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Autor: Kashima, Satoshi / Sano, Yukihiro / Sakamoto, Mutsushige

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Construction of Akashi Kaikyo Bridge Foundation

Satoshi KASHIMA
Gen. Mgr, First Constr. Bureau
Honshu Shinkoku Bridge Authority
Kobe, Japan

Yukihiro SANO
Civil Eng.
Honshu Shinkoku Bridge Authority
Kobe, Japan

Mitsushige SAKAMOTO
Machinery Eng.
Honshu Shinkoku Bridge Authority
Kobe, Japan

Kozoo HIGUCHI
Civil Eng.
Honshu Shinkoku Bridge Authority
Kobe, Japan

Summary

The Akashi Kaikyo Bridge is supported by two anchorages both positioned on each side of the 4 km width strait and by the two tower foundations located in the deep-water region. Owing to the heavy load of the superstructure and being that the bearing stratum is deep, the volume of concrete cast in each foundation exceeds 200,000 m^3, totally amounting to more than 1.4 million m^3 as a whole. The harsh physical conditions of the Strait such as swift tidal currents exceeding 8 knots and its heavy maritime traffic in which more than 1,400 ships navigate a day, made certainty, safety as well as readiness as the subjects for consideration in executing work.
This paper gives a description of the work in deep-water slurry wall, high fluidity concrete, installation of caissons, scour protection, underwater concrete which were developed to solve the problems stated above.

1. Foreword

The Akashi Strait is 4 km in width, 110 m in maximum depth on the bridging route in which the tidal velocity reaches up to 8 knots, and a navigation lane of 1,500 m width is set up in the center. The Akashi Kaikyo Bridge as shown in Fig. 1 is a suspension bridge with a center span of 1,991 m and an overall length of 3,911 m. Foundation work conducted were for 2 anchorages at both ends of the strait and 2 tower foundations on both sides of the navigation lane. From among these four foundations, the 1A anchorage and 2P tower foundation, in which a large amount of work was involved shall be described.
The 1A anchorage located in shallow water was, after coffering and filled, soil guarded by an underwater slurry wall of 85 m in diameter, 76 m in depth, and then excavated to the bearing ground 64 m below the surface. After pouring 260,000 m^3 of roller compacted concrete in the interior, 230,000 m^3 of high fluidity concrete was cast for the anchorage structure.
The 2P tower foundation located in deep-water zone is a cylindrical shape foundation 80 m in diameter, 70 m high. After excavating the seabed from 45 m to 60 m below the sealevel with a grab bucket dredger, a steel caisson fabricated on a dry dock was installed. Then, scour protection composed of filter units and riprap was executed in a range of 240 m in diameter around the caisson, and desegregating underwater concrete of 270,000 m^3 was deposited in the caisson interior.
The work had progressed favorably since commencing in March 1988, the 1A work was completed in September 1992, and 2P work in June 1992.

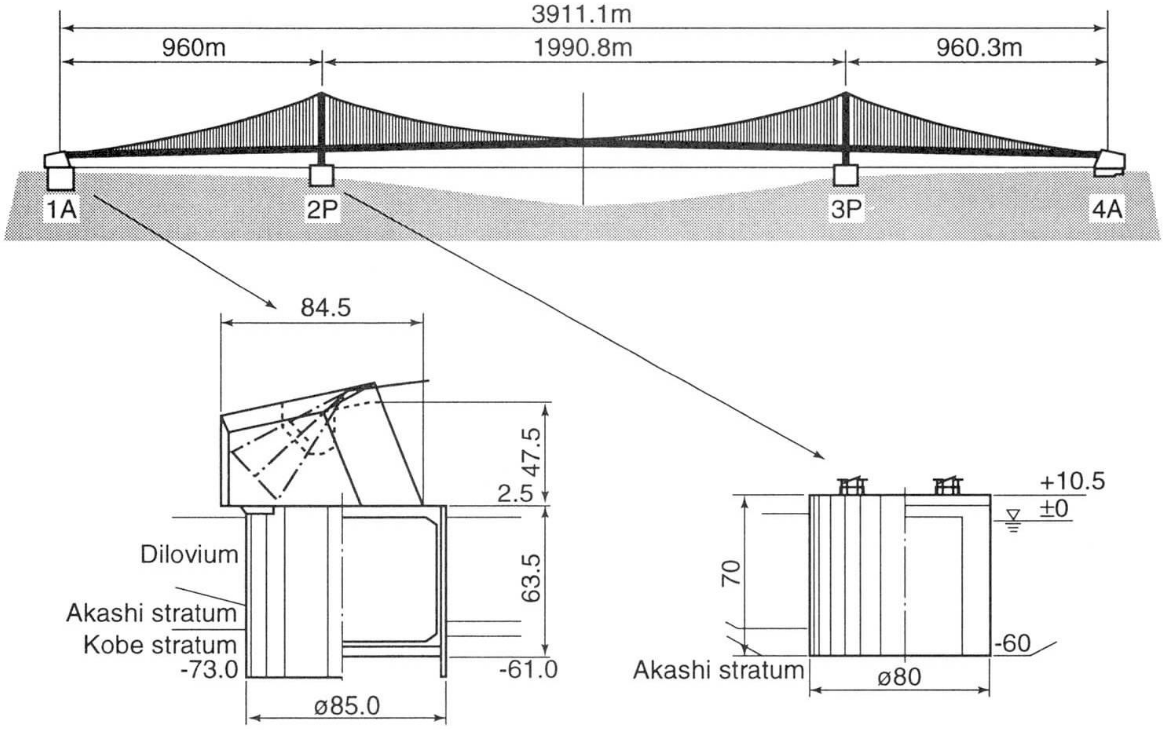

Fig. 1 Profile of Akashi Kaikyo Bridge

2. Work Execution of 1A Anchorage

2.1 Deep-water Underground Slurry Wall

Photo 1 Work of Underground Slurry Wall

The foundation of 1A anchorage was constructed by excavating the reclaimed ground 64 m below the sealevel. The underground slurry wall, which is 2.2 m in width, 85 m in diameter and a depth of 76 m, serves as the soil stopper during excavation work. Since the structure during construction has to resist with circumferential compressive force against the enormous earth and water pressure, it was necessary that the structure should be made as circular as possible, and water stoppage capability improved.

The excavator, as shown in Photo 1, a horizontal multi-bit-drill with a wall thickness of 1.5 to 3.2 m and digging length of 3.2 m, was used. At first, 23 preceding blocks, each consisting of 3.2 – 2.1 – 3.2 m elements (total length of 8.5 m) were constructed setting apart 3.2 m in distance. Latter elements of 3.2 m were fabricated between the preceding blocks to form a polygon of 92 angles. Also, when digging of latter elements, about 20 cm of the preceding blocks was cut off to allow adhesion of concrete so that a vertical accuracy of 1/1,000 is maintained. The extent of leakage of water from the joint of elements during digging of internal soil showed only oozing, demonstrating that water stoppage was satisfactory.

2.2 High Fluidity Concrete

The anchorage structure was constructed on the upper part of the foundation by casting to the interior of the precast concrete wall. The volume of concrete deposited in this structure amounted to 140,000 m^3, and in order to withstand the tensile force of 1.2 million kN applied from the main cable to the foundation, the interior was arranged with anchor frames and innumerable reinforcements.

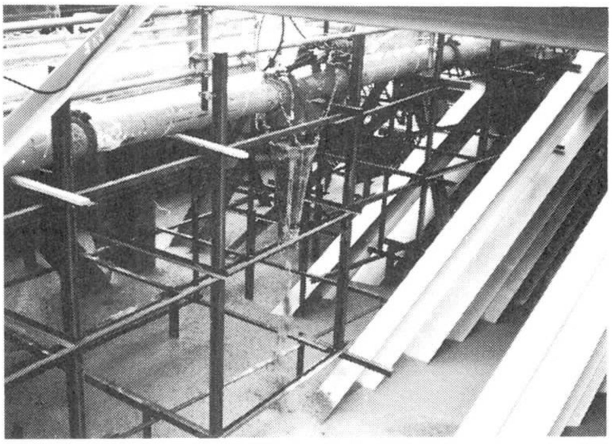

Photo 2 Casting of High Fluidity Concrete

The subjects in executing work were the suppression of heat cracking of concrete and the rapid work method to shorten the construction period. For this reason, low-heat cement with fine granulated blast-furnace slag and fly ash added was used, as well as precooling was applied by replacing part of mixing water with ice. Also, the plane was divided into 5 blocks, and 3 m width slots were provided between the blocks to accelerate natural heat radiation for relieving tensile stress.
The cement cast exceeded a maximum of 1,900 m^3 per day. Moreover, as anchor frames and innumerable reinforcements were arranged in a confined area, difficulties were in levelling and compaction of concrete. To slove these problems, high fluidity concrete was developed by replacing a portion of fine sand aggregate (1,500 kg/m^3) with pulverised stone mixed with highly effective plasticizer. This concrete possesses a self levelling character which spreads horizontally by its own weight, as well as required material segregating resistivity. Casting of concrete is shown in Photo 2. Concrete, when discharged from valves provided at an interval of 10 m on the conveying piping, will flow in by self-weight and fill the interior of the casting form. About 20 of these valves are provided in each block, and which will open or close automatically at an interval of several minutes to allow uniform discharge over the entire area.

3. Work Execution of 2P Tower Foundation

3.1 Installation of Caisson

The caisson, which becomes the form for shaping the main tower foundation, is a steel structure with an outer diameter of 80 m, 65 m in height and weights 19,000 metric tons. For the purpose of towing, it is a double-wall structure with the inside diameter of 56 m, and the sections of buoyancy on the outer side are partitioned into 16 sections to prevent the decline of stability caused by free water. As shown in Photo 3, the caisson was towed by 16 tug boats into the site during slack tide, and moored to the sinkers which were installed in advance. The mooring work, coupling the mooring cables of sinkers to those of winches on the caisson, must be finished within 2 hours. But it is no easy matter since the mooring cable is a wire rope of 120 mm in dia. Therefore, a quick joint, which couple the cables within a few seconds, was developed to facilitate

Photo 3 Mooring of Steel Caisson

mooring operation. Also, it is necessary that the winch rewinding the mooring cable is of low tension high speed winding capacity of 200 kN by 30 m/min. during mooring operation, as well as high tension low speed winding capacity of 4,000 kN by 2 m/min. at time of positioning. Thus, a special winch combined with a drum winch which performs the former work and a linear winch for the latter was developed.
The work of installing caisson was divided into tow steps. One is guiding the caisson to position by operating 8 winches, and another is lowering and setting the caisson on the seabed using 32 water sealing pumps. As both operations needed a higher accuracy positioning, georgmeters were placed at two points on land of level terrain to radio transmit the position to the caisson. The height was surveyed by installing ultrasonic bathymeters at four locations on the caisson. Aside from positioning data, more than 300 kind of information such as tidal variation, winch tension, water level of each section and the like, would be required. The various information was processed by computers, and arranged comprehensively to display on CRTs. The data was displayed in a cycle of 2 seconds allowing to grasp information by real time. The system was remarkably effective in installing the caisson, achieving the resulted positioning accuracy of less than 5 cm.

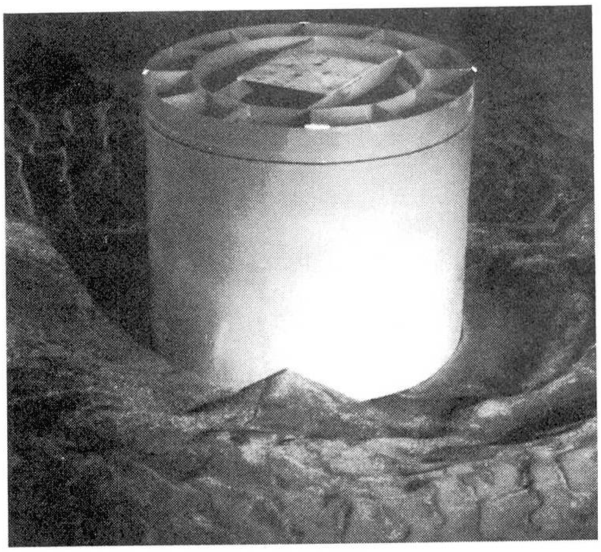

Photo 4 Scouring without Countermeasure

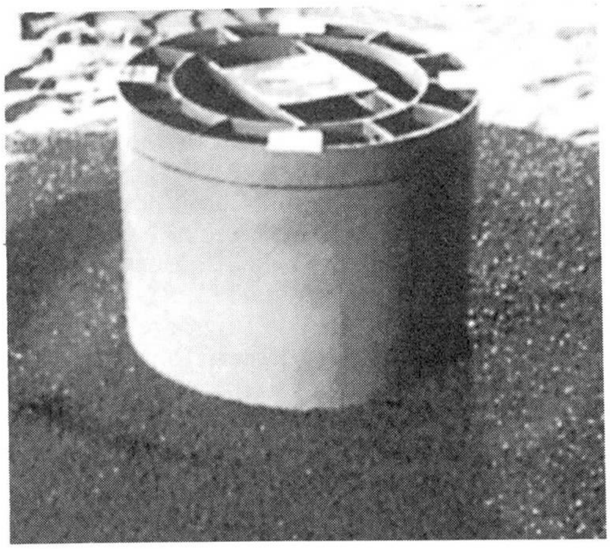

Photo 5 Scouring with Countermeasure

3.2 Scour Protection

The periphery of 2P is an area of strong tidal currents where maximum water velocity exceeds 7 knots. When the caisson was installed, accelerated currents or horse-shoe eddy generated around the caisson. Scouring began to advance from about a tidal speed of 4 knots and scour the foundation ground as shown in Photo 4. Basically the peripheral ground had been overlaid with ripraps, each weighing about 1000 kg, to prevent scouring as shown in photo 5. However, it was confirmed that, around the caisson, a sucking phenomenon of ground soil through gaps of riprap aggregate would occur if the thickness of layer was inadequate. It was found that scouring could be prevented by installing filtering layer with the thickness of 2 m, in a range of 10 m around the caisson in short term, then covering with ripraps of 8 m thick on the top. The filter unit is a netbag, weighing about 1 metric ton, filled with crushed stones the size of 30 to 150 mm dia. These filter units were put together like a grape arbor and quickly installed by a floating crane. Also, the surrounding in an area of 240 m dia. was covered with riprap to a thickness of 3 — 10 m. After this, according to a continued investigation extending over 7 years, scouring was locally found at the outmost peripheral, but is currently stabilized maintaining a satisfactory condition.

3.3 Underwater Concrete

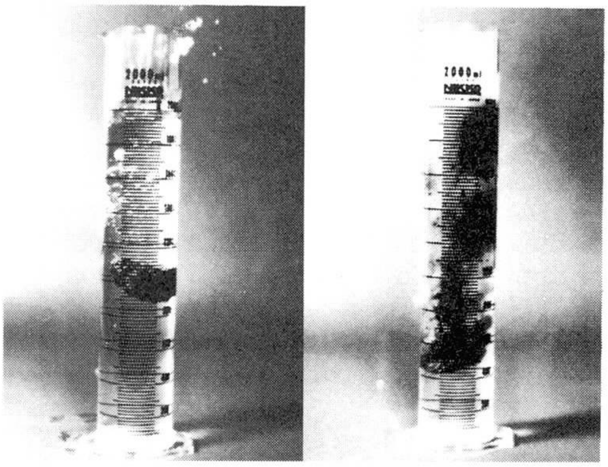

Photo 6 Comparison of Underwater Desegregation

Desegregated underwater concrete, in which desegregating admixture and superplasticizer are added to ordinary concrete, was deposited. This concrete by the workings of desegregating admixture is of high desegregating resistivity as shown in Photo 6, as well as favorable fluidity by addition of superplasticizer. As shown in Photo 7, a special plant barge was employed, equipped with 2 plant units, each with an output capacity of 90 m^3/h and a storage facility for storing 9,000 m^3 of material to cast concrete. After one batch of concrete was fully produced in about 9 days, the concrete was cast for 3 consecutive days, and this cycle was repeated 30 times in total.

The caisson which becomes the form is a double-wall cylindrical structure, so the area to be cast is divided into two blocks. In order to alleviate temperature stress, concrete was cast to the inner block first, then to the outer block. The total area of the inner block, which its diameter is 56 m, was concurrently cast with concrete using 24 casting pipes by a 3.5 m lift, repeating this operation 14 times. Each construction joint was treated with the newly developed underwater green-cut robot. On the other hand, the outer block is partitioned into 16 sections, each section was cast one by one, at a time from 60 m up to 5 m down below sealevel.

Due to the 270,000 m^3 mass concrete, it was necessary to mitigate temperature stress. The volume of unit cement was reduced to 320 kg/m^3 and 50 % of water was replaced by ice to maintain the temperature at cast to less than 20 °C. Also, low heat cement, which is a mixture of ordinary Portland cement, fine granulated blast-furnace slag and fly ash in the ratio of 16: 54: 30, was used. As a result, internal maximum temperature was below 50 °C, and cracking had not occurred. It was found that boring core collected from the foundation was fully adhered at the construction joint with a mean strength of 2,500 N/cm^2 with a standard deviation of 200 N/cm^2, which was of sufficient strength against the design value of 1,800 N/cm^2.

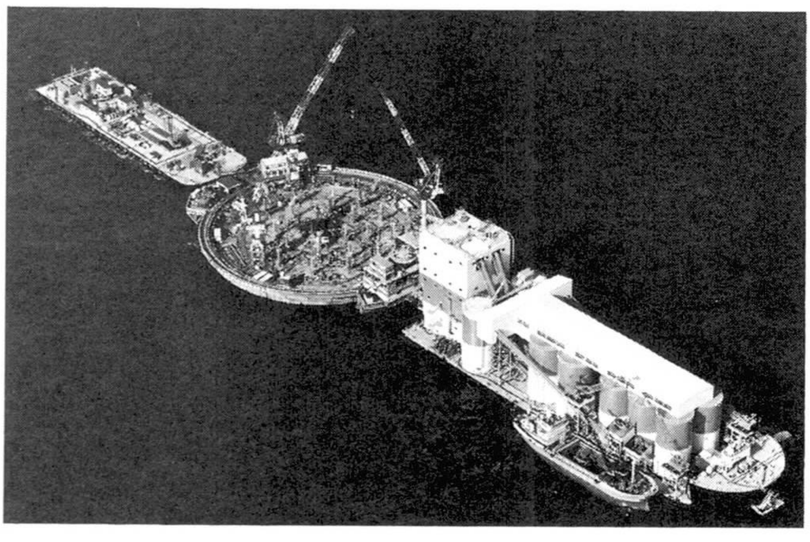

Photo 7 Condition cast Underwater Concrete

4. Conclusion

In executing work of the Akashi Kaikyo Bridge substructure, the scale of work, physical conditions, social environment, etc. were those which surpassed the standard of ocean civil engineering in present Japan, by all work had progressed smoothly. The primary factors to this success should be attributable to facilities having sufficient capacity functioning reliably, accurate and prompt information control systems, and the ability and skills to master those facilities and systems. Knowledge which were acquired from this work are enumerated below.

[1] Building of the underwater slurry wall polygonal and of quasi-circle, the soil-guard wall resisting earth pressure by the circumferential compressive force is effective in reducing wall thickness.

[2] Improvement in vertical accuracy of slurry wall, and cutting off the portion of preceding element to improve adhesion of concrete with the latter element will ensure excellent water stoppage.

[3] A portion of fine aggregate replaced with pulverized stone as well as adding high effective AE plasticizer to provide self levelling and segregating resistivity in high fluidity concrete, enable to fill the form without levelling and compaction.

[4] A low tension high speed drum winch and high tension lowspeed linear winch combined, can be controlled of the mooring cable length by 1 cm order, and is effective in improving positioning accuracy.

[5] Work information control system is exceedingly effective which displays by real time the level position, distance to the seabed, water level of each section, speed and direction of tidal current at time of laying the caisson, which needs to be accomplished within a short period of time during slack tide.

[6] Quick installation of filter units is feasible by a floating crane for measures against initial scouring. Scouring can be prevented by conjointly covering the surface with riprap.

[7] Controlling the volume of concrete by adequately arranged casting pipes, will allow to lift up the total area uniformly, in casting desegregating underwater concrete.

[8] By adequately eliminating marine snow and laitance sedimentation on the surface of desegregating underwater concrete will allow to integrally continue casting.