Utilization of Tunnels and Underground Space in Tokyo

H. Akagi
Waseda University, Tokyo, Japan, akagi@waseda.jp

ABSTRACT: This paper summarizes the two recent case histories of tunnels and underground space utilization within the Tokyo metropolitan area and introduces a new textbook on underground construction technology in Japan, published by the Japanese Geotechnical Society.

1 INTRODUCTION

In the bulletin of this international workshop on geotechnical infrastructure for mega cities and new capitals, the motivation of this workshop is described as follows. The infrastructure of mega cities (and new capitals that eventually may become mega cities) requires geotechnical engineers to have distinct expertise as they have to deal with a variety of geotechnical fields and areas. The high cost of land results in high-density urbanization with high-rise buildings and expensive foundations; in certain communities, the poor population is forced to settle in inconvenient and cheap areas that have high geotechnical risks, such as unstable grounds in steep natural slopes and marshy and flood zones. The congestion in urban areas necessitates the use of underground space; shortage of land forces the use of abandoned industrial districts as residential areas in which there are inherent environmental risks for living on potentially contaminated ground.

One should invite geotechnical engineers to share their experience on foundations, slope stability, soft soils, tunnels, excavations, environmental geotechnics, etc. The idea is to invite experts from these fields, who are also members of other technical committees of ISSMGE, to interact with each other.

Taking this idea forward and representing the Technical Committee TC28 on Underground Construction in Soft Ground, this paper covers workshop theme No.5: Tunnels and Underground Space in Metropolises and summarizes the two recent case histories of tunnels and underground space utilization within the Tokyo metropolitan area. It also introduces the new textbook on underground construction technology in Japan, published by the Japanese Geotechnical Society.

2 TOKYO METROPOLITAN UNDERGROUND EXPRESSWAY

2.1 Project Overview

The Central Circular Route is a loop road around the centre of Tokyo, with a radius of about 8 km and a total length of about 46 km. This road can prevent chronic traffic congestion, and therefore its construction is vital. The north and east sections of the Central Circular Route (length of 26 km) have already been completed. The design and construction of the remaining sections has been proposed, as shown in Fig. 1. The Central Circular Shinjuku Route is the western part of the Central Circular Route (length of 11 km). It will have 4 lanes for two-way traffic, a design speed of 60 km/h, 5 entrances and exits, 3 junctions connected to other metropolitan radial expressways, and 9 ventilating shafts, as indicated in Fig. 2.

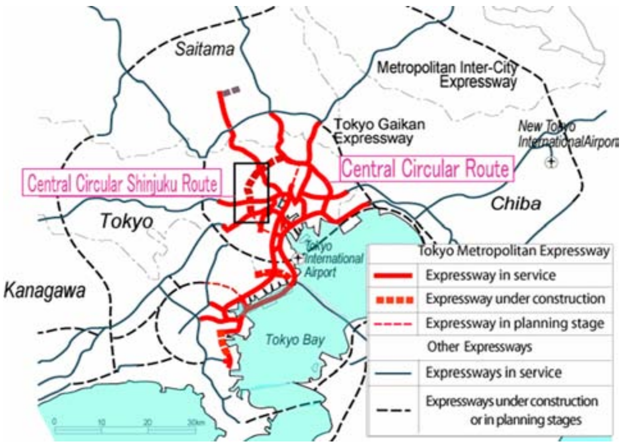

Figure 1. Outline of the route.

The Central Circular Shinjuku Route has recently been constructed under the loop Route No. 6, which is one of the trunk roads and has a spot traffic volume of approximately 30,000 vehicles/day. Therefore, the construction of the route should be carried out by retaining the present number of lanes currently in use, so that the traffic on the streets is not impacted in any way. This project has to be planned in a way so that there is minimal influence on the traffic in the neighbouring streets. 70% of the 11-km-long tunnel section will be constructed without cut-and-cover tunnelling methods. The shield tunnelling method will be mainly employed for the construction of the tunnel. This will help in reducing both the construction expenses as well as the time required for the construction.

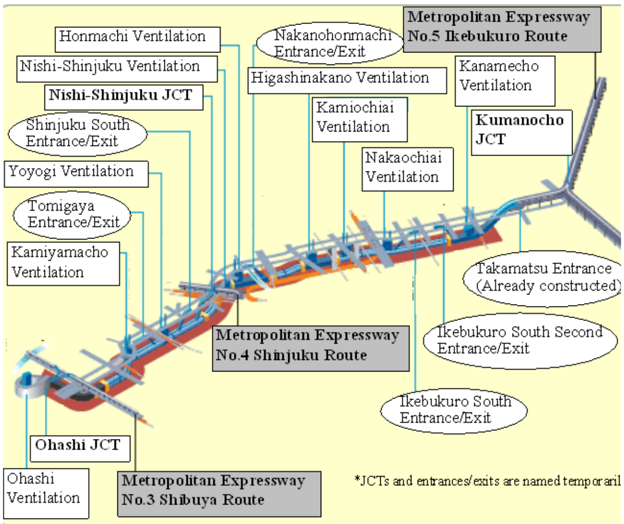

Figure 2. Entrances and exits of Central Circular Shinjuku Route.

While the surface layer of the ground at the site for the Shinjuku Route is composed of loam layer and the intersections of the road with rivers have alluvial deposits, the ground at the design depth is composed of the hard gravel stratum found in Tokyo and the Kazusa layer group with N-values exceeding 50. Moreover, since there are aquifers in this stratum, especially sand layers and gravel layers, ground water must be considered in both the design and construction of the tunnel.

2.2 Cut-and-cover Method With Special Procedure of Cutting Existing Steel Segments

The Central Circular Shinjuku Route (total length of 11 km) is mostly composed of a tunnel structure. The large-dimensional shield method is used for the construction of 70% of the total route. Eight ramp or junction sections are provided for the Central Circular Shinjuku Route. Five out of the eight ramps or junction sections of the route, such as the entrances and exits, are constructed in the shield tunnel sections.

The cut-and-cover method for shield tunnels with special procedure of existing cutting steel segments has been employed for the construction of a ramp or junction section. In this method, after two shield tunnels are constructed in parallel to each other, the ground over the ramp or junction section is excavated using the cut-and-cover method. The steel segments for each tunnel are cut open and a reinforced concrete frame body for supporting the ramps or junctions is constructed in them.

Usually, a shield tunnel is cut open after the completion of tunnel driving. However, in order to reduce the construction period in this project, the tunnels should be cut open right after the shield machines pass through the ramp or junction section. Consequently, the workspace for cutting the tunnels is greatly limited, as there must be adequate space for supplying materials to the tunnel face.

Conventionally, entrances or exits of underground tunnels are constructed as an integrated structure of the tunnel using the cut-and-cover method. However, the width of the entrances or exits in this project will be significantly wider than those in conventional cases. This is a cause for concern as the installation work would exert a large influence on the traffic in the streets and other underground structures.

The special cut-and-cover method for shield tunnels with cutting steel segments can limit such an influence on street traffic and reduce the scale of excavation, which can reduce costs and the construction period. With this method, the entrances and exits can be constructed at any location along a tunnel. This makes it possible to extend the length of the tunnel constructed by one shield TBM machine. This is the first application of the special cut-and-cover method for the construction of entrances and exits of road tunnels, and it involves many challenges. Some attempts have been made to overcome these challenges, and the feasibility of the method has been confirmed as described below.

2.3 Underground Structure

Figure 3 outlines the structure of the ramp or junction section constructed by the special cut-and-cover method for shield tunnels with cutting steel segments. The structure of the ramp or junction sections is complex because the depth of excavation by the cut-and-cover method and the area of steel segments cut open vary along the longitudinal direction of the route. This is because the shape of the reinforced concrete frame body varies along the route. The standard structure of the branching and joining section is shown in Fig. 4. This structure is a combination of the reinforced concrete frame body with relatively high rigidity and steel segments with flexibility. These two components are connected with shear connectors welded to steel segments.

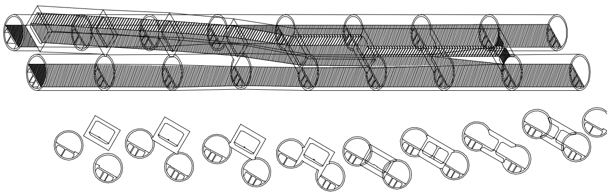

Figure 3. Structure of a branching and joining section.

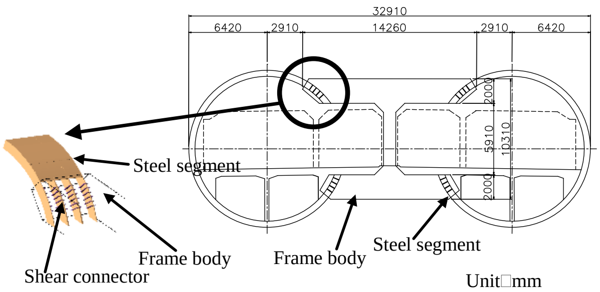

Figure 4. Standard structure.

2.4 Construction Procedure

Figure 5 shows the procedure for the construction of the ramp or junction sections. In this procedure, earth-retaining walls and water cut-off walls are constructed before the shield drive. Then, the ground is excavated from its surface after the tunnel has been provided with internal reinforcement to prevent its deformation by the excavation.

The top slab, bottom slab, and centre diaphragm are formed while the ground between the tunnels is excavated. Then, parts of the steel segments are removed. In this procedure, because the excavation with the shield machine is continued even after it passes through the ramp or junction section, as seen in Step 1, special cut-and-cover technique with cutting steel segments (as seen in Steps 2 to 6) is implemented simultaneously with segment supply and other work.

2.5 Project Summary

In August 2004, the tunnel was cut open in parallel with shield tunnel driving. The ramp and junction sections were constructed for entrances and exits. The route has been in use since December 2007.

The design details of the steel segments to be used in the cut and cover sections were influenced by the diverse nature of the ground deformation along the route of the tunnel. However, because this work includes processes that are employed for the first time, it is essential that the problems that may arise be resolved during the construction work. The construction has been carried out under various types of sustained measurement and management to ensure safety during work operations and produce high-quality structures.

3 TOKYO METROPOLITAN SUBWAY

3.1 New Subway in Central Tokyo

The Fukutoshin Line (subway No.13 in Tokyo), the section extending south from Ikebukuro, with Shibuya as the terminal, was originally planned by the Policy Report No. 7 of the Council for Japan Transportation**.** Subsequently, Policy Report No. 18 formulated in January 2000 planned the implementation of a reciprocal through-service with the Tokyu Toyoko Line.

As a part of this report, the sections between Shiki and Wakoshi, on the Tobu Tojo Line, and from Wakoshi to Ikebukuro on the Yurakucho Line (the section between Kotake-mukaihara and Ikebukuro has a quadruple track line) are already in operation.

The 8.9 km Ikebukuro-Shibuya section has been constructed by the Tokyo Metro Corporation, as shown in Fig. 6. The Fukutoshin Line is made up of the following sections: between Wakoshi and Kotake-mukaihara (common section, shared with the Yurakucho Line), between Kotake-mukaihara and Ikebukuro (quadruple track line, already in use) and between Ikebukuro and Shibuya (recently available for use).

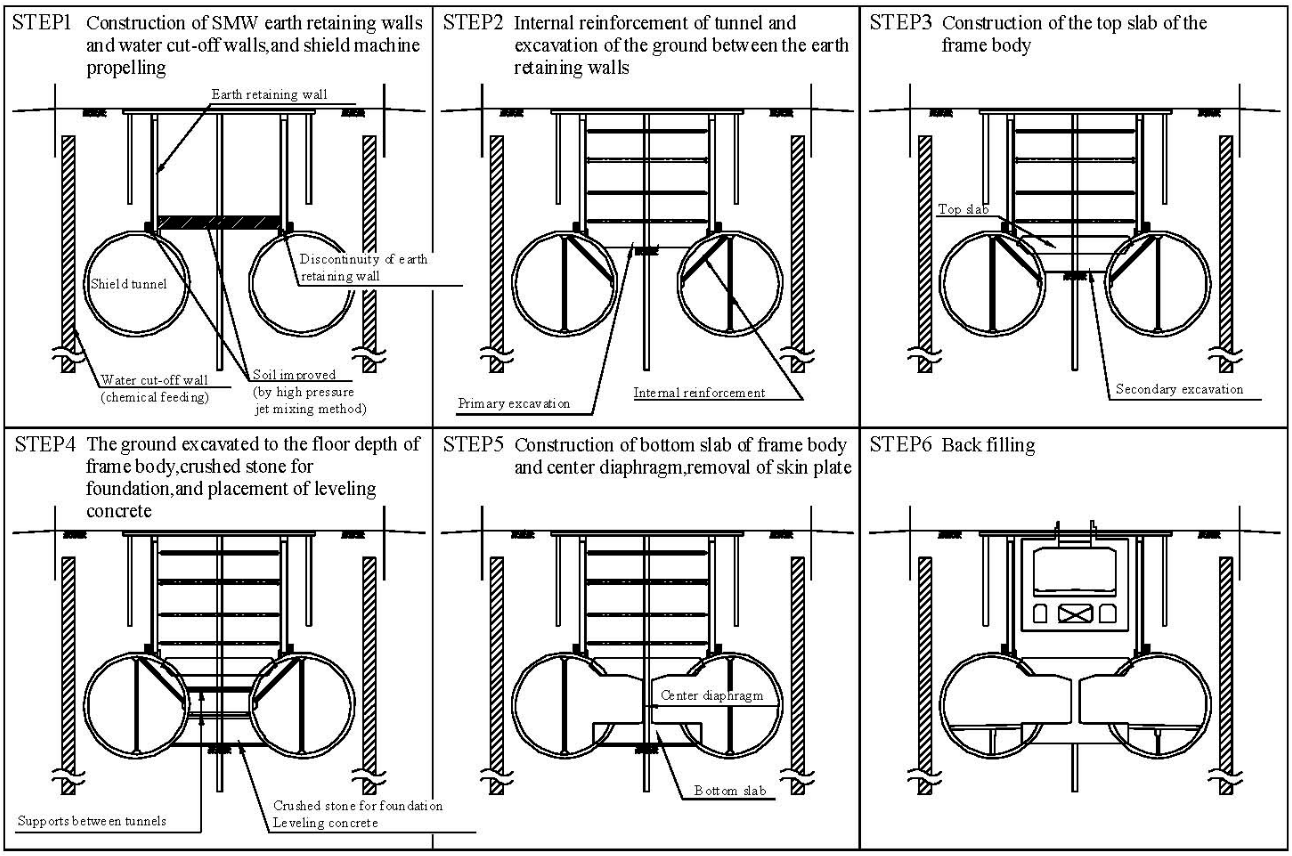

Figure 5. Construction procedure.

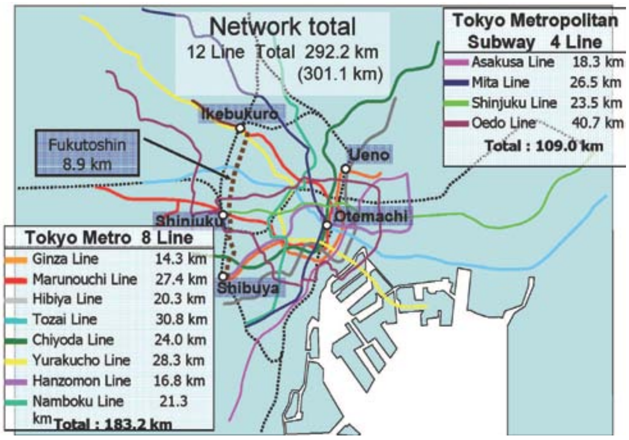

Figure 6. Outline of shield TBM work by Tokyo Metro.

3.2 Construction Procedure

The construction work on six stations, other than Zoshigaya Station, is being carried out below Meiji Street that is congested with pedestrians and vehicles. The tunnel connecting Ikebukuro and Shibuya is complete, and the construction work for the opening of the Fukutoshin Line has finished on schedule. As always, safety has been the top priority during the underground construction.

Geologically the Fukutoshin Line is mostly diluvial ground except for a small area of alluvial ground, as shown in Fig. 7. Nine tunnel sections have been built using Shield TBM machines, and the average depth of overburden is around 20 m. The following were the technical challenges faced during the construction of the Fukutoshin Line.

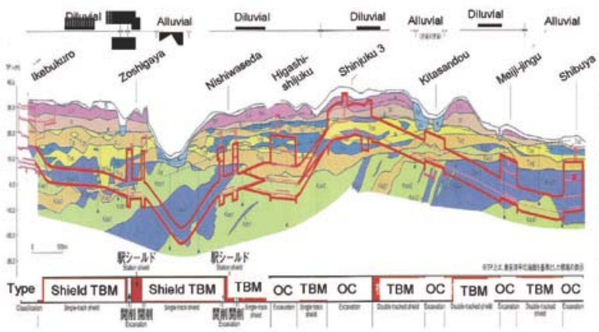

Figure 7. Geological condition.

Figure 8 shows the oval-shaped tunnel cross section, which reduces the soil volume due to the slurry-type TBM excavation. Specially designed TBM and tunnel segment linings were employed for this oval-shaped cross section.

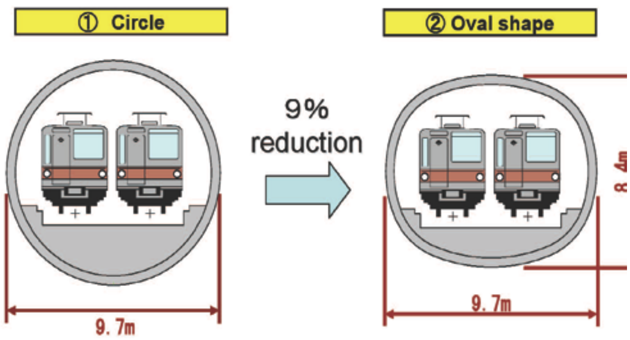

Figure 8. Oval shaped cross section.

In order to construct stable tunnel segments behind the TBM, a specially designed apparatus has been used, as shown in Fig. 9. This apparatus has been successfully used to expand the segmental linings behind the tail of the TBM.

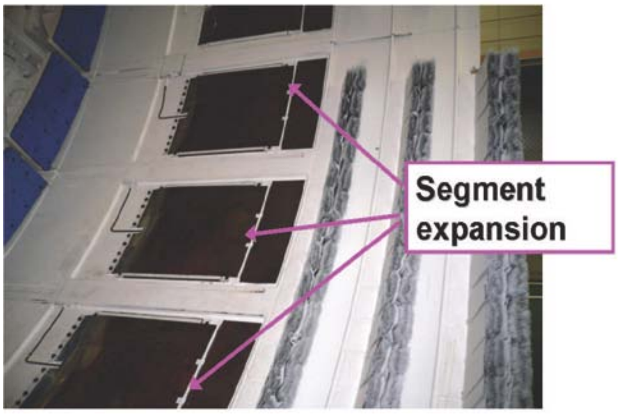

Figure 9. Segment expansion.

Figure 10 introduces an example of a boltless segment, which consists of a one-push connector between the segments to reduce the construction time needed to install the tunnel segments for the primary lining.

The width of the tunnel segment was also increased in order to reduce the number of segments needed and the construction cost, as shown in Fig. 11.

Controlling the amount of soil removed during construction along with the weight reduction of equipment and materials involved in the construction has contributed to reducing the impact on the environment.

The excess slurry and excavated soil from the slurry shield is reused as the filling material for the invert section of the shield tunnel and as the refilling material for the open cut work, as shown in Fig. 12.

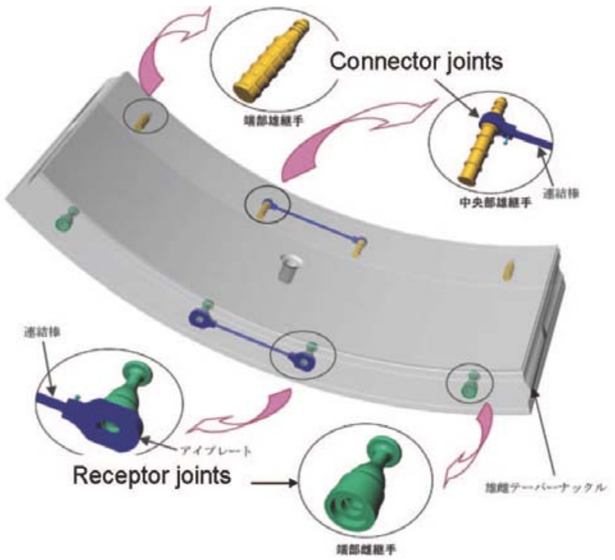

Figure 10. Boltless segment.

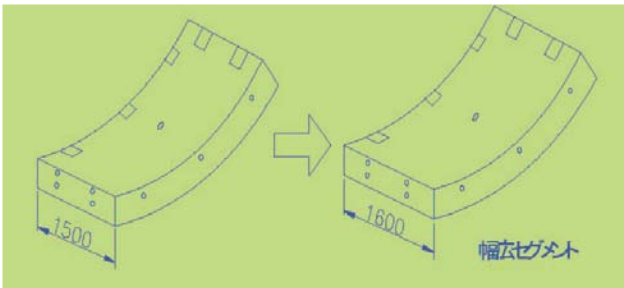

Figure 11. Increase in segment width.

Figure 12. Employment of wasted soil.

4 TEXTBOOK ON UNDERGROUND CONSTRUCTION TECHNOLOGY IN JAPAN

Underground structures play a crucial role in the development of urban areas. In highly congested and populated areas, performing underground construction near various existing structures is inevitable.

The textbook has been created from the texts for the specially offered course in Construction Technology in Underground - Geotechnical Aspects of Underground Construction in Soft Ground - provided by the Japan International

Cooperation Agency, for the fiscal years 2000 and 2001. The committee responsible for the organization of the curriculum for this course was the Japanese Geotechnical Society (JGS) in conjunction with the International Affairs Division, Economic Affairs Bureau, Ministry of Land, Infrastructure and Transport, Government of Japan. The lecturers for this course were selected from Japanese experts in this field.

The Japanese Geotechnical Society has prepared a technical committee for supporting this course and has decided to publish this textbook by collating the excellent course texts on the current underground construction technology in Japan. Selected lecturers have been requested to rewrite their course text for this textbook. This textbook contains latest information on underground construction technology in Japan and will prove to be a vital resource for young geotechnical engineers around the world.

The textbook covers all the major topics in underground construction technology, which are listed as follows:

1. Overview of the technology for subsurface development.
2. Geotechnical aspects of underground construction in Japan.
3. Soil mechanics.
4. Hydraulics in soil.
5. Determination of the shear strength of soft clay.
6. Soil investigations.
7. Method for field monitoring.
8. Concept behind current tunnel design method.
9. Case studies of tunnel construction.
10. Design method for open cut mechanics for tunneling.
11. Ground deformation due to open cut.
12. Construction methods and construction machines for open cut.
13. Case studies of open cut.
14. Observational construction.
15. Prevention of accidents and safety management.
16. Legal issues concerning safety management.
17. New finite element modelling of excavating and tunneling.
18. Exercises.

.

5 CONCLUDING REMARKS

This paper summarizes two recent case histories of underground space utilization within the Tokyo metropolitan area and introduces a new textbook on underground construction technology, published by the Japanese Geotechnical Society (JGS). First, the construction of the underground expressway is described. Second, the construction of a subway within the central Tokyo area is explained. Finally, the new textbook on underground construction technology, published by JGS, is presented. This textbook will help provide useful information to young geotechnical engineers particularly in South America.

ACKNOWLEDGEMENT

The author is very grateful to Messrs. T. Nishimura (Tokyo Metro Corporation) and N. Kawada (Metropolitan Expressway Public Corporation) for providing valuable information on the underground construction of the Central Circular Route of Tokyo Metropolitan Expressway and the Fukutoshin Line of Tokyo Metro Subway system.

REFERENCE

Akagi, H., Komiya, K., Standing, J. and Jardine, F. 2006. *Underground construction technology in Japan*, Japanese Geotechnical Society. http://www.jiban.or.jp/e/e-top.htm.