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Objekttyp: **Article**

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

Band (Jahr): **80 (1999)**

PDF erstellt am: **23.06.2024**

Persistenter Link: https://doi.org/10.5169/seals-60768

Design and Construction of Foundations for Akashi Kaikyo Bridge

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ABSTRUCT

The Akashi Kaikyo Bridge, the longest suspension bridge as ever, is just completed in 1998 as part of the Honshu-Shikoku Bridge project. This bridge has a main span length of 1991m and a total length of 3991m, and crosses over the Akashi Strait which is 4km in width and 110m in maximum depth on the bridging route. The maximum tidal current in the strait is as high as 4m/sec.

This paper describes outline of Honshu-Shikoku Bridge Project and some technical features of Akashi Kaikyo Bridge's foundation as follows.

- All foundations were designed against severe earthquake with a newly established seismic design method.
- Big and deep foundations for the anchorages were constructed with various new technologies.
- The main piers were constructed as spread foundations by Laying-down caisson method under the condition of deep sea and rapid tidal current.
- Newly developed low heat type cement and concrete of various mixtures were used.

1. INTRODUCTION

The purpose of the ongoing Honshu-Shikoku Bridge (HSB) Project is to link the island of Honshu and Shikoku via three routes, and thereby promote balanced regional development in Japan. The Honshu-Shikoku Bridge Authority was then founded in 1970 based on a law as an execution body of the project. Fig.-1 shows a concept and bridges of the project.

The Kobe-Naruto Route, the eastern route of the HSB Links, provides an 89 km, 6-lane (partially 4-lane) highway with a design speed of 100km/hr, and is just completed in 1998. This route contains two long span suspension bridges: the Akashi-Kaikyo Bridge and the Ohnaruto Bridge.

The Kojima-Sakaide Route, the central route of the HSB Links, features a 37km, 4-lane highway with a design speed of 100km/hr and a 2-track railway for ordinary trains. This route was opened to traffic in 1988 as the first direct link between Honshu and Shikoku. It contains six long span bridges over the 9.4km strait, which are collectively known as the Seto-Ohashi Bridges.

The Onomichi-Imabari Route, which includes ten long span bridges linking nine relatively large islands, is a 60km. Construction work on this route will be completed in the spring of 1999.

The foundations for Honshu-Shikoku Bridges are mainly located on the shore and the rest in underwater and generally bedded on granite or Izumi Formation layer, which is hard and old rock before the Oligocene or Cretaceous.

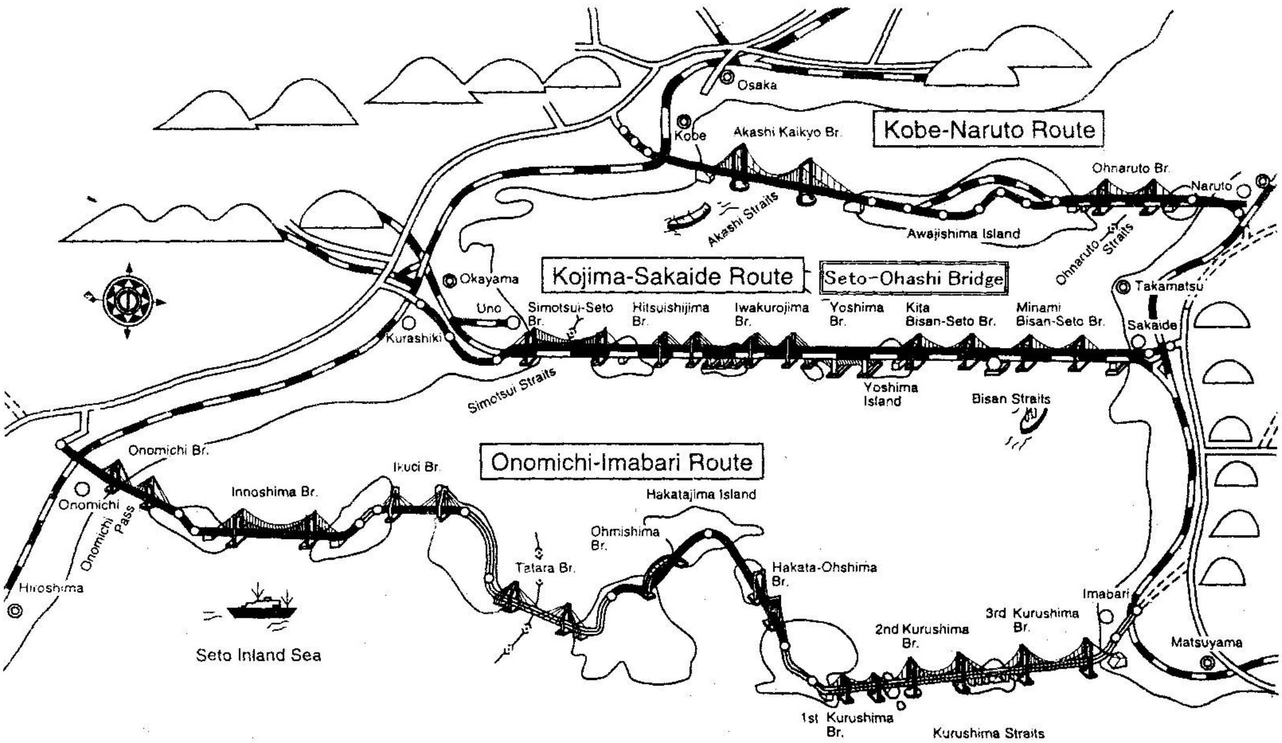

Fig.-1 Bird's Eye View of Honshu-Shikoku Bridges

2. AKASHI KAIKYO BRIDGE

2.1 Outline of the bridge

The Akashi-Kaikyo Bridge, crossing over 4km wide Akashi Strait, is a strengthened steel truss suspension structure with 3 spans and 2 hinges at 2 main piers. A total length of the bridge is 3911m and length between the 2 main piers is 1991m and fraction in each length is due to the Hyogo-ken Nanbu Earthquake. The bridge is supported by 2 anchorages (1A and 4A) and 2 piers (2P and 3P) on direct foundations, as shown in Fig-2.

The foundations of Honshu-Shikoku Bridge are generally bedded on hard rock layer mentioned above. As the foundations of Akashi-Kaikyo Bridge except for that of 4A, however, the granite bed is so deep, it was impractical to form on granite bed, eventually had to construct on relatively soft and young rock.

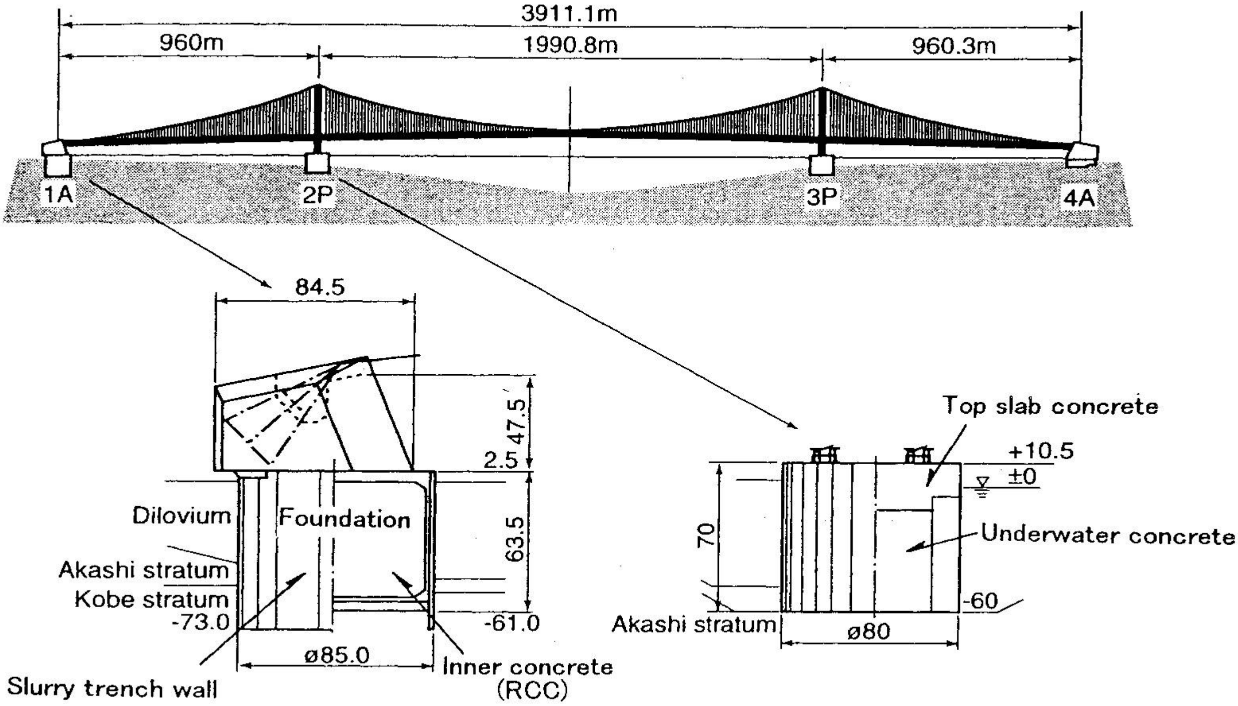

Fig.-2 Profile of Akashi-Kaikyo Bridge

2.2 Design condition

2.2.1 The Akashi Strait

The Akashi Strait is designed as a statutory waterway with width of 1500m where approximately 1400 ships pass daily.

The maximum water depth in the central part of the strait reaches approximately 110m.

The maximum current speed is approximately 3.5m/sec at 2P and 4m/sec at 3P. An observation near the site showed that mean wave height is 51.4cm and the maximum wave height is approximately 6m during a typhoon. Tidal level change is observed to be approximately 1m.

2.2.2 Geological condition

The seabed consists of recent and upper Pleistocene deposits, Akashi Formation of the Pleistocene to Pliocene, Kobe Formation of the Miocene and granite as shown in Fig-3. The Akashi Formation is composed of semi-cemented gravel and sand, and contains a lot of decayed gravel. The Kobe Formation is made of weakly cemented soft rock with complicated alteration of thin sandstone and mud-stone layers. Namely, 1A and 3P are founded on the Kobe Formation, and 2P is put on the Akashi Formation. On the other hand, 4A is designed to be rested on weathered granite.

3. DESIGN OF FOUNDATIONS FOR AKASHI KAIKYO BRIDGE

3.1 Soil investigation

In order to obtain the engineering properties of the subsoil for the foundation design, geotechnical investigations were carried out in several phases. They included geophysical survey, exploratory drilling, laboratory soil and rock tests, seismic activity investigation, etc. Immediately before the construction started, a detailed investigation was carried out to finalize the foundation design.

The detailed investigation had the following features.

- Large-size self elevated platforms (SEP) were used to conduct exploratory drilling in deep water with rapid current.
- Undisturbed samples were collected continuously from various types of rock including 300mm diameter continuous sampling from semi-cemented gravelly sand layer of Akashi Formation.
- Engineering properties of rocks were determined using various types of in-situ tests such as geophysical logging, pressure-meter tests and permeability tests.

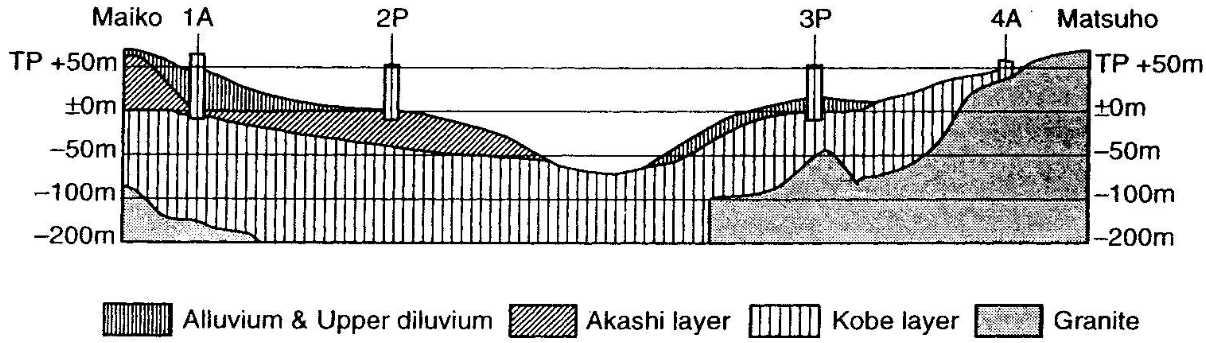

Fig-3 Geological Section of the Akashi Strait

3.2 Seismic Design

Conventional seismic design standard for Honshu-Shikoku Bridges is mainly applicable to the foundations supported with hard and old rock layers. However, Akashi-Kaikyo Bridge in which huge foundations was to be constructed upon softer and younger layers, a new seismic design standard had to be formed, because non-linearity of the bearing layer as well as dynamic interaction between the ground and foundation were judged to be not negligible.

The concepts of the new seismic design standard for the Akashi-Kaikyo Bridge's foundations are as follows.

- The response of the foundations is to be obtained through the response spectrum method with corresponding 2-degree of freedom system, which models both rigid foundation and ground springs to express the oscillation in rocking mode as well as swaying mode.
- The modes should be established with consideration of dynamic interaction between the foundation and the ground (see Fig.-4).
- In order to evaluate the dynamic interaction, local ground condition around the foundations should be precisely taken into account.

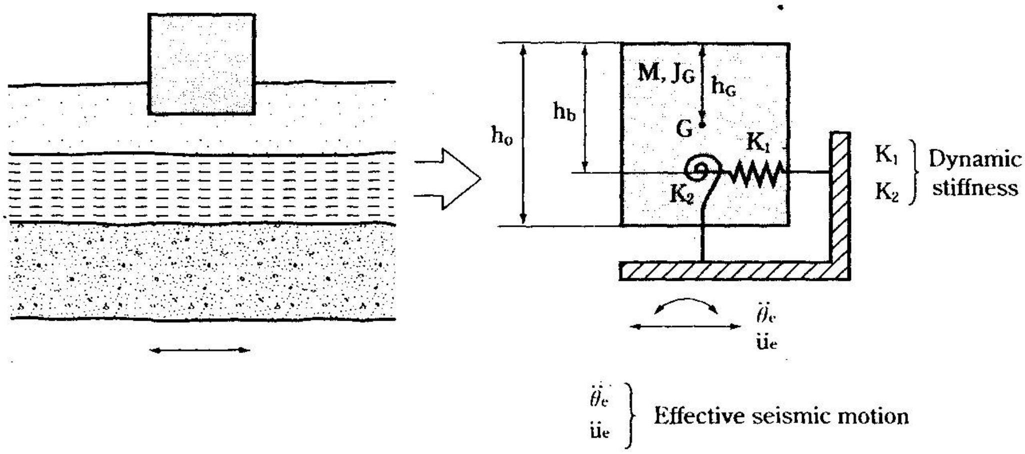

Fig-4 Dynamic response analysis model

4. CONSTRUCTION OF FOUNDATIONS FOR AKASHI KAIKYO BRIDGE

4.1 Deep-water underground slurry wall

The bedrock which could serve as the supporting ground for the 1A anchorage is approximately 60m below sea level. After repeated consideration, a method that may be called "deep-water underground slurry wall method" was employed. In this method, retaining walls arranged in circular form were installed first, and the soil inside these retaining walls was excavated in the open-air while the ground water inside was pumped out. A continuous underground wall with 92 sections of the same length was constructed using an excavator for continuous wall construction that was one of the largest in Japan. Using this as a retaining wall, the 84m diameter inside ground was excavated. The excavation work was started at 2.5m above sea level and reached about 61m below, taking about 11 months in total to complete, during which approximately 330,000m^3 of soil was excavated. After the excavation, RCC (Roller Compacted Concrete) was applied to make a foundation consolidated with the retaining wall.

4.2 Laying-down caisson method

Construction method for the foundation of the two main piers (2P and 3P) has been named "Laying-down caisson method" and used in many bridges in the Honshu-Shikoku Bridges including Seto-Ohashi Bridges. Although it is called "caisson", a foundation constructed by this method is not, in fact, a caisson (a rigid foundation which has an effective embedment), but a spread foundation rested on the pre-excavated bearing layer without any embedment.

The main characteristics of this method are as follows.

- Excavation up to the sufficient bearing layer and the building a caisson (a steel form for underwater concrete) are split into separate procedure.
- As a result of this separation, the method of excavation and machinery for it are not restricted from the inner size of the caisson. It is thus possible to shorten a time for excavation.
- After completion of the excavation, the caisson is towed to the site as shown in Photo-1, sunk with high accuracy to the position specified in the design, whereupon underwater concrete is cast into the bulk of the foundation as rapidly as possible, and ordinary reinforced concrete is applied to the top part so as to complete the entire main pier.

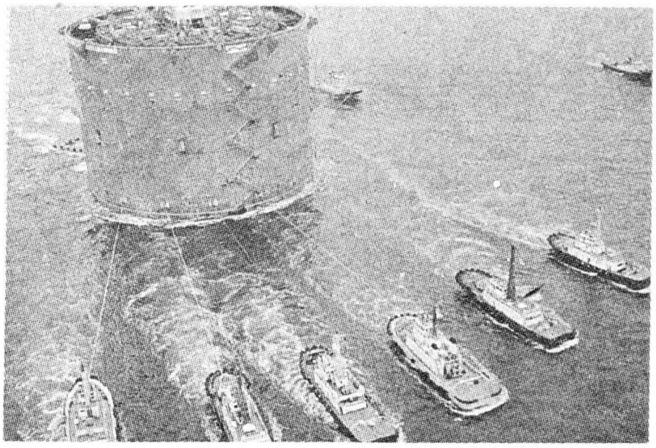

Photo-1 Laying-down Caisson Method (Towing Steel Caisson of 2P)

4.3 Concrete material

4.3.1 Low-heat cement

The cement previously used for mass concrete in the Honshu-Shikoku Bridges was either portland blast furnace slag cement or low heat type blast furnace slag cement.

However, occurrence of thermal cracking could not be always suppressed within satisfactory level, because the concrete was rather rich mix with 280kgf/m^3 (2740N). The adiabatic temperature rise of this concrete was measured to be about 45℃.

It was thus decided to develop a low heat cement for the Akashi-Kaikyo Bridge, by which the concrete with the unit content of 260kgf/m^3 (2540N) can be mixed so as to have the adiabatic temperature rise of less than 25℃. This cement utilizes pulverized blast furnace slag, whose content can be enhanced to 80% at maximum, and fly ash is sometimes added to adjust component design of cement. This newly developed cement was widely used in various part of the substructure of the Akashi-Kaikyo Bridge.

4.3.2 High fluidity concrete

For the concrete work of the anchorage, a large volume of concrete was required to cast into the space congested by re-bars and structural steel, within the limited construction period. Large amount of workers and equipments are necessary by the conventional methods. Hence, the newly developed highly fluidity (self-compactable) concrete was adopted for the concrete of the anchorage. It is a mixture of low-heat cement with an admixture of limestone powder, adding air entraining and high-range water reducing agents. The fluidity is controlled by a slump-flow, prescribed within 45cm to 60cm. Due to the high fluidity of the concrete, it flows into the very complicated space without any vibrators operated by workers. The adoption of the high fluidity concrete results in the reduction of workers and construction period, without losing the quality of the concrete.

5. CONCLUDING REMARKS

The important technical aspects in the design and construction of foundations for the Akashi-Kaikyo Bridge are briefly described in this paper. Many other technologies, not described in this paper, were developed and actually applied to the construction.

The authors believe that all the technologies, developed and applied in the Akashi-Kaikyo Bridge, can contribute to the accomplishment of ultra-long span bridge projects in the future.