

# Design & Construction Stages for Urban Subway in Densely Populated Areas: Case Study for Seoul Metro Subway

TUNNELLING AND UNDERGROUND SPACE ENGINEERING TECHNICAL DIVISION

reported by



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There are many factors to be considered in the design and construction of tunnels in urban areas, especially those running under densely populated areas. The appropriate tunnelling method has to be selected in consideration of a variety of factors, which include subsoil conditions, civil complaints, potential third-party damages, constructability and construction cost.

In a talk jointly organised by both WTC 2020 Organising Committee and Tunnelling & Underground Space Technical Division (TUSTD) on 27 February 2018, Mr. Lee Jae Hoon, Vice President of Dong Il Engineering Consultant Co. Ltd, presented a case study on the Seoul Metro Subway tunnel.

First, he gave an overview of the status of transportation tunnels in South Korea in 2016 (Table 1). South Korea has seen a drastic increase in tunnel constructions for the past 30 years due to the following:

- Topography: Approximately 60-70% of South Korea consists of mountainous and hilly areas, so the tunnel solution is preferably adopted.
- Environmental protection: As tunnelling is underground construction, it is a far better option than an "open construction" method, which can cause more environmental damages.

Table 1: Transportation Tunnels in South Korea

CLASSIFICATION		Length (km)
Railway & Subway tunnels	Conventional Railway	514.2
	High Speed Railway	196.5
	Subway	674.2
Road & Highway tunnels		1626.0

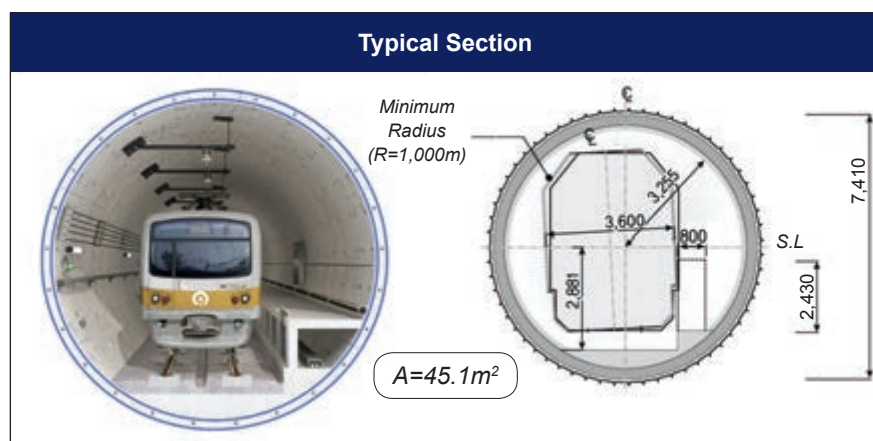


Figure 1: Typical Section of Seoul Metro Tunnel

- Civil complaints: From past experiences, more civil complaints were lodged due to construction nuisances and traffic noises, so tunnelling is a preferred construction method.

The Seoul Metro Subway No. 00, 1.65kms of twin tunnels of 6.5m diameter, runs under densely populated area that include high-rise buildings, underpass structures, underground utilities and trunk roads (8-10 lanes), etc. The typical section, plan and profile are illustrated in Figures 1 and 2 respectively. The geological layers along the alignment consist of filled material, alluvial layers, weathered layers and bedrock with groundwater able varies between 4.5m and 10m below ground level.

To mitigate civil complaints, ground settlement and third-party damages, various schemes were studied at design stage with regards to ground improvement, operational scheme of TBM and mucking/disposal method

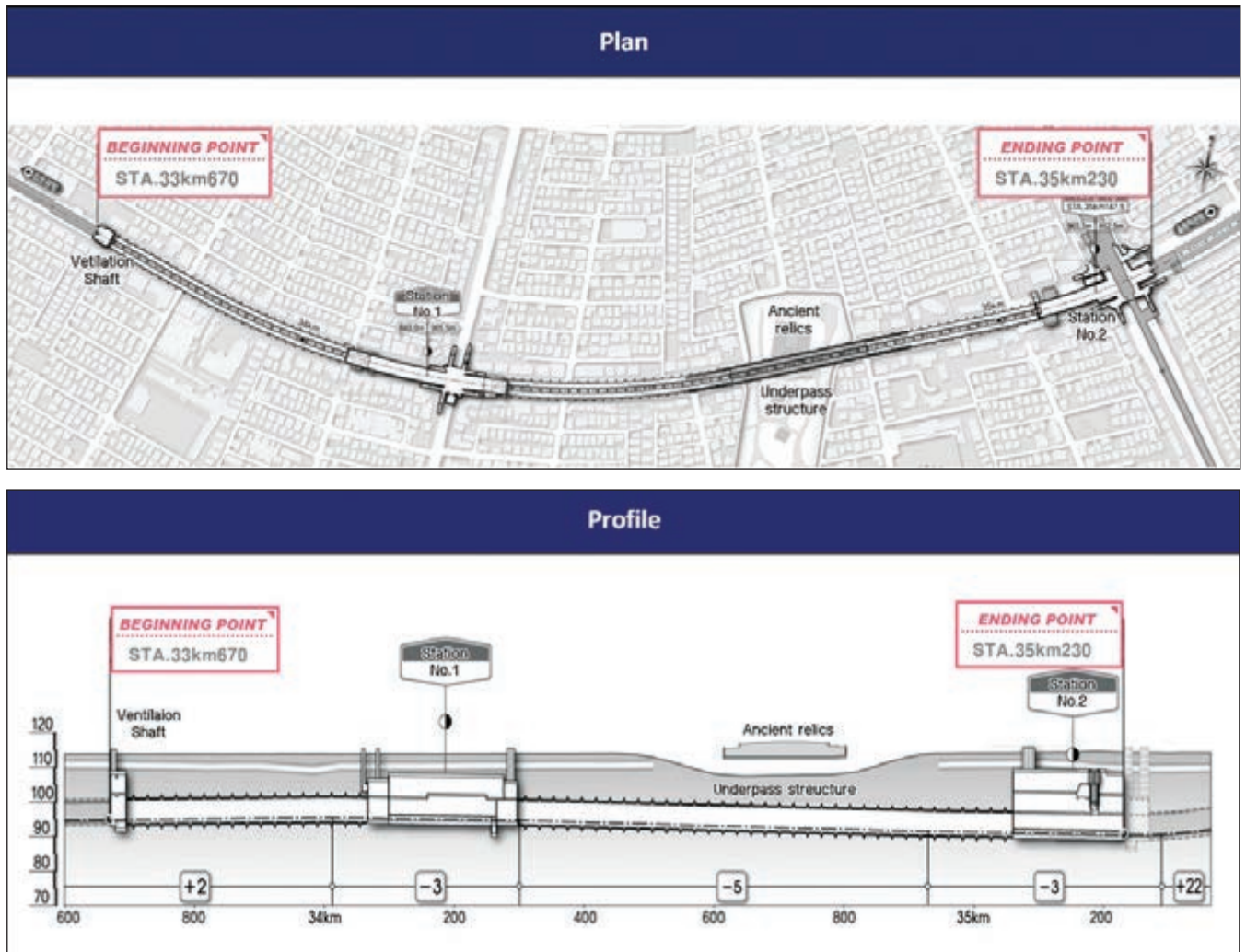


Figure 2: Plan & Profile of Seoul Metro Subway No.00

of slurry, etc. In this context, Mr. Lee discussed in detail the decision-making process of the tunnelling method, which was decided based on various considerations and site conditions (Table 2). Above all, stability analysis was carried out and ground improvement techniques were considered at design stage to minimise either settlement or damage of buildings and underpass structures. To secure passenger safety, fire safety measures were also incorporated, e.g. escape tunnels and cross passages.

To safeguard nearby buildings, structures, ancient relics, underground utilities and other facilities, various geotechnical investigations and field tests were performed. Damage assessment and structural analysis of the tunnel in relation to adjacent structures were carried out and

ground displacement calculated. Where prediction and/or verification of ground behaviour and structural safety were concerned, appropriate instrumentations for monitoring purposes were installed.

In order to facilitate smooth and efficient operation of the TBM, various management plans were adopted including the following:

1. Launching and demobilisation plan of machine.
2. Tests for drill-ability analysis to predict drilling speed and for selection and arrangement of cutters, i.e. analysis of quartz content ratio, sieve test, brittleness test, abrasion test, etc.
3. Control of machine drive by measurement of earth pressure and muck quality.
4. Prediction of optimum time for cutter replacement through

operating data analysis, i.e. drilling speed, thrust force and rolling angle.

However, untoward incidents of sinkholes (cave-in from undetected cavities) did occur during tunnelling due to malfunction of TBM and the inefficient grouting from inside TBM, causing some damages to nearby structures. After a thorough investigation of the causes, the damaged parts were satisfactorily reinforced by external grouting and the necessary countermeasures were adopted as described below:

- a) External grouting (from ground surface) was carried out around the tunnel face and sinkholes.
- b) More ground investigations and tests were carried out to detect existing cave-ins.

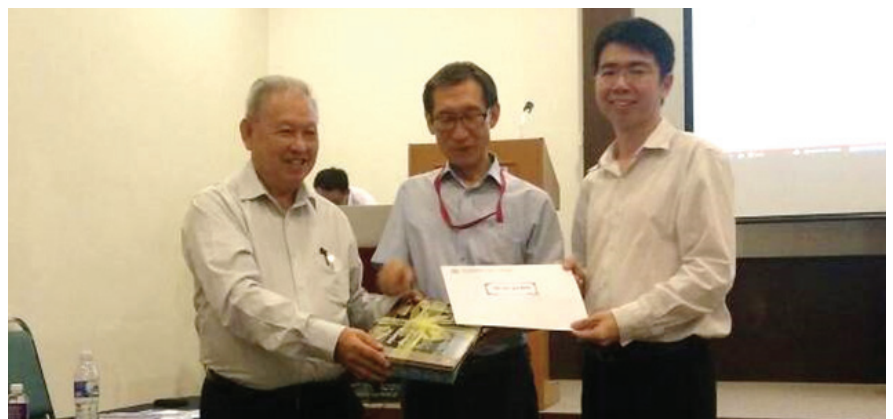
Table 2: Decision Process of Tunnelling Method

	Step	Major Considerations	Site Conditions
1.	Selection of Tunnelling Method <b>NATM vs. TBM</b>	Geological condition	<ul style="list-style-type: none"> <li>Filling material, alluvial, weathered layer (IV, V, VI) and rock (III); complicated and combined geology along the Metro line</li> <li>High ground water table</li> </ul>
		Third party damage	<ul style="list-style-type: none"> <li>High-rise building, ancient relics, trunk road, residential houses and underground utilities</li> </ul>
		Civil complaints	<ul style="list-style-type: none"> <li>Serious civil complaints due to construction nuisances are anticipated.</li> </ul>
		Construction cost	<ul style="list-style-type: none"> <li>For NATM, staged construction and heavy ground improvement to be applied and noise and vibration due to blasting are unavoidable. In order to mitigate the vibration effect, more costly blasting technique shall be required.</li> </ul>
		Constructability	<ul style="list-style-type: none"> <li>In case of TBM tunnel, total length of twin tunnel will be approximately 3.2km.</li> </ul>
	<b>Recommendation</b>	<ul style="list-style-type: none"> <li>TBM tunnelling was recommended as a more favourable method than NATM</li> </ul>	
2.	Selection of TBM type <b>EPB vs. Slurry</b>	Geological condition and water pressure	<ul style="list-style-type: none"> <li>Geological condition: as described above</li> <li>Water pressure: less than 3 bars</li> </ul>
		Availability of construction yard and working space	<ul style="list-style-type: none"> <li>Highly limited construction yard and working space</li> </ul>
	<b>Recommendation</b>	<ul style="list-style-type: none"> <li>EPB type was selected as an appropriate option mainly in coping with the combined geological conditions/low face pressure and considered more favourable than Slurry TBM with respect to availability of construction yard.</li> </ul>	

c) Increased number and places of the instrumentations for monitoring.

d) Increased numbers of grout holes at the face-plate of the TBM to facilitate effective internal grouting.

Despite the manifold challenges faced during both design and construction stages, the tunnel project was successfully completed. Mr. Lee concluded his presentation with a summary of the lessons learnt from this case study. He stressed that the importance of geological investigation and detection of underground features cannot be overstated. In addition, efficiency in grouting techniques must be checked beforehand, control of machine drive must be systematically managed by data



Ir. Dr Ooi Teik Aun and Ir. Khoo Chee Min presenting a token of appreciation to Mr. Lee Jae Hoon

analysis (i.e. measurement of earth pressure and muck quantity, drilling speed and thrust force, etc.) and constant monitoring of instrumentation must be executed properly during the construction stage. Lastly, he fielded a couple of questions from the floor.

To conclude the event, WTC 2020 Organising Chairman Ir. Dr Ooi Teik Aun and Deputy Chairman of TUSTD Ir. Khoo Chee Min presented a token of appreciation to Mr. Lee. ■