CHALLENGE IN DESIGN AND CONSTRUCTION FOR THE TOYOSHIMA BRIDGE (TENTATIVE NAME)

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Abstract

The Toyoshima Bridge is the only long-span suspension bridge that is currently under construction in Japan. New construction technologies including the transferring and streamlining of existing technologies have been adopted to reduce the construction cost of the bridge. This paper presents Japan's first "rock anchorage method" and the world's first "7 mm wire spinning for cables (AS method)."

1. The Toyoshima Bridge as a part of the Akinada Islands Connecting Bridges

The Seto Inland Sea lies between Honshu (Main Island) and Shikoku. Scattered across the Akinada area in Hiroshima Prefecture, the western part of the Sea, are several islands. The Akinada Islands Bridges Project (Fig.1) is a plan for connecting these islands with 8 bridges. This area is known for its mild climate and beautiful scenery, and also for citrus production and its fishery industry. Six bridges including the Kamagari Bridge (truss bridge, 1979) and the Akinada Bridge (suspension bridge, 2000) were constructed in the area. They have contributed to the development of local industries and improvement in local people's lives.

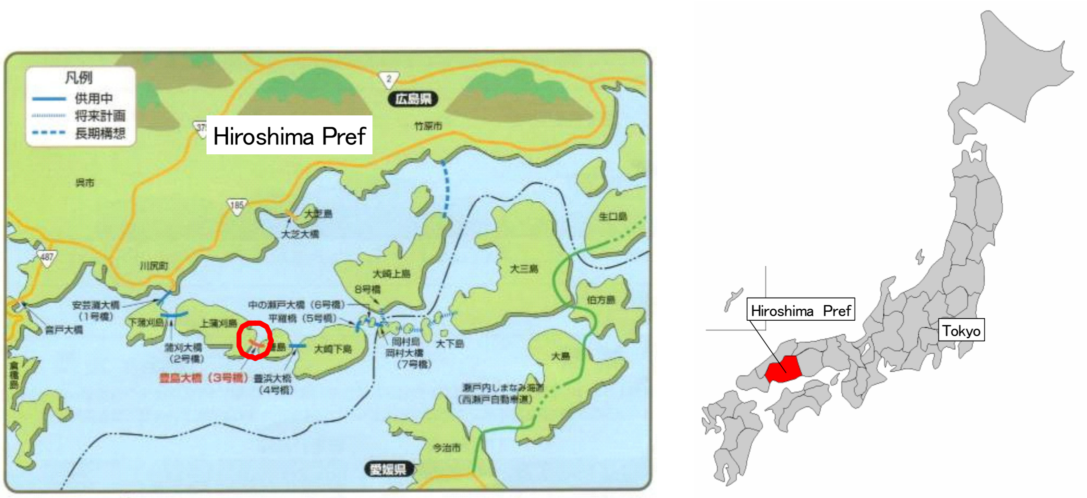

Fig. 1: Akinada Islands Bridge Project

Since 2002, Hiroshima Prefecture and Hiroshima Prefecture Road Public Corporation have been constructing the Toyoshima Bridge (suspension bridge, Fig. 2). This bridge is a single-span suspension bridge (total length: 903.2 m, center span:

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540.0 m) which will connect Toyoshima Island and Kamikamagari Island in Kure City. The anchorages, foundations, main towers and cables have been completed, and the girder has been under construction since October 2007 (Photo 1).

The Toyoshima Bridge is scheduled to be completed in the spring of 2009.

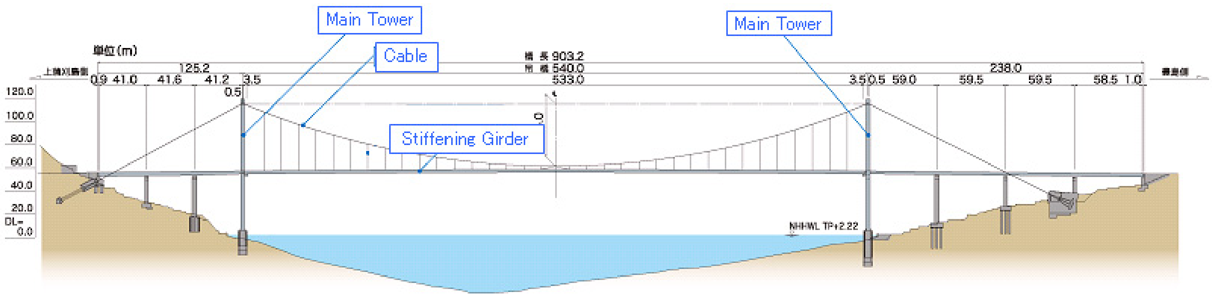


Fig. 2 General view of the Toyoshima Bridge

Photo 1: Current status of the construction of the Toyoshima Bridge（October 2007）

<u>2. The Toyoshima Bridge as a Part of the Long-span Suspension Bridge Project in Japan</u>

The construction of long-span suspension bridges in Japan started with the Wakato Bridge (center span: 367 m) in 1962. In 1973, the Kanmon Bridge (center span: 712 m) was constructed and then the Honshu-Shikoku Bridges were completed. The project continued to the completion in 2000 of the Akinada Bridge (center span: 750 m) (Fig. 3).

Throughout the project, suspension bridges exceeding the size of conventional bridges were constructed one by one, the Akashi-kaikyo Bridge (centre span: 1,991 m) being the longest.

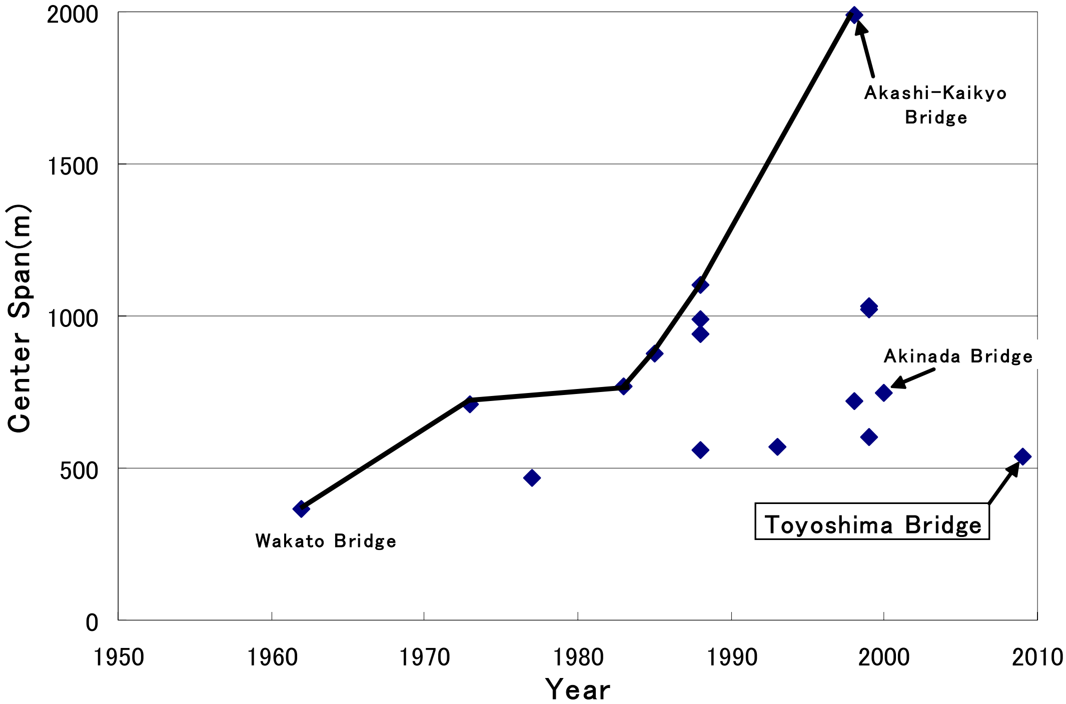


Fig. 3 Change in Suspension Bridge Main Span

The Toyoshima Bridge ranks 15th in center span length among suspension bridges in Japan and belongs to the medium-sized suspension bridge class because bigger and longer bridges were constructed in the past. However, the bridge is the only large-scale suspension bridge in Japan on which construction began after 2000. New technologies have been used during the construction to meet the social demand for cost reduction. The main technologies are as follows:

- Adoption of the rock anchorage method
- Adoption of 7-mm-diameter wire for suspension bridge cables
- Large-block erection of main towers
- Stiffening girders with a wind-resistant structure based on a horizontal plate
- Wind-resistant stability check for towers with a friction damping effect resulting from side bridge sliding bearing
- Dehumidification system for the main towers, stiffening girders and suspension bridge cables

However, the technologies listed above have not been developed exclusively for the construction of the Toyoshima Bridge. They include the checking and designing method and the transferring and streamlining of the construction process developed to construct larger suspension bridges in more difficult locations in the past.

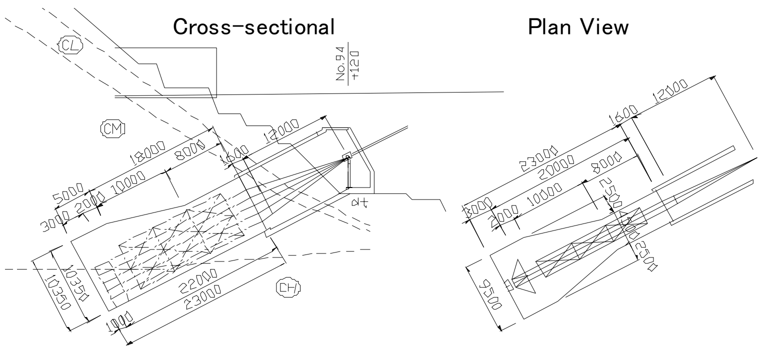
As described below, this paper presents Japan's first "rock anchorage method" and the world's first "use of 7 mm wire for suspension cables (AS method)."

3. Rock Anchorage Method

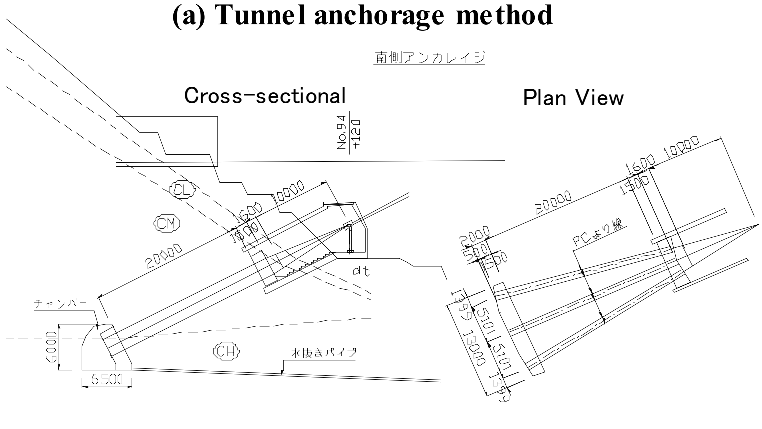
3.1 Outline

Anchorage has the function of safely and efficiently transmitting tensions such as the horizontal tension of suspension bridge cables to the bedrocks. Generally, gravity-type anchorage is adopted to resist friction with bedrock caused by anchorage self-weight, and in most cases, requires a large-scale excavating process due to the large concrete construction.

In addition to the gravity method, the “tunnel method” (Fig. 4(a)) is available for the construction of bridges. This is a method for resisting horizontal force with the adhesion of the concrete structure to the bedrock. If good quality bedrock is available and the construction area is limited, this method will be adopted. Examples are the Shimotsui-Seto Bridge 1A and the Kurushima-kaikyo Bridge 10A as parts of the Honshu-Shikoku Bridges.



(a) Tunnel anchorage method



(b) Rock anchorage method

Fig. 4: Anchorage method

The “rock method” (Fig. 4 (b)) is a construction method for transmitting cable tension to the bedrock and ensuring the pulling resistance of the bedrock. This method is based on the same concept as that of the tunnel method. The difference is that the tunnel method is a construction method for constructing an anchor frame in a slanted tunnel created by drilling the bedrock and filling concrete into it to construct the structure foundation of a bridge, while the rock method is a construction method for strengthening the bedrock as the structure foundation of a bridge by putting prestress with prestressing tendons on the bearing plates installed on the front and rear sides of the bedrock. This latter method has an advantage of reducing the occurrence of looseness in bedrock which may result from drilling.

3.2 Adoption of the rock anchorage method

The Toyoshima Bridge 1A is located in a steep valley where good quality bedrocks stronger than the C_M class are found in relatively shallow places. The tunnel anchorage method and the rock anchorage method were compared and analyzed to choose a construction method suitable for the bridge. Given the geomorphological features of the area, the rock anchorage method has a greater advantage in terms of construction period and cost. As a result, the rock anchorage method has been adopted for the bridge construction.

Stability checking was conducted according to the tunnel anchorage method to estimate the drawing-down area (expected sliding distance) and ensure the predefined safety factor to designed cable tension (normal condition: 40,600 kN/Cable) by the total resistance of adhesive resistance, friction resistance and gravity resistance. For the check, 1 case and 2 cases were based on basic sliding checking and on permanent anchor checking respectively. For each case, a suitable drawing-down area, adhesive and friction resistance limits, and a safety factor were defined.

3.3 Outline of structure

Figure 5 shows a general view of the rock anchorage method. North and south anchorages are each composed of a front tunnel, a front bearing plate, a prestressing tendon, and in addition, below them is a chamber for both the north and south sides which is a room for strengthening or loosening the prestressing tendon, and around them is an approach tunnel leading to the chamber from the ground.

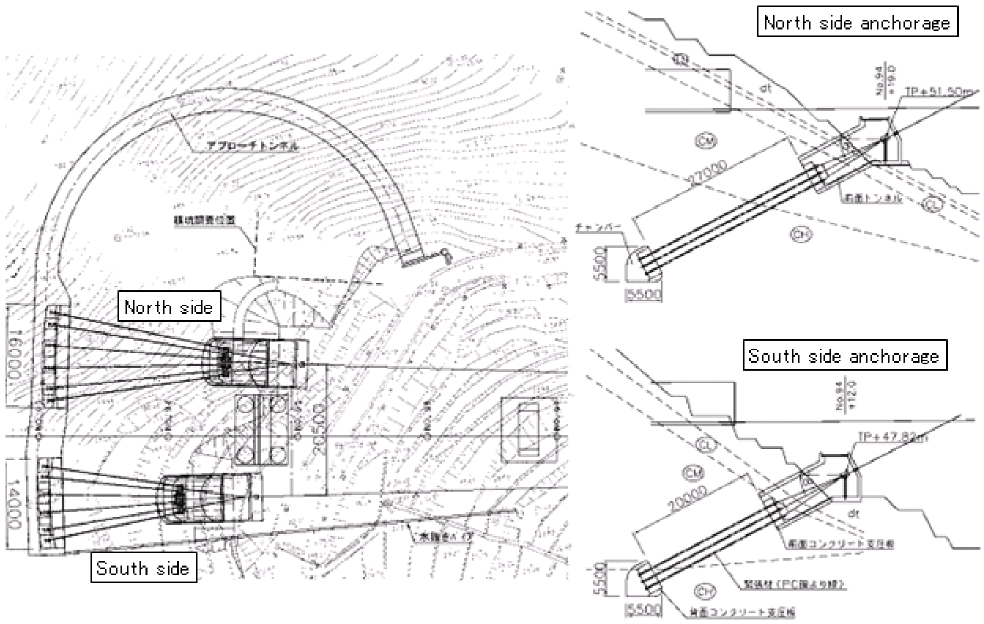


Fig. 5: General view of rock anchorage

3.4 Points to consider at the time of construction

The points to consider in the construction of rock anchorage are to check on site and ensure the required performance predefined at the time of planning and designing as follows:

(1)Looseness of bedrock caused by excavation

Machine drilling was used as much as possible near the front tunnel and the anchorage of the chamber.

(2)Bedrock checking (Checking the strength of bedrock and the discontinuous section of bedrock)

Block shear experiments were carried out to confirm that the bearing bedrock met the conditions of the C_M class (adhesive force C＝1,500 kN/m^2, angle of shear resistance φ＝40°)

In addition, the points (the orthogonal crossing of the direction of the bedrock discontinuous plane and the tension direction of the suspension bridge cable) checked and confirmed in the preliminary study (slant boring and bored hole camera) were identified again by observing the face of the bedrock at the time of excavation.

(3) Ensuring the precision of hole drilling on the bedrock parts for inserting prestressing tendons

The control value was set to 1/100 of drilling hole length (eccentricity: north side 270 mm, south side 200 mm) and observed.

(4) Ensuring the precision of the set-up of rod installing plates

The control value was set to ±15 mm (square-root of the sum of the squares of X, Y, and Z directions) and observed.

4. Spinning of 7 mm Wire for Cables (AS method)

4.1 Outline

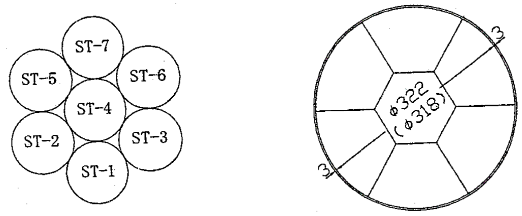
"PWS method" (Prefabricated Parallel Wire Strand method) and "AS method" (Aerial-Spinning method) are used for the erection of cables.

In most of Japan' suspension bridges, zinc-coated steel wires were bundled into a stranded steel wire cable at a factory and erected by the PWS method to install the cable on the site.

AS method is a method for drawing rolled wires over a pulley called spinning wheel and forming wires into a stranded steel wire cable by moving them back and forth specific times between anchorages at the ends of a suspension bridge. This method was adopted for the constructions of the Hirado Bridge (Nagasaki Prefecture, 1977) and the Shimotsui-Seto Bridge (Honshu-Shikoku Bridge Authority, 1988) in Japan.

In both PWS method and AS method, ϕ 5 mm in diameter wire was used for the earlier constructions, and ϕ 7 mm wire was first adopted for the construction of the Toyoshima Bridge. The specification and sectional structure of the bridge cable are shown in Table 1.

Table 1: Cable specification & cross-sectional view

Number of cables		2
Erection method		AS
Wire diameter		7.02 mm
Number of wires		1,680 wires /cable
Number of wires per strand		240/st
Cross-sectional structure		7 st/cable (Diagram below)
Tensile strength of wire		1,570 N/mm^2
Elastic modulus		1.99×10^5 N/mm^2
Safety factor		2.5
Cable cross-sectional area		65,024 mm^2
Cable internal diameter (void ratio)	general	322 mm (20%)
	band section	318 mm (18%)
Wrapping wire diameter		3 mm (S type)
Cable External Diameter	general	328 mm
Cross-Sectional Structure	 ( ) : band section	

4.2 Reasons for adopting the AS method

The reasons that the AS method using ϕ 7 mm wire was adopted are described below.

(1) The AS method requires fewer strands than the PWS method. As a result, the compacted strand installed section (shrunk anchorage) is expected to contribute to cost reduction.

(2) The sectional area of ϕ 7 mm wire becomes twice the size of ϕ 5 mm wire. As a result, the AS method enables the reduction of Aerial Spinning time, and thereby is expected to shorten the construction period.

4.3 Technological elements required for adoption

The technological elements to consider when the AS method using ϕ 7 mm wire is adopted are described below. The tests on each technological element began to be conducted by the Honshu-Shikoku Bridge Authority (now Expressway Company Limited) and the cable erection companies (Nippon Steel Corporation and Kobe Steel Co. Ltd.) from 1985 in order to apply the ϕ 7 mm wire spinning to the construction of the Akashi-kaikyo Bridge and some other bridges.

(1) Wire performance

For suspension bridges, ϕ 5 mm wire has been set as standard since parallel wire cables were adopted. However, it is proved that ϕ 7 mm wire has the same performance as ϕ 5 mm wire (mechanical property, zinc coating quality, radius and radius deflection, external look and linearity).

(2) Performance of wire connection

The AS method requires wire connection. A static tension test, tension fatigue test and rotating bending fatigue test have proved that ϕ 7 mm wire connection does not pose any problems in practical use.

(3) Wire handling

In order to install wire on the strand shoe portion of the anchorage, construction workers need to handle ϕ 7 mm wires, but the handling test has proved that they do not pose any problems when handled by humans.

4.4 Erection procedure and outline

The procedure for cable erection is described below. The procedure（1）to (3) refers to construction work No.1 to No.7 strand and the process is repeated for each strand.

（1）Aerial Spinning

The Aerial Spinning procedure with spinning wheels is shown in Fig.6. For the approach route, some of the wires pulled out from the unreeler, called dead wire (wires not moved after being pulled out) were made to fall into the cable former set up at the catwalk (aerial platform) and at the same time live wires were hung over the temporary roller. For the return route, these live wires pulled out from the spinning wheel were made to fall into the cable former (Photo 2).

The process is repeated a predefined number of times. The beginning and the end of the wires pulled out are connected with wire connected nodes and thereby the wires become a loop strand.

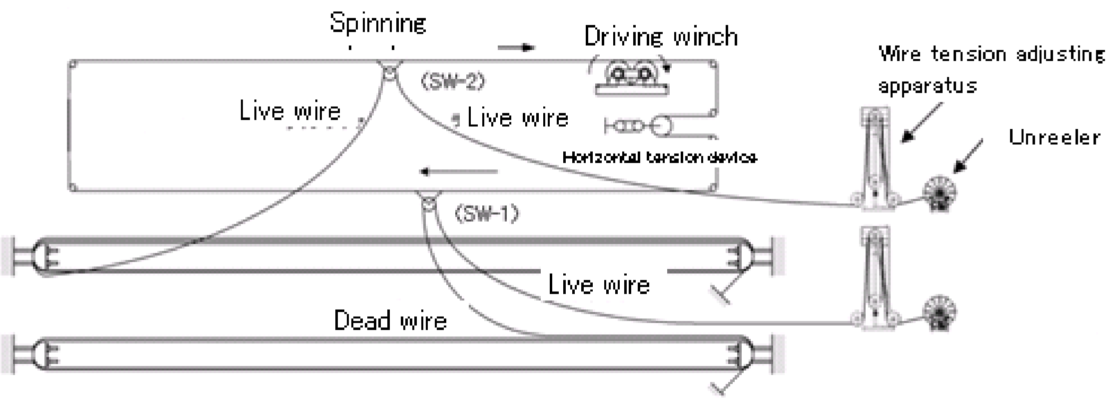


Fig. 6: AS Overview diagram（SW-1：approach route，SW-2：return route）

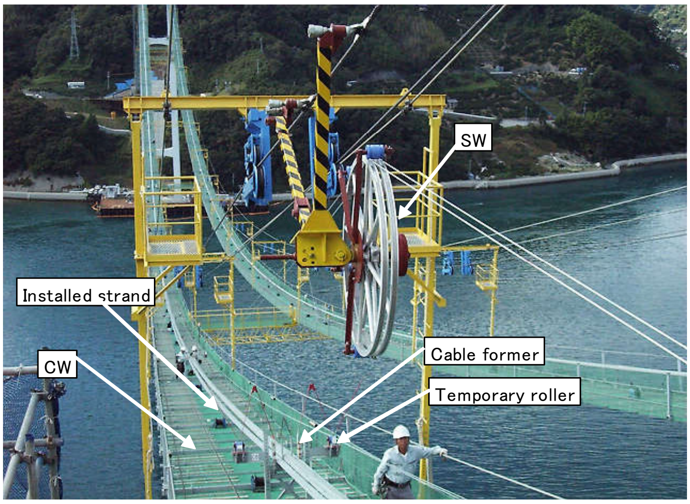


Photo 2: AS (Aerial Spinning) work (return route)

(2) Binding

During the binding process, the strand is formed into a round shape after the Aerial Spinning work. After this process, the strand is lashed with aluminum bands in a 2 m pitch.

(3) Measurement and adjustment of strand form

This is a process for measuring and adjusting the whole strand form during the night after the completion of binding.

(4) Adjustment of the strand tension at the anchor span

After completing all the strand installation, this work is conducted during the night

(5) Cable squeezing

This is a process for bundling 7 strands together to form a round shape and transforming them into a cable section which allows for the attaching of a cable band.

Practically, in pre-squeezing, placement confirmation, cable former removal and cable lashing (40 m pitch) was conducted during the night, and another cable lashing (10 m pitch) was carried out during the daytime. Squeezing was completed with a squeezing machine with 6 x 100-ton jacks during the daytime (Photo 3).

Photo 3: Cable squeezing

4.5 Points to consider at the time of AS work

(1) Wire placement work

Wire placement work on the tower top saddle portion (2P, 3P), the spray band portion (1A, 4A) and the strand installation portion (strand shoe) was conducted according to the wire placement table posted at each work position after checking dead wires and live wires by one cycle of Aerial Spinning work.

(2) Wire handling

Special care was not given to the installation of ϕ 7 mm wires in the strand shoe, but the work was completed without placing too much force on the wires (Photo 4).

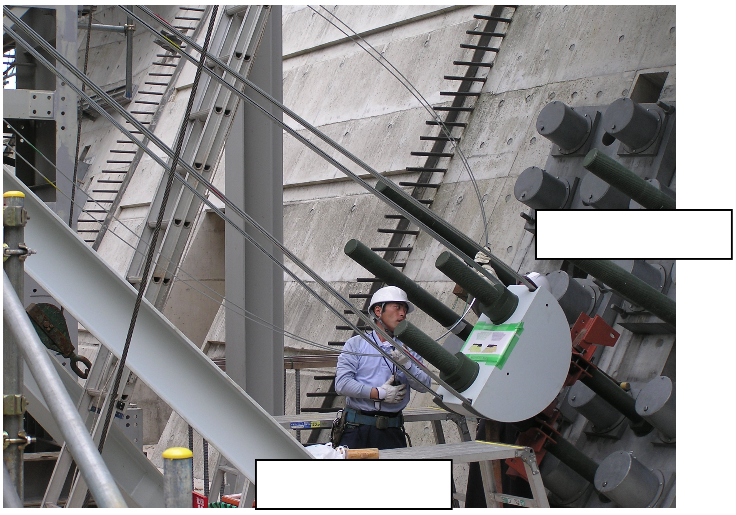


Photo 4: Work for installing wires in the strand shoe

(3) Treatment of loosened wires at the spray band portion

The Toyoshima Bridge is a single-span suspension bridge which enables a cable spray point at the bottom edge of girder to be set up and is comparatively small in size. As a result, the “Aerial Spray method” (Fig.7) was adopted because it is not necessary to fold a cable at the spray point of the cable. This is a construction method based on spray bands and steel poles, rather than spray saddles and RC saddle bents. This structure is flexible in the direction of the bridge axis and sufficiently solid in the vertical direction and at a right angle to the bridge axis.

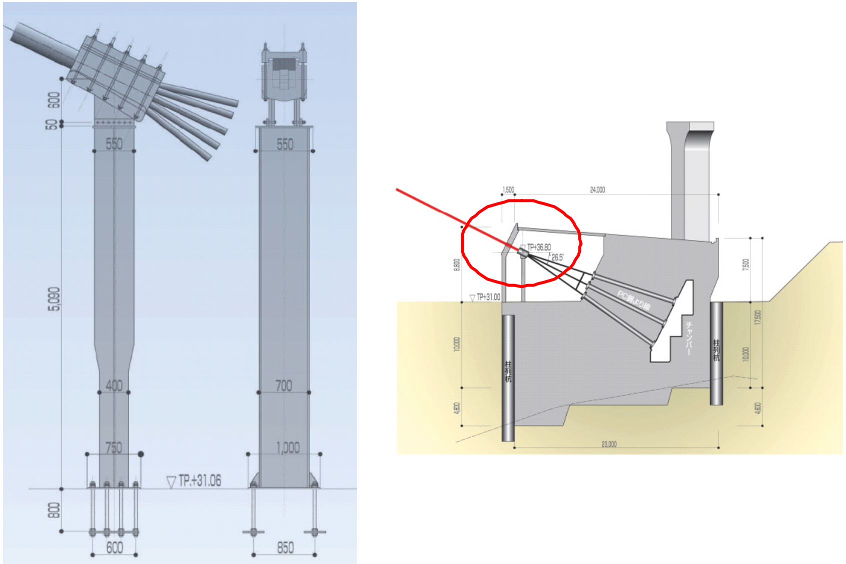


Fig. 7: Aerial spray method (the case of 4A)

The adoption of the aerial spray method caused upward force in No.4 to No.7 strand. During Aerial Spinning work, it was not possible to place the upper cap of the spray band. Because of that reason, a tool for preventing the upward force of wires was used for post-No.4 strand installation. For No.5 and No.6 strand installations, placement work was carried out with wires fixed in the horizontal direction (Photo 5).

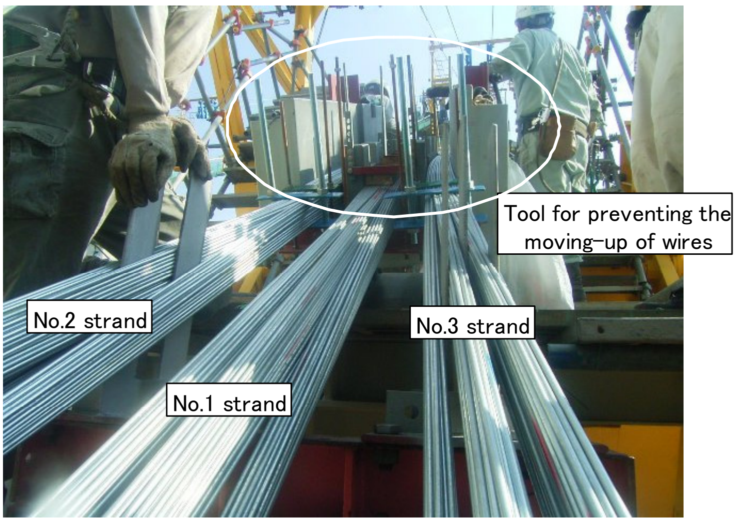


Photo 5: Measure for preventing the moving-up at spray bands(Aerial spray portion)

(4) Wire connected node handling

If harmful deformation occurs in wires, and when factory wire connected nodes enter into the strand shoe and the beginning and the end of wires are connected at the completion of AS work for one strand, on-site wire connection is conducted, but the same wire section was not processed to reduce a negative effect on the cable section form.

4.6 Result of AS construction method with ϕ 7 mm wires

All AS work was conducted during the daytime. 3,360 wires (240 wires×7 strands×2 cables) were all installed in two and a half months. However, cable form measurement and cable adjustment were conducted during the night.

The spinning speed in the central span was a standard 3.5 m/sec. (max. 4 m/sec.) and the speed in the side spans was approximately 1.7 m/sec.

For cable finished form checking, the cross-sectional shape and the overall shape of the strand and the cross-sectional shape and the overall shape of the cable were checked, and both of them produced good results. Especially, the cross-sectional shape of a cable as a finished form was checked based on the void ratio. The result was that, compared with the quality control standard 20%±2%, the observed value was 20.6%.

5. Addendum

The construction of the Toyoshima Bridge (tentative name) is progressing smoothly. Hiroshima Prefecture as a business entity, Hiroshima Prefecture Road Public Corporation, the “Toyoshima Bridge Technology Committee” (Committee chief: Naruhito Shiraishi), Japan Bridge Engineering Center, design consultants and builders for foundation engineering work and superstructure work are involved in this project.

This paper has been co-authored by representatives from the business entity, the owner and the organizations for the technological support of bridge construction. Lastly, we express our thanks to the people involved.

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