Effective Underground Use Enabled by Subway Construction in Narrow Area Where Many Other Lifelines Lie

Hiroyuki Nabeshima, Tomohiro Shiotani, Akira Matsushita

Osaka Municipal Transportation Bureau, Japan

ABSTRACT
Osaka City, the central hub of Western Japan, manages 129.9km of subway line. At December 2006, we opened a new subway line (Line No.8) in the eastern part of the city to expand the subway network further. The construction was initiated in 1999, and the line opened in operation in 2006. The vehicle on Line No.8 drives by liner-motor. Advanced technologies were required in the construction because the tunnels lie adjacent to important facilities. In this paper, we will introduce some problems which we forced in construction and their solution method.

1. INTRODUCTION

1.1 Subway development as infrastructure of Osaka City.

Urban functions of Osaka City have been improved, and it kept Osaka the central city of western Japan. As a part of the improvements, we have developed excellent public transportation network consists of core subway lines, newtram (AGT) and bus routes mutually combined effectively. The subway routes form grid pattern in downtown, and extend radially effectively into suburban areas. The system transports as many as one billion passengers annually.

The subway service in Osaka was initiated between Umeda and Shinsai-bashi (3.1km) in 1933 as the first public-operated subway in Japan. After that, the city continued to improve the downtown service area to meet the population concentration and urbanization. In 1970, the length of operation reached 64km. Thereafter, the subway lines were extended to suburbs of the city and adjacent cities. Now, mutually direct train services through private railway lines are in operation. The subway system in Osaka has grown to 129.9km in operation length.

The environment and the functions of the city used to be severe condition due to extensive amount of motorized vehicles. With the effort to encourage public transportation use to motorists by improving subway network, for example, the car traffic was eased in the city. Therefore the city achieved better environment and was revitalized by improving mobility.

1.2 Construction of the subway Line No.8

As stated so far, the subway system is an essential infrastructure for the substantial city activity, and its extension encourages motorists to use public transportation, prevents air pollution and global warming, and finally improves global environment. Consequently, we believe that we should expand our subway systems.

We assessed the land use pattern, traffic conditions, estimated travel demand, and projected rail routes plan, we reached our thought about necessity of route expansion and its method. In the thought, we will construct the subway route No.8 (Imazato-Suji line). The construction between Itakano and Imazato, a section of the Line No.8 initiated in March, 2000.
Fig. 1. Location of Osaka (Japan).

Fig. 2. The location of Line No.8 in Osaka City.
1.3 The route plan of the subway Line No.8

In the subway Line No.8, which will have 11.9 km in operation length, 6 out of 11 stations are connecting stations enabling the Line No.8 as apart of the rail network. Other stations are located with the consideration of suburban center location like dense populated area, projected development plans, distance between the stations, and technical conditions like underground infrastructure facilities, and so on.

From the vertical-section view, the Line No.8 crosses five rivers, existing Lines No.2, 7, and 4 underneath. The deepest point will be under Daini-Neya River area, and the depth of the rail level will be approximately 38 meters from the ground.

Between Shinmori-Furuichi station and Gamo 4-Chome station where large-scale underground utility line lies, two shield tunnels lie in a vertical line to enable effective use of underground space. The design plan of Sekime-Seiiku Station is the best example that has two vertically aligned platforms.

![Fig. 3. Outline of subway line No. 8.](image)

2. THE CONSTRUCTION OF THE SUBWAY LINE NO.8

2.1 Construction in soft ground

Generally, stations and tunnels were constructed using cut-and-cover method and shield method respectively.

Geologically, Line No.8 runs through the eastside of Uemachi-Daichi Plateau which consists of relatively hard layers. The layers used to be under the inland sea and raised above the water level 1000 to 1500 years ago, so they are thick and very soft layers that accumulated less than 10,000 years ago. Consequently, the clay layers in shallow area are under normal consolidation condition and salt has melted out for they are made of marine clay, the clay layers are sensitive to distance, and it means easy to lose strength by disturbance. The thickest soft layers are approximately 20 meters thick and distributed between Gamo 4-Chome station and Midori-Bashi station. Under the soft layers, relatively hard clay layers and sand layers appear by turns with a couple of meters thick.
The construction took place in dense, urbanized area where a lot of residential buildings and commercial buildings locate, so it is very important to control the displacement of the soft layers to prevent harmful influence to adjacent buildings and underground facilities. To achieve this and keep surrounding environment normal, we employ rigid watertight retaining walls and numerical analyses and high precision measurements of the retaining wall displacement.

![Geological cross section and Osaka map 4000 to 5000 years ago](image)

Fig. 4. Geological cross section and Osaka map 4000 to 5000 years ago

### 2.2 Dealing with important adjacent structures

We built Line No.8 in the established city area where many residences crowded. In Osaka City, Subway lines were built beneath the busy highways. Many lifelines were buried under the road where Line No.8 was to be built, and huge traffic volume goes on the road, because the road is one of the trunk roads in Japan, and connects Tokyo and Osaka. Due to the construction circumstance, very prudent construction was required for Line No.8, not to damage their important infrastructures. Also various protection methods were used in the construction. We introduce these construction outlines in the following sections.

#### 2.2.1 Model selection

We adopted linear motor metro in new subway. Linear motor metros’ merit is as follows.

i. Using thin flat linear motor, the vehicle can be low-floored while retaining ceiling height and floor area, enabling the vehicle more compact size. Consequently, the construction cost can be reduced by 20% than regular subway by reducing tunnel cross-section size 40%.

ii. The driving system is non-adhesive system which does not depend on friction between wheels and rails, so that the vehicle can ran through slopes. Setting maximum steepness of the Line No.8 to 50/1000, the stations can be shallower than the case of regular subway when the route crosses rivers or existing subways underneath.

iii. With the wheels can be steered like an automobile, the vehicle can pass through sharp curves smoothly. For the Line No.8, the minimum curve radius is set at 80m.

#### 2.2.2 Protection of the large size communication shield tunnel

Along in most part of the section, communication shield tunnels are adjacent to the Line No.8 structures. Sekime-Seiiku station and Gamo 4-chome stations are especially close to that shield tunnels. At Gamo 4-chome station, our assessment shows that influence of the subway station excavation is so severe that we plan to install reinforcing steel segments inside the communication tunnel that is vulnerable to the influence of the construction.
2.2.3 Four storied structure of the station avoided large communication shield tunnel

Usually, the new station structure which we designed is the island platform. But at Sekime-Seiiku Station, another communication tunnel, with a diameter of 5m was already constructed there. So we couldn’t construct new subway tunnel there. Therefore, we changed new stations’ construction plan. As a result, Sekime-seiiku Station has 4 floors, and north and south bound platform are at the separated floor.

Fig. 5. (a) Station close to the Communication tunnel (Gamo 4-chome St.)
(b) Four storied structure of the station (Sekime-seiiku St.)
(c) Close construction of tunnels (Southern part from Shimizu St.)

2.2.4 Close construction of tunnels

Four shield tunnels, two of them for main truck and the other two for branch truck to the depot, are particularly close each other along 400-meter section at southern part from Shimizu Station where draw out line branches out from the main line. Spaces between tunnels are only less than 1D due to the narrowness of the roadway above, which is as narrow as 25 meters, so that we need precise construction work management to avoid harmful influences to another shield tunnels. Moreover, another two multi-utility shield tunnels’ construction are projected in couple of years that will influence to the existing four shields, so we designed the four shield tunnels to have enough strength for the influence during the projected construction.

2.2.5 Overcrowded large-size underground facilities

For the route is adjacent to many large-scale existing underground structures, protection for each structure with consideration of its condition and situation is necessary. At Midori-bashi Station, for example, sewer shield tunnel (Diameter 3450mm) is in the excavation area, and sewer pipe (1940x1820mm rectangle) and communication shield tunnel (Diameter 3550mm) are behind the retaining wall. Due to these large underground utility lines, we protected that tunnel, in advance. The method for protect is at first we dig that shield tunnel in the excavation area, and bind a steel segment so that it may not break by the pressure from inside. Second we hung that tunnel by wire rope, and changed protection by using pile and beam for protect. So we protected that shield tunnel, we were able to finish construction safely since 5years.

For example, at Imazato Station, also sewer structure (3800×4800mm rectangle, 3800×4200mm horseshoe-shaped) and water pipe (1500mm Diameter) are in the excavation area. Especially sewer structure (3800×4200mm horseshoe-shaped) was built in 1940. For these structures, such as Midoribashi Station, we constructed very carefully. These sewer structures were so big that the strut interval was so wide (about 5m). So we adopted pre-loading method so that the retaining wall might not bend.
2.2.6 Neighboring construction for Tokaido Shinkansen
Tokaido Shinkansen, which connects Tokyo to Osaka, is a main arterial railway of Japan. Line No.8 passed through the underground under the elevated bridge of Tokaido Shinkansen. Most minimum interval between subway tunnel and pillar of Tokaido Shinkansen was 80cm. Tokaido shinkansen is running at 270km/h, and carrying 400,000 passengers per day. So having harmful influence of the Shinkansen for construct subway tunnel was never allowed. We installed the measurement machine on the bridge, and constructed with observing the real time measurement result. Consequently, we were able to limit the influence for piles of Shinkansen viaduct within the target value (3mm).

Fig. 7. Figure of the cross section close to Tokaido Shinkansen.

3. CLOSING
As this report, shaved there are many important infrastructure varied underground in the established city. If these lifelines were damaged, very serious influences would happen on our everyday life. When we construct new infrastructure under the ground, we should never damage these buried infrastructures with deliberations for each administrator and it becomes important what kind of protection method we choose. In this case, we were able to complete construction safely by using the technologies cultivated while our subway construction experience for these 80 years. We hope construction technology enhances effective underground use.