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Deep intervention shaft excavation in Kuala Lumpur limestone formation with pre-tunnelling construction method

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ABSTRACT: In Malaysia, Klang Valley Mass Rapid Transit Line 2 (KVMRT2) is consisting of 38.7km elevated tracks and 13.5km underground tunnels with several shafts. For intervention shaft 2 (IVS2), deep soil mixing (DSM) block was designed to provide excavation support in overburden alluvial soil, followed with vertical rock excavation until 57.5m deep in Kuala Lumpur limestone formation. Ground treatment in limestone was established to minimize groundwater drawdown during deep excavation to prevent excessive ground settlement. A mined adit was constructed to connect from the shaft at mid-depth to south-bound tunnel. Meanwhile, north-bound tunnel at bottom of the shaft was constructed by tunnel boring machine cutting through concrete-filled block inside the shaft compartment. This paper covers the challenges in design and construction of the deep excavation works for the shaft, ground improvement scheme for the bored tunnelling near the shaft, temporary works for mined adit and unconventional construction sequence of bored-through tunnel.

1 INTRODUCTION

It is estimated that the demand for travel in the Malaysia's Klang Valley to reach 18 million trips per day by year 2020. Hence, a public transportation network capable of ferrying large numbers of passengers efficiently in the form of rail-based mode is needed. The first line of the Klang Valley Mass Rapid Transit project (also known as KVMRT1) begins from Sungai Buloh at the north-west, runs through the city centre of Malaysia's capital city (i.e. Kuala Lumpur) and ends in Kajang, which is located at the south-east of the city. This Sungai Buloh-Kajang line began operations in two phases respectively on 16 December 2016 and 17 July 2017. The 51-km length transit line is estimated to serve a daily ridership of about 400,000 passengers in the city.

Meanwhile, the second line of the MRT project (KVMRT2) was given the approval by the federal government in October 2015 in order to complement the KVMRT1 line to serve a corridor with a population of around 2 million people. While this transit line is currently being constructed, it will have a length of 52.2km stretching from Sungai Buloh, through the centre of Kuala Lumpur and Serdang until Putrajaya, which is Malaysia's federal administrative centre. This on-going KVMRT2 line will have a distance of 13.5km running through underground tunnel as compared with only 9.5km of the KVMRT1 line. The tunnels will be built using tunnel boring machines and/or the cut-and-over method depending on the depth of the tunnels.

For the underground sections of KVMRT2, total of six escape shafts and intervention shafts are provided for the purpose of emergency escape and ventilation. Among them, Intervention Shaft 2 (also known as IVS2) is the largest in size and the deepest. It is a circular shaft with maximum diameter of 19.7m between two sides of the excavation faces. The maximum depth of the shaft is up to 57.5m until final excavation level below existing ground level (i.e. RL42m). Twin bored tunnel lines bounding for North and South respectively are running at different elevations while interfacing with the IVS2. The south-bound tunnel is located at higher elevation and is connected to the shaft via a mined adit. Meanwhile, north-bound tunnel is directly crossing through the bottom section of the shaft.

2 GENERAL SITE CONDITIONS

2.1 *Site Location*

The site for IVS2 shaft is located at the center of a roundabout (known as Bulatan Kampung Pandan), which is an intersection between Jalan Tun Razak and Jalan Kampung Pandan, located in the Kuala Lumpur city center. A landmark building of Berjaya Times Square is just 1.3km away from the site. Location of the site with existing buildings and roads is shown in Figure 1.

The shaft is located in close proximity to KVMRT Line 1 tunnel as well as its Escape Shaft 3 building, Stormwater and Roadway Tunnels (SMART) motorway and North Junction Box, and several existing buildings (including IKEA Cheras). Besides that, at the time of designing, it is known that future vehicular viaduct of Duta Ulu-Kelang Expressway (DUKE) will be running adjacent to IVS2, potentially with some piers located close-by. All these structures and some other services/utilities are posing major constraints to the design and construction of the shaft.

It is very crucial to ensure that the temporary retaining structure system for the excavation of the shaft would be designed to limit ground movements and does not cause damaging impacts to those structures during the entire construction period.

2.2 *Ground Condition*

Based on available boreholes within the close vicinity of the shaft, it is found that the site is underlain by Alluvium overlying the Kuala Lumpur Limestone as shown in Figures 2 & 3. The Alluvium is very loose sand/very soft to soft silt with SPT-N not more than 30 overlying the limestone bedrock. The depth of bedrock varies from 4.5m to 8.0m below ground level around the shaft area. The limestone bedrock consists of highly fractured rock to strong rock with Rock Quality Designation (RQD) ranges from 0% to 93%. The interpreted groundwater level is 2m below ground level based on available water standpipe readings. Summary of geotechnical design parameters for Intervention Shaft 2 is presented in Table 1.

Kuala Lumpur Limestone is well known for its highly erratic karstic features, such as irregular bedrock profiles, variable weathering condition, cavities, pinnacle zone and slime zone. Challenges in such karstic limestone formation are faced by the designers in designing an appropriate temporary retaining structure system to facilitate the underground excavation works.

Figure 1. Location of Intervention Shaft 2 (IVS2).

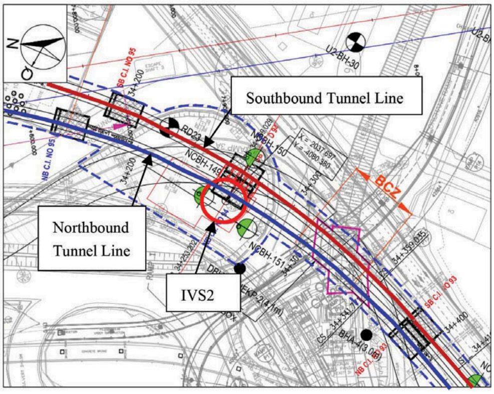

Figure 2. Boreholes layout plan.

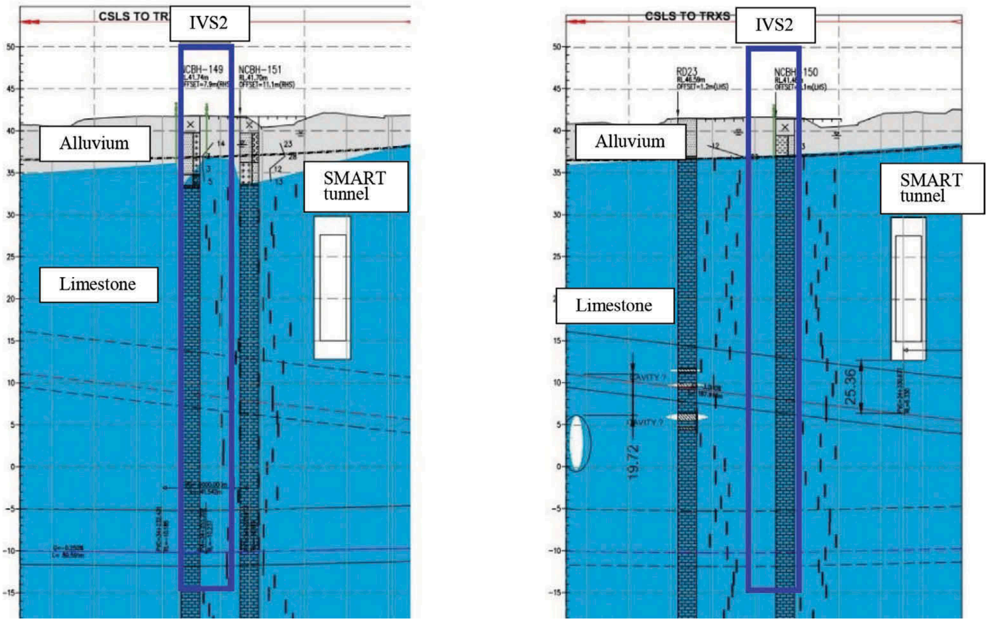

Figure 3. Borehole and geological profile along Northbound tunnel (left) and Southbound tunnel (right).

Table 1. Geotechnical Design Parameters.

Geological Formation	Alluvium	Limestone
Depth below ground	0m – 8m	>8m
Average SPT-N	5	-
Unit Weight	19 kN/m^3	24 kN/m^3
Loading Stiffness	15,000 kPa	1.0E6 kPa
Unloading Stiffness	45,000 kPa	-
Effective Cohesion	1 kPa	400 kPa
Effective Friction Angle	29°	32°
Permeability	1.0E5 m/sec	1.0E6 m/sec
At Rest Lateral Earth Pressure	0.52	0.50

3 TEMPORARY RETAINING STRUCTURE SYSTEM

3.1 *Deep Soil Mixing Wall*

3.1.1 *Design Considerations*

The Intervention Shaft 2 consists of a circular shaft. The advantage of circular shaft is there will be unobstructed excavation area and working space which results in faster overall construction, especially for deep underground shafts. Given such shape of shaft, the proposed temporary retaining structure system is therefore configured in the same circular form. Referring to Tan et al. (2016), the design of this circular retaining structure is also based on the hoop stress concept in which the induced hoop stress due to earth pressures shall not exceed the allowable compressive stress of the material of the retaining structure.

Deep soil mixing (DSM) wall is adopted where the entire block of soil will be mixed with cement grout to form an interlocking columns block, rather than a conventional retaining wall with or without lateral supports (e.g. steel struts, ground anchors and etc.) as shown in Figure 4. The width of DSM block is 4m all around based on design assumption of 8m thick overburden subsoil above bedrock. Typical arrangement of the DSM interlocking columns arrangement is shown in Figure 5.

The DSM technique involves the process of mixing soil with cement slurry by using a mechanical tool, which is drilled into the ground. The cement-mixed soil block will have enhanced compressive strength, reduced permeability and increased stiffness as compared to the original soil. As the DSM wall is designed as a circular block based on hoop stress concept, steel reinforcements and lateral supports are not required. Furthermore, rock socketing is also not needed as compared to conventional retaining wall.

3.1.2 *Monitoring and Performance*

The execution practice and quality control of DSM works are in accordance to British Standard BS EN 14679:2005 (Execution of special geotechnical works – Deep Mixing). An inspection and test plan were established in which the frequency of strength tests on the DSM samples extracted from the ground is set as four cores per 1000m^3 of DSM area. Core samples were collected from the center of the DSM columns and at intersection between columns for

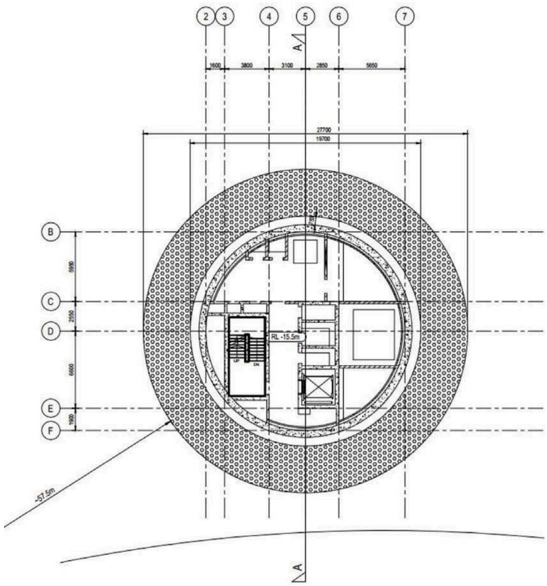

Figure 4. Deep soil mixing layout plan.

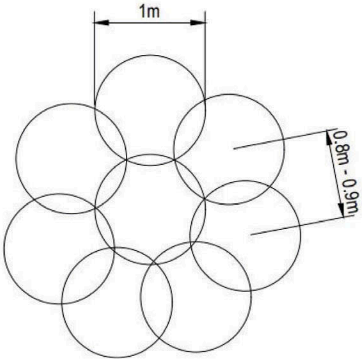

Figure 5. Typical DSM columns arrangement.

unconfined compressive strength (UCS) tests. Generally, UCS strength of all test samples are more than the designed allowable compressive strength of 1.0MPa after 28 days.

Monitoring scheme is also implemented to monitor the actual performance of the DSM wall in terms of wall movement and settlement. For this purpose, four inclinometers were installed within the DSM block zone and thirty-two settlement markers were placed on the ground surface along two section lines across the circular shaft. Maximum wall movement monitored throughout the excavation works was less than 4mm. The deflection profile of one of the inclinometer is shown in Figure 6. Meanwhile, the maximum ground settlement over the same period only recorded less than 6mm. The measured deflection profiles and ground settlement readings could imply a very stiff circular DSM block given the hoop action and counter-balancing effect. The overview of the shaft excavation works is shown in Figure 7.

3.2 *Rock Slope Strengthening Works*

Bedrock is anticipated at about 8m below ground level and thereafter rock excavation works will be carried out for another 50m until the final excavation of 57.5m deep. Rock excavation

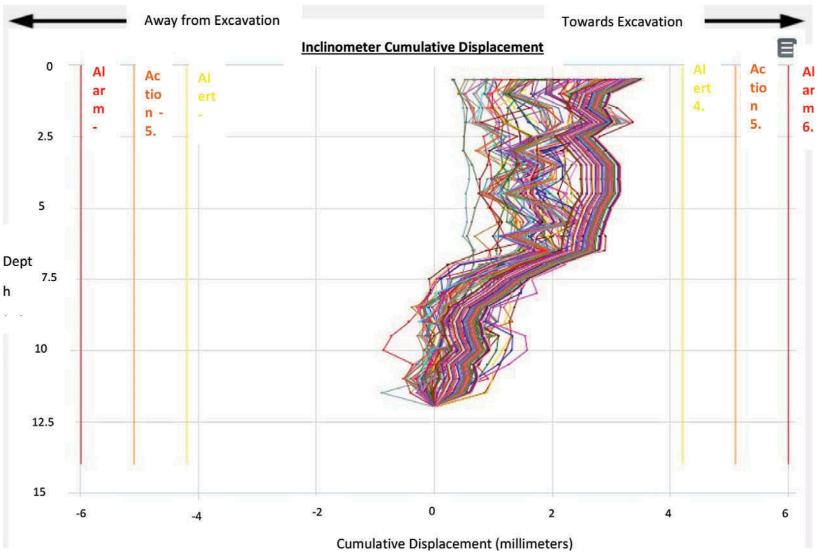

Figure 6. Deflection profile of DSM block during shaft excavation works.

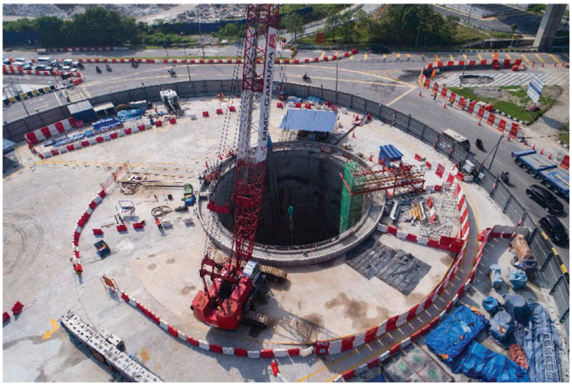

Figure 7. Overview of Shaft Excavation Works.

by controlled blasting method is the most practical way to use. Excavation in rock will be carried out in stages of every 2 to 3m height.

After exposing the finished rock face, on-site rock mapping will be conducted by suitably qualified and experienced engineering geologist. The rock mapping data which includes dip angle and dip direction of visible joints/faults will feed into Stereonet analysis to determine any potential planar, toppling or wedge failures. Subsequently, stability analyses will be performed to calculate the factor of safety of the identified failure modes and the stabilization works using mainly steel reinforcement rock bolts will be designed.

Glass fibre reinforced polymer (GFRP) type rock bolts will be used to create a soft-eye where tunnel bored-through is anticipated. GFRP reinforcement will be designed in accordance with ACI 440. Shotcrete with steel wire mesh will be applied to the full surface of the exposed rock face to obtain a uniform surface for water proofing for permanent reinforced concrete works in later stage and also to prevent any localized rock instability.

3.3 *Grouting Works*

In consideration of the potential cavities and solution channels in limestone formation, water ingress into the excavation site is a key safety concern for the construction works. Therefore, rock fissure grouting was carried out around the perimeter of the circular shaft from the rock head level until 10m below final excavation level. This is aimed to minimize the risk of groundwater ingress and groundwater drawdown during rock excavation which also to prevent excessive ground settlement that could cause distress to adjacent buildings and structures.

In order to form an effective curtain surrounding the shaft, primary grout points were carried out at a distance of 6m away from shaft excavation surface with grouting spacing of 4m

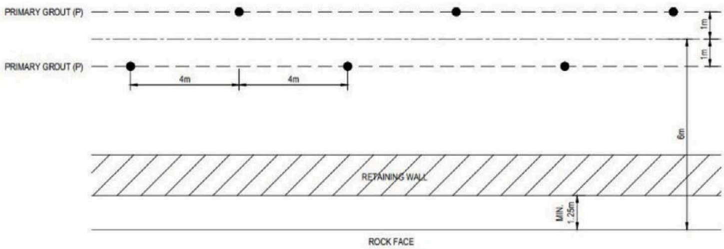

Figure 8. Typical arrangement of primary fissure grout points.

staggered all-round the shaft perimeter. Secondary grout points were added at middle spacing between the primary grouted points if high grout intake of more than 5,000 liter for a prescribed pressure at a given depth or cavities are detected. Tertiary holes and further grout points could be added if needed. Schematic arrangement of the curtain grouting is shown in Figure 8.

4 GROUND IMPROVEMENT SCHEME FOR ADITS

As mentioned in Section 1 of this paper, there is an adit that connects the shaft to the South bound Tunnel. The adit is inside the limestone rock. Before the mined adit excavation works, fissure grouting works were carried out 5m all around the adit to create a grouted block.

Meanwhile, for TBM break-in at the receiving locations of the shaft, ground improvement/grouting is also carried out for a minimum length equivalent to the length of the TBM shield plus one ring of tunnel lining. The respective ground improvement zones are shown in Figure 9.

The main purpose of the ground improvement zones are (1) to provide the ground with sufficient strength (2) to reduce the permeability of the ground over the adit length (3) to allow TBM to reduce face pressure from full face pressure of balancing earth and hydrostatic pressure to atmospheric pressure without causing instability of ground and excessive water inflow into the receiving shaft.

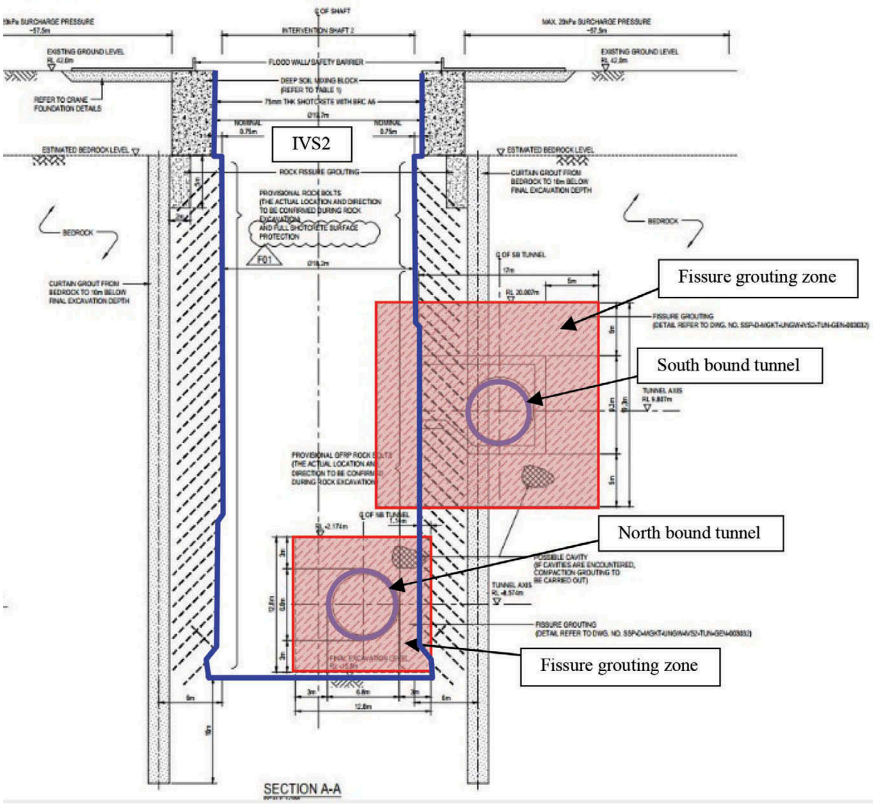

Figure 9. Cross section of ground improvement zone for adit and TBM break-in.

5 TEMPORARY CONSTRUCTION WORKS FOR TUNNEL/ADIT

5.1 *Adit connecting to South Bound Tunnel*

The adit is in a horseshoe shape with a clear width between the side walls of 8m. The internal height of the adit close to the shaft is 8m and the height will increase to 10.85m (while the crown remains at a constant level) after the first 3m length of the adit from the shaft side.

Generally, the mined tunnel will be constructed using the Sprayed Concrete Lining (SCL) approach which is characterized by installing temporary support in the form of rock bolts and Steel Fibre Reinforced Shotcrete (SFRS) during excavation. When excavation is completed, a permanent support, in the form of a cast in place concrete lining, is installed.

With the objective of expediting the construction of permanent shaft structure and tunneling schedule, it was decided to complete the adit structure first when vertical excavation in shaft reaches this adit level prior to arrival of tunnel boring machine (TBM) at South Bound line. The length of the mined adit is until the entire bored tunnel section and then allow for TBM bore-through at the 'soft-eye' on the receiving adit wall.

Besides that, it is crucial to create a temporary wall in between the shaft and the bore-through area to cater for the tunnel bore through impact (50kPa pressure). This temporary wall is going to connect to the permanent lining of the adit and to be demolished once the TBM operation is completed. The compartment behind the temporary wall, where tunnel is coming through, is filled up with mass concrete (minimum 5 MPa compressive strength). After all these are in place, then South Bound tunnel drive can bore through into the adit. Figure 10 shows the general arrangement of the adit. Meanwhile, the overview of the adit construction works is shown in Figure 11.

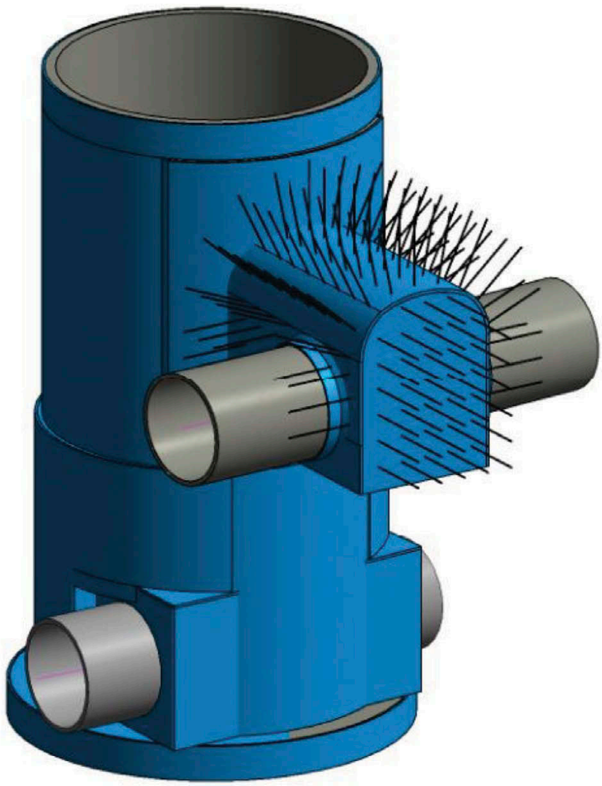

Figure 10. General arrangement of adit and TBM break-in area.

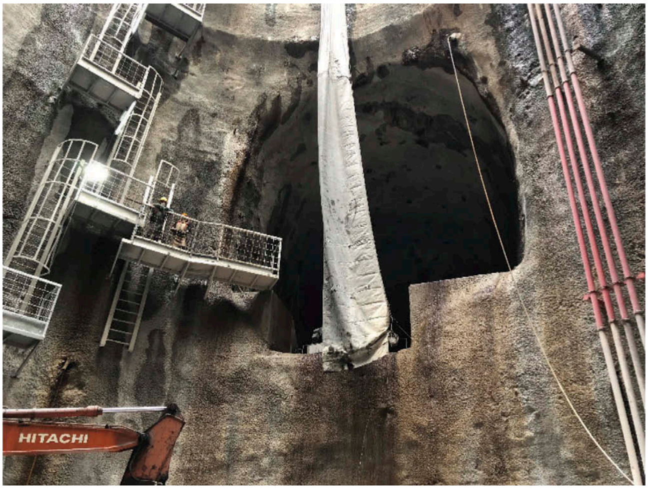

Figure 11. Horseshoe shape adit in construction.

5.2 *Bore-through North Bound Tunnel*

The construction sequence for the shaft connection to North Bound Tunnel is planned such that shaft is excavated until the final level in precedence over the TBM arrival. After the final excavation level of the shaft is reached, permanent base slab, permanent upper slab, all external walls and tunnel eye are then constructed.

Similar to the adit connecting to South Bound Tunnel, a temporary reinforced concrete wall is to be constructed with connection to the permanent base slab and upper slab creating a room for TBM bore through. This room is filled up with mass concrete and back grouting is carried out to fill any voids in the crown of the room. After that, North Bound tunnel drive can bore through the tunnel eye coming into the concrete-filled room inside the shaft. The temporary wall and mass concrete will be excavated after completion of the tunnelling operation.

6 CONCLUSION

Deep soil mixing wall was successfully used as temporary earth retaining scheme for shallow overburden subsoil up to 8m depth above limestone bedrock. Ground improvement scheme with rock fissure grouting works were carried out around the perimeter of the circular shaft to prevent excessive groundwater ingress into excavation pit as well as to control groundwater drawdown at the surrounding area of shaft. Rock excavation was carried out with stages of control blasting and follow by rock condition mapping by engineering geologist up to maximum excavation depth of 57.5m below ground. Necessary rock slope strengthening measures will be assigned at every stage of excavation with rock mapping data and condition assessment before allow to next stage of excavation work. Considering overall tunneling schedule, post-tunneling construction method was adopted. The permanent structure of connection adit will be completed in advance before TBM arrive by providing required bore-through facility without affecting tunneling schedule.

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