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Innovative Application of Combined Steel and Concrete Constructions

Procédés nouveaux de mise en œuvre de ponts mixtes

Neuere Methoden in der Ausführung von Verbundbrücken

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SUMMARY
To develop an innovative idea or method in erection of bridges, the application of steel and concrete hybrid constructions will have great possibilities in practice. Recently, Japan has experienced various innovative applications of hybrid constructions to the bridge erection. Among them, three examples are introduced and their features are discussed for further development of the similar technology.

RESUME
Les ponts mixtes acier-béton permettent, suscitent même de nombreuses méthodes de mise en œuvre. Récemment, de nouvelles méthodes ont été utilisées au Japon. Au travers de trois exemples, on décrit ces méthodes et on discute d'éventuels développements.

ZUSAMMENFASSUNG
Das Bestreben neue Ideen für Entwurf und Ausführung von Brücken zu entwickeln, erhöht die Bedeutung der Anwendung von Hybridkonstruktionen aus Stahl und Beton. Kürzlich wurden in Japan diverse neue Verfahren für Verbundkonstruktionen im Brückenbau erprobt. Drei ausgewählte Beispiele werden vorgestellt und ihre Impulse für die weitere Entwicklung vergleichbarer Technologien diskutiert.

1. STEEL-CONCRETE HYBRID LARGE CAISSON

The Honshu-Shikoku Bridge Authority has started the construction of a series of double-decked highway and railway long-span bridges consisting of three suspension bridges, two cable-stayed truss bridges and one truss bridge, on Kojima-Sakaide Route over the Inland Sea. The total length of the bridges over the sea is 13.6 km.
The most difficult problem in the construction of the two consecutive suspension bridges, the center spans of which are 990 m and 1100 m, was to build as many as seven substructures. Except the anchorage of cables on the northern side, which was a direct foundation on land, all the other foundations were underwater. In particular, the cable anchorage on the southern side required huge excavation at a water depth of up to 50 m. Also, the Bisan Straits over which the two suspension bridges cross, is an important navigation channel in the Inland Sea, and the number of vessels passing through the Straits is about 1000 per day.

1.1 Laying-down caisson method

To secure the safety of the vessels navigating the Straits and to overcome difficulties due to geological conditions, waves and swift current, large-scale excavation of the sea bottom and a large amount of underwater concreting, both in a short time, were required. A laying down caisson method was developed to fulfill such a heavy task. The main technology is a construction system of excavation of the sea bottom, setting of a large steel caisson and underwater concrete work. The works were simple and could shorten the site construction period.

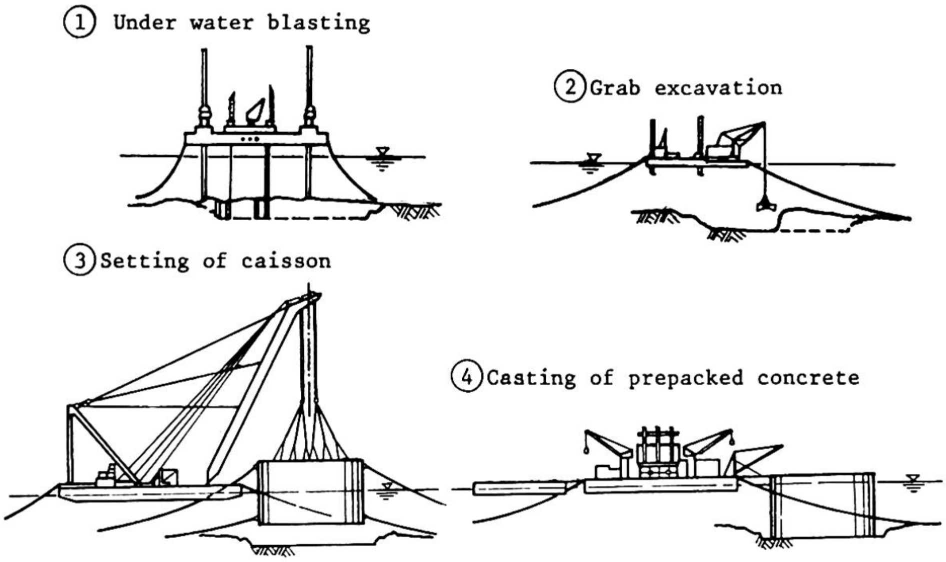

Fig.1 Laying-down caisson method

The laying-down caisson method is illustrated in Fig.1. Making use of a two-hull type of self-elevated working platform in 70 m x 8.0 m x 5.5 m, underwater boring and undersea blasting of the sea bed by underwater explosives were carried out. Then, the undersea excavation was done by a grab dredger.

1.2 Steel caisson work

During the excavation, a large-scale steel caisson was fabricated at a shipbuilding yard on land, because such a large steel caisson had to serve as a

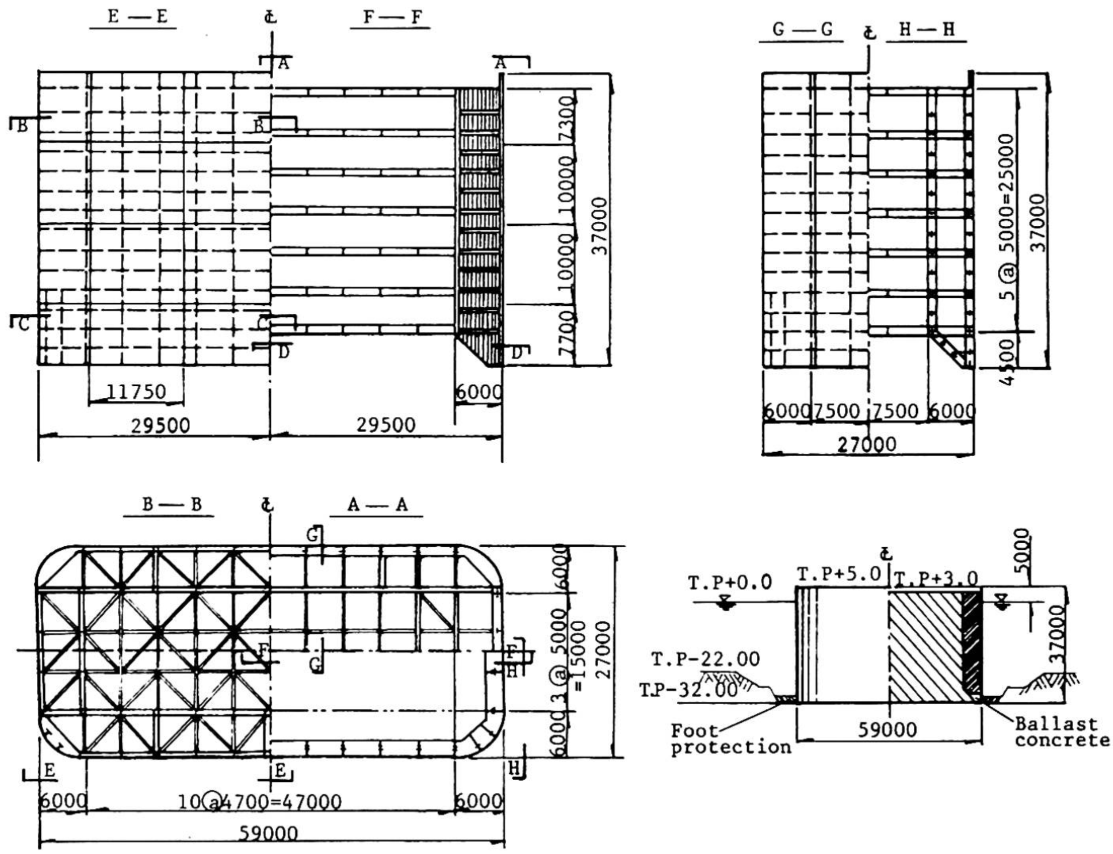

Fig.2 Steel caisson

cofferdam and a form for the underwater concreting. Fig.2 shows one example of such a steel caisson which was used for the foundation of a tower pier. The main part of the steel caisson consists of double walls with the interval of six meters, which were divided into ten cells by inside bulkheads. The thickness of the wall plates was 12 mm of SM50 steel.

It was towed to the site during calm weather. Then, after equipped for mooring and setting, it was moored by anchor cables. Finally, it was set on the sea bed by pouring water in several partitions individually and by winch operation.

The allowance of the setting of the steel caisson was within $\pm$ 50 cm in a position.

1.3 Underwater concrete work

Among the foundations on this Route, there were 33 foundations which were fully underwater. Four of them were to be constructed at a water depth of 30 to 50 m. The amount of concrete necessary for those foundations was 20,000 m^3 to 250,000 m^3 per foundation, and about 700,000 m^3 were required for all of the foundations. For such mass concreting at such a water depth, the prepacked concrete method was used because of its reliability and efficiency. For example, the pier foundation with the steel caisson shown in Fig.2 required 55,000 m^3 for the underwater concrete in the depth of 34 m.

For such mass concrete casting, a mortar mixing plant vessel of 90 m x 32 m x 4 m was developed with the capacity of 6000 l/min. With the help of the mortar plant ship, the casting of pre-packed concrete into the steel form was successfully carried out to make such a large-scale steel-concrete hybrid structure. This is really a good example of the combination of ship-building technology and steel-concrete construction technology.

2. STEEL-FRAME REINFORCED CONCRETE HIGH PIERS

2.1 Steel-frame reinforced concrete structure

A steel-frame reinforced concrete structure, called SRC structure, is defined as a structure in which steel frames are encased in steel-bar-reinforced concrete so that they may act compositely with the concrete. The encased steel frames may be either H-shaped steel beams, welded steel girders or trusses composed of shape steel bars. The steel frames are expected to act like reinforcing bars in ordinary reinforced concrete constructions, provided that a certain portion of lateral force or shearing force might be resisted by the encased steel frames as well as the steel-bar-reinforced concrete.
In the field of building engineering, SRC structures have been remarkably developed since the Tokyo Earthquake in 1923, for the purpose of improving the resistance of the buildings to earthquakes. It is since about 1960 that the SRC construction began to be applied to civil engineering structures other than buildings, mainly to piers of bridges. Now, various structures of the SRC construction in addition to bridge piers have come into wide use in the civil engineering field in Japan.
Two methods, the superimposed strength method and the conventional reinforced concrete method are now adopted in various codes for SRC highway and railway constructions in Japan. In the former, members are proportioned by adding the strength of the steel-frame part to the one of the reinforced concrete part. In the latter, the members are proportioned by regarding the steel-frame part as the same as the reinforcing bars in the conventional RC members.

2.2 Application of SRC construction to high piers

The most extensive application of SRC constructions in highway structures is to bridge piers. High piers of bridges crossing a deep valley or of access bridges to long suspension bridges, and piers of viaducts in urban expressways, are often designed with the SRC constructions.
Two examples of the high piers are given by 67 m and 37 m high piers in Fig.3. When a pier was constructed with the height of 67 m to support a continuous steel box girder birdge of a national highway, a truss-type steel frame consisting of H-shape rolled steels was assembled, and reinforcing bars were placed

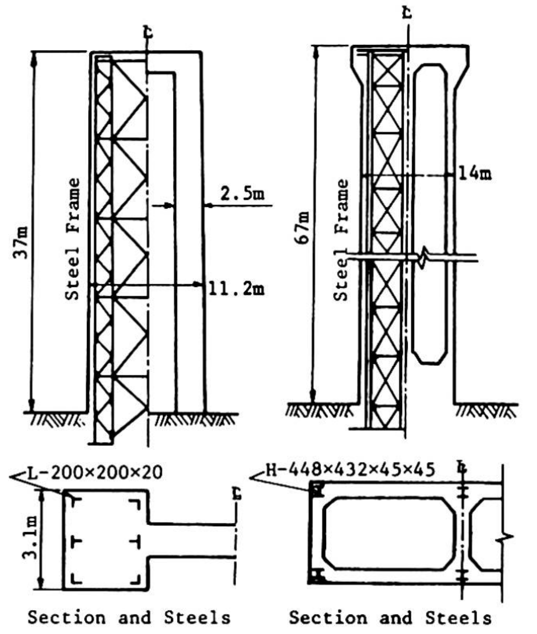

Fig.3 SRC high piers

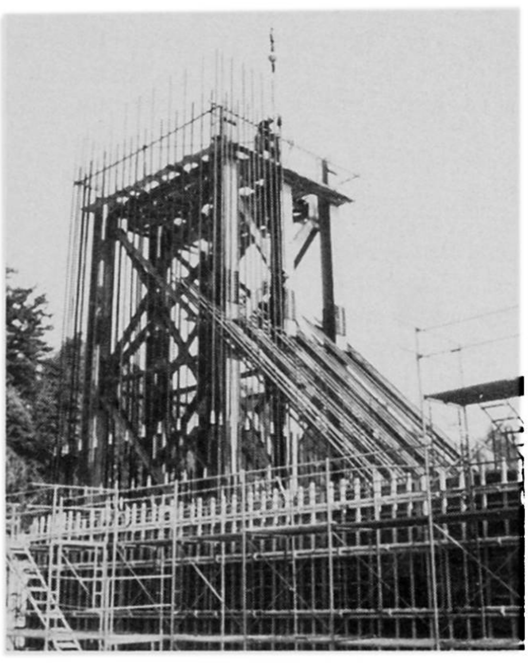

Fig.4 Assembly and setting of steel frame and steel bars

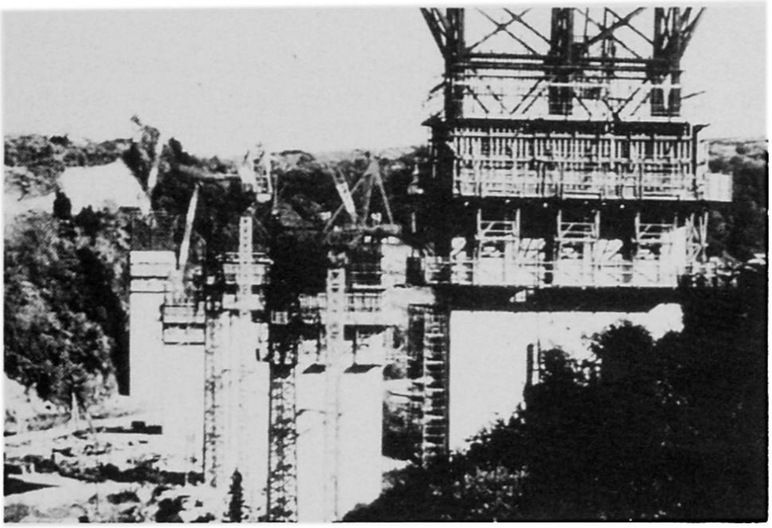

Fig.5 Construction of SRC piers

around the steel frame. Then, they were encased in concrete by a self-climbing form system. Fig.4 shows the assembly of the steel members and bars at the site. Fig.5 is a picture of the construction of the SRC high piers.
The reasons for selecting the SRC construction method were
1) to reduce the number of reinforcing bars by replacing them with a steel frame,
2) to improve the accuracy of construction works by using the steel frame for positioning the reinforcing bars, and
3) to increase the ductility of a concrete pier against earthquake.
For the same reasons, the piers of access birdges to a suspension bridge are often designed as the SRC construction illustrated by 30.5 m high pier in Fig.6. In this design, stud shear connectors were used at the anchor part of the steel frame, so as to transmit axial forces of the steel frame to the concrete footing.

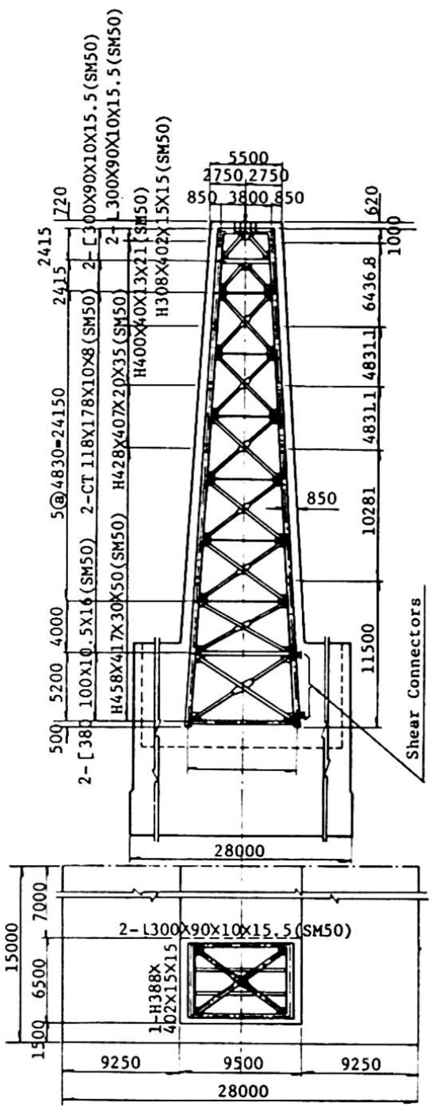

Fig.6 Detail of SRC pier

2.3 Other application to piers

In the piers for viaducts of urban expressways, which are generally designed as rigid frames spanning either other roadways or rivers, the location, shape and size of the columns are often restricted. Under such conditions, steel-frame piers are generally used for the convenience of the erection. The SRC constructions, however, are also used from their economical and anti-corrosive reasons.

3. CONCRETE ARCH BRIDGES WITH STEEL-FRAME ARCH RIB

Recently in Japan, long-span reinforced concrete arch bridges with steel frames in the middle portion of the arch rib, which were later encased in conrete, were built. Fig.7 illustrates the erection of one of such bridges which is a reinforced concrete fixed arch bridge with the span of 204.0 m. The erection was carried out by so-called "Melan-Pylon Method" without any false work for concreting over a valley of 80 m depth.
The concrete arch ribs over each 50 m lengh from the springing on the both sides

were constructed with wagons by a cantilever method, while supported by inclined steel bar hangers anchored to the end posts.
Then, the middle portion of the arch rib of 100 m length was provided with steel members called "Melan Frame". The half section of the steel-frame consisting of four plate girders of I-section is shown in Fig.8. The steel frames on the both sides were hung up by inclined steel bars which were supported by pylon columns set on the end posts. The erection of the steel frames proceeded toward the crown until the arch rib was closed. Finally, the lining of concrete was carried out around the steel frames to complete a three-cell box section.

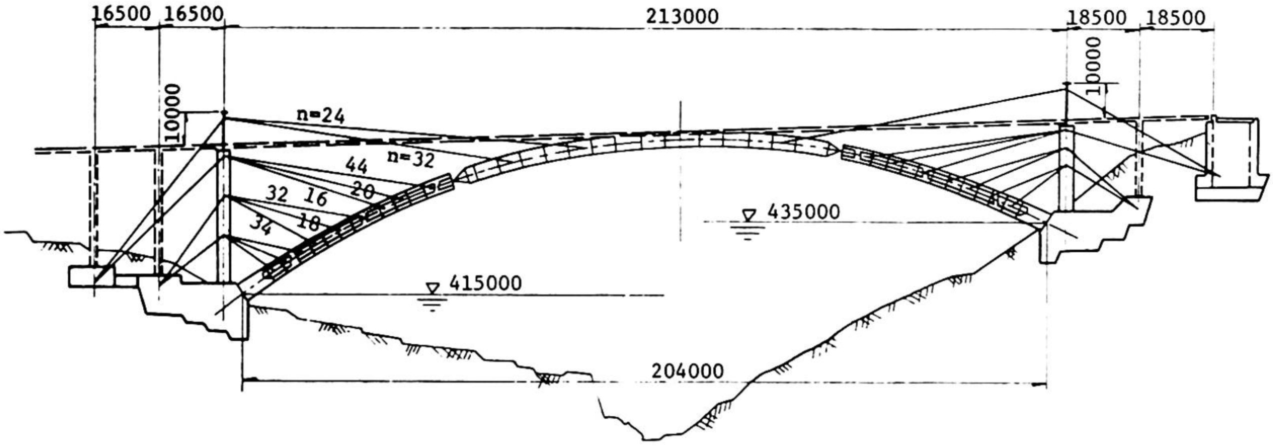

Fig.7 Erection of concrete arch bridge with the help of steel frames

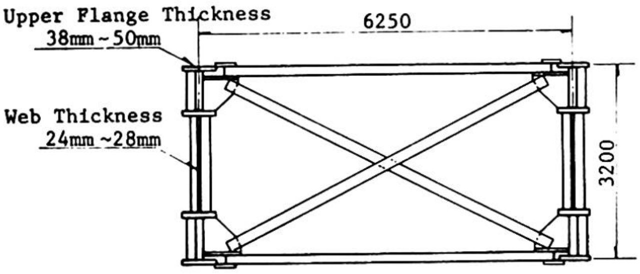

Fig.8 Section of steel frame

4. CONCLUSION

All of the constructions outlined above are quite unique, but have been guaranteed by various practical experiments as well as long-term experiences. Innovative constructions or structures should not be fantastic just from ideas, but the safety and serviceability should be fully assured by well-experienced practical technology, taking into account an increase in traffic and possible maintenance works in future.
Fortunatelly, we structural engineers have experienced steel constructions as well as concrete constructions for a long time. From such experiences, steel-concrete hybrid constructions including composite constructions and mixed structural systems, will be able to produce new innovative structures or erection methods furthermore in future.