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Research paper

Analysis of Slope Stability with Wire Mesh and Nailing as Slope Protection System Using Finite Element Method (PLAXIS)

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Abstract

This study is based on the slopes at Ulu Jelai Ringlet, Pahang. The slope stability assessment is carried out by using finite element modeling with the approach of PLAXIS software with activation of slope protection system application to a cut slope. From the analysis, it is found that the factor safety of the slope is 1.395, less stable and lower than the allowable FOS which is 1.50. Stabilization methods, wire mesh nailed to slope are proposed to improve the slope stability. The assessment results by the software with the application of stabilization methods proposed showed an increase in the value of factor of safety and decrease in soil displacement. The slope with 60˚ inclination of cut slope with activation of wire mesh and soil nail obtained an overall factor of safety 2.831 satisfied the highest minimum requirement for both risk of life and economic risk. The reinforcement reduced displacements of the soil surface, increased the slope stability. The tension in the mesh is concentrated in the point where the mesh is nailed to the slope. The axial force is higher in the nailed points situated in the lower point of the slope. Total displacement occur more in soil 1 (soft clay) due to the stiffness of soil. The effect of the nailed mesh makes it possible to reach higher slope height without failure, than if the construction is done without reinforcement. This proved that the proposed stabilization methods can be implemented to improve the slope stability. Some remedial and maintenance works were recommended to improve the slope stability.

Keywords: *slope stability, finite element modeling (FEM), factor of safety (FoS), wire mesh*

1. Introduction

Slope is a topography condition often found in various civil construction works[1]. The slope can occur naturally or deliberately made by humans on a particular purpose[2][3]. There are several factors that contribute to the instability of the slope occurred in natural or artificial slope gradually or suddenly with or without early symptom such as changes in stress conditions and increment in groundwater table which caused by rainfall[4][5]. Furthermore, changes in geometry, external forces and loss of shear strength will led to slope instability[6][7].

Slope stability analysis is conducted to determine the safety factors with calculating the shear strength to maintain the stability of the slope[7][8]. In general, there are two stage of slope stability analysis. Stage one is to calculate the factor of safety for specific serface and second is to calculate the critical surface that will be in associated with the lowers foactor of safety[3]. Therefore, the analysis of slope stability is very important in planning civil construction; design of slope in the construction of highways, tunnels, railroads, quarries and mines[2][9]. Unstable slope is dangerous to society, property and the environment[10]. The slopes at risk of landslides must be solved with an appropriate slope reinforcement methods and take into consideration of the costs and effectiveness in stabilizing slopes[11].

Application of flexible steel mesh facing covering the slope is one of the most popular and effective approach to achieving long-term slope stabilization[12]. The high resistance mesh advantage is combination of traditional rock/soil nailing with tensioned act as an active slope stabilization, providing stability in the surface layer[12].

Generally, this study aims to analyse the slope stability by using finite element method. Specifically, the objectives of this matter are to compute the factor of safety of man-made and natural slopes by using finite element methods, to examine the performance of wire mesh nailed to slope systems for slope stability protection and to simulate the behaviour of wire mesh and nailing constructed on different type of soil using the finite element program PLAXIS.

The study area is located in Ulu Jelai, Pahang. The area is situated on the hilly terrain. A slope is formed due to the movement of roots of trees at the slope areas. Site investigation and soil sample are collected from area of study. The study also focuses on the repair work and stabilization method to enhance the stability of slope.

2. Literature review

Ground movement on slopes can take place through the movement of soil, shear failure at the surface geology and on soil occur in horizontal and small movements off grid, known as creep[13]. This movement can occur simultaneously or separately. This failure usually happens slowly on the base of the slope and involving depreciation soil strength and influenced by climatic factors[14][2].

This condition can be prevented if the force (driving force) does not exceed resistance force shear strength comes from the field of landslides as shown in Figure 1. The driving factors for failure especially those that are reducing the slope of shear resistance on the slopes, such as rainfall and increasing groundwater levels. Slope failures and debris flow occurs when the force to move the mass of soil becomes larger than the shear resistance.

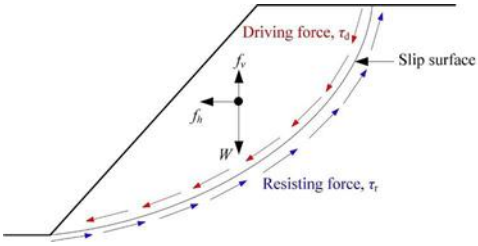

Figure 1: Forces on cross-section of a slope in two-dimensional analyses [15].

In these systems of meshes of high strength steel wire nailed to the face of slope used to prevent instabilities and act as active slope stabilization where the mesh develops some curvature under deformation, so that, it exerts a normal pressure to the slope face[12]. Figure 2 show a tension state in the mesh, and a compression state in the soil. Higher the soil strength is, the smaller are the tension in the mesh and its deformations. These are the states produce on the soil and the mesh.

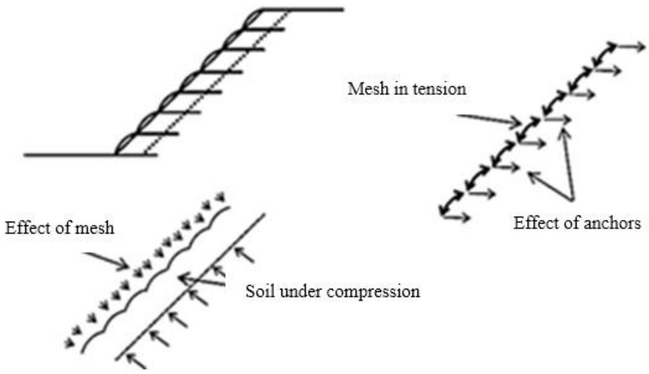

Figure 2: States produce on the soil and the mesh [16].

Table 1: Soil parameters input for Plaxis software

Type of Soil	Soil behaviour	γ_{unsat} (KN/m^3)	γ_{sat} (KN/m^3)	E_{ref} (KN/m^2)	Poisson's ratio, υ	C_{ref} (KN/m^2)	φ (º)
1.Soft clay	Undrained	16.0	16.0	1.000E+04	0.3	30	24
2.Stiff clay	Undrained	16.5	16.5	1.000E+04	0.3	38	26
3. Med stiff clay	Undrained	18.0	18.0	1.000E+04	0.3	16	31
4. Stiff silty clay	Undrained	18.5	18.5	1.000E+04	0.3	18	33
5. Very stiff silty clay	Undrained	19.0	19.0	1.000E+04	0.3	20	34
6. Rock	Drained	20.0	20.0	2.000E+04	0.499	50	36

3. Methodology

This research gives some details on the methodology applied in the study including the study area, a data collection, fieldworks study and laboratory testing and numerical simulation study. It followed by a numerical modelling PLAXIS to shows the results of slope characteristics and details parameters slope hazard. In order to achieve the objectives of the research, proper planning of methodology in the study is important.

This research focused on the finite element method in analysing slope stability and selection criteria in order to choose the most suitable method in designing a slope. This research is done to obtain the Factor of Safety from finite element method analysis by PLAXIS simulation for slope modelling.

The Mohr-Coulomb (MC) material model was used to simulate 6 type of soil including rock as shown in Table 1. The MC model has a fixed yield surface and the yield surface is not affected by plastic straining. For MC-type yield functions, the theory of associated plasticity overestimates the dilatancy. Therefore, in addition to the yield function, a plastic potential function is introduced. The elastic plastic MC model involves 6 basic input parameters: soil unit weight (γ_{unsat}), Saturated soil unit weight (γ_{sat}), elasticity modulus (E_{ref}), Poisson's ratio (v), cohesion (C_{ref}), and friction angle (φ)..

In the investigation, slope were designed by using the data gained from site investigation such as total height of the slope, width of slope, the soil parameters for the soil, soil nail parameters and wire mesh parameters to determine the actual factor of safety, shear strength and stresses at soil nail and wire mesh.

From site investigation, height of slope is determined and layers of soil with soil properties were obtained from SI report by IKRAM geotechnical lab. Based on case study investigation, an original slope including ground water table were created. Then, cut slope with depth 5m and 60° inclination. After cut slope, wire mesh as facing with soil nailing plate were applied. The cutting of slope will be carried out in four stages. Cut 1 will refer to the highest slope and will go down to Cut 4 at lower slope. The parameters for the soil nail with an inclination of 30° and 8 metre length. Nail 1 is refer to soil nail at Cut 1, Nail 2 refer to Cut 2, Nail 3 refer to Cut 3 and Nail 4 at Cut 4 as shown in Figure 3. Acceptance criteria for selection of combined parameters based on FoS (Design) = 1.5, Bond Resistance 20-30 kN/m and Safety Factor by Public Works Department, Malaysia (JKR) >1.5.

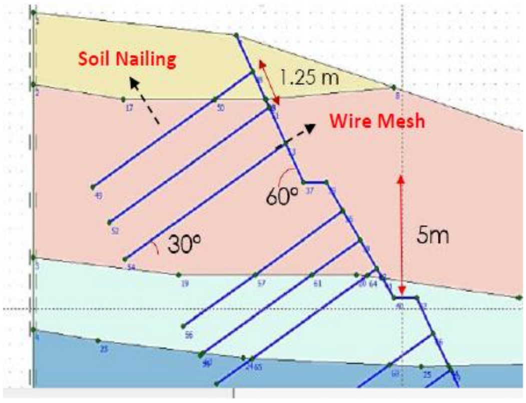

Figure 3: Input of nailing in Plaxis

These are the wire mesh and soil nailing input properties as list in Table 2 and Table 3;

Table 2: General structure of reinforcement's Wire Mesh and Nailing

Wire Mesh Facing Thickness, t	200 mm
Dia. Drill hole, D_{dh}	100 Mm
Dia. Reinforcement, d	20 mm
Modulus of elasticity of grout material, Eg	22 Gpa
Modulus of elasticity of nails, En	200 Gpa
Length of nails, L	8 metre
Nails Inclination, °	30 degree
Spacing, S_h x S_v	1.25m x 1.25 m

Table 3: Plaxis input properties

Parameters	Wire Mesh	Soil Nailing
EA (Axial Stiffness)	2.250E+09 KN/m	2.290+05 KN/m
EI (Bending Stiffness)	1.050E+06 KNm^2/m	142.99 KNm^2/m

4. Results and conclusion

The result obtained from the 'output' from PLAXIS. The factor of safety of the original slope is 1.395 increased to 2.831, the highest factor of safety obtained after an activation of slope reinforcement.

4.1. Factor of safety

The value for factor of safety of slopes with 60 o is obtained for each nail with facing's wire mesh and shown in Table 4 and Figure 4 for each level of slope cutting. The factor of safety been increased to 2.83 with an activation of wire mesh and nailing as shown in Table 5.

Table 4: Factor of safety for 60˚ degree of slope and bar chart of the result

Stage	F.O.S
Original	1.395
Cut 1	1.912
Nail 1	1.992
Cut 2	2.237
Nail 2	2.275
Cut 3	2.443
Nail 3	2.831
Cut 4	2.242
Nail 4	2.343

Table 5: Result for slope 60º with an activation of wire mesh and nailing

lope 60°	**Factor of safety**	
Method	With ground water table	Remark
Finite Equilibrium Methods	2.83	> 1.4 (Adequate) > 1.5 by JKR

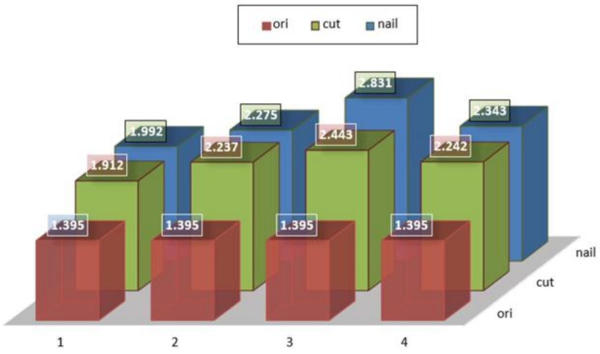

Figure 4: Bar chart of F.O.S the result

4.2. Total displacement

Mass movement of surface material influenced by gravity. Water aids in the downslope movement of surface material in several ways. This decreases the resistance of the material to movement. If the angle is overly steep, gravity will pull the material downward, causing a higher total displacement. Result shown in Table 6 are the total displacement for original slope is higher than the 60° cut slope inclination with wire mesh and nailing.

Table 6: Total displacement

Type of slope	Total displacement	Total incremental
Original slope	10.01 X 10^{-3} m	624.20 m.
Slope 60 with nailing and wire mesh	50.56 X 10^{-3} m	92.72 X 10^{-6} m.

4.3. Axial force of soil nailing

Result for extreme axial force for the soil nailing with facing's wire mesh for 60˚ cut slope, the extreme axial force for wire mesh is 28.26 KN/m and the highest the extreme axial force for soil nailing is 44.08 KN/m located at soil nail 1.
Slope failure will occurred when shear stress exceeds the shear strength. Therefore, factor that leads to decrease the shear strength will have a big chance to failure the slope. Plate's Wire mesh and soil nail is the factor that cause shear strength to decrease. The critical extreme shear stress that acting on the plate were occurred at the face of plate itself. For every plate the critical part will be at the face where the slip curve occurred. The extreme shear force for wire mesh is 47.87 KN/m and for the nailing is -8.05 KN/m located at Cut 1 as shown in Table 7.

Table 7: Extreme Axial Force and Shear Force for wire mesh and soil nailing

Type of Plate	Wire Mesh	Soil Nailing
Extreme Axial Force	28.26 KN/m	44.08 KN/m
Extreme Shear Force	47.87 KN/m	-8.05 KN/m.

5. Conclusion

Finite element methods bring the best analysis for factor of safety in these research slopes. The factor of safety is the key of slope stabilization to sustain the load from the soil or movement of force towards the slope. The slope with 60˚ degree cut slope with wire mesh and soil nail with an overall factor of safety 2.831. The soil nail that were used maintained 8 metre length and same properties from start until last calculation and penetrate 2m deep into rock layer. Factor of safety obtained satisfied the highest minimum requirement for both risk of life and economic risk satisfied the Geotechnical manual from JKR Geotechnical office which is more than 1.5.

The factor of safety increased from 1.395 to 2.831 with the wire mesh nailed to slope makes it possible to reach higher slope safety factor without failure, than if the construction is done without reinforcement. The reinforcement will reduce the displacements of the soil surface, increasing the slope stability. The axial force in the mesh is concentrated in the point where the mesh is nailed at the highest axial force where the nailed points situated in the lower point of the slope. Total displacement occur more in soil 1 (soft clay) due to the stiffness of soil.

Based on result of research, to obtain more accurate result and graph curvature can be determined with 3-Dimensional PLAXIS. Multiples of cut slope degree inclination need to be done and application of reinforcement specification such as the length of nailing and the strength of plate used should be variety depends on area of were most displacement occur for more accurate conclusion.

Generally the growth of vegetation on an actively eroding soil slope is desirable to reduce erosion. Thus, some management of vegetation growth through the mesh may be required to ensure long-term performance of the system. For most slope conditions, the recommended design methodology presented above should result in an installation requiring minimal maintenance over the design life of the system and it is very important to study and understanding of slope stability analysis by followed the guidelines of slope design in proper with satisfying the requirement to prevent slope instability.

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