1. INTRODUCTION

The recent focus of transportation experts has been to develop methods that effectively utilize underground space. Such methods include the implementation of subway systems or underground roads that are used to ease the traffic in cities that encounter high congestion in their current surface routes. Until the mid-eighties, the Cut-and-Cover Method was used for the construction of underground transportation. This practice involves excavating the road and covering the surface with a lining board that allows traffic to pass through or detour while construction is in progress. However, this method has fundamental drawbacks such as inevitable damage to adjacent buildings and underground facilities, as well as shortening the average life span of road surfaces in close proximity to the excavated area. As a consequence, improved underground construction methods that do not require road surfaces to be excavated became popular, especially within highly developed urban areas. The Non-Cut-and-Cover Method minimizes the area affected by the underground construction, indirectly reducing costs by not increasing traffic congestion. This case study presents the findings from the construction of the Subway Line No.9 Express Bus Terminal station.

2. PROJECT OVERVIEW

Subway Line No.9 runs from east to west in the south of Han River and was built to promote balanced development throughout the city of Seoul. Additionally, the development was expected to increase the number of subway commuters and to diversify the economic activity in the city. The total length of the Subway Line No.9 is 38km from Kimpo Airport to Bang-ih via Yeouido, Seoul Express Bus Terminal and COEX. 37 stations shall be totally installed along Subway Line No.9. The overall project was divided into three phases; the first phase of the route was constructed from December, 2001 to July, 2009 and is now in service. It is 25km of the first phase’s length which has 25 stations along the Subway Line No.9. An overview of Subway Line No.9 is shown below in Fig. 1. The Express Bus Terminal station, the main subject of this case study, is located on Sinbanpo road in Seo-cho gu district. In the area surrounding the Express Bus Terminal various commercial properties, such as the Central City Mall and Gang-nam underground shopping center are conveniently located. However, this convenience results in constant congestion, making the area one of the busiest zones in town (As shown in Fig. 2).

Geologically, the surface layer of the construction site is composed of alluvial deposits. The composition of soil causes damage to existing underground structures if excavation of this layer was to be performed during the project. Also, Subway Line No.3 is in service and would cross Subway Line No.9 just 15 cm above the construction area. Due to these circumstances, the application of the Cut-and-Cover Method was impractical. In consideration of these issues, the combination of the TRcM (Tubular Roof construction Method) and the CAM (Cellular Arch Method) was employed to ensure the safety of existing structures and maintain smooth traffic flow
on the surface during construction. Using the TRcM, The shafts were built along each sidewalk of an 8-lane road, and four launch and arrival chambers were constructed from the shafts. Then CAM was applied to complete the successful construction of a tunnel-type subway station with a width of 29.6m, a height of 20.85m, and a length of 220.0m.

![Fig. 1. Project location](image1.png)

3. GEOTECHNICAL INVESTIGATION

The geotechnical investigation was performed in the year of 2002. Several common techniques were adopted to get information about the position of buried objects and the nature of the ground. And the five different sections, BH-6, BH-7, BH-8, DB-17 and DB-18, were drilled up to the depths of 47m to collect the samples of soil. The samples revealed that the soil was composed of four layers: fill, alluvial, weathered rock and unweathered rock (ordered from the top). The alluvial layer contains silt, sand and gravel. The diameter of gravel varies from 5cm to 20cm and the gravel forms 30~50% of the soil. The weathered layer takes up around 1m in depth and the unweathered rock is composed of Gyeonggi gneiss complex. This rock has complex characteristics as a result of the number of metamorphisms and diastrophisms. The value of RMR (Rock Mass Rating) lies between 31 and 67 and that of RQD (Rock Quality Designation) varies from 50% to 100%.

G.L (Groundwater level) varies from G.L (-) 7.9~9.1m and is placed on top of the TRcM structure, namely launch and arrival chambers. And the permeability coefficient of alluvial layer, one of the
major route of groundwater intrusion during construction, was $1\sim 2\times 10^2$ cm/sec. The result of the geotechnical investigation is shown below in Fig. 3.

4. TRcM (Tubular Roof construction Method)

4.1 INTRODUCTION

The TRcM, introduced by Smet Boring of Belgium, is the construction method that involves constructing a temporary structure after the roof was formed by jacking the steel pipes. This method prevents the collapsing of surface soil, minimizing damage to existing adjacent structures, and maximizing the usable work spaces at the same time. This method has been popularly employed in many construction projects in Korea. Some such projects include the construction of Subway Lines, Water-Supply Facility, Underground Structure.

4.2 APPLICATION AND CONSTRUCTION SEQUENCE

In order to construct the arch-like Pipe Roof using CAM, the launch and arrival chambers were temporarily installed by TRcM. These chambers, a width of 12.0~15.6m, a height of 14.0~15.9m and a wall thickness of 1.5~1.6m, are built to jack steel pipes as well as to create the base for the lower part of the tunnel and to manage underground water. In Fig. 4, two different views of these chambers can be found. The TRcM requires the use of two different types of steel pipes: gallery pipes (D=2,500mm) and slab pipes (D=1,500mm). Two gallery pipes are jacked parallel to each other by using an oil pressure. From the interior gallery pipe, slab pipes are jacked to the other gallery pipe, connecting them together. Using these pipes as a roof, the trench wall is built by vertically installing P.C panel with help of struts. Then, the reinforcing cages are put into the trench wall and the concrete is filled in. Finally, the main body of the chamber was excavated. These procedures are illustrated in Fig. 5.
### 5. CAM (Cellular Arch Method)

#### 5.1 INTRODUCTION

The CAM is commonly used for cases where an underground structure is to be built under shallow soil. The mechanism of CAM is to jacked steel pipes (D=2,000mm) using the oil pressure jack and placing these pipes in arch-like form. As shown in Fig. 7, The total of thirteen steel pipes (D=2,000mm) are jacked at the beginning and end of section (TYPE-1). In the section where it crosses Subway Line No.3 (TYPE-2), an additional ten steel pipes are inserted to construct the roof of tunnel. Subsequently, the roof is constructed by installing the girder in transverse direction to support steel pipes. By joining the roof and the interior of the pilot tunnel before excavation, it...
effectively prevents the displacement of existing structures. Thus, it has been proved that the CAM is suitable for tunnel constructions where structures exist on top.

Fig. 7. Girder section of CAM tunnel

5.2 APPLICATION AND CONSTRUCTION SEQUENCE

As described earlier, the steel pipes were jacked to form an arch on ceiling of tunnel, then the excavation was completed and reinforced concrete was filled. The procedure is illustrated in Fig. 8. Within rock, it was impossible to jack steel pipes directly, so the DARDA Method was used to excavate rock before jacking pipes. In addition, if the pressure of the oil pressure jack was increased, we judged that there appeared to be large cobble and boulder from the upper layer. To resolve this issue, the jacking was put on hold until they were safely removed. When it was being removed, horizontal grouting was made a progress in order to prevent possible collapse.

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td><img src="image" alt="Steel Pipes Injection" /></td>
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<td><img src="image" alt="Construction of Side Walls" /></td>
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<tr>
<td><img src="image" alt="Girder Construction" /></td>
<td><img src="image" alt="Excavation of Main Tunnel" /></td>
<td><img src="image" alt="Installation of Internal Structures" /></td>
</tr>
</tbody>
</table>

Fig. 8. Construction sequence of CAM
5.3 ASSESSMENT OF IMPACTS ON TUNNELING

The CAM was used the first time in Korea for the construction of the Subway Line No.9 Express Bus Terminal Station. The safety and impact testing for each construction sequence and adjacent structures was simulated thoroughly using 3D FEM (Finite Element Method) as shown in Fig. 9. Two of main cross-sections, Banpo shopping center and Central City, were selected for modeling, and the impacts on adjacent structures and tunnel behavior was able to predict through the result of 3D modeling. Maximum vertical displacement was evaluated to be stable within an allowable range ($S_a=20\text{mm}$) every construction phase.

![Fig. 9. Phase modeling](image)

6. CHALLENGES DURING THE CONSTRUCTION

6.1 ALIGNMENT CONTROL FOR STEEL PIPE JACKING (CAM)

It was very difficult to control the pipe movement when steel pipe was jacked. Whether or not steel pipe maintains the shape of alignment, we couldn’t predict it. Therefore, we installed the laser level at the reaction wall and the laser target at the leading part of the steel pipe for instant judgement of the pipe alignment. We can control the alignment and prevent the interference and tilting to one side. Adjusting the oil pressure jack, pipe was jacked in the movement allowance limit (2.0 cm).

![Fig. 10. Alignment control](image)
6.2 APPLICATION OF DEEP WELL METHOD FOR GROUNDWATER DRAINAGE

The measured underground water level was G.L (-) 7.9~9.1m in the vicinity of TRcM construction area. This value was bit higher than the expected value of G.L (-) 13.0m. In order to lower the water level, deep wells were installed inside of gallery pipe at intervals of 6.0m in terms of safety and stability as shown in Fig. 10. When the steel tubes reach down to upper part where rock lies, we pumped water using 7.5HP submarine motor pump installed at the bottom of well. In a result, the water level was lowered properly to construct trench wall. One of main concerns related to the construction of the well was that adjacent buildings might collapse as a result of the drainage. But the simulation data showed that the maximum settlement was about 11.9mm. This satisfied the allowable limit of 20.0mm.

6.3 ESTABLISHMENT OF THE MONITORING SYSTEM

Prevention about accident was the top priority during the construction, especially in consideration of the narrow spacing between structures. Therefore, we used automatic and systematic monitoring system for immediate action such as passage prohibit or site inspection. Approximately 300 sensors, for example inclinometer, water-level gauge, ground settlement gauge, crack gauge, E.L Beam sensor, displacement gauge and so on, were installed on tunnel and adjacent structures. So, we could get measurement information of construction site. Also, The host computer collected the data from the sensors and it identifies the risk level automatically. When the excessive deformation were detected, it alarms to the construction office. Actually, none of excessive deformation had been detected. It proves the excellent performance of the combined method in minimization of tunneling effect.

Table. 2. Measurement result

<table>
<thead>
<tr>
<th>Section</th>
<th>Measuring instrument</th>
<th>Unit</th>
<th>Measurement Result</th>
<th>Official Standard</th>
</tr>
</thead>
<tbody>
<tr>
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<td>E.L Beam</td>
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<td>±2.0</td>
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<tr>
<td></td>
<td>Crack Guage</td>
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<tr>
<td>Gang-nam underground shopping center</td>
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<td>-0.85 ~ 0.82</td>
<td>±1.0</td>
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<tr>
<td></td>
<td>Crack Guage</td>
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<td>-0.37 ~ 0.08</td>
<td>0.5</td>
</tr>
</tbody>
</table>

7. CONCLUSION

The surrounding area around the Subway Line No.9 Express Bus Terminal station is very busy, with constant traffic flow and major buildings such as Gang-nam Express bus terminal, Gang-nam
Underground shopping mall, and Subway Line No.3. In addition, the population is dense in the area. Due to these circumstances, it was impractical to construct an underground station using the conventional Cut-and-Cover Method. Therefore, the combined method of the TRcM and the CAM was applied to construct the Subway Line 9 Express Bus Terminal station, a tunnel-type subway station with a width of 29.6m, a height of 20.85m and a length of 220.0m as shown in Fig. 11. The combined method overcame the shortcomings of the Cut-and-Cover Method by minimizing traffic issues and securing the safety of existing structures. Also, it minimizes the demolition of existing compartments in underground shopping mall. In return, it removes the impacts on store owners in the area and reduces the inconvenience to the general public. During the design and construction phase, thorough examination and simulation was done to prevent damage to the adjacent area. This construction case was recorded as the first to build the tunnel-type subway station using the combined method of TRcM and CAM in the world. It was also awarded ‘2009 The Grand Prize’ as an outstanding civil structure in KSCE (Korea Society of Civil Engineers). ICE (Institution of Civil Engineers) awarded ‘The Brunel Medal’ to Ssangyong E&C in England, too. Therefore, this structure has been recorded as a successful application of the excavation techniques. We hope that the results of this case study will prove useful to other engineers and contribute to the improvement of underground excavation techniques.

Figure 12. Completion of 923 subway station

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Ssangyong Engineering & Construction Co. Ltd, Detail Design Report of Seoul Subway No.9, 2002

Ssangyong Engineering & Construction Co. Ltd, Instruction of Construction Method Applying TRcM and CAM to Station of Large Section Tunnel, 2006