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The Reinforced Soil Wall Construction with High Stiffness Geocomposite Reinforcement and Modular Segmental Block, Pengerang, Johor Darul Ta'zim

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ABSTRACT Pengerang is a municipality in Kota Tinggi district in Johor at the southern tip of the Peninsular Malaysia. It is home for the mega oil and gas hub Pengerang Integrated Petroleum Complex (PIPC) in Southern Johor state, which is one of the region's largest hubs for oil and gas, petrochemical industries, oil storage and trading activities. The area is experiencing significant development, both residential and commercial in nature. In this development plan, the retaining wall system plays a crucial role in providing a larger development area, enhancing the aesthetic view, and achieving a higher elevation platform. The focus of this paper is on an internally stabilized reinforced soil wall system which involves reinforcing the soil with high stiffness geocomposite reinforcement and utilizing modular segmental blocks as facing elements. This combination creates a 1 vertical: 0.14 horizontal gradient (82°) wall that is implemented for a mixed development at Pengerang. The single-tier reinforced soil wall reaches a height of 13 m. In addition, the maximum 14 m high wall was designed as a two-tier wall and the maximum 19 m high wall was designed as a three-tier wall. The design of the reinforced soil wall includes the evaluation of various potential internal and external failure modes. This paper also discusses the construction sequences employed for the reinforced soil wall. Ultimately, the combination of the high stiffness geocomposite reinforcement with modular segmental blocks has proven successful, resulting in a constructed wall that satisfied the client requirements.

KEYWORDS Reinforce Soil Wall; Segmental Block Wall; High Stifness Geocomposite Reinforcement; Modular Segmental Block

1 INTRODUCTION

The development is a 150-ha residential and commercial project located a few tens of kilometres from the mega oil and gas hub Pengerang Integrated Petroleum Complex (PIPC) in Johor. This development is in hilly terrain which involve major cut and fill earthworks to form the required housing development platform levels. Retaining structures play a significant role in creating platforms at desire elevation to fulfil project development and architectural plan.

At the project site, different platform elevation was required for development objective. To create the flat platforms for the housing development three reinforced soil walls were required on site. The single-tier reinforced soil wall reaches a height of 13 m. In addition, the maximum 14 m high wall was designed as a two-tier wall and the maximum 19 m high wall was designed as a three-tier wall. Total reinforced soil wall length was approximately 830 m. The reinforced segmental block reinforced soil wall system chosen for the site consisted of a modular block facing with layers of high stiffness geocomposite reinforcement. The reinforced soil wall location in the development is indicated in Figure 1.

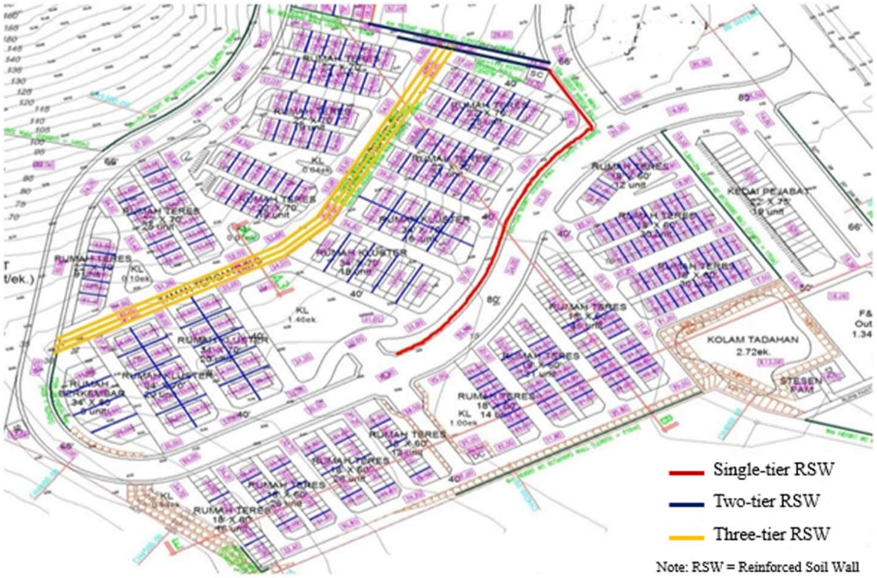

Figure 1. Project development plan view

2 SITE TERRAIN AND SOIL CONDITION

The development site, situated in a hilly terrain, required significant earthwork in the form of cut and fill operations to create a suitable platform formation. To assess the soil conditions on-site, a soil investigation was conducted, which involved conducting Standard Penetration Tests (SPT) in fifteen boreholes spanning the entire development area. Three of these boreholes, namely BH1, BH2, and BH3, were specifically located near the reinforced soil wall site and served as reference points for the foundation soil investigation.

Based on the results obtained from these three boreholes, it was determined that the foundation conditions at the site comprise several layers. BH2 has a softer soil profile compared to other two boreholes. It has been adopted as the design foundation soil profile applied to the reinforced soil wall area. BH2 with the uppermost layer consists of thin firm clay, with SPT N-values ranging from 5 to 9. Below the thin firm clay layer is a layer of stiff sandy clay, with SPT N-values ranging from 10 to 32. Finally, a firm stratum is observed, with SPT N-values exceeding 50. These soil layers and their characteristics are depicted in Figure 2. The water table was identified to be at a depth of 2 meters below the ground level.

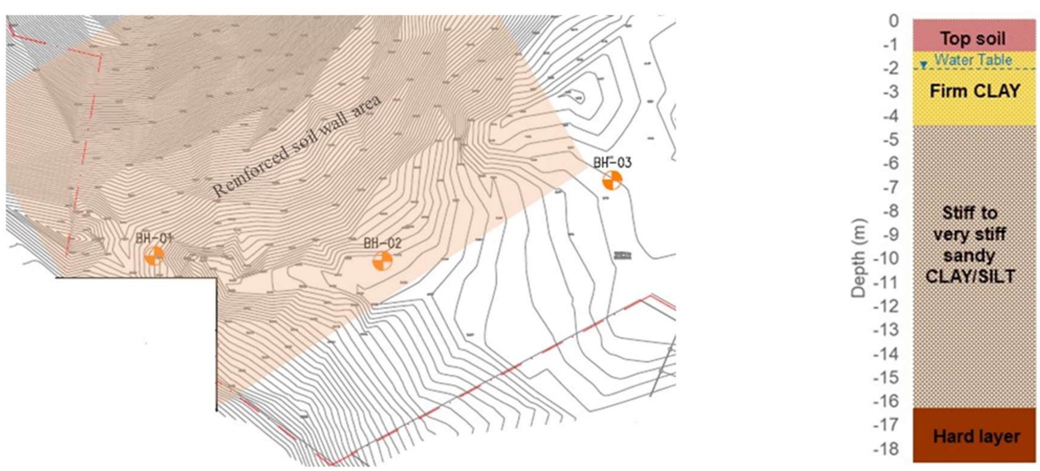

Figure 2. Boreholes locations and BH2 foundation soil profile

3 THE REINFORCED SOIL WALL SYSTEM

The retaining structures can be classified into two major principles according to the load support mechanism. The categorization of the stability component of walls can be divided into two major principles, as described by O'Rourke and Jones (1990). The first category is externally stabilized systems, which utilize an external structural wall to generate stabilizing forces. The second category is internally stabilized systems, which involve reinforcements placed within the retained soil mass and extending beyond the potential failure plane. Figure 3 illustrates the reinforcing mechanism in walls and slopes (BS8006-1, 2010).

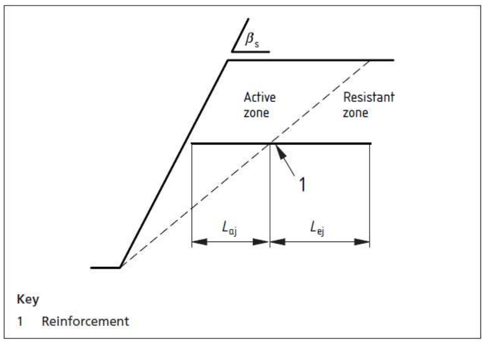

Figure 3. Reinforcing mechanism in walls and slopes (BS8006-1, 2010)

Basically, external stabilized system regards all traditional types of walls. In the modern day, the demand of the internally stabilized system is increasing especially mechanically stabilized wall reinforced with polymeric element. These systems are economical solutions for retaining soil and can withstand greater deformation compared to reinforced concrete walls (Berg et al., 2009a). These structures enhance the strength of the soil by incorporating tensile reinforcing elements. By implementing a facing system that prevents soil erosion and movement between the reinforcing elements, it becomes possible to construct steep slopes and vertical walls securely. The reinforced soil wall is categorized as internal stabilized system has been chosen for this development due to huge fill area required. The reinforced segmental block reinforced soil wall system provides a cost-effective solution and good aesthetics that meets the client expectation.

3.1 Wall Facing

The wall facing plays a crucial role in preventing soil erosion and facilitating the construction of steep slopes and vertical walls. Simultaneously, it serves as an erosion control measure for the exposed surface. In recent times, modular block dry-cast facing units have gained popularity due to their cost-effectiveness and wide availability in the market (Berg et al., 2009a). In the project, modular block units were utilized, comprising dry-cast concrete blocks measuring 0.25m in width, 0.2m in height, and 0.5m in depth. These blocks were designed with an interlock system, featuring a tongue and groove concept at the top and bottom, which significantly enhances inter-unit shear resistance. One notable advantage of the modular block units is the incorporation of vegetation within the block facing, resulting in improved aesthetic appeal after the construction of the reinforced soil wall. The blocks were stacked to achieve an inclination with a gradient of 1 vertical to 0.14 horizontal (82°).

3.2 Backfill Material

Extensive research has demonstrated that reinforced soil walls offer significant cost savings in comparison to traditional earth-retaining systems (Simon & Cameron, 2012). Backfill material, being a major cost component, typically contributes around 30% - 40% to the overall expenses of reinforced soil wall systems (Christopher & Stulgis, 2005). By utilizing locally available soils, not only can save costs and time associated with importing soils be minimized, but it also eliminates the need to export excavated soils. Studies have indicated that friction cohesive soils can be effectively employed as backfill material if a comprehensive drainage system is incorporated into the system

(Zornberg and Mitchell, 1994). This approach proves to be advantageous in terms of cost-effectiveness and efficient resource utilization.

3.3 Drainage Blanket

The stability of reinforced fill structures relies on the implementation of an effective drainage system. Elevated pore water pressure within the reinforced block can lead to a decrease in soil shear strength and an increase in destabilizing forces (Berg et al., 2009a). Consequently, a subsurface drainage system, commonly known as a drainage blanket, is designed to collect and remove water away from the reinforced mass. To ensure proper drainage, an adequate number of discharge points, such as drainage pipes, should be provided and connected to appropriate outlets. For the reinforced soil wall, it is proposed to incorporate a typical 300mm thick drainage blanket at the back and base of the reinforced soil mass, as well as at the rear of the facing. The design of the drainage blanket should accommodate the anticipated water flow without causing backup or blockage. To prevent potential blockage issues, the drainage material should be protected by a suitable filter material (Jones, 2002). It is suggested to utilize a filter nonwoven geotextile to wrap the drainage blanket and drainage pipes, thereby ensuring the prevention of blockages in the system.

3.4 Geocomposite Reinforcement

The geocomposite reinforcement layers in the segmental block reinforced soil wall system were designed with varying strengths, lengths, and vertical spacings, based on their specific locations. The utilization of geocomposite reinforcement in this system offers two significant advantages. Firstly, the geocomposite reinforcement comprises high modulus PET fibers, providing well-defined long-term strength and strain characteristics that are ideal for reinforced soil applications. Secondly, the geocomposite reinforcement possesses in-plane drainage functionality and excellent filtration capabilities, enabling the reinforcement of poorly drained soils. Its superior performance in dissipating pore water along the geocomposite reinforcement reduces pore water pressure and enhances structural stability. Figure 4 illustrates the positive and negative pore water pressures recorded at various locations within the fill over time. Notably, the pore water pressure measurements for the geocomposite reinforcement exhibit lower values compared to those observed for the woven geotextile and retained fill.

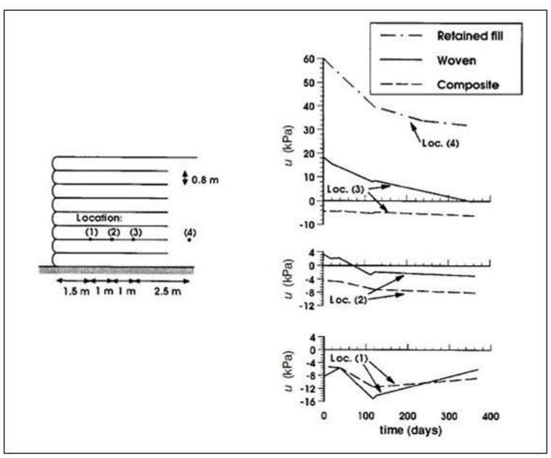

Figure 4. Pore water pressures (u) recorded in the Rouen reinforced wall, along a woven and a nonwoven/ geogrid composite, at different locations within the silty backfill (Zornberg and Mitchell, 1995)

4 THE REINFORCED SOIL WALL SYSTEM

The design of the reinforced soil wall aims to ensure sufficient safety against potential failure modes. The design process adhered to the guidelines outlined in BS8006:1-2010, which is a British Standard Code of Practice for Reinforced Soil, as well as the recommendations provided by the National Concrete Masonry Association (NCMA). To conduct a proper evaluation, it was essential to gather adequate information, including the site location, on-site foundation conditions, wall geometry, backfill soil properties, water table level, surcharge loading, reinforcement element characteristics, facing element specifications, and other relevant factors for proper evaluation.

4.1 Foundation Soil Parameters

The foundation soil of the reinforced soil wall predominantly comprises firm to stiff clay or silt, as indicated by the soil investigation report. For the design purposes, the water table was assumed to be at a depth of 2 meters below the ground level. The design parameters for the foundation soil are presented in Table 1.

Table 1. Foundation soil parameters

Soil properties	Unit	Foundation soil parameters
Unit weight, γ	kN/m^3	18.5
Friction angle, Ø	°	30.0
Cohesion, c	kPa	5.0

4.2 Backfill Soil Parameters

The backfill material for the reinforced soil wall comprises residual sandy silt sourced locally from the site, as well as imported soil due to the large quantity required. To meet the minimum project requirements, the backfill material should have a plasticity index of less than 20. Two types of backfill materials were utilized in this project: earth fill and compacted earth fill meeting the 95% standard protocol requirement. The compacted earth fill was employed within the reinforced soil zone. The soil parameters adopted for the design are provided in Table 2.

Table 2. Backfill soil parameters

Soil properties	Unit	Compacted Earth Fill	Earth Fill
Unit weight, γ	kN/m^3	19	18
Friction angle, Ø	°	30	28
Cohesion, c	kPa	5	5

4.3 Surcharge Loading

In this project, the reinforced soil wall is designed to accommodate traffic on top of it. To account for the future traffic loading, a uniformly distributed live load of 20 kPa was adopted for the design analysis. It represents the expected loading from traffic. The dead load was not considered in the reinforced soil wall design. The dead load was adequately addressed by other supporting systems, such as the pile system. Therefore, the design analysis focused solely on the surcharge loading imposed by the traffic to ensure the stability and integrity of the reinforced soil wall.

4.4 Reinforcement Long-term Design Strength

In the case of walls and slopes, the design load is assumed to remain constant throughout the chosen design life. The design strength to be determined is the strength required at the end of the selected design life of the wall or slope (BS8006-1, 2010). The long-term design strength derivation for the reinforcement considers various factors such as creep rupture, installation damage, and environmental effects, as specified by the procedure outlined by the Federal Highway Administration (FHWA). Three types of geocomposite reinforcement were determined to be necessary to achieve an adequate factor of safety for the reinforced soil wall. Table 3 presents the derived long-term design strength values for the geocomposite reinforcement utilized in the project. These values were calculated considering the aforementioned factors to ensure the long-term stability and performance of the reinforced soil wall.

Table 3. Geocomposite reinforcement long-term design strength

Property	Symbol	Unit	Type 1	Type 2	Type 3
Characteristic initial strength	T_u	kN/m	100	150	200
Partial material factors					
Creep rupture	f_{cr}		1.55	1.55	1.55
Installation damage	f_{id}		1.00	1.00	1.00
Environmental effects	f_{en}		1.10	1.10	1.10
Long-term design strength for 120 years design life $T_D = T_u / (f_{cr} \times f_{id} \times f_{en})$	T_D	kN/m	58.7	88.0	117.3

4.5 Stability Analysis

The stability analysis of the reinforced soil wall design encompasses two primary aspects: internal and external stability. External stability focuses on the overall stability of the reinforced soil structure as a unit. On the other hand, internal stability encompasses factors such as internal behaviour mechanisms, stress distribution within the structure, arrangement and behaviour of reinforcements, and properties of the backfill material (BS8006-1, 2010). To ensure structural integrity and safety, the stability analysis considers various potential failure modes. The minimum factor of safety required for each failure mode is outlined in Table 4.

Table 4. Potential failure modes and minimum factor of safety required (NCMA, 2010)

Failure mode	Minimum factor of safety
Internal stability	
Reinforcement rupture	1.5
Reinforcement pullout	1.5
Connection	1.5
External stability	
Slip failure	1.5
Sliding	1.5
Overturning	2.0
Bearing capacity	2.0

The slip surface failure analysis was carried out by using the Geostudio Slope/W design software. Circular slip surface analysis was conducted to determine the slip failure mode of the reinforced soil wall. Figure 5 shows the result of the three-tier wall that achieves minimum FOS of 1.4 as required for this project. Spreadsheets were used to analyze the internal stability, sliding, overturning, and bearing capacity.

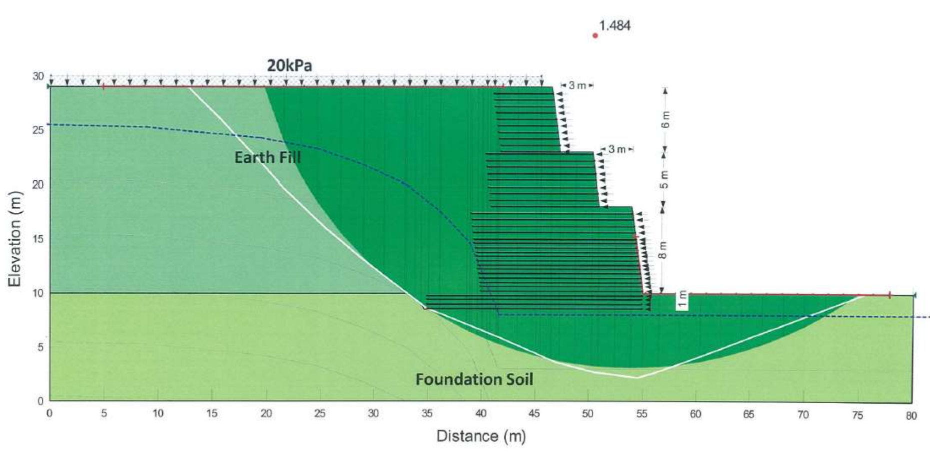

Figure 5. Three-tier wall circular slip surface analysis result

4.6 Reinforced Soil Wall Detailing

Figure 6 depicts a representative cross-section of the reinforced soil wall design, showing a three-tier wall with a maximum height of 19 meters. It highlights key components, including the geocomposite reinforcement length, modular block facing, and drainage blanket. This detailed representation provides a visual understanding of the arrangement and configuration of these elements within the reinforced soil wall structure.

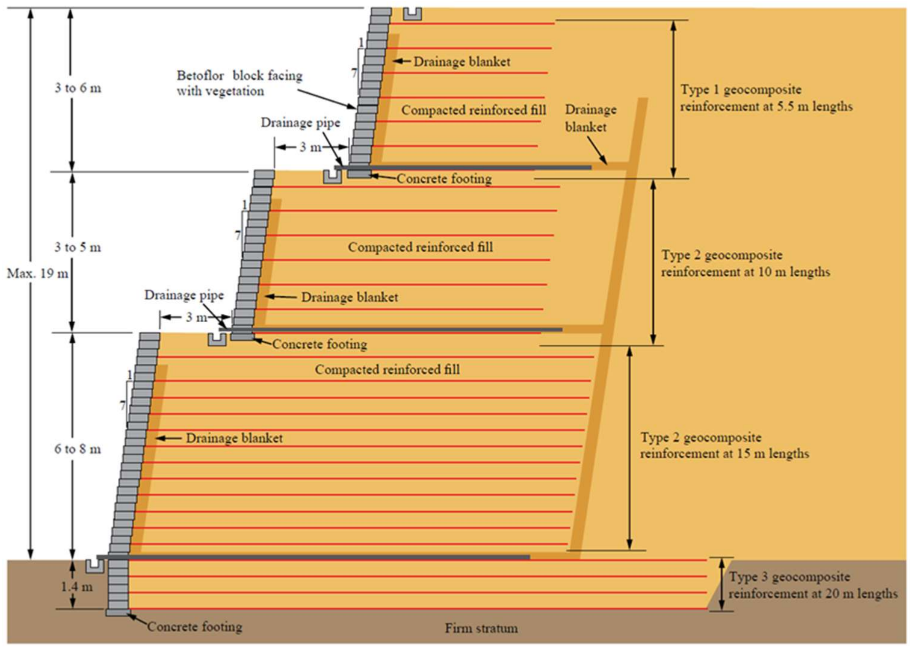

Figure 6.Typical cross section through the tree-tier reinforced soil wall

5 THE REINFORCED SOIL WALL SYSTEM

The construction process of the reinforced soil wall in the hilly area involved several key steps. Initially, the existing platform for the wall was created by excavating the hilly area. The foundation of the wall was then excavated, removing the softer surface layer and establishing a solid base by excavating to a depth of 0.8m to 1.4m. To provide a strong and level base for the modular block placement, concrete footings were installed at the bottom of each tier.

The geocomposite reinforcements were pre-cut to the designed anchorage length and laid side by side. Adjacent geotextile panels were overlapped to ensure continuity of reinforcement coverage across the entire wall structure. The geocomposite layers were connected to the block units and pulled tight to remove any wrinkles. The reinforced fill material was then spread on top and compacted to achieve 95% Standard Proctor compaction in lifts of 200mm. The geocomposite reinforcements were laid layer by layer, following the designed grade, vertical spacing, and anchorage length.

Extensive surface drainage measures were implemented throughout the reinforced soil wall. Horizontal drainage blankets were incorporated at the base of each tier, extending up behind the reinforced soil zone. A vertical subsurface drainage layer was included at the rear of the modular block facing. These drainage layers consisted of granular drainage material wrapped with filter nonwoven geotextile. Drainage pipes were installed to facilitate the easy exit of seepage water through the wall facing. Additionally, berm drains and base drain were constructed to collect water flowing through perforated drainage pipes and swiftly drain away surface water runoff.

Figure 7. Installation of geocomposite reinforcement behind the reinforced soil wall

Figure 8. Drainage blanket and concrete drain incorporated in the reinforced soil wall

Figure 9. Completion of three-tier reinforced soil wall

Figure 10. Overview of the reinforced soil wall

6 CONCLUSION

In conclusion, the construction of the reinforced soil walls in the development area was completed successfully within a year timeframe. The utilization of geocomposite reinforcement proved to be an economically viable solution, allowing for the construction of walls using locally available residual soil with straightforward installation. The reinforced soil wall system not only adhered to a tight schedule but also provided a safe and aesthetically pleasing solution for the development.

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