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HYBRID EARTH RETAINING SYSTEM FOR THE CONSTRUCTION OF AN UNDERGROUND METRO STATION IN VARIED GROUND

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Abstract: The Thomson East-Coast Line Contract T202 Woodlands North Station was constructed beneath a secondary forest in hilly terrain. The 800-metre-long cut-and-cover underground structures comprise three main components: the northern overrun tunnel, the station structure, and southern crossover tunnels. The site's geology features hard granite bedrock overlaid by undulating residual soil of highly weathered granite.

The selection of an appropriate earth retaining support system for deep excavation required careful consideration of multiple factors: site constraints, groundwater movement, economic viability, programme requirements, permanent structure configuration, and the availability and competency of domestic specialist contractors. The implementation complexity was further heightened by the varied ground conditions.

A hybrid system was adopted for the cut-and-cover construction, incorporating,Contiguous Bored Pile Walls, Soldier Pile-Timber lagging and open-cut excavation with perimeter soil drains.

The design complexity was further increased by the need to accommodate future integrated underground development adjacent to Woodlands North station, requiring specific temporary earth retaining systems to protect the constructed station from unbalanced movement during future excavation works.

This paper examines the considerations, experiences and challenges encountered throughout the design and construction phases of this hybrid earth retaining system.

Keywords: Hybrid-Earth Retaining System, Contiguous Bored Pie Wall, Soldier pile-timber, open-cut excavation, highly weathered granite

1. INTRODUCTION

The 43km Thomson East Coast Line (TEL) is Singapore's sixth MRT line, adding 31 new stations to the existing rail network. It enhances connectivity between the north, central and eastern part of Singapore. Contract T202 is located at the northernmost point of the whole TEL as shown in Figure 1 below.

Figure 1. Contract T202, being the northernmost contract in Thomson East Coast Line

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This paper focuses on the cut and cover excavation within this contract and discusses the various types of Earth Retaining and Stabilising Structure (ERSS) system that were adopted. A key aspect of this project was that, due to constraints such as geological conditions, existing hilly terrain, and requirements of construction access, a combination of various ERSS systems was required to facilitate the excavation. Employing a single approach, such as maintaining a consistent open cut slope gradient across the site, was not feasible in certain areas due to site limitations. Likewise, using structural retaining walls throughout the entire project proved impractical. As a result, the ERSS was designed as a hybrid system, with different methods applied to suit specific locations.

2. PROJECT SITE

Contract T202 comprised of the construction and completion of Woodlands North Station (WDN), at grade cut and cover overrun tunnels North of WDN, cut and cover for crossover tunnels South of WDN, Tunnel Boring Machine (TBM) launch shaft and 2 mainline bored tunnels. WDN is approximately 270m-long and 48 m-wide and 22m below ground when completed, as shown in **Error! Reference source not found.**

Figure 2. Overall layout plan of Contract T202

2.1. Site Topography

The reduced level of the original forest with hilly terrain around the site ranged from RL145m to RL130m (see Figure 3 below). The forest was cleared and excavated to reach the general target formation level at RL102m.

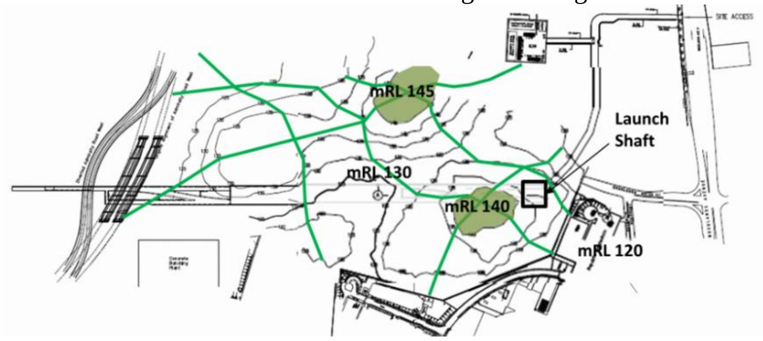

Figure 3. Existing Topography before excavation

2.2. Geological Profile

The project site is situated within the Bukit Timah Granite Formation (BTG), which is the predominant rock formation in Singapore. Along T202 WDN, the BTG exists in various weathering states, ranging from residual soils (Grade VI) to intact, unweathered, unstained rock (Grade I). Sharp boundaries are frequently observed between residual soils (GV/GVI) and moderately to slightly weathered granites (GIII/GII). The rockhead level undulates significantly, featuring numerous valleys and considerable depth variations throughout the site. Large boulders are commonly encountered during excavation, with the largest specimens measuring approximately 8 metres. These geological characteristics present substantial challenges for the design of Earth Retention Stabilising Systems (ERSS) and foundations.

Figure 4 below illustrates the elevation view of the permanent structures in relation to the geological profile, specifically at the central portion of the WDN permanent structures. The rock-head exhibits an undulating profile, with some sections rising above the permanent structure level. Rock outcrops that impeded excavation to formation level necessitated removal through controlled blasting techniques followed by excavation. These rock outcrops were also a crucial factor in determining the most suitable Earth Retention Stabilising System (ERSS) for the project.

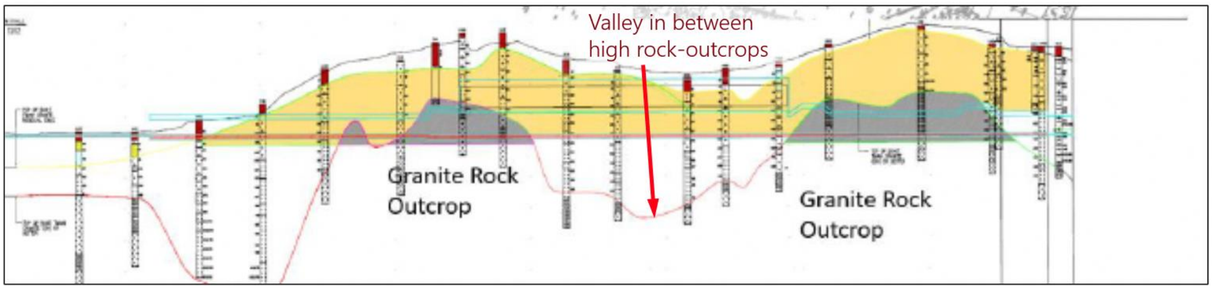

Figure 4. Elevation view of WDN permanent structure levels relative to the Granite Rock-Head Levels

3. OVERALL CONSIDERATIONS ON THE GEOMETRY OF EARTH AND RETAINING STABILIZING STRUCTURES (ERSS)

3.1. Considerations During Development of ERSS Scheme Geometry

The site was situated in a relatively green area, where open cut slopes were considered as the Earth Retention Stabilising System (ERSS) for most WDN structures. However, open cut slopes were not feasible throughout the site, necessitating a combination of ERSS schemes. The following factors were considered during the ERSS scheme development:

a) Sufficient horizontal space was required to create safe slope gradients. With excavation heights exceeding 30 metres in some areas, the horizontal distance from the edge of the WDN permanent structure to the slope crest would readily exceed 60 metres.

b) Even where horizontal space was adequate, assessment was necessary to determine whether existing structures at the slope crest could be affected by potential settlement.

c) The impact of groundwater drawdown from open cut slopes required evaluation, as this could adversely affect surrounding buildings, even those situated at considerable distances from the excavation site.

d) Due to the extensive width of the slopes, material delivery to the lowest excavation point was not feasible using cranes positioned at the slope crest. Consequently, construction access routes were required to serve the lower areas.

e) Interface management with other ERSS types was crucial. Open cut slopes required excavation in nearly all four directions to form a closed excavation. In some instances, these interfaced with other ERSS types, such as rock slopes or structural retaining walls.

3.2. ERSS Scheme

Considering these factors, The ERSS scheme for the overall site resulted in what was reflected Figure 5 below. The stretch of the excavation was approximately 650m length, and the whole excavation open at the same time at one point.

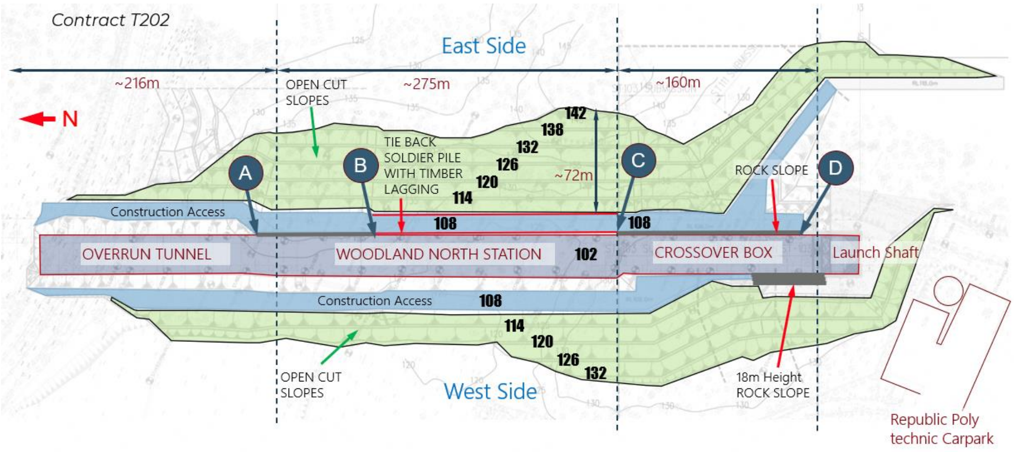

Figure 5. ERSS Overall Layout Plan for WDN

Taking advantage of the good rock properties of the high rock-head outcrops along the East length of the excavation, a steep gradient was formed on the rock slopes between Point A and B, and between Point C and D. Tie-back soldier piles with timber lagging were used between Points B and C, where there was a valley between the rock outcrops.

4. DESIGN AND CONSTRUCTION CONSIDERATION OF THE INDIVIDUAL TYPES OF ERSS

4.1. Open Cut Soil Slopes

The extensive site area for T202 construction permitted the implementation of an open cut excavation method. This involved forming a 1(Vertical):2(Horizontal) soil slope, incorporating turfing and drainage systems as the earth retaining solution for the project.

The open cut slope design utilised both limit equilibrium analysis and finite element analysis through the c'-phi reduction method in Plaxis 2D, ensuring a minimum factor of safety of 1.4. Given the site's hilly terrain, groundwater levels were expected to vary significantly across the location. For design purposes, assuming a full groundwater table would have resulted in an impractically conservative design. Conversely, assuming too low a groundwater level could have compromised safety.

To establish an appropriate initial design groundwater level, a correlation graph was developed, as shown in Figure 6. This graph plots the relationship between existing ground levels and their corresponding water levels, based on data collected from various water standpipes across the site over a minimum monitoring period of six months, as documented in the factual report.

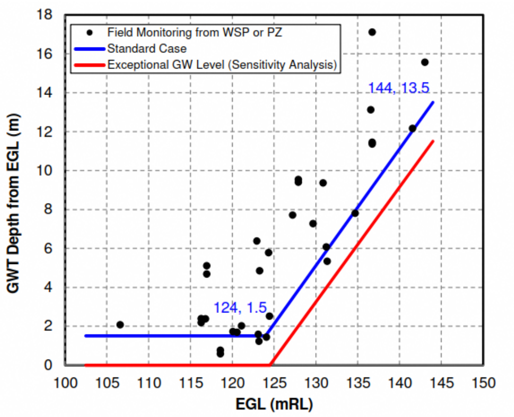

Figure 6. Proposed Initial Groundwater Table obtained from piezometers and water standpipes

The ground water profile for soil slopes had to be kept below the designed ground water drawdown to maintain a high degree of stability. To achieve this, the slopes were turfed to channel surface runoff to a system of surface C7 drains, limiting percolation into the soil, followed by a system of subsoil drains to drain off groundwater to the same system of C7 drains, as shown in Figure 7 below.

Figure 7. Soil Slopes Surface Protection using turfing, subsoil pipes and cut-off drains

4.2. Rock Slope Excavation

In areas where rock was encountered, controlled blasting techniques were employed to create 3.75(Vertical):1(Horizontal) rock slopes, as illustrated in Figure 8.

Rock slope stability was assessed through detailed rock mapping conducted by a competent geologist. The 'Q' system was specified to determine the necessary degree of treatment for the rock slope. Areas with the highest Q-value required only a 50-millimetre thick shotcrete treatment, whilst those with the lowest Q-value necessitated a 120-millimetre thick shotcrete application with rock dowel reinforcement. The rock quality mapped in T202 generally exhibited high Q-values, eliminating the need for rock dowel installation.

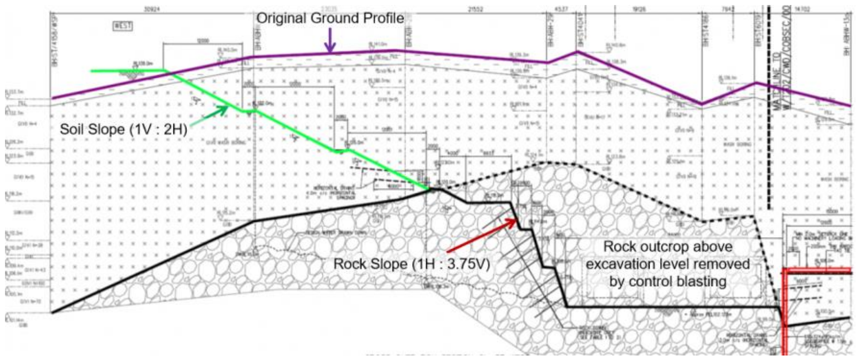

Figure 8. Typical Cross Section View of a Rock Slop below Soil Slope Sections

4.3. Use of Soldier Pile and Timber Lagging Wall with Open Cut Excavation

A line of soldier pile and timber lagging wall with tie backs was introduced along the Eastern open cut excavation section to create a 15m wide construction access as well as to reduce the extent and volume of slope cutting. The wall is depicted in Figure 9 below.

Figure 9. Soldier Pile and Timber Lagging Wall with Open Cut Excavation

4.4. Launch Shaft – Strutted Excavation with CBP Walls and Rock Slopes

The launch shaft cofferdam measured approximately 36.8 metres wide, 48 metres long and 17 metres deep from the pre-excavated working platform. The retaining system, as shown in Figure 10, comprised contiguous bored piles (CBPs) of 1.5-metre diameter spaced at 1.6-metre intervals, supported laterally by multiple levels of steel laced struts. Although initially designed as a four-sided cofferdam, the contractor modified the design to a three-sided configuration. This modification involved removing the retaining wall at the rear of the cofferdam, creating space for the TBM back-up gantry facilities to be installed concurrent with the initial drive operation. This design adaptation enabled the main drive to commence immediately following the completion of the initial drive.

Figure 10. Plan View of the Launch Shaft

4.4.1. Design Considerations

Due to the open-end nature, the design had focused on identifying the load path due to the imbalance load from the South Wall, then taking steps to ensure the load from the South Wall is transferred to the foundation, as shown in Figure 11 below.

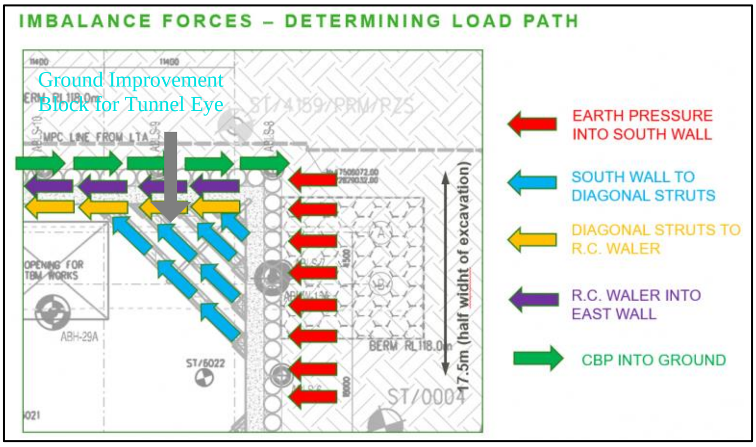

Figure 11. Expected Load Path from South CBP Wall to East CBP Wall

The stability was achieved through geotechnical resistance provided by shaft friction between the soil/rock interface and the contiguous bored pile (CBP) wall. Although the surrounding open cut excavation permitted groundwater drawdown for slope stability, weep holes were installed along the bored pile interface gaps to maintain groundwater flow. The remaining gaps were shotcreted to prevent soil loss whilst preserving the drainage function.

4.4.2. Construction of the CBP-Rock Slope Hybrid System

Figure 12 illustrates the extent of the contiguous bored pile (CBP) system with steel struts and the rock slope with steel struts. Boulders presented significant challenges during both the CBP installation and subsequent excavation work. To navigate through boulder layers during CBP boring operations, drilling speeds were reduced. During the excavation phase, exposed boulders were systematically broken down using hydraulic breakers, as demonstrated in Figure 13.

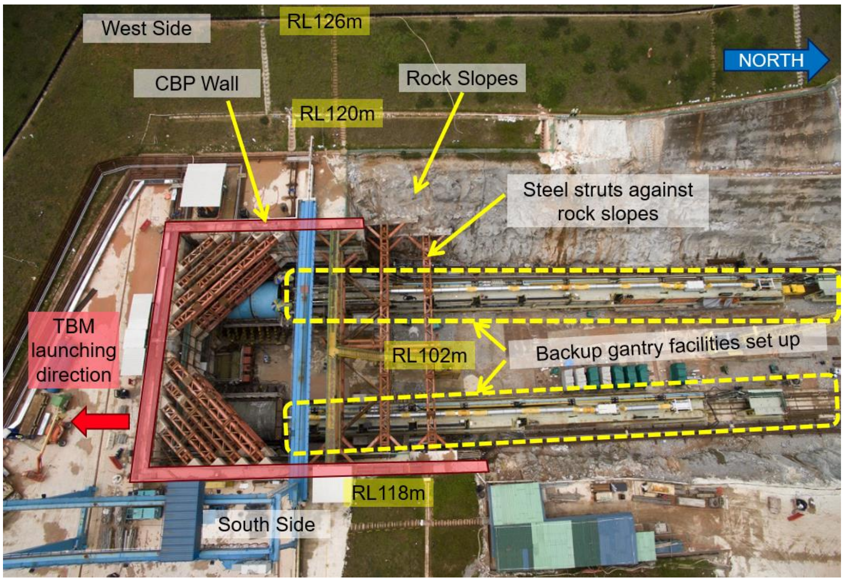

Figure 12. Aerial View of the Launch Shaft – some steel struts were strutted against the rock slopes

Figure 13. Boulders broken by hydraulic breakers

5. CONCLUSION

Despite various constraints, including limited space, undulating rock-head profiles, and construction site access requirements, a comprehensive excavation scheme was successfully developed and implemented. This scheme enabled simultaneous exposure of the entire excavation length (as illustrated in Figure 14) without requiring sectional backfilling and re-excavation. This strategic approach proved crucial in completing the extensive excavation works within the prescribed timeline.

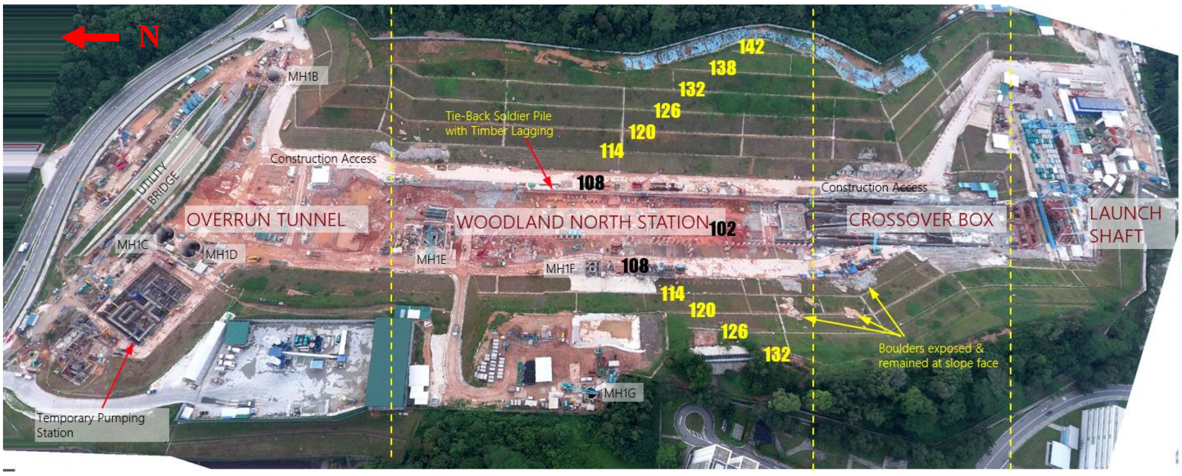

Figure 14. Aerial View of Overall WDN Station Excavation

Close collaboration between the construction and design teams proved essential in understanding the builder's constraints, limitations and operational requirements. Although the construction phase presented various challenges, the Earth Retention Stabilising System (ERSS) scheme proved successful, enabling the achievement of all project objectives.

6. BIBLIOGRAPHY

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