Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 44 (1983)

Artikel: Safety measures for construction of the Honshu-Shikoku bridges

Autor: Shimokawa, Hirosuke

DOI: https://doi.org/10.5169/seals-34080

Safety Measures for Construction of the Honshu-Shikoku Bridges

Mesures de sécurité dans la construction des ponts de Honshu-Shikoku

Die Sicherheitsmassnahmen bei der Ausführung von Honshu-Shikoku-Brücken

Hirosuke SHIMOKAWA
Counsellor for Engineering
Honshu-Shikoku Bridge Authority
Tokyo, Japan

Hirosuke Shimokawa, born 1926, got his civil engineering degree at the University of Kyushu, Fukuoka in Japan. He realised many projects of highways and bridges in the Ministry of Construction for 30 years and he left from the director of Kyushu Construction Bureau in 1979. Hirosuke Shimokawa, now in the Authority, is responsible for the design and construction of the structures.

SUMMARY
This report describes the safety measures taken for the construction work of the Honshu-Shikoku Bridges which is one of the largest projects in Japan. Emphasis is put on the construction of the Ohnaruto suspension bridge.

RESUME
Ce rapport présente les mesures de sécurité dans la construction des ponts Honshu-Shikoku qui est un des plus grands projects actuels au Japon. La construction du pont suspendu à Ohnaruto est considérée en particulier.

ZUSAMMENFASSUNG
Die Sicherheitsmassnahmen bei der Ausführung des Honshu-Shikoku-Brücken-Projektes, das zur Zeit das grösste Projekt in Japan ist, werden hier kurz beschrieben. Im Besonderen wird die Ausführung der Ohnaruto-Hängebrücke behandelt.

PREFACE

This report describes in outline the safety measures taken for the construction work on the Honshu-Shikoku Bridge. This report will describe the specific safety measures taken in the construction of large span bridges at straits, which is this project's most important characteristic.

1. OUTLINE OF CONSTRUCTION WORK

Constructing of the Honshu-Shikoku Bridges aims to provide efficient and smooth transportation between Honshu and Shikoku islands. The bridges will become part of the national trunk highway and railroad networks. In addition, they will relieve the congested marine traffic in the Seto Inland Sea and so reduce the number of marine accidents.

An overall view of the Honshu-Shikoku Bridges is shown in Fig. 1 and Table 1. The bridges completed and under construction are shown in Table 2.

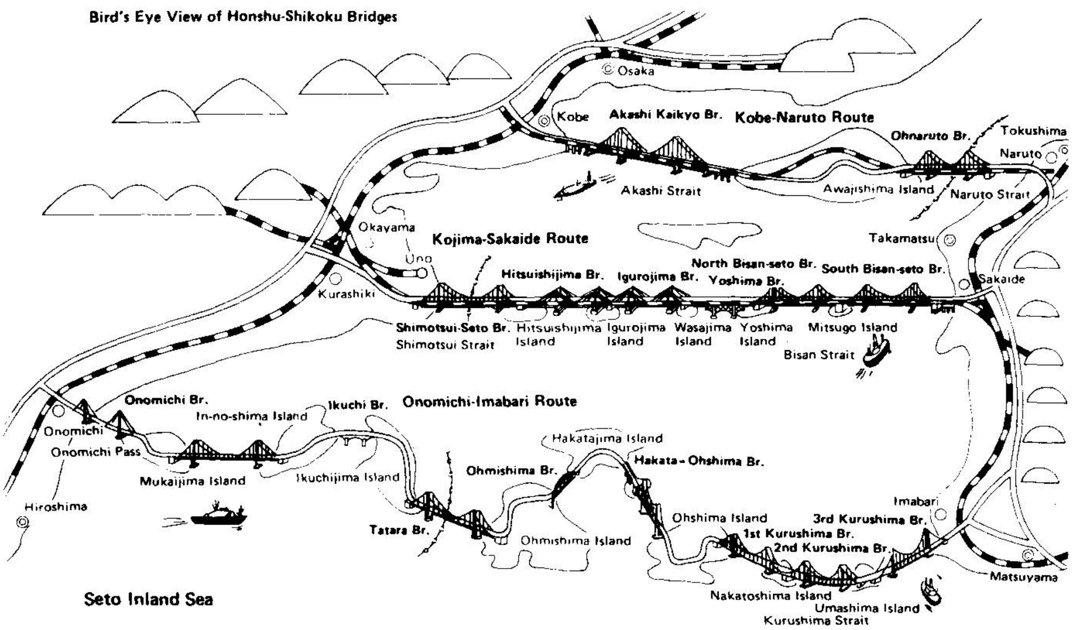

Fig. 1 Overall View

Item	Category	Particulars	Kobe-Naruto Route	Kojima-Sakaide Route	Onomichi-Imabari Route
Length (km)	Highway		81.1	37.8	60.1
	Railway		89.8	49.2	-
Structural standards	Highway	Classification	Type 1, 2nd class	Type 1, 2nd class	Type 1, 3rd class
		Design speed (km/h)	100	100	80
		Number of lanes	6 (partially 4)	4	4
	Railway	Classification	Shinkansen	Ordinary line and Shinkansen	-
		Number of tracks	2	2+2	-
Construction cost (billion yen) (FY1977) 2,400			1,150	840	410

Table 1 Length, Structural Standards and Construction Cost

Name	Type	Span length (m)
Ohnaruto Bridge	Suspension	93 + 330 + 876 + 330
Shimotsui-seto Bridge	Suspension	230 + 940 + 230
Hitsuishijima Bridge	Cable-stayed	185 + 420 + 185
Igurojima Bridge	"	185 + 420 + 185
Yoshima Bridge	Truss	154 + 204 + 154
North Bisan-seto Bridge	Suspension	274 + 990 + 274
South Bisan-seto Bridge	"	274 + 1,100 + 274
In-no-shima Bridge	Suspension	250 + 770 + 250
Ohmishima Bridge (completed)	Arch	297
Hakata-Ohshima Bridge	Girder	90 + 145 + 90
	Suspension	140 + 560 + 140

Table 2 Bridges Completed and Under Construction

The construction works are performed in areas of the Seto Inland Sea National Park having sea, many islands and complicated shorelines and some of the most beautiful natural scenery in Japan. In addition, strong winds frequently blow in this area and the size of the bridges is very large, so the highest precautions shall be taken for the safety of the construction workers and the conservation of the natural environment. Various kinds of industries have been developed in the Seto Inland Sea area to make it an important industrial zone in the southern part of Japan. The Seto Inland Sea has served as a main waterway connecting Honshu, Shikoku and Kyushu islands and is congested with many ships. On the other hand, the bridges must be constructed under severe natural conditions of submarine topography, tidal currents and fog, so that various measures must be taken to secure navigational safety.

2. SAFETY FUNDAMENTALS DURING CONSTRUCTION

The prevention of accidents is the most important problem in the construction of the Honshu-Shikoku Bridges, and various kinds of safety measures have been taken as well as ordinary precautions.

General items related to the safety of construction work will be described in this section.

2.1 Organization for executing the work

The main portions of construction work such as the superstructure and substructure are preformed by construction companies in contract with the Authority in the form of joint ventures (JV) of two or three special companies, chosen from this country's top firms. All of the important items related to safety are described in the contract documents and are under the direct guidance and supervision of the Authority and the safety officials of the Ministry of Labor.

2.2 Laws

Construction work is carried out in accordance with laws, government ordinances and ministry rules. The most basic laws are the Labor Standards Law and the Labor Safety and Health Law but the work is also carried out under various laws for the safety of navigation, ports and harbours, prevention of ocean polution, natural parks, fire prevention, and so on.

2.3 Engineering standards

Design standards accepted widely in Japan for ordinary structures cannot be perfectly applied to the Honshu-Shikoku Bridge Project, so many engineering standards must be established by the Authority itself. These standards contain very sophisticated techniques as well as newly developed ones, which were thoroughly investigated and prepared by excellent researchers and engineers in this country. Principal examples are listed in Table 3.

General specifications for construction work
Guidelines for the safety of common construction works
Guidelines for the safety of marine construction works
Design standard for multi-cell type buffer
Design standard for composite type buffer

Table 3 Examples of Standards for Safety

2.4 Contracts

The specifications require the contractors to execute the work while maintaining the safety and to submit a plan for the actual work before its commencement. Important portions including the safety measurements shall be approved by the Authority. The contractors are obligated to execute the work in accordance with the specifications and the plans approved by the Authority, and the Authority is to supervise and inspect the work.

Principal safety items imposed on the contractors are as follows:

1) Submission of the plan for the execution of work and its approval by the Authority
2) Obedience to the Guideline for the Safety of Common Construction Works
3) Obedience to the Guideline for the Safety of Marine Construction Works
4) Determination of meteorological conditions and sea phenomena during which work is not to be performed
5) Assignment of traffic controllers on land
6) Assignment of safety supervisors
7) Participation and cooperation with the navigation control room
8) Arrangement of observation ships, which give informations, warnings, guidances and so on to the common ships if necessary.

2.5 Safety control system

2.5.1 Organization for field safety control

The contractor shall establish a safety control organization for each construction area. An example of this is shown in Fig. 2. The safety controllers and health controllers must be the full-time workers.

Safety organization for the district controlled by o o o Construction Office
(an example of relation between the Authority and JV)

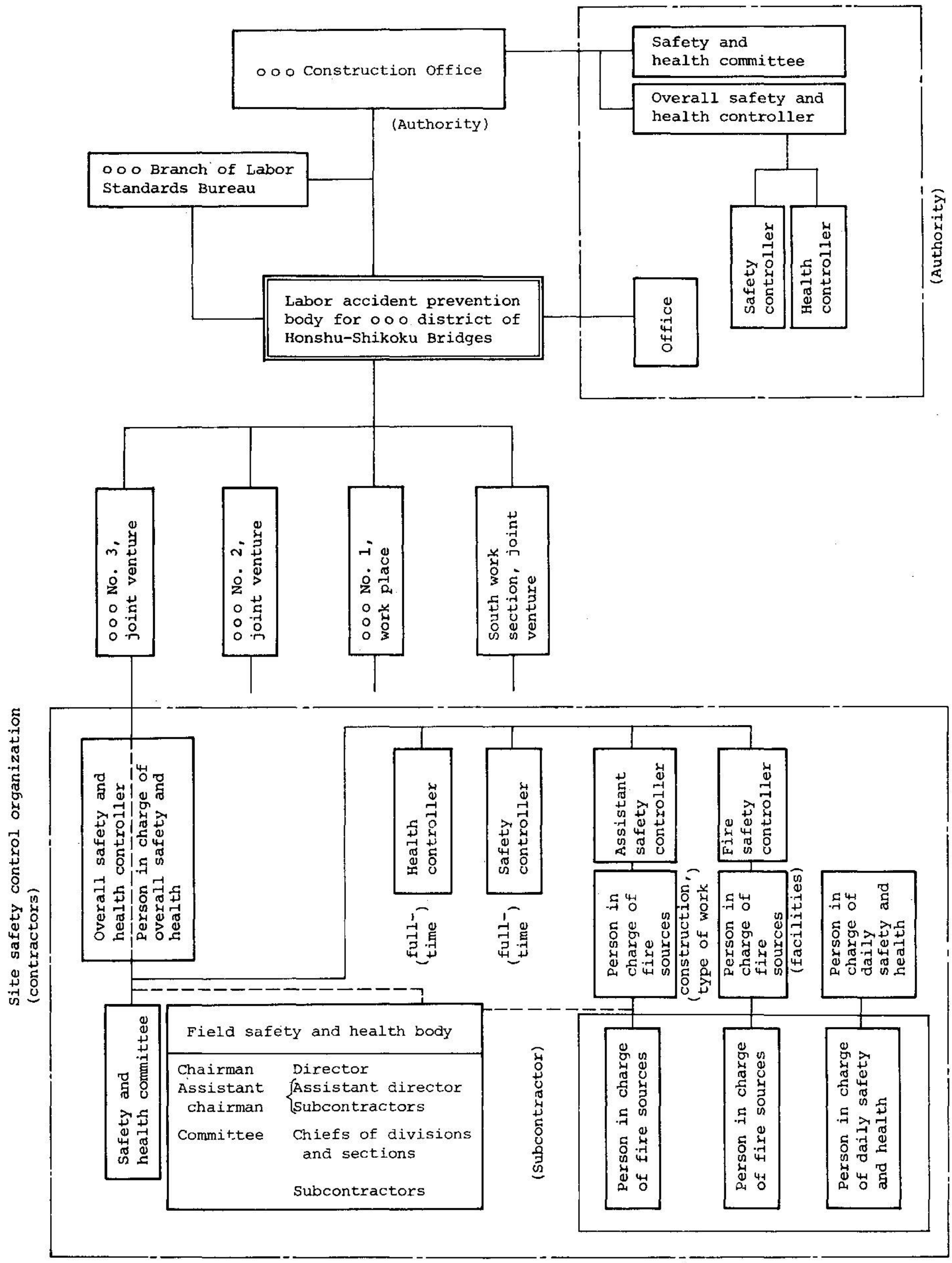

Fig. 2 An Example of safety control for the construction of the Honshu-Shikoku Bridges

2.5.2 District labor accident prevention body

This is a united body of the safety control organizations provided for each district where several works are being carried out. Ordinarily, this body is provided for each construction office of the Authority, and its members consist of staff of the Authority, Labor Standards Bureau and contractors of the works under the Authority's office. This body provides coordination between several works since the work sites overlap and construction roads and facilities are being commonly used. Also the body gives convenience of guidance and coordination by the Authority and the Labor Standards Bureau.

2.5.3 Liaison committee for the promotion of construction safety for the Honshu-Shikoku bridges

This committee consists of the staff of the Ministry of Labor and the Authority, and meetings of regional staffs of both organizations are periodically held to promote safety on the Honshu-Shikoku Bridge Project, designated as a special large scale project by the Ministry of Labor.

2.5.4 Navigation control room

This control room is provided for each sea work zone, in order to collect and transmit information related to work, weather, marine conditions and traffic, and is expected to promote the safe sailing of common ships around the site and the smooth execution of construction work by centrally controlling of the sailing of construction vessels and observation ships.

2.5.5 Committee for review of construction safety

This committee consists of staff of the Authority and collects information related to work safety on the project. If any accident occurs, the committee investigates the situation, determines the cause of the accident and reviews the necessary measures to be taken. Every month the committee receives safety inspection and accident reports from each site. The situation of occurrence of the accidents of the project is shown in Table 4.

As of end of June 1982

	Total number of hours of labor (man-hour)	Numbers of the dead and the injured (persons)				Number of labor days lost (days)	Frequency factor	Intensity factor
		Deaths	Absence of more than 8 days	Absence of less than 7 days	Total			
No. 1 Construction Bureau	9,174,046	2	25	3	30	16,812	3.27	1.83
No. 2 Construction Bureau	7,441,116	3	4	2	9	22,680	1.21	3.05
No. 3 Construction Bureau	5,739,505	1	22	5	28	9,629	4.88	1.68
The Authority as a whole	22,354,667	6	51	10	67	49,121	3.00	2.20

References		Frequency factor	Intensity factor
	National average in 1981 for road construction	3.84	1.38
	National average in 1981 for bridge construction	3.24	0.65

Frequency factor: Number of deaths and the injured due to labor accidents per 1 million labor hours $= \frac{\text{Number of deaths and injured}}{\text{Total labor hours}} \times 1{,}000{,}000$

Intensity factor: Number of labor days lost per 1,000 labor hours $= \frac{\text{Number of labor days lost}}{\text{Total labor hours}} \times 1{,}000$

Note: Values shown in the above table are the totals for the works (including works under construction) executed by the Authority.

Table 4 Labor accidents on the Honshu-Shikoku Bridge Project

3. NAVIGATIONAL SAFETY

The straits around the construction are important navigational areas for east-west and south-north bound sea traffic in the Seto Inland Sea and have been good fishing grounds since long ago. For these reasons, the bridges will greatly affect safety of the navigation not only during their construction but also after completion and thus, it is extremely important to carry out the bridge project while securing the safety of sailing ships and fishing boats in the area.

3.1 Survey and study by the Authority

In order to establish actual safety measures for navigation, the Authority has been studying the following items in collaboration with researchers and the administrative bodies concerned: ⓐ actual situation of the sailing of ships and required span lengths and clearance of the bridges based on future forecasts, ⓑ navigational aids such as center lights in the waterway, lighting for bridge piers, fog signals and so forth, ⓒ Collision prevention facilities, and ⓓ arrangement of safety facilities during work, arrangement of observation ships, and thorough information exchange.

False images occasionally appear on ships radar due to large bridges and these create a navigational safety problem for ships. Thus, the Authority is now carrying out studies on the following items: ⓐ development of a forecast method for the appearance of false radar images, ⓑ forecast of appearance of false radar images for each bridge, ⓒ degree of interference to navigation, and ⓓ development of radio wave-absorbing materials.

3.2 Navigational safety measures

In order to fully secure safety of the navigation for ships around the site during construction, a navigational control room has been established to centrally control information and maintain close coordination with authorities arrange safety system. They function as listed below in response to the traffic environment and natural conditions in the sea areas where construction work is being carried out: ⓐ established the working sea surface and indicating it by buoy lights, ⓑ arrangement of patrol ships, ⓒ assignment of members for safety patrol, ⓓ arrangement of communication network, and ⓔ transmission of construction information.

As for the safety measures for navigation after completion, the influence of the bridges upon ship traffic was studied, and facilities required for the safe navigation of ships were examined for each bridge in response to traffic, environment and natural conditions in the sea areas. By checking the increases in future traffic, the Authority will take positive and effective navigational safety measures.

4. SUBSTRUCTURES

In substructure construction works for the Honshu-Shikoku Bridges, safety measures have been considered from the planning stage. As typical examples, some actual measures concerning multi-column foundations and the laying-down caisson foundations were newly developed in the Honshu-Shikoku Bridge Project. These will be described.

A multi-column foundation consists of several columns embedded into the sea bed and a rigid footing at the top connecting them, as shown in Fig. 3. Natural conditions at the pier sites of Ohnaruto Bridge, where this foundation is used, are very severe because of the maximum depth of 6.2 m, the maximum tidal velocity of 8 knott, and direct strong storms from the Pacific Ocean.

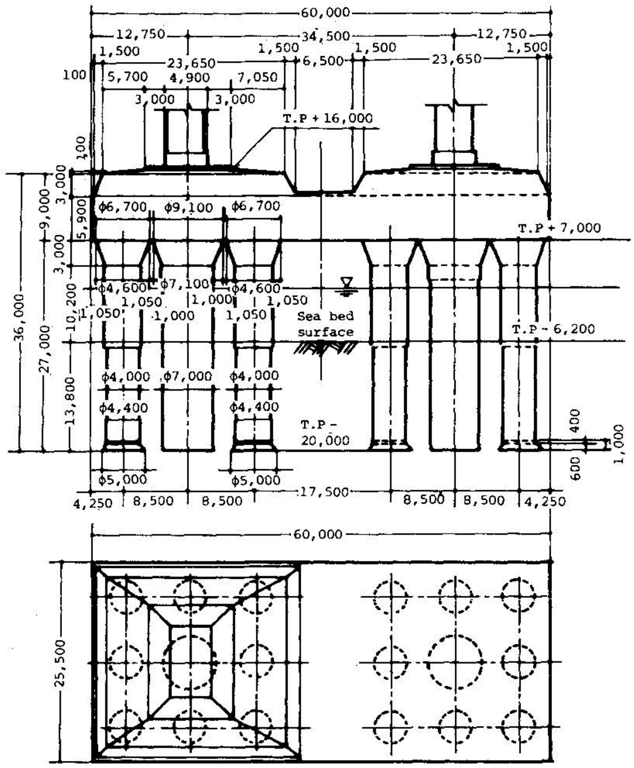

Fig. 3 Multi-column foundation

The sea bottom with alternate layers of sandy rock and shale is so complicated topography that ships have difficulty passing through there. On the other hand, the surrounding areas are famous places in the Seto Inland Sea where National Parks and fishery prospers. Therefore, environmental pollution is never permitted.

Under such conditions, there is a pneumatic caisson, one of the types of alternative foundation, except a multi-column foundation. Finally a multi-column foundation was selected, because the pneumatic caisson needs an island vulunerable to storm and manual excavation in compressed air under the sea level. Multi-column foundation work consists of constructing a platform around the foundation and of columns and footings. This platform is composed of steel pipes and settled by a crane vessel, step by step in a big block, for the reasons in order to decrease the works on the sea, in order to avoid the ocean wave and in order to evade a disaster under construction by reduction of operations at site. The platform founded on the sea bed rock directly is planned to withstand violent climate.

A multi-column foundation has the advantage of machine excavation being possible from the sea platform. But, sea pollution due to leakage of drilling mud water must be prevented. In order to perfectly prevent leakage, a water sealing frame was arranged and sealing concrete was cast at the bottom of a casing tube. After drilling muddy water using is purified by a plant on land and was then discharged in the sea.

Because of such perfect preparation, the construction of multi-columns foundations has successfully finished notwithstanding severity of site conditions. It is remarkable that the foundations have been completed without accident in spite of the construction work using various heavy machineries on the platforms.

An outline of a laying-down caisson method is illustrated in Fig. 4. Firstly, the sea bed is excavated and trimmed upto the bearing layer so that a steel caisson fabricated at a shipyard may be placed at the accurate position. After setting a caisson, precast concrete is cast inside. Finally it becomes a rigid foundation.

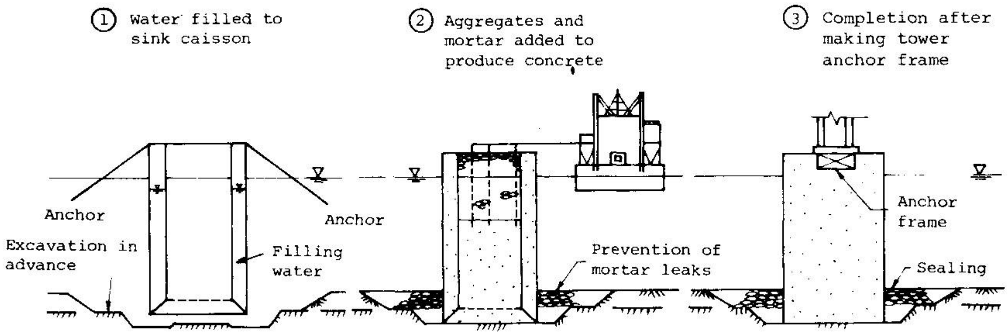

Fig. 4 Method of laying-down caisson

The South and North Bisan-Seto Bridges to which this foundation method is applied, consist of two suspension bridges of 3 spans continuous stiffening girders with a total length of 3,335 m. Six foundations, which are 2 anchorages and 4 piers, of 7 in total are to be constructed in the sea. At these sites, the maximum depth is about 50 m and the maximum tidal velocity is 5 knotts. The sea bed is granite, but the rock is so weathered that it needs the excavation of much rock to reach the bearing layer. More than 1,000 ships pass through the strait every day and fishery is prospering there. For these reasons, several restrictions are imposing on the Authority's demand to occupy some sea area as the construction area.

Under the conditions mentioned above, several types of foundation including pneumatic foundations are possible. However, among them, a laying-down caisson method was selected, because it decreased risky submerged works in such deep places, complicated works on the sea and influence on the navigation and the fishery by reduction of construction period at the site.

Under-water blasting was adopted for rock excavation. Almost all works for the excavation was performed on a self-elevating platform except insertion of explosives and supervising. After blasting, crashed rock is dredged by grabs on vessels. Surface of the rock under the edges of the caisson are trimmed by drilling machines on a self-elevating platform.

For blasting work, some severe guidelines have been established, and the time and the zone of blasting has been thoroughly informed to the public. Also special underwater blasting methods and explosives were newly developed in order to satisfy various situations of the construction work, as shown in table 5. These explosives were water-proof and effectiveness for a long time so that they can endure tidal currents, water pressure and impact. A new method was developed to enable to simulate blasting effects, propagation of vibration, sound, pressure and so on with an electronic computer. Using this method, the construction work was carried out without undesirable influence to fish and shellfish.

Blasting method	Initiating method	Applicable foundation	Characteristics
Detonating fuse initiation	Detonating fuse	3P 4A	a. Where the explosive can be loaded by divers, large-scale blasting can be made relatively easily, safely and surely. b. Good for shallow water and low speed tidal currents.
Supersonic wireless initiation	Wireless (supersonic type)	5P	a. Not affected by tidal currents. b. Detonating elements are to be held on the sea bottom where the sedimentary layer is thick. c. Can be used in the sea far from land.
Electro-magnetic induction initiation	Wireless (electro-magnetic induction)	6P	a. Not affected by thickness of sedimentary layer. b. Loop antenna is to be retained where tidal current is high. c. Installation accuracy of loop antenna and electromotive force are to be fully controlled.
Wired, phased initiation	Wired	7A P: Pier A: Anchorage	a. Phased blasting by timer of blaster is possible. b. Retaining of circuit is difficult where tidal current is high. c. On-land or SEP is required.

Table 5 Underwater blasting method

So far there has been no accident during rock excavation whose maximum volume at one foundation is 600,000 m^3. On the other hand, supporting facilities have been used in cooperation with the Authority and Japan Marine Science and Technology Center in order to improve safety of the divers and health management.

The steel caissons have been set very exactly by operations of a special control system and a large-capacity crane vessel. After setting a caisson, to fulfil precast concrete inside, a special mortar plant vessel is used. Owning to the utilization of this vessel, a big reduction of construction period and minimization of the sailing of the working ships crossing the waterway have become possible.

The Authority has made many safety measures not only for foundation works but also for navigation and fishing boats.

5. SUPERSTRUCTURE WORK

An outline of work with an emphasis upon the safety measures actually taken will be described here for the main towers, the cables, and the stiffening girder of Ohnaruto Bridge. A schematic drawing of Ohnaruto Bridge is shown in Fig. 5.

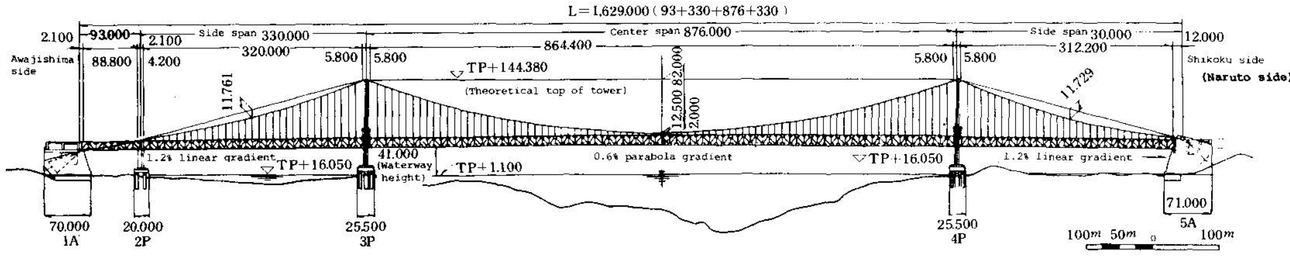

Fig. 5 General view of Ohnaruto Bridge

5.1 Main Tower Work

As shown in Fig. 6, the structure of the main tower is divided into 13 parts in its height, and each part is separated vertically into three blocks excepting the top portion of tower and the fifth part for installing horizontal member. Each tower is divided into 84 blocks including blocks for diagonal and horizontal members.

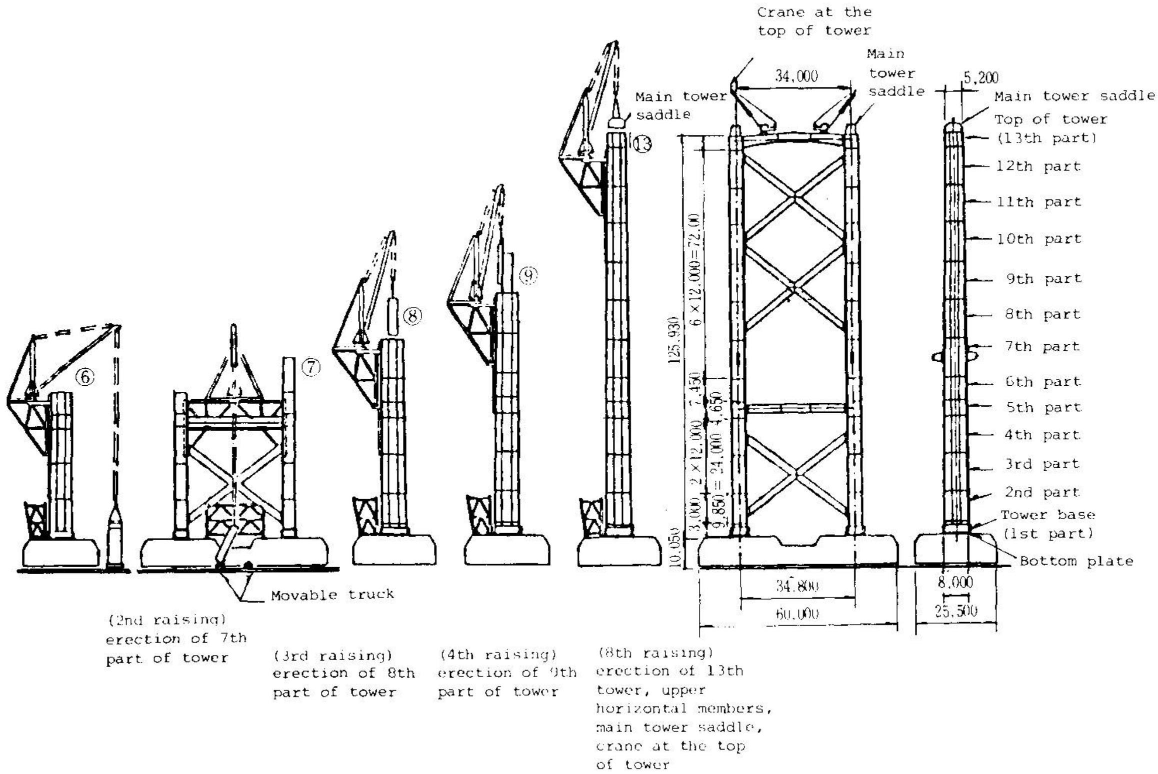

Fig. 6 Steps of erection of main tower

During the erection procedure, blocks which were transported by a pontoon from the fabricating factory in accordance with the work schedule are unloaded by a tripod derrick crane, moved laterally by a truck and then lifted and erected by a creeper crane.

The first to fourth parts of the tower are erected by the creeper crane standing itself, but the parts after the fifth part are erected by the creeper crane which is sequentially installed to the tower already erected.

Blocks are connected with bolts and scaffolds are installed in advance to the joints of the previously erected blocks. These scaffolds are used for work such as the driving of drift pins, tightening of final bolts and painting. Since assembly of these tower scaffolds is the most dangerous work on the tower, special safety measures are being taken as shown in Fig. 7. That is, for reducing the work at high places to a minimum, all portions other than handrails shown by the dotted line in the figure are assembled on the ground and installed in advance to the blocks. Upon completion of erection of all 3 blocks of A, B and C, scaffold boards are assembled for the remaining portion and handrails are installed to provide the scaffold more safety. Other safety measures taken include the spreading of the scaffold boards around the tower shafts, elimination of gaps between the scaffold boards and the structure, installation of protection nets to all portions of the floor and handrails in order to prevent small tools and materials from dropping, and attaching ropes to the tools in order to avoid accidents caused by their droppage.

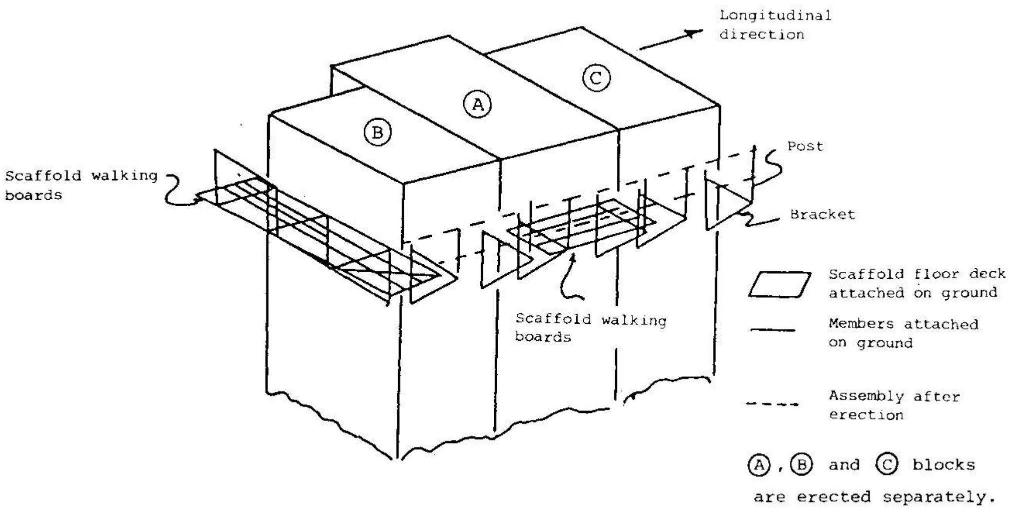

Fig. 7 View of on-ground assembly

Also, since the creeper crane is the most important machine for erecting the tower, it is carefully inspected and maintained. Thus, daily and monthly inspection tables for its mechanical and electrical systems are provided in detail.

5.2 Cable work

The size of the main cable of Ohnaruto Bridge is 840 mm in diameter and 1,722 m in length, and the cable consists of about 20,000 galvanized steel wires, of 5.37 mm diameter. One main cable consists of 154 strands, and each strand comprises 127 wires bound in parallel at the factory and has a regular hexagonal section.

The strands are pulled out one by one along the scaffold in the air called the "catwalk" from the anchorage at the Naruto side to the anchorage at the Awajishima side and they are anchored to the cable anchor frames.

The kinds of work requiring special safety measures include the stretching of the pilot rope and the erection of the catwalk.

The spinning of pilot ropes was to be performed in the sea area where there are many reefs and tidal current is very fast. In order to provide safety to the work at such place, a free hang method was adopted, which aerially stretches a rope from the tower by a boat without floats. However, since the spanning of the pilot ropes would fully block the strait, many efforts were made to ensure safety of third parties such as fishing boats and marine workers. The spanning work had been publicly announced and observation ships were on duty on the day of the spanning. Public announcements were made through television, radio, newspapers as well as by the distribution of posters to those concerned. Posters written in English were also mailed to various organizations in the world about two months prior to the date of spanning work.

Because the catwalk must be useful for a long period of time not only for the erection of strands but also for adjustment strand sag at night, squeeze work, erection of cable bands, and erection of hanger ropes, it must be strong and provide high safety. The structure has lateral beams, welded wire mesh, drop prevention nets,walking steps and handrails all which are installed to the top of the catwalk ropes. (Fig. 8)

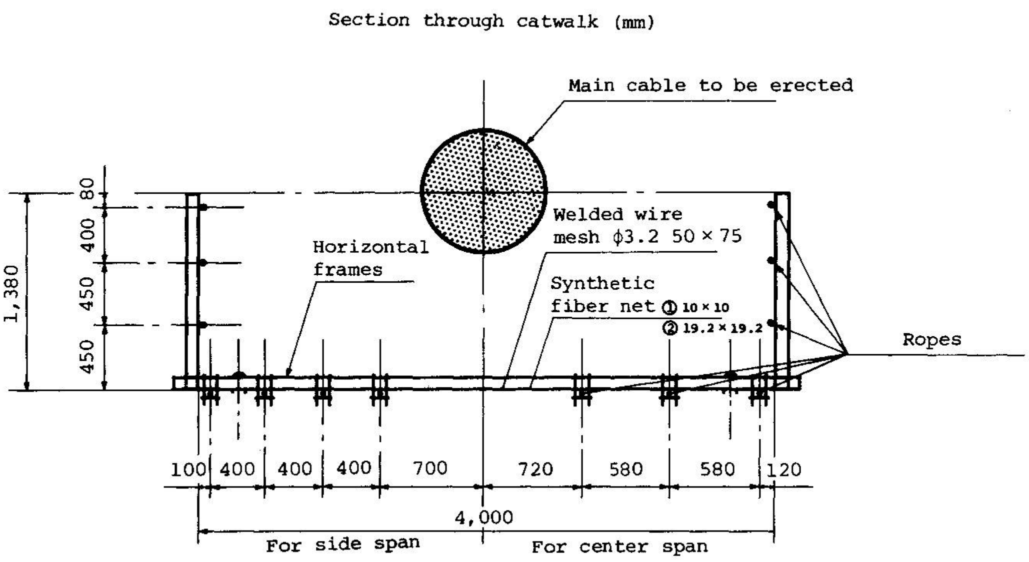

Fig. 8 Structure of catwalk

In erecting the floor assembly of welded wire mesh and nets, it was necessary to reduce work on the sea surface and high places to a minimum, so the wire mesh was rolled into a coil in advance, which enabled us to do the work easier.

Works conventionally performed in a narrow space at the top of the tower was transferred to the ground in order to simplify the work, and works carried out at the top of the tower was only to install the lateral beams and the handrails according to uncoiling of the wire mesh.

5.3 Stiffening girders

The erection method was the so-called "plane block erection" which handled pre-assembled members as one plane block weighing upto 90 tonnes and was adopted for the stiffening girder erection, because it had several advantages regarding the severe natural conditions and sailing ships.

In the erection of the girders, they will be sequentially extended from the main towers 3P and 4P in both directions of center and side spans. To provide high wind-resisting stability, connections between the members will be made fully rigid by immediately splicing after their erection. The erection procedure will be described below. Blocks transported by pontoon site are unloaded by tripod derricks on the platforms. Temporary storage, arrangement and pick-up of these blocks is performed by the derrick and the towered jib crane. Lifting to the height of the erected girders is conducted by the towered jib crane. The blocks are carried by truck to the extremities of the girders as shown in Fig. 9, and are then sequentially attached at both sides using the travelling derrick.

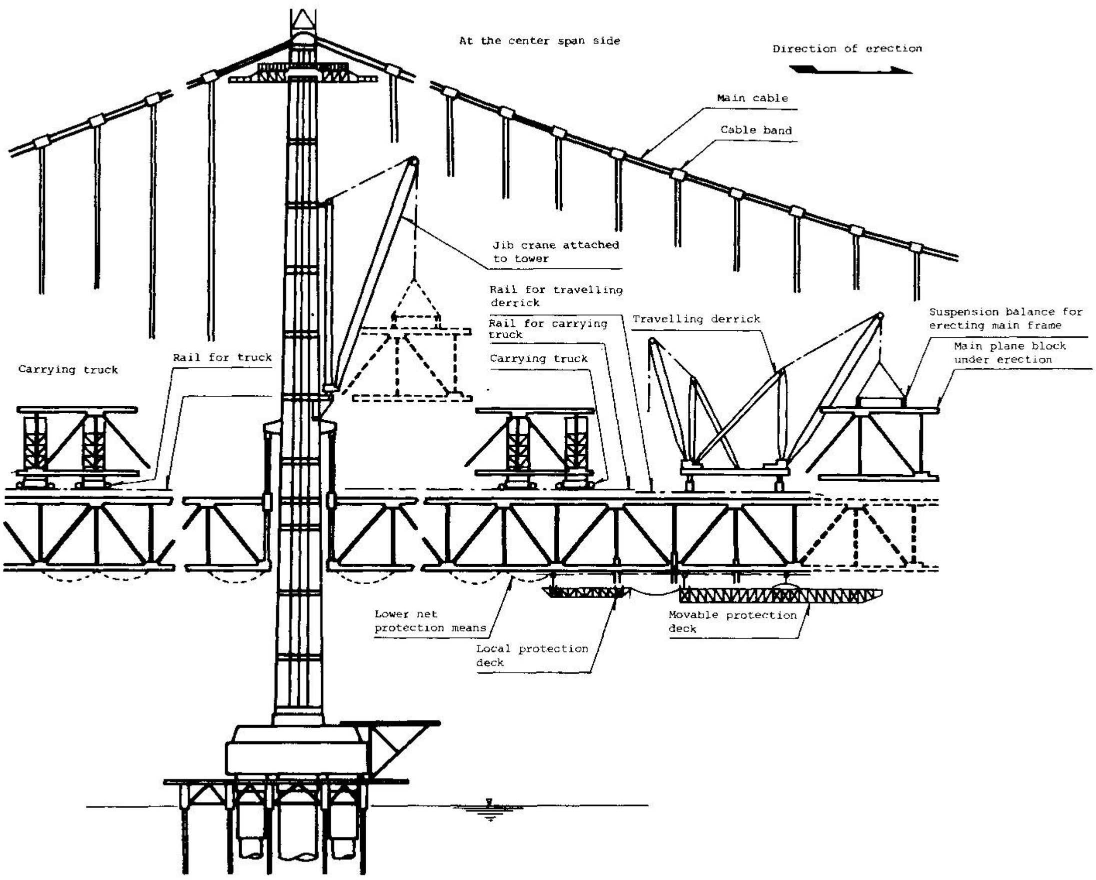

Fig. 9 Stiffering truss

During splicing of the members and the installation of hanger ropes to the erected block, a movable protection deck will be placed just below the erection block. Local protection decks and lower protection nets are also installed at other places in order to assure safety for the workers and to prevent any small tools or bolts from falling. Great precautions will be necessary to prevent any items from falling, because about 600 ships and many fishing boats pass through the strait daily and sight-seeing boats travel frequently around the site to see the famous tidal whirlpool of the Naruto Straits.

At the splice points of the erection block, temporary scaffolds with small steel pipes, wooden plates and chains are provided for fastening the bolts (about 800,000 bolts for the whole stiffening girders). Though the movable protection deck is provided below, installation of the temporary scaffolds itself is dangerous work. Since the girder is 12.5 m high, the work of the joints of the upper chord at such high places shall be reduced to a minimum in the same manner as described for the main tower work.

The main safety measures taken for erection of the superstructure of the suspension bridge have been described above. Though the superstructure work for a long suspension bridge has some peculiarities as large scale, special construction machinery and compound working methods, a unit operation must be handled by each man as the same manner as other ordinary construction works. It is vitally important to plan the appropriate safety measures, based on the risk analysis of accident by considering the character and ability of the workers.