

Long-span Bridges: Technology Spanning the Future

Yoshitaka KISHIMOTO

Director of Long-span Bridge Engineering Center
Honshu-Shikoku Bridge Authority

The Development of Long-span Bridge Technology

In the field of long-span bridges, the Akashi Kaikyo Bridge and the Tataro Bridge of the Honshu-Shikoku bridges are the world's longest suspension bridge and cable-stayed bridges, respectively. In addition to this, many other bridges are listed among the world's long-span bridges, indicating that Japanese long-span bridge technology now ranks high among the world. In addition to bridge span, there are many matters that are noteworthy such as the fact that the bridges with large deepwater foundations are numerous and that the Seto Bridge is the world's first large-scale road and rail bridge.

Long-span bridge technology in Japan originated from studies of Western bridge technology, which was half a century ahead and began with Wakato Bridge and Kanmon Bridge. Technology made rapid advances during the construction of the Honshu-Shikoku bridges that followed. Since the Honshu-Shikoku bridges were built in phases, the technology developed was maintained while new technology was developed to resolve the issues of the next bridge. The lines of long-span bridge technology that developed under these circumstances can be seen in the bridges awarded the Tanaka Award (Division of Outstanding Bridge Design and Construction) by Japan Society of Civil Engineers. These technologies cover a broad area ranging from survey, design, construction, maintenance and management. However, this article will focus on construction technology for the superstructure of long-span suspension bridges and cable-stayed bridges.

Koji KAWAGUCHI

Manager of Engineering Information Division
Long-span Bridge Engineering Center
Honshu-Shikoku Bridge Authority

Award-winning Bridges and Technological Development

Table-1 and Table-2 show the Honshu-Shikoku bridges that were awarded the Tanaka Award (only suspension and cable-stayed bridges are shown in Photos 1-5) as well as an outline of the technology developed.

Construction Technology of the Suspension Bridge Superstructure

Main Tower

Building the main towers frequently call for the construction method established with the building of Kanmon Bridge where blocks fabricated at a factory with high precision was transported to the site and built with a crane. For the Akashi Kaikyo Bridge, the main tower reached greater heights and was roughly 300m above sea level. Also, to ensure construction efficiency of the increasingly large tower pillar cross-section, factory equipment was upgraded and the capacity of building cranes was enhanced so that the weight of one block increased from 55t for the Innoshima Bridge to 160t for the Akashi Kaikyo Bridge.

Creeping cranes (special machine equipment where tower pillars are constructed by climbing the rails installed on the tower pillars) were used for the building cranes since the main towers of the suspension bridges were generally high but since the building cycle will also include preparation for the cranes to climb and other tasks, the scheduling becomes an issue. For this reason, the Akashi Kaikyo Bridge utilized a tower crane that climbs and

Table 1: Awarded Bridges and Major Technological Development (Suspension Bridges)

Name Year of completion, span	Major Technological Development
Ohnaruto Bridge 1985, 876m	<ul style="list-style-type: none"> ● Establishment of multi-column foundation construction method ● Improvement of cable length measurement systems and construction methods ● Establishment of superior wind-resistant girder construction method
Ohshima Bridge 1988, 560m	<ul style="list-style-type: none"> ● Japan's first box girder suspension bridge ● Direct lifting construction of girder using a barge with one point moorage
Seto Ohashi Bridge 1988, 940, 990, 1100m	<ul style="list-style-type: none"> ● Establishment of design methods for road-rail suspension bridges ● Development of inclination angle adjustment and track expansion devices ● Welding and inspection methods for high-strength steel material ● Establishment of laying-down caisson method ● Underwater blasting method ● Development of pre-packed concrete method ● Cable construction using the new AS method ● Girder construction using crane ship
Akashi Kaikyo Bridge 1998, 1991m	<ul style="list-style-type: none"> ● Flutter analysis using a large-scale wind tunnel tests ● Earthquake resistant design considering dynamic interactions between the foundation and ground ● Development of undisturbed sampling method for soft rock and gravel and improvement of indoor testing methods ● High-strength wire and reduced preheat high-tension steel ● Fluoroplastic paint (long-term rust-resistant paint) ● Grab excavation in strong currents and deep water ● Mooring and sinking system of caisson ● Development of desegregating underwater concrete and high fluidity concrete ● Development of low-heat cement ● Development of scouring prevention for foundations ● Development of scouring prevention for foundations ● Development of underground linked wall construction method for high-depths and great thickness ● Improvement of cable structure and a corrosion prevention system using dry air supply ● Sea crossing of pilot ropes using helicopter
Kurushima Kaikyo Bridge 1999 600, 1020, 1030m	<ul style="list-style-type: none"> ● Improvement of earthquake resistant design methods for the bedrock foundation ● Improvement of laying-down caisson method ● Direct lifting of girder blocks using a self-positioning barge

Table-2: Awarded Bridges and Major Technology Development (Cable-stayed Bridges)

Name (Completion year, span)	Major Technology Development
Hitsuishijima Bridge Iwakurujima Bridge 1988, 420m	<ul style="list-style-type: none"> ● The world's first and longest road-rail cable-stayed bridge ● Elastic earthquake support using disk springs ● Vibration control during tower construction using TMD ● Vibration control during tower construction using TMD ● Anti-bending measures for fixed cable sections
Ikuchi Bridge 1991, 490m	<ul style="list-style-type: none"> ● Composite structure for long-span cable-stayed bridge design method ● Elastic support using rubber bearing ● Construction of large blocks for the main tower using crane ships
Tatara Bridge 1999, 890m	<ul style="list-style-type: none"> ● Development of design methods for the 900m-class cable-stayed bridge ● Confirmation of load-bearing capacity of a 900m-class cable-stayed bridge ● Structural improvement of steel slab and fixed cable sections ● Ensuring wind stability after completion and during construction ● Cable vibration control

descends a post separate from the pillar (Photo 6). This crane has full swiveling capacity and can also self-adjust its height in accordance with the pillar's height. This crane was later used for constructing the towers of the Kurushima Kaikyo Bridge and the Tatara Bridge.

Since the main tower in construction is not steadied by a cable, even relatively low velocity winds can cause vortex-induced oscillation. Since this vibration disrupts tower construction, the usual approach for suspension bridges is to extend a wire from the top of the tower to the tip connected to weight and oil damper on the ground. For the Akashi Kaikyo Bridge, the installation of a Tuned Mass Damper (TMD) was used for the main tower itself (Figure 1).

Cable

The cable of a long span suspension bridge is composed of tens of thousands of 5mm diameter steel wires bundled into a cable. Construction methods include the air spinning construction (AS method) and pre-fabricated strand construction (PS method).

The AS method requires the individual lining of steel wires on site. It was developed roughly 150 years ago and was used in the laying of cables for major suspension bridges in Europe and in the U.S.

On the other hand, in the PS method (Figure 2), a hundred of elemental wires are bundled into a strand in a factory and erection at the site is conducted strand by strand. This method was first adopted for the Newport Bridge in the United States during the 1960s. This method was mainly used for suspension bridges in Japan such as the Kanmon Bridge and many Honshu-Shikoku bridges, building a steady track record. For the Kanmon Bridge, one strand was composed of 91 steel wires but for bridges since the Innoshima Bridge each strand is composed of 127 wires. The Akashi Kaikyo Bridge also adopted the PS method (Photo 7) but the length of the cable strand became approximately 4,100m, or more than twice the previous length. These raised concerns on whether construction on site was possible and whether it ensures quality as a parallel wire cable. Therefore, a full-size strand was test manufactured and



Photo 1: Ohnaruto Bridge



Photo 4: Kurushima Kaikyo Bridge



Photo 2: Seto Ohashi Bridge



Photo 5: Tatara Bridge



Photo 3: Akashi Kaikyo Bridge



Photo 6: Tower construction using a tower crane (Akashi Kaikyo Bridge)

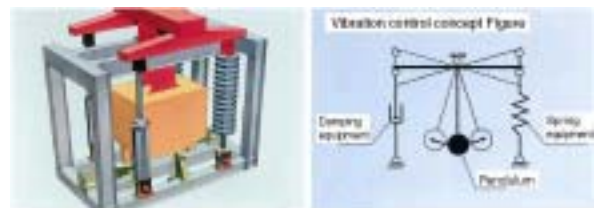


Figure 1: Tower vibration control (TMD)

wound on a reel to confirm that construction was possible.

The first step of the cable erection process begins with the sea crossing of the pilot rope that connects the all spans. This crossing developed from a method where floats are attached to the rope and pulled by a tugboat to a method where the rope is tensed by tugboats and crane ships while pulled from the sky in order to reduce the impact on passing ships. However, since the Akashi straits is an international sea route that carries a heavy volume of ship traffic, which would be disturbed by such a method, a new method was developed (Photo 7), involving the carrying of a light-weight, high-strength synthetic fiber with a large helicopter (Photo 7). This method was also used for the Kurushima Kaikyo Bridge.



Photo 7: Cable strand construction (left), sea crossing of pilot rope (right) (Akashi Kaikyo Bridge)



Photo 8: Large block construction for the stiffening girders (Seto Ohashi Bridge)

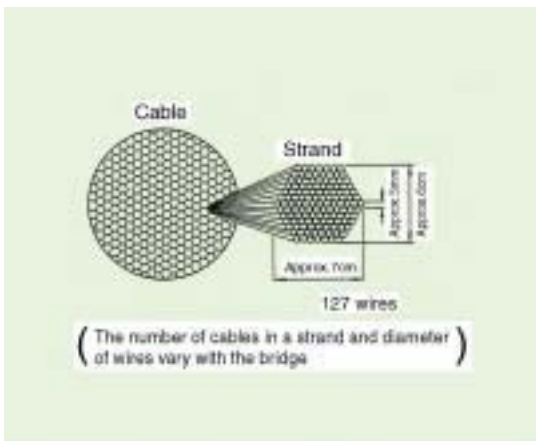


Figure 2: Cable cross-section using the PS method

Stiffening Girders

For stiffening girders, the truss type was adopted for many suspension bridges since it can be constructed without using the sea surface directly below. The construction method involves consecutive rigid coupling hinge construction method with plane blocks which was developed for Kanmon Bridge and used in Innoshima Bridge construction. This method involves the coupling of newly constructed truss plane blocks manufactured at the factory to existing components on the site and then the hanger rope is pulled into the new component and stabilized. This method allows for

greater wind-resistant stability during construction when compared to the all hinge construction methods used in Western suspension bridges.

This construction method usually requires hinges to remedy excessive stress on the diagonal truss bracing and the hanger rope on the end of the erection, but this was improved to a hinge without rigid coupling by adjusting the pulling tension with a multiple joint as used at Ohnaruto Bridge. This method was later used at the Seto Bridge and Akashi Kaikyo Bridge.

Also, when an ocean construction zone close to the main tower can be secured for work ships to be moored, the large-scale block construction method is used where stiffening girders are fabricated as large blocks at the factory and erected at once by large-scale crane ships to shorten construction period and relieve complicated tasks in the initial phases as used for the

Seto Ohashi Bridge and Akashi Kaikyo Bridge (Photo 8).

The Ohshima Bridge is the first Japanese suspension bridge that adopted box type which is economical and easy to maintain for stiffening girders. The construction method used involved lifting from the sea level directly below while a barge loaded with the girder block maintaining moorage at one point on the upstream side of the current to shrink the sea space needed and reduce the effect on ship traffic.

The Kurushima Kaikyo Bridge also used box type as stiffening girders. The Kurushima strait has rapid currents and a bent course that serves as an international waterway so barges cannot moor for long in the waterway where there is heavy ship traffic. Therefore, a self-positioning barge that can keep the same position directly under the construction site without mooring under strong currents was developed (Photo 9). Self-positioning barges were equipped with full-rotation propellers in all four corners and were combined with a survey system that used light waves from the land. The position of the barge is measured and a computer steers it to the designated spot using the automatic position control system. This barge was also used for Akinada Bridge in Hiroshima Prefecture.



Photo 9: Girder construction using a self-positioning barge (Kurushima Kaikyo Bridge)

The Construction Technology of the Cable-stayed Bridge Superstructure

In Japan, the Onomichi Bridge completed in 1968 with a span exceeding 200m was the pioneer bridge for the full-scale cable stayed bridge and for many of the cable-stayed bridges that followed a rapid increase in span length. Currently, there are over 40 bridges with a span exceeding 200m in Japan. In Japan many noteworthy cable-stayed bridges were constructed including the Hitsuishijima and Iwakurujima Bridges among the Honshu-Shikoku bridges, that became the world's first and longest road and rail cable-stayed bridge and the Ikuchi Bridge was a combination cable-stayed bridge that used steel box girders for the central span and PC box girders for the side span.

The Tatara Bridge completed in 1999 with a center span of 890m became the world's longest cable-stayed bridge by exceeding France's Normandy Bridge (completed in 1995), which has a center span of 856m. The girder construction for the Tatara Bridge required the installation of supports in the sea to facilitate construction and used a construction method based on "balancing construction from the tower combined with overhang construction of the central span." The construction length was 150m from the tower for the balancing construction and 435m for the overhang from the center span (Photo 10 and 11). In adopting this construction method, structural analysis was carried out after and during construction while a 1/70



Photo 10: Balancing construction of the girder (Tatara Bridge)

scale full model was used for wind tunnel tests to ensure safety.



Photo 11: Overhang construction of the girder (Tatara Bridge)

Future Developments

Currently in Japan there is a vision for a strait-crossing project. This project aims for a new transport axis that creates a multi-axial land structure. This will require the construction of an extreme long-span bridge surpassing the Akashi Kaikyo Bridge.

Considering the changing social environment surrounding public works, in order to construct such a long-span bridge in the future, it will be necessary to pass on the technology accumulated while developing new technology to make possible a drastic reduction of costs and construction period.

Such technology from a design and manufacturing perspective would include the adoption of new structural forms that have superior wind and earthquake resistance, the implementation of new design methods, relaxing material quality requirements, streamlining of manufacturing, and development of new materials. Also, for site construction technology, this would require the promotion of technology development to include the development of construction methods and machine equipment that can withstand harsh natural conditions, optimization of required construction precision, and streamlining of temporary facilities to reduce site workloads.