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A Typical Design of Soil Nailing System for Stabilizing a Soil Slope: Case Study

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Abstract

Slope failures, is a common issue in construction industry, such that engineers have to avoid its risk on human lives and properties by an appropriate technical design of stabilizing methods. Soil nail is one of such stabilization methods. In this paper, soil-nailing system was studied in terms of inclination, spacing and length to determine the most appropriate values for effective stabilization of soil slope. To find the optimum soil nail system, different soil nail inclination, length and spacing were applied to a hypothetical homogenous soil slope (with inclination of 30°, 40°, 45°, 60°, 70° and 90°) and the Factor of Safety (FOS) was evaluated in each case. To validate the results, the optimum soil nail angle corresponding to a slope of 50° was applied to a case study slope, and the FOS of the case study slope was evaluated as well. The case study slope is located at Cadangan Menjalankan Kerja-Kerja Forensik Di Persiaran Endah, Seputeh Wilayah Persekutuan Kuala Lumpur. Results showed that the soil nails inclination; spacing and length have significant effect on the stability of the soil slope. For soil slope with steepness of 30°, 45°, 60°, 70°, and 90°; the best FOS was found with soil nail inclination (to the horizontal) of 50°, 40°, 20°, 15°, and 10° respectively. The effect of soil nails inclination on the stability of the soil-nailed walls is slight when the degree of inclination of the soil nails varies within 5°–20° to the horizontal. The stability of the slope decreases with the increase of spacing between soil nails. Soil nail length has significant effect on the stability of soil slope with deep-seated slip surface and less effect with shallow slip surface. The bond length behind the slip surface should be enough to allow the nail to use its allowable load.

Keywords: Landslide, Slope Stability, Soil Nails, Soil, Slope Failure

1. Introduction

Slope stability issues are amongst the main problems in construction industry in Malaysia because of nature of the topography and the weather conditions. Soil nail method has gained popularity in Malaysia due to its technical suitability, ease of construction and relative free maintenance[1]. Soil nailing strengthen and improve the stability of slopes by installing a closely-spaced steel bars into a slope and the construction process, proceeds from top to down[2–4]. Soil nail are usually installed into pre-drilled holes and grouted by grout hose under pressure; the grout transfers loads through friction to the soil nails which leads to the stability of the ground[5]. Soil nailing significantly increase the stability of slopes. An increased length of the soil nail, results in improved stability of the slope. Furthermore, soil nails delays the occurrence of local deformation[6].

The design of soil nail in loose fill slope needs to consider static liquefaction and sliding. According to a numerical study, the installation of soil nails nearly perpendicular to the slope face could lead to significant slope movement due to interface liquefaction, and this movement could be reduced by the provision of embedded toe wall to increase the structural rigidity of the soil nail facing system along the potential slip surface[7].

Soil nails inclination has an influence on the performance of soil-nailed slopes. This is evident in an experimental study conducted on the effect of soil nail inclination subjected to seepage flow at 30g; the crest

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settlement of a slope with 79° and nail inclination of 25° to the horizontal was found to be 4.1% of the slope height while it was 2.6% of the same slope with 10° of nail inclination[8]. Soil nails inclination effectiveness is maximized when they are installed at their corresponding optimum soil-nail orientation[9]. Another numerical study conducted on the behavior of steep soil nailed slope under seismic conditions, indicated that the magnitude of displacement was greater in horizontally placed nails than that of inclined nails. Therefore, the installation of inclined nails for steep slopes is a better option than the installation of horizontal nails[10]. The friction angle of the soil has the highest impact on FOS for soil-nailed slope followed by the soil cohesion and then the nail's length[11]. A numerical study conducted on the effect of nail inclination on soil nailed wall stability, found that the variation of FOS is small when nail inclination varies between 10–20° and increasing the nail inclination decreases the factor of safety. Nails' length has a significant effect on the location of the slip surface and the factor of safety[12]. Soil nails length for analysis of preliminary cross section is estimated to be 70% of the slope height and longer nails will be needed for weaker soils which having a deep-seated slip surface[13]. Strut nails are installed in case of surcharge or heavy load on the top of the soil nailed or if the walls are thick and the required bearing resistance is higher than the bearing resistance of the soil[13].

Designers should consider and identify all modes of failure in the design of soil-nailed system under the specific ground and groundwater conditions. The installation of widely spaced soil nails may not be effective in ensuring that the soil nails and the ground act as integral mass and avoiding local instability between the nails. Closely-spaced soil nails are not economically effective and difficult to install properly[9]. The soil nail spacing should be close to achieve massive soil nails interaction within the soil mass and it is recommended to be 1m to 2.5m in either horizontal or vertical directions[14]. The main objective of this study is to apply the most effective design of soil nails system to a case study soil slope so that the highest FOS is achieved.

3. Materials and Methods

The effect of soil nail's inclination, length, and spacing was examined using Slope/W software with homogenous soil slope. Then a cross-section of a case study soil slope was identified for a stability check, before and after application of soil nails. The optimum degree of soil nails inclination, which yielded the highest FOS in homogeneous soil slope, was compared with the optimum degree in the case study soil slope. The analysis method used in this analysis was Spencer's method.

2.1 Model Parameters to Determine the Effect of Soil Nail Inclination on Slope Stability

Several values of soil nails inclination were chosen for this study. The inclinations varied between 15 - 60° to the horizontal with an increment of 5° in each analysis. As for the hypothetical homogenous slope, 30°, 45°, and 60° inclination with specific height of 15m were considered. In addition, 70° and 90° soil slopes with specific height of 10m were considered. These considerations were deemed sufficient to yield a generic representation of slope failure problems in Malaysia, as the considered case study slope is located in Malaysia as well. The soil properties used in this modeling are taken from the laboratory result of case study soil shown in Table 1. The length of soil nails spacing were assumed to be 12m and 1.5m respectively. Six rows of soil nails were applied into the slope for this modeling to determine the ideal degree of soil nail inclination by knowing the highest factor of safety.

2.2 Model Parameters to Determine the Effect of Soil Nail Length on Slope Stability

Tow slopes with 40° and 60° steepness were considered for determination of the effect of soil nail length. Six rows of soil nails, with different soil nail inclination (ranging between 0 - 70°, with increment of 5°) were installed on the slope. The soil properties used in this modeling is shown in Table 1. The proposed soil nails length were 15m, 12m and 8m, which corresponded to 100%, 80%, and 53% of the slope height respectively.

Table 1. Soil properties of the slope

Parameter	Unit Weight, γ (KN/m³)	Cohesion, *C* (KN/m²)	Angel of friction	Nail spacing (m)
Value	18.34	0	34°	1.5

2.3 Model Parameters to Determine the Effect of Soil Nail Spacing on Slope Stability

Similar to the modeling of soil nail inclination, six rows of soil nails were applied into the slope for this modeling. The soil properties used in this modeling are taken from the case study soil data shown in Table 2. The proposed soil nails spacing were 1, 1.5, 1.8, 2 and 2.5m, these values are similar and close to the values used in practical industry in Malaysia in order to find the optimum value of soil nail spacing by knowing the highest factor of safety.

2.4 Case Study: Site Description and Properties

The site of the project, named Cadangan Menjalankan Kerja-Kerja Forensik Di Persiaran Endah, Seputeh Wilayah Persekutuan, located along Seputeh highway, Kuala Lumpur has failed slope, which is approximately 25m in height. The overall slope angle is about 50˚. The soil profile and its properties in the area of the slope are shown in Table 3. The information regarding the soil profile was based on two boreholes located at the top and the bottom of the slope. During the drilling, groundwater measurements were carried out.

2.4.1 Stability Analysis of Case Study Soil Slope

The stability check for the case study at " Persiaran Endah, Seputeh Wilayah Persekutuan Kuala Lumpur " is divided into two parts as follows:

- The slope before soil nailing
- The slope after soil nailing

The slope stability analysis for the first part of the case study slope was to determine the FOS for the slope before the application of soil nailing. The second one is to determine the FOS for the slope after the application of soil nailing for various soil nailing analysis in order to find the ideal soil nailing inclination and compare it with the previous part of analysis.

The slip surface is chosen to be along the cross-section G-G (SI report). The geometry of nailed slope is designed into three cut slopes of 6m in height for each cut and 50º inclination to the horizontal as shown in Figure 1. Six rows of soil nails were installed on the slope with 1.5m spacing, after that the slope was analyzed in different angle of soil nail inclination to obtain the optimum factor of safety.

3. Result and Discussion

3.1 Inclination Effect of Soil Nails on Slope Stability

Figure 2 shows the factors of safety for the slopes which are influenced by the soil nails inclination. The FOS tends to decrease after an optimum inclination of soil nails is attained. For the slope (with 30º steepness) the maximum FOS obtained was 2.368 with 50º nail inclination. The maximum FOS for slope (with 45º steepness) was 1.670 with 40º nail inclination, whereas it was 1.455 for 60º soil slope with 20º nail inclination. Soil nailed walls are slightly affected by soil nails having inclination between 0º – 20º. The highest FOS obtained for 90º soil nailed wall was 2.799 with 10º nail inclination, while the optimum FOS for 70º soil nailed slope was 3.512 with 15º nail inclination. This result clearly indicates that the ideal soil nail inclination should be 50º, 30º, 20º, 15º, and 10º to the horizontal, for slopes with steepness of 30º, 45º, 60º, 70º and

Table 2. Soil properties of the slope

Parameter	Unit Weight, γ (KN/m³)	Angel of friction	Cohesion, *C* (KN/m²)	Nail Inclination (Ø)
Value	18.34	34º	0	40º

Table 3. The properties of soil layers according to SI report

Layer	Cohesion, C (kpa)	Angel of Friction (degrees)	Unit weight γ (KN/m3)
Soft yellow sandy clay	0	34	18.34
Firm reddish yellow sandy clay	4.5	34.5	18.84
Very stiff brownish yellow sandy silt	2	35	18.84

90° respectively. These findings are consistent with the findings reported by[15]. The ideal inclination is attained when the available bond length behind the slip surface is long enough for the bar to use its allowable load as shown in Figure 3.

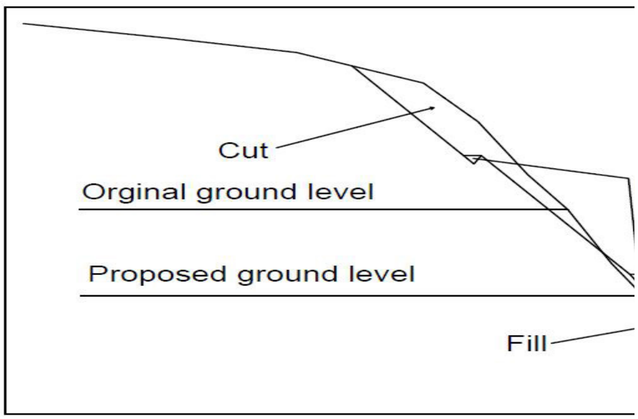

Figure 1. Proposed geometric design for the case slope before applying soil nails.

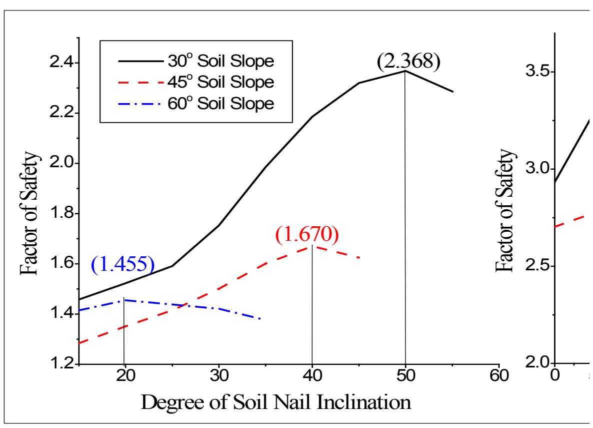

Figure 2. The resulted FOS with several soils nails inclination for 45° and 60° soil slope.

In the ideal inclination of soil nail, the nails mobilize maximum load when the available bond length behind the slip surface is long enough to allow the nail use its maximum load. The specified bar capacity is 300 KN[16] with a bar safety factor of 1.5 and spacing of 1.5m. As a result, the maximum applied load is 133.333 KN (300/1.5/1.5). The specified bond skin friction is 100 Kpa[16] with a bond safety factor of 1.5. Therefore, the applied bond resistance is 44.444 KN/m (100/1.5/1.5). In this case, the required bond length for the bar to use its allowable load of 133.333 KN is 3m (133.333/44.444). If one looks into the bottom bar, the available bond length is 3.530 m, which is more than the required bond length. Therefore, maximum bar load is used. The dashed lines indicate that the governing component is the nail bar, and the nails are long enough. For the top nail, the available bond length is 0.568m. Therefore, the maximum allowable nail load is 25.235KN. However, because of the maximum bar load is 133.33KN, the governing components is the bond.

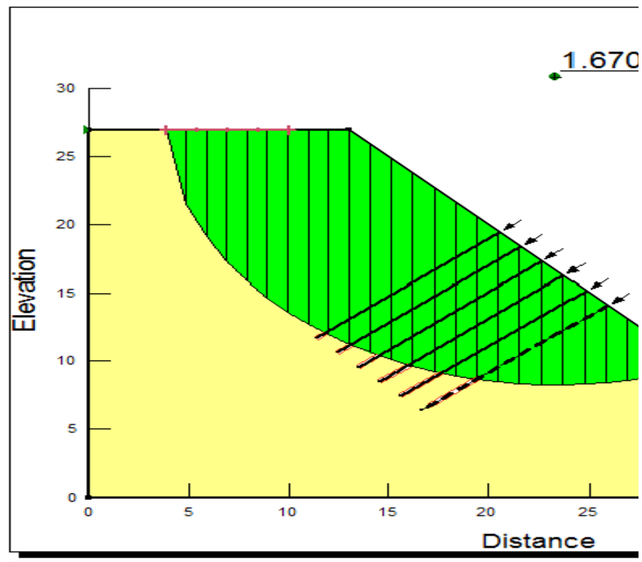

Figure 3. Sample modeling to show the effect of soil nail inclination.

3.2 The Effect of Soil Nails Length on Slope Stability

Figure 4 shows the FOS for the slope which is influenced by the soil nails' length. The nails' length has a significant effect on slope stability for slopes with deep-seated slip surface while it has less effect on slopes with shallow slip surface. It is clear that short soil nails need higher soil nails inclination in order to use their allowable load while long soil nails tend to attain their maximum allowable load within 10 – 20° of nails inclination because long nails attain the required bond length in a gentle angle of nail inclination comparing to the short nails. Short nails obtained the highest FOS with 65° and 45° nail inclination for 40° and 60° soil slope respectively. Long soil nails recorded the highest FOS with 20° and 15° nail inclination for 40° and 60° soil slope respectively. Moderate soil nails recorded the highest FOS with 20° and 40° nail inclination for 40° and 60° soil slope respectively.

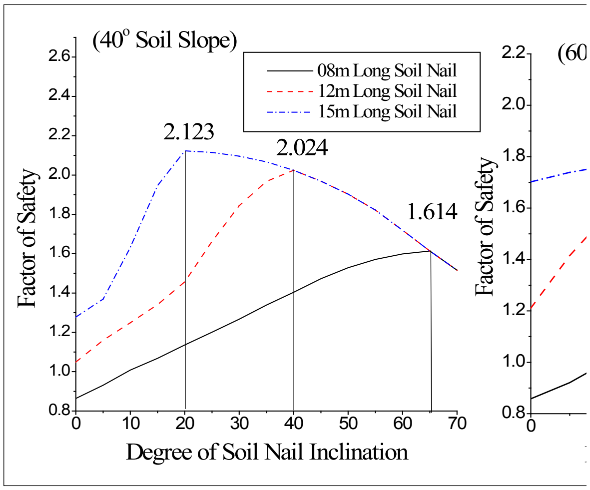

Figure 4. The resulted FOS with several soils nails length for 40° and 60° soil slope.

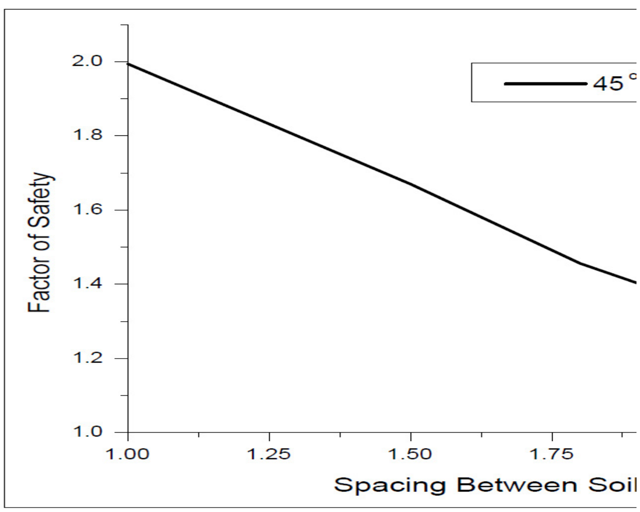

Figure 5. The result of FOS for various soils nailing spacing.

3.3 The Effect of Soil Nails Spacing on Slope Stability

Figure 5 shows the FOS for the slope which is influenced by the soil nail spacing. As the bar's capacity is divided on bar spacing, it was noticed that the FOS decreases proportionately with increase in the soil nail spacing. This is due to increased stability resistance obtained when more nails were installed. Installing more nails, translates to decrease in nail spacing. The installation of closely-spaced soil nails in a soil nailed wall results in a higher FOS than the FOS when installing the same number of widely spaced soil nails because the closely-spaced soil nails obtain the required bond length almost with the same angle nail inclination so that they use their maximum allowable load. The ideal soil nails spacing ranges between 1m to 2m. Similar results had been reported by[14].

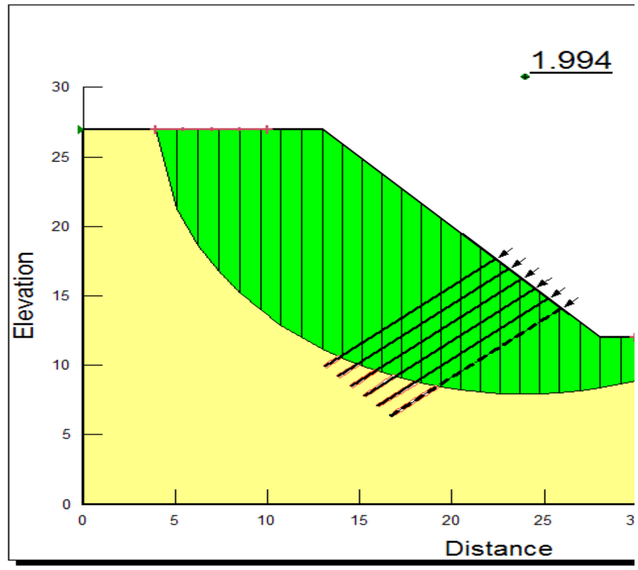

Figure 6. Sample modeling to show the effect of soil nail spacing.

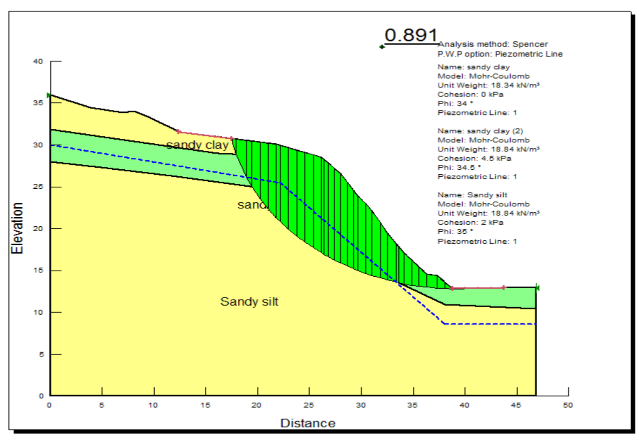

Figure 7. Modeling analysis to determine the FOS for the case study at Persiaran Endah, Seputeh Wilayah Persekutuan Kuala Lumpur.

When the spacing between soils nails horizontally and vertically equals to 1m the resulting FOS equal to 1.994 as shown in Figure 6. When the spacing is increased to 1.5m, the resulting FOS decreases to 1.670. Similarly, when the spacing reaches 2.5m, the resulting FOS decreases to 1.153, which is less than the design criteria of more than 1.3. Therefore, the slope is in an impending failure. The spacing between nails should be as wide as possible, such that a FOS of more than 1.3 is achieved. This ensures compliance with the design criteria and minimized installation cost of the soil nails.

3.4 Case Study Slope Stability Check without Soil Nails

The analysis result for case slope before soil nailing shows that the FOS of the slope was 0.891 as shown in Figure 7. The approaching failure result showed that the FOS was below 1.3, which means the slope did not fulfill the design requirement. Therefore, the soil nailing is essential to stabilize the slope.

3.5 Slope Stability Analysis for Case Study after Applying Soil Nails

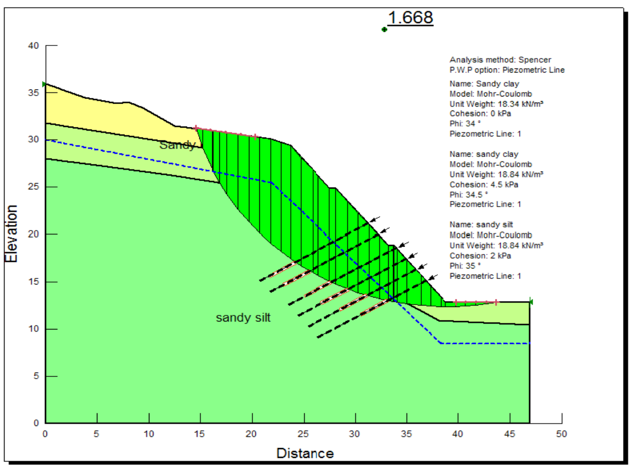

Figure 8. Shows the maximum FOS after applying soil nails for the case study soil slope.

Table 4. The resulting F.O.S for various soil nail inclinations to determine the optimum FOS for the case study soil slope

Nail inclination (Degrees)	15°	20°	25°	30°	35°
FOS using Slope/W 2007	1.244	1.364	1.457	1.668	1.644

As proved in the previous analysis of the homogenous soil slope, the maximum FOS obtained was when soil nails inclination is 30° degrees to the horizontal and 80° to the slope surface. The FOS improved from 1.244 with 15° soil nail inclination to 1.668 with 30° soil nails inclination. It then started to drop as the soil nails inclination continue to increase as shown in Table 4. The drop occurred because the available bond length behind the slip surface is longer than the required one. The extra bond length will not mobilize any working load because the required bond length has mobilized the maximum load to the slope. Figure 8 shows the stability check for case study soil slope after applying the soil nails with inclination of 30° to the horizontal; the red boxes that appeared on the nails indicate that the bars are long enough. The nails are drawn with dashed lines to indicate that the governing components are the nail bars. In general, if the nail is very strong it is likely that the governing component is the bond, but if the bond resistance is high and the nail is very long, then the governing component is the nail bar. The maximum FOS (1.668) obtained meets the design requirements for the case study slope, which is more than 1.3.

4. Conclusion

The soil nails inclination has a significant effect on the stability of the soil slope; the inclination of soil nails depends on the slope angle. The angle of nails inclination for a steep slope should be less than the angle of soil nails of a gentle slope. Typical nails inclination should be 50°, 40°, 20°, 15°, and 10° to the horizontal for slopes 30°, 45°, 60°, 70°, and 90° respectively. Soil nailed walls are only slightly affected when the soil nails inclination varies within 5 – 20°.

Soil nails length has significant effect on slope stability and it should be long enough to provide sufficient bond length behind the slip surface. In case of short nails (50% of the slope height), the optimal FOS is attained when the soil nail inclination is 20 - 25° higher than the moderate and long soil nails.

Soil nails spacing should be considered in the design of soil nails system, as the stability of the slope decreases proportionately with increase in spacing between the soil nails. The ideal spacing ranges between 1m to 2m.

The case study slope was in an impending failure with FOS of 0.891. After applying soil nails, the FOS increased to its optimum value of 1.668 with nail inclination of 30° to the horizontal and 80° to the ground surface.

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