Design and construction of Trans-Tokyo Bay highway bridge

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Etude et construction du pont-route de la baie Trans-Tokyo

Entwurf und Bau der Brücke des Trans-Tokyo Bay Highway

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SUMMARY

Construction of the Trans-Tokyo Bay Highway, a 15 km toll highway connecting the east and west sides of the Tokyo Bay, started in 1989 and is expected to be completed in 1995. The highway consists of bridges, tunnels and two manmade islands. Design and construction of the bridge superstructures and sub-structures are presented in this paper. Design for ship collision and seismic forces for the bridge structures are also included.

RESUME

La construction de la route de la baie Trans-Tokyo, d'une longueur de 15 km et reliant les rives est et ouest de cette baie, a commencé en 1989 et sera terminée très probablement en 1995. Cette route comporte des ponts, des tunnels et deux îles artificielles. Cet article présente le projet et la construction des superstructures et des infrastructures de ce pont-route. Cette présentation comporte aussi le calcul de la structure porteuse sous l'effet de la collision d'un bateau et sous celui des forces sismiques.

ZUSAMMENFASSUNG

Der Bau des Trans-Tokyo Bay Highway, einer 15 km langen gebührenpflichtigen Autobahn, welche die Ost- und Westseite der Bucht von Tokio miteinander verbindet, begann 1989 und wird voraussichtlich 1995 vollendet sein. Er umfasst Brücken, Tunnels und zwei aufgeschüttete Inseln. Der Aufsatz stellt Entwurf und Bauverfahren der Über- und Unterbauten des Brückenzuges einschliesslich der Bemessung für Schiffsanprall und Erdbebenkräfte dar.

1 OUTLINE OF THE TRANS-TOKYO BAY BRIDGE

The Trans-Tokyo Bay Highway (TTBH) is a 15.1 km toll highway connecting Kawasaki and Kisarazu which are situated at both sides of the Tokyo Bay, as shown in fig.1. The highway consists of two 10 km long tunnels under the Kawasaki waters where marine traffic is heavy, a 4.5 km bridge over the Kisarazu waters where marine traffic is sparse, and two gigantic man-made islands. The size and scope of these structures are beyond the conventional ones. In addition, soft under-ground and possibility of large earthquakes have made the construction more challenging. The TTBH will form the Tokyo metropolitan highway network connecting to main highways across the nation and is expected to activate harmonious economic development and relieve traffic congestion in the metropolitan areas. Although most of the public highways have been constructed by the public corporations, a new project system was adopted for the TTBH in order to utilize financial and human resources of private companies.

The highway carries dual two lane carriageways in the first stage, and other two lanes will be extended in the future. However, the decision on the extension must be made judging by the future traffic volume. Traffic volume is estimated approximately 33,000 veh/day which is expected to reach 64,000 veh/day in 20 years after opening. Vehicle design speed is 80 km/h. 10 years of construction period is estimated including negotiation for fishery compensation and legal procedures. The construction is expected to be finished by 1995. Total construction cost is estimated ¥1,150 billion.

The bridge is 4.4km long with 43 piers. The navigation areas exist at water depth about 20m, where the span is extended up to 240m. The layout of the bridge is shown in fig.2 and fig.1, where the soil layers are also illustrated. Alluvial sand and clay layers (As & Ac) exist 5m to 20m deep under the seabed. In some alluvial layers sands are soft with N value of the standard penetration tests under 10 and the grains are uniform and medium size, which might create a liquefaction problem. Below the alluvial soils follow diluvial soil layers with different ages, D1 to D4, where sands and clays exist alternately. D5 layer observed overall the highway layout is stiff with N value over 50 and earthquake shear wave velocity over 400m/s, and has been taken as the input base of seismic design waves.

2. Bridge super-structure

The steel box girders with orthotropic decks have been adopted as super-structure because of its light dead weight and rapid construction. The maximum web height is 10.5m, and the width is 29.9m which accommodates dual two lane carriageways in the first stage, and extra two lanes in the future stage. The cross section of the super-structure is shown in fig.3.

The bridges are designed to have long continuous girders so as to improve both the seismic resistance by sharing seismic horizontal forces with many piers and road surface smoothness by eliminating expansion joints. Ultra-long continuous girders are planned culminating 1,630m long ten-continuous-span girder, P3-P13, utilising high steel flexible piers. In the shallow water where piers are concrete and relatively low and stiff, rubber bearings are to be used to absorb the elastic expansion of girders due to temperature change.

The girders are fabricated and assembled at a factory, but two different erection methods will be used at the site. In the deep water parts a large block of girders is towed to the site and set on the piers by floating cranes, as shown in fig.4. In the shallow water area where a floating crane barge cannot be used, a girder block is carried on the barge and set by jacks during the high tide period, as shown in fig.5. The barge does not float but stays on the sea bed during the low tide periods.

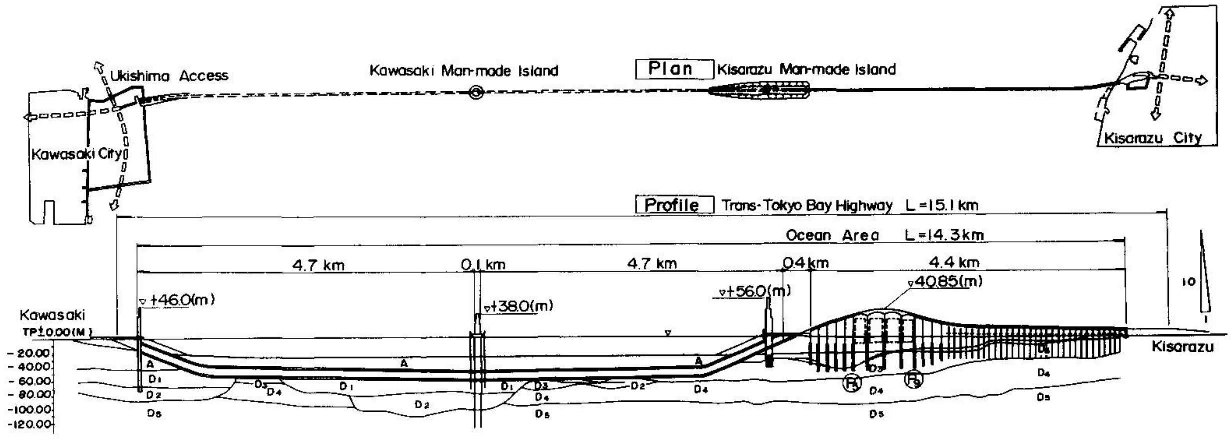

Fig.1 Trans-Tokyo Bay Highway

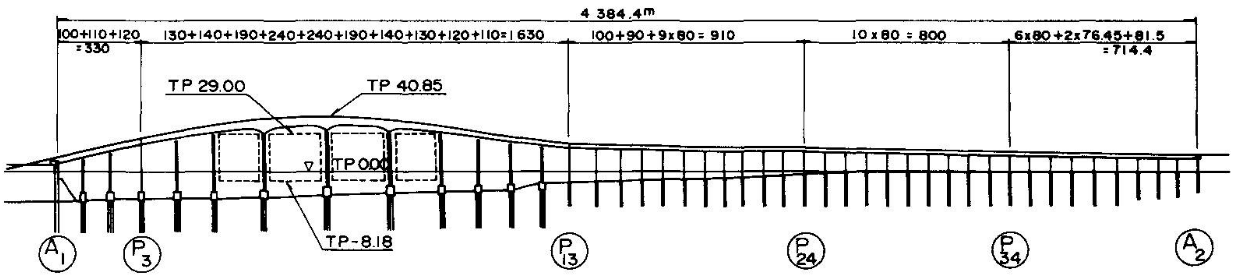

Fig.2 Layout of the Bridge

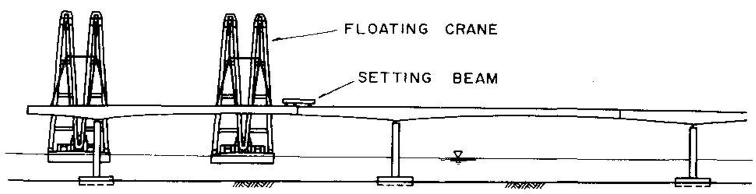

Fig.4 Erection of Super-Structures (Deep Water)

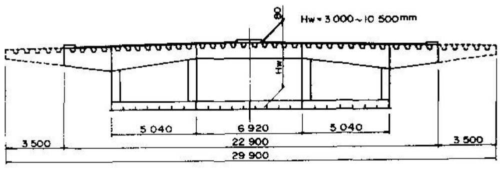

Fig.3 Bridge Cross Section

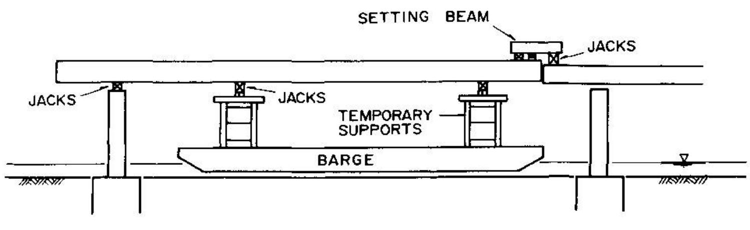

Fig.5 Erection of Super-Structures (Shallow Water)

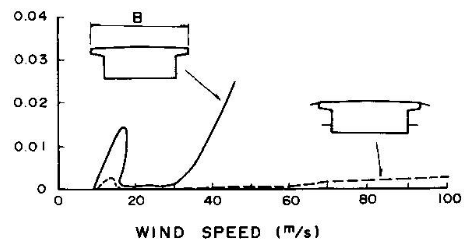

Fig.6 Wind Test Results

Long-term durability is a very important factor to decide paints for the girders. A combination of zinc-rich paint, epoxy resin and fluoric resin will be used for the outside of the box girder, and non-bleed tar-epoxy resin for the inside of the box girders. The cross section will form one large box to improve accessibility of repainting works.

The structure will suffer strong typhoon winds which may create aerodynamic problems. Since the box girder has much larger torsional stiffness than vertical stiffness, flutter is not a problem but galloping and vortex shedding may result due to bluff sections. Wind tunnel tests have therefore been carried out using sectional models (scale 1/30) and 3-dimensional models (scale 1/170). Design wind speed at 10m height is 49m/s which increases 67.7m/s for the highest girder elevation. The test results indicate that the original girder in the first stage is vulnerable because of poor aerodynamic cross section and needs some measures to improve critical wind speed. A measure with plates on the web and scarts at the hand rails is proved to be a efficient solution, as shown in fig.6. The critical wind speed of the bridge in the second stage is sufficiently high for the galloping.

3. BRIDGE SUB-STRUCTURES IN DEEP WATER

The piers of P1 to P12 are constructed in the 15m to 25m deep water and will suffer strong horizontal forces due to ocean waves and earthquakes as well as huge vertical reactions from the super-structure, requiring massive structures and difficult construction. Open-caisson, pneumatic-caisson, steel pile well foundation, and composite steel piers shown in fig.7 were compared technically and economically, concluding that the last one is the best in all the aspects such as cost, period and easiness of construction.

A steel column and footing are fabricated and assembled into one piece at the fabrication yard, and transported to the site. The site is first dredged and sands are placed on it to form a foundation. Steel piles are then driven using a template. The steel pier is set by floating cranes on the piles driven beforehand, and both are then united with water concrete. Finally, concrete is cast into a column, as shown in fig.8, to increase the ultimate capacity and ductility with the composite action of steel and concrete.

Corrosion protection is vital for the steel piers under severe corrosion environment. The column above the sea level is painted with zinc-rich paint, epoxy resin and fluoric resin. Aluminium sacrifice anodes will be attached to the under-water columns and footings with tar-epoxy coating. For the splash zones, which is most corrosive and hard to repair, thin titanium clad steel plates (1mm titanium and 4mm steel) is welded to the surface of the columns.

4. BRIDGE SUB-STRUCTURES IN SHALLOW WATER

Environmental protection is extremely important for the area from the shoreline to 5km nearshore where seaweeds and sea shells are bred. Numerical prediction on wave propagation, water verocity and seabed sand movements were extensively carried out to minimise the effect to the sea environments due to the construction of structures.

Steel pile well foundation and concrete column with 6m by 4m cross section has been adopted for the shallow water portion, as shown in fig.9. The construction procedure is as follows. After the template is set, steel piles with 800mm diametre are driven and the gaps in between piles are sealed with cement mortal.

The inside circular area is then dried up to build a concrete footing and column. The piles are then cut off at the seabed and removed. The environmental effects during construction have also been carefully investigated such as vibration and noises caused by pile driving, pH, BOD, SS and so on.

5. SHIP COLLISION DESIGN

The Tokyo Bay forms an oval shape of 70km by 20km, along which six major port facilities are spotted. The ports handle nearly 450,000 vessels annually, among which over 90% cross the Kawasaki water (tunnel area) and others the Kisarazu water (bridge area) in the TTBH.

Crash guards are being planned for the Kawasaki Island and the five bridge piers (P5 to P9) in the navigation channel. 130,000 GT and 3,000 GT vessels are assumed to crash the Kawasaki Island and the bridge piers respectively. The field survey in the bay has shown that most of the vessels travel with 12 knots, although it is assumed in designing the crash guards that the vessel would slow down the speed to avoid the collision. It is also considered the case that a huge oil tanker may be drifted in the storm and hit the structures. Dolphin type crash guards with steel piles and top concrete slab will be adopted for the protection structures. A round or triangle top slab is expected to divert the ship direction if the ship should hit the crash guard.

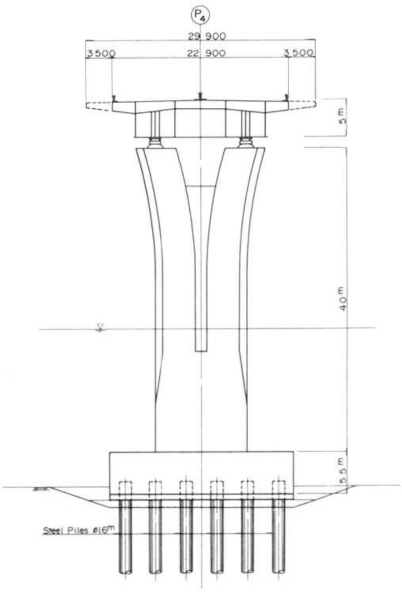

Fig.7 Composite Steel Pier

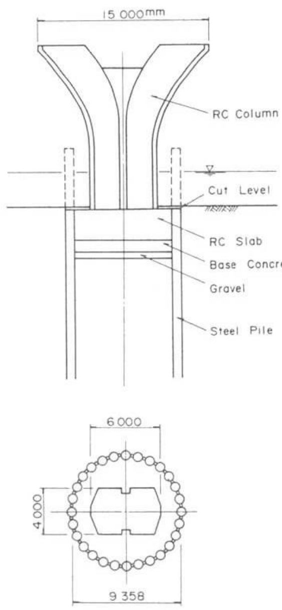

Fig.9 Steel Pile Well Foundation

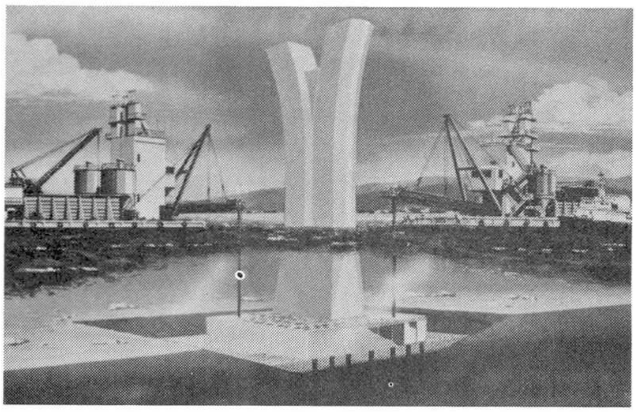

Fig.8 Erection of Composite Steel Pier

6. SEISMIC DESIGN

Seismic activities have been very active in the Tokyo Bay area. The structure is designed by the following design horizontal loads, which is dead loads multiplied by horizontal seismic coefficient K which depends on geographical zone, underground soils and natural frequency of structure. The K value for this bridge is 0.3.

The bridge is also checked by dynamic analyses with two level earthquake waves. It would be irrational if structures were designed to resist the huge earthquakes with rare possibility and the medium size earthquakes by the same design philosophy. Two design earthquake levels (L1 & L2) have been therefore adopted for seismic design. L1 earthquakes would occur at least once during the design life of 100 years, while L2 earthquakes would be the largest one which have occurred and will occur at the Tokyo Bay in the future. Structures should not suffer heavy damages nor disturb the traffic in the highway by the L1 earthquake waves. On the other hand, structures might be allowed to have some damages but must not collapse and sustain ultimate strength by the L2 earthquake waves. Fig.10 shows design acceleration response spectrum of L1 and L2 with damping ratio h of 5%. It should be reminded that these spectra are used as input forces on the base stratum, therefore they may be amplified through soil layers until waves reach the structures.

7. CONCLUSION

The structures in the highway are situated at the front gate of the marine and air traffic to Tokyo, and will surely attract attentions of people from all over the world. Furthermore, as the structures are in the center of the bay, they should maintain harmony with surrounding natural environments. Aesthetic designs have been therefore carried out to satisfy such requirements for the man-made islands and bridges.

'Creation of the harmonious new metropolitan area in the 21st century' has been adopted as the fundamental concept. Key words have been also introduced to achieve the fundamental concept: 'harmony', 'symbol', 'quality' and 'continuity. The bridge elevation is smoothly curved and the pier shape in deep water is also moderately curved to form the Y-shape to achieve 'continuity', as shown in fig.11. Further aesthetic studies are now under way to make the whole highway more attractive such as color, surface materials, lighting-up the structures, light posts, guardrails, and other miscellaneous facilities.

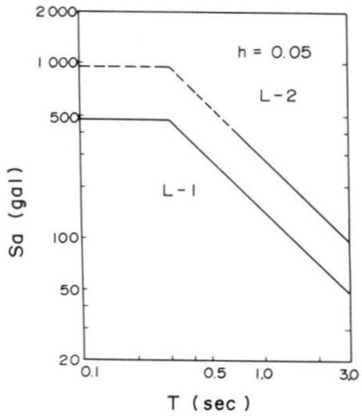

Fig.10 Acceleration response spectra on the base stratum

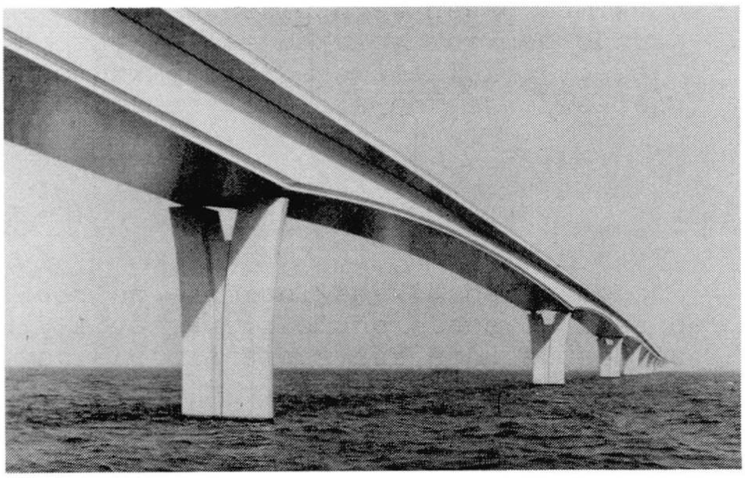

Fig.11 Perspective of Bridges