Cross passage mining in highly permeable and soft ground

K.H.Yi \(^1\) and S.Y.Marcus Tong \(^2\)

\(^1\) Senior Engineer, Amberg & TTI Engineering, Singapore.
\(^2\) Director, Amberg & TTI Engineering, Singapore.

ABSTRACT

Over the last 2 decades, there is a huge development in Singapore’s Rail Infrastructure projects. Downtown Line 2 (DTL2) is part of this major rail network. This paper will focus on the construction of 4 mined cross passages work for one of the contracts under DTL2. As the cross passages were located in very high permeable soft ground condition mining for the cross passages posed huge challenges. In addition, the allowable settlement in this project was very stringent as the construction was located underneath a busy 6 lanes dual carriageway with congested utilities. The construction was also in close proximity to high rise residential area. This paper will discuss the construction difficulties encountered on site related to face stability, basal heave, water ingress and the distortion of cross passage lining and how these construction difficulties were overcome during construction stage without causing major impact to the surrounding road, utilities and building structures.

Keywords: excavation, cross passage, permeable ground, weak ground

1. INTRODUCTION

2.3km long twin bored tunnels were constructed in one of the contracts under DTL2 which is located in the western part of Singapore. After the construction of twin tunnels namely Expo Bound and Bukit Panjang Bound tunnels, 7 numbers of cross passages were constructed by mining. These cross passages will serve as fire escape passage ways between the Expo and Bukit Panjang Bound tunnels. The cross passages are located in different types of ground condition such as in rock, in soil and in mixed ground. This paper will focus on the 4 numbers of cross passages which are located in bukit timah granite residual soil.

2 GEOLOGICAL CONDITION

The project is situated in Bukit Timah Granite Formation with overlying Fill of 1m to 8m thick. Along the alignment, there were also localized Kallang Formation consisting of Fluvial Sand, Fluvial Clay and Estuarine Layer overlying the Bukit Timah Granite Formation. The intrusion of the Bukit Timah granite is believed to have taken place during early to early-middle Triassic period, from 200 to 250 million years ago. Bukit Timah Granite Formation is weathered with weathering grade varying from G-I to G-VI. The classification of Grade 1 to Grade VI is depending on the weathering grade as Grade 1 represent very intact rock and Grade VI represents completely weathered granite. Cross passages no 4, 5, 6 and 7 are located in the Bukit Timah Granite Formation residual soil.

Typical geological profile of these cross passages is shown in Figure 1. The depth of the cross passages varies from 22 to 28 meters (ground level to cross passage spring line) and the length varies from 12 to 27m (center to center of the twin bored tunnels). Due to the hilly terrains within the vicinity of the cross passages, some vibration wire piezometers indicated high piezometric level and in some case piezometric level is as high as 20m above the existing ground. The general ground water table at the cross passage location is about 1m below ground level.

Figure 1. Typical geological profile for cross passage

3 CROSS PASSAGE PROFILE AND DETAILS

Each of the cross passages consists of two parts, the collar section and tunnel section. Tunnel section was typical cross passage section determined from the...
minimum width considering fire safety requirement and construction accessibility. The collar section was slightly bigger than the tunnel section (Figure 2) as it has to accommodate the strengthening columns at the junction of bored tunnel and cross passage to compensate for the loss of strength of the removed segment of bored tunnel lining due to cross passage opening. The construction of cross passages was carried out using New Australian Tunneling Method. Construction of each section was further divided into top heading and bench/invert excavation. The initial support system included shotcrete, lattice girder and wiremesh. Both temporary and permanent lining profiles for this project was oval in shape which satisfied the stability requirement and also achieved the smallest possible excavation profile.

4 DESIGN METHODOLOGY

The analysis was carried out using geotechnical finite element software. Plane strain analysis adopting Mohr Coulumb material model was carried out. Both drained and undrained analyses were carried out to capture the critical case. The excavation will be carried out using NATM approach and its concept is to provide some relaxation to the ground by utilizing the available stand-up time (related to shear strength & ground cohesion) of ground so as to optimize the requirement of primary support system. To activate this soil relaxation behavior before the lining installation work, 10% to 30% of soil relaxation was considered in the analysis. If 10% relaxation was used, it will give a higher lining force as compared to 30% relaxation, which is a reasonable approach for the lining design and also not as conservative as the 0% relaxation case. For the settlement checking for the surrounding structures and ground surface, a higher relaxation factor was applied as it will give more ground settlement and hence 30% soil relaxation case was used.

5 CONSTRUCTION CHALLENGES AND GROUND MOVEMENT BEHAVIOUR

5.1 Control of face stability

The original design intent was to carry out the top heading excavation then followed by bench/invert excavation for cross passage. This was to close the excavation profile of cross passage as soon since possible as a complete profile is structurally more stable. However, during the construction stage, there were some signs of face instability encountered on site. Some of these signs included localized soil collapse, high settlement and high water ingress. In addition, the settlement markers installed along the cross passage (Figure 3), showed increasing trend in settlement during construction work. This face instability issues mainly occurred due to low shear strength exhibited by the soil encountered on site and it was further weakened due to high water pressure encountered during excavation work. To prevent further deterioration to the soil, the best possible way was to limit the excavation exposed faces, as much as possible, so that to minimize the instability and water ingress. Several measures were carried out on site to prevent these problems and some of the measures implemented were listed as follows.

(1) Carried out whole top heading excavation. Bench excavation was carried out only after whole top heading excavation was completed so that to limit the exposed soil face (Figure 4)
(2) Further divided the top heading excavation to two drifts (Figure 5)
(3) Original advance length of 1m was further reduced to 0.5m
(4) Upto 40 numbers of soil nails were installed at the excavation face to increase the face stability (Figure 5)

After taking these measures on site, the excavated face was stable and the settlement trend also become stable.

Figure 2. Cross passage longitudinal profile

Figure 3. Settlement trend for cross passage excavation

Figure 4. Settlement trend for cross passage excavation
5.2 Control of base stability

During top heading excavation work, it was observed that there was heave encountered at the base although invert of the top heading was already sealed with 150mm thick shotcrete. There was also indication of soil material flowing into the excavation area especially at the bottom corner of the top heading excavation. It was concluded that there were some basal heave and base instability issues. To strengthen the base of the excavation and to increase the bearing capacity of the base, vertical forepoles or spiles were installed at the base of the top heading. Figure 6 showed the workers installing the spiles and these spiles had shown to eliminate further base instability problem.

5.3 Control of ground water ingress

One of the major challenges in underground excavation or mining work is ground water ingress. The ground was very weak and permeable in this project and hence to prevent any catastrophic failure during construction, probe drillings (Figure 7) were carried out to investigate the ground water ingress. The recorded ground water flow during that time was not very high and hence, excavation was carried out without any ground treatment work. However, during the excavation, high ground water ingress was encountered in some of the cross passages. In some cases, ground water ingress increased upto 90l/min and its associated immediate ground settlement was also quite high as a result of high water table draw down. Consolidation settlement was not a major concern here as the ground was over consolidated. There was no major problems occurred due to high settlement as the settlement influence zone was at the green verge near the road. However, ground stability can be a concern as inflow water could bring soil particles into the excavation as shown in Figure 8 and resulted in excavation instability, and therefore, inflow water was carefully monitored whether the inflow water was clean or with soil particles (mucky). If the inflow water was clean and settlement was within allowable limit, no major measure was taken during the construction work. In some cases, the water seemed to bring soil particles into the excavation. For these cases grouting works are carried out to prevent further ground water ingress during the excavation work.

Figure 5. Worker marking positions for face nail installation

Figure 6. Spiles installation works in progress

Figure 7. Probe drilling works before segment removal

Figure 8. Water ingress measurement on site showing soil particles inside inflow water
5.4 Control of cross passage distortion

Horizontal movement of the cross passage can be monitored either by inclinometer or convergence monitoring installed on the cross passage wall. During the excavation works for cross passage no 6, it was realized that convergence monitoring showed high movement as shown in Figure 9. In reality, convergence monitoring points were installed after the lining installation; hence high movement should not be recorded as most of the soil movement was expected to happen before the lining installation. Therefore, investigation was carried out. During the design stage, as this cross passage was located in very weak ground condition, ground treatment work was specified. However, jet grouting from ground surface was not possible due to the congested utilities and busy road above. Hence, treatment was carried out from within the bored tunnel. In this case, 42 nos of grout holes were installed from the completed bored tunnel and treated the cross passage excavation area. Although the ground was treated, based on the movement behaviour of the ground, the ground did not appear to be well treated especially at the side of the cross passage walls. As mitigation measures, some numbers of horizontal forepoles were installed at the side of the cross passage to strengthen the ground. In addition, since the side wall was moving, the horizontal strut was installed across the cross passage wall to prevent further movement. The details are shown in Figure 10. By doing so, the movement of the cross passage is stable.

6 CONCLUSION

Construction of 4 numbers of cross passages in Bukit Timah granite residual soil was carried out under this project. Overall construction project for these cross passages took about 9 months. Some of the cross passage construction works were completed within 3 months and some took as long as 7 months. The construction period varied for each cross passage because some of the cross passages encountered quite a number of construction challenges as mentioned in this paper. The main challenge encountered in this project was the face stability issues and control measures for the face instability were stated in this paper. This paper also addressed appropriate measures in resolving potential basal heave issues. Control measures for water ingress issue, was also highlighted. Water ingress will not be a major issue as long as it does not result in very high settlement and compromise the ground stability during excavation. Otherwise, ground treatment work should be carried out. The paper also addressed the distortion of segment lining encountered during the cross passage mining works. This paper pointed out the importance of convergence monitoring which were installed inside the cross passage primary lining.

ACKNOWLEDGEMENTS

The authors would like to thank the Land Transport Authority and SK E&C (Singapore Branch) for their support and contribution to the success of this project; their kind permission to allow this paper to be published, and assistance in helping to review this paper.

REFERENCES

1) Yi, K.H., Marcus Tong, S.Y: Ground Movement Behavior from Cross Passage Mining in Hard Rock and Very High permeable Soft Ground, Underground Singapore 2014.