Tokyo-wan Aqualine - Experience of Traffic and Safety

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1. General planning

The area around the Tokyo Bay locates the major Japanese industries, at the same, the dwelling area of about 30 million people, a quarter of the Japanese population.

The conditions for this project have been difficult. The tunnel is located in a seismic active area, which consists of very soft soil that might be compared with soft cheese. In addition, the route crosses an important sea route with many international vessels, and it was necessary to maintain safety standards at highest level.

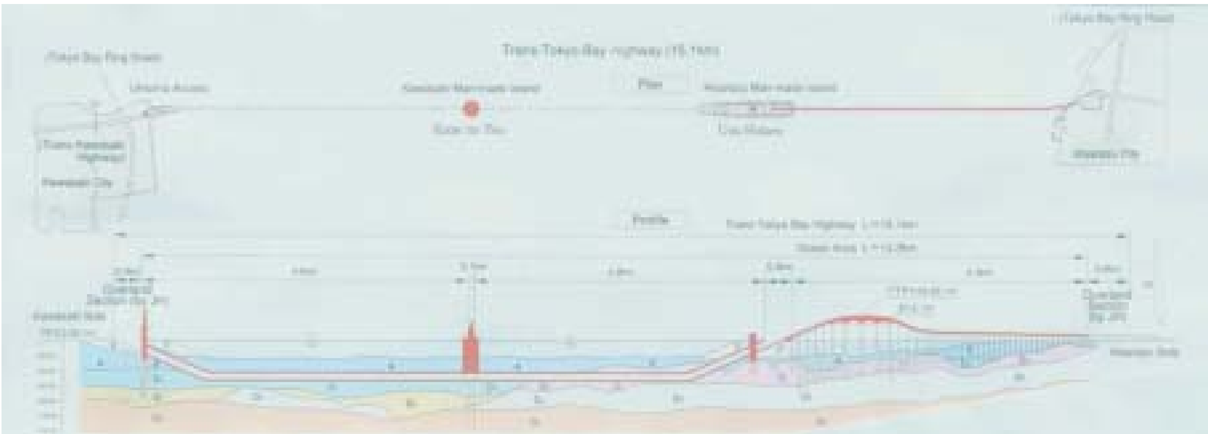
In spite of these and other conditions, the road was realized with a total length of 15 km, consisting of a 9.5 km long tunnel to the west, a 4.4 km long bridge to the east, and two man-made islands. The connection was opened to traffic on December 18, 1997, and an average traffic volume of around 10,500 vehicles per day has been observed in January 2001 (Figure 1).

In the first stage, the design consisted of an immersed tunnel with rectangular cross section and transverse ventilation, in combination with a bridge structure under the heavy sea traffic. Since the 1970's, however, tunnel construction based on the shield methodology has been applied in Japan for a wide range of purposes such as High Speed Rails, metros, sewerage etc. In addition, the sea traffic on the west side of the route is very heavy. In 1985 it was therefore decided to change the first plans and to apply the shield methodology to construct a tunnel consisting of two tubes with an outer diameter of about 14 m, each with two traffic lanes (Figure 2).

The excavation works were finished in June, 1997, and the route was opened to traffic on December 18, 1997. Figure 3 presents the general layout of the tunnel. This layout is representative for the whole tunnel.

Figure 1: Location map

Figure 2: Shield machine transportation



Symbols	Layer	
F	Embankment	
A	Yurakucho layer	
D_1	No.7 layer	Upper layer
D_2		Lower layer
D_3	Layer equivalent to lower Narita layer	
D_4	Layer equivalent to Naganuma, Byoubugaura layer	
D_5	Upper Joso layer	

Figure 3: General layout of Tokyo-Wan Aqualine [1]

Figure 4 presents Ukishima portal with ventilation building, which is located at west side of tunnel. The Kawasaki Man-Made Island (Japanese: “Kaze no Tou” or “Tower of Wind”) with a diameter of 100 m (Figure 5) has a twofold function: vertical shaft as base where the shield machines started during construction, and for tunnel ventilation during operation.

Figure 4: Ukishima Ventilation tower and entrance (west exit)

Figure 5: Ventilation tower Kawasaki Man-Made Island (Kaze no Tou)

The Kisarazu Man-Made Island (Japanese: “Umi-Hotaru”, or “Sea-Firefly”) located on the east portal of the tunnel forms the connection between the bridge and the tunnel section. In the five story building on this island the power equipment room and equipment for tunnel users are installed, including:

- Information center for T.T.B. and the total Metropolitan Highway network
- Technical information center about T.T.B.
- Exhibition hall with information about emergency equipment
- Rest lounge with free of charge tea
- Restaurants, shops
- Parking area (for 80 trucks, 396 passenger cars).

Because of its architecture and layout, the building gives the impression of being a large passenger ship (Figure 6). Figure 7 shows the Bridge section of Trans Tokyo Bay Highway.

Figure 6: Kisarazu Portal on man-made island (Umi-Hotaru)

Figure 7: Bridge section [1]

2. Safety Facilities for the Tokyo-Wan Aqualine

2.1 Ventilation system

As described above, in the first planning stage an immersed tunnel was considered with a transverse ventilation system. Since the late 1960's, emission of exhaust gas from vehicles has been regulated, resulting in a reduction of carbon monoxide emission, and required air volume for tunnel ventilation is often controlled by visibility based on the haze. After that, longitudinal ventilation with electrostatic precipitators was developed in the 1970's. This system removes soot from the tunnel space and the ventilation air volume can be reduced, and was verified to be more economic both in terms of cross section and power consumption for ventilation system for T.T.B. in this way.

Table 1 presents the basic conditions of the tunnel ventilation planning. Table 2 presents the calculated results of required air volume for tunnel ventilation. Figure 8 presents the total ventilation system.

Type of ventilation	Longitudinal system with vertical shaft and electrostatic precipitator
Design traffic volume	2,470 veh./hour/tube
Large veh.(diesel)content	28%
Design vehicle velocity	50 km/h
Cross section	A_r=78.4 m^2
Hydraulic diameter	D_r=9.1 m
Visibility τ ,K	τ =40%(per 100 m), K=9×$10^{-3}m^{-1}$
Concentr. carbon monox.	CO:100 ppm

Table 1: Condition for tunnel ventilation [3]

(m^3 / s x tube)

	Smoke visibility	Carbon monoxide
East bound	1,622	461
West bound	1,532	461

Table 2: Required air volume [3]

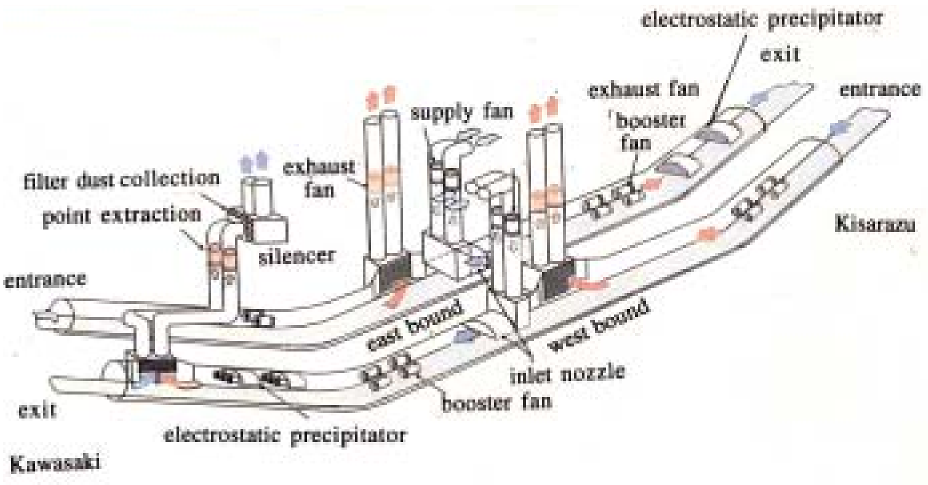


Figure 8: Total ventilation system of T.T.B. [2]

Five electrostatic precipitators have been applied to the ceiling near the exit portal at the Kisarazu Man-Made Island in the up grade section of the east bound tube. Normally, a by-pass tunnel is constructed for electrostatic precipitators, but in this tunnel built with shield method this was not possible for construction reasons. Instead, the electrostatic precipitators were installed at the top of the roadway space.

2.2 Smoke and fire control in the case of fire

The Japanese law does not allow the transportation of dangerous goods through underwater tunnels and long tunnels of over 5,000 m, which law also applies to the tunnel. The ventilation operation system for tunnels with a longitudinal ventilation system is such that in case of fire outbreak, a flow with velocity of more than 4.5 m/s in entrance part (with 4 % vertical inclination) and 2.5 m/s in other parts must be maintained in the same direction as the traffic, in order not to let the smoke flow in the direction of the tunnel entrance.

2.3 Safety equipments

2.3.1 Introduction

In order to limit the damage in case of fire and other incidents as much as possible, safety facilities are installed in accordance with the Japanese Road Law. The design and installation of the tunnel equipment follows the principles as other large-scale road tunnels.

Figure 9 shows the representative layout of the safety system in the tunnel.

Table 3 presents the safety facilities of the Tokyo-wan Aqualine.

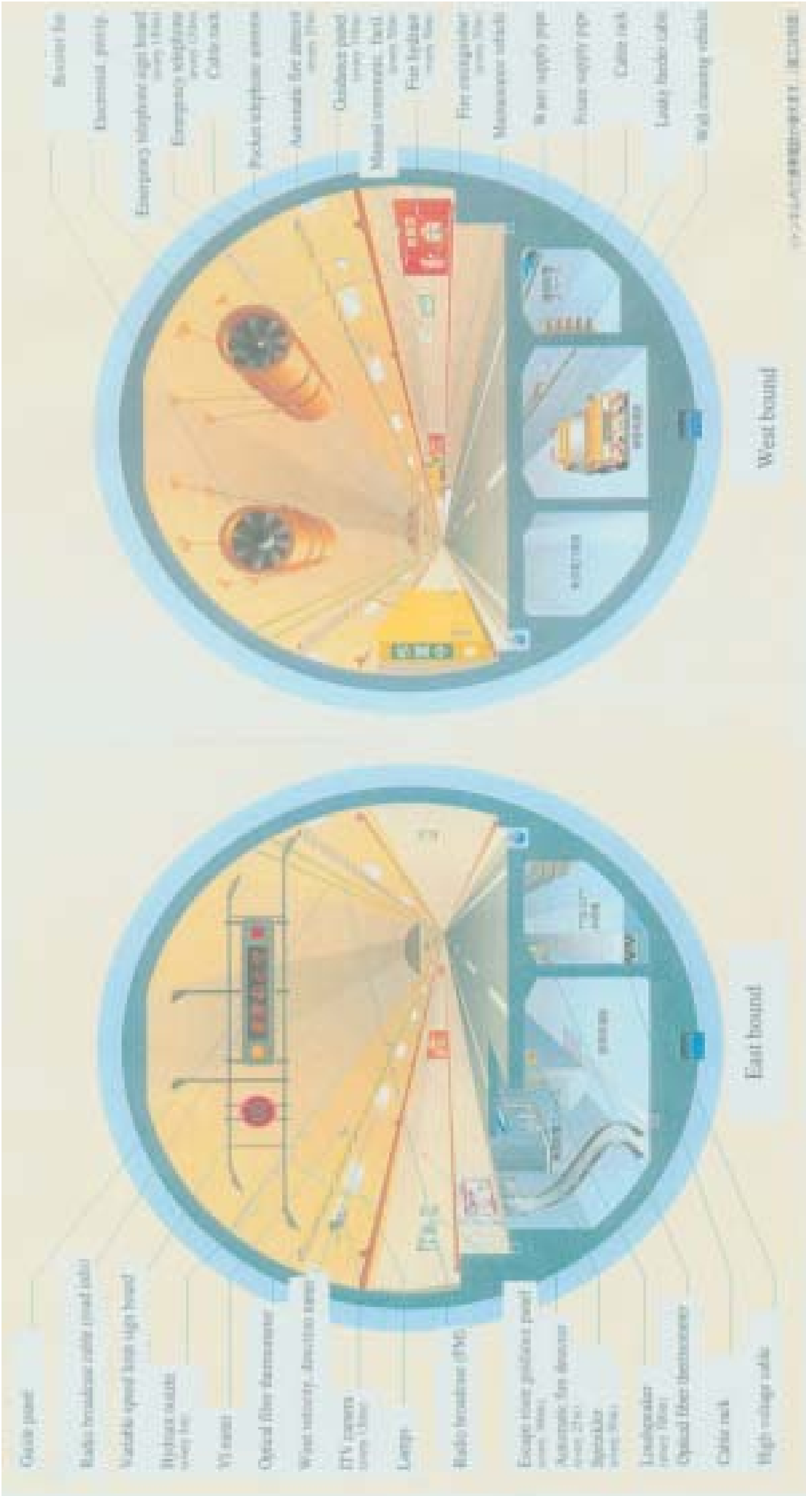


Figure 9: Standard cross section tunnel section [2]

Function		**Item**		**Spacing, Position, etc**		**Remark**
				Above road surface	**Evacuation space carriage way**	
Fire detection		Emergency telephone		150 m	Near escape route	
		Push button		50 m	-	Combined with fire hydrant
		Fire detector		Approx. 25 m	-	
Situation monitoring		ITV cameras		Approx. 150 m	-	
Initial fire fighting		Fire extinguisher		50 m	-	Combined with fire hydrant
		Fire hydrant		50 m	-	
Control of fire spread		Water sprinkler		Installed	-	With foam possibility
Guidance for evacuation	Escape ute	Escape route (slide)		300 m		Located in combination with Fire Brigade entrance
	Information to drivers	Emergency sign board	Before entrance or in tunnel	Near portal or in tunnel	-	
		Broad casting		Installed	-	Leaky feeder cables
	Guidance facilities	Guidance panels		150 m	300 m	Above road surface: escape guidance panels, emergency indication lamp In duct under road way: located near escape route
		Loudspeakers		Near evacuation way		
Fire fight support	Access	Fire bridge entrance		300 m		Located in combination with evacuation route
		Tunnel information facilities		Installed	-	On Kawasaki and Kisarazu side
		Rescue Vehicles in evacuation space		-	Installed	Specialized 2 t truck
		Helicopter platform		Kawasaki, Kisarazu Man-made Island		
		Ship landing space				
	Equipment	Water hydrant		150 m	Near route for Fire Brigade	Above road surface: located in accordance with entrance for Fire Brigade
		Water hydrant system		Near portal or at Kawasaki Man-made Island	-	
		Wireless communication (tunnel inside to tunnel entrance)		Installed		Leaky feeder cable
Safety environment		Smoke extraction in combination with ventilation system		Installed		Overpressure for smoke control
		Lighting		Installed		
Uninterruptible power equipment		Uninter. Lighting system		Installed		
		Uninter. Power supply		Installed		

Table 3: Safety facilities of Trans Tokyo Bay Tunnl [3]

Figure 10 presents the whole view of carriageway after open to traffic in 1998.

Figure 10: Whole view of the carriageway

2.3.2 Evacuation facilities

In the earliest planning stage, on emergency cross-passage between the two tubes was planned at intervals of approximately 750 m, as presented in Figure 11. According to surveys and research carried out in Japan, the size of the emergency exit should be designed to be wide enough to allow two people to pass simultaneously, i.e., an effective width of at least 1.7 m.

Because the two tunnel tubes will move separately in case of an earthquake occurring in soft soil 60 m under the sea level, resulting in a large stress-strain force working on the connecting part, it was decided not to install cross-passages (Figure 11). Instead, it was decided to use the space below the road surface as evacuation space. The basic policy is as shown in Figure 12, consisting of equipment to evacuate from the inspection gallery to the space under the road surface. Such an arrangement reduces the space of the tunnel structure, installing it impossible to install ordinary staircases.

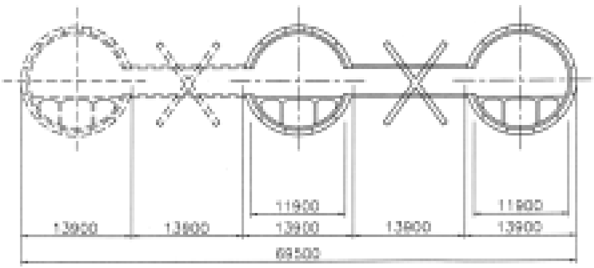


Figure 11:
Abandoned plan of cross passage

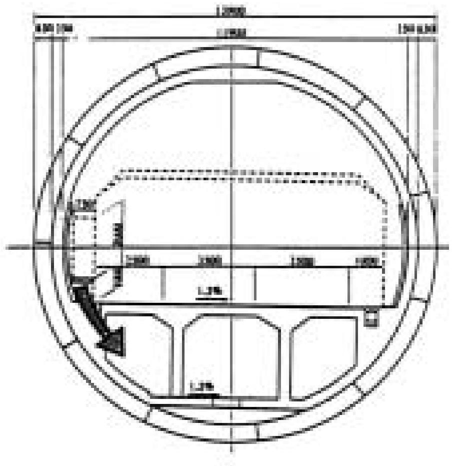


Figure 12:
Principle of evacuation from road surface to evacuation space under road revel

To produce a full-scale test structure of wood and verify the performance for actual tunnel users and fire brigade. These test structures were placed in a test tunnel to carry out a first survey, which resulted in the slide to be selected as the best structure for an evacuation route. Figure 13 shows members of a rescue team inspecting the slide.
Following this test, the fire brigade was allowed to verify the fundamental quality of the slide, since firemen will also use the slides during their activities. Figure 14 shows the fire brigade testing the slide in the full scale model.

Figure 13:
Simulation of evacuation facilities

Figure 14:
Firemen verifying the quality of slides

The capacity of the evacuating people for the slide is about one-half to one-third that of connecting routes with escape doors. Therefore, in order to obtain the same capacity as ordinary cases in Japan, it was necessary to install the slides at intervals of one-half to one-third of normal cases. Because intervals between connecting routes are about 750 m, the slides had to be installed at intervals of about 300 m.

During the full-scale experiment, it was relatively easy to evacuate from the road surface to the evacuation space under the road surface, but ascending to the road surface from the evacuation space was rather difficult. Also, if the slide gets wet from water used in fire-fighting, the slide gets slippery, and the slide was made anti-slip.

Figure 15 shows an example of a slide installed in a real tunnel. Based on experiment results, the slide consists of pipes. Figure 16 shows the service tunnel below the carriage way.

Figure 15: Slide connecting the carriage way and the evacuation space

Figure 16: Service tunnel below carriage way possibility to operate small emergency vehicle)

2.3.3 Tunnel structure for safety

On the side of the road there is a sidewalk 1 m high and 75 cm wide. This type of high side walk is generally applied in large scale tunnels in Japan. A main advantage of this height is that normal maintenance works can be carried out safely and rapidly, even with traffic passing by at high velocities.

Because maintenance of this equipment over the whole length of the tunnel is time-consuming, small vehicles can run over a rail on the sidewalk for maintenance works without having to regulate the traffic (Figure 17).

Figure 17: Maintenance vehicles

3. Public Relations for Tunnel Safety

3.1 General

In 1979, a serious tunnel fire occurred at the Nihonzaka Tunnel in Japan, leaving seven people dead, two people injured and 173 vehicles burnt out. Following the incident, many discussions between related agencies resulted in the recognition that public relation towards the tunnel users is highly important. The following two measures have since been implemented:

- Full-size emergency equipment is placed at service areas near tunnels for demonstration. Explain how equipment is used and let tunnel users try to use this equipment (Figure 18).

- Leaflets are placed at all service areas and parking areas to explain clearly about how to use the tunnel equipment and which activities to take in case of emergency in the tunnel. The leaflet is free, can be obtained by anyone, and is compact so that it can be kept in the vehicle for reference at all time (Figure 19).

Figure 18: Display of fire-fighting equipment and systems at the service area near tunnel

Figure 19: Front page of emergency leaflet ("In case of tunnel emergency")

3.2 Public Relations for Safety at the T.T.B Tunnel

The T.T.B. Tunnel is the longest under water road tunnel in Japan, and is equipped with safety equipment that combines the newest technology. On the other hand, most drivers have never used these facilities. Also, the tunnel layout and structure is different from other Japanese tunnels. Therefore, it is necessary to well inform tunnel users about the newest tunnel facilities. For these reasons, there is an exhibition hall in the service area of the Kisarazu Man-Made Island (Umi Hotaru). Displays of the tunnel facilities, safety equipment, and the tunnel characteristics (Figure 20-23) are available, including:

- An introductory video describing the total T.T.B. Project;
- A driving simulator and video about emergency situations;
- A full-scale emergency door and slide;
- A fire hydrant, fire extinguisher, emergency telephone;
- A leaflet explaining emergency facilities;
- An information center.

The exhibition hall is open to public everyday at no charge, and visitors can touch all of the equipment a display.

Figure 20: General view of exhibition hall

Figure 21: Full-scale fire fighting equipment and push button displays

Figure 22: Full-scale slide for evacuation

Figure 23: Driving simulator for emergency

3.3 Operation system of the Trans Tokyo Bay Highway

The control system of the total route is incorporated in the highway network of Tokyo area, which control is carried out by the main control center located at about 100 km from the tunnel. The communication in case of emergency is regulated in such way that the Police and Fire Brigade are alerted immediately, in order to assure optimal action in accordance with the accident scale.

Before opening, a large scale exercise was conducted in the completed T.T.B. tunnel, involving tunnel controllers, Police, Fire Brigade, local hospital and other related parties. The management system for emergency cases was further explained and tested. Also after opening to traffic, similar exercises have been conducted.

In case of tunnel fire, the variable message boards at the tunnel entrance and inside the tunnel are set to stop vehicles from further entering the tunnel. At the same time, the vehicle velocity at downstream from fire point is higher than the smoke velocity. Therefore, no information is given to the drivers between fire and tunnel exit, in order to let them leave the tunnel at normal speed and without panic. This means that information to drivers will not be the same over the whole length of the tunnel.

4. Conclusions

The T.T.B. Highway project represents the highest levels of Japanese construction and technology. The project is internationally well known for its rapid completion time of 8 years 7 months. It will serve as experience for future project, both in Japan and internationally. No fire has occurred in the tunnel, and the tunnel is operating successfully in serving to transport drivers across the Tokyo Bay rapidly and safely.

In recent years, a number of large-scale fires have occurred in vehicle tunnels. We, as tunnel engineers, should take these facts very seriously, and should at the same time ensure that correct information about these facts is available to each other.

In Japan, a number of road tunnels, including large-scale urban tunnels, are in planning and construction phase at the moment, and investigations concerning tunnel fire and tunnel safety are being repeated.

In order to further improve the technology level for tunnels, also from now on it is necessary to maintain information exchange on an international level.

References

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[2] Trans-Tokyo Bay Highway Corporation 1997. Tokyo Bay Aqualine (brochure, Japanese)

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