

**Zeitschrift:** IABSE reports of the working commissions = Rapports des commissions de travail AIPC = IVBH Berichte der Arbeitskommissionen

**Band:** 032 (1979)

**Artikel:** Honshu-Shikoku Bridge planning in Japan

**Autor:** Kawasaki, I.

**DOI:** <https://doi.org/10.5169/seals-25606>

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## **Honshu-Shikoku Bridge Planning in Japan**

Projet de ponts entre Honshu et Shikoku, Japon

Brückenprojekte zwischen Honshu und Shikoku, Japan

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### **SUMMARY**

The main sections of the Honshu-Shikoku Bridge Project consist of long-span suspension bridges over the sea. The bridges laid on two of three routes of the project are combined highway and railway double-decked bridges. This report shows how various problems confronted in this large-scale project have been solved, thus resulting in a better project.

### **RESUME**

Les éléments principaux du projet de ponts reliant Honshu et Shikoku sont formés de ponts suspendus de grande portée. Les ponts de deux des trois axes du projet sont à deux étages, et sont à la fois ponts-routiers et ferroviaires. Le présent rapport expose la façon dont divers problèmes de ce projet de grande importance ont été résolus pour obtenir un meilleur Projet.

### **ZUSAMMENFASSUNG**

Die Verbindungsbrücken zwischen Honshu und Shikoku bestehen jeweils aus Hängebrücken mit grossen Feldern, die sich zum grössten Teil über das Meer spannen. Bei zwei von drei Objekten handelt es sich um zweigeschossige Strassen-Eisenbahnbrücken. Im folgenden soll darüber berichtet werden, wie die vielfältigen mit diesem grossen Projekt verbundenen Schwierigkeiten überwunden wurden, im Sinne des „Weges zum besseren Projekt“.



## 1. INTRODUCTION

Japan consists of four main islands, Hokkaido, Honshu, Shikoku and Kyushu. It is a long-cherished national desire to connect these four islands by land transport routes to make the country into really one land. To attain this national desire, an over 50 km long undersea railway tunnel connecting Hokkaido and Honshu with each other is under construction. Honshu and Kyushu have already been connected with each other by two undersea railway tunnel, one undersea highway tunnel and one 712 m span high-way bridge known as the Kanmon Bridge. Thus, the realization of a direct connection between Honshu and Shikoku will fully accomplish the long-cherished national desire. To connect Honshu and Shikoku by bridges, a national project is under way.

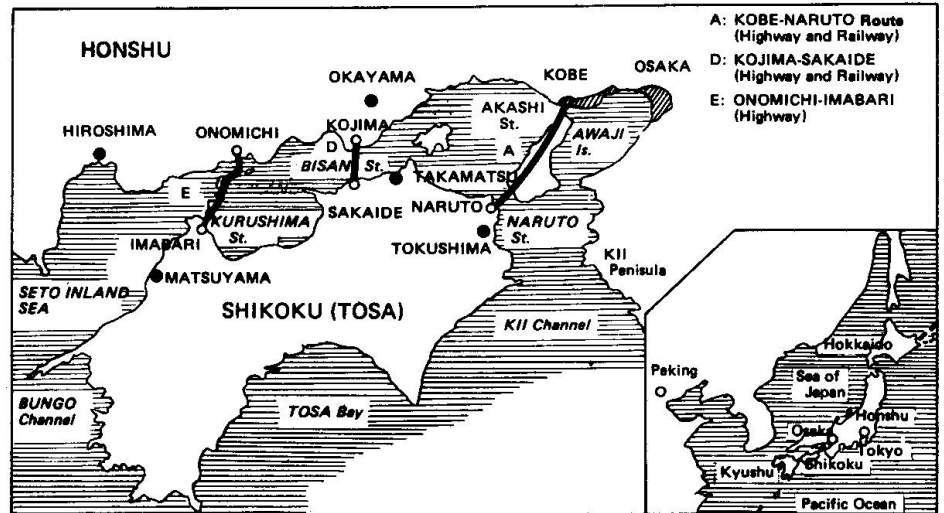


Fig. 1 The routes of the Honshu-Shikoku Bridges

Table - 1 The outline of project

Item		A	D	E
Highway	Length	81.1 km	37.8 km	60.1 km
	Classification	Expressway	Expressway	Expressway
	Design speed	100 km/h	100 km/h	80 km/h
	Number of lanes	6 lanes	4 lanes	4 lanes
Railway	Length	89.8 km	49.2 km	—
	Classification	Shinkansen	Ordinary line and Shinkansen	—
	Number of tracks	2	2 + 2	—
Construction cost (1977) (billion yen)		1,150	840	410

The feasibility study of this project in terms of railway bridge was commenced in 1955 by Japanese National Railways, and that in terms of highway bridge was started in 1959 by the Ministry of Construction. Later, the former study was taken over by Japan Railway Construction Public Corporation and the latter by Japan Highway Public Corporation. The results of the respective studies were laid before the Technical Committee created in the Japan Society of Civil Engineers to discuss the technical aspect of this project. As a result of such discussion, the present three connection routes, namely, Routes A, D and E, were selected out of five routes initially proposed. On the basis of the report submitted by this Technical Committee and plans of projects of both public corporations, the Government decided, in 1970, to implement this National Project and organized the Honshu-Shikoku Bridge Authority by enacting a special law for this purpose with consent of the Diet. Plans of construction works for three routes finally selected are as given in Table 1.

It was initially planned to commence simultaneously the construction works for three routes. However, the oil crisis toward the end of 1973 put the Project in deepfreeze. In 1975 when the Project was unfrozen, the initial plan was modified: it was decided to proceed, for the time being, with the construction works of the whole of Route D (central route) as well as Ohnaruto Bridge on



Route A and Innoshima Bridge and Ohmishima Bridge (completed) on Route E. It is planned to commence the construction of a 560 m span suspension bridge called the Ohshima Bridge on Route E in 1980.

During the past 100 years, the Japanese bridge construction technology has been modernized. In particular, this modernization has been remarkable since 1950. The arch bridge constructed in 1955 and called the Saikai Bridge is the first bridge with a span exceeding 200 m in Japan. The Wakato Bridge opened for traffic in 1962 is a 367 m span suspension bridge, and the Kanmon Bridge which is a 712 m span suspension bridge was opened for traffic in 1973. These bridges give an example of rapid advancement of technology for construction of long-span suspension bridges in Japan. The Minato Bridge with a span of 510 m, completed in 1974, is used two types of quenched and tempered high strength steel manufactured in accordance with special specifications, which have tensile strengths of 70 kg/mm<sup>2</sup> and 80 kg/mm<sup>2</sup>, respectively. Knowledge and experience gained from the construction of these bridges contribute largely to the successful realization of this Honshu-Shikoku Connection Project. On the other hand, technical achievements obtained from this Project have contributed, in their turn, to the development of techniques of construction of the Kanmon Bridge and other bridges in Japan.

This big and ambitious project of construction of long-span double-decked combined highway and railway suspension bridges across the inland sea, which is the first of its kind in the world, has however just been under way. A great deal of effort must be made to work out the best enforcement plan and execute it. For this purpose, government agencies, universities, related academic societies and associations, and related private enterprises are co-operating with the Honshu-Shikoku Bridge Authority to further various technical developments.

## 2. ENVIRONMENTAL CONDITIONS TO BE TAKEN INTO CONSIDERATION IN BRIDGE PLANNING

### 2.1 Natural Environment

(1) Topography: It is reported that the Seto Inland Sea was created by the subsidence of lowlands partially containing faults. The geology consists generally of granite. Narrow portions of straits, where the bridges are to be constructed, often take the form of bluffs scoured by tidal currents for a long time. On the sea bed, outcrops of rock having a steep slope are often encountered.

(2) Geology: The geology of the Akashi St. consists of the bedrock of granite composed of Neogene Kobe Group and Pleistocene Akashi Formation. Near the shore, alluvial deposits are sometimes encountered. Kobe Group and Akashi Formation are considered to serve as foundation rock for the bridge.

The geology of the Naruto St. consists of the Cretaceous Izumi Group which is an alternation of sandstone and shale. This stratum presents a dip of about 45°. Care must therefore be taken during execution of the construction works on this bedrock. However, it constitutes a satisfactory foundation rock for the



bridge. At certain points, there exists a deposit layer of which thickness can sometimes reach nearly 10 m. As for the geology along Kojima-Sakaide and Onomichi-Imabari routes, the granite outcrops generally. Though it is considerably altered at some places, such granite constitutes a satisfactory foundation rock for the bridge. On the Shikoku side of the South Bisan Seto Bridge on Kojima-Sakaide Route, such granite is covered by the Mitoyo Group consisting also of a granite bed rock, and thick layers of diluvial and alluvial deposits overlie this group.

(3) Temperature and precipitation: The annual mean temperature of the Seto Inland Sea area is 15°C, while minimum and maximum temperatures are -8°C and +38°C, respectively. Annual precipitation is 1,000 to 1,400 mm. Relative humidity is high during summer season when the temperature is also high. The atmosphere on the sea is highly salty. Thus, the bridges will be placed in a badly corrosive environment.

(4) Wind: The Seto Inland Sea is frequently visited by typhoons every year. In the past, maximum instantaneous wind velocity of 80 m/sec was recorded at the Naruto St. In view of this fact, observation posts are placed at main St. for the purpose of making observations of direction, velocity and angle of incidence of wind. Basic wind velocity (mean wind velocity for ten minutes at a height of 10 m above the sea level), on the basis of which the design wind velocity is determined, is obtained by determining a correlation between values observed at these posts and those at the neighbouring meteorological observatories keeping long-ranged records. For a return period of 150 years, such basic wind velocity is fixed as indicated in Table 2 below:

According to the result of site observations, the vertical profile of mean wind velocity adopted for sea is  $V_z/V_{10} = (H/10)^{1/7}$ .

Table 2 - Basic wind velocity

Route	Location	Basic wind velocity (m/s)
Kobe-Naruto	Akashi St.	43
	Naruto St.	50
Kojima-Sakaide	Entire route	43
Onomichi-Imabari	Kurushima St.	40
	Rest of the route	37

(5) Earthquake: Earthquake taken into account for the aseismic design is that of magnitude of the order of 8, which will probably occur off the Kii Peninsula or Tosa once or twice every 100 years. The design horizontal acceleration of seismic force on the foundation rock for structural foundations at bridge construction sites, used for aseismic design of bridges, is determined at 180 gal for all routes since the three routes are located at a substantially equal distance from the assumed seismic center.

(6) Tidal current and wave: Difference between high and low water levels is about 3 m. Maximum tidal current velocity is 4.5 m/s in the Akashi St., 5.5 m/s in the Naruto St., 2.5 m/s in the Bisan St. and 5 m/s in the Kurushima St. Wave is highest in the Naruto St. opening into the open sea, registering a wave height of 10 m.



## 2.2 Social Environment and Environmental Protection

(1) Ship navigation and overhead clearance: Taking into consideration the navigation of passenger ships for sight-seeing in the Inland Sea as well as cargo vessels, tankers and floating cranes sailing to and from the coastal industrial areas, overhead clearance of 65 m or more and span of 900 m or more are adopted for bridges across Akashi Sts., Bisan Sts. and Kurushima Sts., which are routes of international shipping.

(2) Environmental protection: The whole of the Inland Sea is designated as a national park, and most of land sites for construction of bridges are specified within the framework of the national park. The beauty of the Inland Sea lies essentially in its neutral tint scene created by steam generated from the sea and veiling deep blue of the sea, green of small islands and light blue of the sky. Therefore, types and colors of bridges enhancing such natural beauty of the surroundings are selected. In addition, this sea is rich in marine resources. Bridge construction sites are therefore selected so as not to interfere with spawning and fry growing grounds. Further, bridge construction methods are selected so as not to affect adversely the spawning and fry growing. Thus, care is taken not to prevent the reproduction of such marine resources.

## 3. DESIGN AND CONSTRUCTION OF UNDERWATER FOUNDATIONS

### 3.1 Selection of Type of Foundations

Sites selected for most bridges crossing straits are located at places where the width of the straits is reduced. Topographically, the water becomes abruptly deep just at the shore lines at these sites. In addition, the traffic is heavy in these narrow places of straits. As a result, it is avoided to build these bridges on piers constructed in the sea: these bridges cross the straits without any support between the shore lines. However, where a strait is too wide for a bridge to cross it with only one span, and where reefs exist in a strait so that it is more advantageous from an economic point of view to construct piers in such shallows, the construction of bridges on underwater foundations has been planned, and type of foundations and method of construction thereof which are considered most suitable to conditions of each site have been selected on the basis of the results of a thorough comparative study.

As for underwater foundations, multi-column foundations are adopted for tower foundations constructed on reefs for the Ohnaruto Bridge, while laying-down caissons are employed for foundations of South Bisan-seto Bridge and North Bisan-seto Bridge crossing wide straits where the sea bed is relatively flat.

Among all underwater bridge foundations planned by the Authority, the foundations of the Akashi Sts. Bridge will encounter the severest conditions, such as scale of the bridge, depth of water, depth of foundations, tidal current, effect on the navigation, etc. For these foundations, a study is now under way to design a better type of foundations. At present, various surveys and tests, including construction tests on plans so far worked out, are being carried out at the site.



### 3.2 Multi-column foundation of the Ohnaruto Bridge

In selecting the type of underwater foundations for the Ohnaruto Bridge, a comparative study was made on rigid foundation and multi-column foundation. On the basis of the results of this study, the multi-column foundation was adopted mainly for the following reasons:

- 1) The underwater foundation construction work can be executed by constructing individual columns independently of each other, and after completion of columns, they can resist to the external force as if they were a single column. Thus, the period of unstable condition can be shortened. In addition, the still water area where a foundation is to be constructed can

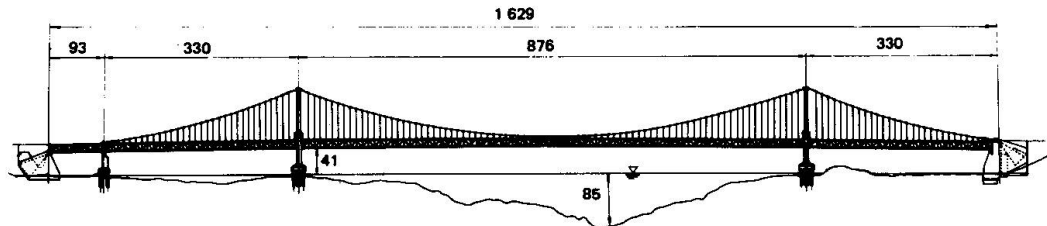


Fig. 2 Ohnaruto Bridge

be divided into small units, and the underwater construction work can be executed successively from one unit to another.

- 2) The volume of underwater construction work is reduced.
- 3) Eddies caused by reefs around the bridge construction site are largest in scale in Japan. Multi-column foundations have only very little influence on such eddies.

(1) Development of a new multi-column excavation method: Since 1965, various types of machines were fabricated and experiments were made both on land and in the sea with a view to establishment of a satisfactory mechanical multi-column excavation method. In 1973, the site test of construction was conducted to obtain the final verification on this method. Such a series of experiments were made not only on the performance of excavation, but also on sea water pollution control measures, construction of a frame on which the drilling machine is mounted, holding mechanism for drilling casing, relocation of the machine, etc. Through these experiments, the multi-column excavation method has been improved so that it may be put in practical use. The excavation method actually used for construction of a largest column of 7 m in diameter is as shown in Fig. 3.

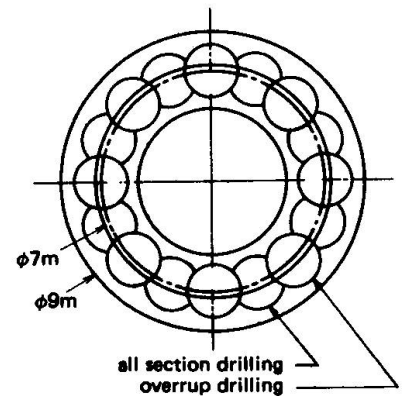


Fig. 3  $\phi 7\text{m}$  Column

According to this method, a cut is made by means of a 4.4 m diameter rotary drilling machine and its periphery is then drilled in a lapped manner by means of a 1.5 m diameter rotary drilling machine. Thereafter, the remaining unexcavated portions are broken down and the bottom of a hole thus formed is finally finished.

(2) Design of a multi-column foundation: Adoption of a multi-column type for a bridge foundation subject to a large external force, like suspension bridge tower foundation, is the first attempt in the world. In addition to the stress analysis, a structural analysis was established through an experiment on a

large-scale model for the purpose of ensuring the safety. Multi-column foundations of the Ohnaruto Bridge are as shown in Fig. 4. Initially, a drilling diameter of 3.6 m was considered for all columns. However, at a relatively early stage of study, it was decided, in view of a relation between stiffness and stress distribution of the footing, to adopt a drilling diameter of 7.0 m for the foundation column situated just under the tower column. On the other hand, nearly at a stage of final design, a through comprehensive study on structure and foundation rock as a whole revealed that the drilling diameter of 3.6 m adopted for foundation columns than that situated just under the tower column should be enlarged. At such stage, however, the test of construction using a newly developed drilling machine had already been completed and there was no sufficient time to conduct further experiments. In consequence, the results obtained from the experiments so far made were minutely analyzed to determine to what extent the drilling diameter could be enlarged without modification of the drilling mechanism already developed and without extreme reduction in efficiency. As a result of this analysis, a drilling diameter of 4.4 m was adopted for these columns as final design. The footing slab was designed as a 9 m thick one, taking account of distribution of load applied from the main tower and internal stress distribution.

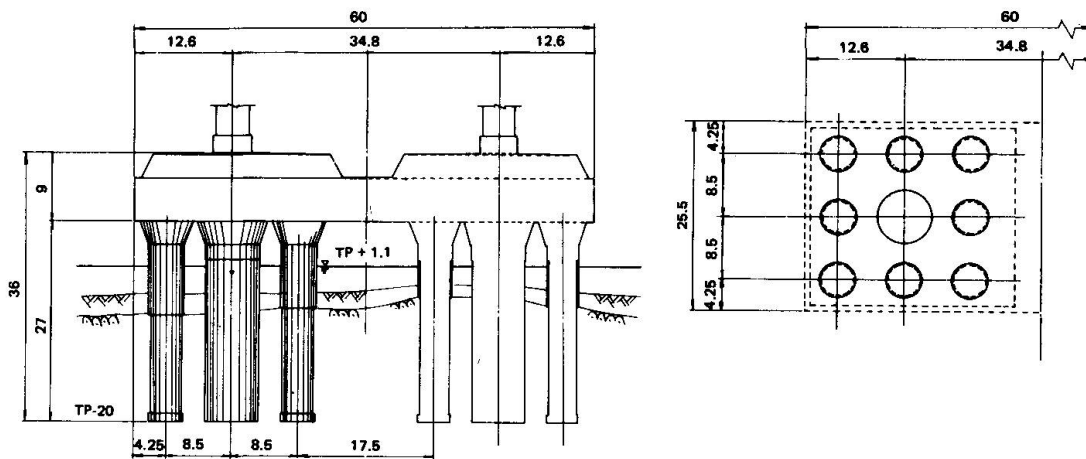


Fig. 4 Multi-column foundation of Ohnaruto Bridge

### 3.3 Laying-down Caissons of South and North Bisan-seto Bridges

(1) Outline of laying-down caisson method: As shown in Fig. 9, South Bisan-seto Bridge and North Bisan-seto Bridge are two 1,000 m class suspension bridges connected with each other. Construction of such two suspension bridges is necessitated by the fact that international sea-lanes pass on both south and north sides. Except for its south side (6P, 7A), the site foundation rock consists of an outcrop of a weathered granite having a high bearing power. To construct bridge foundations under such site conditions while ensuring the safety of navigation, it is necessary to reduce the period of construction work executed on the sea to minimum. To meet this requirement, this laying-down caisson method has been developed. As for the sequence of construction with this method, the seabed is first bored in a concentrated manner with the aid of a self-elevating platform, and the group blasting is then carried out to loosen the surface rock. The rock thus loosened is excavated by means of a large grab dredger. The bottom finishing is executed by means of a rotary drilling machine equipped on the self-elevating platform. Then, a shop-fabricated steel caisson is sunk in place and prepacked concrete is placed in this caisson. In





this way, the foundation is completed. This construction method is economic since all piers can be constructed by the same practice so that large facilities can be diverted for this purpose.

(2) Seabed excavation and blasting: The surface of seabed rock is considerably weathered. It is therefore necessary to remove such weathered zone down to a sound rock bed and to excavate level the whole area. For lack of experience of large-scale construction under these conditions, the following experiments were carried out:

- 1) Experiment for development of an excavation system:

This experiment is to realize a working platform provided with a mechanism capable of moving a drilling machine to any desired position and fixing it at that position in a tidal current.

- 2) Open-cut experiment by percussion drilling machine or large-diameter rotary drilling machine, using the excavation system.
- 3) Seabed blasting experiment using supersonic sonoblaster and overburden drilling machine.
- 4) Rock excavation experiment using a large grab dredger for hardpan.

As a result of these experiments, it has been decided to use a large grab dredger to excavate efficiently the soft rock accounting for the greater part of the volume of excavation work. Where the rock becomes harder along with the progress of excavation and results in a reduction in efficiency of excavation only by such grab dredger, the excavation is executed by a combination of submarine blasting and grab dredger. After completion of rough excavation, the bottom finish excavation is executed by means of a large-diameter drilling machine combined with the above-mentioned excavation system to improve the setting accuracy of caisson.

Conventional submarine blasting is limited in its application to a depth of water upto about 10 m. However, this construction work must be executed at a depth of water of 50 m. Under such a high water pressure, the explosive power of conventional explosives would remarkably be reduced. To solve this problem, new types of explosive and detonator, which have excellent water-pressure resistance and impermeability, have been developed. It has verified that performances of such new explosive and detonator can not be reduced in any way even after submersion in water for ten days under a pressure equivalent to a water depth of 100 m. In addition, a supersonic sonoblaster system where drawbacks of a wire blasting system are eliminated has been put into practical used.

(3) Installation of steel caissons: Each steel caisson is towed afloat to the site, where it is sunk in place by filling its double-wall section with water. Its horizontal position is adjusted by operating, with the aid of a winch mounted on it, a wire rope tied to an anchor installed in the seabed as shown in Fig. 6.

(4) Prepacked concrete: Each caisson must be filled with an enormous volume (250,000 m<sup>3</sup>) of prepacked concrete. For this purpose, the Authority has caused

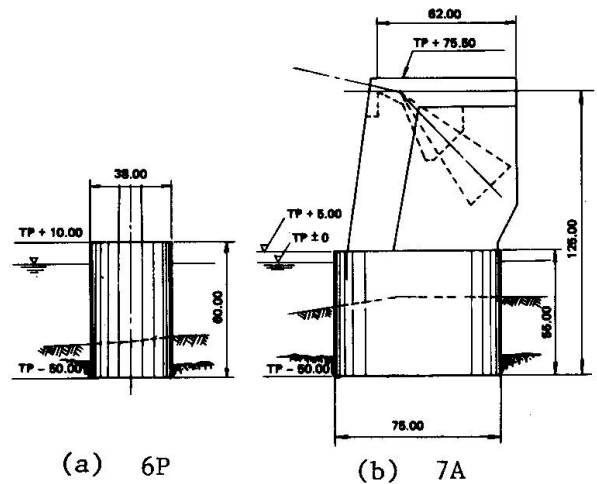


Fig. 5 Substructures of South and North Bisan Seto Bridge

to be built a mortar plant ship having displacement of 11,500 tons and equipped with three mortar plant systems, each having a mortar production capacity of 2,000 liters/min. Two of these three systems can be put in normal service. One mortar injection pipe covers an area of about 80 m<sup>2</sup>.

#### 4. SELECTION OF TYPE OF SUPERSTRUCTURE

##### 4.1 Type of Long-Span Bridge

Type of structures of long-span bridges crossing straits along each route are as given in Table 3. For a combined highway and railway suspension bridge, which is constructed with a double-deck where upper and lower decks are used for highway and railway, respectively, stiffening girders of truss type are adopted. In an example, the case of the Bisan-seto Bridge is shown in Fig. 7. For highway bridges of Route E, suspension bridge stiffening girders of truss type is also adopted with a view to ensuring the safety against wind. However, box-girder type is also studied for the Ohshima Bridge in this route, where the influence of wind is not so great. Towers of all suspension bridges are constructed of steel.

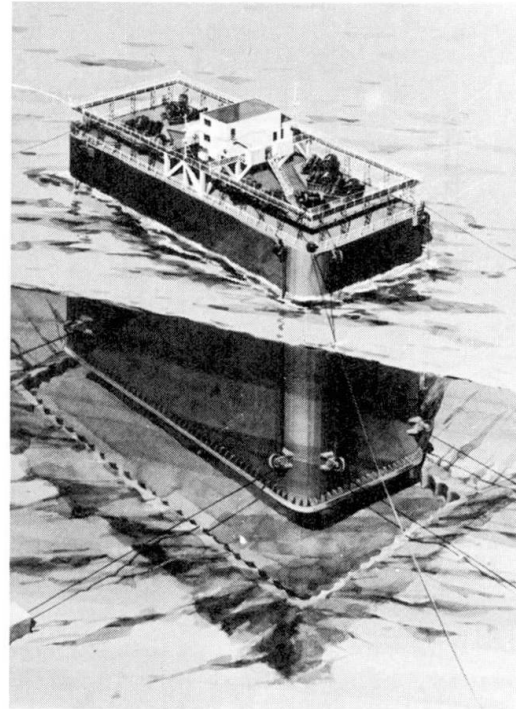


Fig. 6 Installation of caisson

Prefabricated parallel wire strands are planned to be used for cables of suspension bridges, with the exception of those still under study. Number of wires of strands used in Innoshima Bridge and Ohnaruto Bridge now under construction is 127.

Table 3 Principal Dimensions of Bridges Over the Sea

Type of bridge	Route	Name of bridge	Structural type of bridge	Span length (m)
Suspension bridges	A	Akashi Kaikyo Br.	3 spans with 2-hinged truss	890+1,780+890
		Ohnaruto Br.	3 spans with 2-hinged truss	(93)+330+876+330
	D	Shimotsui-seto Br.	3 spans with continuous truss	230+940+230
		North Bisan-seto Br.	3 spans with continuous truss	274+990+274
		South Bisan-seto Br.	3 spans with continuous truss	274+1,100+274
		Innoshima Br.	3 spans with 2-hinged truss	250+770+250
	E	Tatara Br.	3 spans with 2-hinged truss	300+890+300
		Ohshima Br.	3 spans with 2-hinged truss	140+560+140
		1st Kurushima Br.	3 spans with 2-hinged truss	(80)+190+860+194
		2nd Kurushima Br.	3 spans with 2-hinged truss	110+550+110
		3rd Kurushima Br.	Simple span with 2-hinged truss	260+1,000+260
other bridges	A	Muya Br.	4 spans continuous girder	105+160+160+105
	D	Hitsuishi-jima Br.	3 spans cantilever truss	185+403+185
		Iguro-jima Br.	3 spans cantilever truss	185+403+185
		Yoshima Br.	3 spans continuous truss	135+210+165
	E	Onomichi Br.	3 spans cable stayed girder	85+210+ 85
		Ikuchi Br.	8 spans PC girder	50+85+150+250+ 150+85+85+50
		Ohmishima Br.	Simple span solid rib 2-hinged arch	297
		Hakata Br.	3 spans continuous girder	90+145+90

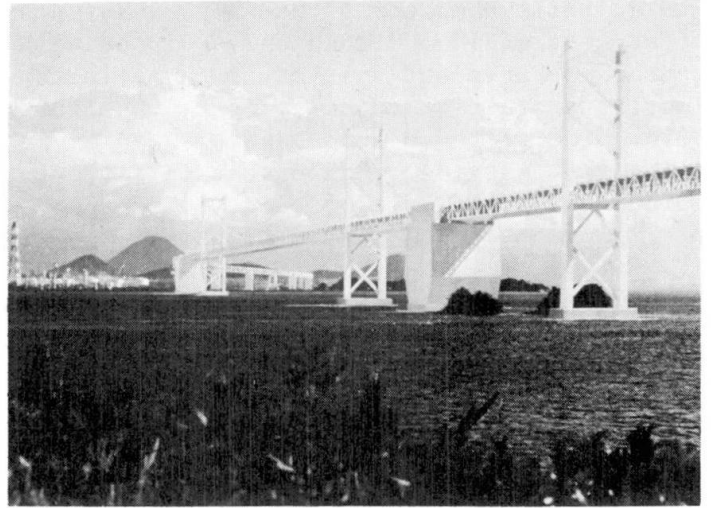
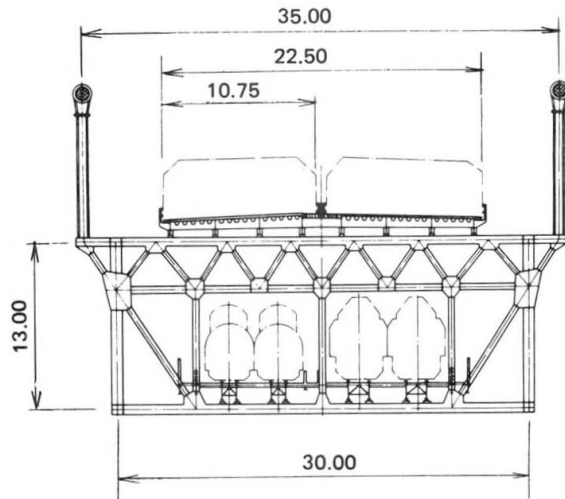


Fig. 7 Section of Bisan-seto Bridge      Fig. 8 Example of Photomontages

For the purpose of establishing a design of each bridge matching the surrounding beauty, conceptional drawings in distant view, middle distance view and close-range view of each bridge are prepared by photomontage method to examine the design in all aesthetical aspects. Fig. 8 gives an example of the North and South Bisan-seto Bridge.

#### 4.2 Bridge Planning of Kojima-Sakaide Route

This route must cross the strait over a distance of about 10 km. In this straits, five islands, large and small, are scattered along the route. The horizontal alignment of this route is selected with due regard to national park, cultural assets, villages and fishery harbors, and also taking into consideration the standard curvature ( $R=1,300$  m) of the Shinkansen as well as the necessity of exclusion of any curvilinear section from a long-span bridge like suspension bridge. The greater part of this route is located within the national park. Therefore, the bridge planning of this route has been made taking also the possible effects of structures to be constructed on the surrounding environment into consideration. Fig. 9 shows the type of each bridge.

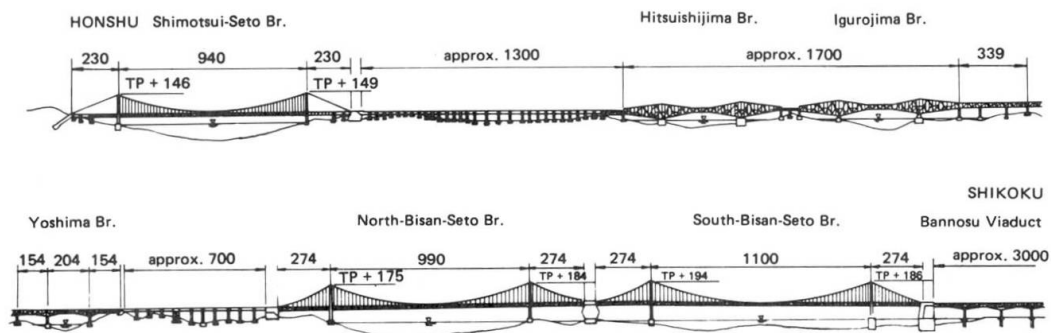


Fig. 9 Bridges of KOJIMA-SAKAIDE Route

(1) Shimotsui-seto Bridge: Running past the Mt. Washu from the Honshu side, this route encounters an about 1 km wide strait called "Shimotsui-seto", where the Shimotsui-seto Bridge having a center span of 940 m is laid. The anchorage on the north side of this bridge is a tunnel anchorage with inclined excavation

over a distance of 60 m. This type of anchorage is adopted from topographic and environmental points of view. On the south side, the gravity anchorage is adopted.

The stiffening truss of this suspension bridge is of single span type, with 130 m long cantilever truss girders on both side of the tower. This type, which presents a truss end deflection angle equivalent to that for an ordinary truss bridge, is preferable from a viewpoint of train runnability. For erection of main cables, an air spinning method is contemplated to reduce the anchorage area to minimum so that the sectional area of the tunnel anchor can be reduced.

(2) Hitsuishi-jima Bridge and Iguro-jima Bridge: On the basis of the results of an comparative study of suspension bridge, truss bridge, arch bridge, cable-stayed bridge and some other types of bridge, the cantilever truss type was initially adopted for these bridges from an economic viewpoint and in view of the experience so far obtained. At present, however, the cable-stayed type is considered for these bridges because of airy feature of this type, long range of consecutive bridges and recent advancement of bridge technology.

(3) North and South Bisan-seto Bridge: About 4 km strait called "Bisan-seto" will be crossed by two suspension bridges having a center span of 990 m and 1,100 m, respectively. Since a group of three small islands located nearly in the middle of this strait can be used as foundation, an anchorage common to both bridges is provided on this group of islands. The depth of the foundation rock is, from north to south, -10 m at 2P, 3P and 4A, -32 m at 5P, and -50 m at 6P and 7A. These foundations 2P to 6P and 7A are constructed by laying-down caisson method. Stiffening truss adopted for these bridges is a continuous stiffening truss which does not present any remarkable deflection angle and dilatation around the main tower and is therefore preferable from a viewpoint of train runnability.

#### 4.3 Wind-resistant Design, Aseismic Design and Train Runnability

(1) Wind-resistant design: As is clear from Fig. 7, the cross-section of suspension bridges presents a complicated non-streamline shape. It is therefore difficult to determine theoretically wind force acting on these suspension bridges and their response. As a result, the determination of such wind force and response must finally be verified by wind tunnel tests. For this purpose, wind tunnel test standards have been established to ensure a uniformity of results of tests even if a plurality of wind tunnels are used. Conformity of many wind tunnels with each other are thus ensured. However, natural wind can not be simulated by any air flow in a wind tunnel. In view of this fact, two dimensional model on a scale of about 1/10 of the actual size of a bridge was prepared and installed at a place on site where a relatively strong wind blows. By observing in detail the response of such model to the natural wind, such problems as may be encountered by actual bridges were determined.

(2) Aseismic design: Experimental analysis based on partial bridge model and overall bridge model experiments using a large shaking table, analysis of results of earthquake damage researches, and analysis of behaviors of bridges and other structures obtained by a network of strong-motion seismographs were made



in addition to the theoretical analysis. From a comprehensive examination of these analysis, aseismic design standards were established. The basic philosophy for the aseismic design is that, on the basis of parameters obtained by modified seismic intensity method using a spectrum of response of structures, the design should be checked by direct response analysis. Since any appropriate input seismic wave has not yet been observed in and around the Seto Inland Sea, earthquakes observed in Japan and El Centro earthquake are used for the aseismic design.

(3) Runnability of trains: Heavy trains running at a high speed on flexible and swinging structures such as suspension bridges will pose many problems, which should be studied from many points of view. Concretely, to study the problems of fatigue caused by vibration and repeated load of bridges with trains running thereon, runnability of trains on deflected or vibrating tracks, etc., the theoretical analysis as well as model experiments and running tests using "Shinkansen" and ordinary train were carried out. In addition, since a long-span bridge like suspension bridge presents a considerable dilatation at the truss end (for example, 1.2 m in case of the Bisan-seto Bridge), and expansion joint for railway line capable of taking up such dilatation was developed.

## 5. PROJECT IMPLEMENTATION SYSTEM

As already mentioned, the Honshu-Shikoku Bridge Authority has been organized as public corporation specializing in implementation of this Project and placed under direct control of the Government. This is because this Project will radically change the conventional traffic system and give a great impact on the local society. It is therefore necessary for the Government to assume the responsibility not only for the construction of the Project, but also for the future maintenance thereof. In addition, any private enterprise could not take such a long-term responsibility.

At stages of study, planning and design, the Authority makes a comparative study of various solutions in cooperation with many consultants. But, it selects a final solution on its own responsibility. The Authority obtains the cooperation of outside persons and organizations, from time to time as required, to solve technical problems with a view to establishment of optimum plans, as mentioned in Section "Introduction".

Contracts for construction works are awarded, for each phase of the Project, on the basis of a specified basic design. Consequently, there is no alternative proposed by contractors. For substructures, contracts are awarded on the basis of detail designs. However, such contracts for construction of superstructures are awarded separately for towers, cables and stiffening girders. In consequence, fabricators undertake only detail designs. Supervision of execution of the works is carried by the personnel of the Authority. For such supervision, the Authority receives some cooperation of consultants, but these consultants are placed under direct control of the Authority.