Application of High Strength Steels to a Long Span Truss Bridge — Osaka Port Bridge

Application des aciers à résistance à un pont à poutres en treillis de longue portée — Pont du port d'Osaka

Anwendung hochfester Stähle für eine weitgespannte Fachwerkbrücke — Osaka Hafenbrücke

ICHIRO KONISHI
Professor Emeritus
Kyoto University
Kyoto, Japan

TOSHIE OKUMURA
Professor
Saitama University
Tokyo, Japan

SHUNJI MINAMI
Adviser
Nissho-Iwai Co., Ltd.
Osaka, Japan

MATSUJI SASADO
Manager
Hanshin Expressway Public Corp.
Osaka, Japan

1. INTRODUCTION

The Osaka Port Bridge is a cantilever truss bridge having a total length of 980m (=235m+510m+235m), including a suspended span of 186m. This bridge has double decks with four lanes each.

The type of the bridge was determined considering location of piers, navigation channel and soil condition.

High-strength steels of 70kg/mm^2 and 80kg/mm^2 classes up to 75mm in thickness which had high weldability were newly produced for the construction of this bridge. Out of the total bridge weight of 40,000 tons, the following amount of the high-strength steels was used.

80kg/mm^2 class high-strength steel (HT80): 4,197tons
70kg/mm^2 class high-strength steel (HT70): 1,075tons

In the application of high-strength steels to a long-span truss bridge, due considerations should be given to design, materials, fabrication and erection.

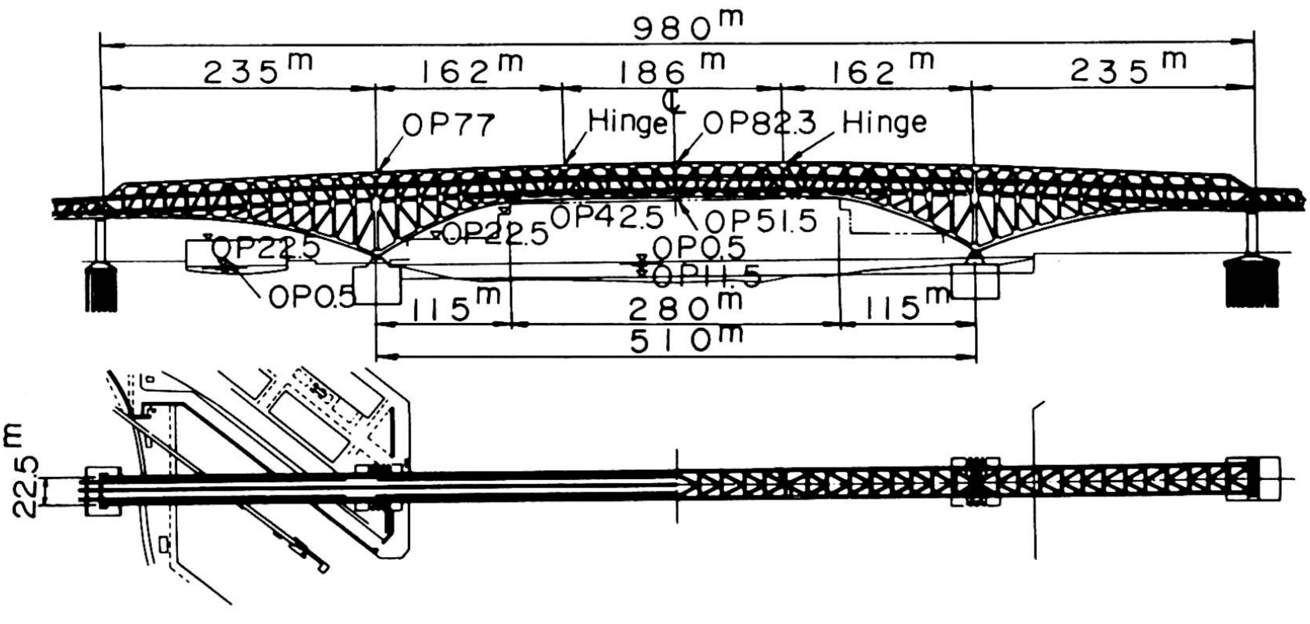

Fig.1 Osaka Port Bridge

2. DESIGN

The conventional truss bridge designs are based on an assumption that the both ends of a truss member are pin-jointed, thus causing axial force alone as section force. In recent years, however, there have been changes in the joint details of the actual truss, from the pin joint to the rivet joint and further to the high-strength bolt joint, which results in the prevention of free rotation of the members at the joints due to the increased rigidity of the connection.

In case of the Osaka Port Bridge, analysis shows that secondary stresses due to the additional bending mements and shear forces caused by connecting members rigidly at panel points are beyond negligible values.

One of the effective ways to minimize the secondary stresses is the use of members with lower flexural rigidity. But, there is a limit to this when a member is subject to higher stresses. In América, "Prebend" method is usually employed to reduce secondary stresses due to the dead load in a long span truss. In this method, however, difficulty lies in the implementation of procedure control and in the method of checking the residual stresses.

It was concluded in the design of this bridge that the secondary stresses due to the bending moments and shear forces caused at the panel points were to be analyzed and evaluated as one of the design stresses, and that thick plates with higher strength were to be used as the material for the chord members for the purpose of obtaining higher member strength without increasing the flexural rigidity of the member sections.

Box sections were employed as the chord members of this bridge. (Fig.2) The depth of each web was limited to one-tenths of the panel length, and the ratio of the sectional area of each flange to that of the entire cross section was made as low as practicable, which led to the use of 75mm thick plate of HT70 and HT80 steels as the web plates.

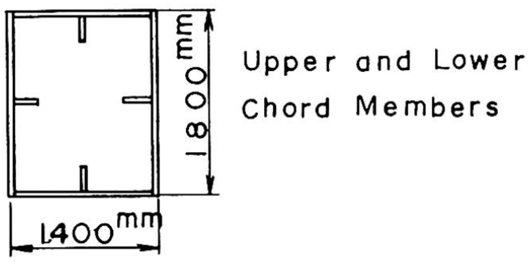

Fig.2 Sectional Form

Longer panel length can present a better proportion between the main truss height and panel length in a long truss bridge, which will result in less slenderness ratio l/r of the members and hence in less effects of the secondary stresses. Therefore, in this bridge the panel length was taken to be 18m to 19m, which is much longer than that of the conventional bridge.

3. MATERIALS

High-strength steels of $70 kg/mm^2$ and $80 kg/mm^2$ which were then available in Japan were considered to have too many unresolved problems to be applied for the construction of this bridge. In preparing a new specification it will be an important matter to our technical judgement which limit should be paid attention to - limit of steel manufacture or that of bridge fabrication. In the case of the Osaka Port Bridge, judging the matter in the balance of the above two limits, it was decided, in view of the highly advanced techniques of steel manufacturing in Japan to leave the solution of the problem to steel material wherever possible, and then requirements for the steel manufacture were set forth. In determing the mechanical properties and chemical compositions of the tempered high-strength steels to be employed for this bridge,

Table 1 Specification of HT70 and HT80 steels

	Thickness (mm)	Chemical Composition (%)						Mechanical Property					Toughness
		C	Si	Mn	P	S	Ceq	Y.P. (kg/mm^2)	T.S. (kg/mm^2)	E L. Thickness (mm)	E L. Test Specimen (JIS)	E L. %	
HT70	$6 \leqq t \leqq 50$	$\leqq 0.15$	$\leqq 0.55$	$\leqq 1.50$	$\leqq 0.03$	$\leqq 0.03$	$\leqq 0.49$	$\geqq 63$	70~85	$6 \leqq t \leqq 16$	NO.5	$\geqq 17$	$vE_{-15} \geqq 4.8$ kg·m (V Notch Charpy Value)
										$t > 16$	NO.5	$\geqq 23$	
	$50 < t \leqq 100$	$\leqq 0.17$	$\leqq 0.55$	$\leqq 1.50$	$\leqq 0.03$	$\leqq 0.03$	$\leqq 0.53$	$\geqq 60$	68~73	$t > 20$	NO.4	$\geqq 17$	
HT 80	$6 \leqq t \leqq 50$	$\leqq 0.14$	$\leqq 0.55$	$\leqq 1.50$	$\leqq 0.03$	$\leqq 0.03$	$\leqq 0.53$	$\geqq 70$	80~95	$6 \leqq t \leqq 16$	NO.5	$\geqq 16$	$vTrE \leqq -35°C$ (Transition Temperature)
										$t > 16$	NO 5	$\geqq 22$	
	$50 < t \leqq 100$	$\leqq 0.17$	$\leqq 0.55$	$\leqq 1.50$	$\leqq 0.03$	$\leqq 0.03$	$\leqq 0.57$	$\geqq 68$	78~93	$t > 20$	NO. 4	$\geqq 16$	

Y.P. : Yield Point T.S. : Tensile Strength EL. : Elongation JIS : Japan Industrial Standards

special considerations were given to the occurrence of cracking, and softening and embrittlement in the bond of weld joints of HT70 and HT80 steels to prevent the possible occurrence of these phenomena in practical use.

The material specification of the steels to be used for the Osaka Port Bridge was set forth in accordance with the following basic conditions; (Table 1.)

(1) The maximum plate thickness of each class of steel shall be as follows.
75mm for $60kg/mm^2$ class steel
100mm for $70kg/mm^2$ and $80kg/mm^2$ class steels
(2) The steels shall have such fracture toughness that they will not be brittle fractured at the service metal temperature of -15°C.
(3) The heat input by welding shall be determined so that the requirements in item (2) above can be met. (50KJoule/cm)
(4) The temperature of preheat is dependent on the grades and thickness of materials. As for the materials to be used for this bridge, it shall be aimed that welding of $80kg/mm^2$ class steel, 100mm in thickness with preheat temperature of 150°C and under, may not result in any weld defects.
(5) The flatness of the steel plate shall not exceed 2mm/m to maintain subsequent fabrication accuracy.

A series of tests were conducted on plate thickness, 25, 50, 75 and 100mm of both HT70 and HT80 in six major mill makers in Japan to confirm the characteristics of materials concerning these phenomena. These tests were intended to investigate chemical compositions, shape and dimension accuracy, mechanical properties, weldability and weld joint performance.

From these tests it was proved that HT70 and HT80 steels can be satisfactorily applied to this bridge. It was also found out that materials produced by the current mass production process to be used for the construction of this bridge had excellent properties.

4. FABRICATION

As a procedure test to determine welding condition, fabrication accuracy, and inspection procedure, the following tests were conducted prior to fabrication;

(1) lamellar tear test,
(2) restrained cracking test,
(3) tests on the performance of corner weld joints,

(4) tests to check residual stresses due to welding, and
(5) tests to investigate the various chracteristics of the actual members using full scale models.

Welding conditions including minimum preheat temperature, maximum preheat temperature, interpass temperature, and preheat temperature for tack welds and baking conditions of welding materials were determined from the results of these tests, under the condition that over 50KJoule/cm of heat input was in no case permitted in the fabrication of this bridge.

Major characteristic procedures employed for the fabrication of this bridge are as mentioned below. Unlike the conventional preheat control method, the following three types of preheating methods were used;
(1) electric preheating type with automatic control,
(2) fixed burner type, and
(3) manual burner type.

The separate preheating method was specified for each type of weld joints. In welding major members, symmetrical preheating and symmetrical welding methods were employed to secure higher fabrication accuracy and minimize residual stresses. To prevent the occurrence of cracking, the welding material having the strength lower than the base metal that is "soft joint" was employed. It was also specified that the fabricators should submit reports of preheat temperature, amount of heat input, amout of angular deformations in butt joints, and dimentional accuracy of members after tack welding and final welding, respectively.

As for the drilling of holes at joints, discussions were made on efficiency and accuracy of drilling, partly because the grip lengths of joints were large due to the use of thick plates and partly because the high-strength steel with high hardness was used. In this bridge, an interchangeable method in which drilling of holes was performed using a template with a bush inserted in each hole was employed, wherever practicable.

5. ERECTION

This bridge has long panel length, which resulted in increase in the weight of single members. Larger members weigh 75 to 110 tons each. This was the biggest factor in determining the erection method. Erection methods are shown in Fig. 3. Erection loads which would be resulted from the below-mentioned erection method were investigated and evaluation of stresses caused by these loads was carried out for each stage of erection.

The two panels at the tower part was fabricated into an assembly of about 540 tons which was then installed by means of 3000 tons floating crane, in order to secure accuracy as well as safety and erection time saving, since these two panels would be the reference points for the erection accuracy.

The anchor and cantilever spans were erected by cantilever method and the maximum weight of a single member at these spans was limited to 80 tons so that it could be erected by a traveller crane.

The suspended span whose length was 186m and whose weight was about 4500 tons was preassembled into one block at the shop and towed to the site by 15,000 tons capacity barge. Finally on February, 26, 1974 suspended truss span was lifted to the height of approximately 60m above sea level using lifting equipment to the final position. For this lifting it took only about 3.5 hours.

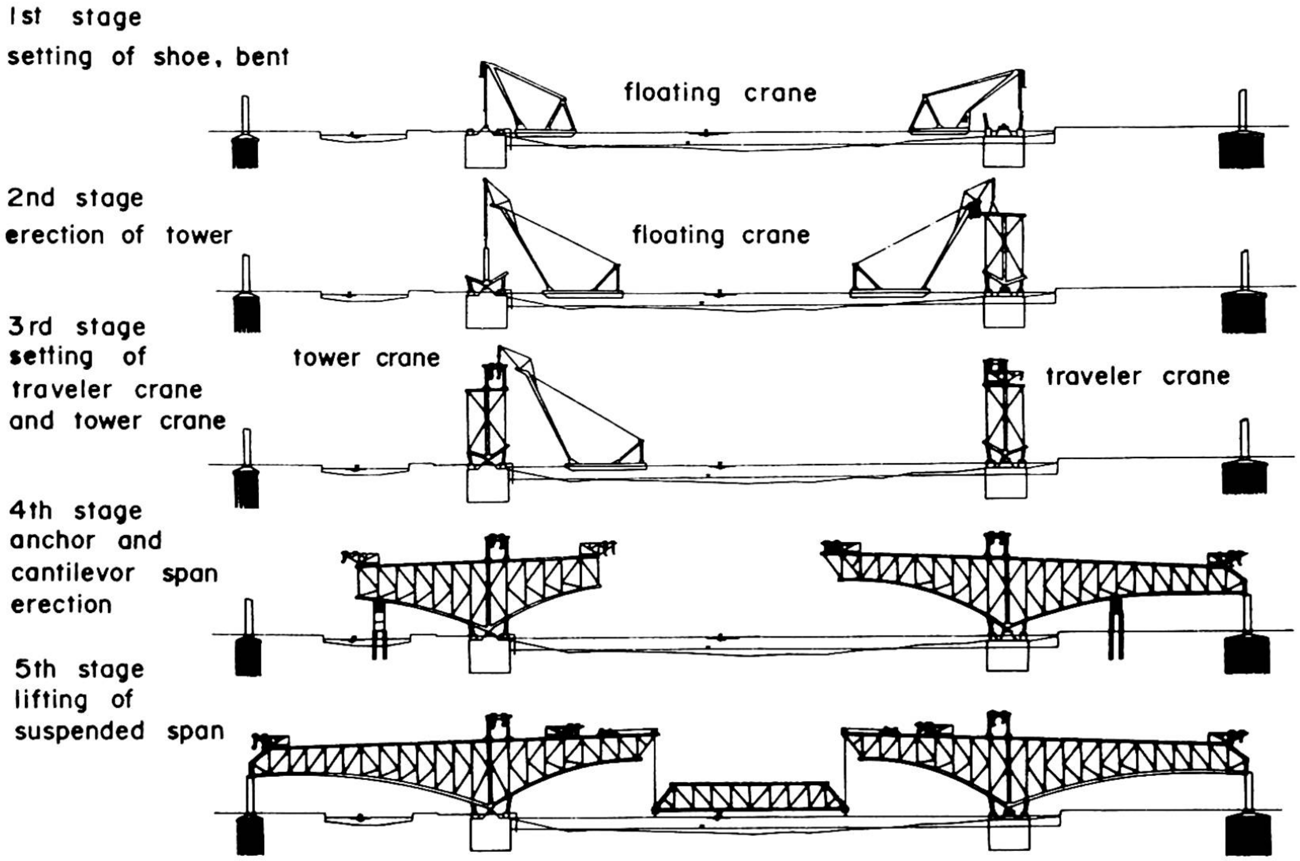

Fig.3 Erection Methods

Photo 1 Lifting of Suspended Span

SUMMARY

High-strength steel was applied in the Osaka Port Bridge after sufficient investigations. The choice of this material lead to compact cross sections and permitted to reduce the secondary stresses at panel points. This choice was confirmed by a serie of tests for different plates of HT70 and HT80 with thickness of 25, 50, 75 and 100 mm. Due attention was paid to the problem of cracking and embrittlement of welded joints during fabrication. This bridge will be ranked as the third longest modern cantilever truss bridge.

RESUME

Les aciers à haute résistance ont été appliqués au pont du port d'Osaka après des recherches approfondies. Ce choix a rendu les sections de membrures compactes et a réduit les contraintes secondaires aux points de jonction. Les matériaux ont été choisis avec soin; ils ont été mis à l'epreuve d'endurance sur des plaques de HT70 et HT80, d'épaisseur 25, 50, 75 et 100 mm. Il a été fait attention que ni fissure ni rupture de fragilité dans les joints soudés ne se produisent en cours de fabrication. Ce pont est le troisième pont moderne cantilever le plus long dans le monde.

ZUSAMMENFASSUNG

Nach verschiedenen ausführlichen Untersuchungen wurden hochfeste Stähle für die Osaka Hafenbrücke verwendet. Damit wurde es möglich, die Querschnitte einzelner Bauteile zu verkleinern, und dadurch die Nebenspannungen an den Knoten zu verringern. Bei der Fertigung wurde besonders die Vermeidung von Rissen und Sprödbruch im Bereich der Schweissstellen berücksichtigt. Für HT70 und HT80 wurde eine Serie von Eignungsprüfungen, jeweils mit Blechstärken von 25, 50, 75 und 100 mm, durchgeführt. Diese Brücke ist nun die drittlängste moderne Fachwerkbrücke mit Kragarmkonstruktion in der Welt.