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Enhancing Slope Stability with Different Slope Stabilization Measures: A Case Study using SLOPE/W Software

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ABSTRACT

This paper presents a case study of an existing slope at Taman Kelab Ukay, Ampang, Selangor. A potential slope failure is predicted as the nearby surrounded slope failed due to low self-retaining strength caused by prolonged and intense rainfall. The slope stability is analyzed by the Limit Equilibrium Method (LEM) using Geo-Studio 2018 (SLOPE/W) software to investigate the slope's Factor of Safety (FOS). The slope stability analysis confirms that the existing slope only provides the FOS of 1.028, which does not meet the minimum FOS of 1.30 of JKR Guidelines for Slope Design (2010) for untreated slope. The slope is subsequently re-analyzed as a treated slope, and the proposed remedial actions are soil nailing and geotextiles. As a result, the soil nailing and geotextiles achieve a minimum FOS of 1.50 for treated slope, with values of 1.899 and 1.845, respectively. For remedial work, soil nailing is recommended to be employed at the slope since the method is commonly used in the construction industry as it offers an inexpensive and uncomplicated installation technique. The sufficient soil nailing design characteristics proposed for the slope is three (3) bars of 7 meters length of soil nails at a 25° inclination angle. Soil nailing is a reliable and cost-effective method for slope stabilization and remedial work due to its ability to provide a durable, long-term solution for slopes that are prone to instability, erosion and landslides.

Keywords: Slope stability; SLOPE/W software; factor of safety (FOS); soil nailing; geotextiles

INTRODUCTION

In recent years, many cases of landslides and slope failures have killed numerous human lives and caused massive destruction to the properties. Slope failures have become a common issue in the construction industry for hillside development (Alsubal et al. 2017) as it is a phenomenon where the slope collapses due to the weak self-retainability, along with various triggered causes such as erosion, rainfall, and earthquakes. Slope failures caused a lot of damage worldwide, and the losses have increased due to the expanded population and new development in unstable areas.

The behaviour of landslides is affected by many factors, including geological environment, lithology, geomorphological process, in-situ stress distribution and groundwater conditions (Cheng et al. 2021). In tropical regions such as Malaysia, slope instability caused by rain is a common geotechnical hazard. Rainfall has been identified as one of the primary causes of landslides in areas with high annual rainfall. Rainwater can easily infiltrate a slope and cause saturation at shallow depths in the field during the service life due to prolonged and intense rainfall, especially during the two monsoon seasons each year (Niroumand et al. 2012). At the same time, the level of groundwater recharged by rivers and excessive rainfall is high, and there will be profound instability of slopes.

Construction activities on hillside slopes have increased and generally cause a change in an area's natural topography. Gue & Wong (2009) mentioned that the failures are due to inadequate design resulting from a lack of knowledge of subsurface conditions and geotechnical issues. The failures also come from construction errors, either from workmanship, materials or a lack of site supervision, which contributed to 8% of all landslide cases, and the combination of design and construction errors caused approximately 20% of the investigated landslides.

Due to that, slope engineering has become the primary focus for housing and infrastructure development on hilly terrain. Proper slope instability behaviour and consequences assessment are essential for slope instability risk management. Understanding the critical processes of slope evolution and disasters can provide insight into the causes and triggers of slope instability (Dille et al. 2019). Slope stabilizations, also referred to as corrective works, are actions taken to improve the stability of a slope. Slope stabilization or slope protection prevents the slope from surface runoff erosion, reduces infiltration, and improves the sloping landscape's environmentally appearance. Slope stabilization requires selecting the proper method, specifications, construction procedures, and maintenance (Niroumand et al. 2012). Engineers have several options when attempting to stabilize an existing slope failure. With the availability of computers and slope analysis software, there is now even less excuse for not performing the proper slope stability analysis.

Two landslides that brought a significant impact to Malaysia until this day are the landslide of Highland Towers and the landslides that happened at Bukit Antarabangsa, Selangor. The tragedy of Highland Towers occurred on December 11, 1993, resulting in Block 1 of the building collapsing and involving 48 deaths (Kazmi et al. 2017), while the landslides at Bukit Antarabangsa, Selangor happened in December 2008, affected public safety as they caused four (4) deaths and fourteen (14) injured people (Mariappan et al. 2016). From these cases, it can be proved that slope stability analysis is the most crucial aspect due to the nature of Malaysia's weather and topography conditions. The slope must be designed with the best protection measures to avoid failure. Many slope reinforcement methods can be applied where the best approach will provide a better value in terms of Factor of Safety (FOS) and cost-effectiveness.

This study aims to analyze a case study of an existing slope at Taman Kelab Ukay, Ampang, Selangor using the Limit Equilibrium Method (LEM) by Geo-Studio 2018 (SLOPE/W) software and to propose the most effective slope remedial measure at the slope in order to increase its Factor of Safety (FOS). The existing slope is analyzed by Morgenstern Price's method using SLOPE/W software to determine its FOS. SLOPE/W software offers a 2D and 3D modeling of slope including the geometry and material properties. The visual representation of the results from this study can also assist in understanding the factors that influence the stability of the slope.

METHODOLOGY

SLOPE/W software is utilized for assessing slope factor of safety due to its user-friendly interface that makes it accessible to use for both experienced and novice users. The software also has advanced analysis capacities that can deal with complex soil and rock slope stability problems. It also can accomplish both two-dimensional and three-dimensional analysis. The SLOPE/W has a variety of material models that can be used to simulate various type of soils such as linear and nonlinear Mohr-Coulomb, Bishop and Hoek-Brown models.

The study area is located at Taman Kelab Ukay, Ampang, Selangor, as shown in Figure 1. The existing slope is analyzed using SLOPE/W software to determine its FOS using Morgenstern Price's method. The FOS of a slope must fulfil the Guidelines for Slope Design from Jabatan Kerja Raya Malaysia (JKR, 2010) to ensure the safety of the slope meet the minimum requirement. When the FOS of the untreated slope (existing condition) does not meet the criteria, the slope needs to be re-analyzed with any remedial measures to prevent the slope from failing.

The process of acquiring soil parameters from a Site Investigation report includes reviewing the information presented in the report and interpreting it to recognize the significant soil characteristics. The relevant soil properties needed for a project include the soil classification, soil strength, soil compressibility, soil permeability and soil bearing capacity. The existing slope has a height of 60 m with an inclination angle of 45°. The slope area comprises three (3) layers of rock, clay, and sand, and the parameters for each layer are required in the software for analysis. The soil parameters for the existing slope, such as the soil type and unit weight (γ), soil cohesion (c), soil angle of internal friction (ϕ), and pore water pressure (u), were obtained from the Site Investigation (SI) report gathered from Civil Engineering consulting firm; MegaConsult Sdn. Bhd. Table 1 tabulates the soil properties used in the slope analysis. Within this investigation, two surcharge loads; 10 kN/m and 15 kN/m are set at the crest of the slope. Surcharge loads are employed in the analysis to simulate the loads generated by structures, vehicles, equipment, and material placement on slopes.

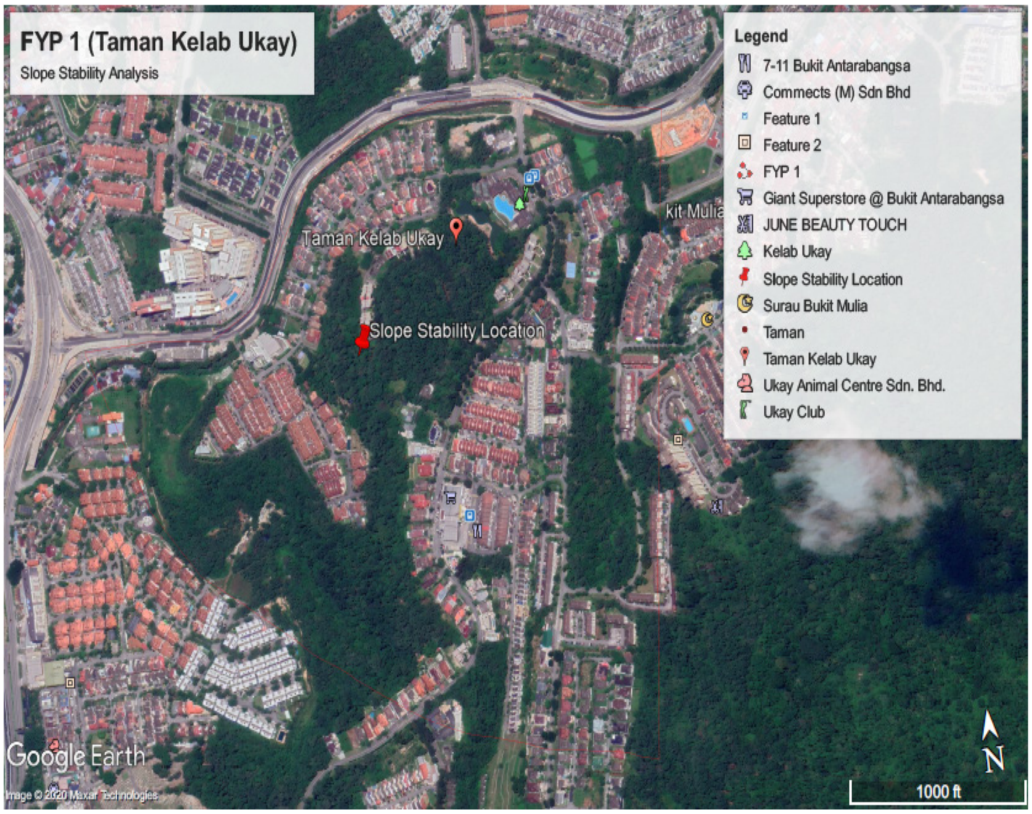

FIGURE 1. The slope location for the case study (Source: Google Earth)

TABLE 1. The soil properties of the existing slope from Site Investigation (SI) report

Layer	Unit Weight, γ (kN/m^3)	Cohesion, c (kN/m^2)	Angle of internal friction, ϕ (°)
Sand	18	0	30
Clay	18	2	34
Rock	18	200	40

The Factor of Safety (FOS) of a slope is a primary consideration in determining the slope stability analysis. When a slope is unsafe with a low FOS, it can be overcome by stabilizing the existing slope with the appropriate remedial measures. The slope stability analysis for the case study is divided into two (2) parts, which are the analysis of the slope before applying the remedial measure (untreated slope) and after applying the corrective action (treated slope). The corrective actions that have been proposed in this study are slope protections using geosynthetics and soil nailing. The FOS of untreated and treated slopes must fulfil the Guidelines for Slope Design from Jabatan Kerja Raya Malaysia (JKR, 2010) to ensure the safety of the slope meet the minimum requirement. Based on the results of SLOPE/W, the most effective measure that can improve and provide the great FOS is chosen to treat the slope.

RESULTS AND DISCUSSION

SLOPE STABILITY ANALYSIS OF THE EXISTING SLOPE (UNTREATED SLOPE)

The slope stability analysis result shows that the existing slope's FOS is only 1.028, as shown in Figure 2. The output indicates that the existing slope does not meet the minimum FOS of 1.30. According

to JKR Guidelines for Slope Design (2010), all untreated slopes, either cut slopes, fill slopes or embankments, shall be designed with 2 meters berm width and 6 meters berm height with a minimum FOS of 1.30, while treated slopes must have a minimum global FOS of 1.50.

When the FOS of a slope does not meet the requirements, the slope needs to be re-analyzed with remedial measures to prevent the slope from failing. The measures adopted for this study are geosynthetics (geotextiles) and soil nailing.

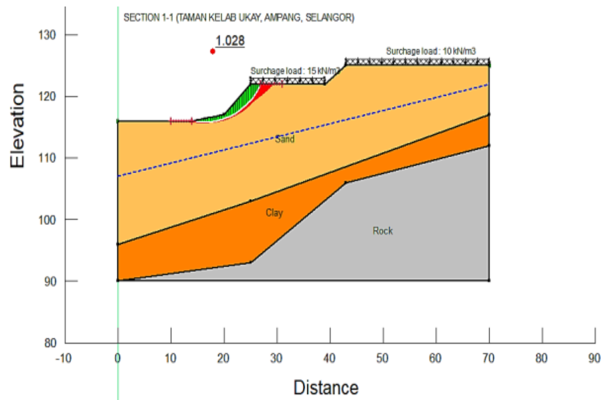

FIGURE 2. The existing slope with a FOS of 1.028 (output from SLOPE/W software)

SLOPE STABILITY ANALYSIS WITH GEOTEXTILES

Geosynthetic is widely used in geotechnical and geoenvironmental structures to perform reinforcement, drainage, filtering, separation, barriers, and protection (Palmeira & Tatto 2015). Geotextile is one of the corrective measures acting as tensile reinforcement to stabilize the slope. In this study, different geotextile characteristics are investigated, and the results of slope stability with three (3) layers at various lengths from 4 meters to 7 meters are shown in Figure 3.

Figure 3 shows the apparent trend of increasing FOS where the value is improved from 1.213 to 1.845. The implementation of 4 meters length indicates the lowest FOS of 1.213. In contrast, the 7 meters geotextiles offer the most significant FOS value of the slope, which is 1.845. From the findings, it is proved that the 7 meters length fulfils the minimum requirement of JKR. The parameters for designing geotextiles as a remedial measure for this case study are listed in Table 2, and Figure 4 shows the output of the slope stability analysis from SLOPE/W software.

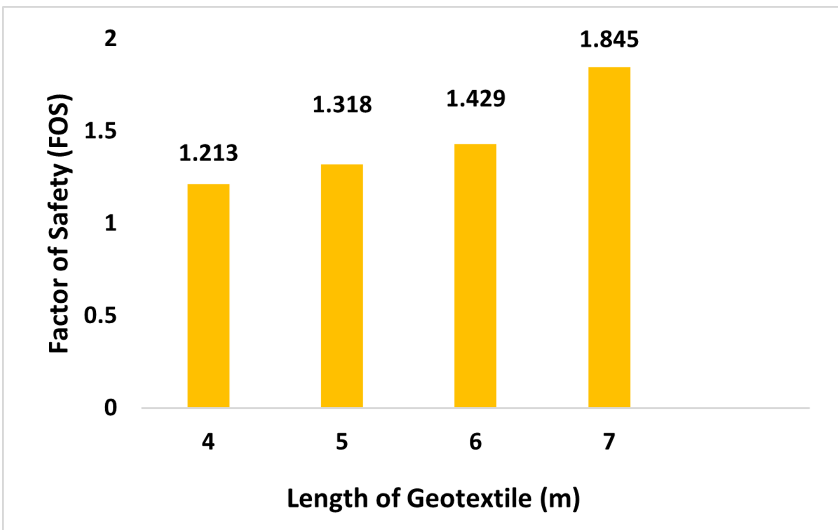

FIGURE 3. The result of FOS for various geotextiles length

TABLE 2. The proposed design for geotextiles

Slope Remedial Measure by Geotextiles	
Number of Geotextile Layer	3
Length of Geotextile Layer (m)	7
Factor of Safety (FOS)	1.845

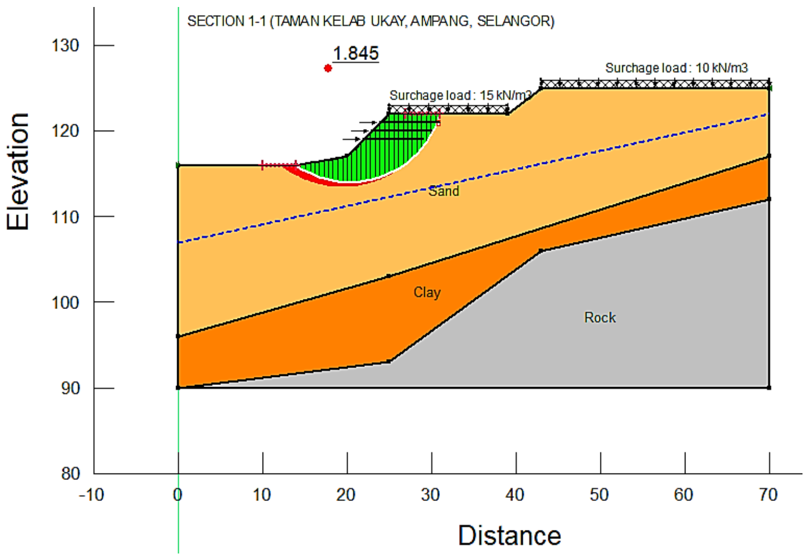

FIGURE 4. The slope analysis with 7 meters length of three (3) geotextile layers (output from SLOPE/W software)

SLOPE STABILITY ANALYSIS WITH SOIL NAILING

Soil nailing is a remedial measure for slope stabilization that can increase the resisting force. Due to technical applicability, soil nails are considered an effective slope stabilization method, which is easy to construct and requires low maintenance (Gue & Wong, 2009). The effects of different characteristics, such as the number, length, and inclination angle of the nailing bar, are examined in the slope analysis. The existing slope with three (3) nailing bars has been analyzed with various lengths of 4 meters to 8 meters.

Figure 5 shows that the FOS is improved from 1.435 to 1.899. The effect trend is in line with research conducted by Alsubal et al. (2017); the slope stability improves as the length of the soil nailing increases. The most significant value of FOS for the slope is 1.899, with the length of soil nailing at 7 meters and 8 meters, respectively. In contrast, the implementation of 4 meters length of soil nailing indicates the lowest FOS of 1.435, which does not fulfil the minimum requirement of JKR Guidelines for Slope Design (2010). The 7 and 8 meters give the same result of FOS because the required bond length has mobilized the maximum load to the slope so that the additional bond length will not mobilize any working load anymore.

Then, three (3) nailing bars of 7 meters in length are designed for the following analysis to determine the ideal inclination angle of soil nailing. The proposed nail's inclination is between 25° to 45° with an increment of 5°. Figure 6 shows the graph of FOS versus soil nail's inclination angle.

Figure 6 demonstrates that the result of FOS is dropped from 1.899 to 1.740. All results from 25° to 45° fulfilled the JKR minimum requirement of 1.50 for treated slope, and this finding is consistent with the results from a previous study by Alsubal et al. (2017). They had mentioned that after achieving the optimum inclination of soil nails, the safety factor tends to decrease as the nails mobilize the maximum load in the ideal inclination when the available bond length behind the slip surface is long enough to allow the nail to use its maximum load. The results show a clear trend of decrease in FOS where 25° nail's inclination is the optimum inclination of soil nails, giving the FOS of 1.899 before it drops. The soil nailing parameters implemented in the design of this case study are listed in Table 3, and Figure 7 shows the output of the slope stability analysis from SLOPE/W software.

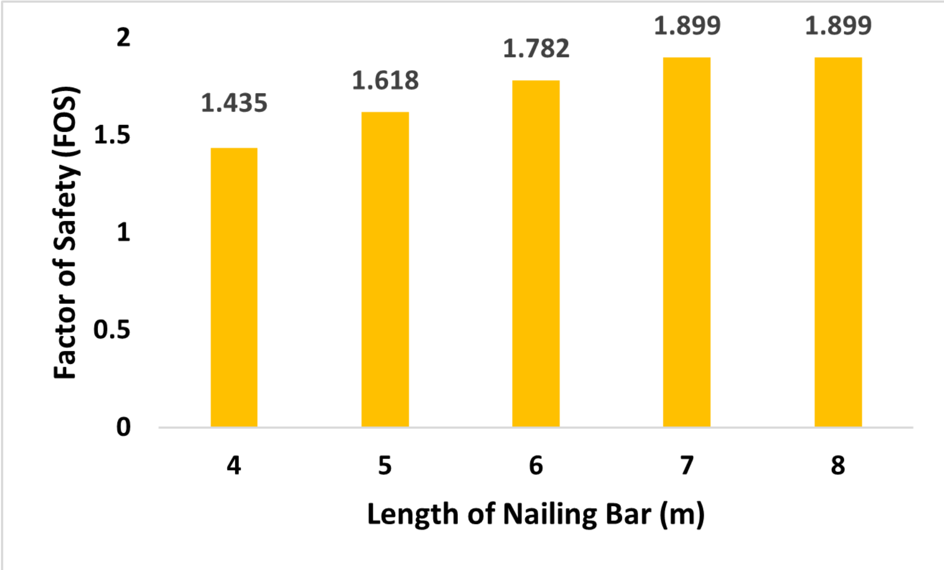

FIGURE 5. The result of FOS for various lengths of soil nailing bar

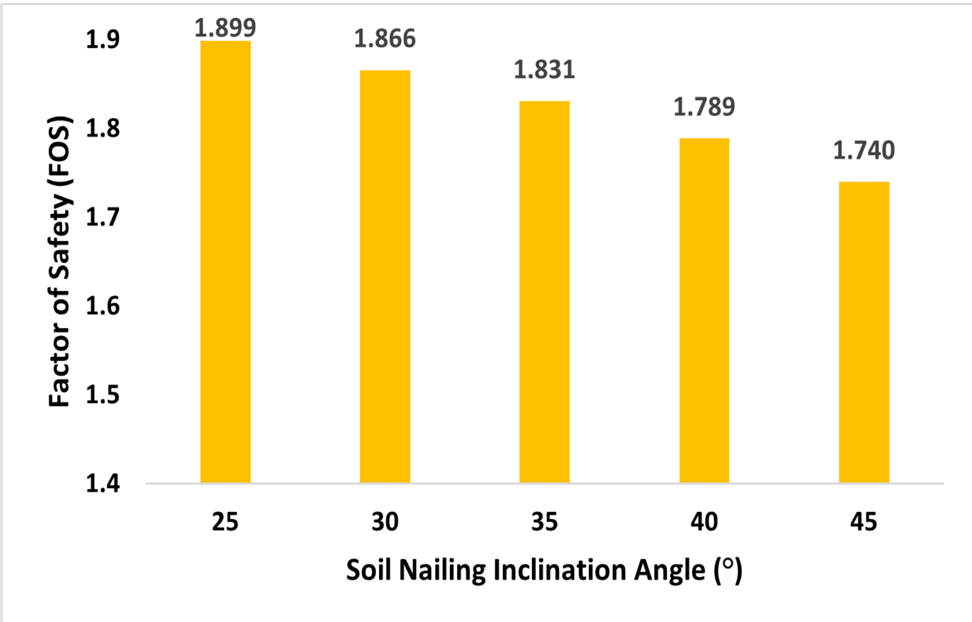

FIGURE 6. The result of FOS for various inclination angles of soil nailing bar

TABLE 3. The proposed design for soil nailing

Slope Remedial Measure by Soil Nailing	
Number of Soil Nailing Bar	3
Length of Soil Nailing Bar (m)	7
Inclination Angle (°)	25
Spacing between Soil Nailing Bar (m)	2
Factor of Safety (FOS)	1.899

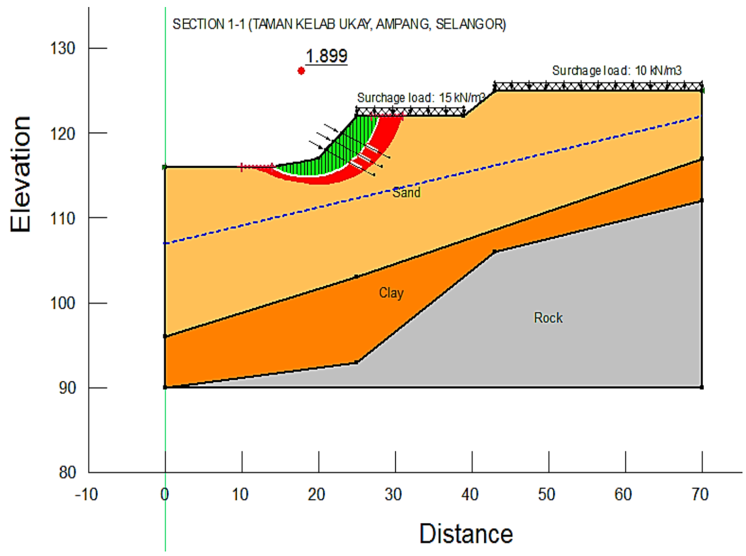

FIGURE 7. The slope analysis with 7 meters of three (3) soil nailing bars at a 25° inclination angle (output from SLOPE/W software)

SUMMARY RESULTS OF SLOPE STABILITY ANALYSIS

The Factor of Safety (FOS) is the primary key to analyzing the problem of slope stability. As shown in Table 4, the FOS of the untreated slope (existing slope) only provides 1.208, which does not meet the minimum requirement of the JKR Guidelines for Slope Design (2010). In order to enhance the stability of this existing slope, geotextiles and soil nailing are designed with the proposed parameters to be applied at the slope. As a result, the FOS for soil nailing and geotextiles achieved the minimum FOS requirement of 1.899 and 1.845, respectively. Even though the FOS of geotextiles is not much different from soil nailing, the soil nailing is chosen to be implemented at the existing slope as the method is commonly used in industry due to its cost and simple construction techniques.

TABLE 4. The minimum FOS for untreated and treated slope from JKR Guidelines for Slope Design (2010)

Slope Condition	Factor of Safety (FOS)		JKR Guidelines for Slope Design (2010)
Untreated Slope	1.208		1.30
Treated Slope	Geotextiles	Soil Nailing	1.50
	1.845	1.899	

CONCLUSION

Slope analysis was carried out to investigate the stability of an existing slope located at Taman Kelab Ukay, Ampang, Selangor, using the Limit Equilibrium Method (LEM) by Geo-Studio 2018 (SLOPE/W) software. Some conclusions can be drawn from this case study:

1. The FOS for untreated slope (existing slope) is only 1.028, which does not meet the minimum 1.30 requirement from JKR Guidelines for Slope Design (2010).
2. The slope is re-analyzed by Morgenstern- Price's method using SLOPE/W software with two (2) proposed remedial measures;
3. geotextiles and soil nailing for improving the FOS of the slope.
4. For geotextiles, the slope protection requires three (3) geotextile layers, with a length of 7 meters at a 0° inclination angle. The FOS obtained from the proposed design is 1.845, fulfilling the minimum 1.50 (treated slope) of JKR Guidelines for Slope Design (2010).
5. For soil nailing, the slope protection involves three (3) soil nailing bars with a length of 7 meters at an inclination angle of 25°. The spacing between each bar is fixed at 2 meters. The FOS obtained from the proposed design is 1.899, also fulfilling the minimum 1.50 (treated slope) of JKR Guidelines for Slope Design (2010).
6. Although the FOS of geotextiles is not significantly different, the soil nailing method is the most effective remedial measure to implement at the existing slope due to its low cost and simple construction technique.

7. The significance of this study is to ensure and provide a slope with a better design, explicitly providing a safe and better life for the public and environment.

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DECLARATION OF COMPETING INTEREST

None

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