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COMPARISON OF SLOPE STABILIZATION ANALYSIS METHOD BY USING CHANGING GEOMETRY AND SOIL NAILING FOR SLOPE FAILURE

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ABSTRACT

Slope stability analysis is the process of analysing the stability and safety of a particular slope, assuring that the pertaining slope is safe for the human surrounding and any related construction activity. SLOPE/W of Geostudio software was utilised in this study to determine the factor of safety (FOS), both before and after slope stabilisation work was applied. Laboratory tests such as the Atterberg Limit, Moisture Content, Sieve Analysis, and Hydrometer tests were carried out to determine the physical characteristics and parameters of the slope. From Ordinary and Spencer methods, the slope's FOS values before stabilisation were 2.965 and 2.985. Then, using Changing Geometry method, both FOS was increased to 4.536 and 4.632, respectively. The same slope was analysed using Soil Nailing, and the FOS value were results 3.972 and 4.205 for Ordinary and Spencer's methods, respectively.

Keywords:
Key words: Slope stabilisation, Factor of Safety (FOS), SLOPE/W, Ordinary Method, Spencer Method, Changing Geometry, Soil Nailing.

INTRODUCTION

Slope failures are common phenomena in a tropical country like Malaysia, characterized by a humid, tropical region and thick weathering profile. The increase in construction industry development has mugged and progressed heavily into hilly areas which has resulted in Malaysia being exposed to frequent landslides and several major slope failures, which have caused damage and inconvenience to the public. Thus, as a mitigation measure, it is crucial to undergo a reliable slope stability analysis so that such an event does not repeat in the future. Besides understanding the importance of slope analysis, we also need to know the causes of slope failures to propose suitable repair work. The FOS from slope stability analysis can classify the slope hazards for the slope area according to Farazi et. al (2018). It is important to do analysis for the slope failure in order to get the finding and give the suggestion of slope stabilisation method. The three main objectives of this study are first to determine the physical properties and parameters of the slope. The second objective is to identify the FOS during failure, and the third objective is to identify the FOS after the proposed slope stabilisation work. The laboratory tests such as the Atterberg Limit test, Moisture Content test, Sieve Analysis and Hydrometer test were conducted to achieve the first objective. Then, the results obtained were used as an input for soil properties, and the software analysis using SLOPE/ W of GeoStudio software was carried out. The slope area chosen for the slope stability analysis was Infrastructure University Kuala Lumpur (IUKL) in Kajang**.**

LITERATURE REVIEW

The resisting force is defined by the cohesion times as the area of the failure surface plus the frictional shear strength were determined using the effective normal stress on the failure plane according to Suman (2014). In addition, the driving force on other hand is defined as the sum of the component of the weight, water forces, and all other external forces acting along the failure surface. All these factors and component as mentioned from the previous researcher was carried out for this study. The slope stability The SLOPE /W of GeoStudio software was used as the method and model for the research analysis and Limit Equilibrium (LE) analysis was used for its simplicity and accuracy in calculating the FOS. These methods use the concept of cutting the slope into fine slices and applying an appropriate equilibrium equation (the equilibrium of forces or moments) in calculating the FOS. Over the years, many improvisations and alternatives have been proposed in these equilibrium equations, such as the Fellenius and Bishop methods. Besides that, SLOPE W is GeoStudio software to determine slope safety in assessing slope stability. SLOPE/W can be used to compute FOS for discrete shear surfaces, such as circular, non-circular and user-de fined surfaces for various shear surfaces. Then, FOS is the ratio of resisting force to driving force, where resisting force is the force preventing the sliding while driving force is the force that causes the sliding of the slope. In this study, SLOPE/W with LE method was used with the Ordinary and Spencer analysis method for the equilibrium equation to calculate the FOS for each analysis.

To use the LE method using SLOPE/W, specific laboratory tests such as the Sieve Analysis test, Hydrometer test, Moisture Content test and Atterberg Limit test were carried out to determine the physical properties and parameters of the slope. The hydrometer test and sieve analysis test were to determine the particle size distribution of the soil and the type of soil on the slope as the Moisture Content test was to determine the unit weight and the Atterberg Limit test to determine the cohesion and angular friction of the soil covering the slope, which the data will then be used as an input for SLOPE/W software. Hence, once the laboratory test was completed, the software analysis using the SLOPE/W was done to determine the FOS of the slope during failure using the Ordinary and Spencer analysis method. With the value of FOS during failure as a benchmark, two types of slope stabilisation work, such as the Changing Geometry method and Soil Nailing, were proposed to increase the stability and safety of the slope. A Changing Geometry method is converting the slope from steeper to gentler by trimming the slope or reducing the extra load applied on the slope, while Soil Nailing is constructed to withstand or resist against downward forces or pushing forces of soil masses. According to Shiferaw (2021), the method of Changing Geometry consider as one of the type chosen for the slope stabilaization work. Then again, the FOS will be computed using SLOPE/W to compare on stability increase of the slope due to the proposed stabilization work.

METHODOLOGY

This study is divided into three (3) parts. Where the first part was the site visit, at the site of the slope, it is being investigated was visited to determine the slope parameters and to obtain the soil samples to conduct laboratory tests. Then, the second part was the laboratory test, where the soil sample obtained from the site visit was used to conduct four (4) laboratory tests: the Sieve Analysis test, Hydrometer test, Atterberg Limit test and Moisture Content test. The laboratory test was conducted to determine the physical properties and parameters of the soil sample taken from the slope, which was then used as an input in computing slope stability analysis through the software SLOPE/W. Lastly, the third part was the software analysis to compute the FOS of the slope during failure and after applying slope stabilization work by using the data obtained from laboratory tests as input parameters. In the software analysis, SLOPE/W of Geo-Studio software was used with Limit Equilibrium (LE) method and Ordinary and Spencer as the analysis method under LE for FOS computation. The two (2) types of slope stabilization work proposed were the changing geometry where the height/elevation of the slope was reduced, and the second type of remedial work was the retaining structure, the application of soil nailing. The software analysis was initially conducted on a trial and error basis, with around 15 trials for each section to determine the most approximate parameter and properties to be used for accurate analysis results.

RESULT

LABORATORY TEST RESULTS

The **Table 1** below shows all the results obtained from the four (4) laboratory test conducted which was to determine the physical properties and parameters of the slope and the required outcome that has been used as an input in the software analysis.

Table 1 Physical Properties Result

Determination	Experiment	Result	Outcome
Type of Soil	Hydrometer & Sieve Analysis test	76% silt	**Silty soil**
Type of Soil	Moisture Content test	W=40%	**Soft Clay**
Unit Weight of Soil	Moisture Content test	Dry Unit Weight, γd= 11.5-14.5kN/m^3	**Unit weight,γ=18.2kN/m^3**
Plasticity	Atterberg limit test	LL=52, PL=33 and PI=19	**MH(Silty soil with high plasticity)**
Angular friction	Atterberg limit test	Medium dense, 36° to 42°	**40°**
Cohesion	Atterberg limit test	5 to 10 kN/m^2	**8kN/m^2**

The **Table 2** below shows the particle size distribution of soil for the slope failure that has been tested.

Table 2 Physical Properties Result

Type of soil	Clay<0.002mm	0.002mm<Silt<0.063mm	0.063mm<Sand<2m	Gravel>2mm
Percentage	4%	76%	20%	0%

As shown in the above **Table 1** and **2**, through the Hydrometer test and Sieve analysis test the type of soil has been ascertained as the silty soil with the detailed description on the soil tested. Where 76% of the soil was tested to be silt hence, the type of soil finalized as silty soil. Then, through Atterberg Limit test, the Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI) of the soil has been identified, through which the soil type was further detailed as Silty Soil with High Plasticity (MH). Through Atterberg Limit test also the angular friction, phi (φ) was finalized as 40° with cohesion, c=8 kN/m^2. Besides that, from the Moisture Content test the soil was seen to exhibit the nature of soft clay and the Unit weight of the soil was identified as 18.2kN/m^3.

SOFTWARE ANALYSIS RESULTS

Below are the results obtained from the SLOPE/W software analysis using the Limit Equilibrium method for both the Ordinary and Spencer analysis method in computing the FOS of the slope. **Figure 1** shows the results obtained for all the software analyses, the results of FOS of the slope during failure, FOS value of the slope after the application of slope stabilization work for Changing Geometry where the slope height or elevation was decreased from 2.5m to 2.0m and for soil nailing remedial work for both Ordinary and Spencer method of analysis. From this, the FOS of the slope during failure was determined as 2.965 and 2.985 for the Ordinary and Spencer method. Then, the FOS of the slope after the application of remedial work the Changing Geometry was an increase in FOS to 4.536 and 4.632 and for Soil Nailing also there was an increase in FOS to 3.945 and 4.205 for both Ordinary and Spencer method of analysis from 2.965 and 2.985 during failure indicating an increase in stability of the slope.

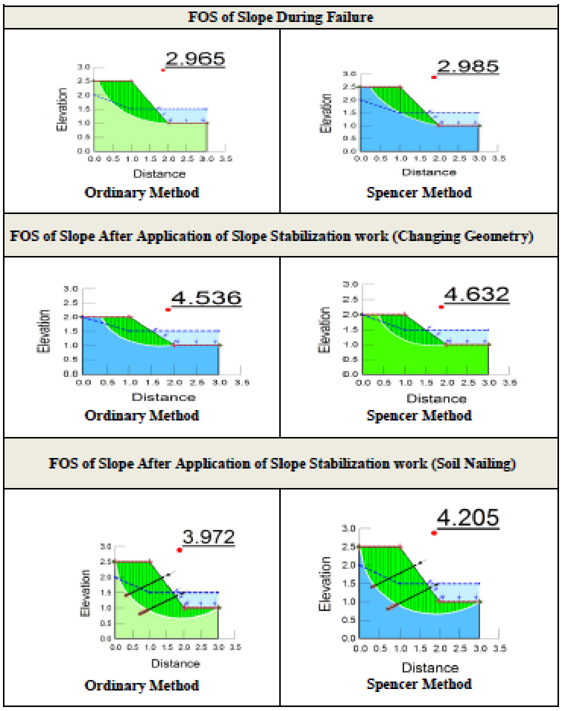

Figure 1 FOS Result based on Slope/ W software analysis

DISCUSSION

The discussion is summarized as shown in **Table 3** below, with an overall summary of all the results obtained from this study. The laboratory test conducted on the soil sample taken from the slope, the soil's physical parameters and properties were ascertained with the soil being classified as silty soil with a little mix of clay and the soil was further classified as silty soil with high plasticity (MH) based on Atterberg limit test by using the plasticity chart. The data obtained from the Atterberg limit test, the frictional angle of the soil was then gauged to be between 36°- 45° from the SPT table for angular friction, with silty soil being classified as soil with medium dense relative density from which phi 40° chosen as an input for software analysis. Besides that, with the soil being tested having a plasticity index of 19%, the soil was classified as cohesive soil with a high degree of plasticity. Hence, the cohesion c of the soil was classified between 5 to 10 kN/m^2 with 8 kN/m^2 chosen for software analysis input. For moisture content test, the moisture content of the soil is identified as 40% from which the unit weight of the soil has been computed as © = 18.2 kN/m^3.

Apart from that, with these physical properties and parameters of the slope soil used as an input, the FOS value is computed using SLOPE/W software. Where the FOS value of slope during failure for both Ordinary and Spencer methods of analysis was identified as 2.965 and 2.985, this FOS value, if compared with the minimum allowable FOS of 1.5 based on the JKR (PWD) guideline, indicates that the slope is safe. Still, in reality, the slope is undergoing what is known as spot failure, the initial stage of failure such as soil erosion, instead of visible massive failure such as translational or rotational failure. Hence it was logical for the value to be more significant than the minimum FOS. Thus, these 2.965 and 2.985 will be used as the failure threshold for this research from here onwards. Any FOS value less than this indicates slope failure, and any value more than this is to be gauged as safe. As for the FOS after the application of slope stabilization work, as a result of reducing the slope height from 2.5m to 2.0m for the geometrical method, the FOS value has increased from 2.965 to 4.536 for the Ordinary method and from 2.985 to 4.632 for Spencer method, improving the slope stability by reducing the steepness of the slope. Apart from that, by using soil nailing reinforcement, the stability of the slope has been increased, which can be ascertained by the increase in FOS value from 2.965 to 3.972 for the Ordinary method and from 2.985 to 4.205 for the Spencer method.

Table 3 Overview of Discussion

Properties	Condition during Analysis	Analysis method	Result FOS	Outcome	Remarks
Unit weight, γ= 18.2 kN/m^3 **Angular friction, phi (φ) = 40°** **Cohesion, ć = 8 kN/m^2**	**During failure**	Ordinary	**2.965**	-	-
		Spencer	**2.985**	-	-
	After the application Slope Remedial work				
	Changing Geometry	Ordinary	**4.536**	4.536>2.965	OK!
		Spencer	**4.632**	4.632>2.985	OK!
	Soil nailing	Ordinary	**3.972**	3.972>2.965	OK!
		Spencer	**4.205**	4.205>2.985	OK!

CONCLUSION

Based on the laboratory experiments conducted, the physical properties and parameters of the soil sample taken from the research slope have been successfully identified. The soil is classified as silty soil (76%) with plenty of clay mixture. Besides that, based on the liquid limit value (LL) and plastic limit value (PL), which were 52% and 33%, respectively, the plasticity index value (PI) was determined to be 19%. Hence, from the plasticity index (PI) and liquid limit (LL) value, the soil sample was further classified as (MH) silty soil with high plasticity; thus, with this parameter, the angular friction value and cohesion property of the soil was further computed, where phi (φ) is finalized as 40° and cohesion, ć as 8 kN/m^2. Apart from that, the moisture content of the soil sample tested was computed to be 40%, hence through which the unit weight, © of the soil sample is calculated as 18.2kN/m^3.

Furthermore, from the software analysis conducted to determine the FOS of the slope during failure using SLOPE/W, the FOS has been identified as 2.965 and 2.985 for both Ordinary and Spencer methods, respectively, which is higher than the minimum allowable FOS by PWD guidelines indicating that even though based on the FOS the slope can be considered safe. Still, it is undergoing spot failure; hence if a structural loading is to be applied to the slope, the slope will undergo massive failure known as sliding. Thus, for the convenient purpose, the FOS value of 2.965 and 2.985 will be used as the threshold value of FOS for this research; any value less than this indicates slope failure, and any value above this indicates that the slope is safe for which the Spencer method of analysis will be more preferable as it is more realistic and accurate as it considers both the force and moment parameter. Then, the FOS after applying slope stabilization work was identified as 4.536 for Ordinary and 4.632 for Spencer for the Changing Geometry work. While, for the Soil Nailing method, the FOS is computed as 3.972 for the Ordinary method and 4.205 for Spencer's method, respectively, using the SLOPE/W software. From both the analysis, the stability of the slope increases, which is vividly visible through the increase in the FOS value from the application of slope stabilization work, making the slope more stable and safer for use and the surrounding activities.

AUTHOR BIOGRAPHY

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