

Slope stability analysis of granitic residual soil in UPNM campus using strength reduction method

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Abstract. Geological hazard such as slope failure poses a great threat to human life and properties all around the world. Slope stability analysis is conducted to identify the critical slip surface and the factor of safety of the slope. It may be induced by many factors such as the infiltration of rainwater and surcharge loading including the groundwater movement where all the possible causes may reduce the strength of residual soil that is tremendously influenced by weathering condition. Commonly, the stability analysis is conducted by using the Limit Equilibrium Method (LEM) utilising analysis by using various method of slices. Alongside the innovation of technology and the development of knowledge, the Finite Element Method (FEM) has come to its function as a quick and robust tool for slope analysis. The main objective of this paper is to determine the stability of a slope in Universiti Pertahanan Nasional Malaysia (UPNM) campus based on finite element utilizing strength reduction method (SRM) using Plaxis software. The new slope construction on granitic residual soil in UPNM campus requires a study concerning the stability of slope as high groundwater table in this area had been discovered with spring water that seeps through soil and fractured rock at several locations particular at slope section greater than 45°. From the result, it is observed that the safety factor for slope angle reduced from 2.254 to 1.188 when the inclination angle increased from 15° to 45° respectively by limiting the height up to 10 m at the uphill section. The results of this study had shown that FEM software such as Plaxis can be practically used to accessed stability of existing slope by utilising strength reduction method approach. In comparison, the slope with greater angle of 45° exhibits the least value of safety factor and smaller slip surface compared to that of more gradual slope in this study. This could help us identify the potential failure zone and implement possible remedial measures.

1 Introduction

Slope stability analysis is an essential issue among geotechnical engineers and researchers. It is crucial to conduct slope stability analysis in order to analyse the critical slip surface of a slope and determine the factor of safety for the slope as geo-hazards pose a great threat to human life and properties all around the world where this hazards often happened especially near a slope. There are several factors that affect the stability of slope, including the surcharge loads from building or construction, infiltration of rainfall and surface runoff, groundwater seepage, earthquake, contiguous construction activities, etc. [1]. Slope failure and landslide occurs frequently in Malaysia due to the rainfall event although the terrain consist of only less than 25% of hills and mountains. However, rainfall event is not the only causal factor for landslide to occur in Malaysia but most of the landslide occurs on man-made slope [2].

Preliminary, Universiti Pertahanan Nasional Malaysia (UPNM) Campus located in the Sungai Besi military base. Hilly topography is one of the main geological features of residual soil that can be found around the area formed through a weathering process of granitic rock. Generally, residual soils cover about more than 60% of the Peninsular Malaysia's land area [3]. Predominantly it comprises medium-grained muscovite and occasionally contains tourmaline. According to Ayob [4] it is sourced predominantly from the weathered rock. This granitic rock which is largely consist of sandy silt and

silty sand with traces of gravel deposited during the Quaternary period. Among important geotechnical properties of the soil are specific gravity, particles size, clay contents percentage and shear strength that are primary important to develop a clear vision for new researchers and civil engineering activities [5].

Currently, analysis of slope stability can be categorized into two main methods that are limit equilibrium method (LEM); and finite element method (FEM). The LEM and FEM results usually comparable, but care and engineering judgement is important for assessing proper solution in case they vary by a lot [6]. The slope stability analysis using LEM is the most important methods and has been widely adopted by researchers and engineers throughout the years due to the simplicity approach [7]. Further development and expansion of the campus in UPNM that require exploration of new hillside area are inevitable and it needs of slope safety assessment against any probable failure in near future. Previously, study had been made to assess the stability of existing made-made slope using numerical software utilising LEM [8, 9].

However, it is not the most definite method for analysis since it doesn't consider the internal stress - strain relationship. It also has several disadvantages due to a non-unique definition of factor of safety that cause by the assumptions regarding the force acting between the slice and the shape of the failure plane [10]. Other than that, we do need to assume the critical sliding surface and not suitable for the calculation of the non-homogeneous material and complicated slope [11].

In general, slope stability analysis conducted using FEM method can be employed by utilising strength reduction method (SRM) that can consider the nonlinear constitutive relationship of rock and soil medium. In this method, the slip failure surface can be obtained automatically in which no assumption of the shape of the failure mechanism is needed [12, 13]. This method of strength reduction is made by continuously adjusting the reduction factor in order to obtain the slope safety factor, as this method combines strength reduction theory with elastic-plastic finite element method in the analysis. According to Cheng *et al.* [14], it was found that the results from both LEM and SRM are commonly in good agreement except when internal friction, ϕ' is zero. There are various implementation of analysis utilising numerical software for strength reduction method including using ABAQUS, FLAC and more convenient software such as PLAXIS [15, 16, 11].

2 Background of study

Currently, the hillside area around Bukit Gemilang in UPNM became the main subject of study due to the existence of man-made slopes originally constructed for road infrastructure project. The slope has an approximate maximum height of about 22m and inclination angle as much as 70° at certain section. The existing surrounding slopes has been subjected to a safety concern over possible slope failure after noticeable rock fractures and open cuts found in many locations with nearby ongoing construction project adding more complication to the problem. Previous research conducted by Jelani *et al.* [8] revealed that there is a high groundwater table in this study area approximately 2 to 9 m below the ground surface with spring water is seen seeps through soil and fractured igneous rock. However, other reassessment of slope safety has to be extended to other nearby area as new facilities development and construction over hillsides area is inevitable due to limited area available for further development of hilly topography feature around the campus.

Recent study using LEM had been conducted on a critical slope section employing the SlopeW software by evaluating the Safety Factor (FOS) value and critical slip surface formation to obtain the peak load carrying capacity just ahead of the occurrence of failure [9]. The study showed that the FOS decreased with an increasing surcharge load. Furthermore, by height reduction of 40% slope, it would increase the stability of slope to 44% while the value of FOS increased to 1.03 from initially 0.736 due to reduction of slope height.

On the other hand, FEM has been widely used to conduct the stability analysis of a slope as there are some others disadvantage and limitation of LEM method. Generally, there are two FEM approaches for slope analysis where one approach is to reduce the strength characteristics and the second approach is to increase the load gravity [17]. The factor of safety can be determined, and critical slip surface can be located by using the SRM within FEM analysis where the strength parameter of the soil such as cohesion, c and angle of friction, φ is reduced to bring the slope to a state of limit equilibrium or until the slope fail. Geotechnical engineers have agreed that the FEM is a good tool that it can solve many complicated geotechnical problems [18].

Conveniently, slope stability analysis employing FEM method can be modelled and studied using various finite element platforms including Plaxis software [19, 6, 15]. Using this software, the results of these computer codes are examined for both 2D or 3D cases for a range of element types and geometries and validated against the inbuilt SRM of the geotechnical Finite Element package [20].

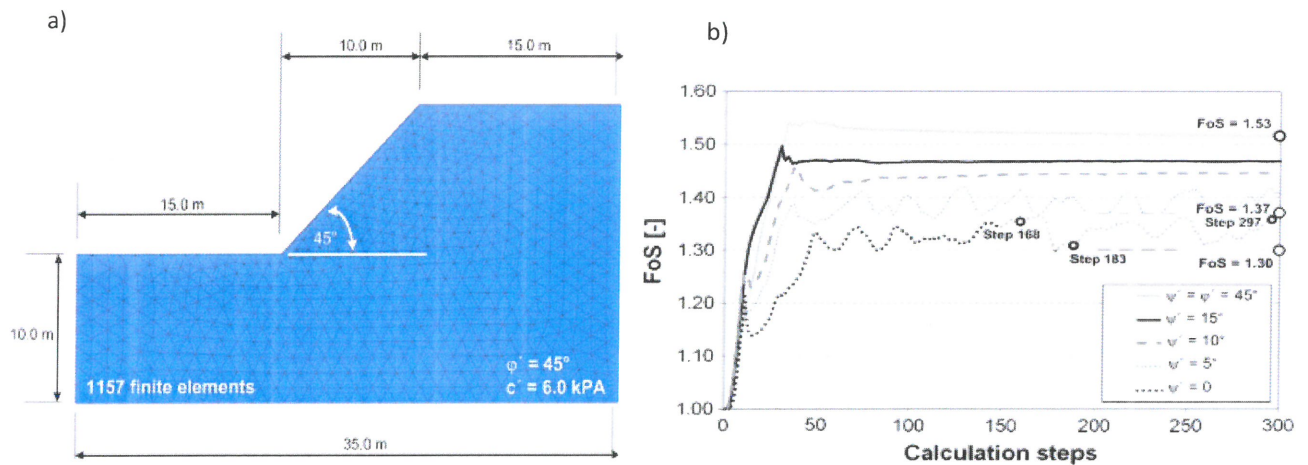


Figure 1. (a) Finite element model, and (b) Factor of safety [21]

Other than that, dilatancy angle also one of the concerns when modelling the slope stability using SRM method. Tschuchnigg *et al.* [21] stressed that in the study of slope stability the issue of non-associated plasticity is not relevant for the angle of friction up to about 35° . In his study, five different values of dilatancy angle is use to investigate the effect of it on the analysis. The boundary of the model and the computed value of the factor of safety is shown as the results in figure 1. However, Cheng *et al.* [14] was found that the choice of the parameters such as dilation angle and soil moduli is usually not critical to be included in the analysis.

3 Research methodology

The study was conducted to determine the effect of imposed load replicating reduction of strength of the slope using numerical model. Since reliability of SRM also can be achieved with the commercial finite element codes found in Plaxis 2D and 3D software [15], stability analysis of the slope has been conducted by taking advantage of its robust numerical modelling embedded in the program. Series of numerical tests were conducted in this study to establish varying critical equilibrium states through which concurrently strength reduction and the safety factor definition were evaluated.

The properties of local soil were preliminary determined, and classification has been made from the result of various laboratory test including sieve analysis, direct shear test, and permeability test. These parameters were used as an input parameter in Plaxis-2D software utilising strength reduction method (SRM) to define the safety factor of the slope. According to Shiferaw [22], decreasing slope angle will increases the factor of safety of slopes while decreasing slope height increases the factor of safety at

different rates. For a particular slope, it is more sensible to decrease the slope angle in this study in order to increase the factor of safety, rather than reducing the slope. In other cases, it is more efficient to decrease the height to improve the safety factor, but it was not covered in the study.

In this study, Mohr-Coulomb constitutive model has been used to conduct the numerical analysis. A model of one slope section of 10 m high identified on site have been chosen as a study case that found to have severe indication of deterioration due to several markings appear on slope surface that would likely triggered slope failure occurrence in near future. Thus, the boundary condition of slope has been modelled of having a height limited to 10 m, a base of 5 m, and a slope angle varied from 15°, 30°, and 45°. Figure 2 shows geometrical model that includes meshes, points and nodes for slope with 30° angle modelled and generated for this study. The model of slope was then subjected to a uniformly distributed surcharge load of 50 kN/m and width of 6 m. However, the influence of ground water fluctuation and runoff water was not considered in this study.

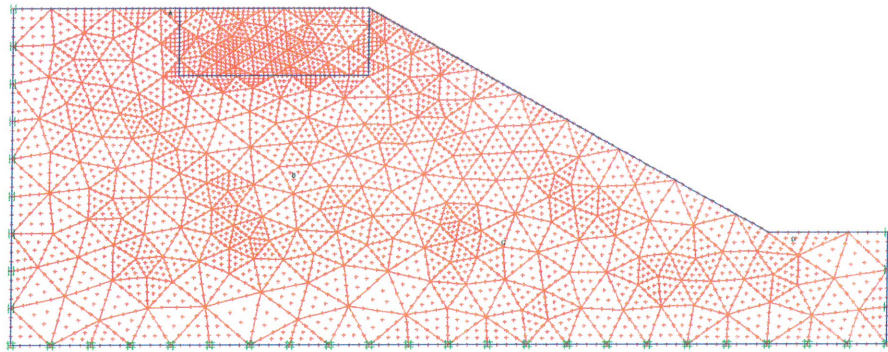


Figure 2. Finite element model of slope with 30° angle showing nodes, point and meshes.

The total multiplier function ($\sum M_{sf}$) in Plaxis is defined as the ratio of the input values of the strength parameters over the reduced strength parameter as depicted in Eq. 1. Before calculation start, the $\sum M_{sf}$ is set to 1 to set all material strength to their unreduced values and the strength parameter of the soil are thereby reduced automatically step by step with an incremental value until fail [23].

$$\sum M_{sf} = \frac{\tan \varphi_{input}}{\tan \varphi_{reduced}} = \frac{C_{input}}{C_{reduced}} \quad (1)$$

Prior to the numerical modelling and simulation, material parameters were obtained from series of laboratory test. Index properties test such as sieve analysis test for soil classification and sampling procedure were carried out according to BS 1377 Part 2: 1990. The soil was classified in accordance with the BS 5930:1981 criteria. For direct shear test, a loading of 1 kg, 2 kg, and 4 kg were used and sheared to fail with a shear displacement rate of 40 mm/hr in accordance with BS1377 – Part 7. The permeability test was carried out using falling head test according to BS 1377: part 5.

4 Results

4.1 Index properties

According to BS 5930:1981, the soil tested in this study is classified as slightly silty or clayey sand, since the percent finer of the soil which is less than 0.063 mm is 3.8%. The sand is well graded hence having a group symbol between S and G which is called well-graded gravelly sand. Figure 3 shows the grain size distribution curve of the soil.

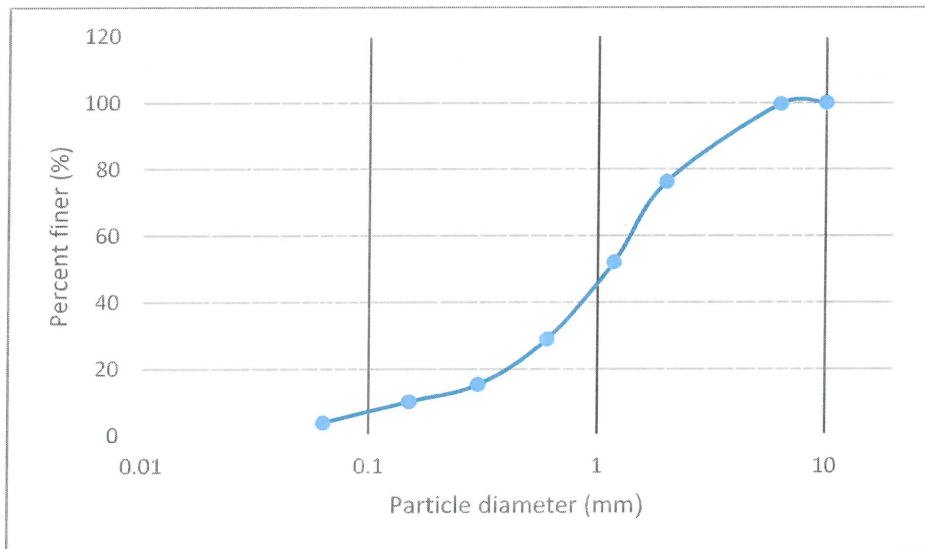


Figure 3. Grain size distribution curve

For determination of shear strength properties, three samples of the soil were used and tested under direct shear test using a different loading of 1 kg, 2 kg, and 4 kg respectively. From the test that have been conducted, the peak shear stress for the loading of 1 kg, 2 kg and 4 kg are 51.39 kN/m², 56.67 kN/m², and 103.61 kN/m² respectively. The maximum value of shear stress was used to plot the shear vs normal stress. From the shear failure envelope plotted as shown in Figure 4, the resultant cohesion and angle of friction are 27.9 kN/m² and 16°, respectively.

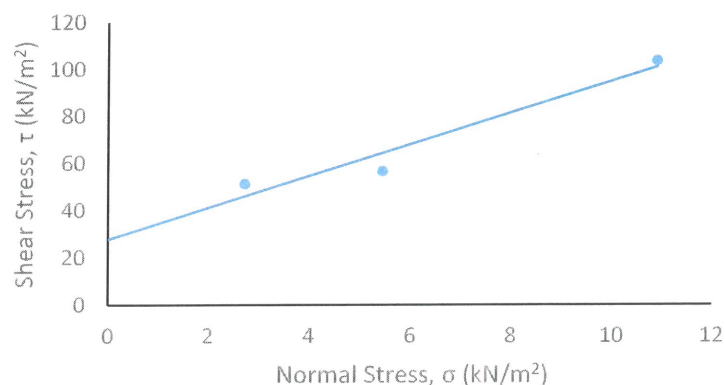


Figure 4. Shear failure envelope

The data for the falling head test was recorded for four sets where the initial head, h_1 and final head, h_2 are kept constant having a value of 130 cm and 90 cm respectively. The average permeability value for

the four sets of samples that is obtained is $1.9894 \times 10^{-4} \text{ ms}^{-1}$. From the conducted laboratory test, the summary of the result obtained for index properties of soil are tabulated in the following table 1.

Table 1 Summary of soil properties

Soil group and subgroup	S - SPu/SPg
Unit weight, γ	19.22 kN/m ³
Moisture content	20.34%
Angle of friction, ϕ	16°
Cohesion, c	27.9 kN/m ²
Permeability, k	$1.9894 \times 10^{-4} \text{ ms}^{-1}$
Liquid Limit	16.0 – 24.85%
Plasticity Index	4.31 – 10.31

4.2 Numerical analysis and safety factor

The index soil properties and shear strength parameters of the soil from preliminary test were used as input parameters for soil model whereas the dilatancy angle is assumed to be the same as friction angle as the analysis will be based on associated plasticity. This was carried out so that there were no irregularities in the factor of safety during the computation of phi-c reduction phase during simulation.

As a result, the factor of safety that was obtained for the slope angle of 45° is 1.188. During the computation of phi-c reduction, the displacement of the slope decreased from 0.08 m to 0.041 m and started to rise back and achieved the maximum displacement of 0.226 m when the slope failed. The failure mechanism of soil likely exhibited dense granular soil or over consolidated clay properties as the mobilization of strength achieved its peak rapidly due to the steeper slope angle of 45°. Figure 5 shows the factor of safety against displacement curve for slope inclined at 45° to the horizontal.

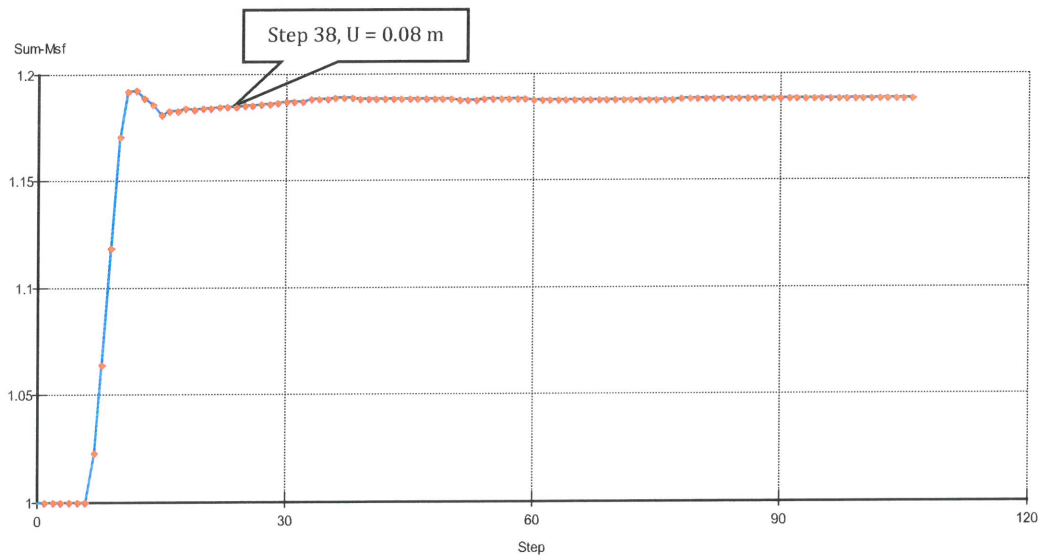


Figure 5. Factor of safety against displacement (45°)

For the slope with 30° inclination angle, the factor of safety obtained is 1.498 as depicted in the following figure 6 that shows the factor of safety against displacement curve. The figure shows that the displacement of slope started to decrease during the phi-c reduction phase at 23rd step with displacement of 0.062m and continued to drop to 0.044 m where the slope failure occurred.

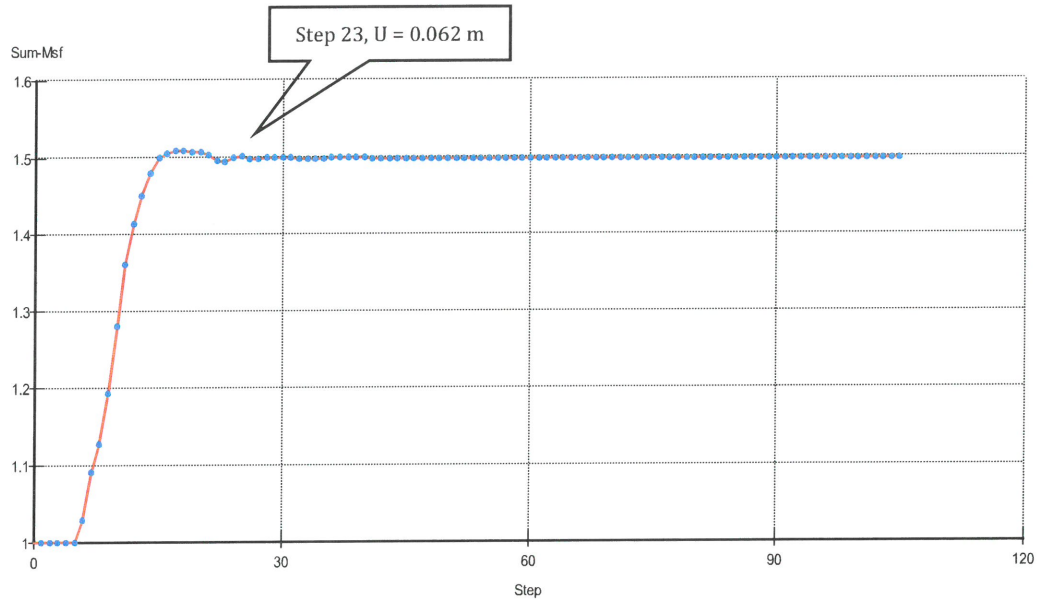


Figure 6. Factor of safety against displacement (30°)

The safety factor for the slope with inclination angle of 15° is slightly higher than the slope with 30°, and 45° angle which is 2.254 (figure 7). Since the angle of slope moderately smaller than the others, it shows an easing curve profile that exhibits higher score of safety factor. It replicates the maximum strength of loose sand or normally consolidated clay properties that gradually gains its strength as mobilisation of soil strength achieved its peak with lower displacement recorded. The displacement of the slope decreased during the phi-c reduction phase and started to increase at the 25th step with the displacement is at 0.032 m. The maximum displacement of the slope is recorded at 0.152 m.

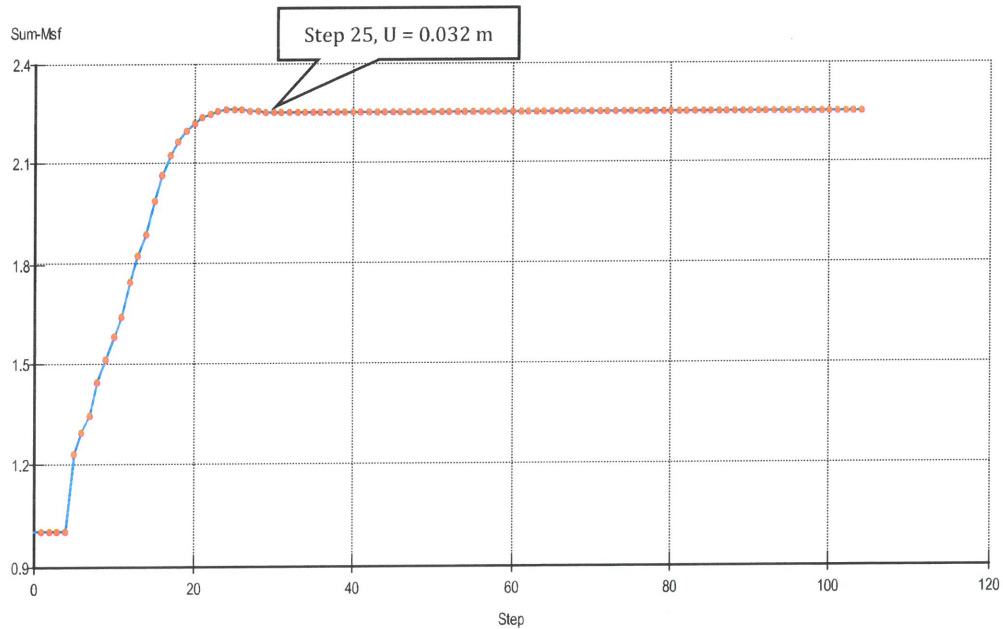


Figure 7. Factor of safety against displacement (15°)

From the results, it is obvious that steeper slopes exhibit lower factor of safety with greater displacement recorded. Overall, the slip surface yield on the slope with inclination angle of 45° is smaller than the slip

surface yield on the slopes with inclination angle of 30° and 15°. The slip surface for 45° ends on the toe which is known as toe failure whereas for the 15° slope, the slip surface passed through the toe of the slope that known to be as base failure. The factor of safety for 45°, 30°, and 15° are 1.188, 1.498, and 2.254 respectively. Figure 8 represents the critical slip surface of the slope for inclination angle of 30° that slightly passed through the toe.

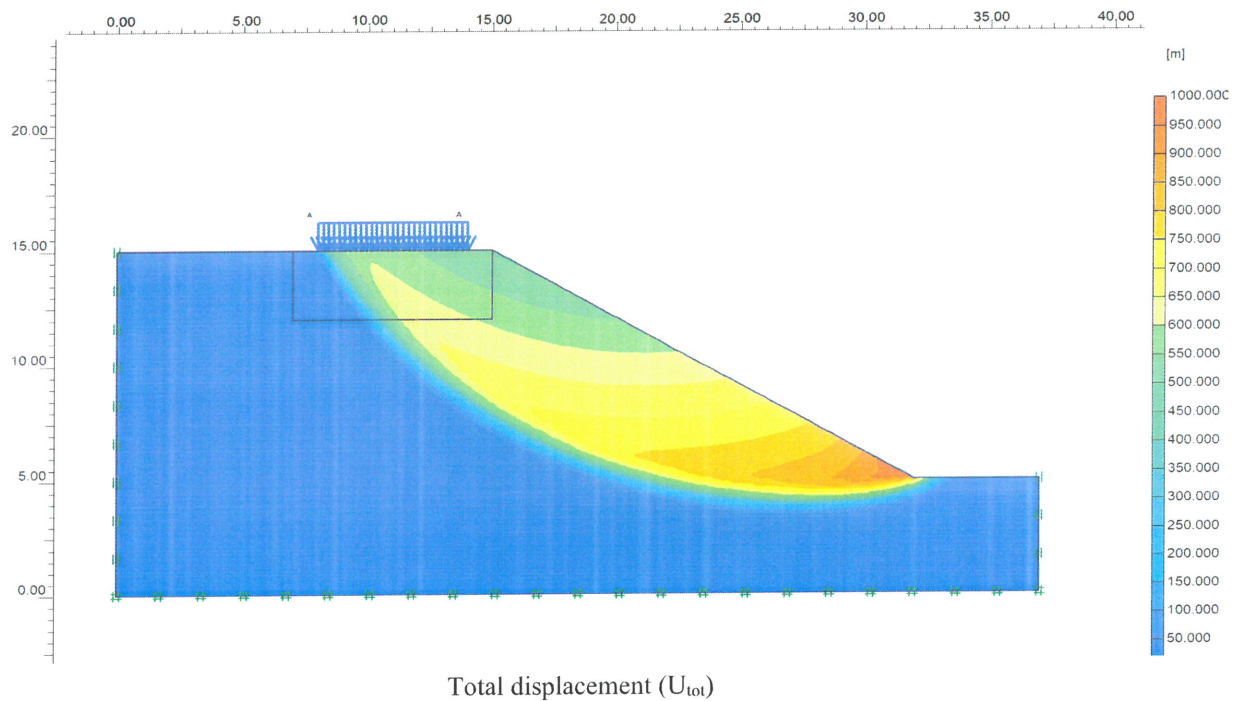


Figure 8: Critical slip surface of slope angle 30°

5 Conclusions

As for conclusion, the laboratory test provided a reliable data for the soil properties such as the shear strength parameter, the particle size distribution, and the permeability of the soil. The unit weight, moisture content and other essential parameters were also calculated by using the data obtained from the standard laboratory test. Thus, one of the objectives of the study is achieved for determination of input parameter for material modelling of the soil to further support numerical modelling of the slope using FEM method utilising SRM approach.

From the numerical analysis, it can be concluded that the factor of safety for the local soil tested in this study is low when the inclination angle of the slope is higher. It is in a good agreement with previous findings by other researchers that angle of the slope could be conveniently manipulated to analyse the safety factor of the slope. Other than that, the assumption on the dilation angle in the study is recommended if the properties cannot be analysed from laboratory test. Assumption must be based on the associated plasticity which mean that the dilation angle is assumed to have a same value as the friction angle since this value is decrease incrementally in the same way as friction angle during the strength reduction calculation phase. This will reduce the inconsistency of the computed factor of safety in this phase as experienced during the simulation work.

As the factor of safety is higher when the slope angle is smaller, it is safe to say that any new embankment construction at the location of the study should have slope angle not more than 30°. It will ensure that the slope could maintain in a good order with high safety factor for the longer run of stability. It is also in agreement with previous research findings by others that proposed to maintain more tolerable angle of slope in order to maintain the integrity of the slope stability in the surrounding campus area.

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