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# Slope stability analysis under different soil nailing parameters using the SLOPE/W software

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**Abstract** Slope failure is one of the major geological phenomenon that happen due to the topography and weather conditions which cause a wide range of ground movements which needed engineers to plan in order to avoid its risk on human lives and properties by an appropriate stabilizing method. Soil nailing system is considered as one of the major preventive methods and economic systems to overcome the slope failures. In this paper, soil nailing system was studied in term of inclination to determine the most appropriate values for effective stabilization of soil slope using the SLOPE/W software. To validate the results, different soil nail inclinations were applied to a case study, and the Factor of Safety (FOS) of the case study was evaluated as well. The case study is located at Genting Highlands, Pahang. Results showed that the soil nails inclination has significant effect on the stability of the soil slope. For soil slope with steepness of 30°, 45° and 60°, the best FOS found with soil nail inclination (to the horizontal) of 60°, 50° and 40° respectively. The effect of soil nails inclination gives small difference in FOS when the degree of inclination of the soil nails varies within 5° - 20° to the horizontal.

## 1. Introduction

The major purpose of conducting stability analyses is to measure the safety and present the most economical design of slopes such as excavation, landfills, embankments and road cuts. FOS is the primary consideration in assessment of slopes to figure out the degree of closeness to failure. One of the most commonly used construction remedial measure in Malaysia slopes is soil nails which are installed at site for purpose of stabilizing distress slopes and for excavation which involves steep cut. Recently, 25m high of soil nail slopes are being implemented in Malaysia [9].

Reinforcing action of soil nails are developed through soil nail interaction due to the ground deformation which results in increment of tensile forces in soil nail. Development of axial force which is mainly a tension force is considered as the major part of resistances. Conservatively, it is assumed that shear and bending grant little contribution in providing resistance. The function of soil nailing is to improve the stability of slope or excavation through the enhancing the normal force on shear plane which contribute to increase the shear resistance along slip plane in friction soil and lessen the driving force along slip plane in cohesive soil and friction [5].

In this study, FOS is being used as the dependent variable to analyze the stability of a slope, besides the independent variable such as inclination angle which influence the stability of slopes. In this study, two objectives had been identified which are, (i) To determine the optimum inclination angle of soil nail

for higher slope stability by using SLOPE/W solution (ii) To verify the effectiveness of soil nailing system in case study.

## 2. Research Methodology

The procedures that had been followed in this study is shown in Figure 1. The study was divided into four steps; data collection, slope stability analysis for the optimum soil nail inclination and verification of case study as well as comparison of FOS obtained discussion and conclusion.

The effect of soil nail inclination was examined using Slope/W 2012 software with homogenous soil slope. Then a cross section of a case study soil slope was identified for a slope stability analysis, before and after application of soil nails. For the parametric study, the half scale of the case study was used with same soil properties. The optimum degree of soil nails inclination, which yielded the highest FOS in homogenous soil slope, was compared with the optimum degree in the case study soil slope. The analysis method used in this analysis was Morgenstern Price Method in which the moments and forces are at equilibrium. Besides that, the slip surface type that was implemented in this analysis is the entry and exit method in order to obtain a better control of trial slip surfaces.

Several values of soil nails inclination were chosen for this study. The inclination varied between 20° - 90° to the horizontal with an increment of 10° in each analysis. The specific height of the homogenous slope was 15m. These considerations were sufficient to represent a slope failure problem in Malaysia. Soil properties used in the modelling were taken from the soil laboratory results as shown in Table 1. The length of soil nails and spacing were assumed to be 8m and 1.5m respectively. Six rows of soil nails were applied into the slope for this modelling to determine the ideal degree of soil nail inclination by knowing the highest FOS.

A commercial development project with basement parking at Lot PT 21650 (HSD 16956) and part of Lot 15131 (Grn 25954), Genting Highlands, Pahang was proposed over an approximately 31.716 acres of land in the vicinity of Sri Layang Cable Car Station, Genting Highlands, Pahang. This project has a slope which is approximately 31 m in height. The overall slope angle is about 30°. The soil profile and its properties in the area of the slope are shown in Table 2. The information regarding the soil profile was based on a borehole located at the top of the slope. A standpipe piezometer was installed at the borehole to obtain the ground water measurement.

The stability analysis for the case study is divided into two parts such as the slope before soil nailing and 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.

**Table 1.** Soil properties of the slope.

| Parameter | Unit Weight, $\gamma$ (kN/m3) | Cohesion, C (kN/m2) | Angle of Friction ($\varphi$) |
|---|---|---|---|
| Value | 19.0 | 5 | 34 |

**Table 2.** The soil properties of soil layers according to site investigation report.

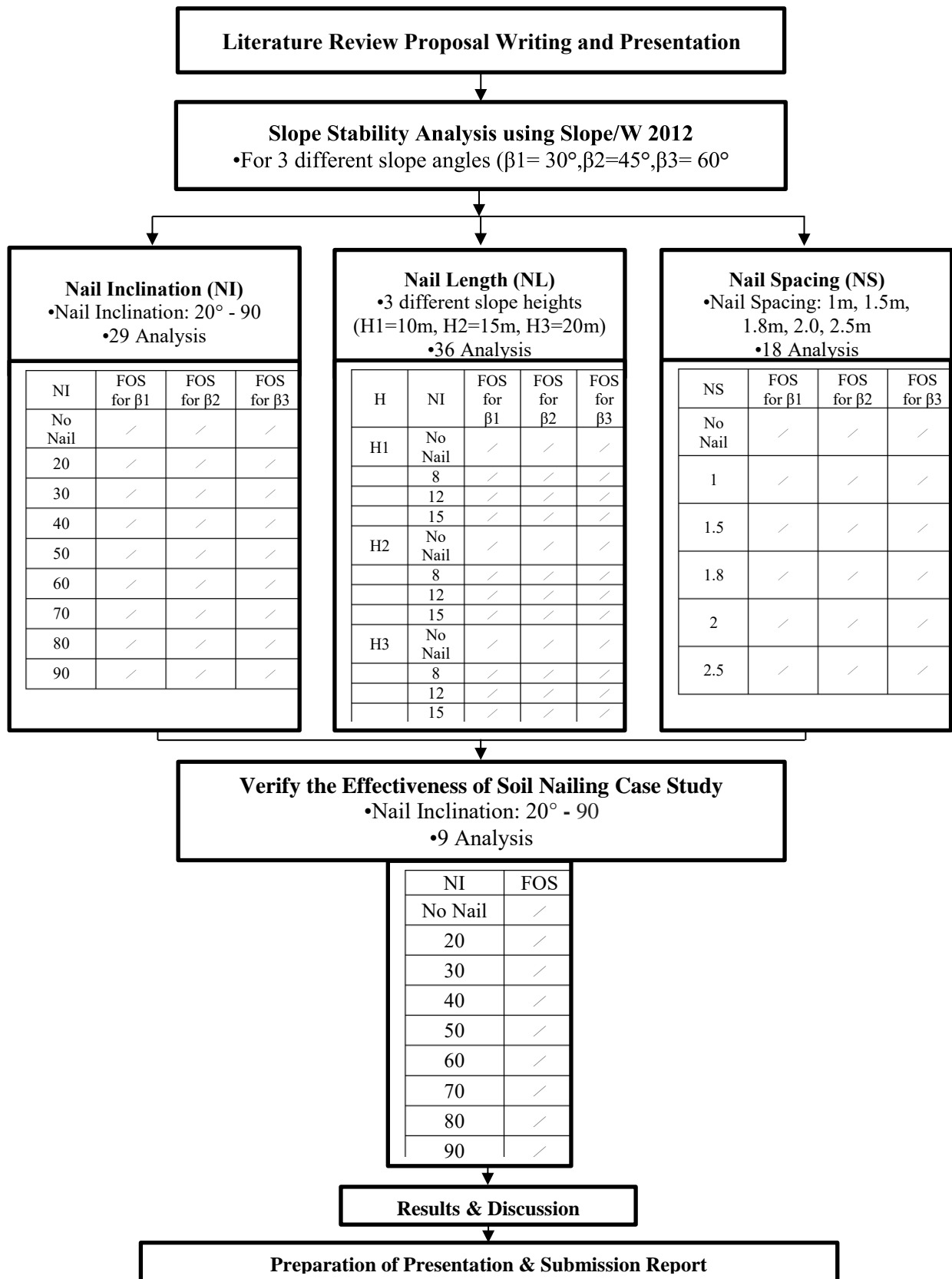| Layer | Cohesion,C (kpa) | Angle of Friction (Degrees) | Unit Weight, $\gamma$ (kN/m3) |
|---|---|---|---|
| Silt with gravel | 5 | 34 | 19 |
| Stiff Silt with gravel | 10 | 36 | 20 |

**Figure 1.** Schematic diagram of the flow chart of research methodology.

### 3. Result and Discussion

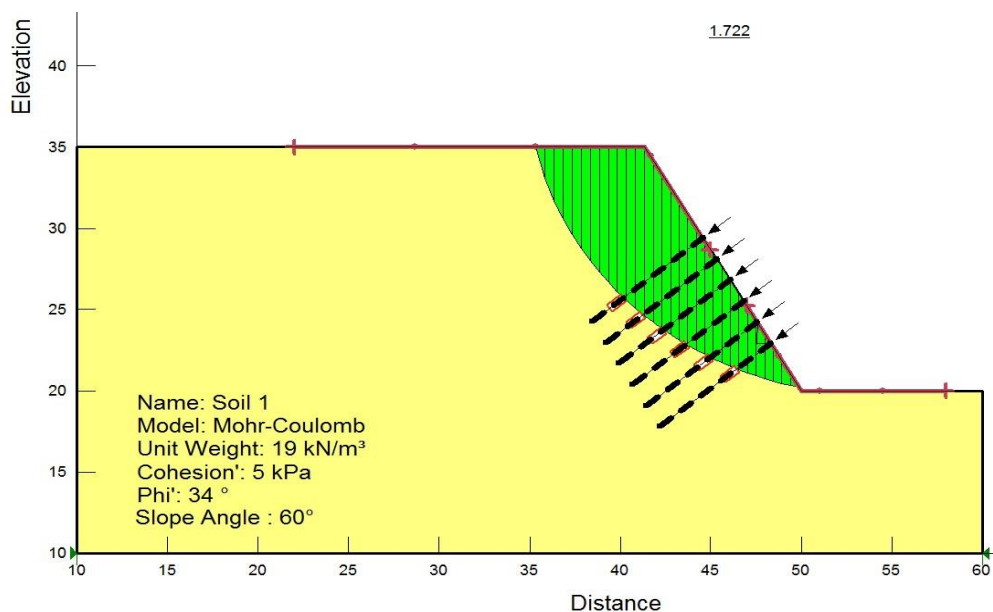#### 3.1. Inclination effect of soil nails on slope stability

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 2. 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 tensile capacity is 300 kN with a bar safety factor of 1.5 and spacing 1.5 m. As a result, the maximum applied load is 133.3 kN (300/1.5/1.5). The specified bond friction is 100 kPa with a bond safety factor of 1.5. Therefore, the applied bond resistance is 44.4 kN/m (100/1.5/1.5). In this case, the required bond length for the bar to use its allowable load of 44.4 kN is 3.0 m (133.3/44.4).

If one looks into the bottom bar in Figure 2, the available bond length is 5.54 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 2.28 m. Therefore, the maximum allowable nail load is 25.2 kN. However, because of the maximum bar load is 133.3 kN, the governing components is the bond. The results of this research show that the FOS decreases after an optimum inclination of soil nails is attained.

The graph of FOS versus various soil nails inclinations was developed and shown in Figure 3. From the results acquired in this research, it can be concluded that the nail inclination should be 60°, 50°, and 40° to the horizontal, for slope with steepness of 30°, 45° and 60° respectively in order to achieve the optimum FOS. These results are consistent with the findings reported by [2].

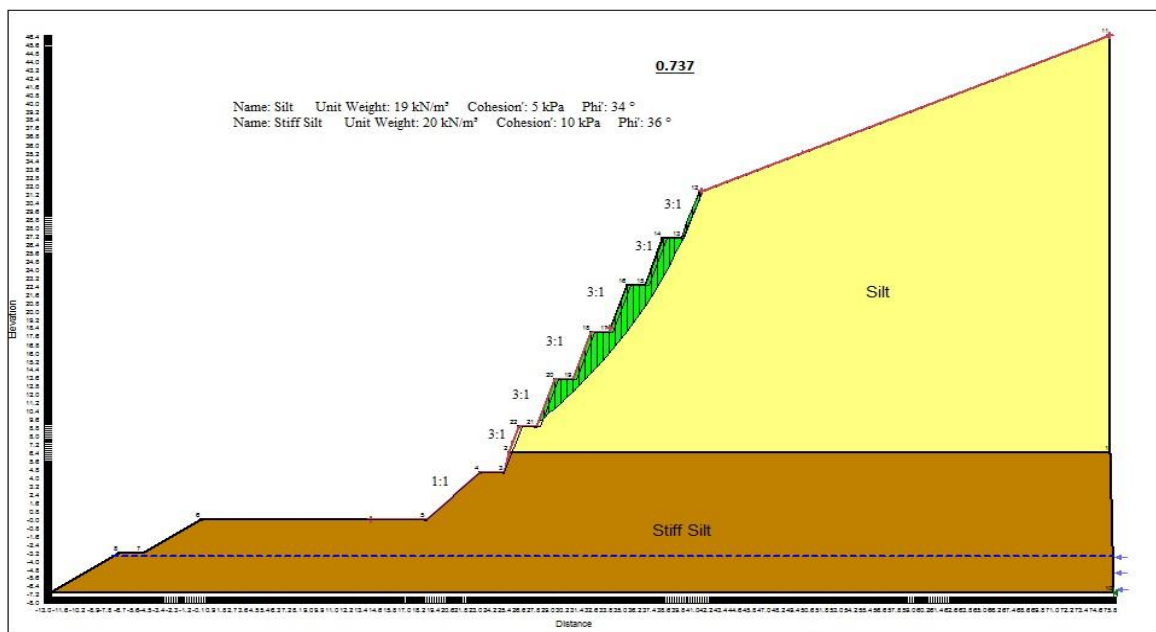#### 3.2. Slope stability analysis without soil nails for case study

The geometry of the case study slope was designed into seven cut slopes of 4 m in height for each cut. The slope comprised of two layers of soil which are silt and stiff silt and slope gradient of 3V:1H was used as shown in Figure 4. The analysis result for case study before soil nailing shows the FOS of the slope was 0.737. The approaching failure result showed that the FOS was below 1.3, which means the slope did not fulfil the design requirement. Therefore, the soil nailing is essential to stabilize the slope.



**Figure 2.** Sample modelling to show the effect of soil nail inclination.
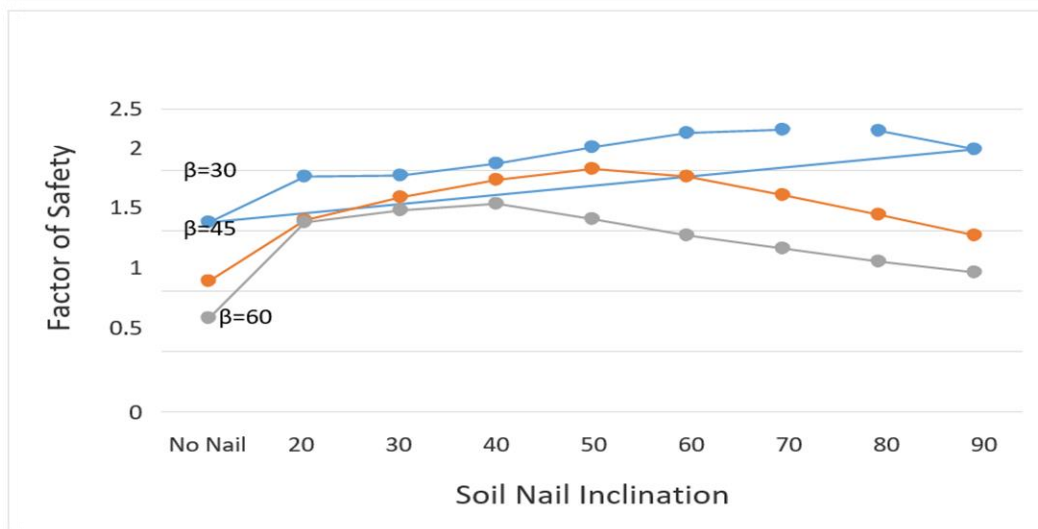
**Figure 3.** The results of FOS with soil nail inclination for 30°, 45° and 60° soil slope.



**Figure 4.** Modelling analysis to determine the FOS for the case study at Genting Highlands, Pahang.

### 3.3. Slope stability analysis with soil nails for case study

The geometry of nailed slope is 30° inclination to the horizontal. 18 rows of 18 m soil nails were installed on the slope with 1.5 m spacing, after that the slope was analysed in different angle of soil nail inclination to obtain the optimum FOS.

As proved in the previous analysis of the homogeneous soil slope, the optimum FOS was obtained when soil nails inclination is 60° to the horizontal. The FOS improved from 1.443 with 20° soil nail inclination to 1.689 with 60° soil nails inclination. It then started to drop as the soil nails inclination continue to increase as shown in Figure 5. 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.
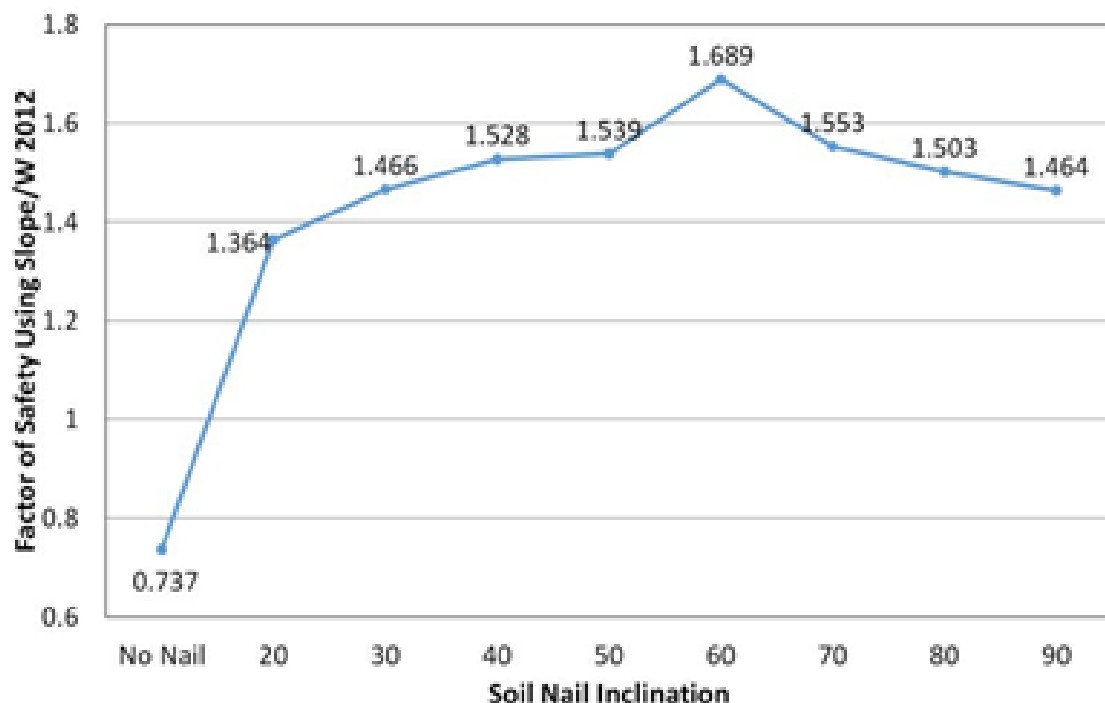
Figure 6 shows the FOS for the case study soil slope after applying the soil nails with inclinations of 60° to the horizontal which has resulted in optimum FOS. The red boxes that appeared on the nails indicate that the bars are long enough. The nails are drawn with dashed lines to indicate that the 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 strong, then the governing component is the nail bar.

The case study slope is considered safe once after the soil nails had been introduced into the situation. The soil nail inclination starting from 20° - 90° are safe to use for this case study as the FOS obtained are more than the required FOS which is 1.3. However, the trend of FOS in Figure 5 explains that the nail inclination should be 60° to the horizontal, for case study slope with steepness of 30° in order to achieve the maximum FOS. Therefore, from the results that had been acquired in this research, it can be concluded that the nail inclination should be 60°, 50°, and 40° to the horizontal, for slope with steepness of 30°, 45° and 60° respectively in order to achieve the optimum FOS.

## 4. Conclusion

From the results obtained from the analysis and assessment carried out in this study, it can be concluded that the soil nails inclination has significant effect on the stability of the soil slope. The inclination of soil nails depends on the slope angle. Besides that, 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 60°, 50°, and 40° to the horizontal, for slope with steepness of 30°, 45° and 60° respectively. Soil nailed walls are only slightly affected when the soil nails inclination varies 5° - 20°.

On the other hand, the case study slope was in an impending failure with FOS of 0.737. After applying soil nails of 60° inclination to the horizontal, the FOS increased to its optimum value of 1.689.



**Figure 5.** The resulting FOS for various soil nail inclinations to determine the optimum FOS for the case study soil slope.
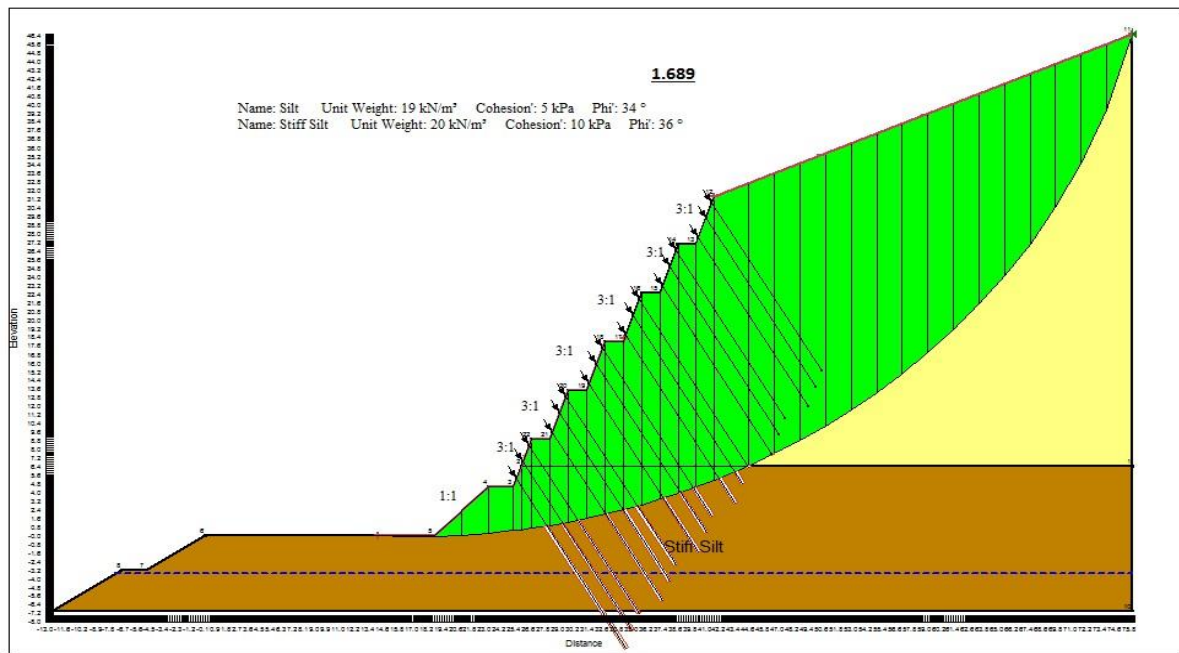
**Figure 6.** The FOS after applying soil nails for the case study of the slope at nail inclination of 60°.

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