

Effect of Soil Nail on Stability of Slope

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DOI: <https://doi.org/10.30880/rtcebe.2023.04.03.022>

Received 06 January 2022; Accepted 15 May 2023; Available online 31 December 2023

Abstract: The behavior of the soil and the characteristics is important before developing any construction of structures. All the information data collections are to ensure that no errors happen during construction and to provide an efficient economic solution. Soil conditions with high water content tend to lead slope failure compare to slope with less water content. The rainfall infiltration changed the soil condition as well as reduced the stability of the slope. The uses of soil nailing are chosen because it increases the stability and is critical in enabling the slopes to take increased loads. It is used due to its characteristic to withstand the shear strength and slope based on the soil condition. By doing this study, the pore water pressure can be determine and achieved the slope stability. The rainfall infiltration changed the soil condition as well as reduced the stability of the support system. The support system is used in the PLAXIS LE software to observe the slope factor of safety value. case study at Putrajaya, Kuala Lumpur is conducted for model verification. In this study, the analysis of soil nailing is conducted in the parametric study by using Finite Element software. The function of PLAXIS LE is to determine the effect of rainfall on the deformation of the slope with the input of soil nails. Plus, the stability of the slope can achieve by obtaining the higher factor of safety with the installation of the soil nails.

Keywords: Viable, Shear Strength, PLAXIS LE

1. Introduction

Current slope soil failures in Malaysia are attributed to a variety of variables, although rainfall is the main cause of slope failures in tropical countries. The presence of rainfall affected the matric suction of the soil. Negative pore pressure exists in this area, mainly in Malaysia, above the groundwater table. Climate and hydrological variations such as precipitation, infiltration, evaporation, and transpiration have a strong influence on these residual soils [1].

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Water infiltrates the slope during and after a rainstorm event, with a portion of the rainwater converting to surface runoff [2]. This resulted in alterations to the soil structure, since the cohesive strength of the soil particles reduced as the matric suction dropped. This occurrence will have an effect on the soil instability of a slope. As mentioned before, a decrease in the soil slope factor of safety is caused by an increase in the rate of infiltration [3]. Due to the strong non-linearity of soil water characteristics and soil permeability, the event of rainwater infiltration is complicated. This is supported by the fact that the complexity of the rainwater infiltration process is linked on the soil's basic moisture state, water retaining capacity, porosity, and evaporation rate, among other factors. Thus, in order to comprehend the properties of the soil under varying rainfall intensity and duration, it is essential to investigate the infiltration processes.

The aim of this research is to study the effect of the rainfall infiltration on the slope stability with and without the input of soil nails. Using PLAXIS LE software, the slope stability against the rainfall infiltration can be model by analyze the rainfall distribution and the soils properties PLAXIS LE may be used to design and analyze slope stability, groundwater flow, consolidation, and a variety of other unforeseen circumstances. To discover answers, use computerized strategies, information management, investigation work methods, and admission to extensive testing approaches. There are several benefits to adopting this software, including increased efficiency in design, cost savings on construction, compliance with design standards, and reduced risk to project timetables [4]. For engineering works, Finite Element method can be used for groundwater module and the slope stability can be determine by Limit Equilibrium.

2. Properties of PLAXIS LE

The research was performed using the finite-element modelling package PLAXIS LE, which includes fully linked flow deformation. In relation to unsaturated situations, the shear strength of soil was determined using the Mohr-Coulomb failure criteria and the bishop's effective stress ideas given in equation 1[5]. GLE Fredlund was utilized as the hydrological process to model transient flow over unsaturated soil. The total of the flow rate fluctuations at equilibrium is similar to the head rate changes with respect to time at equilibrium.

$$\tau = c' + (\sigma n - ua) \tan\phi + X (ua - uw) \tan\phi \tag{1}$$

is Shear strength of unsaturated soil; n is the total normal stress; ua and uw are the pore air and pore water pressures, respectively; ua = net normal stress; ua-uw = matric suction; c' = effective cohesion; φ = internal soil friction angle; and X is the scalar multiplier[6]. Permeability is shown in unsaturated zones by the soil water characteristics curve (SWCCs). SWCC is the abbreviation for the relationship between pressure head and moisture content. SWCC and the permeability function are explained by Fredlund and Xing Fit, respectively. Equation (2) illustrates the Fredlund and Xing Fit models.

$$f(\Psi) = \frac{m_f \cdot n_f \cdot \left(\frac{\Psi}{a}\right)^{n_f - 1}}{a_r \left[e + \left(\frac{\Psi}{a}\right)^{n_f} \right] \cdot \left\{ \log \left[e + \left(\frac{\Psi}{a}\right)^{n_f} \right] \right\}^{m_f + 1}} \tag{2}$$

With r equal to the suction equal to the residual water content. The model parameters r, ar, nf, and mf are as follows.

As for the Soil Water Characteristics Curve (SWCC), it is commonly used term that refers to the connection between matric suction and moisture content. It is used to ascertain the hydraulic and mechanical properties of unsaturated soils as well as to forecast soil water storage. Direct measuring is time expensive and complicated [7]. There have been several empirical models created to describe SWCC. This study's purpose is to validate the Fredlund and Xing model. SWCC values were

determined using PLAXIS LE Hong Kong tutorials at Presint 9, Putrajaya, Kuala Lumpur, Malaysia. Moisture content and degree of saturation are shown against matric suction. The SWCCs were fitted using the Fredlund and Xing equation.

3. Methods and Materials.

In a manner consistent with the study's aims, there were two models conducted, first on groundwater and another on slope stability. Both modules are modelled in the PLAXIS LE programme for the purpose of obtaining results.

3.1 Groundwater module

First method involving the input of the soil coordinate. There are 3 types of soil that involve which are silt, gravely silt and bedrock. The soils coordinate, soils properties and initial water table are based from previous study [2]. The rainfall data are taken from Malaysian Meteorological Department and the period of rainfall distribution is for 3 days starting from 1st March to 3rd March 2021 around the study area. Figure 1 show the slope illustration that have been modelled using PLAXIS LE. Next, is to determine the materials manager of the slope model. For the SWCC data, Fredlund and Xing method is used for the calculation method to obtain the parameters af , nf , mf and hr . While Kunsat method for the slope modelling is using Modified Campbell Estimation. For the boundary conditions, it is divided into 2 phase which are rainfall and head constant. the boundary of the conditions is selected by coordinate through the slope model. The process of the boundary conditions is shown in Figure 2. Finally, the finite element mesh is created by generating the mesh of the slope model to obtain the output of the ground water pore pressure.

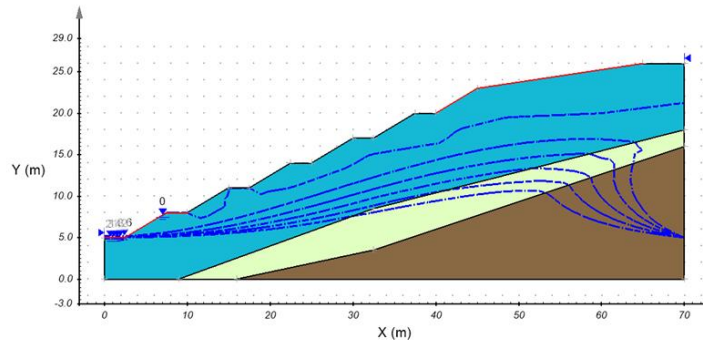


Figure 1: Slope illustration

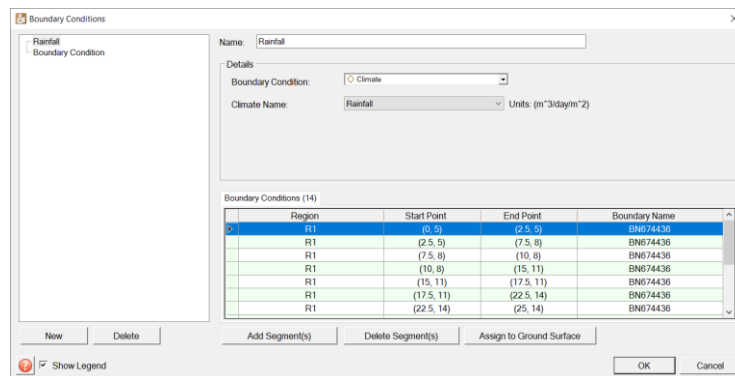


Figure 2: Boundary conditions

3.2 Slope stability module

Slope stability module is created after the mesh process in the groundwater module. The calculation process for the slope stability module is by (GLE) Fredlund. The soil properties are model based on previous study at Putrajaya Presint [2]. For the soil constitutive model are using Mohr-Coulomb. For the slope stability, soil parameters such as unit weight, cohesion, friction angle and hydraulic conductivity are necessary for data input in the PLAXIS LE. For this model, silt and gravely silt are included in unsaturated soil, while bedrock is in saturated condition. Table 1 show the soil properties used in the PLAXIS LE slope stability modelling. Next, entry and exit method is use for the slope stability search method. The entry and exit is to determine the factor of safety due to the circular of the slope to obtain the factor of safety. The coordinate is set between the entry range and exit range with increment of 4 and radius increment of 7. The entry and exit method is shown in Figure 3 Then, soil nails are used as a support for the slope model to achieve the densification of the soil as shown in Figure 3[8]. The soil nails properties and the SWCC results are obtain from the PLAXIS LE Hong Kong tutorial. Lastly, the slope module is then going an analyze process to obtain the factor of safety and suction output.

Table 1: Soil properties

Soils	silt	Gravely silt
Soil Constitutive Model		Mohr-Coulomb
Unit weight (kN/m^3)	18.67	17.79
Cohesion (kPa)	14	36
Friction angle($^\circ$)	23	18
Hydraulics conductivity (m/s)	1.17×10^{-10}	2.42×10^{-10}

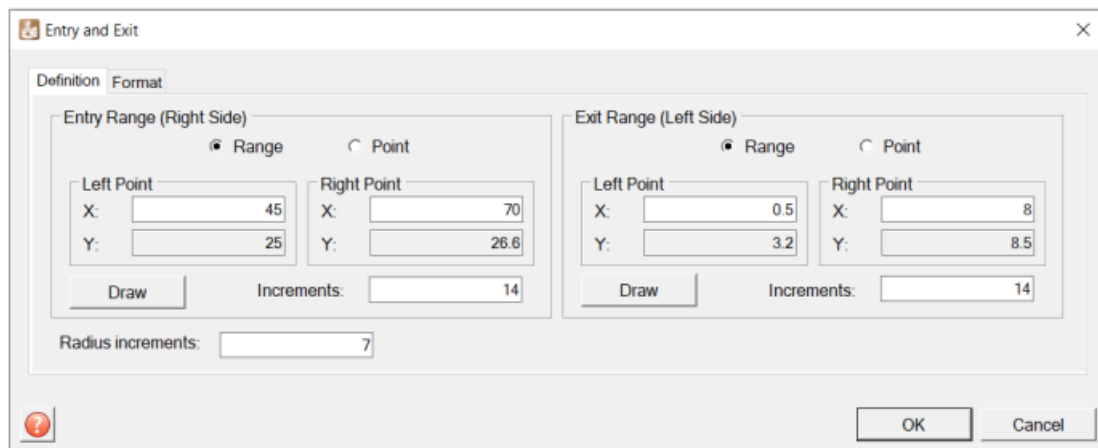


Figure 3: Entry and exit range

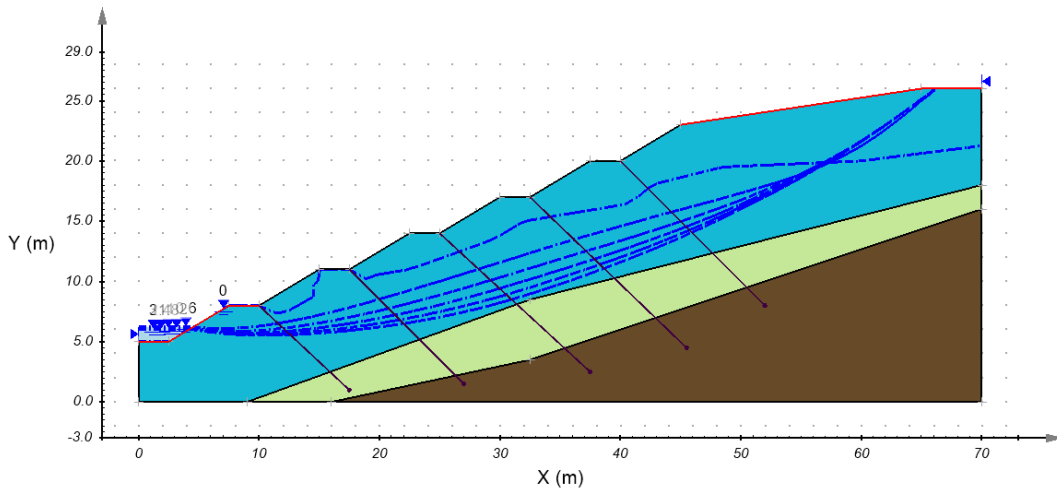


Figure 4: Soil nails as a support system

4. Results and Discussion

The outcome and analysis of this study's slope stability investigation focused on the factors of safety and soil suction on the model slope. The PLAXIS LE programme results are recorded in table forms and displayed on a graph.

4.1 Pore-water pressure

The results of the pore-water result were compared between the effect of rainfall infiltration on the slope stability with or without the input of soil nail. The properties of the soil are same while the support system react as variables. Pore-water pressure refers to the pressure that water trapped in voids in a wet soil mass face. This happens as a result of the soil's position or external influences. The location of the groundwater table and seepage caused by flow-through also has an effect on the pore water pressure. The comparison between the presence of rainfall is shown in Figure 5 and Figure 6.

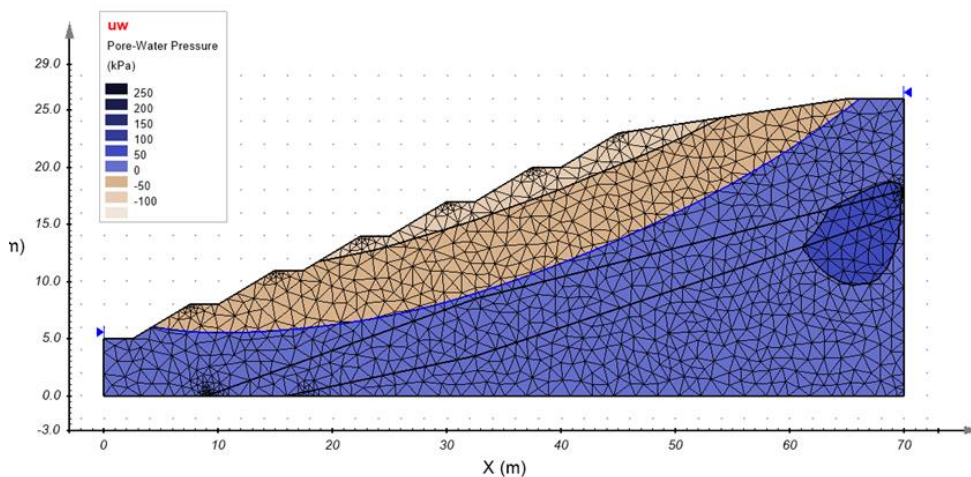


Figure 5: Pore-water pressure with rainfall

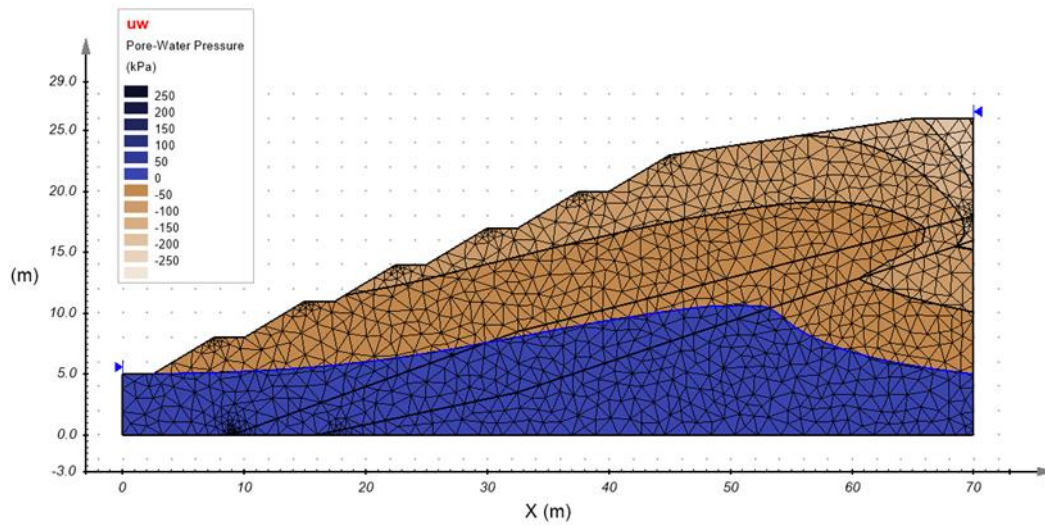


Figure 6: Pore-water pressure without rainfall

4.2 Factor of safety

The results of the groundwater pressure are then transfer to the slope stability module to obtain the factor of safety results. The value factor of safety is to determine the stability of the slope with a minimum value of 1.00. Otherwise, slopes with a low value of 1.00 have a dangerous possibility for a long period of time. The factor of safety from the slope model have been recorded within 3 days to compare the stability of the slope shown in Table 2. Slope with the input of soil nail has a high safety factor value that drives more durability compared to slope which does not have soil nail installation. It is because the soil nail able to helps the slopes stability due to its high strength characteristics. The results that obtain is then plotted in graph chart with the relationship factor of safety against day. The comparison of the graph is shown in Figure 6 and 7. From the Figures, the differences of the safety of factor have a slightly differences because the short duration of the rainfall.

Table 2: Differences factor of safety for 3 days

Days	Soil nail	Without soil nails
1	2.389	2.197
2	2.404	2.275
3	2.410	2.304

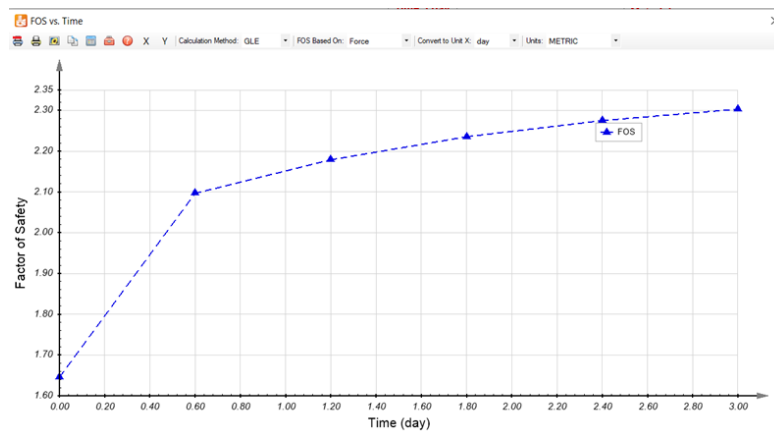


Figure 6: FOS against day without soil nail

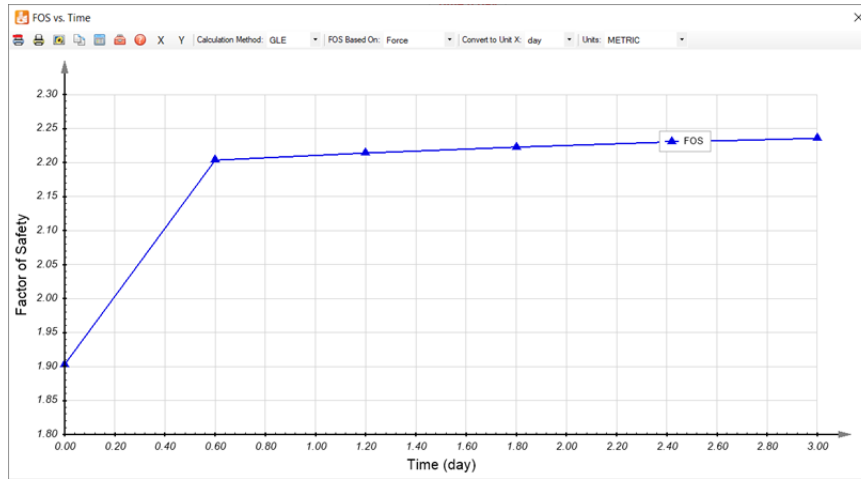


Figure 7: FOS against day with soil nail

4.3 Matric suction

Suction is critical for the development of strength and volume changes in soils that are located above the natural water table. Suction is especially significant in the analysis of slopes because, if pore-water pressure rises, the stability conferred by suction-induced strength increases might be endangered. The changes in slope soil suction with and without the rainfall input demonstrate the variance in suction range values presented in Table 3. The table summarizes the soil suction data obtained from the PLAXIS LE when the slope is infiltrated by rainwater. The comparison demonstrates that the data from the slope with the rainfall input has a higher soil suction than the data from the slope without rainfall. This is owing to volume of the rainfall infiltrate into the slope.

Table 3: Differences in soil suction range

axis	With soil nail	Without soil nail
X	0 – 66	-71 – 1916
Y	0 – 49	-58 – 938

5. Conclusion and Recommendation

The findings show that the soil nail input and its effect on the slope deformation are very diverse. At the Serviceability Limit State (SLS), the foundation structure is made. It takes into account how the structure should work. It makes sure that the structure doesn't bend, break, or vibrate beyond the point where it should. Soil nails and rainwater infiltration were used to find out how stable the slope was in this study. Both slope simulations are within the safest range. However, the slope with soil nails in it had a better safety factor and it was more stable than the other simulation.

To sum up, soil nail materials can hold a heavy load in both tension and compression. The material properties of the soil nail have a significant role in determining their stability. It was shown in this study that by installing soil nails, slope stability can be achieved and soil density can be raised. Because soil nails are strong, the slope with the soil nail has a lower deformation value than the slope without the soil nail. When the factor of safety and acceptability of the slope is more than one, the slope will be stable. In places where rainwater can get into a slope, the soil nail construction helps it stand up to the weight of the slope's unstable mass. Also, soil nails, like soil nails, can be put at any angle to keep structures from settling.

Acknowledgement

Special acknowledgement to the Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia (UTHM) for providing the technical support and facilities, which without the technical support and facilities, the study would not have been possible completed.

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