Case study on the application of shield TBM in the gravel layer with high water pressure underpassing the Han River

Chang-soo. Kim i, Jae-yoon. Kim ii, Soo-ho. Lee iii, Hyun. Cho iv and Dong-ahn. Hwang v

i) Deputy General Manager, Civil Engineering Team, Ssangyong Engineering & Construction Co., Ltd., 299, Olympic-ro, Songpa-gu, Seoul, 138-726, Korea.
ii) Assistant Manager, Civil Engineering Team, Ssangyong Engineering & Construction Co., Ltd., 299, Olympic-ro, Songpa-gu, Seoul, 138-726, Korea.
iii) General Manager, Yongjong-Gyoha Main Gas Line (Section 2), Ssangyong Engineering & Construction Co., Ltd., 103, Seongmo-ro, Yangchon-eup, Gimpo-si, Gyeonggi-do, 415-824, Korea.
iv) Vice President, Institute of Construction Technology, Ssangyong Engineering & Construction Co., Ltd., 299, Olympic-ro, Songpa-gu, Seoul, 138-726, Korea.
v) Senior Manager, Inchon District Division Construction Team, Korea Gas Corporation, 103, Seongmo-ro, Yangchon-eup, Gimpo-si, Gyeonggi-do, 415-824, Korea.

ABSTRACT

Recently, shield TBM is widely used for shallow tunnel, super long tunnel, downtown area where blasting method cannot be applied, as well as subsea and riverbed tunnels. A case study on the design and construction for shield TBM tunnel which is the construction case of tunnel underpassing the Han River would be explained in this paper. TBM tunnel on this site was designed on the basis of the results of preliminary geotechnical investigation. The dimension of tunnel is 45m of maximum depth, 15m of maximum water depth and total length is 1,497m. Tunnel diameter is 3.01m, equipment type is EPB and segment thickness is 20cm. In this case, the advance rate of shield TBM fell short of its design advance rate due to the geological condition which is consist of multiple layer (i.e., high water pressure layer including sand and gravel layer) and is different with the designed condition. As a result of efforts to overcome the unexpected difficulty, the construction was completed safely securing the stabilities of the tunnel. On this paper, application of shield TBM in the gravel layer with high water pressure case will be introduced based on the data for solution to overcome the difficulty in tunnel excavation.

Keywords: shield TBM (EPB type), underpassing the Han River, gravel layer with high water pressure

1 INTRODUCTION

A case study on the application of shield TBM at Yongjong-Gyoha main gas line (Section 2) that is the construction case of tunnel underpassing the Han river would be explained in this paper. Analyze the adequacy of application for EPB (Earth Pressure Balanced) shield TBM and basic causes of construction troubles between difference with geological condition on original design and construction. Also, Evaluate performance of a TBM drive using construction data adopted in site. The design overview for tunnel excavation and the countermeasures and basic cause for the problems that occurred during the construction in these site would be useful on similar construction case.

2 APPLICATION OF SHIELD TBM

2.1 Project summary

Figure 1 shows the TBM tunnel line of the underpassing the Han river of Yongjung-Gyoha, Korea. Total length of the tunnel underpass the Han river is 1,497m. All of the tunnel of the underpassing Han river was designed shield TBM in original design. But, the ground condition of the tunnel line was different with preliminary geotechnical investigation. Construction trouble will be expected because of the changed ground condition. So, tunnel excavation method was changed shield TBM to conventional tunneling method (NATM) where the length 350m of 1,497m near the receiving shaft.

Fig. 1. Tunnel line of the underpassing the Han river.
Table 1. Project overview.

| Tunnel length | Total length: L=1,497m |
|---------------|------------------------|
| Tunnel type   | EPB shield TBM tunnel: 1,147m, NATM tunnel: 350m |
| Tunnel diameter | Ø2.4 m |

Launching shaft
- Gusan-dong, Ilsanseo-gu, Goyang-si, Gyeonggi-do, Korea (Ø15 m, H=39.93 m, Diaphragm wall)

Receiving shaft
- Nusan-ri, Yangchon-eup, Gimpo-si, Gyeonggi-do, Korea (Ø15 m, H=39.94 m, Diaphragm wall)

2.2 Geological characteristics of the tunnel underpassing the Han river

The project site is located in proterozoic layer which is composed of gneiss and schist and it intruded by jurassic pluton. It can be classified based on the lithology as biotite gneiss, mica schist, mica-quartz schist and it intruded by granitic gneiss. It is covered unconformity by quaternary alluvial layer. Biotite gneiss distributed in this site are intercalated quartzite and gneiss and composed of schistosity similar to schist. In addition, biotite gneiss form overlaped fold which is distributed in muscovite-quartz-feldspar schist (Fig. 2).

Fig. 2. Geological profile.

2.3 Specification of TBM

EPB shield TBM which is made by kawasaki in Japan was adopted in this project. The size of TBM machine is diameter of 2,930mm, total length of 7,400mm which was designed to reflect the tunnel section (Fig. 3).

Fig. 3. EPB shield TBM.

2.4 TBM tunneling

The excavation at TBM tunnel begins on August 21, 2013 and completed on October 23, 2014. There are some kind of construction trouble was occurred during the construction. It is groundwater inflow into the tunnel face and unexpected ground condition which is difference with original design. Especially, station 0+350~0+450, length of 100m, was consist of bigger size gravel. TBM drive rate was reduced compare to other section because of ground reinforcement and disk cutter change that caused more construction time (Fig. 4).

Fig. 4. Cumulative TBM drive length by date.

2.5 Problem and countermeasure of TBM drive in the high water pressure

The layer of consist of sand(80%) and silt(20%) mixed layer and high water permeability was appeared where it was consist of rock from the initial geotechnical investigation. Specifically, suddenly began to water pressure is applied to a later point of 49 Ring and 3 bar or more high water pressure occurred at about 100 Ring around. Because of this, when open the screw conveyor during the shield TBM excavation water, sand and silt were ejected at a pressure of 3.2 bar. In addition, until the 53 Ring construction, water up to 3,800 ton/day was introduced into the tunnel. Polymer, bentonite, etc such as additive were applied in order to solve the tunnel face stability problem according to the high water pressure. It was improved the stability of tunnel face and operation efficiency of shield TBM. Additive is applied by considering a high water pressure conditions, tunnel face consist of heterogeneous layer, etc. It was considered to find the optimum ratio and the best type for excavation. Tunnel was excavated correspond to the equilibrium by generates the earth pressure in chamber counteract the hydraulic pressure within the tunnel face.

2.6 Problem and countermeasure of TBM drive in multiple ground layer with gravel

There are consist of multiple ground layer of bedrock or weathered rock in STA.0+350~0+500 (L=150m). It was weathered rock and soil at original design. So, the countermeasure to the tunnel excavation such as the following was applied.

First of all, for the safe replacement of the disc cutter is deemed necessary prior to tunnel face reinforcement was performed using a urethane grouting.
After drilled ahead of tunnel face, urethane and cement grout was injected into the bored hole where the first encountered section (STA. 0+353) geological conditions contained gravel layer (soil 50% + gravel 30% + soft rock 20%). The urethane and cement grouting was carried out for additional reinforcement. Table 2 shows the grouting in gravel layer for ground reinforcement. Figure 5 and 6 shows grouting at the front and rear of the tunnel.

Table 2. Grouting for ground reinforcement in gravel layer.

| STATION | Ground reinforcement | Injection period |
|---------|----------------------|------------------|
| 0+353 m | urethane & cement grouting | 12 days |
| 0+382 m | urethane grouting | 3 days |
| 0+435 m | urethane grouting in tunnel face | 3 days |
| 0+452 m | cement grouting at the front of TBM cutterhead | 3 days |

In addition, bottom slime cleaning time was shortened by facilitating the muck taken out for shield TBM excavation injecting bentonite slurry into the tunnel face.

The work efficiency was improved by adopting disk cutter integrated with cutter ring and cutter body to minimize disk cutter uneven wear and damage and adjust the aperture ratio of cutter head.

2.7 Analysis of excavation data for the EPB shield TBM

The average thrust of EPB shield TBM is 2,982 kN, the maximum thrust is 6,638 kN. TBM required thrust is about 31% and 69% of the maximum thrust. It was confirmed that TBM drive is made without trouble for the mechanical aspects. In addition, 2,000 ~ 3,500 kN thrust range of the TBM include average value is the most frequently issued on TBM excavation (Fig. 7).

![Thrust of TBM](image)

Torque of the TBM also showed a similar trend with thrust. The average torque is 224 kN·m, the maximum torque is 369 kN·m. This is only about 44% and 67% of the TBM maximum torque which is 550 kN·m in normal condition. It is significantly lower level when compared to the TBM maximum torque capacity of 1,250 kN·m (Fig. 8).

![Torque of TBM](image)
Cumulative excavation tunnel length by date encountered construction problems is shown in figure 2.9. This graph can be seen TBM drive was successful beginning of the tunnel excavation approximately 100m. However, about 100m (STA.0+330–0+430) was driven about 4.5 months from December 30, 2013 until May 15, 2014. This is in consonance with the high load on the disk cutter appeared in the station of 0+350–0+450 shown in Section 2.4. Excavation of this section has been delayed due to grouting etc to deal with appearance of unexpected cobble stone. However, the slope of cumulative TBM excavation tunnel length tends to increase constantly since May 15, 2014. It can see the excavation of TBM tunnel is going smoothly (Fig. 9).

Fig. 9. Cumulative TBM drive length by date and appearance date of cobble stone.

3 CONCLUSIONS

A case study application of shield TBM in the gravel layer with high water pressure underpassing Han river was explained in this paper. Through this case study for the construction using the EPB shield TBM, the results are as follows.

According to the preliminary geotechnical investigation during the design stage ground condition of will excavation by TBM was composed of bedrock and weathered rock. Also, additional geotechnical investigation result which reflect lower the tunnel linear expect that TBM tunnel will be passed through the bedrock layer. However, irregular geological conditions that are not identified in the preliminary investigation emerged from the about 50m TBM excavation. It was a main reason of lower the TBM advance rate. In particular, the analysis of the existing geotechnical investigation data and actual geology data of TBM excavation, there expected global tectonic activity similar with trust, fold activity, differential weathering and irregular sedimentation activity at river bed at 55–600m away from the launching shaft. This global geological activities have led to complex ground conditions that is emergence of siallitization of rock, gravel layer in deep depth than expected, gravel layer from bottom of the rock, inclined sedimentary layer consist of rock, gravel and soil, etc.

As for the resistance of water pressure in TBM tunneling, The 3.5–4.5 bar water pressure measured during the excavation could be solved through applying double screw conveyor and multistage tail seal of shield TBM. Review the compatibility of EPB shield TBM which is adapted in this project by statistical model of based on the general design and manufacturing of shield TBM. As a result, required specification of shield TBM is similar to the result of statistical model. EPB shield TBM was design and manufactured suitable for the site conditions. Maximum thrust and torque of EPB shield TBM is design and manufactured 6.8–9.1% larger than estimated value of statistical model. So, shield TBM has been confirmed to have a sufficient factor of safety. Analyzed result of shield TBM excavation data until the end of excavation, The thrust and torque of shield TBM was controlled below the maximum capacity. On the other hand, cutter penetration depth is in a very low level, while the vertical force of cutter shown to occur very significantly in STA.0+350–0+450m. The construction delay is determined to be due to the unexpected emergence of gravel containing cobble stone that is observed muck from the tunnel excavation. However, the analysis result of 1 day TBM advance rate shown 14m/day to a record maximum since STA.0+450m until completion of the TBM excavation. It was confirmed that shield TBM excavation was completed safely securing the stabilities of the tunnel.

REFERENCES

1) Japan Tunnelling Association (1988): Handbook for tunnel engineering.
2) Jee, W. Y., and Lee, H. S. (2001): Principle of shield TBM rock excavation, Tunnel and Underground Space Vol. 11, No. 3, 191-199.
3) Lee, C. W., and Hwan, C. K. (2006): Shield TBM, Tunnelling Technology Vol. 8, No. 4, 13-53.