

Effect of Geotextile Reinforcement on the Stability of an Embankment Constructed over Soft Marine Clay

Semala Raman*, Bakhtiar Affandy Othman

Centre of Tropical Geoengineering, Faculty of Civil Engineering Technology, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia

*Corresponding Author

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ABSTRACT

Embankment construction over soft marine clay presents significant geotechnical challenges because of the low undrained shear strength and high compressibility of the foundation soil. In such conditions, adequate stability during construction is essential to prevent excessive lateral deformation and potential slope failure. This study evaluates the contribution of basal geotextile reinforcement to the stability of an embankment constructed over soft marine clay at a development site in Kuala Langat, Selangor, Malaysia. The assessment was based on site investigation data obtained from five boreholes and the corresponding soil parameters established for the stability analysis. The investigated ground profile consists predominantly of very soft to soft marine clay, underlain by sand and suitable fill material. The embankment configuration comprises approximately 1.5 m of platform fill and a 2.0 m surcharge, with high-strength GML-20 geotextile installed beneath the embankment fill. Slope stability analyses were performed using the Limit Equilibrium Method with Bishop's modified method to determine the critical factor of safety for the temporary unreinforced condition, temporary reinforced condition, and permanent condition. The GML-20 geotextile has an ultimate tensile capacity of 200 kN/m and was considered to provide tensile resistance against lateral deformation of the soft foundation soil. The calculated factor of safety increased from 1.113 for the temporary unreinforced condition to 1.230 when geotextile reinforcement was incorporated, representing an improvement in the calculated stability of the embankment. The permanent condition produced a factor of safety of 1.415. The results indicate that basal geotextile reinforcement can provide a measurable increase in embankment stability during construction over weak marine clay. The findings also demonstrate the importance of considering reinforcement capacity, soil–geotextile interaction, embankment geometry, and construction sequence when assessing reinforced embankments on soft ground.

Keywords: Soft marine clay; Geotextile reinforcement; Embankment stability; Limit Equilibrium Method; Bishop's modified method; Factor of safety; GML-20; Soft soil.

INTRODUCTION

Soft soils, known for their weak shear strength, high compressibility, and tendency to create major issues for geotechnical engineers and designers [1][2].

Addressing long-term settlement of infrastructure and ensuring cost-efficient foundations with sufficient load-bearing capacity are critical objectives for infrastructure development in many countries. Poor soil conditions can lead to excessive settlement, risking undrained infrastructure failure if adequate soil improvement is not implemented [3]. Consequently, applying suitable ground improvement techniques to soft soils before construction is essential to prevent uneven settlement and enhance the load-bearing capacity of foundations [4].

The primary focus of embankment design lies in ensuring the stability and settlement of the foundation. Constructing on soft soil typically leads to significant challenges, such as substantial settlement [5]. To improve the performance of embankments on soft soil, ground improvement is necessary. Several common techniques, including the use of piles [6], geotextiles [7], and stone columns [8], are employed.

Thus, this study assessed the performance of geotextiles installed beneath the embankment to evaluate their effectiveness. Additionally, a slope stability analysis of the embankment was conducted using the limit equilibrium method (LEM) which is Bishop Simplified Method.

Geotextile Reinforcement In Soft Clay

Geotextiles may be woven or nonwoven and can provide reinforcement, separation, filtration and drainage functions depending on their structure and application. Woven geotextiles generally provide tensile reinforcement and lateral restraint, while nonwoven products are commonly used where filtration and drainage are also required. Previous studies have investigated geotextiles for dewatering soft clay and for controlling interaction between fill and fine-grained foundation soils [7,8].

For reinforced embankments, the geotextile develops tensile resistance as the foundation soil deforms laterally. This reinforcement mechanism can reduce lateral spreading and increase the available resistance along potential failure surfaces. Previous research has also demonstrated that the combined use of reinforcement and vertical drainage can improve embankment performance on soft, rate-sensitive soils [9,10,11].

The present assessment focuses on the stability contribution of the basal GML-20 geotextile used beneath the investigated embankment. PVD treatment forms part of the broader ground-improvement scheme at the site, but the stability comparison presented here focuses on the change associated with geotextile reinforcement.

SITE CONDITIONS AND METHODOLOGY

The study site is situated in Mukim Bandar, Daerah Kuala Langat, Selangor, and proposed a development Phase 1 and Phase 2 which is comprises of 3 storey factories and infrastructural facilities such as roads, drains, water supply, sewage system, parks.

Based on the Geological Map of Selangor (Scale 1: 63,300) 1976, the proposed development site is located in Quaternary Formation. Figure 1 shows the site geology. Quaternary deposits consist of marine and continental deposits comprising of clay, silt, sand, with minor gravel. Figure 3 shows subsoil profile of five (5) deep boreholes.

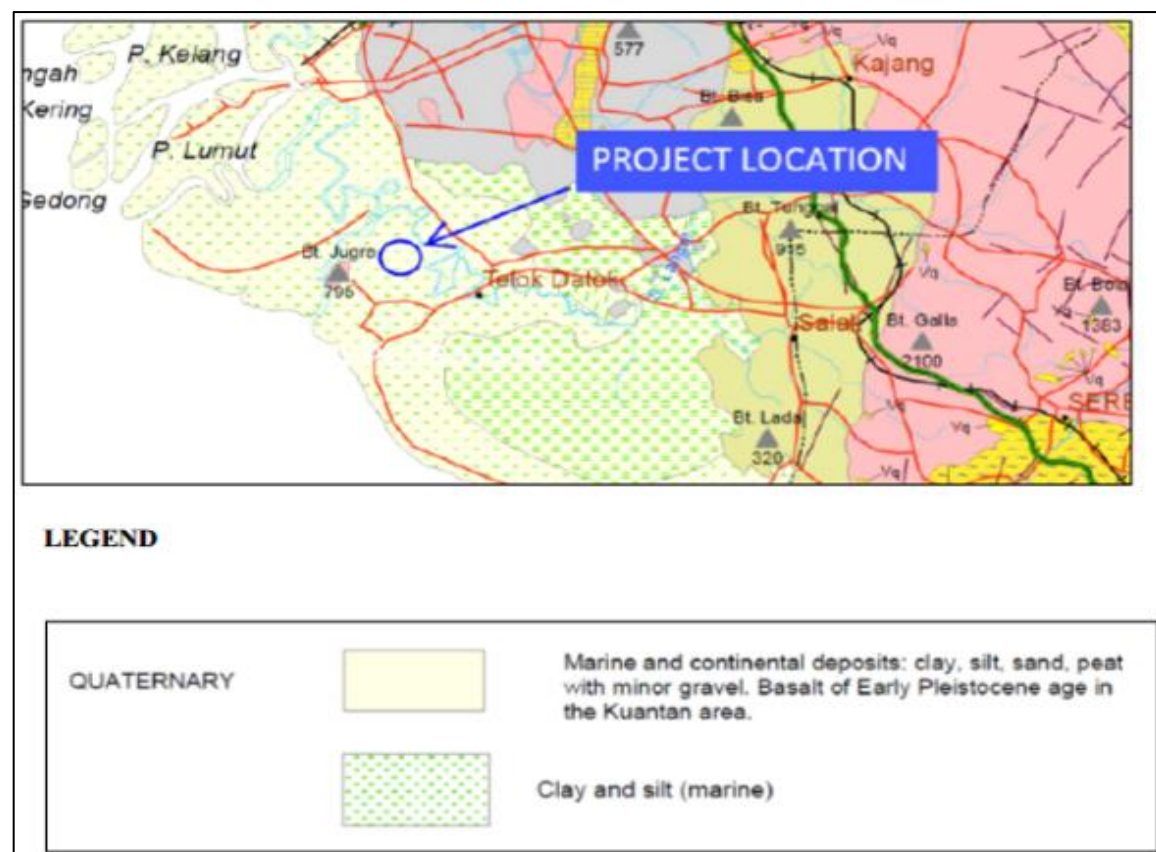


Figure 1 Site Geology

The subsoil profile comprises as follows: 9 m of very soft clay, followed by 10 m of soft clay, and a 1.5 m sand blanket. Beneath this layer, a 1 m thick homogeneous soil is present, suitable for use as fill material.

Marine Clay (Alluvium soils) - These are surface deposits that mainly comprises of sediments of very soft to soft silts and clays. The SPT values are generally less than about 4 blows/300m. These soils are generally weak and are highly compressible. The depth of these soils varies from about 1.5m to 9m and 12m to 30m for Zone A and 1.5m to 9m and 10.5m to 37.5m for Zone B across the site.

Residual soils - This unit comprises of residual soils derived from weathered formation. The thickness of the layer varies from about 1.5m to 22.5m. The SPT N value of the layer is less than 20 blows/300mm.

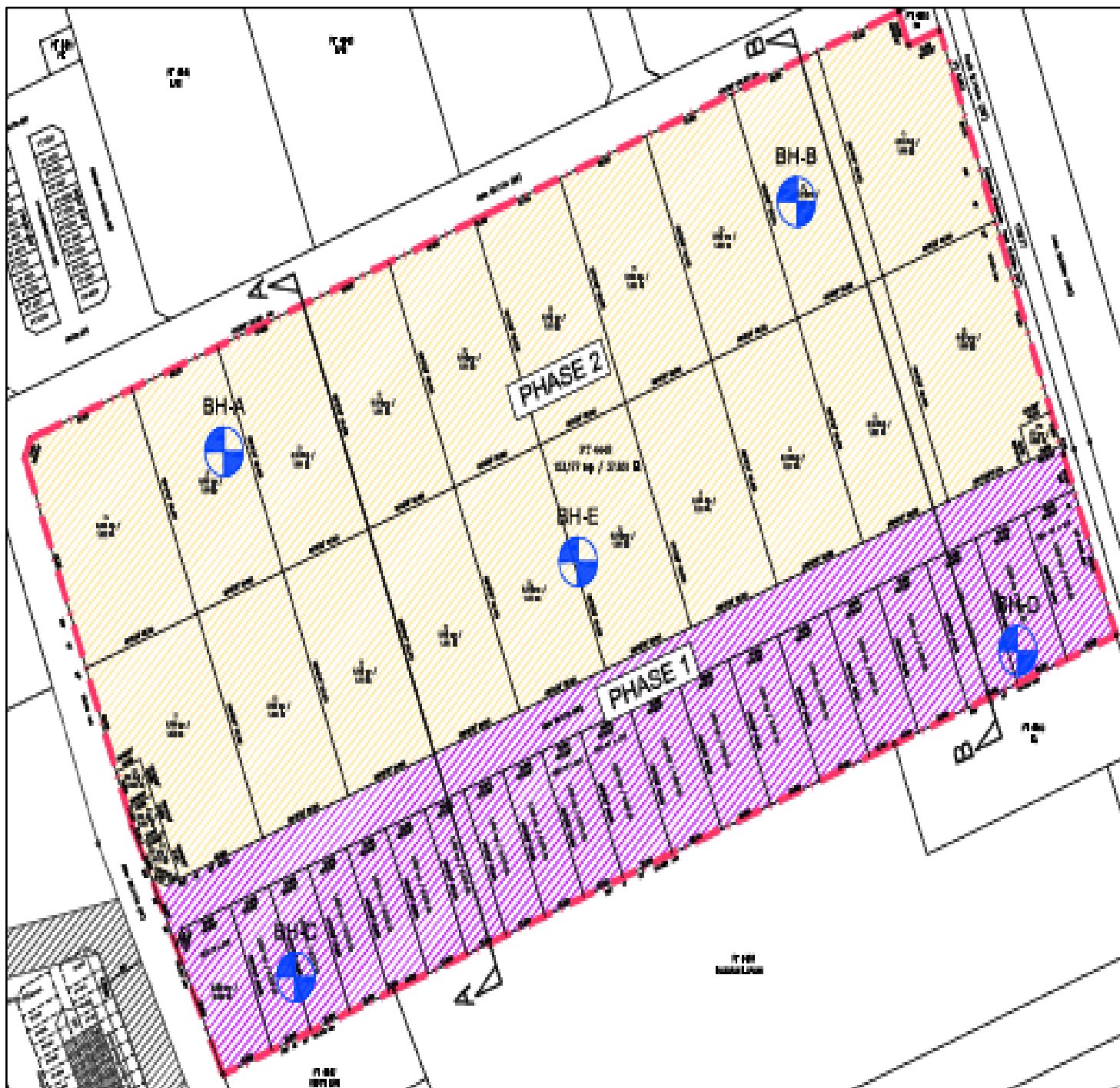


Figure 2 Soil Investigation

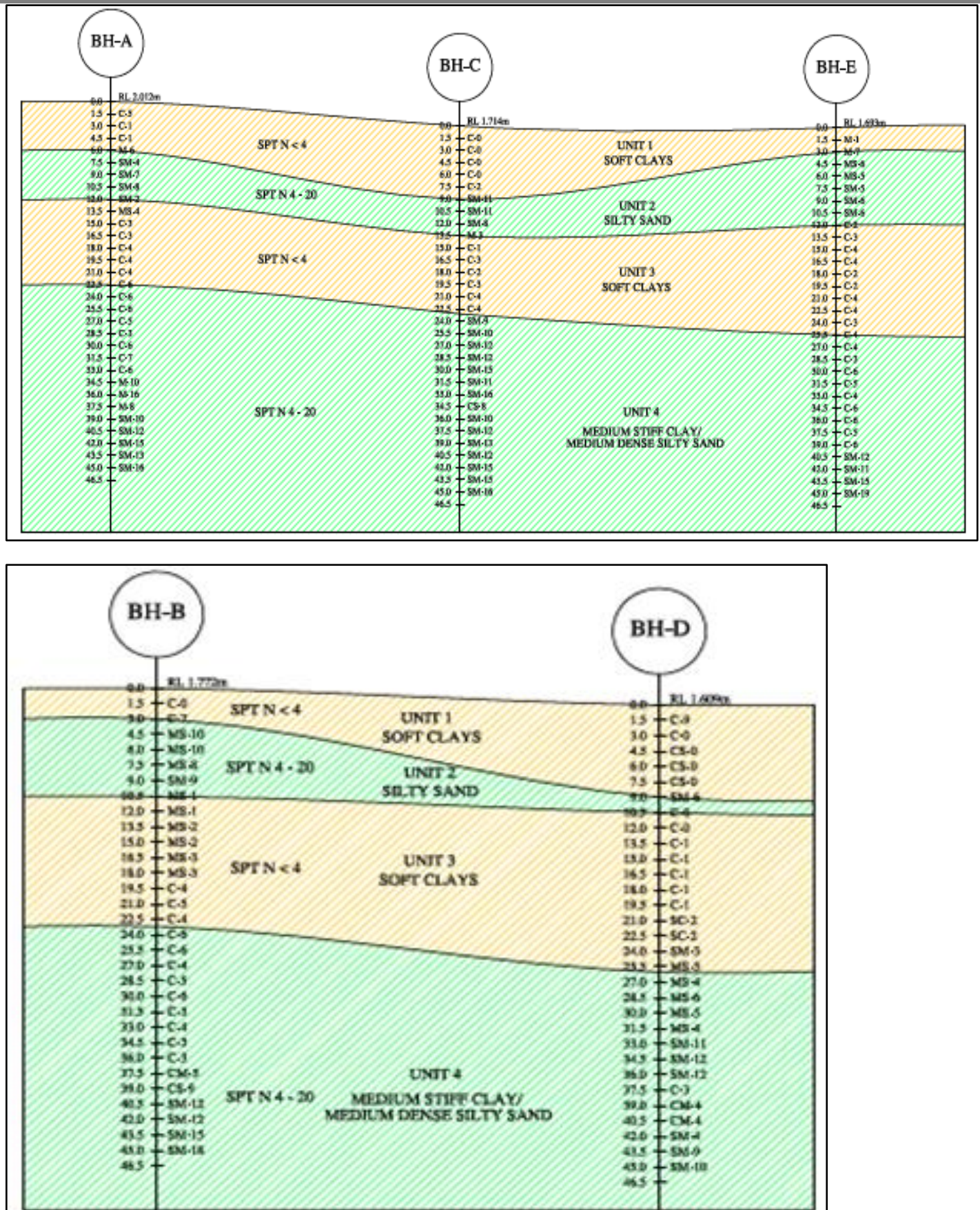


Figure 3 Subsoil profile Section A-A and Section B-B

The data will be analysed and summarized based on the parameters necessary for settlement evaluation using empirical methods. Subsoil characteristics were derived from the site investigation. Table 1 outlines the soil parameters.

Table 1. Summary of Soil Parameters for Stability Analysis

Soil	Depth (m)	Unit Weight (kN/m ³)	Undrained Shear Strength (kN/m ²)	Friction angle (°)
Sof Clay Layer 1	0 - 5	15	14	0
Sof Clay Layer 2	5 - 10	15.2	17	0
Sof Clay Layer 3	10 - 15	15.5	20	0
Sof Clay Layer 4	15 - 20	16.0	25	0
Sof Clay Layer 5	20 - 25	16.5	30	0

A. Geotextile Reinforcement

The adopted geotextile is GML-20 with an ultimate tensile capacity of 200 kN/m. The reinforcement is placed beneath the embankment fill to provide tensile restraint against lateral deformation of the soft foundation during construction.

B. Stability Analysis

Slope stability was assessed using the Limit Equilibrium Method with Bishop's modified method. This approach is widely used for evaluating embankment stability and identifying the critical circular failure surface corresponding to the minimum factor of safety [12,13,149,15].

Since the soft clays have low shear strengths, edge slope stability of the fill is critical. Several sections have been analysed to assess the slope stability using limit equilibrium software GSTABL6 employing Bishop's modified method of analysis. Minimum factor of safety for temporary condition is 1.2. Internal slope stability analyses were conducted using high-strength geotextile reinforcements. The geotextile, GML-20, has an ultimate tensile capacity of 200 kN/m were used. Typical sections are shown in Figure 5 which is showing the geotextile reinforcement. The location of these sections is shown in Figure 4.

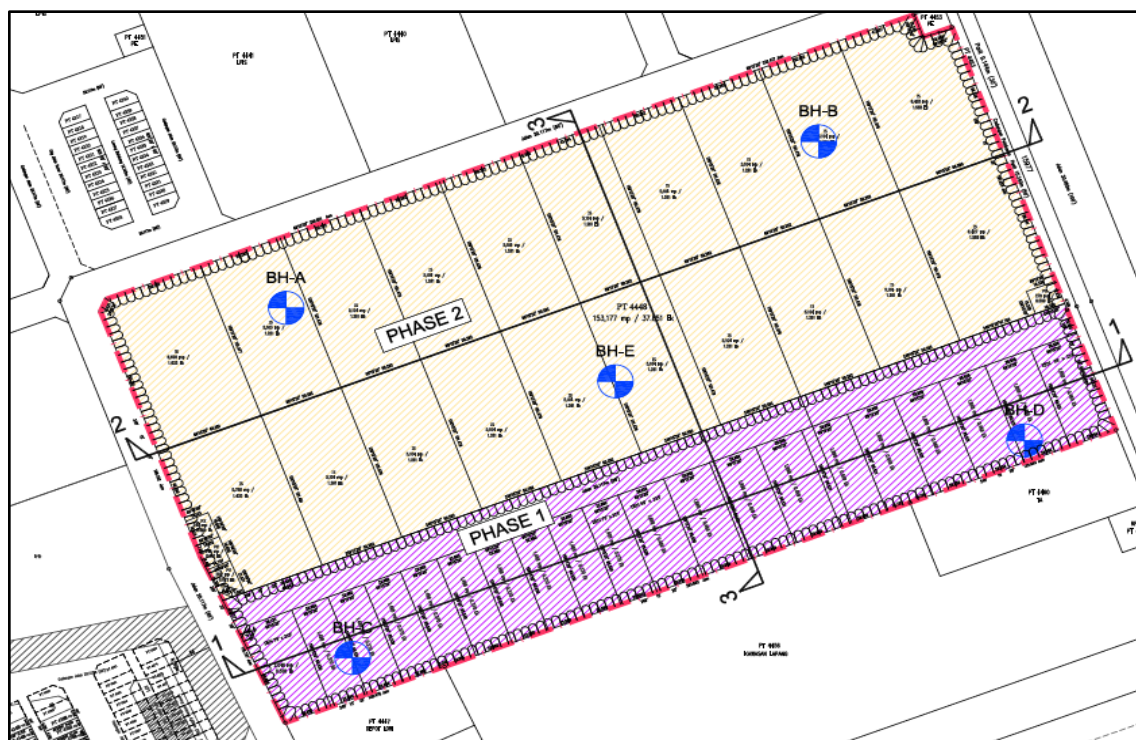


Figure 4 Cross Section Layout Plan

This study is focusing on the Phase 1 (Section 1-1 which is using geotextile reinforcement to stabilize the embankment).

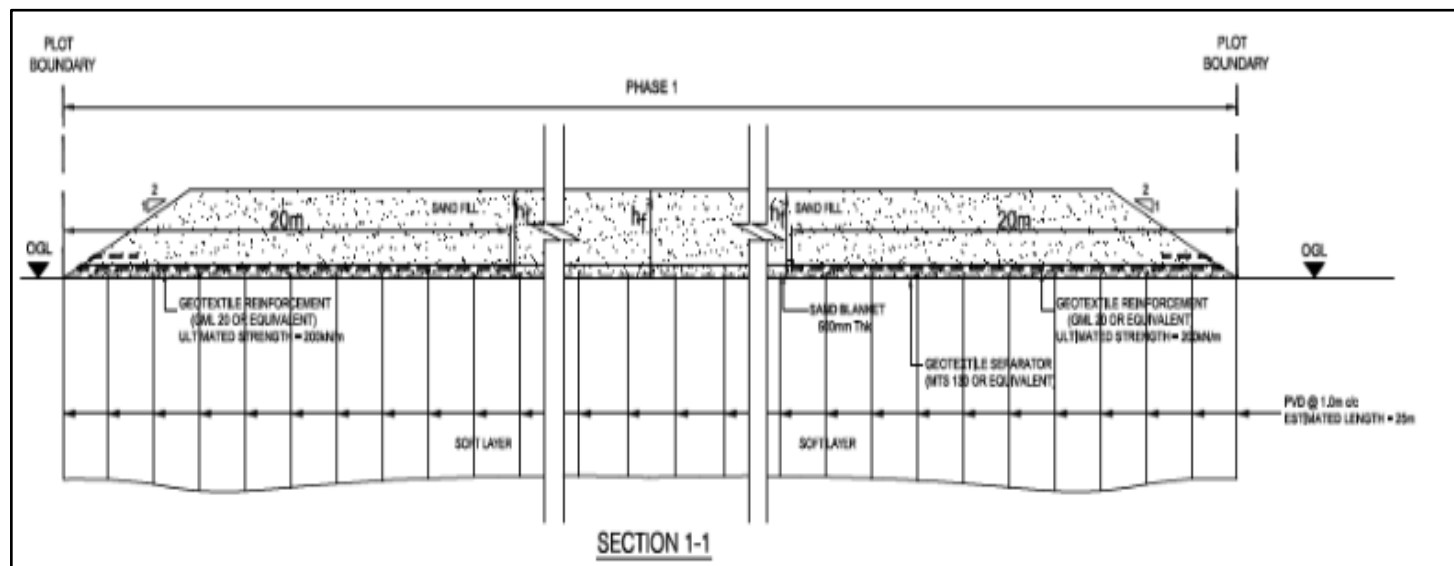


Figure 5 Cross Section Layout Plan

RESULTS AND DISCUSSION

Factor of Safety

The Limit Equilibrium Method (LEM) defines the FOS as follows [15]:

$$FOS = \frac{\text{Shear strength of soil}}{\text{Shear stress required for equilibrium}}$$

Stability analysis was conducted to evaluate the variation in the factor of safety (FOS) for different ground treatment methods. The FOS values for three scenarios which are without reinforcement installation, with reinforcement installation and permanent condition are presented in Table 2. Additionally, Figure 6 illustrates the LEM analysis simulation for without geotextile reinforcement, while Figure 7 depicts the simulation for the reinforced embankment. Figure 8 illustrates permanent conditions. The results indicate that the FOS for the untreated embankment was 1.113, whereas the stability of the embankment with 200 kN/m reinforcement (GML-20) increased to 1.230. This finding suggested that the installation of the geotextiles results in higher stability values.

Table 2 Summary of Stability Analysis for an Embankment

Condition	Factor of Safety	Remarks
Temporary (during construction without geotextile reinforcement)	1.113	
Temporary (during construction with geotextile reinforcement)	1.230	With 200kN/m geotextile reinforcement
Permanent (after treatment)	1.415	

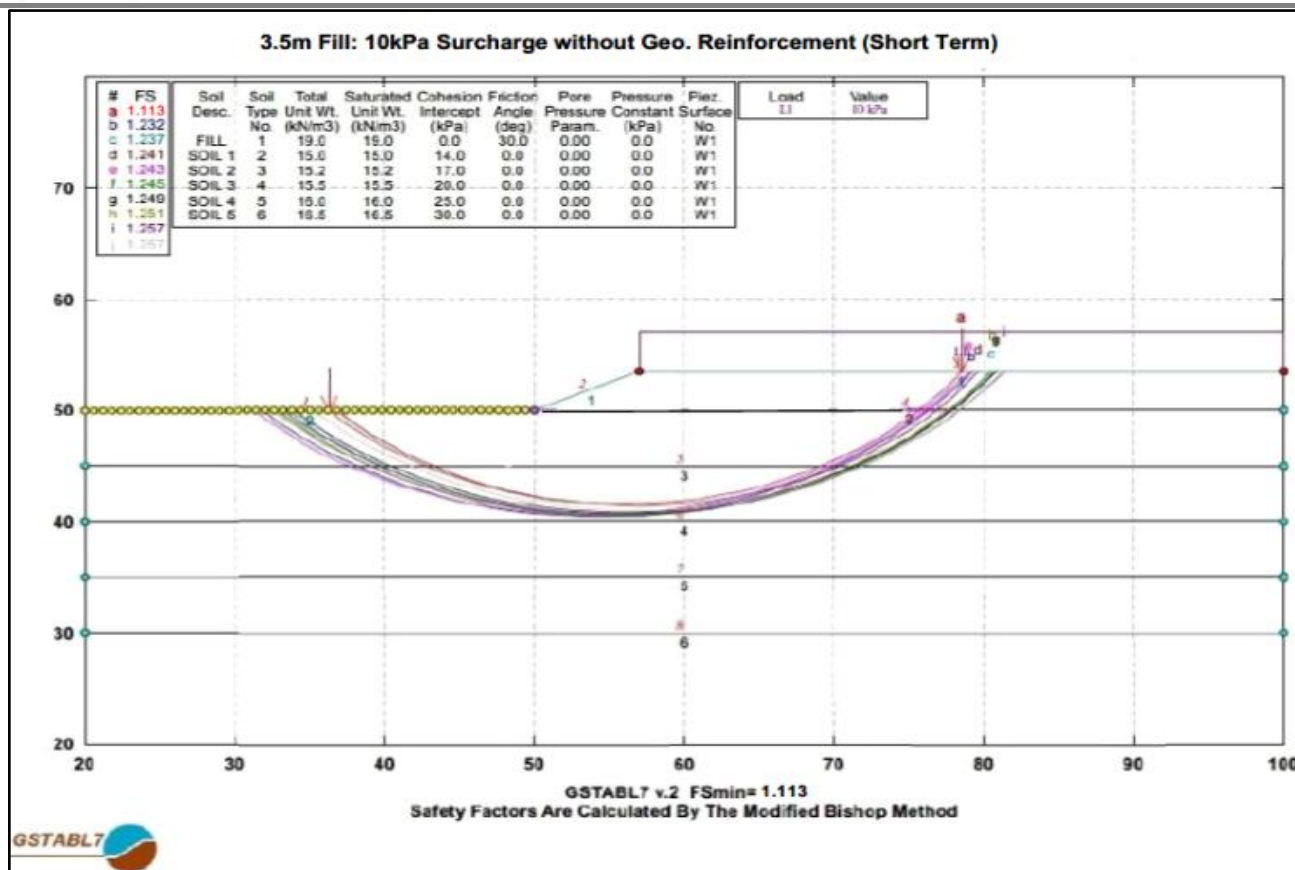


Figure 61 Results of Stability Analysis using Limit Equilibrium Method (Without Geotextile Reinforcement for temporary Condition)

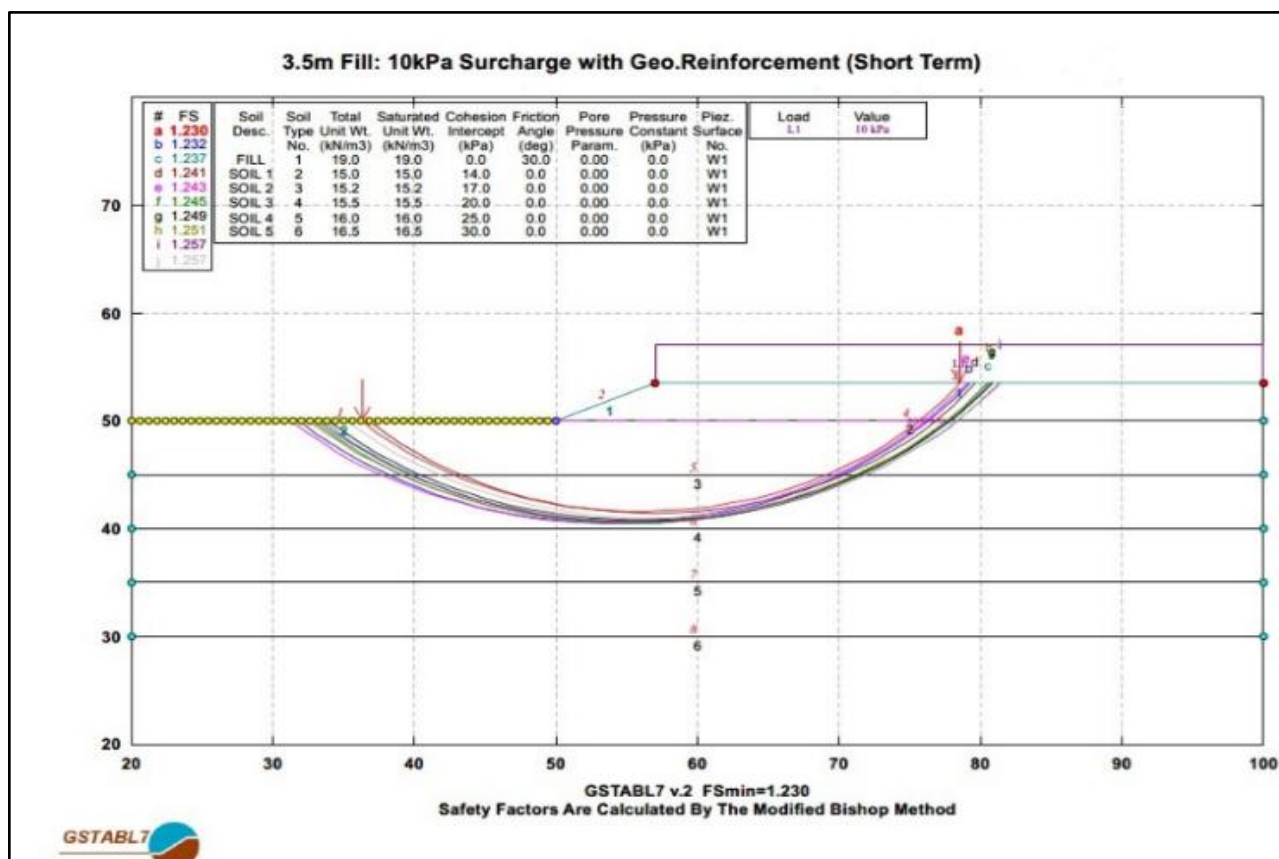


Figure 7 Results of Stability Analysis using Limit Equilibrium Method (With Geotextile Reinforcement for temporary Condition)

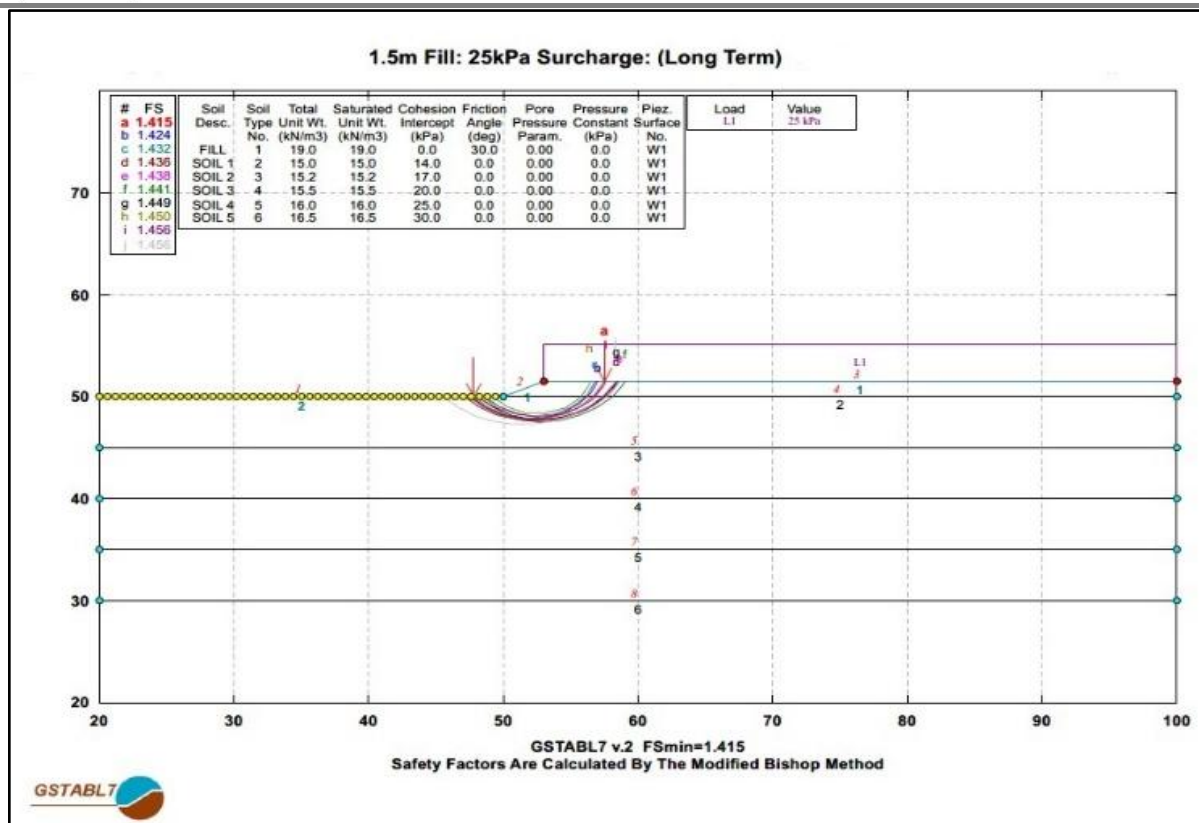


Figure 8 Results of Stability Analysis using Limit Equilibrium Method (Permanent Condition with 1.5m Platform Fill)

B. Engineering Significance

The results indicate that geotextile reinforcement can provide a measurable stability benefit where the foundation soil has low undrained shear strength. The reinforcement is particularly relevant during temporary construction stages, when the embankment load is applied before the soft clay has gained sufficient strength through consolidation.

The effectiveness of the reinforcement remains dependent on tensile capacity, placement, soil-geotextile interaction and construction sequence. Previous studies have shown that reinforced embankment performance is also affected by the interaction between reinforcement and vertical drainage systems [9,10,11]. The factor of safety values reported here should therefore be interpreted as project-specific results for the adopted soil parameters, embankment geometry and GML-20 reinforcement.

C. Engineering Implications of the PVD Scheme

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CONCLUSIONS

The stability assessment of the investigated embankment over soft marine clay shows that basal geotextile reinforcement increases the calculated factor of safety during temporary construction. The factor of safety

increased from 1.113 without reinforcement to 1.230 with the 200 kN/m GML-20 geotextile. The permanent condition gave a factor of safety of 1.415.

The results demonstrate the role of geotextile tensile resistance in limiting lateral deformation and improving embankment stability on weak foundation soils. For final journal submission, the numerical stability results should be supplemented, where available, by construction-stage monitoring of lateral deformation and settlement to provide field validation of the calculated behaviour.

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