Construction of Cocoon Shaped Shield Tunnel in Densely Populated Lowland to Drain Storm Water

Mitsuhisa Hamada
Tokyo Branch of Japan Sewage Works Agency
Yutaka Kashima
Daiho Construction Co., Ltd.

I. Introduction

Narashino City (Chiba), located about 25 km east of Tokyo, is being rapidly urbanized as its population has sharply increased in these years. The Tsudanuma area in this city faces Tokyo Bay and consists mostly of lowlands. Like other areas of the city, this lowland area is densely populated. During the rainy season, not a few houses in this area are often flooded with storm water.

In view of this, a new sewerage tunnel (Kikutagawa River No. 2 Trunk Sewer) is being constructed to drain storm water. This trunk sewer has a total extension of 4.1 km and a drainage area of 601 ha. Planned drainage capacity is 41.6 m^3/s for rain water (design rainfall intensity: 50 mm/hr) and 0.741 m^3/s for sanitary sewage. Both sanitary sewage and rain water are collected by a combined system of sewerage. Along the way, rain water is separated from sanitary sewage and discharged into Tokyo Bay.

In the trunk sewer work, the order for which was placed by Japan Sewage Works Agency in November 1990, a cocoon shaped shield tunnel was constructed for the sewer for the first time in the world.
The salient characteristics of this tunnel are as follows.
(1) The minimum overburden is as small as 2.15 m.
(2) The tunnel runs across two railway tracks underground. The overburden of the railway track on the downstream side is 2.5 m.
(3) Above the tunnel is a 9.5 m wide road where there is much traffic. There are also many houses on both sides of the road.

II. Tunnel Route and Geological Feature

The tunnel was constructed in two phases. In the first phase, a tunnel approximately 586 m in length was built from the starting shaft downstream. In the second phase, a tunnel approximately 117 m in length was constructed from the same starting shaft upstream (Fig. 1).

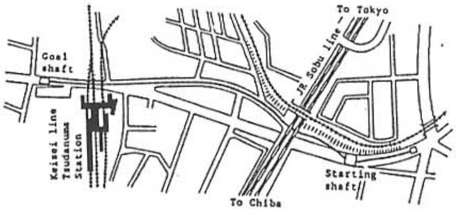

Fig. 1 Tunnel route

The ground of the tunnel site consisted of alluvial deposits sandwiching a humus soil layer Ap, whose maximum water content in percent of dry weight was 380%, and a fine sand deposit Ds, whose N value ranged from 10 to 30 and whose permeability coefficient was approximately 10^{-3} cm/s (Fig. 2).

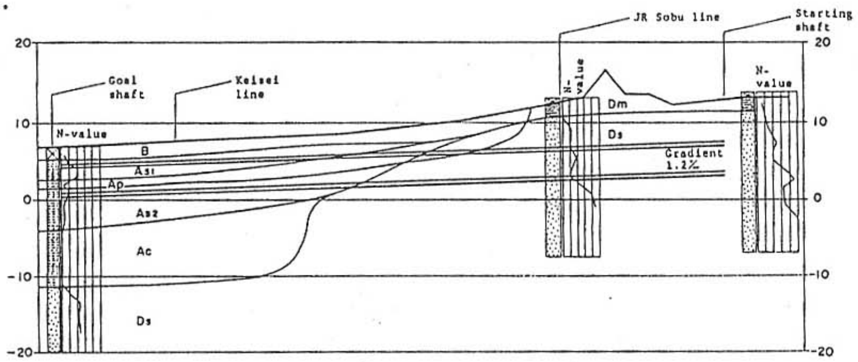

Fig. 2 Soil profile

III. Selection of Tunnel Construction Method

In the tunnel construction project, a double box culvert by the open-cut method was considered first. However, this method was not adopted because it was considered extremely difficult to use the method to construct a tunnel running across two railway tracks underground and because it was expected that applying the method would seriously interfere with the road traffic and cause much inconvenience to the people in the neighborhood.

So, a round shield tunnel was considered next. This idea too was abandoned for the following reasons. With a single round shield tunnel, the tunnel inside diameter must be 4,750 mm (segment outside diameter: 5,700 mm) to secure the design flow rate. In this case, the required overburden can hardly be secured. With a shield tunnel having two round tunnels, each being 3,500 mm ID (4,300 mm OD), the overall tunnel width becomes approximately 11 m because a space of 2.2 m (OD x 0.5) must be provided between the two tunnels. In this case, the tunnel width exceeds the road width (9.5 m), hence the tunnel must be dug under private property.

Finally, a cocoon shaped tunnel was studied. The tunnel of this type that meets the design flow rate is one having a horizontal diameter of 7,500 mm and a vertical diameter of 4,300 mm as shown in Fig. 3. In this case, the tunnel width falls within the road width. Ultimately, this idea was adopted.

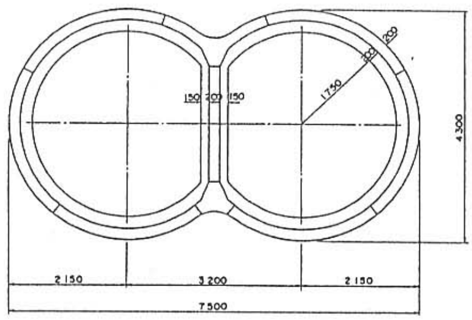

Fig. 3 Cross-sectional view of shield tunnel

To construct the cocoon shaped shield tunnel, the Double-O-Tube (DOT) method which offers a very stable facing was adopted in view of the unusually small overburden and small uniformity coefficient of the fine sand layer through which the tunnel was to be excavated. (DOT was invented by Daiho Construction Co. in 1981.)

IV. Outline of Work Execution

It is extremely difficult to construct a tunnel in a densely populated city, as in the present project. Therefore, various types of advanced new technologies were required to construct the present cocoon shaped tunnel.

(1) DOT shield

The DOT shield consists of a couple of round muddy soil pressure shields. Two spoked cutters engaged with each other in the form of a gear and arranged on the same plane cut the facing. The two cutters turn in opposite direction and are controlled in synchronization (Fig. 4, Photos 1 and 2).

Principal specifications

Shield		
Outside diameter		4450 x 7650 mm
Length		5100 mm
Shield jack		120t x 1050mm x 16
Shield jack		150t x 1050mm x 8
Cutter head (x 2)		
Speed		1.5 r.p.m.
Torque	Maximum	172.5 t-m
	Rated	115 t-m

Screw conveyor (x 2)	
Capacity	$54m^3$/Hr (soil discharging efficiency = 100%)
Length	7100 mm
Blade diameter	520 mm
Speed	0 - 15 r.p.m.
Erector (x 2)	
Speed	1.0/0.8 r.p.m.
Rotational angle	±200

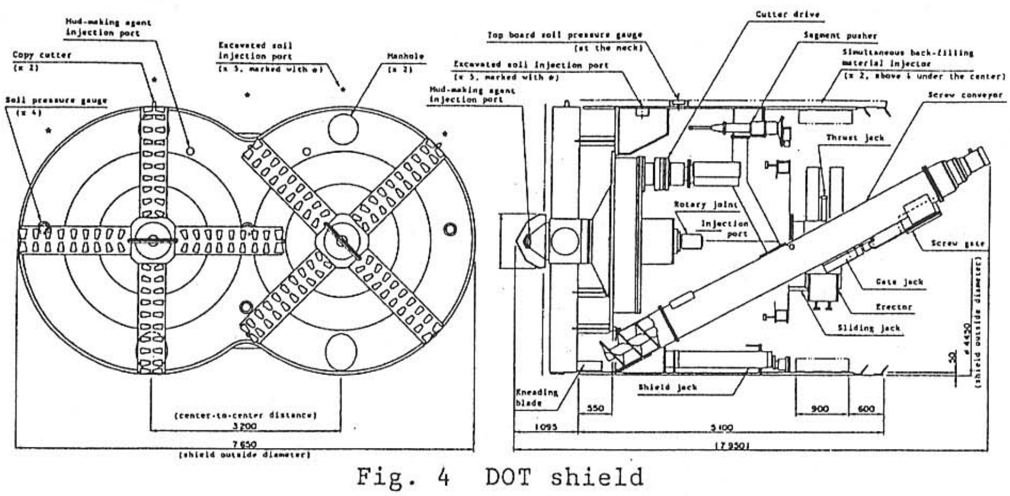

Fig. 4 DOT shield

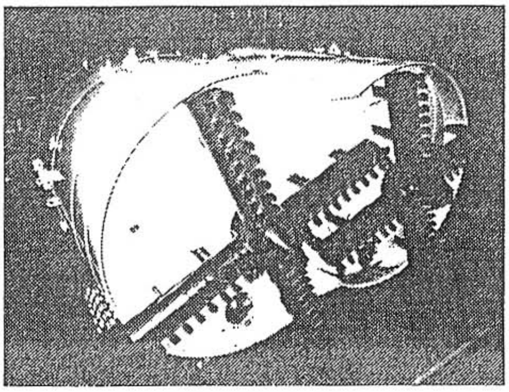

Photo 1

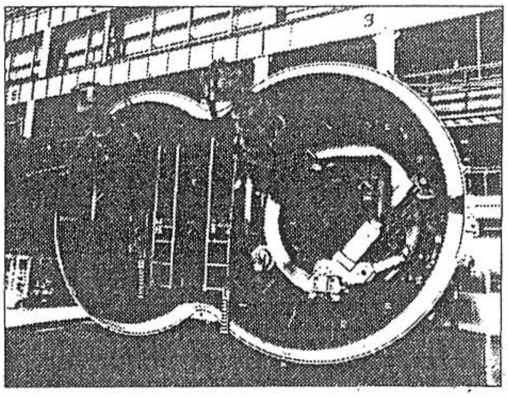

Photo 2

This shield has the following features.

1) Cutter revolution synchronous control system

Each of the cutters is driven by an electric motor. Since the motors are synchronized by a special inverter, the cutters do not hit against each other.

2) Simultaneous back-filling device

The shield necks are provided with a back-filling injection pipes which automatically injects the back-filling material at a proper rate as the shield moves ahead. This enables the gap between the segment and surrounding ground to be instantly filled with back-filling material, preventing the settlement of ground.

3) Injection of lubricant agent

In excavating a section having a small overburden, a lubricant agent is injected from five ports in the front end of the shield to prevent the shield from pulling in the ground above it.

(2) Segment

A special segment was developed for the present cocoon shaped shield tunnel. This segment is made of 900 mm wide reinforced concrete as shown in Fig. 5. It consists of six circular arc segment blocks, two connecting segment blocks, and one column segment.

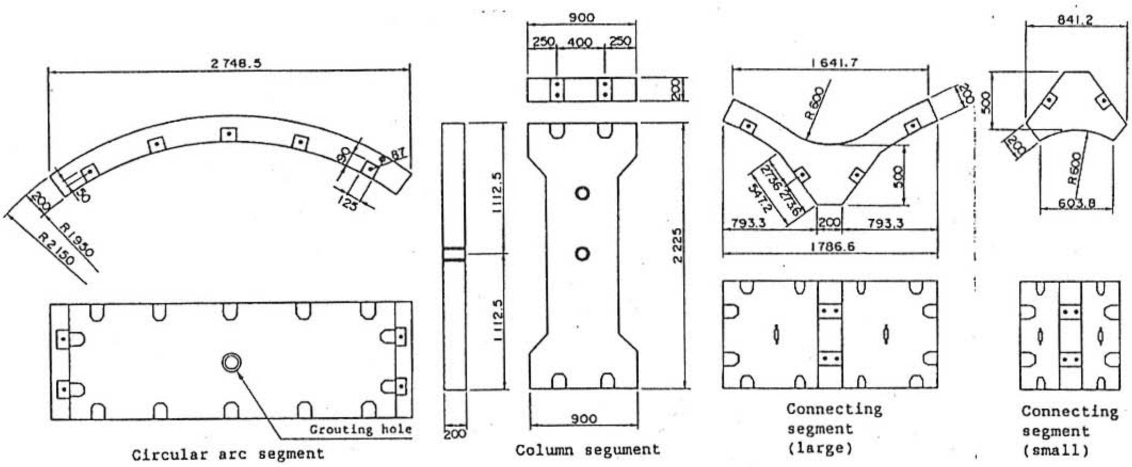

Fig. 5

(3) Discharge of excavated soil
Excavated soil discharged from the screw conveyors on both sides of the shield is pressure-fed to soil hoppers installed on the ground by pressure pumps provided at the back of the shield.

(4) Auxiliary methods
1) Protective work at intersection with JR line: The ground in this section was improved by the dual-pipe double packer injection method.
2) Protective work at intersection with Keisei line: Since this section had a very small overburden (2.5 m), the combination of pipe roof and dual-pipe double packer method was used for protection (Fig. 6).

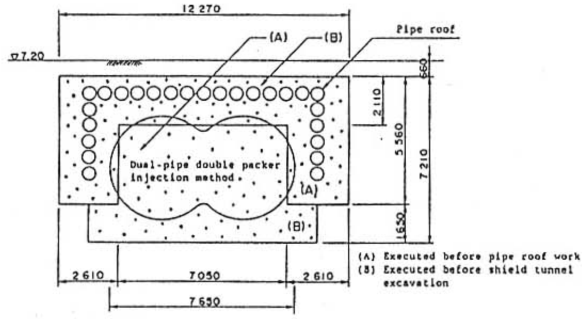

Fig. 6 Cross-sectional view of protection in intersection with Keisei/Shin-Keisei line

3) Protective work in sections with small overburden: In the sections where the overburden was less than 4.45 m, the ground was improved by the column jet method (thickness: 1 m) to prevent the collapse of the ground above the shield during excavation, as well as the settlement of surface ground. In addition, in the sections where there were houses nearby, column jet piles type were driven along the tunnel route to stabilize the ground on both sides of the tunnel.

V. Results of Work Execution

(1) Facing stabilization control
The shield facing was stabilized by controlling the pressure of muddy soil in the chamber. The muddy soil pressure used was 0.5 to 0.7 kg/cm^2 for small overburdens and 0.8 to 1.0 kg/cm^2 for 5 to 6 m overburdens. In addition, the disturbance of ground surface was fed back to control the excavation.

(2) Cutter torque and jack thrust
The shield cutter torque required was 60 to 80 tf·m for each cutter, less than one-half of the maximum available torque. The jack thrust required was 950 to 1,400 tf.

(3) Control of rolling
Thanks to proper functioning of the stabilizer, the shield rolling could be always controlled within the preset critical angle (+-0.15 degree).

(4) Settlement of ground surface

The settlement of ground surface was very small—12 mm or less for small overburdens, 2.5 mm for intersection with the JR line, and 2 mm for intersection with the Keisei line.

(5) Excavation speed

The tunnel was excavated at an average rate of 7.2 m/day (20 hours of work a day), maximum speed being 10.0 m a day.

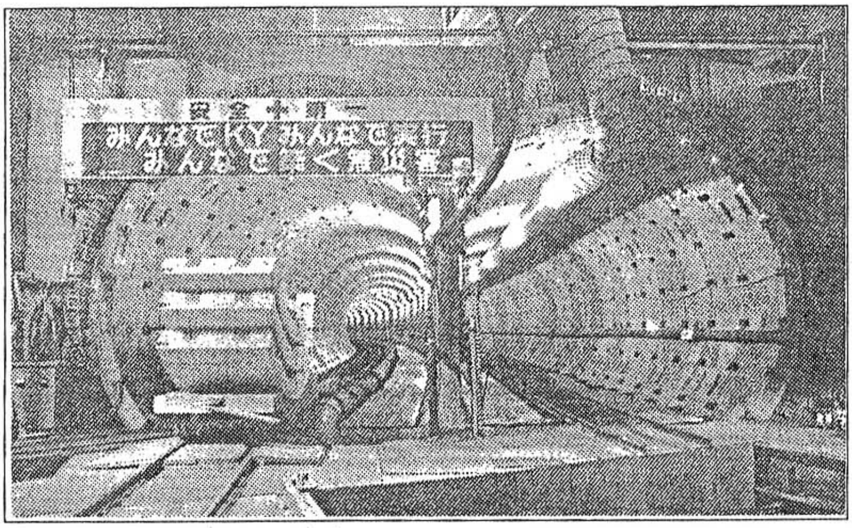

Photo 3

VI. Conclusion

Constructing a storm rain drainage tunnel under a road in a densely populated urban area is an extremely difficult job. Despite the extremely severe conditions, however, we could successfully construct the world's first cocoon shaped shield tunnel for a sewer, comparable to a conventional round shaped shield tunnel, by employing the DOT method. The success in the present project has opened a new way to counter storm water in densely populated urban areas and increased design flexibility.

It is hoped that the present paper will be of help to those who are planning to execute similar projects.

References

1. K. Miya, T. Watanabe, F. Tada, "A Multi-Face Earth Pressure-Balanced Shield Tunneling Method" International Symposium on Unique Underground Structures Proceeding Volume 2, 1990.