girder damper connecting the main tower and the stiffening girder, oscillation of the main tower by wind and of the stiffening girder by earthquake were both controlled.

The Tatara Bridge is a hybrid cable-stayed bridge with a center span of 890 m and overall length of 1 480 m. In a cable-stayed bridge, the horizontal component of force is applied to the main girder for fixing the cable, but in a long cable-stayed bridge, the compressive force in the axial direction is dominant, and the design method was established by the ultimate strength test for overall buckling, and its structural stability was verified. During construction, the cantilever length of the main girder was about 440 m, and the stability against wind measure was determined by wind tunnel tests.

Thanks to these technical developments, the Tatara Bridge was undamaged when hit by a typhoon at the time of maximum cantilever during construction, and there was no problem in stability against wind. To confirm the oscillation characteristic assumed in the wind tunnel test, an actual bridge oscillation test was conducted using the originally developed oscillation machine featuring small size and large excitation force.

The Kurushima Strait Bridge is a three-bridge suspension bridge, and the foundation and ground condition for supporting each bridge are different. Accordingly, the dynamic earthquake analysis technique capable of inputting seismic waves with a phase difference in each foundation was applied. Stiffening girders were installed by the lifting-up erection method just under the bridge, and the stiffening girders were kept in fully hinged condition during the erection period. In this way, both economy and shortening of construction period were achieved. Since the Kurushima Strait includes international navigation routes with fast tidal currents, the working hours of transportation barges were severely restricted. An exclusive self-propelled barge having a fixed point holding function was developed, and the bridge was erected within a short period of time.

These bridge erection technologies contributed later to construction of representative bridges in Japan, including the Rainbow Bridge, Yokohama Bay Bridge, Higashi Kobe Bridge, and Trans-Tokyo Bay Highway.

In 2000, MHI also participated in the construction of the Yume-Mai Bridge (**Fig. 6**), the world's first floating swing arch bridge linking the man-made islands of Yumeshima and Maishima in Osaka Bay. This is a new type of bridge featuring economy in foundation and substructure, since it is required to keep a free space beneath the girder for international navigation. To understand the elastic response in cases where a slender structure such as a bridge is exposed to waves, the "elastic response analysis technology of structures exposed to waves" was developed and applied by combining the ship oscillation analysis technology and bridge elastic response analysis technology accumulated over the years by MHI.

4. Outlook and technical development of bridge business

Construction of longer bridges is one thing, and cost is another thing. The Japanese government having unveiled its action principle concerning reduction of public work cost, the concept of life cycle cost (LCC) and benefit/cost (B/C) ratio has been introduced into the bridge business. Also on the occasion of the Great Hanshin Earthquake, the importance of preventive conservation and maintenance management was newly recognized, and the need for comprehensive technical development is increasing.

Key points of the recent revision of technical standards (Specifications for Highway Bridges) are performance-based design and durability, and one of the objectives is the promotion of efforts toward new technology and new processes.

In the light of such changes in various social needs, MHI is promoting technical developments related to rational structure and process for curtailing the construction cost, maintenance management technology aiming at renewal period of road bridges constructed during the period of rapid economic progress, regeneration of cities and environmental improvement.

4.1 Development of inexpensive bridges

With the purpose of expanding the application of steel two-main girder bridges hitherto employed in inexpensive bridges of span length of up to 60 m, the following subjects are being studied.

(1) Strength and stability against lateral torsional buckling and dynamic stability against wind for torsional vortex-induced oscillation

To realize a longer span, the torsional strength of the entire bridge is increased by installation of lower

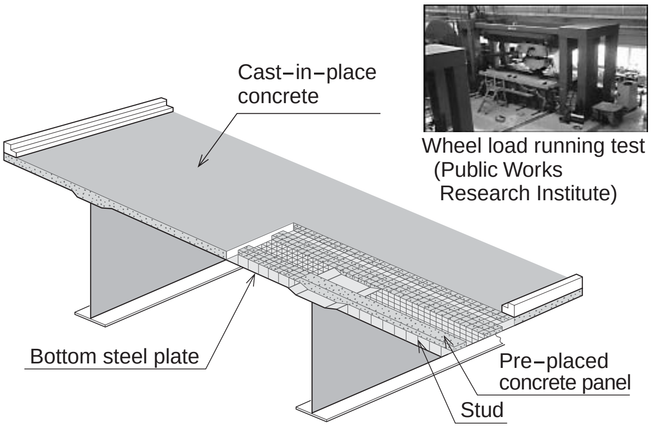

Fig. 7 Development of Dia Slab.

Fig. 8 Fatigue flaw monitoring system

lateral supports in the necessary range of intermediate supporting points, Vierendeel design of lower flanges of lateral girders, and integration of lower flanges (open section box girder), while wind-resistant measures include a wind stabilizer that also serves as a main girder section, and a small, inexpensive damping device.

(2) Rationalization of erection method

In the launching method, which seems to be employed widely at locations where it is difficult to make vents in the river and mountain districts for bridges with longer spans, new developments include a launching device using caterpillar for speedy and continuous launching, and system for controlling the launching point height to minimize the reinforcement of the girder main body. Through further improvements, reduction of erection cost can be expected. As spans become longer, the effect of using high-strength steel material also increases substantially. Concerning problems of fatigue in weld zones and increase of live-load deflection, there is a need to establish a more realistic evaluation method by performance-based design specifications taking account of the floor slab composite effect and oscillation acceleration level.

4.2 Development and expansion of technology conforming with performance design

In the process of transfer of design from the specifications-based type to performance-based type, MHI is developing new rationalization structures of specifications-based type, on the basis of new design techniques including experiment and verification.

(1) "Dia Slab" or composite floor slab without steel stiffener, which was developed as new rationalized floor slab, has already been shown to have high durability and high cracking resistance in dynamic load tests, and the design and construction method has been established (**Fig. 7**).

(2) As rationalization structure of box girder, a system in which the flanged transverse stiffener and web plate are not welded, has been developed, and favorable results have been obtained in load tests and fatigue tests. This has dramatically decreased the job of internal welding, which is a difficult process in the conventional manufacturing method of box girders, and much labor saving is expected in the assembling work.

(3) Necessary feasibility studies are planned through investigation of the problems arising in use of new materials such as low-strain steel plates, fatigue-resistant steel materials, high-strength steel, and super high strength bolts, or applying tensile joint structure in actual bridges.

4.3 Maintenance and management

Since the bursting of the bubble economy, new road constructions have been decreasing, whereas the importance of maintenance and management of public facilities. Maintenance includes checking, repair, reinforcement, and preservation of function. Advanced technology is required in all aspects, and technical development must be promoted in order to operate the road management business efficiently (at lower cost) in the future.

(1) In maintenance and management, it is essential to identify the causes of damage such as fatigue, salt damage and corrosion as a means of determining the renewal period or life-extending measures. As an appropriate technology, the bridge monitoring system is being developed. This system can monitor the fatigue and deterioration status of floor slabs, main girders and other members continuously from a remote place, and can be applied to road network function monitoring in case of earthquakes or other abnormalities for evaluation of the remaining life of bridges (**Fig. 8**).

Individual technologies include a database library of cases of damage to bridges, rational flaw judging method, and aseismic reinforcement of medium-scale bridges using the original damper brace technology.

(2) For road operation management, MHI will also present engineering services on the basis of its con-

Fig. 9 Rapid launching method

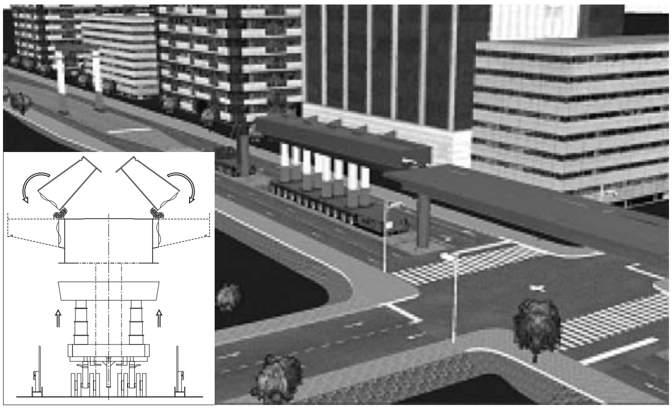

Fig. 10 Rapid grade-separated elevated crossing

struction know-how and monitoring technology.

(3) For disaster inspection, a next-generation inspection system is being studied in order to save labor substantially in investigations of road structures immediately after earthquakes.

4.4 Contribution to urban regeneration

Concerning urban regeneration-related technology, the following new techniques are being developed in order to meet new needs.

(1) At traffic nodal points in cities, a rapid method is required in erection of grade-separated elevated roads in order to ease traffic jams. MHI has developed a “rapid launching method” as an erection method in urban districts, and applied this method in construction of the Arimatsu Viaduct which was completed in 2002 (**Fig. 9**). In the case of this bridge, for the steel girder of 12 000 tons, an overnight launching distance of 130 m was realized, which proved to be an ideal method for continuous grade-separated structures.

Further, for grade-separated crossing at intersections, the "Sui-Sui MOP (Module On Pier) Method" has been developed, which not only shortens construction period but also minimizes traffic jams during consturuction. In the superstructure, the grade-separated road surface repair system was also installed. The module structure is employed by making best use of the merits of the comprehensive heavy machinery manufacturer, and a new rationalization foundation structure suitable for construction in cities is being developed. (**Fig. 10**).

In planning the field construction method, MHI developed the technique of qualitative evaluation of social loss (loss due to delay in work) by combining the traffic flow simulation on the basis of field conditions, construction period and traffic regulation method, with calculation of benefit. A system of selecting the best process comprehensively has been established.

(2) Regarding environmental problems, MHI is planning to develop a system for improving the road side environments and lowering noise levels by fully utilizing its original technologies.

5. Conclusion

As the twentieth century ended, the boom of construction of longer bridges in Japan declined, and public constructions are being criticized from the viewpoints of cost differences between Japan and other nations, deregulation, etc. Further, since the Great Hanshin Earthquake and 10 year’s stagnation of Japan’s economy, the demand for steel bridges has drastically changed. Today, key points are reduction of life cycle cost, road management geared to the new age, and regeneration of cities. Technical standard has also changed from the specifications-based type to performance-based type, and public works are being ordered according to new methods based on new technologies. At present, developing technologies are being highly evaluated and fully utilized. As a comprehensive machinery manufacturer, MHI continues to contribute to society by leading the development of new bridge technologies, including the common technology of environment conservation, disaster prevention and road and traffic technology.

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