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Objekttyp: **Article**

Zeitschrift: **IABSE reports = Rapports AIPC = IVBH Berichte**

Band (Jahr): **79 (1998)**

PDF erstellt am: **09.08.2024**

Persistenter Link: https://doi.org/10.5169/seals-59976

Construction of a Huge Marine Structure in Japan

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Abstract

NKK has contributed to society through fabrication of many marine structures, such as jackets and artificial islands, petroleum drilling systems, steel shells for submerged tunnels, hybrid breakwaters, and pontoons and so on. We fabricated the 5P steel caissons for the South Bisan Seto Bridge of the Honshu-Shikoku Bridge, where the "laying-down caisson method" was used for the first time. Among these experiences, the Akashi Kaikyo Bridge 2P Steel Caisson Project was the largest scale and involved a number of technical challenges. This project was a key to the success of the entire Akashi Kaikyo Bridge Project .The new technologies developed through the project will lead new possibilities to construct huge marine structures in Japan. This paper describes the 2P Steel Caisson of Akashi Kaikyo Bridge.

1. Outline of Akashi-Kaikyo Bridge 2P steel caisson

1.1 Structure of Steel Caisson

The Akashi Kaikyo Bridge is the longest suspension bridge in the world. It connects Kobe City to Awaji Island and is 3,910m long with a center span of 1,900m. The 2P steel caisson was a steel form for casting underwater concrete foundation of the Kobe side main bridge tower. Its shape was double cylindrical, with outer diameter of 80m, inner diameter of 56m and a height of 65m. A bottom plate was attached between outer and inner wall, to provide buoyancy . The bouyant zone had 16 bulkheads to improve strength and stability as floating body. This design permitted continuous casting of underwater concrete. Fig.1 shows a general side view image of the Akashi Kaikyo Bridge, and Fig.2 shows general structural diagrams of the 2P steel caisson.

1.2 Construction Method

The 2P main tower foundation was constructed by the "laying-down caisson method." This was a newly-developed method for underwater foundation construction. For the first, it was applied to the 5P caisson of the South Bisan Seto Bridge of the Honshu-Shikoku Bridge, and about 20 foundations had been constructed by this method in the Honshu-Shikoku Bridge. In the "laying-down caisson method," a steel caisson is towed, ballasted and set on a pre-excavated seabed. The underwater concrete is then cast into it to complete the construction of the foundation. Fig.3 shows a flow diagram for construction using the "laying-down" caisson method.

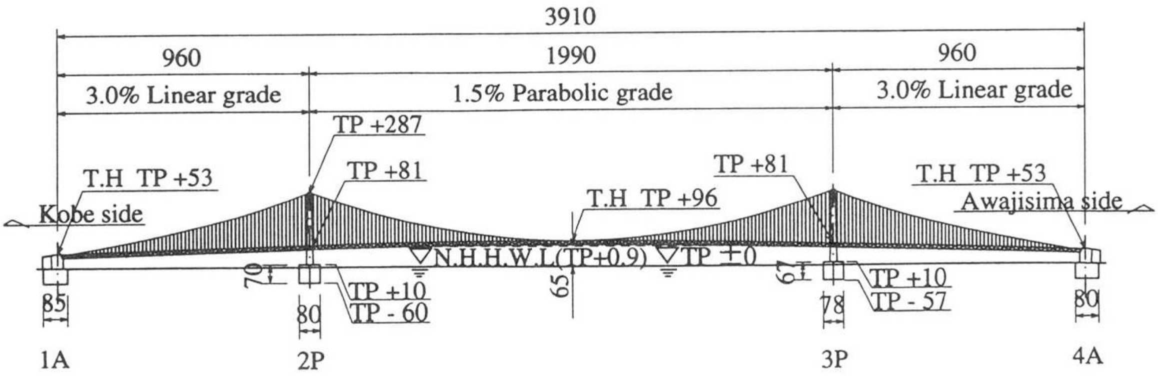

Fig.1 General view of Akashi Kaikyo Bridge

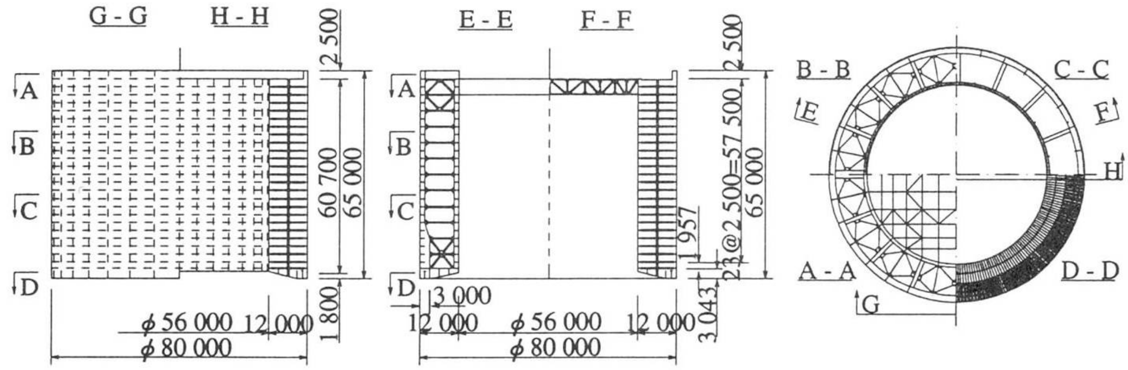

Fig.2 Strucutal Diagrams of 2P steel Caisson

1.3 Design Conditions

In this method, the caisson was used as a form for casting underwater concrete for the main tower foundation. However, it was faced to several different conditions before casting concrete, including launching, towing, mooring and sinking operations. Therefore the caisson had to be safe and functioal under these conditions. Table 1 shows the maximum design tidal current and ocean wave conditions for the caisson, and Table 2 shows the design loads. The combination of loads and safety factors were determined for each construction stage.

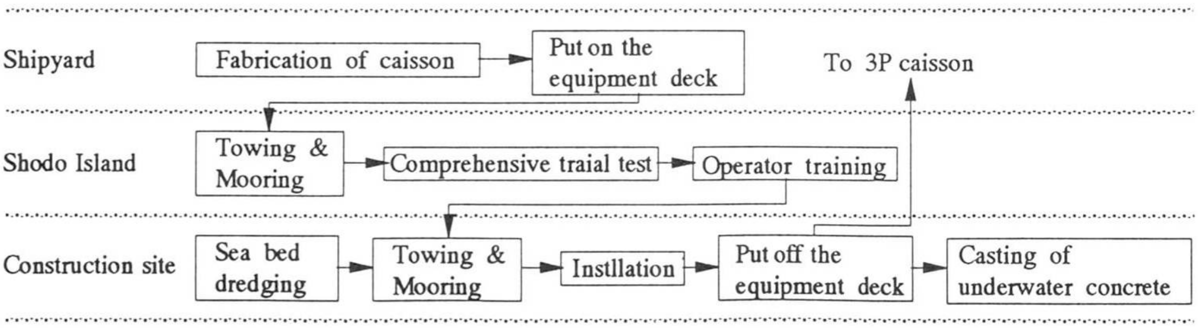

Fig.3 Flow of construction for Akashi Kaikyo Bridge tower foundation

2. Fabrication of Steel Caisson

The steel caisson was divided vertically into 7 stages and circumferentially into 16 sections for a total of 112 blocks. These blocks were fabricated at 6 shipyards in the 4 companies that comprised the consortium. The maximum weight of a single block was 180 tons.
The blocks were then transported to the ocean dock at NKK Tsu Works for final assembly. Assembly work was carried out using three 650-ton and one 450-ton crawler cranes.
In order to achieve the required level of dimensional control for the assembly, datum points were set on the dock floor for the bulkhead and double wall intersections.
Photo 1 shows the caisson being assembled at the NKK Tsu Works ocean dock. To keep the dimensions within the required tolerance, two of the 16 blocks on each stage were adjusted for horizontal dimension, and the 1st and 6th stages were used for vertical dimension adjustments.
Radiographic tests were performed for welded butt joints in the bottom plates, double walls, and bulkheads. The number of radiographs for the block preparation and overall assembly stages was determined using the ABS rules.
Ultrasonic flaw detection tests were performed for complete penetration welds at locations with concentrated loads, such as those for fixing the fairleader, inner core struts, and eyeplates.

Table.1 Maximum Design Tidal Current and Wave Conditions

Item	Condition	Construction Stage
Tidal Current	2.5m/s	Towing,Mooring
	1.75m/s	Install
	3.5m/s	After Install
Effective Wave High	2.4m	Towing,Mooring
	1.0m	Install
	3.4m	After Install

Table.2 Design Loads

Load Name	Contents
Self Weight	Caisson Body 16,500tf
	Equipment 1,000tf
	Scaffolding 400tf
Vertical Load at the top of caisson	Equipment&Deck 2,500tf
	Concrete work load: Inner Core 1.0tf/m^2 Outer Duble Hull 2.0tf/m^2
Concrete Pressure	20tf/m^2
Water Pressure	10tf/m^2
Wind	$Fw=1/2qV^2CA$※
Tide	$Fc=1/2qV^2CA$※
Wave	Drafting Force: Havelock Equation Wave Pressure: MacCamy-Fuchs Equation
Towing	75tf
Mooring	1,000tf
Ship mooring	100tf
Installing Impact	$Pmax=Vo\sqrt{K W/q}$ ※

※: See Reference to 1)

3. Equipment

3.1 Outline of Caisson equipment

The caisson should have two kinds of equipment for installating at the target point and casting underwater concrete. This paper focuses on caisson installation equipment. The caisson installation equipment consisted of systems for mooring, ballasting, monitoring, electrical and other. All these were designed to be mounted on the equipment deck. This special deck could be put on and off the top of the caisson by using a floating crane.
This allowed them to be reused on the 3P caisson after completion of the 2P caisson. However, the water ballast and deballast pumps and sensors were fitted at specified points on each caisson body.
Fig.4 shows a conceptual diagram of the steel caisson equipment.

3.2 Mooring system

The purpose of the mooring system was to hold and adjust the own position against the strong tidal current of the Akashi Strait. The simulation analysis of many different mooring wire layouts was carried out to determine the optimum wire layout and winch capacity. In general, layout of mooring wires parallel and perpendicular to the bridge axis direction is effective. We selected a slightly modified layout (see Fig.5). Accordingly, a holding capacity of 1,000 tons and a winding capacity of 400 tons were determined for the winch. In addition, a high-speed winding and unwinding capacity of 20 tons at 30m / minute was determined to facilitate mooring wire connection and disconnection work. A "linear" type winch was selected. Furthermore, because the connection of mooring wires on site had to be completed within the short slack tide period, and the mooring wires were too heavy to handle by divers, an automatic "quick joint" device was developed and used for connecting and disconnecting the wires.

3.3 Ballast System

The purpose of the ballast system was to pump water into the caisson after it had been moored for installation at the predetermined seabed location. The draft of the caisson was 8m, and the water depth at the site was 60m, so it was necessary to ballast the caisson 52m. It was also necessary to pump water into the caisson up to the top of the inner core to improve stability against the strong tidal currents after ballasting. The ballast system consisted of (1) a main ballast system, (2) an emergency ballast system and (3) a deballast system. Fig.6 shows the specifications of the ballast systems.

(1) The main ballast system consisted of 32 water pumps (2 pumps for each of the 16 tanks).
This system could lower the caisson onto the seabed in a total 6 hours over two consecutive days at a speed of approximately 10m per hour.
(2) The emergency ballast system was a backup system to provide water into any parts of 16 tanks if up to 2 main ballast pumps would fail.
(3) The deballast system allowed the caisson to float off the seabed again for repositioning if the caisson had not been set satisfactorily.

3.4 Monitor system

The monitor system was an information processing system that helped the operation supervisor evaluate, oversee and direct the job of positioning and installing the caisson in a timely and appropriate manner. This system, comprising survey equipment, several types of sensors and a computer, collects measurement data on-line, processes the data into a designated form and displays it on a monitor screen. The system provided integrated control of the position of the caisson, the operation status of equipment, the accuracy of work, and time schedules. All datum were updated every two seconds.
Fig.7 shows a diagram of the monitor system hardware. There were 3 patterns of screens image.

CRT-1: horizontal dimensional information
CRT-2: vertical dimensional information
CRT-3: time series information

The screen selection was made using a button box. Photo 2 shows an example of a display screen (CRT-2).

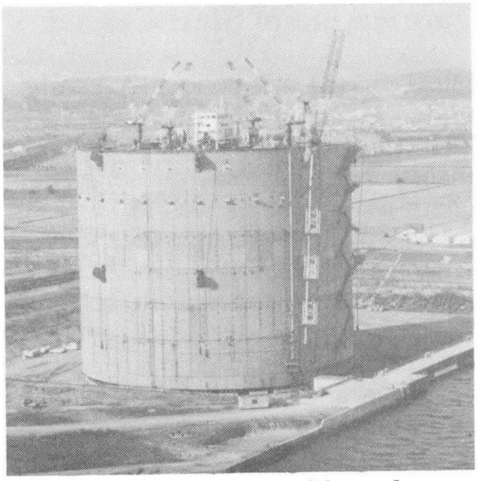

Photo.1 Under Assemble at the NKK Tsu Works ocean dock

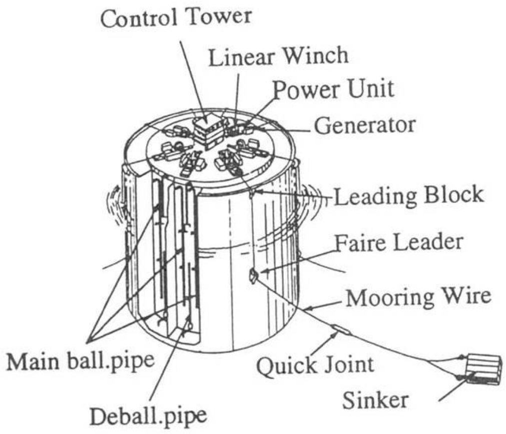

Fig.4 Concept of 2P caisson Equipment

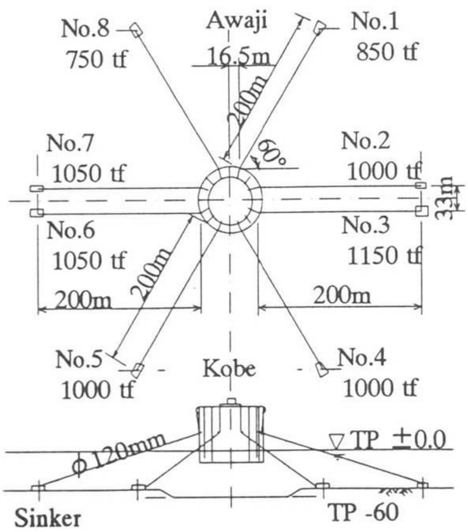

Fig.5 Layout of Mooring Wires

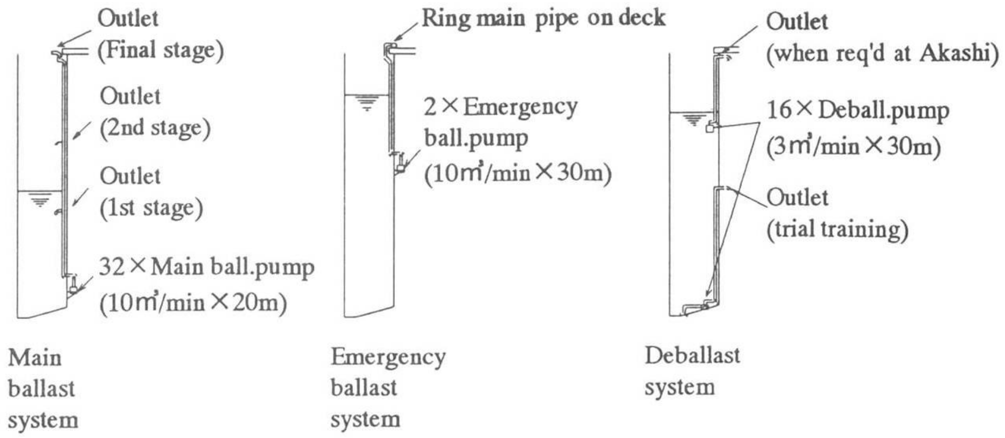

Fig.6 Specificatons of the Ballast systems

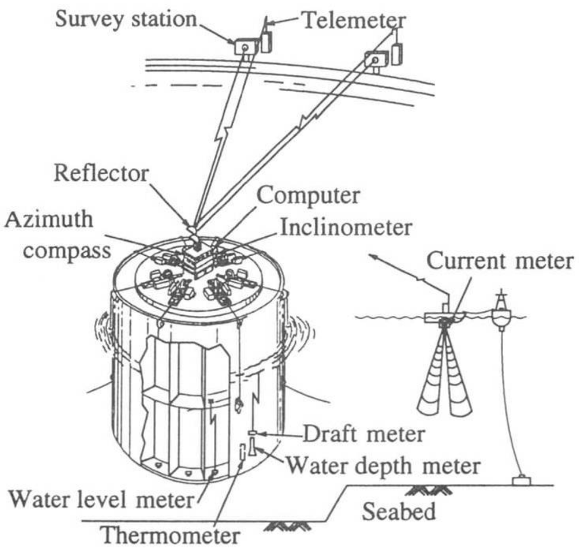

Fig.7 Layout of Monitor System

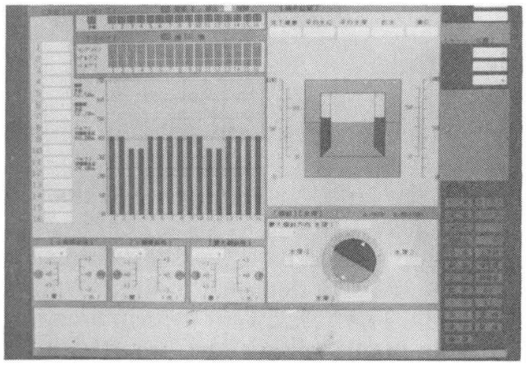

Photo.2 Example of display (CRT-2)

4. Towing

The 2P steel caisson departed from the ocean dock of NKK Tsu Works on January 23, 1989 . It was towed by a group of tugboats and arrived at the location use for comprehensive trial test off the east coast of Shodo Island(Kanagawa Prefecture) on Feb. 1. Fig.8 shows the towing route. The total towing distance was approximately 300 miles. For the section from the Irako Channel to the Tomogashima Channel, a fleet of four oceangoing tugboats (total towing power: 31,600 PS) was used that could easily tow the caisson in the coastal waters of the Pacific Ocean. This was an unprecedented tow in Japan in the sense that the scale of the object towed was huge and the towing distance along the coastal sea was long. Photo 3 shows towing of 2P steel caisson in the Akashi Strait.

5. Comprehensive trial test

A trial test was carried out at Shodo Island during about one month.
This test was simulation and training of prototype. The performance and operability as a total system were checked and confirmed. After the test, the 2P steel caisson was towed and installed on the seabed in the Akashi Strait on March 29, 1989 at 10:20 am. The accuracy of installation was very high, being only a few centimeters off the target position. After the successful installation, casting of underwater concrete was completed in December 1991. And the first important step of the Akashi Kaikyo Bridge Construction Project was completed without any problem.

Fig.9 Towing route of 2P caisson

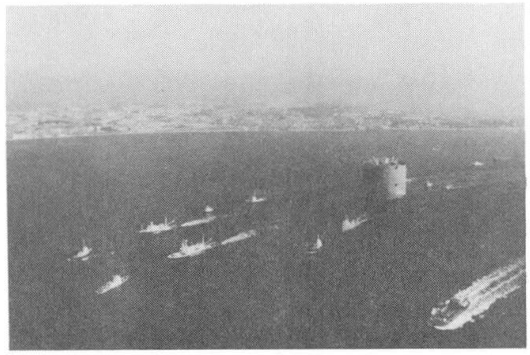

Photo.3 Towing of 2P caisson at Akashi Strait

Conclusions

Two new technologies were developed for the 2P steel caisson of the Akashi Kaikyo Bridge.

The one is the large-scale mooring system. This consists of two basic technologies, namely, a linear winch system and a quick joint system. The linear winch system used in this project was transferred to a large work vessel for reuse after completion of the 2P project. This system is still being actively used, demonstrating its immense potential for large-scale marine structure applications. The quick joint system was further improved after completion of the 2P project and was used in the lifting system for stiffening girders of the Kurushima Kaikyo Bridge. This system is expected to offer great potential for lifting heavy structures and for automatic connection systems in deep water.
The other is the monitoring system. This is a good experience of the utilization of computers for construction. The system demonstrated that computers was used successfully as an effective aid in the construction of large-scale, complicated installations that involve dangerous conditions. We expect that this system will present a leading experience for the use of computers during construction.

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