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A deep excavation case history in the KVMRT-SSP Line: design and construction challenges in geotechnical engineering practice

Une histoire de cas d'excavation profonde dans la gamme KVMRT-SSP: défis de conception et de construction dans la pratique de l'ingénierie géotechniqu

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ABSTRACT: In the Klang Valley Mass Rapid Transit (KVMRT) of Kuala Lumpur Sungai Buloh-Serdang-Putrajaya (SSP) Line, the deepest station is Ampang Park station with a final excavation level of 43 meters below ground. The station was constructed using the top-down construction sequence. The site is founded within the Kenny Hill Formation, consisting of the residual soil of metamorphic rock of quartzite and phyllite, overlying the Kuala Lumpur Limestone Formation. Characteristic of the interface zone is the reduction in SPT-*N* values of the Kenny Hill residual soil close to the limestone rock head. The geological interface has posed challenges to construction. The performance of the deep excavation is studied using measurements obtained from instrumentation and monitoring, and they are discussed in this paper.

RÉSUMÉ : Dans la ligne KVMRT (Mass Rapid Transit) de la vallée de Klang de Kuala Lumpur Sungai Buloh-Serdang-Putrajaya (SSP), la station la plus profonde est la station Ampang Park avec un niveau d'excavation final de 43 mètres sous terre. La station a été construite selon la séquence de construction descendante et le site est fondé dans la formation de Kenny Hill, constituée du sol résiduel de roche métamorphique de quartzite et de phyllite, recouvrant la formation de calcaire de Kuala Lumpur. La caractéristique du sol dans la zone d'interface est une réduction des valeurs de SPT-*N* du sol à proximité de la tête de roche calcaire. L'interface géologique a posé des défis à la construction. Les performances de l'excavation profonde sont étudiées à l'aide de mesures obtenues à partir de l'instrumentation et de la surveillance, et elles sont discutées dans cet article.

KEYWORDS: Deep excavation; diaphragm wall trenching; ground treatment; settlements; buttress wall

1 INTRODUCTION

The deepest station along the alignment of the Klang Valley Mass Rapid Transit (KVMRT) Sungai Buloh-Serdang-Putrajaya (SSP) Line (Line 2) is Ampang Park Station, with a final excavation level of 43 m below ground level (bgl). The station is positioned adjacent to an existing Light Rail Transit station to maximize connectivity (Figure 1). The reasons for its depth are twofold. The first is that the alignment needs to dive below the existing operating LRT tunnels, and the second is due to its stacked tunnel configuration to minimise land merger and acquisition for the station box. The station has to accommodate its future transit-oriented development around Ampang Park Station, with a podium above it and an adjacent basement excavation. Around the station, there are other sensitive high-rise structures with basements, which add complexity to the already challenging deep excavation. In terms of tunnelling logistics, the station had to accommodate the retrieval of four tunnel boring machines.

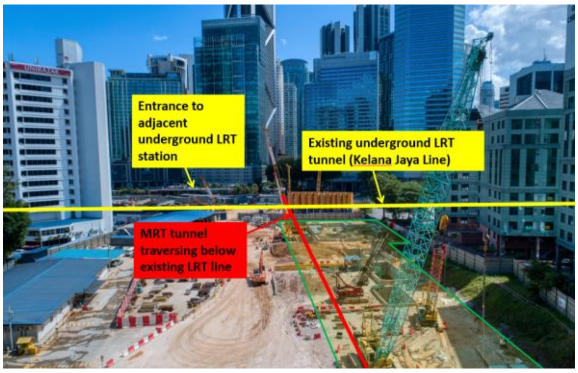


Figure 1. Ampang Park Station Site

2 BACKGROUND OF GEOLOGY AND RETAINING SYSTEM DESIGN

Available information on deep excavations in Kuala Lumpur with regard to KVMRT Line 1 can be found in Boon et al. (2016), Cheah et al. (2016), Goh et al. (2015), Ooi & Ha (2016), and Tan et al. (2015, 2016).

2.1 *Ground conditions*

A site investigation program was devised to establish the soil profile along the station box. From the geology map and initial site investigation, it is known that the site is located within the Kenny Hill Formation, which consists of the residual soil of metamorphic quartzite and phyllite (Figure 2). The strength and stiffness parameters of the Kenny Hill Formation can be found in Nithiaraj et al. (1996), Wong & Muhinder (1996).

Below the Kenny Hill Formation at Ampang Park Station lies the Kuala Lumpur Limestone. The limestone rockhead was found to be erratic, and ranged in depth from between 55 m bgl and more than 120 m bgl along the diaphragm wall alignment. The site investigation was important for the zoning of the design and also to ensure the right machines were mobilized for the construction of the retaining wall and foundation elements.

Characteristic of the interface between the Kenny Hill Formation and the Kuala Lumpur Limestone Formation is the anomalous reduction in SPT-*N* with depth, for the soil close to the limestone rockhead (Figure 3). This observation has been associated with the development of slumped soils which are collapsed materials of the Kenny Hill Formation that overlies the karst features of the Kuala Lumpur Limestone Formation. The soil above the slumped material may be capable of arching but would still be subject to some degree of loosening. More detailed discussions on the geological origins of slumped zone at the interface between the Kenny Hill Formation and Kuala Lumpur Limestone Formation can be found in Tan (2017).

2.2 *Diaphragm wall as retaining system*

A top-down construction sequence was adopted, due to benefits in construction program, as the permanent slabs would be constructed concurrently with excavation. This is ideal as Ampang Park Station would act as a receiving shaft for four tunnel boring machines (TBMs). A top-down sequence was also thought to be more robust with the reinforced concrete struts acting as restraints, particularly since there were adjacent structures. There are also time savings from reducing the installation and subsequent removal of multiple layers of struts, as would typically be required in a bottom-up sequence. A 1.5-m thick diaphragm wall was adopted as the retaining system. For this top-down construction sequence, three layers of temporary struts were required.

The performance of the deep excavation is discussed in this paper and the locations of the monitoring instruments are shown in Figure 4.

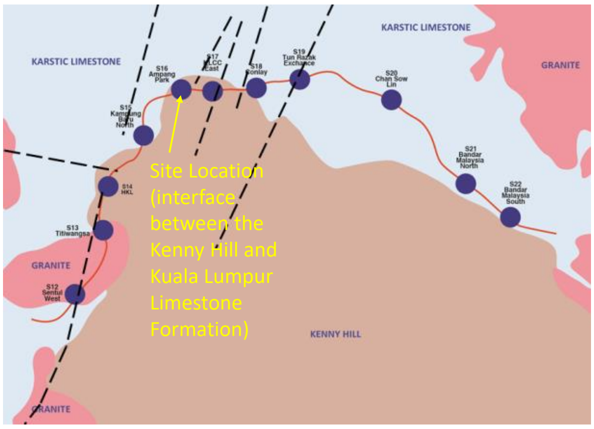


Figure 2. Geological layout plan

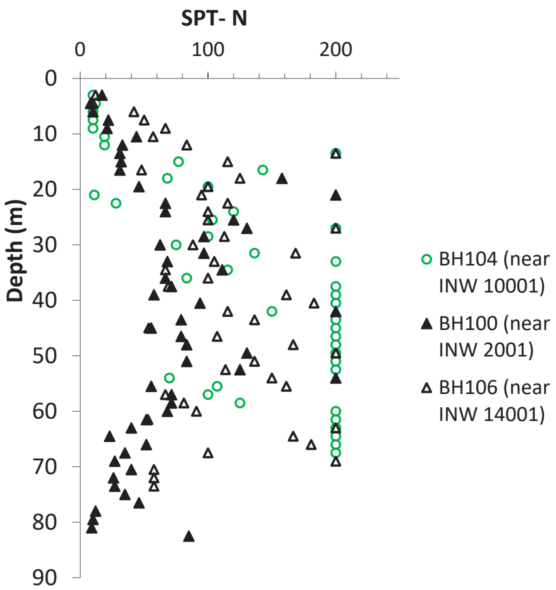


Figure 3. SPT-*N* with depth of three different locations

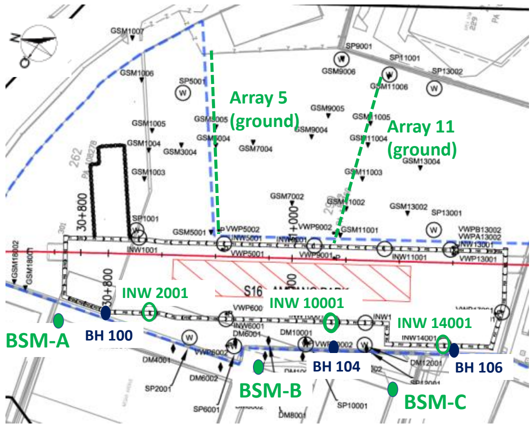


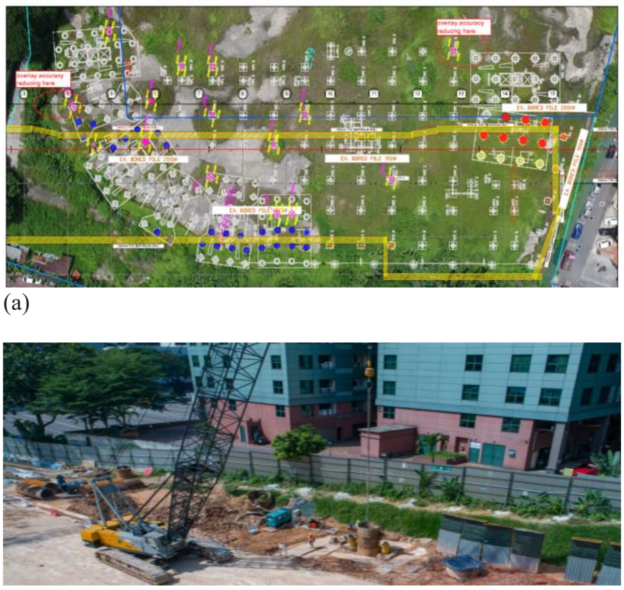
Figure 4. Layout plan of instrumentation and boreholes mentioned in this paper

3 CHALLENGES IN CONSTRUCTION

3.1 *Pile extraction*

A major challenge at the site was that there were numerous existing bored piles from the previous abandoned development, along the diaphragm wall alignment. They had to be identified and removed prior to diaphragm wall trenching (Figure 5). Several methods were adopted, namely removal by extraction or partially crushing the pile, depending on the diameter of the existing piles.

The measurements from the ground surface settlement markers, prior to bulk excavation of the station box, were studied and compared with the readings obtained at an adjacent site within the Kenny Hill Formation. The measurements in Figure 6 show that the settlements were induced largely by diaphragm wall trenching. At Ampang Park Station, the ground settlement magnitudes are larger, and are likely due to the influence of pile extraction works and rock probing works (compare dashed lines with solid lines in Figure 6). The ground response due to trenching of diaphragm wall panels in the Kenny Hill Formation has been studied using 3-D finite element analysis by Cheah et al. (2019).



(a)

(b)

Figure 5. Pile obstructions to diaphragm wall: (a) layout plan of identified obstructions, (b) site view

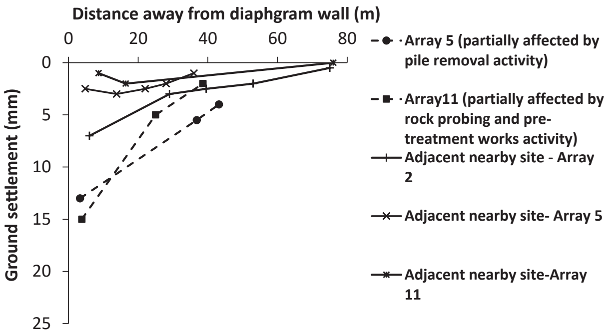


Figure 6. Comparison of ground settlement between sites with and without other disturbances to the ground. The adjacent site has an excavation depth of 38 m below ground and diaphragm wall length of 60m.

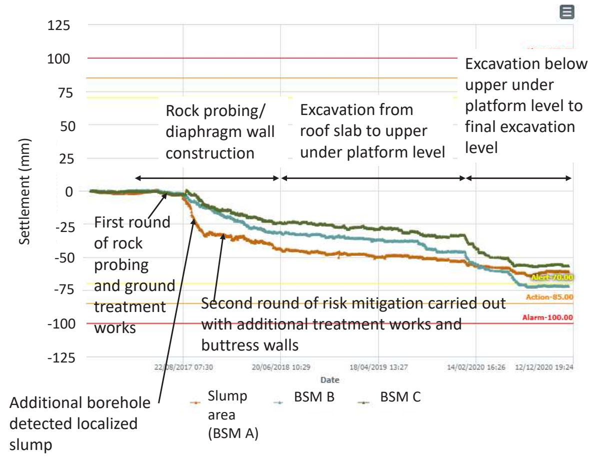


Figure 8. Settlement measurements. Localised slump (SPT-N = 0) observed close to BSM-A is indicated in Figure. 9.

3.2 *Risk mitigation measures for diaphragm wall trenching*

During diaphragm wall trenching works (see example in Figure 7), the limestone rockhead was encountered above the design termination levels. To minimize the risk of bentonite loss, additional rock probing and ground treatment works were commissioned. However, during rock probing works, the adjacent 10-storey structure registered a marked increase in settlement (Figure 8). The probing works were suspended to allow further site investigation to be carried out, which revealed the presence of slump with SPT-N = 0 between the narrow rockhead undulations (Figure 9).

A second round of ground treatment works was commissioned but with improved method of drilling, using roller bit with a duplex system to ensure that the water used for drilling would return to the ground surface, and would avoid risks of excessive washing of fines into the karst features of the surrounding limestone (Figure 10). Bentonite cement grouting was carried out to fill up the voids of the gravelly material, whereas compaction grouting with mortar was used to densify the cohesive slump zone. This ensured that the diaphragm walls could be installed to the design toe levels in the challenging geology (featured in Ground Engineering (2018)).

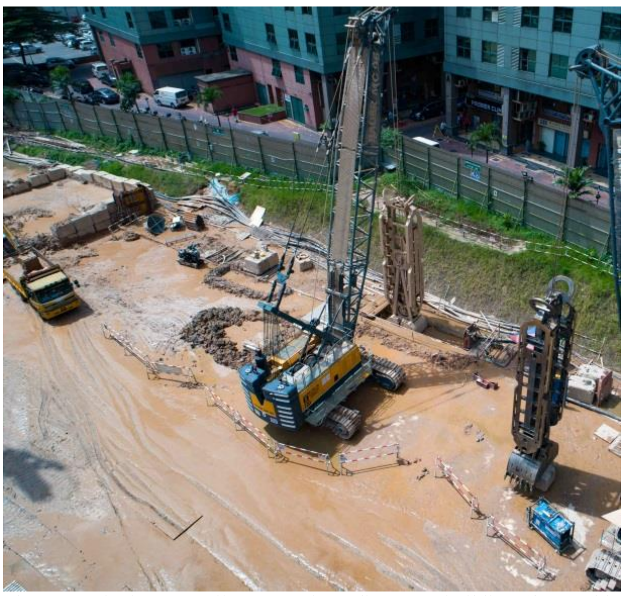
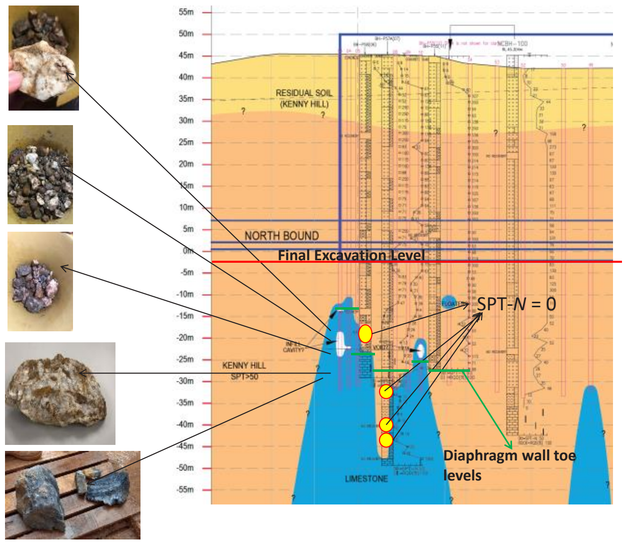


Figure 7. Diaphragm wall construction adjacent to building (featured in Ground Engineering 2018)



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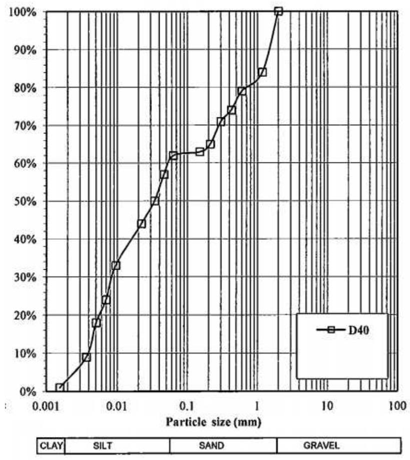
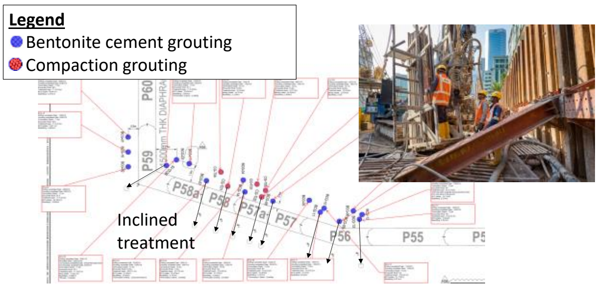


(b)

Figure 9. Ground conditions around diaphragm wall trenching location: (a) soil profile with gravelly material and localised slump zone (SPT-N=0) detected, (b) grain size distribution of soil in Kenny Hill Formation at the slump zone area, specific to the site



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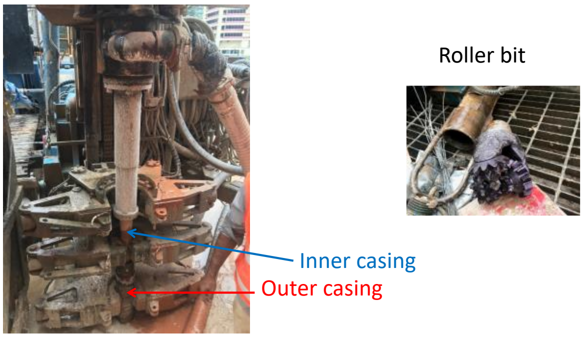
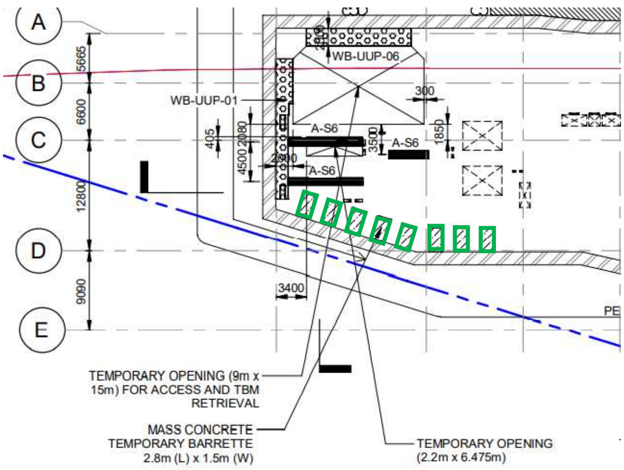


(b)

Figure 10. Ground treatment works for diaphragm wall trenching: (a) layout plan and site image, (b) method of drilling with roller bit and duplex

3.3 *Further risk mitigation for bulk excavation*

A sensitivity analysis was carried out for the building structure to investigate the likely differential settlement at the end of the deep excavation and completion of the station box structure. It was decided to introduce mass concrete barrettes to buttress the diaphragm walls at the localized section of concern (Figure 11). This is to ensure the differential settlements of the adjacent buildings were within tolerance 1:300 (perpendicular to the station box).



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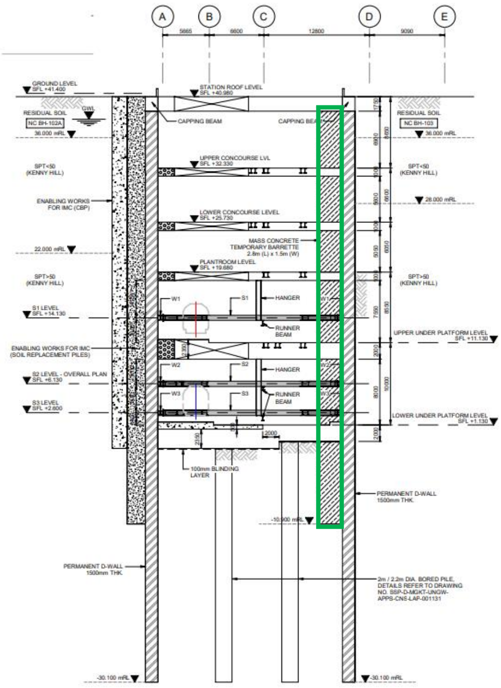

(b)

Figure 11. Mass concrete buttress wall as a risk mitigation measure: (a) layout plan, (b) cross-section

3.4 *Station construction accounting for tunnel boring machine retrieval*

Temporary openings within the reinforced concrete slabs were created to facilitate tunnelling logistics for the retrieval of four tunnel boring machines, ensuring the smooth passage of the TBM shield and retrieval of screw conveyor. The width of the reinforced concrete waler beams around the slab openings took account of the logistics of retrieving the TBM shield, while at the same time ensuring that they were adequate to resist the design loadings of the deep excavation. The slab openings also took account of other requirements such as escalators, ventilation, temporary supply openings for equipment, and they were integrated into the design.

The diaphragm wall panels forming the softeyes were reinforced with glass fibre reinforced polymer (GFRP) to enable the breaking-in of the TBMs. The casting of the permanent slab took into account of the alignment of the TBM, and a recess was provided within the slab for the retrieval of the TBM shield, where required.

As the tunnelling progress from both ends of the station box were distinct, special care was taken to ensure that the interfacing between tunnelling works and station excavation works was tailored to each tunnelling progress to ensure tunnelling would not delay station excavation works, and vice-versa (Figures 12 and 13). In most tunnelling sequences, the lower TBM would be ahead of the upper TBM. Otherwise, this would require special considerations, due to the impact of undermining an existing upper tunnel, as noted in a case history discussed in Boon & Ooi (2018). For the case of the TBMs mining toward Ampang Park Station, the lower TBMs at both ends were ahead of the upper TBMs. As the lower TBM from the Northern end arrived at the station box ahead of the station excavation, it was decided to retrieve the upper TBM first, while the lower TBM would wait outside the diaphragm wall until the excavation platform was ready. Temporary slabs were provided for the retrieval of the TBMs, before casting the permanent slab. However, at the Southern end, the station excavation works were ahead of the arrival of the TBMs, and it was decided to progress with the excavation and concreting works for the structural base slab, with a recess provided for the retrieval. Vertical temporary props were provided for the retrieval of the upper TBM (Figure 14).

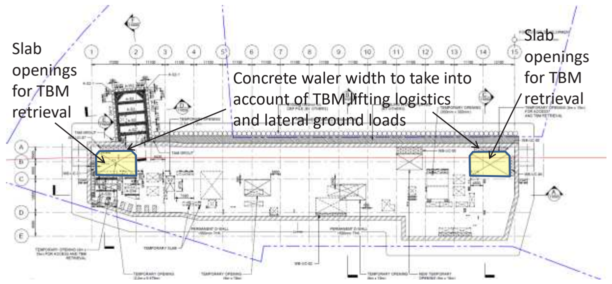

Figure 12. Schematic of boundary conditions of the excavation

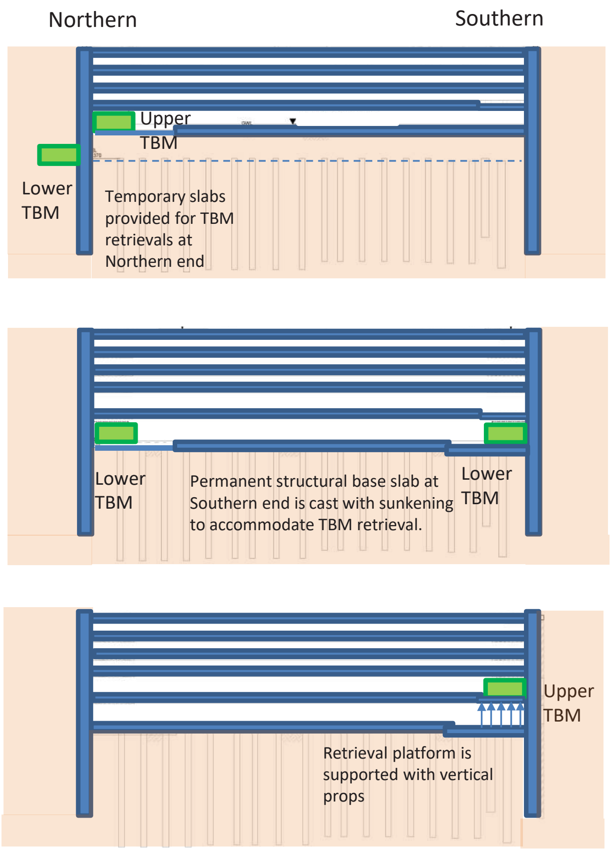

Figure 13. Schematic of TBM retrievals

Figure 14. Vertical props provided to construct the retrieval platform for the upper TBM arriving at the Southern end.

4 PERFORMANCE OF EXCAVATION

The diaphragm wall deflections were monitored using inclinometers and the results at the end of the excavation after strut removal are compared in Figure 15. The wall deflection obtained at INW 10001 (green circles in Figure 15) is believed to be associated with the typical Kenny Hill Formation. However, where there is a decrease in SPT-*N* values close to the limestone rockhead, larger deflections were registered (open triangles in Figure 15). The deflections in the vicinity of the buttress walls are shown by the black solid triangles in Figure 15. The buttresses were found to be effective in reducing the diaphragm wall deflection.

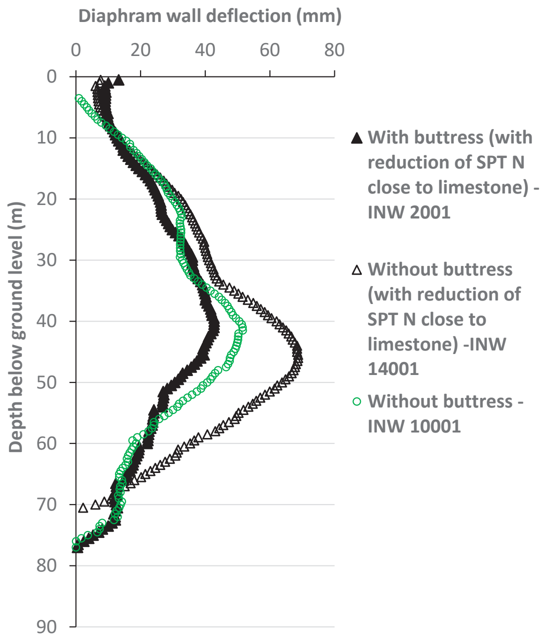

Figure 15. Diaphragm wall deflections measured at the end of the excavation. The soil SPT-*N* values with depth are shown in Figure 3 using the same symbols

5 CONCLUSION

This paper presents a case history of a 43-m deep excavation project. The site was located at the interface between the Kenny Hill Formation and Kuala Lumpur Limestone Formation. Several observations were made in this project, including the ground surface settlements resulting from diaphragm wall trenching and pile extraction works, as well as diaphragm wall deflections due to bulk excavation. The key challenge of the project was the presence of limestone rock, into which the diaphragm walls had to penetrate, to satisfy the design requirements. Ground treatment to mitigate risks of bentonite loss due to diaphragm wall trenching were commissioned, and the method of treatment was tailored to the ground conditions. It is noted that the retaining wall performance during excavation was sensitive to the ground conditions. At some locations, a reduction in SPT-*N* values was observed close to the limestone rockhead, and the diaphragm wall deflections were greater in these areas. In order to further mitigate risks during bulk excavation at a localized slump zone valley, several mass concrete buttress panels were installed to provide additional restraints to the diaphragm walls.

From the perspective of a turnkey contractor for the underground works package, it was important to incorporate the requirements of tunnelling logistics into the station excavation works. The design accounted for different retrieval sequences at each end of the station, to accommodate the construction program of both station and tunnelling works.

6 ACKNOWLEDGEMENTS

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