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Construction of Trans-Tokyo Bay Highway

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Summary

The Trans-Tokyo Bay Highway (TTB highway), which crosses Tokyo Bay and provides a direct transportation link between the west and east sides of the bay, has long been a sort of "dream-come-true" project in Japan. Linked to the Tokyo Bay Shore Highway, Metropolitan Inter-city Expressway, Tokyo Outer Ring Road, Tateyama Expressway, and others, it will play an important role as an integral part of the regional highway network to help promote spatial redistribution. The TTB Highway is a project of 15.1 km in length designed as a toll highway to cross the bay by tunnel and bridge, and the total cost is more than 1,482.^{3} billion yen (US$12.353 billion). The crossing involves a 5-km bridge, a 10-km undersea tunnel, and two manmade islands in the middle of the bay. This report outlines the entire TTB Highway project, including the design and construction method of undersea tunnels.

1. Outline of the Highway Structure

1.1 Highway Structures

The general plan of the highway is illustrated in Fig. 2, and having a highway length of 15.1 km in total, of which the marine section is 14.3 km. At the Kawasaki end, the land section of the highway joins the Tokyo Bay Shore Highway at the Ukishima Interchange. At its Kisarazu end, it is linked to the Tateyama Expressway by the TTB Highway Connector Road (7.1 km). The land sections at the Kawasaki and Kisarazu ends are approximately 0.3 and 0.6 km respectively. An outline of the project under the terms of the project license is given in Table 1 below.

The highway is being constructed as a four-lane facility: two lanes in each direction. For this, two parallel tunnels are being driven in the undersea section. However, in order to accommodate the expected future increase of traffic, the dimensions of major structures such as the man-made islands and the bridge have been determined to make future widening feasible.

1.2 Marine Section

The structural components of the marine section of the highway will consist of a shield-driven undersea tunnel, approximately 10 km in length, for the western two-thirds of the highway where shipping traffic is heavy; and a bridge about 4.4 km in length for the remaining section. Near the middle of the tunnels, a ventilation facility has been provided in the form of the Kawasaki Island, and where the tunnel and bridge meet, the Kisarazu Man-made Island (Kisarazu Island) is being constructed. The Kisarazu Island will serve as a rest area for users of the highway. Both islands have also been used as launching bases for the shield machines driving the tunnel.

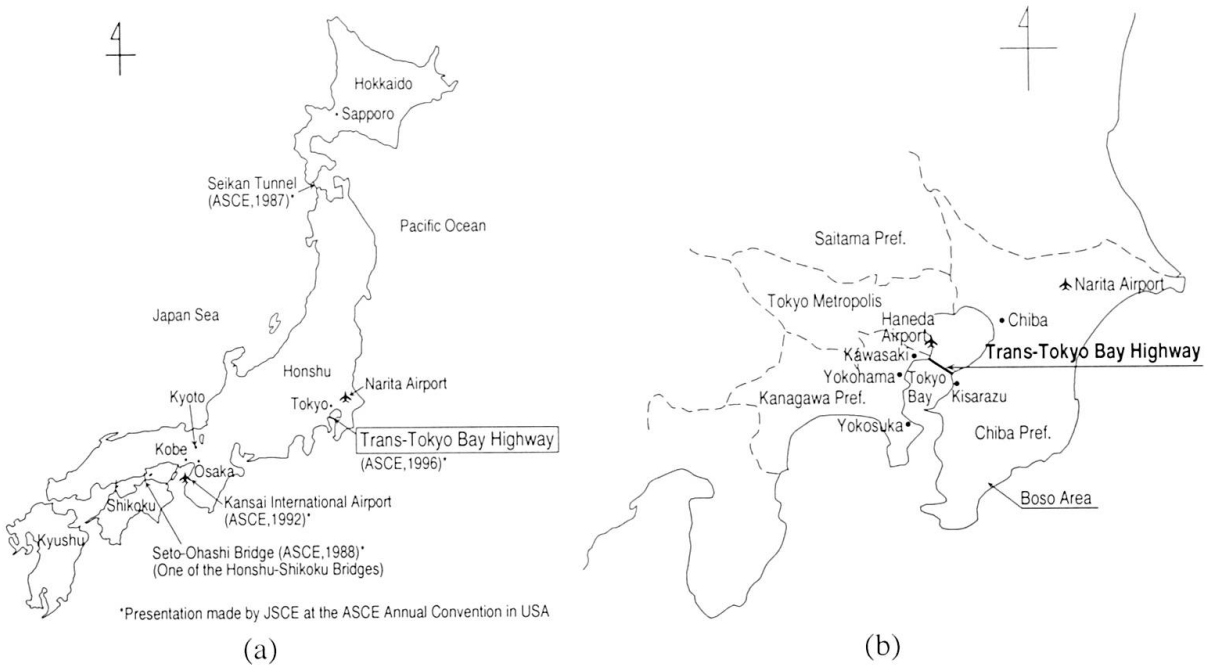

Fig. 1 Location of Trans-Tokyo Bay Highway

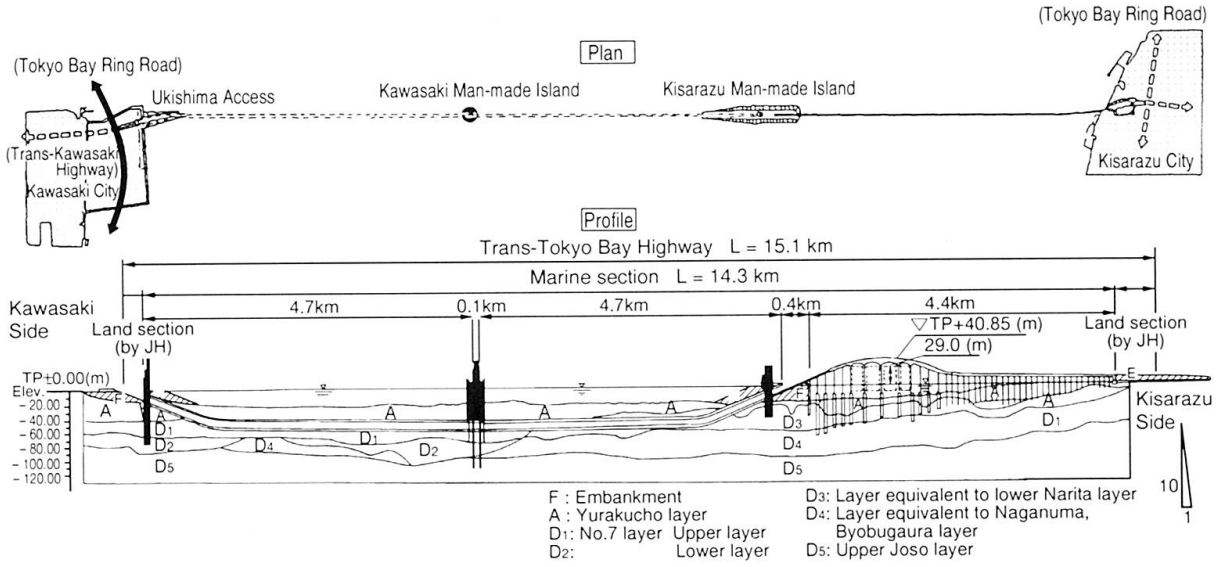

Fig. 2 Project plan and geological profile

Table 1 Outline of the project under the terms of the project license

Name of highway	Trans-Tokyo Bay Highway
Official route designation	National Route 409
Origin and destination	From Ukishima, Kawasaki City To Nakajima, Kisarazu City
Length of highway	15.1 km (Marine section 14.3km)
Number of lanes	Dual 2-lane (6 lanes at final phase)
Design speed	80 kilometers per hour
Design load	TL-20t and TT-43t
Forecast traffic volume	33,000 vehicles per day in the first year of operation (64,000 vehicles per day after 20 years of operation)
Construction period	About 10 years from fiscal 1986 (Completion expected in fiscal 1997)
Total project cost	¥1,482.3 billion (US$12.353 billion)

Exchange rate : US$1 = JPN¥120

1.3 Land Section

The land section on the Kawasaki side serves as an approach section to the tunnel from the interchange, and has structural components of a large U-shaped retaining wall and a box culvert.

1.4 Constructions Schedule

Fig. 3 shows the construction schedule for the highway. Construction began in 1989, and is scheduled for completion by 1997.

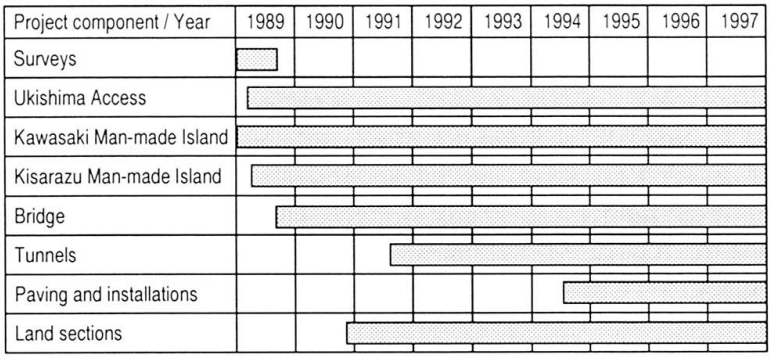

Fig. 3 Construction schedule

2. Design Conditions

2.1 Natural Restrictions and Planning Conditions

The topography of the seabed along the planned highway link is extremely gentle, generally conforming to the shape of a ship's hull, with a maximum depth of approximately 28 m. Geologically, from Ukishima on the Kawasaki side to the center of the Bay, there is a very soft 20-to 30-m-deep layer of alluvial soil, known as the Yurakucho layer; on the Kisarazu side, a relatively dense sand layer has accumulated from the surface. The upper stratum of the Kazura formation, a sandy layer with an N-value greater than 70 at depths below TP-80 to-90 m, is considered to be a suitable bearing stratum for engineering designs.

Along the tunnel route, the geology mainly consists of alluvial and diluvial clay soil layers on the Kawasaki side, with a diluvial sandy layer sandwiched between the two. The Ukishima and Kisarazu ramp sections are on reclaimed land.

2.2 Earthquake Activity

Earthquake activity is common in the Tokyo Bay area. It is believed that 32 major earthquakes occurred in the Bay area in the period from 818 to 1867 A.D.; since 1868, 23 damage-causing

Table 2 Soil Properties and load factors at the tunnel location

Soils	N Blow	q kg / cm	E kg / cm	γ_t ton / m^3	κ	λ	Water in Soils
Ac1	0	0.44	4.8–9.6	1.3–1.5	0	0.75	Combined
Ac2	0	0.87	5.7–22.9	1.6–1.7	0	0.75	Do.
Dic	12	0.96	35.9–289.0	1.4–1.8	1.5	0.65	Do.
Dis	15-5	–	25.0-204.0	1.6–1.8	0.5–4.0	0.35–0.55	Separated
D3c	20	2.11	–	1.7–1.8	2.0	0.65	Combined
D3s	54	1.57	296.2	1.8–1.9	4.0	0.35	Separated
D3g	78	–	195.5	1.7	5.0	0.35	Do.
Manmade	–	7.5–21.3	–	1.6–1.8	3.5	0.6	Combined

A : Alluvial
C : Clayey soils
N : Number of Blows by SPT
qu : Unconfined Compressive Strength
E : Modulus Elasticity
D : Diluvial
S : Sandy soils
γ_t : Unit Weight of soils
κ : Modulus of Subgrade Reaction
λ : Earth-pressure Coefficient

earthquakes have occurred. The great Kanto earthquake of 1923 is representative of these major earthquakes. Fig. 4 shows the epicenters of large earthquakes (i.e., those having a magnitude greater than 6.5) that occurred between 1885 and 1979 within 300 km of the TTBH site.

3. Shield Tunnels

3.1 Outline

The tunnel section of the TTB Highway is about 10 km long, or two-thirds of the total length of the 15.1-km highway. It runs from the Ukishima Access on the Kawasaki coast, sloping down through a sloped section into the seabed, then passing through a level section and finally up through a second sloped section, to the Kisarazu Island. Constructed midway along the level section between the Ukishima Access and the Kisarazu Island (at a point about 5 km offshore from the Ukishima Access) is the Kawasaki Island, where ventilation facilities are located. The horizontal alignment of the tunnel is basically straight. The sloped sections have been designed with a 4 percent grade in order to shorten the sections as much as possible. The level seabed section has a 1.0 D-thick overburden (where D is the tunnel outer diameter), so that the combined weight of the overburden and tunnel structure will counteract buoyancy forces.

Fig. 6 shows the basic tunnel cross section.

3.2 Tunnel Design

Since the tunnels would be driven under the severe conditions outlined below, careful and extensive deliberation went into the design and execution work, including meetings of a committee that included advisory experts.

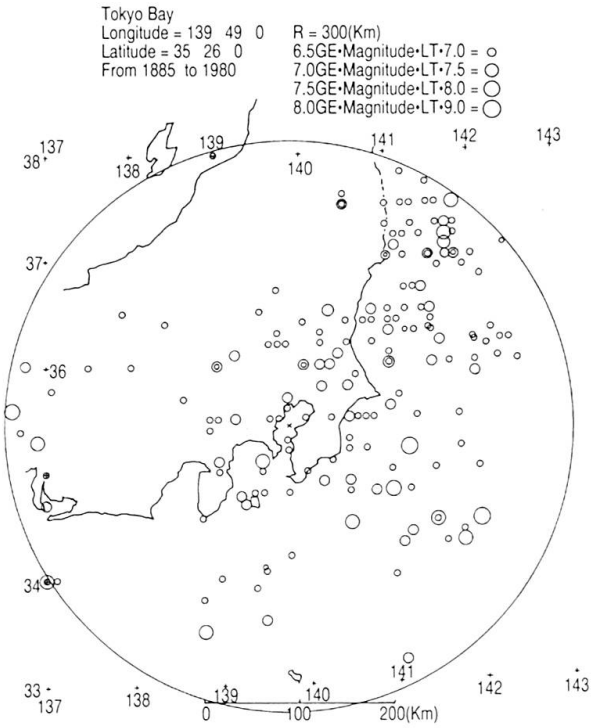

Fig. 4 Earthquakes of magnitude ≥ 6.5 that have occurred within a 300-km radius of the center of Tokyo Bay from 1885 to 1990

Fig. 5 Highway structures of the marine section

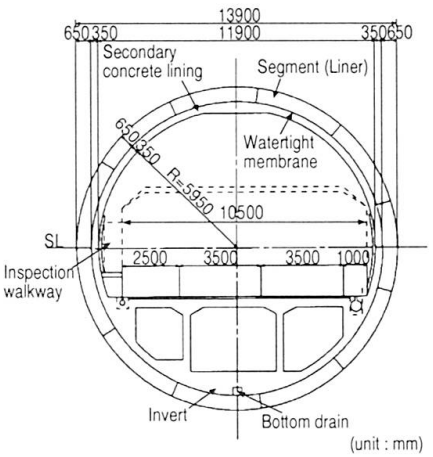

Fig. 6 Tunnel cross section and traffic lanes

1) The roadway configuration would necessitate construction of a shield tunnel having a large cross section (13.9 m in diameter), and requiring long-distance tunneling operations.

2) The tunnels would be driven through soft ground, and in a seismically active area.

3) Since the water depth at the site is high (the maximum head would reach 50 to 60 m), and because there is no impermeable layer, the tunnels would be subject to extremely high water pressure (0.49 to 0.59 MPa).

4) The tunnels would experience the corrosive effects of salts contained in the sea water.

5) The structure being a twin tunnel spaced 0.5 to 1.0 D along the sloping sections and 1.0 D along the level seabed section could cause construction work on one tunnel very easily affecting the other. Shield tunnel cross effects had to be considered in the tunnel design.

6) The tunnels being long, several shield machines would have to advance concurrently from the vertical shafts at the Ukishima Access, Kawasaki Island and Kisarazu Island in order to shorten the construction period. Underground connections would therefore be made below the seabed and under high water pressure.

7) To enhance both safety and work precision, there would be a need to automate various operations such as excavation and assembly of segmental ring liners.

3.3 Standard Specifications for the Shield Machines

Twin parallel tunnels are being driven between the Ukishima Access and the Kawasaki Island, and between the Kawasaki and Kisarazu Islands, making a total of eight work sections. Tunneling involves eight shield machines, each starting from one of the vertical access shafts at the Ukishima Access, Kawasaki Island and Kisarazu Island, to eventually connect below the seabed.

Fig. 7 shows the front view and cross section of the shield machine, and Fig. 8 shows a shield machine assembled at the fabricating plant.

① Basic configuration
a. Bore diameter: 14.14 m
b. Shield machine length: 13.5 m
c. Total weight: 29.4 to 31.4 MN

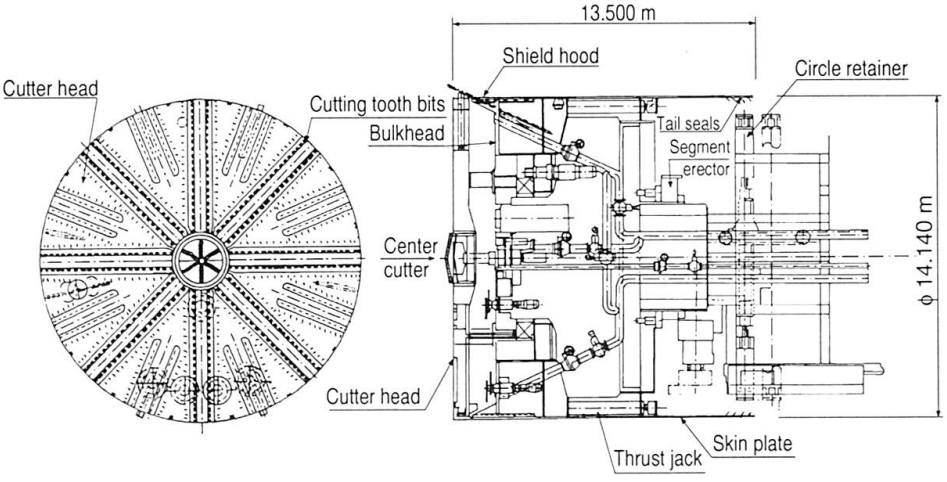

Fig. 7 Slurry shield

② Driving machinery

a. Total thrust: 235 MN (48 jacks with 4.9 MN capacity)

b. Jack stroke: 2,550 mm

Fig. 8 Shield machine

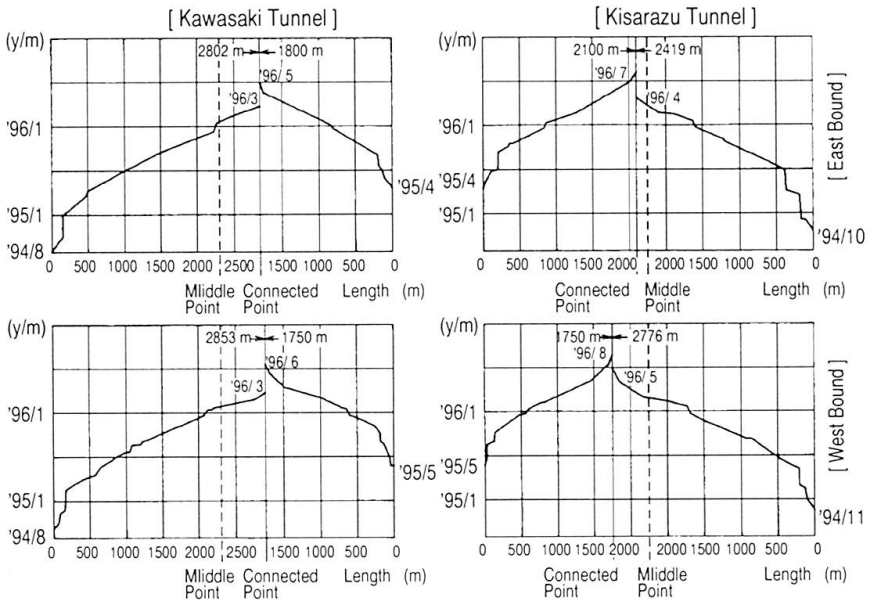

Fig. 9 Tunneling construction process

3.4 Rapid Tunneling

Fig. 9 shows the tunneling progress record of those 8 shields, which bored tunneling length of 1,750 m to 2,853 m. The shields advanced average 150 m or more monthly, which was beyond expected schedule. The best monthly progress is 310.5 m.

4. Afterword

Twenty years after the preliminary feasibility study, the project finally started with a newly organized system taking advantage of vital capacity of the private firms, and it has now achieved over 90 % of completion. It is expected that the highway will be open by the end of 1997. In the project implementation, adequate considerations have been given to the natural and living environment, and navigational safety in the area, and the construction safety. The authors wish to express their indebtedness and thanks to each and every personnel of various organizations involved in the project.