Design and construction of Aomori Bay bridge

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Etude et construction du pont sur la baie d'Aomori

Entwurf und Ausführung der Aomori-Bay-Brücke

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SUMMARY

Aomori Bay Bridge is a prestressed concrete cable-stayed bridge, which is of the largest scale in Japan with the single-plane cable arrangement. This paper describes design characteristics such as studies of seismic performance and of the main girder in the neighborhood of the stay cable anchorages, construction characteristics of the superstructure, construction properties of high-strength concrete used for the main tower, and antivibration measures of stay cables using elastic bearings.

RESUME

Le pont sur la baie d'Aomori est un pont haubané à nappe unique en béton précontraint, dont la taille est actuellement la plus grande au Japon. La communication décrit les caractéristiques du projet, telles que les études de la performance antisismique et de la poutre maîtresse au voisinage des ancrages des haubans, les caractéristiques de la construction de la superstructure, les propriétés du béton à très haute résistance utilisé pour le mât principal, ainsi que les mesures de résistance aux vibrations des haubans à l'aide d'appuis élastiques.

ZUSAMMENFASSUNG

Die Aomori Bay Brücke ist eine Schrägseilbrücke aus Spannbeton – die grösste Brücke mit nur einer Schrägseilebene in Japan. Der Bericht beschreibt Besonderheiten des Entwurfs wie Studien zum Erdbebenverhalten und zur Ausführung des Haupttträgers in der Nähe der Schrägseilverankerungen, ferner das Bauverfahren der Überbaus, die Ausführung des Pylons in Hochfestigkeitsbeton und Dauerschwingungsfestigkeit der Ankerkörper mittels elastischer Lager.

1. INTRODUCTION

At present, Aomori Bay Bridge, a three-span continuous prestressed concrete cable-stayed bridge of the largest scale in Japan, is under construction. The bridge measures 498 m in length, 240 m in center span, and 25 m in width. This bridge is being built as a port road bridge to connect port facilities disconnected by a railway station. Fig.1 shows the general view of the bridge. The main girder is a prestressed concrete (PC) structure of a 3-cell box girder in cross section measuring 25 m in width and 3.5 to 2.5 m in girder height. The main tower is a reinforced concrete (RC) structure in an inverse Y shape. High-strength concrete of a characteristic strength of 60 MPa was used to make the main tower slender in order to reduce the dead load and to improve the aesthetics. The stay cable arrangement is single plane fan system, with two parallel cables in one stay.

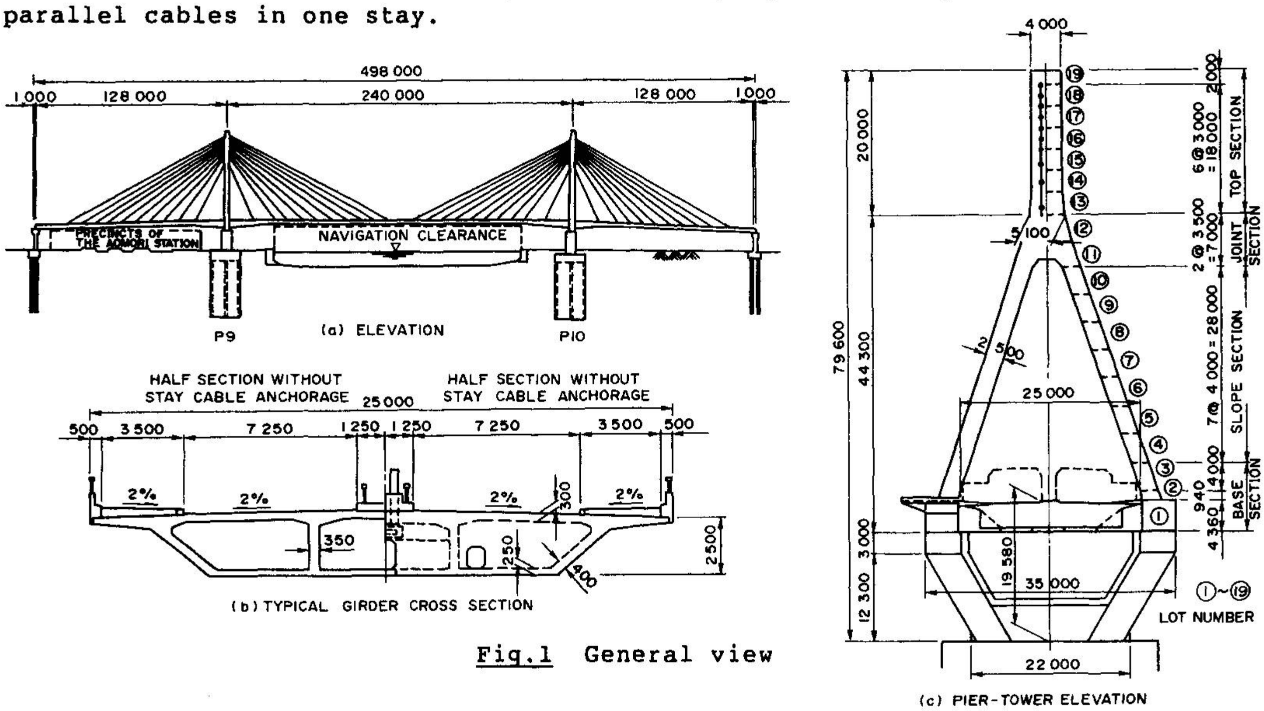

Fig.1 General view

2. DESIGN OF SUPERSTRUCTURE

The sectional forces of members were calculated by plane frame analysis of both longitudinal and transversal directions assuming that the bridge was fixed at pier bottoms. And the members were design d by the allowable stress method. The allowable stresses of the stay cables, σa , after completion and during construction were 0.40 σpu and 0.55 σpu, respectively (tensile strength, σpu, is 1863 Mpa).
The bridge is built in poor subsoil in which bedrock does not exist to a depth of one hundred meters below the surface. For this reason, dynamic analysis of the entire system including the superstructures, foundations, and nearby subsoil was performed to study the aseismatic performance, in addition to static analysis. The input earthquake motion was based on generally-specified motion and earthquake records near the construction site.
The cross section of the main girder is of a 3-cell box-girder type to increase the torsional rigidity since the stay cables are arranged in single plane and because the cable tension adjustment described below is to be performed inside the main girder. Diaphragms are provided in the cable anchoring parts of the main girder to distribute the cable tension to four webs.
As the cable tension is adjusted inside the main girders, the cable anchoring point is located near the upper slab, where the punching shear was studied. Through experiments performed using 1/3 and 1/6 models of this part, it was verified that the maximum load during construction would be below the load at which visible cracks would occur and that the breaking load of the cables would be less than the punching shear failure load.

3. CONSTRUCTION OF MAIN TOWERS

As shown in Fig.1, a main tower was built by dividing it into 19 lots. The tower base was built using a scaffolding from the ground, the slopes by climbing forms, and the joint and tower top by bracket falsework.
The characteristics of the construction are described below. The concrete work is described in detail in section 6.1.
The lot height of each slope block was 4.0 m, and the slope block was built by climbing forms. The climbing form consists of a scaffolding and a form frame and is a self-climbing falsework climbing on guide rails anchored on concrete already placed. Fig.2 shows tower construction by climbing forms. In the reinforcement work, the main reinforcement (deformed bar with a diameter of 38 mm) was joined entirely by hot shear punching gas-pressure welding method. The lap joints of the hoop reinforcement were closed by flare welding to improve the bending ductility. Special wooden forms covered with thin textile were used at the top surfaces of the slopes for better discharge of bleeding water and foam to make the surfaces dense and to reduce pockmarks.

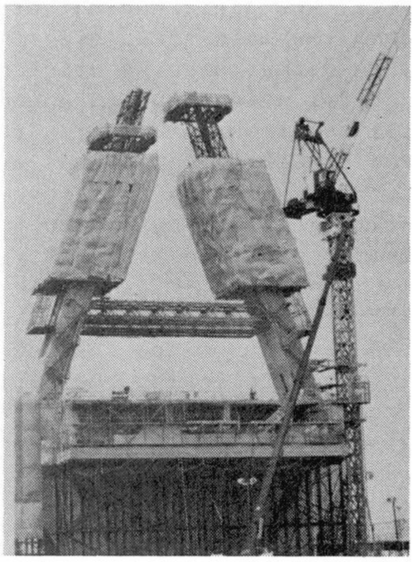

Fig.2 Tower construction by climbing forms

4. CONSTRUCTION OF MAIN GIRDERS

The main girders are divided in 46 segments and are erected by large travellers. The pier table part, 15.0 m in length, is built by falsework on the ground. The closure segments of the side and center spans are built using suspended falsework.
The cantilevering parts are built using standard segments of 5.0 m in length. Stay cable anchoring segments with diaphragms to anchor cables and ordinary segments without diaphragms are arranged alternately.
The construction cycle for two segments is approximately one month. The standard segment length was determined taking the cable anchoring interval and construction period into consideration.
The stay cable anchorages buried in the stay cable anchoring segments are placed using a steel support rack fixed on the segments already in the place. The rack holds two parallel anchorages, allowing the directions and positions of the anchorages to be adjusted. Fig.3 shows a cable anchoring segment being built.

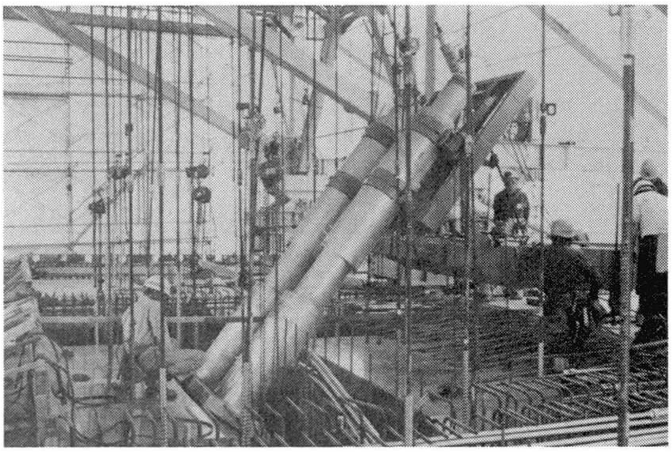

Fig.3 Construction of stay cable anchoring segment

5. CONSTRUCTION OF STAY CABLES

Each stay cable is composed of 61 to 67 parallel prestressing strands (ø15.2 mm). The cables are anchored by the Freyssinet H system. The prestressing strands are protected by fiber reinforced plastic (FRP) tube. The surfaces of the tube are colored gold to improve the tube appearance.

5.1 Erection

All the stay cables are assembled at the site. First, FRP tubes in the standard length of 6.0 m are joined on the bridge. The tubes are suspended on the previously installed erection wire rope and are pulled up in succession to form a stay tube of the required length.
Next, the prestressing strands are inserted through the anchorages and tubes from the main tower side. When the tip of the prestressing strand reaches the main girder side, a wedge is driven at this point. The prestressing strand is cut for stressing and anchoring on the main tower side. This was repeated for the required number of strands to form the stay cable.
The prestressing strands are measured and marked to the required lengths at the factory. All the prestressing strands are stressed to the same length in primary stressing in accordance with this marking to avoid tension variations from one strand to another.

5.2 Tension adjustment

The tension of the stay cables has to be adjusted following the cantilever process of main girder. The adjustment of the tension is performed inside the main girders using a special jack with a stressing capacity of 10.8 MN developed for this bridge. The special jack is equipped with a special vehicle that adjusts the angle of elevation. The tension is adjusted by pulling the stay end with the jack and by adjusting the ring nut position. Fig.4 shows the cable tension adjustment jack.

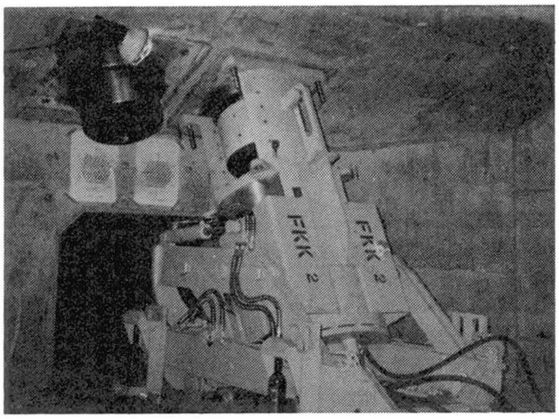

Fig.4 Cable tension adjustment jack

6. TECHNOLOGY DEVELOPMENT

6.1 High-strength concrete

6.1.1 Quality of high-strength concrete

Table 1 shows the mix proportion of high-strength concrete used in the towers of the bridge. Using a high-performance air-entraining and water-reducing agent as an admixture, the required quality was obtained by limiting the unit water content to 135kg/m^3.

Table 1. Mix proportion of high-strength concrete

	Maximum size of coarse aggregate (mm)	Water-cement ratio (%)	Sand aggregate ratio (%)	Unit content (kg/m^3)				Admixture		Placing lot number
				Cement	Water	Coarse aggregate	Fine aggregate	Type	Amount to be added (%)	
A	25	31.4	39.0	430	135	1105	693	I	2.20~2.50	P10 ①~⑤
B	25	35.0	40.3	386	135	1105	729	I	2.30~2.80	P10 ⑥~⑧
C	25	33.8	39.9	400	135	1105	718	I	2.60~2.90	P10 ⑨~⑩
D	25	33.8	42.2	400	135	1063	760	I	2.10~3.00	P10 ⑪~⑲
E	25	35.0	42.6	386	135	1063	771	II	2.90~3.30	P9 ①~③
F	25	33.8	42.2	400	135	1063	760	II	2.10~3.20	P9 ④~⑲

Fig.5 shows the results of the compressive strength tests. The required strength could be obtained satisfactorily. Initially, variations were prominent, but these became small as the construction work progressed. The concrete consistency was evaluated by a slump flow test, and the goal was set at 40 to 55 cm. The high-performance air-entraining and water-reducing agent used in the project was highly temperature dependent. The slump flow was made constant by increasing the amount of the water-reducing agent added as the concrete temperature lowered.

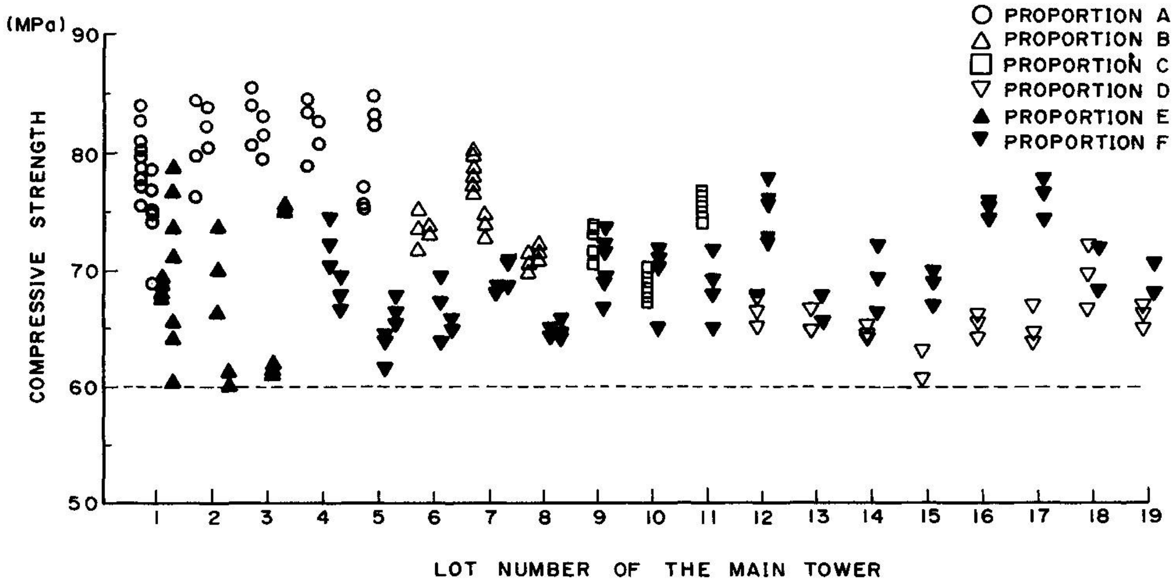

Fig.5 Results of compressive strength tests of high-strength concrete

6.1.2 Properties of pumped high-strength concrete

The high strength concrete for main towers was placed wholly by pumping up to approximately 80 m above the ground. The high-strength concrete used in the bridge excelled in fluidity but was high in viscosity. The concrete was pumped while checking the pumping property of high-strength concrete by measuring the pressure inside the pumping pipe during pumping.
The pressure losses during pumping in vertical pipe were 0.02 to 0.06 MPa/m, which did not differ from those of ordinary concrete (0.02 to 0.04 MPa/m). However, the pressure losses increased 0.01 to 0.28 MPa/m in horizontal pipe, where the friction resistance of pipe walls was prominent, due to the concrete viscosity.
Fig.6 shows the pump front pressure indicating whether or not pumping is possible. The front pressure increases as the pumping head becomes higher. The value provided a sufficient margin to the pump vehicle capacity (maximum 7.85 MPa)

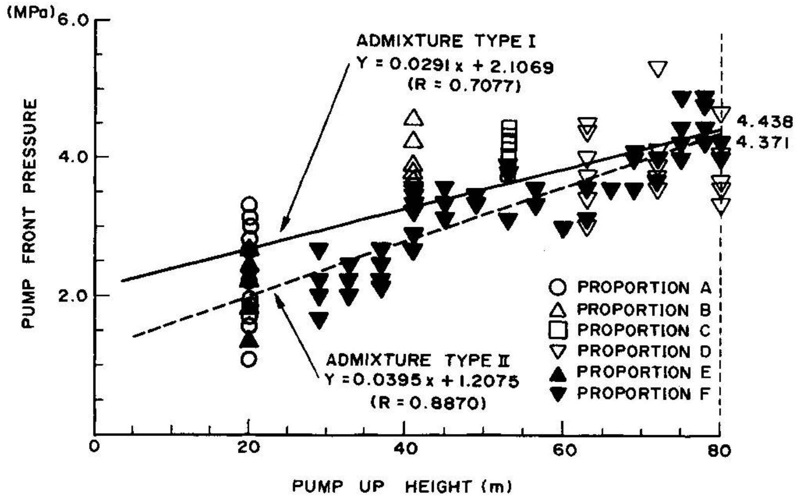

Fig.6 Transition of pump front pressure

6.2 Elastic bearings of stay cables

The stay cables of the bridge consist of prestressing strands which are anchored by wedges. For this anchorage type, the bending fatigue characteristics have not been fully examined. As a countermeasure, elastic bearings were installed inside the cable anchorage to prevent bending at the anchoring points.

A study of the number, layout and spring constant of elastic bearings was made before setting the elastic bearings. The number of elastic bearings in the bridge was set at two for a cable because this was considered to be economically effective.

The bridge has a fixed spring constant for two bearings and a fixed spacing between bearings.

The anchorage developed for the bridge has a double structure, outer and inner tubes, which hold cylindrical synthetic rubber. The bearings can be tightened or released. Fig.7 outlines the concept of the structure.

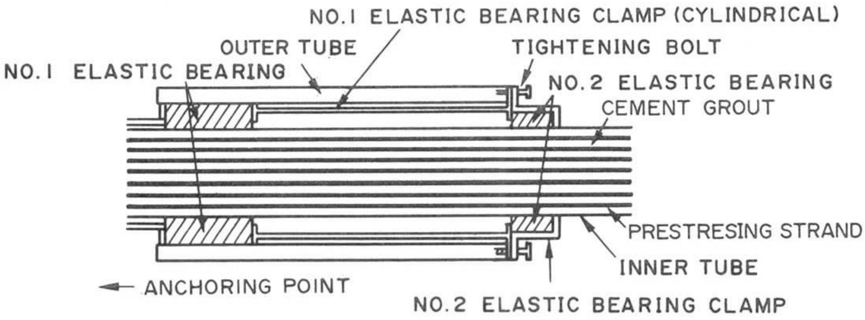

Fig.7 Structural details of the elastic bearings for stay cables

7. CLOSING REMARKS

The bridge is scheduled to be completed in the early summer of 1992. (See Fig.8) This bridge will be a landmark for the city of Aomori and is attracting attention from the citizens of the city. The public was invited to name the bridge. The name selected for this bridge was the "Aomori Bay Bridge" after the name of the city.

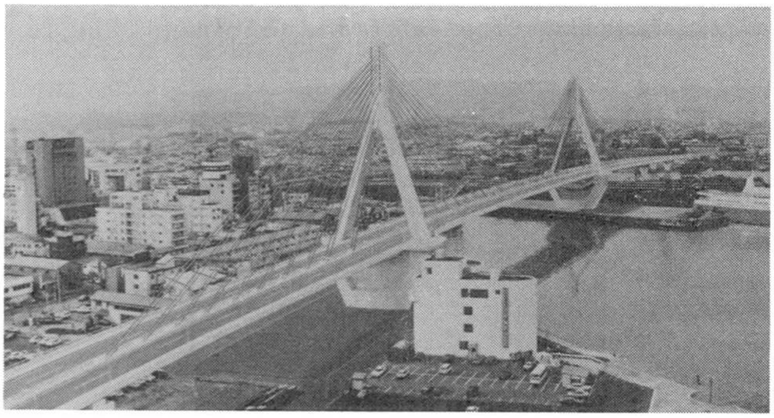

Fig.8 Photomontage of completed Aomori Bay Brige