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A COMPARATIVE STUDY BETWEEN SOIL NAILING AND BERMS FOR SLOPE STABILIZATION: PERFORMANCE, AND ANALYSIS

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Abstract: For any structure in steep places, to function properly, a slope stability analysis must be conducted to understand the behavior of slopes. This paper is concerned with slope stabilization by two different techniques, berming and soil nailing. Analysis is performed by adopting the software (Plaxis 2d) to investigate the effect of different parameters on the behavior of slopes. The examined parameters in soil nailing technique are summarized as nail length, angle of nail inclination with the horizontal and the spacing between nails. For berming technique, the influence of the berm width, berm height and the berm inclination. In the present study, the slope performance is measured by identifying the factor of safety against slope failure. Results indicate that while soil nailing offers advantages in terms of flexibility, rapid installation, and minimal footprint, berm construction excels in providing robust lateral support and erosion control. Moreover, considerations of cost-effectiveness, maintenance requirements, and environmental impact play a crucial role in selecting the optimal stabilization strategy for specific slope condition. This comparative study contributes to the advancement of geotechnical engineering practice by offering insights into the strengths and limitations of soil nailing and berm techniques in slope stabilization.

Keywords: Soil Nailing, Slope Stability, Berm, Safety Factor, Finite Element

INTRODUCTION

Slope failure or slope instability is very common in many projects. The rapid growth of road and rail construction in urban and coastal areas has forced construction to be on different types of soil. Poor ground geotechnical characteristics may cause slope failures. The design and construction of earth slopes on soil with poor geotechnical properties cause the problems of excessive and differential settlements, large lateral displacement and inadequate safety factor. Landslides encompass a broad range of

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slope failures characterized by the rapid movement of soil or debris along a defined surface. Landslides can be triggered by rainfall, seismic activity, anthropogenic activities, or geological factors such as soil composition, slope geometry, and slope vegetation (Hungr et al., 2014). Poorly designed or executed construction activities, excavation operations, and earthworks can disturb slope materials, alter stress distributions, and create localized zones of weakness, leading to slope instability and failure.

The construction of roads, highways, railways, and other infrastructure projects can alter slope dynamics, increase surface runoff, and induce slope movements through cut-and-fill operations, embankment construction, and alteration of drainage patterns (Cruden & Varnes, 1996). So, slope instability is thus one of the main issues that geotechnical engineers face. Stabilization of soil formations is one of the important construction techniques in geotechnical practice. Different stabilization techniques are being used to overcome the problems associated with the foundations and embankments works, these techniques such as soil nailing and berming technique.

One of the more modern in-situ techniques for stabilizing soil slopes is soil nailing, which also could be applied to future construction projects. The stability of nailed slopes depends on the mechanism of transferring resisting tensile forces generated in the nails into the ground through friction at the interfaces. Soil nails act as passive reinforcement elements, transferring tensile forces from the unstable soil mass to the stable soil mass behind the facing system. The interaction between soil nails and surrounding soil enhances shear strength, increases internal stability, and reduces deformation potential (Elahi et al., 2022). Soil nails work in conjunction with facing elements such as shotcrete, reinforced concrete panels, or geosynthetic wraps to form a composite structure that resists external loads and stabilizes the slope or excavation face. The composite action between soil nails and facing materials enhances structural integrity and improves overall performance (Xiao et al., 2020).

Advanced numerical modeling techniques such as finite element analysis (FEA) allow for more detailed analysis of soil-structure interaction, stress distribution, and deformation behavior. FEA enables engineers to simulate complex boundary conditions, non-linear material behavior, and dynamic loading effects, providing insights into the performance of soil nailing systems under various scenarios (Ozcelik et al., 2014). Soil nailing is employed in the construction of permanent and temporary retaining walls to support vertical or near-vertical excavations, provide lateral support, and control ground movements. Soil-nailed retaining walls offer advantages such as reduced construction time, minimal space requirements, and compatibility with variable ground conditions.

The stability of the nailed slope is governed by various factors such as slope geometry, nail parameters, slope angle, backslope gradient, nail inclination, nail length, and the spacing between nails are major important parameters that directly affect the stability of slopes.

PARAMETRIC STUDY

This study takes into consideration nail length, nail inclination and nail spacing considering two different soil types. For berming method, the berm width, berm height, and slope inclination are considered for the two types of soil. A chart of the parametric study is presented in Fig. 1. Finite element analysis is conducted to find the impact of each parameter on the global factor of safety (F.S.).

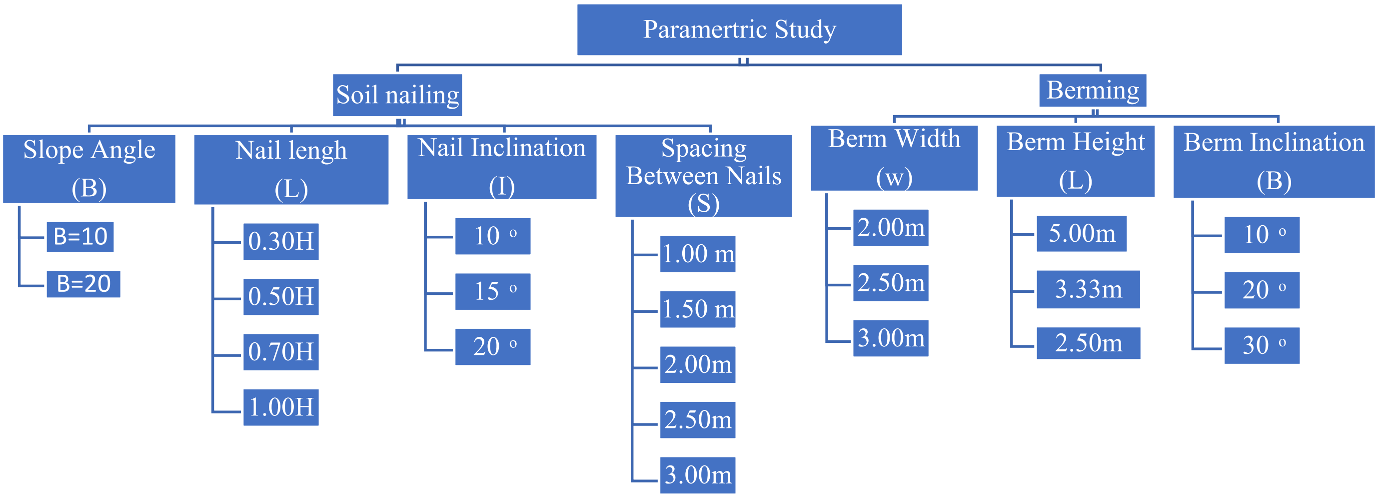

Fig (1): Parametric study plan for the Finite Element analysis.

SLOPE CONFIGURATION

The earth slope considered in the current study is 10.00m high, with a crest width of 15.91 m, as shown in Fig. 2.

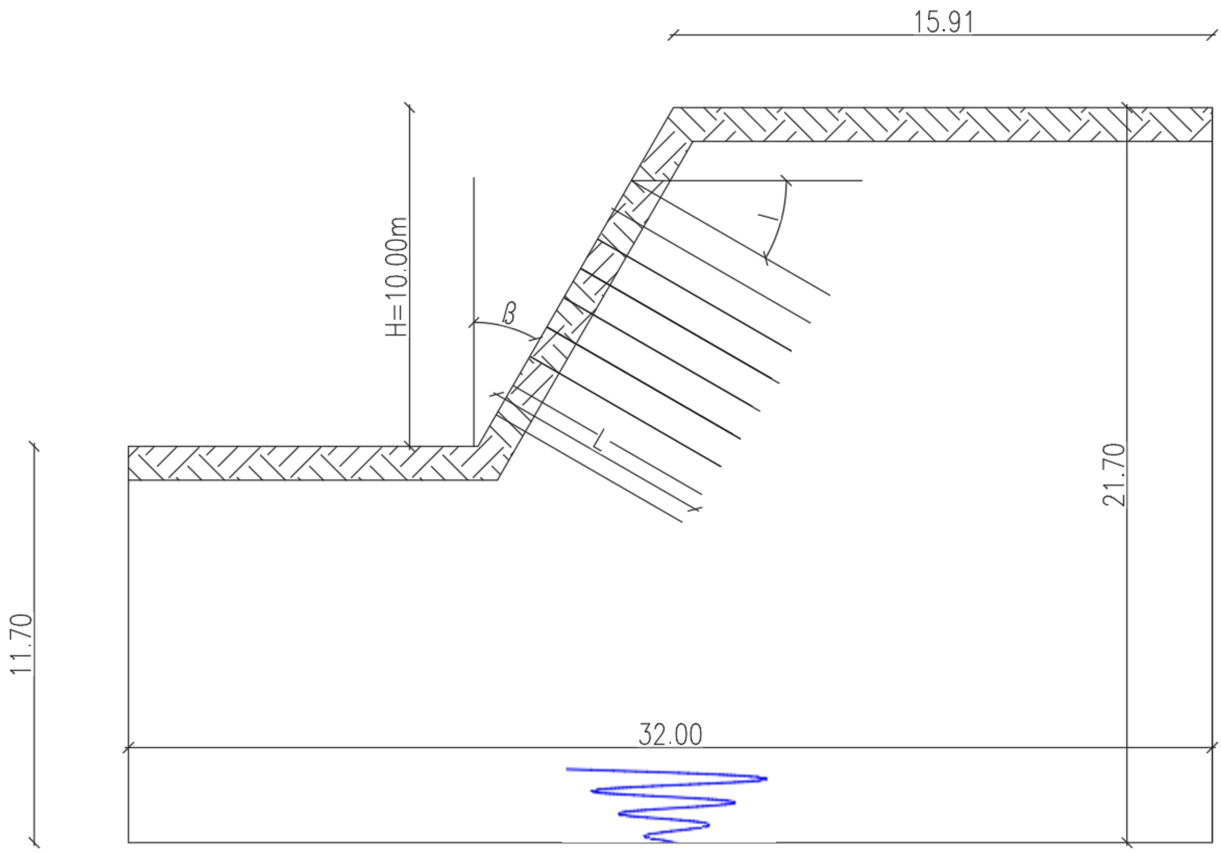

Fig (2): Slope Configuration (soil nailing model)

NUMERICAL ANALYSIS

Two-dimensional numerical models were generated to simulate slope stabilization either by soil nailing or by berming techniques by adopting finite element method. Numerical analyses were conducted using the two-dimensional finite element software PLAXIS. The different soil layers were modeled using the 15-node triangular elements, and the reinforcement was modeled using the geogrid element option. Figure 3 shows the finite element discretization model used in the analysis. The adopted mesh consisted of 4587 nodes and 557 finite elements. The vertical boundaries of the model were assigned zero lateral movements and considered to be impermeable. The bottom horizontal boundary was restrained both vertically and horizontally and was considered to be permeable, sand formation. The global coarseness of the finite element mesh was fine.

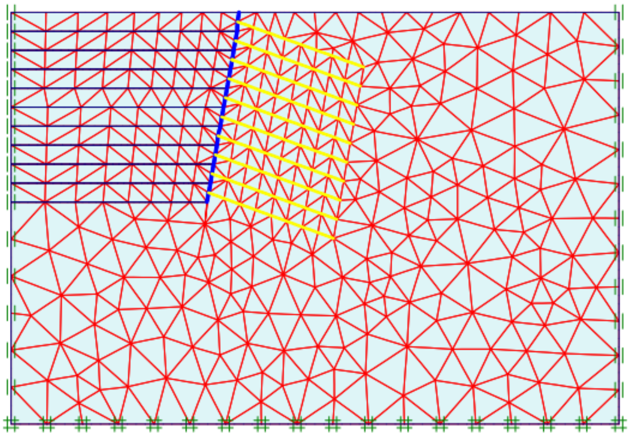

Fig (3): Numerical modeling for soil nailing

Soil Parameters

The soil layers were modelled using the Hardening Soil model offered by PLAXIS software. Table (1) presents a summary of the parameters that were adopted in the numerical analysis.

Table (1): Soil parameters

soil / Parameter	Soil (1)	Soil (2)
Effective friction angel(Ø) (°)	30	35
Dilatancy angel (°)	0	5
E_{50}^{ref} (KN/m2)	30,000	40,000
E_{oed}^{ref} (KN/m2)	30,000	40,000
E_{ur}^{ref} (KN/m2)	90,000	120,000

Results and Discussions

Effect of nail length (L/H)

The L/H ratio equals the ratio between the nail length (L) to the slope height (H). When (L/H) increases, the safety factor increases. Generally, increasing the nail length to wall height ratio can enhance the stability of the soil-nailed structure (Jampani et al., 2017).

Longer nails distribute the applied loads over a larger area, reducing stress concentration at critical points along the wall. This can lead to a more uniform distribution of forces and improved overall stability. However, there may be diminishing returns on safety factor improvement with excessively long nails. Beyond a certain point, the additional length may not significantly increase the safety factor but could substantially increase construction costs. Therefore, optimization choice is crucial to determine the most cost-effective nail length to wall height ratio.

Numerical models have been established to study the effect of (L/H) ratio on safety factor. Figure 4 through Fig. 9 present the relation between factor of safety (F. S) and nail length to wall height ratio (L/H) for soil type (1). Figure. 10 through Fig. 15 present the relation between factor of safety (F. S) and nail length to wall height ratio (L/H) for soil type (2).

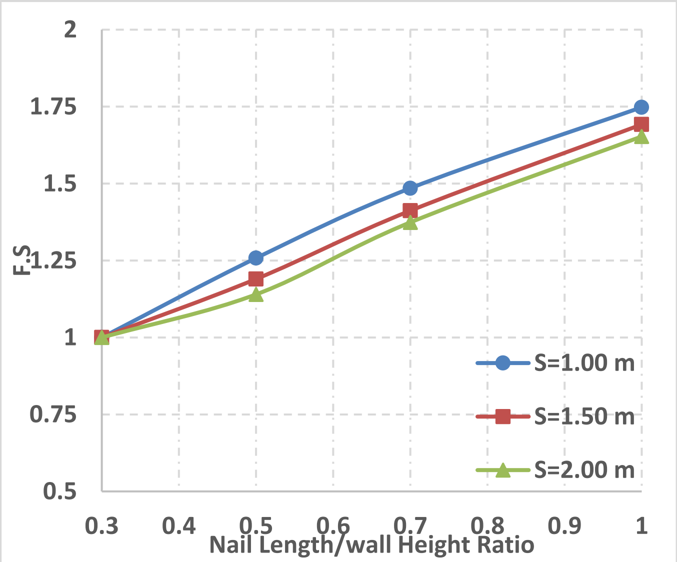

Fig (4): Relation between F.S and nail length to wall height ratio for soil (1) (β=10 ˚, I=10 ˚)

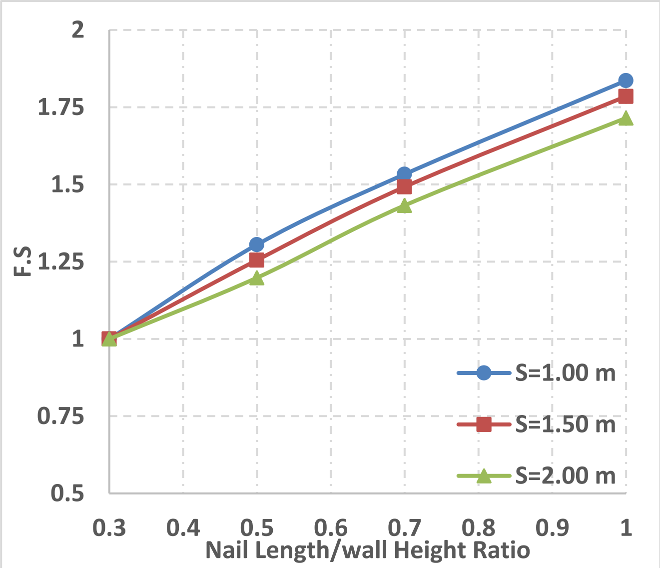

Fig (5): Relation between F.S and nail length to wall height ratio for soil (1) (β =10 ˚, I=15 ˚)

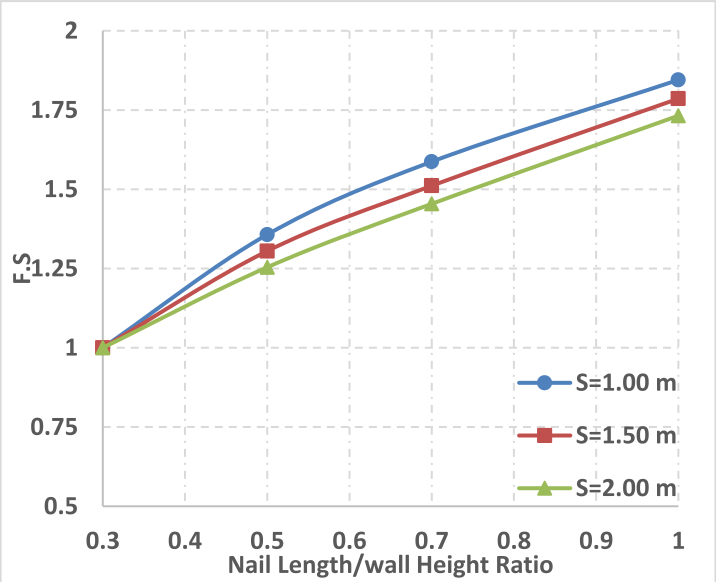

Fig (6): Relation between F.S and nail length to wall height ratio for soil (1) (β =10 ˚, I=20 ˚)

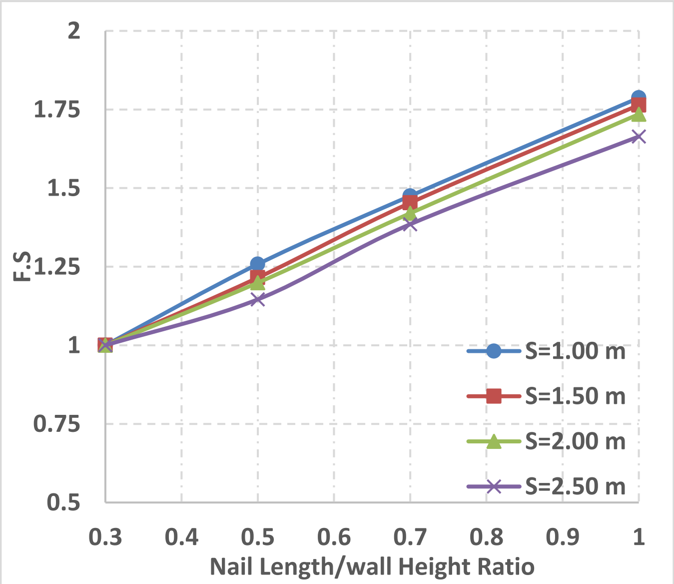

Fig (7): Relation between F.S and nail length to wall height ratio for soil (1) (β =20 ˚, I=10 ˚)

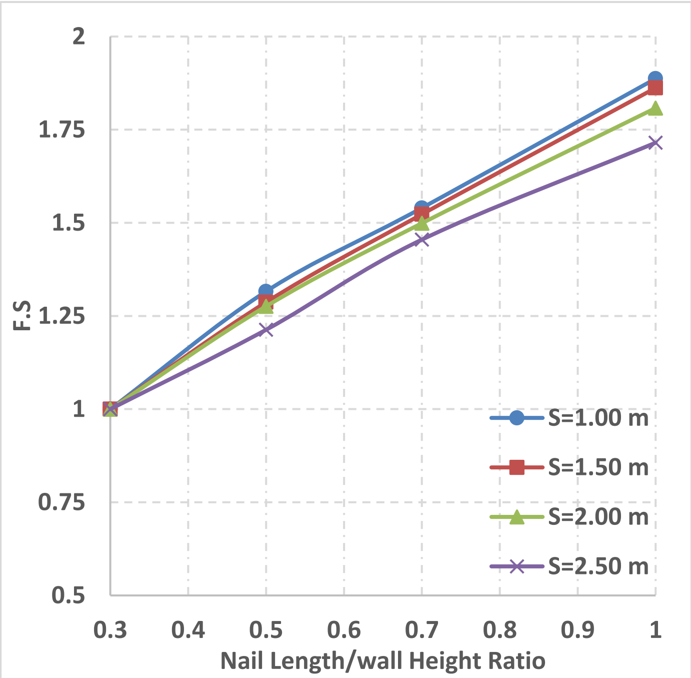

Fig (8): Relation between F.S and nail length to wall height ratio for soil (1) (β =20 ˚, I=15 ˚)

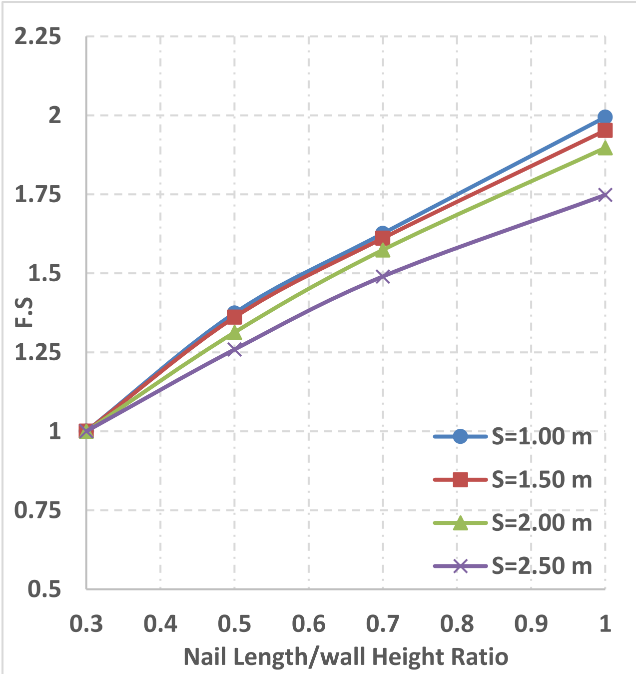

Fig (9): Relation between F.S and nail length to wall height ratio for soil (1) (β =20 ˚, I=20 ˚)

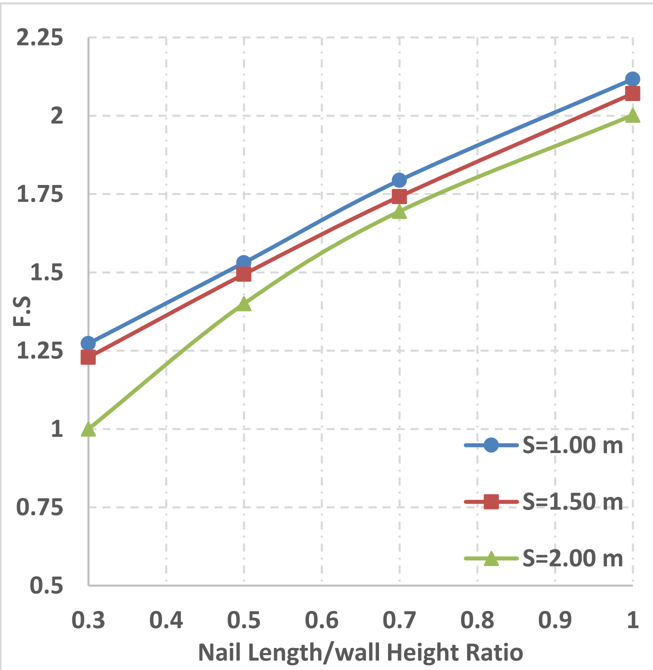

Fig (10): Relation between F.S and nail length to wall height ratio for soil (2) (β =10 ˚, I=10 ˚)

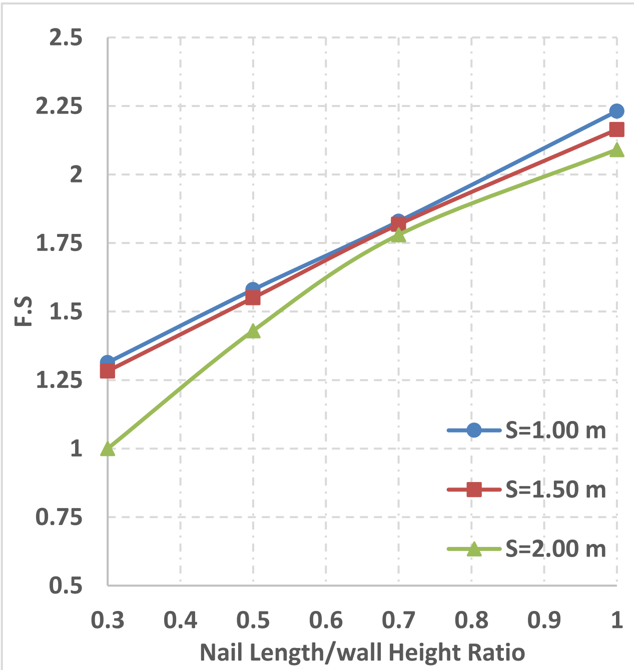

Fig (11): Relation between F.S and nail length to wall height ratio for soil (2) (β =10 ˚, I=15 ˚)

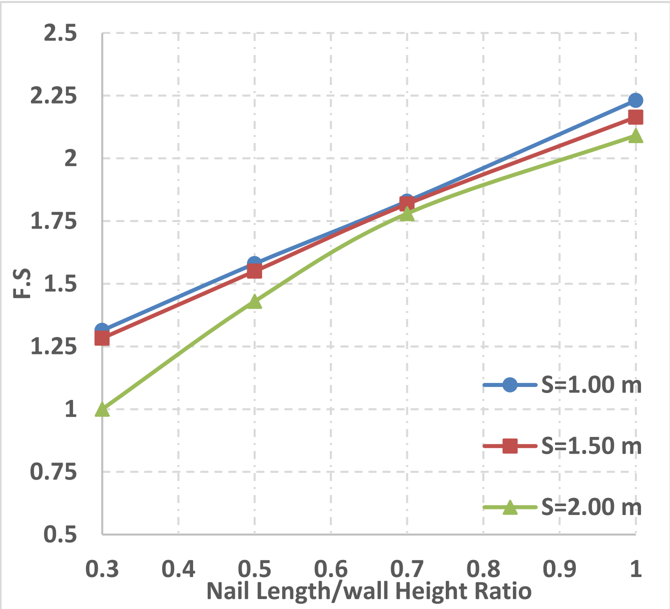

Fig (12): Relation between F.S and nail length to wall height ratio for soil (2) (β =10 ˚, I=20 ˚)

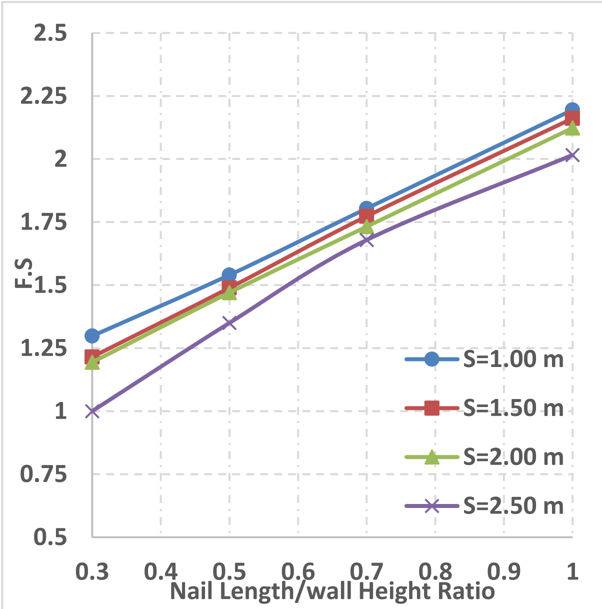

Fig (13): Relation between F.S and nail length to wall height ratio for soil (2) (β =20 ˚, I=10 ˚)

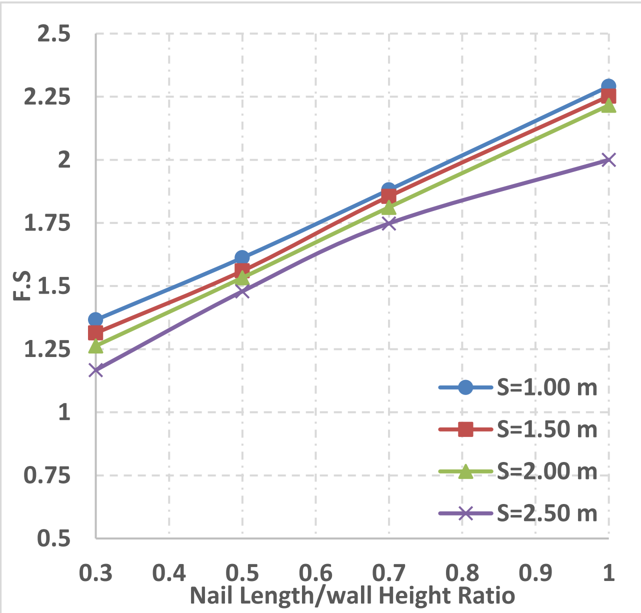

Fig (14): Relation between F.S and nail length to wall height ratio for soil (2) (β =20 ˚, I=15 ˚)

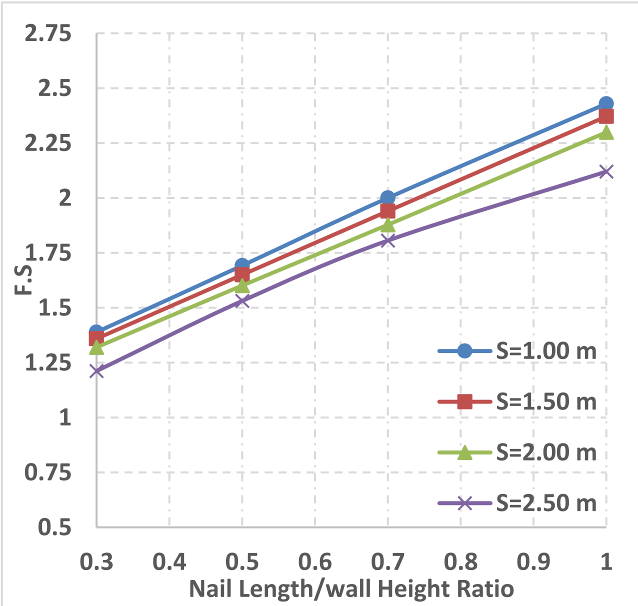

Fig (15): Relation between F.S and nail length to wall height ratio for soil (2) (β =20 ˚, I=20 ˚)

From the above figures, it is revealed that as the ratio of nail length-to-wall height ratio (L/H) increased, the global factor of safety (F.S.) increased, indicating further stability of the soil nailed wall due to longer nails in the passive zone. Specifically, the global factor of safety increased with an average value of 29.64% and 42.60% for soil (l) and soil (2), respectively. It can be concluded that the increase in the F. S was influenced by the soil parameters. The greater the angle of internal friction of the soil, the greater the percentage of increase in the factor of safety. consequently, the optimum length of nailing that satisfies the global safety factor = 1.5 as permanent slope or safety factor =1.3 as temporary slope (According to E.C.P,2001) range between 0.70 H to 1.00 H in case of permanent slope and range between 0.50 H to 0.70 H in case of temporary slope depending on the type of soil and friction angle.

Effect of the nail inclination angle (I)

Increasing the inclination angle of the nails can improve the factor of safety. Steeper angles provide better resistance against lateral forces and tend to enhance the overall stability of the soil-nailed structure. This is because steeper nails create more significant shear resistance along the nail-soil interface. Nails with steeper inclination angles can transfer applied loads more effectively to the surrounding soil (Jampani & Bhupathi, 2017).

The effectiveness of nail inclination angles can vary depending on soil properties such as cohesion and internal friction angle. It's essential to consider site-specific geotechnical conditions when determining the optimal nail angle to achieve the desired factor of safety. In summary, the nail inclination angle plays a crucial role in determining the factor of safety in soil nailing applications.

Researchers have proposed empirical guidelines and design charts for determining the optimal nail inclination angle based on stability analyses and case studies. These guidelines consider factors such as slope geometry, soil properties, loading conditions, and safety requirements to recommend suitable ranges for nail inclination angles (Villalobos et al., 2021). Models were conducted to study the effect of nail inclination on the safety factor. Figure. 16 through Fig. 22 present the relation between nail inclination and safety factor for soil (1) and Fig. 23 through Fig. 29 present the relation between nail inclination and safety factor for soil (2).

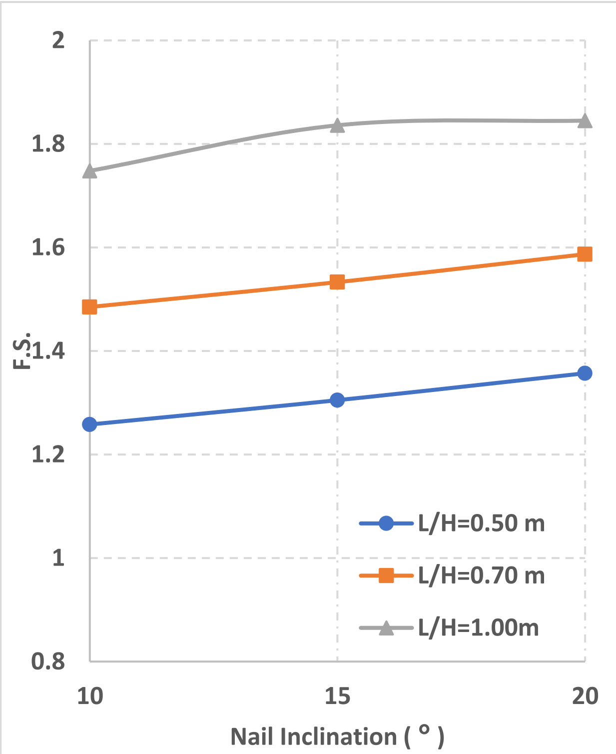

Fig (16): Relation between F.S and nail inclination for soil (1) (β =10 ˚, Spacing = 1.00m)

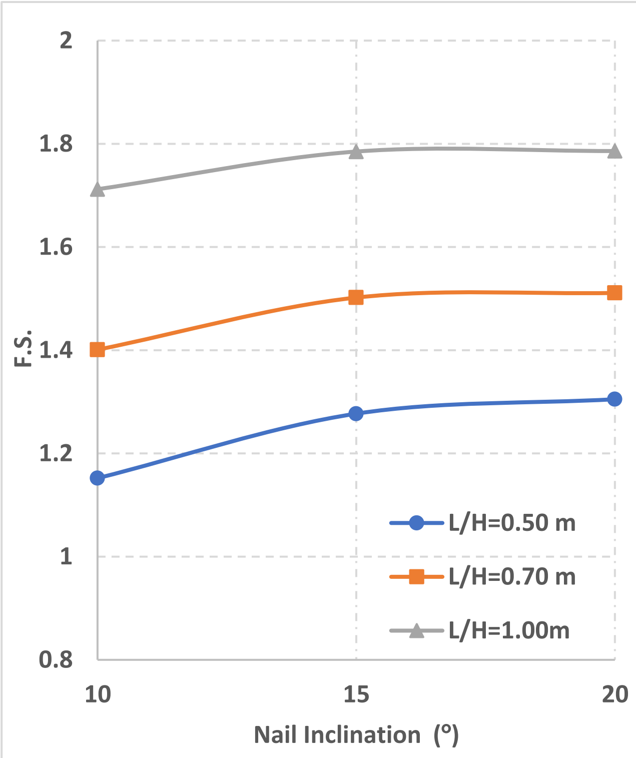

Fig (17): Relation between F.S and nail inclination for soil (1) (β =10 ˚, Spacing = 1.50m)

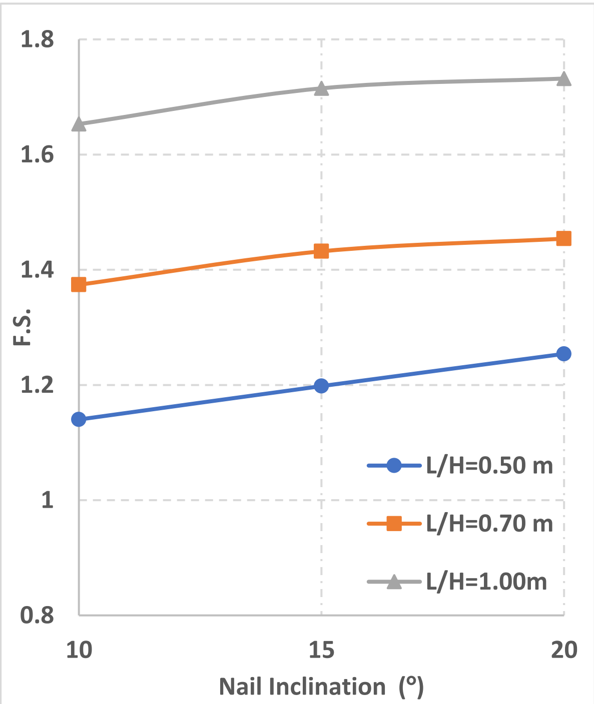

Fig (18): Relation between f.o.s and nail inclination for soil (1) (β =10 ˚, Spacing = 2.00m)

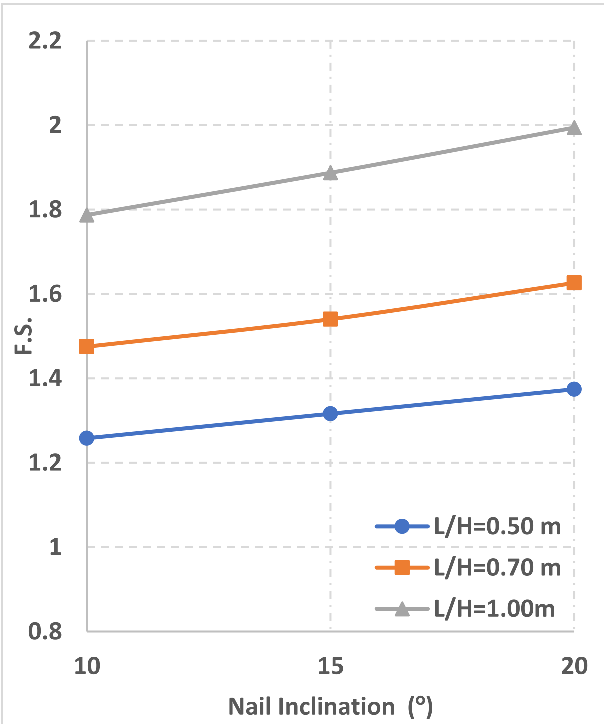

Fig (19): Relation between F.S and nail inclination for soil (1) (β =20 ˚, Spacing = 1.00m)

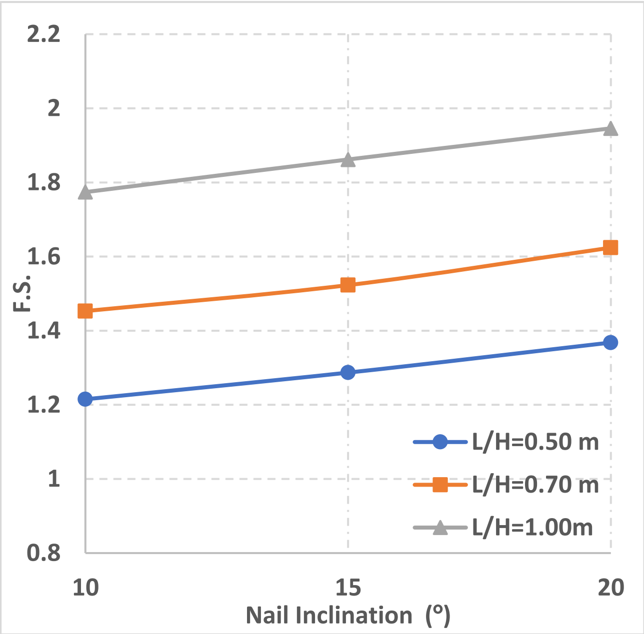

Fig (20): Relation between F.S and nail inclination for soil (1) (β =20 ˚, Spacing = 1.50m)

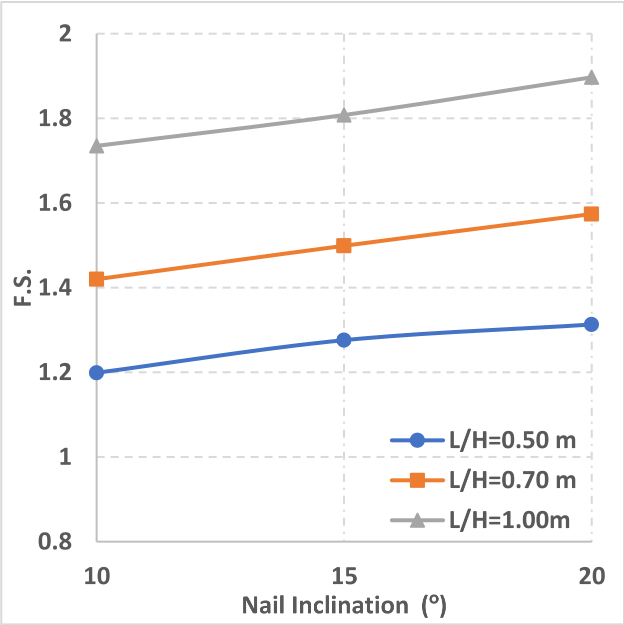

Fig (21): Relation between F.S and nail inclination for soil (1) (β =20 ˚, Spacing = 2.00m)

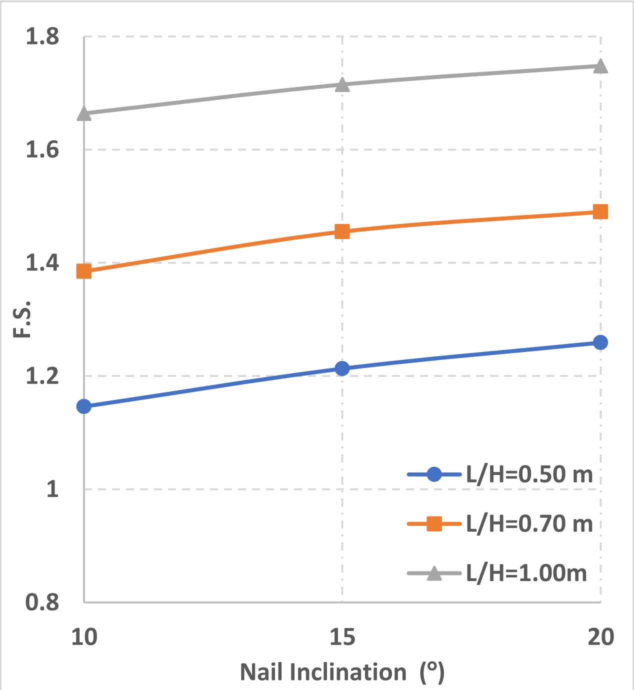

Fig (22): Relation between F.S and nail inclination for soil (1) (β =20 ˚, Spacing = 2.50m)

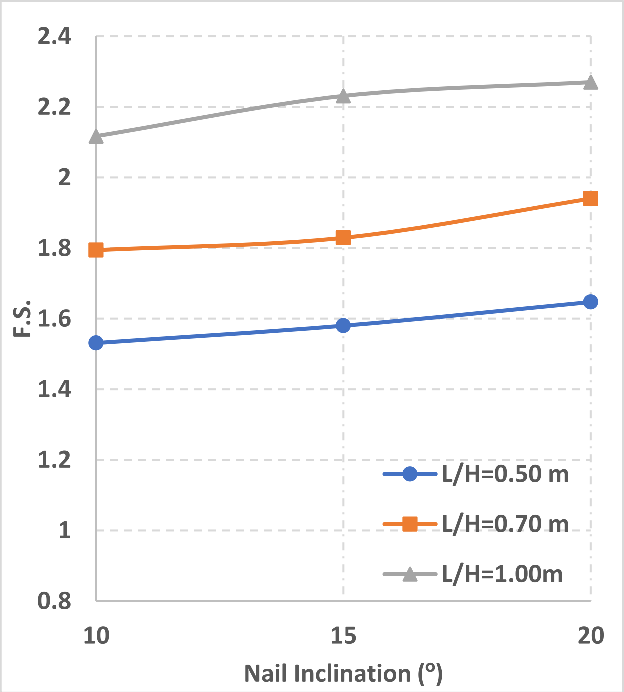

Fig (23): Relation between F.S and nail inclination for soil (2) (β =10 ˚, Spacing = 1.00m)

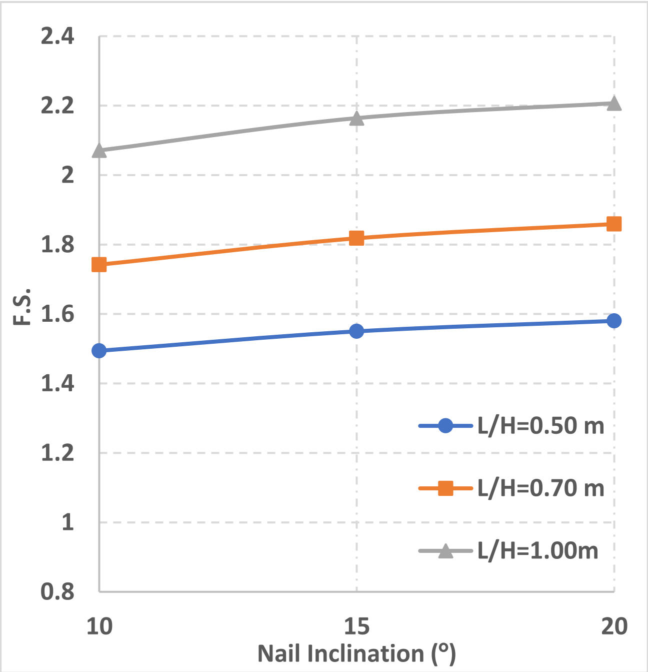

Fig (24): Relation between F.S and nail inclination for soil (2) (β =10 ˚, Spacing = 1.50m)

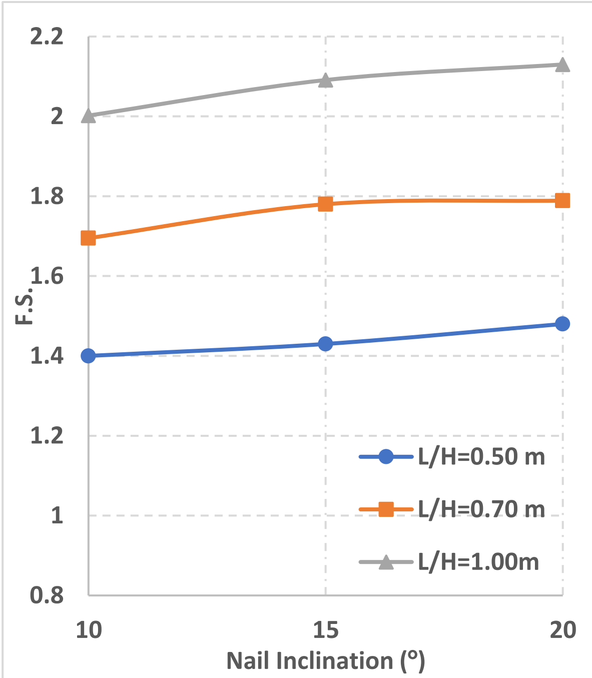

Fig (25): Relation between F.S and nail inclination for soil (2) (β =10 ˚, Spacing = 2.00m)

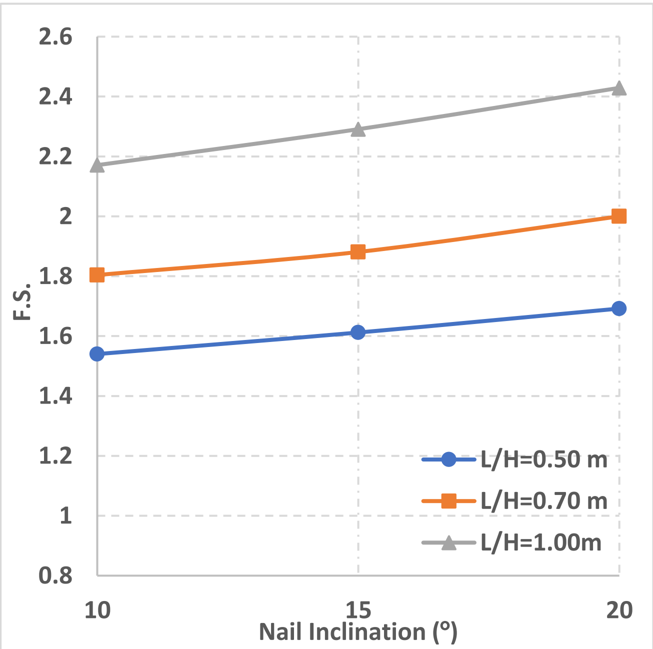

Fig (26): Relation between F.S and nail inclination for soil (2) (β =20 ˚, Spacing = 1.00m)

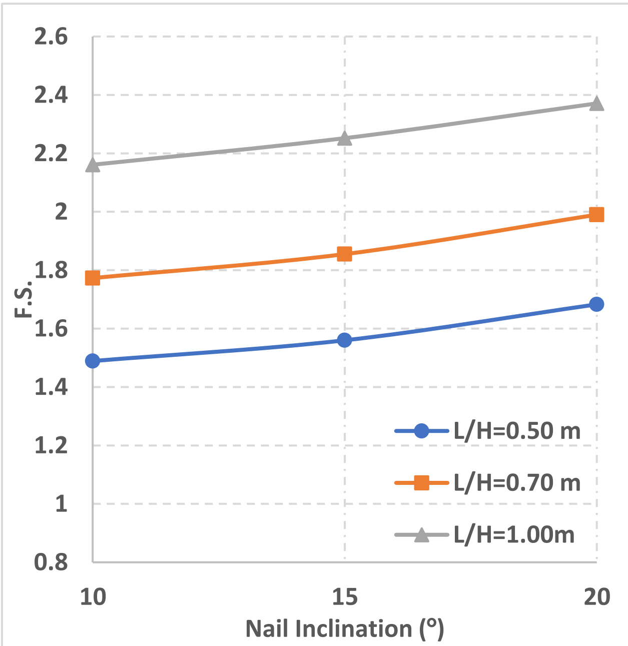

Fig (27): Relation between F.S and nail inclination for soil (2) (β =20 ˚, Spacing = 1.5m)

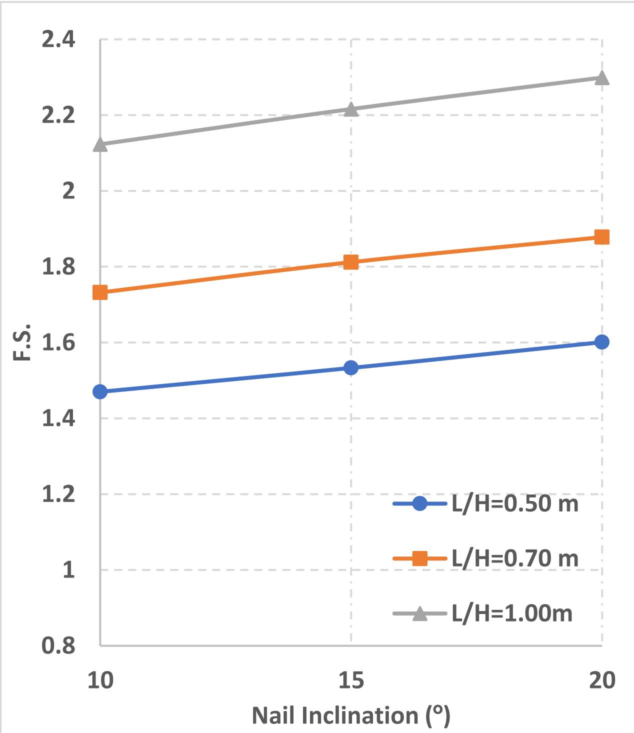

Fig (28): Relation between F.S and nail inclination for soil (2) (β =20 ˚, Spacing = 2.00m)

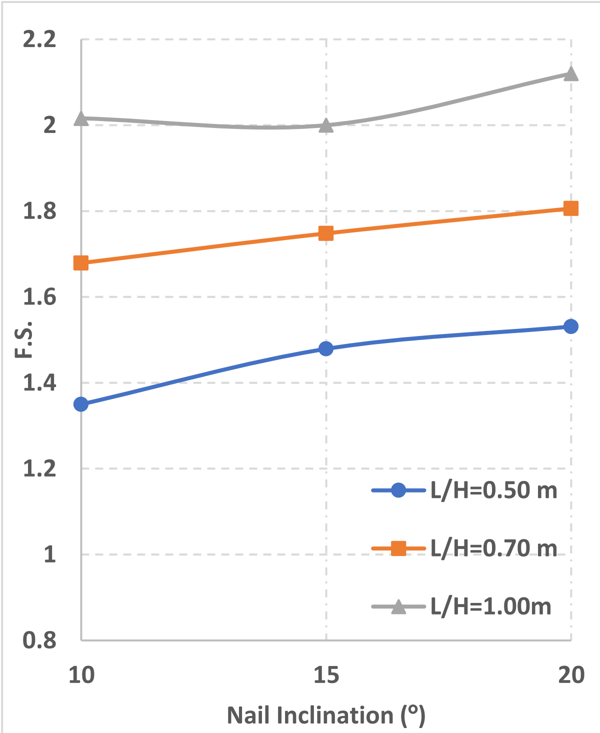

Fig (29): Relation between F.S and nail inclination for soil (2) (β =20 ˚, Spacing = 2.5m)

From the above-mentioned figures, it is revealed that as the nail inclination angle (I) increased, the global factor of safety (F.S) increased. Steeper nail angles result in longer effective nail lengths within the soil mass, increasing the extent of soil reinforcement.

Change in nail inclination angle can lead to greater mobilization of soil against sliding and overturning failure modes. When inclination angle (I) increases from 10 to 20, the global safety factor increases with a negligible percentage by 7.35% for soil (1) and 7.98 % for soil (2).

Effect of spacing between nails (S)

Increasing the spacing between nails tends to reduce the factor of safety of the soil-nailed structure. This is because wider nail spacing results in fewer nails per unit length of the wall, which may lead to decreased soil reinforcement and reduce resistance against lateral forces. Studies have shown that decreasing nail spacing increases the total number of nails and enhances soil reinforcement, resulting in improved factor of safety and stability. Closer nail spacing reduces the size of failure blocks, increases the mobilization of soil arching effects, and provides more uniform stress distribution within the soil mass (Villalobos et al., 2021).

With wider nail spacing, the extent of soil reinforcement provided by the nail's decreases. This reduction in soil reinforcement can result in weaker resistance to sliding, overturning, or other failure modes, thereby lowering the factor of safety. Wider nail spacing allows for larger soil movements between adjacent nails. This can lead to increased soil deformation, potential soil loss, or instability along the nail-soil interface, contributing to a lower factor of safety against failure. The effect of increasing nail spacing on the factor of safety can vary depending on soil properties such as internal friction angle.

Figures 30 through 35 illustrate the effect of nail spacing (S) on the global factor of safety (F.S.) for soil (1). Similarly, Figures 36 through 41 illustrate the effect of nail spacing (S) on the global factor of safety (F.S.) for soil (2).

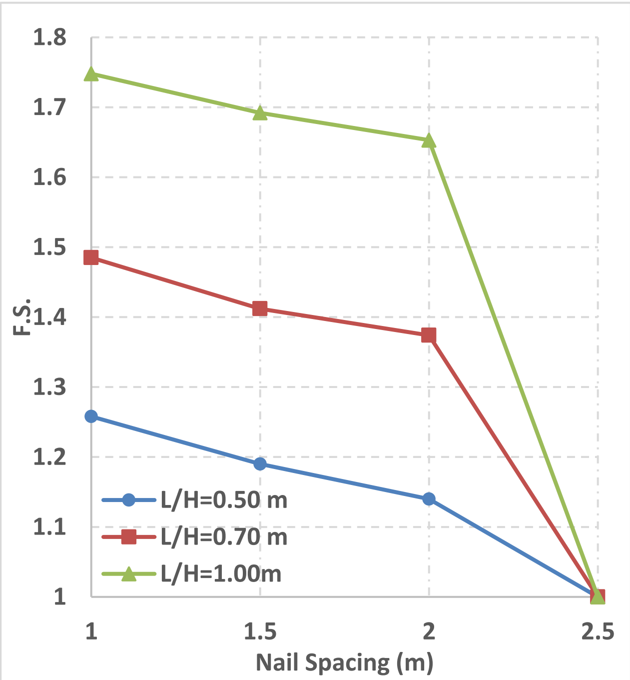

Fig (30): Relation between F.S and spacing between Nails (S) for soil (1) (β =10 ˚, I=10 ˚)

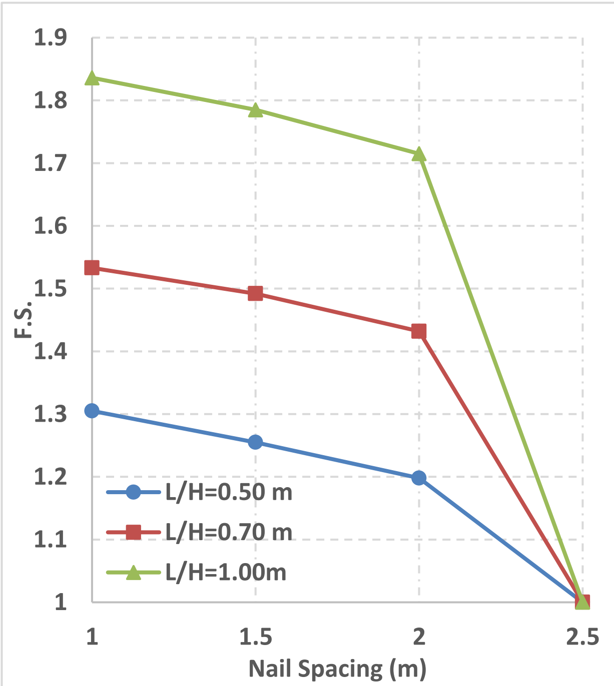

Fig (31): Relation between F.S and spacing between Nails (S) for soil (1) (β =10 ˚, I=15 ˚) `

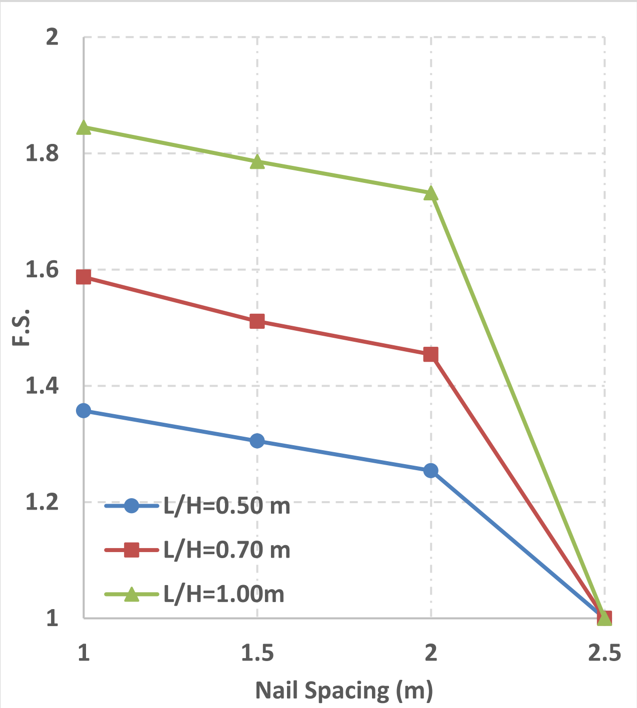

Fig (32): Relation between F.S and spacing between Nails (S) for soil (1) (β =10 ˚, I=20 ˚)

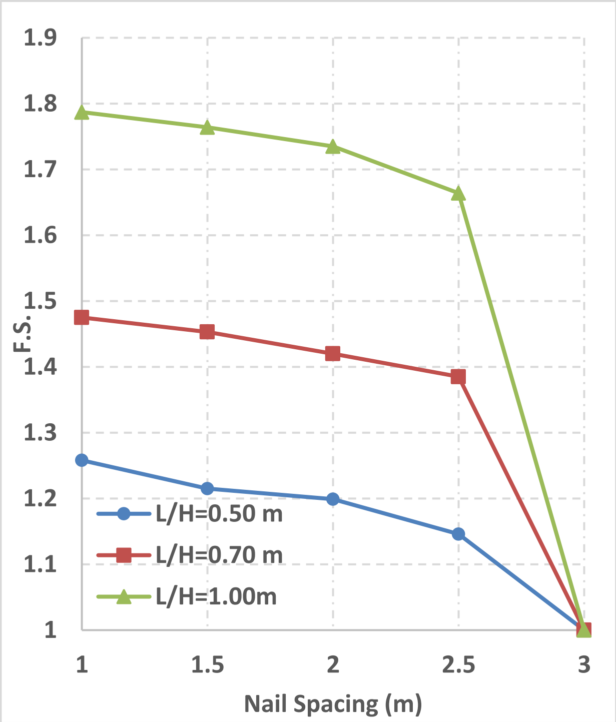

Fig (33): Relation between F.S and spacing between Nails (S) for soil (1) (β =20 ˚, I=10 ˚)

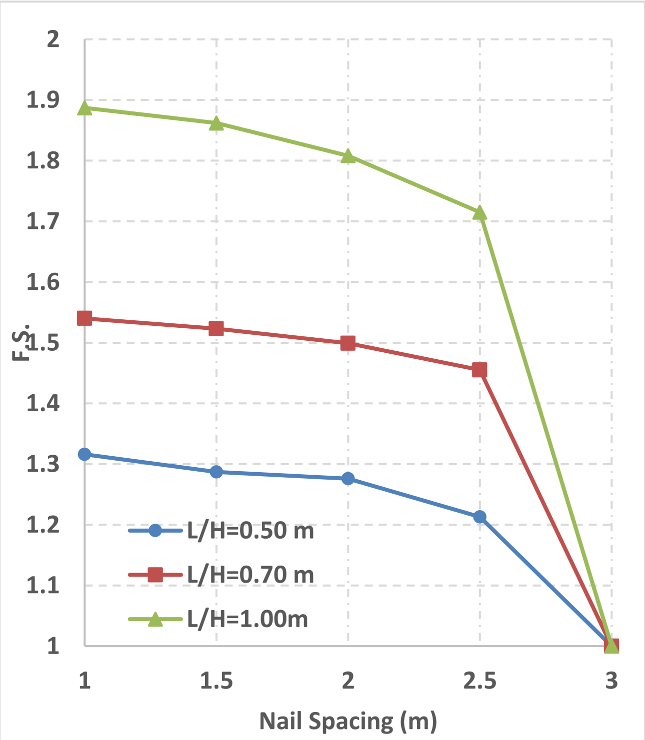

Fig (34): Relation between F.S and spacing between Nails (S) for soil (1) (β =20 ˚, I=15 ˚)

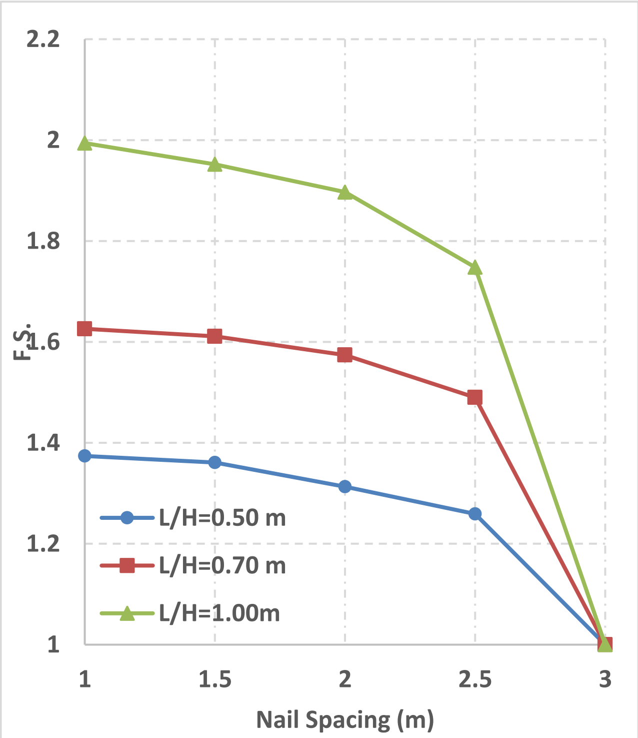

Fig (35): Relation between F.S and spacing between Nails (S) for soil (1) (β =20 ˚, I=20 ˚)

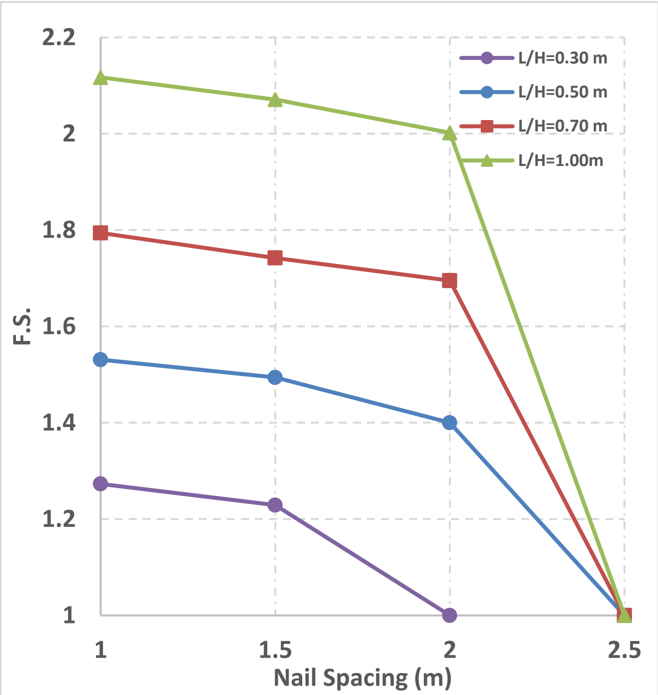

Fig (36): Relation between F.S and spacing between Nails (S) for soil (2) (β =10 ˚, I=10 ˚)

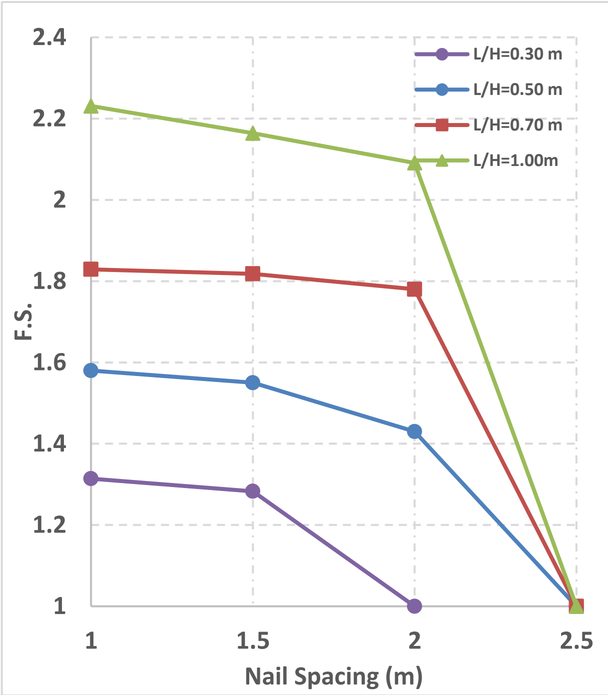

Fig (37): Relation between F.S and spacing between Nails (S) for soil (2) (β =10 ˚, I=15 ˚)

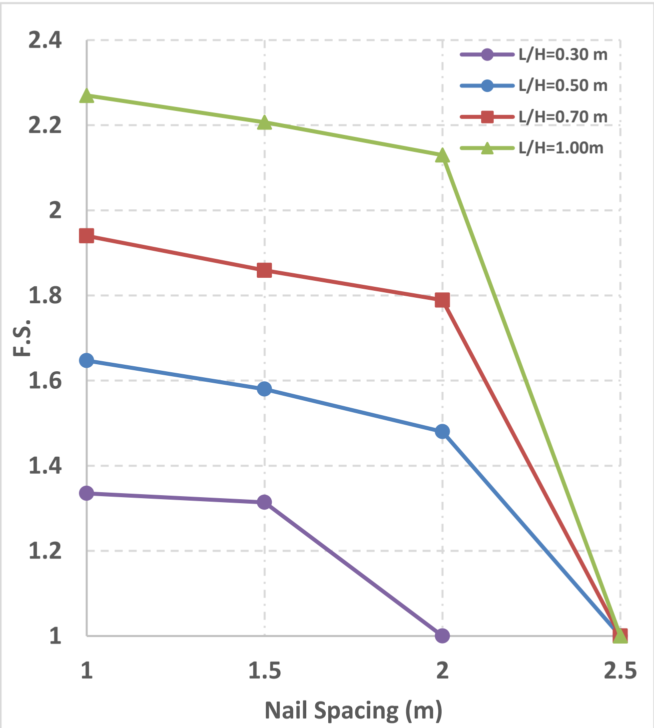

Fig (38): Relation between F.S and spacing between Nails (S) for soil (2) (β =10 ˚, I=20 ˚)

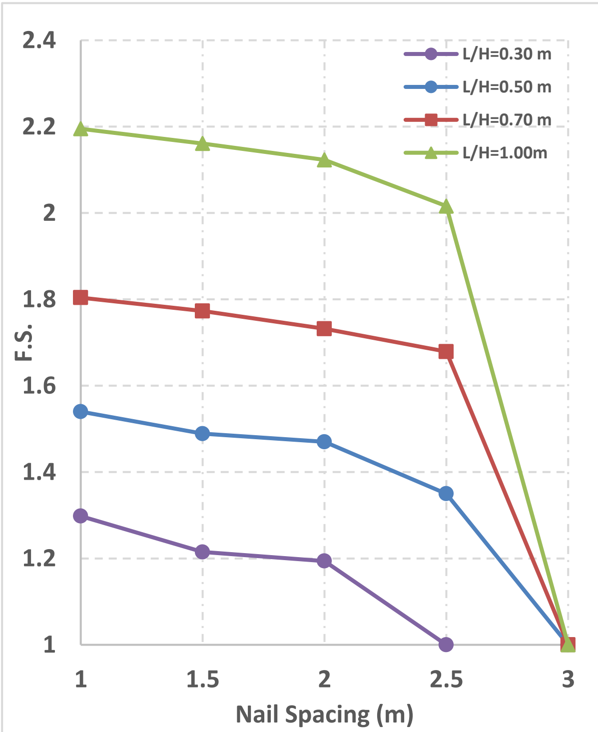

Fig (39): Relation between F.S and spacing between Nails (S) for soil (2) (β =20 ˚, I=10 ˚)

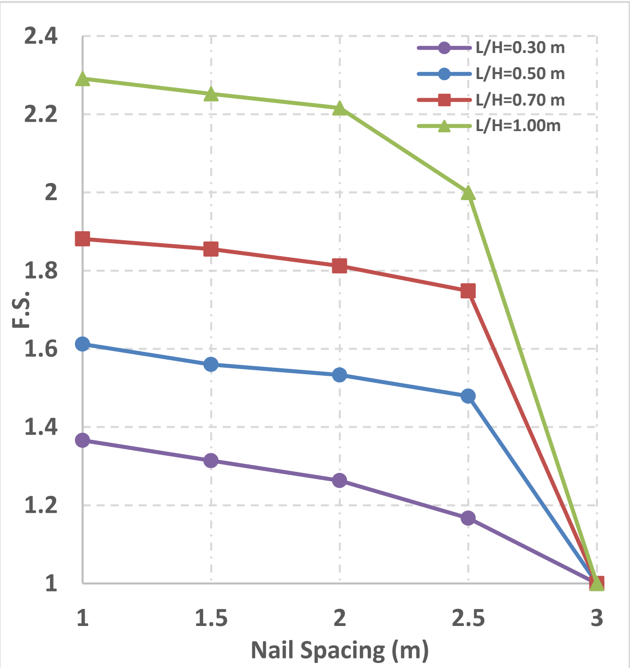

Fig (40): Relation between F.S and spacing between Nails (S) for soil (2) (β =20 ˚, I=15 ˚)

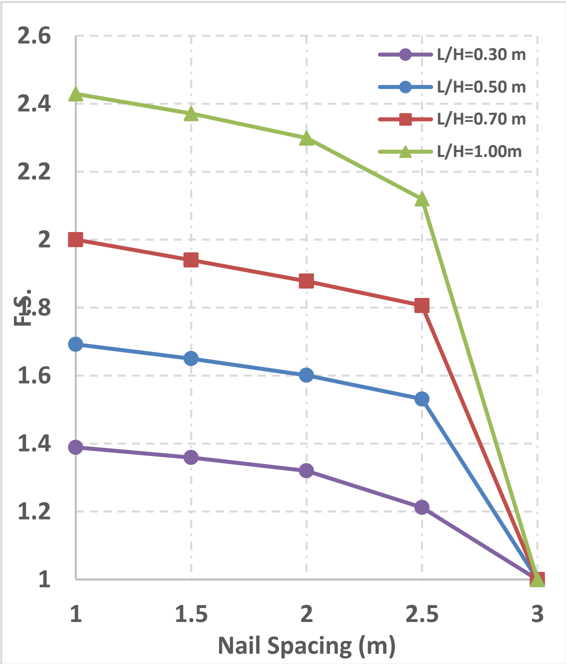

Fig (41): Relation between F.S and spacing between Nails (S) for soil (2) (β =20 ˚, I=15 ˚)

From these figures, it is revealed that optimizing nail spacing is crucial to balancing construction costs with the desired level of stability. While wider spacing may reduce material and installation costs, it should not compromise the safety and performance of the soil-nailed structure. Conducting cost-benefit analyses can help to determine the most economical nail spacing while maintaining an acceptable factor of safety. Wider nail spacing may result in faster installation times and reduced labor costs during construction. However, the potential decrease in the factor of safety should be carefully evaluated to ensure that construction efficiencies do not compromise structural integrity. For soil (1) (for all cases except for L/H=0.30 where failure occurs) and β = 10 °, the maximum spacing between nails that can be used in the design process of nails = 2.00m, and for β = 20 °, the maximum spacing between nails = 2.50 m. On the other hand, for soil (2) and β = 10 °, the maximum spacing between nails = 2.00m except for case of L/H ratio = 0.30, the maximum spacing =1.50 m, and for β =20 º, the max spacing between nails = 2.50 except in case of L/H ratio =0.30 the maximum spacing = 2.00 m.

Stability of Slope Using Berm

Berm construction is a widely employed technique in geotechnical engineering for enhancing slope stability, mitigating erosion, and controlling surface water runoff. Berms redistribute gravitational forces exerted on the slope face by providing horizontal platforms that intercept and redirect downward forces. By increasing the effective width of the slope, berms reduce stress concentrations, stabilize slope segments, and improve overall slope performance (Fay & Shi, 2012).

Berms provide cost-effective and environmentally friendly solutions for mitigating landslide risks, reducing erosion rates, and preserving the integrity of transportation corridors and infrastructure facilities. As shown in Fig. 42 through fig. 44, berms are used to improve the stability of slopes by dividing the overall slope into multiple small slopes which reduces the driving forces and increases the safety factor.

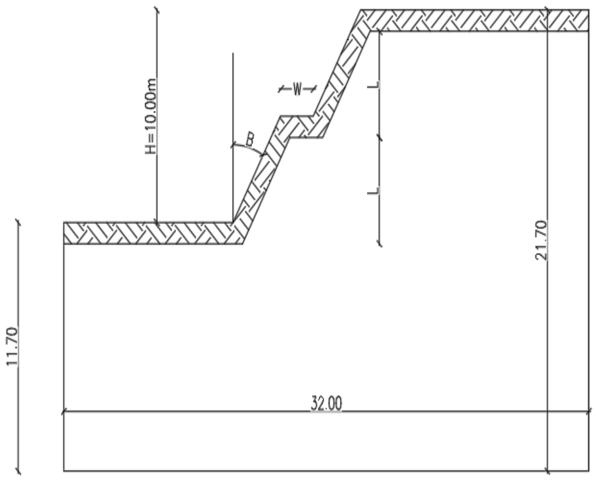

Fig (42): Slope Configuration (Berm with height L=5.00m)

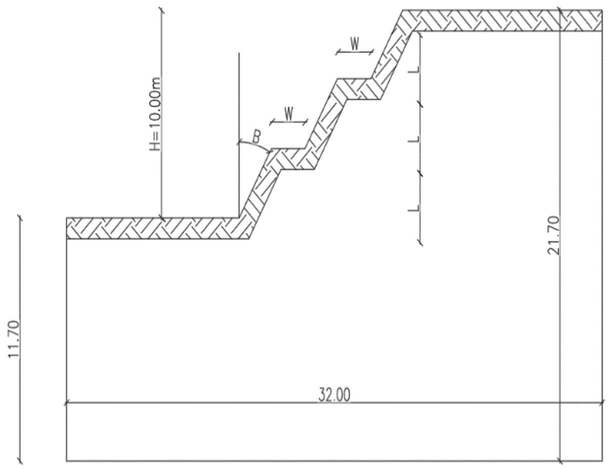

Fig (43): Slope Configuration (Berm with height L=3.33m)

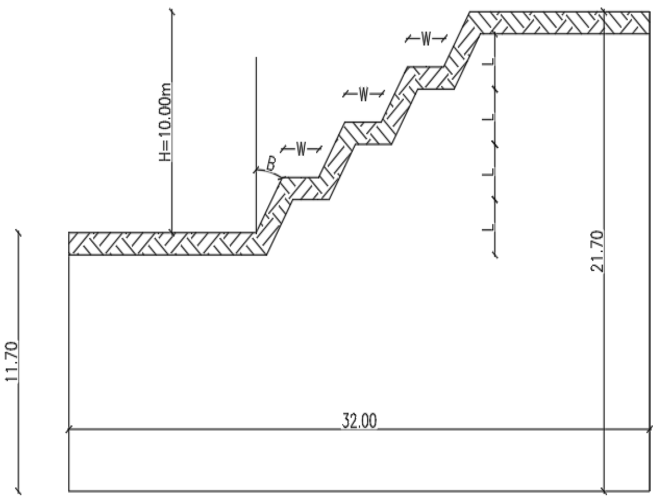

Fig (44): Slope Configuration
(Berm with height L=2.50m)

Effect of Berm Width (W)

The effect of increasing berm width on the safety factor can depend on various factors such as the slope geometry, soil properties, and the intended purpose of the berm. Generally, a wider berm can enhance stability by providing a larger resisting force against slope failure. A wider berm typically increases the resisting force acting against slope failure mechanisms such as sliding or overturning. This can lead to a higher safety factor, indicating greater stability. Field observations and monitoring programs have been implemented to evaluate the performance of berm systems with different berm widths under real-world conditions. Long-term monitoring data provide valuable insights into system behavior, durability, and effectiveness over time, helping validate design assumptions and refine engineering practices

With a wider berm, there is a larger area of soil resisting the downward forces acting on the slope. This reduces the likelihood of failure, thus increasing the safety factor. A wider berm can distribute the load over a larger area, reducing stress concentrations at specific points on the slope. This more uniform distribution of forces can lead to a higher safety factor. Increasing the berm width can provide additional protection against erosion and surface runoff, which can contribute to slope instability. This can indirectly improve the safety factor by preserving the integrity of the slope.

Models were analyzed to study the effect of increasing berm width on the safety factor of slope stability. Figure 45 and Fig. 46 present the relation between berm width and safety factor for soil (1) and soil (2), respectively. From these figures it can be observed that the slope stability increases with increasing the berm width. Also, it is delineated that increasing the berm width is more effective in soil (2) than soil (1).

For soil (1) and berm inclination (B) =20 ° and 30 ° when berm height (L) =5.00 m or 3.33 m, failure occurred. Similarly, for soil type (2) the slope failure occurred when berm height (L) = 5.00 m or 3.33 m. Which means that, for berm height = 2.50 m only

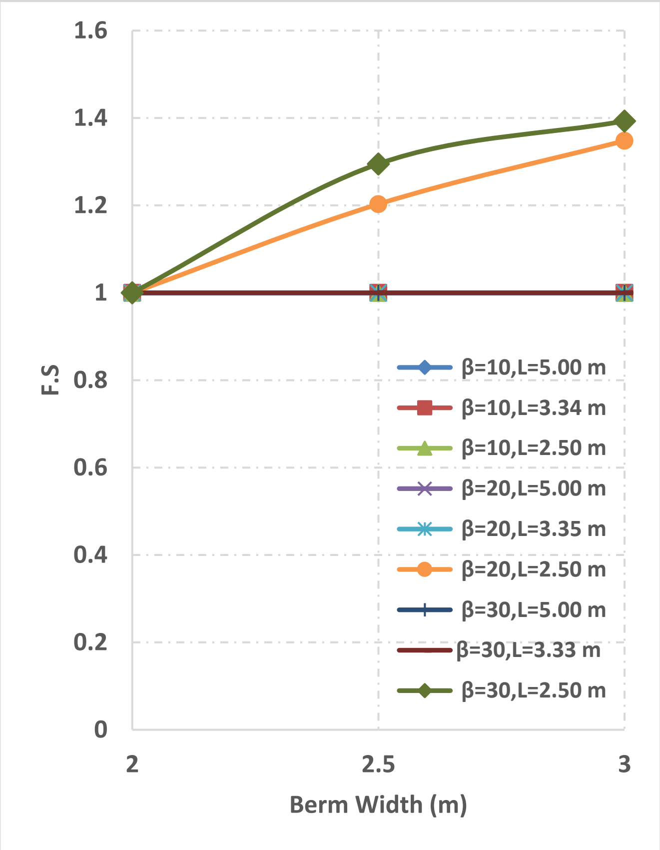

Fig (45): Relation between F.S and berm width (W) for soil (1)

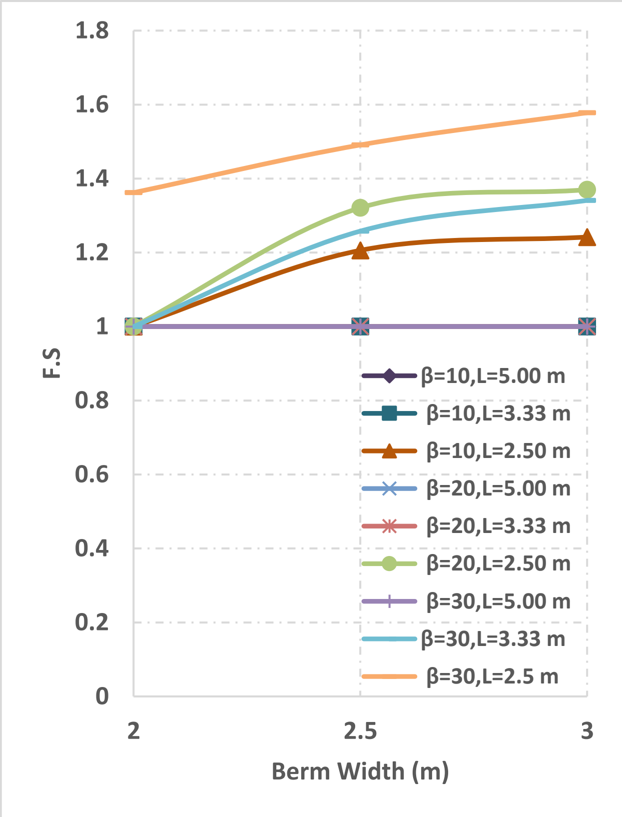

Fig (46): Relation between F.S and berm width (W) for soil (2)

Effect of Berm Height (L)

Decreasing berm height can have several effects on the safety factor, primarily related to the reduction of the resisting force against potential slope failure mechanisms. Berm height plays a crucial role in providing stability to a slope by increasing the resisting force against sliding or overturning. Adjusting the steps of a berm leads to decrease berm height and it can redistribute the mass of soil and alter the distribution of forces acting on the slope.

By modifying the height of berm, the load can be distributed more evenly, reducing stress concentrations, and improving the safety factor. Changes in the steps of a berm may have practical implications for construction methods and materials. Ensuring that the steps are properly constructed and reinforced can contribute to the overall stability of the slope and improve the safety factor. Models were analyzed to study the effect of changing berm height on safety factor. Figure. 47 and Fig. 48 present the relation between berm height and safety factor for soil (1) and soil (2), respectively. These figures show that slope stability safety factor increases with decrease in berm height. It is observed that decreasing berm height is effective in both soil (1) and (2). The reason for increasing safety factor is that the berm divides the overall slope into multiple small slopes, which reduces the driving forces and increase the resisting forces. Hence, it can be inferred that berm height (L) has more effect on slope stabilization compared with berm width (W).

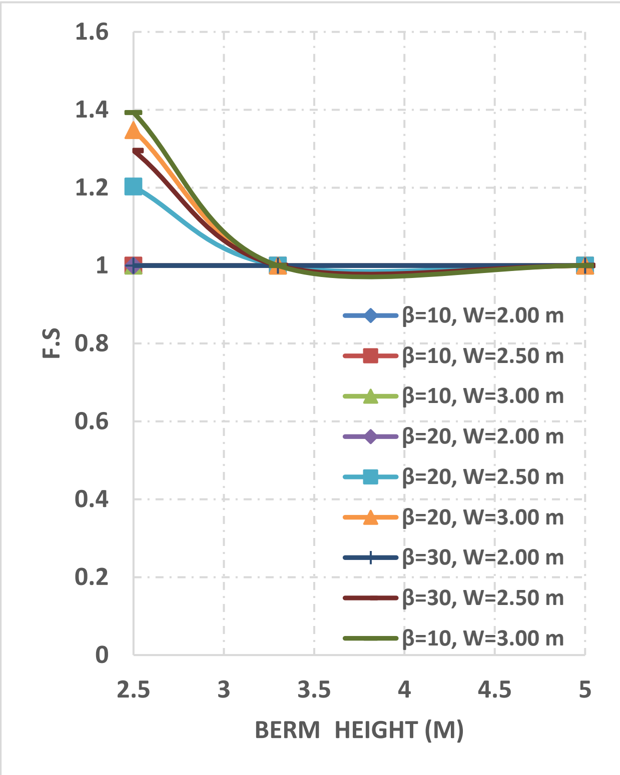

Fig (47): Relation between F.S and berm height (H) for soil (1)

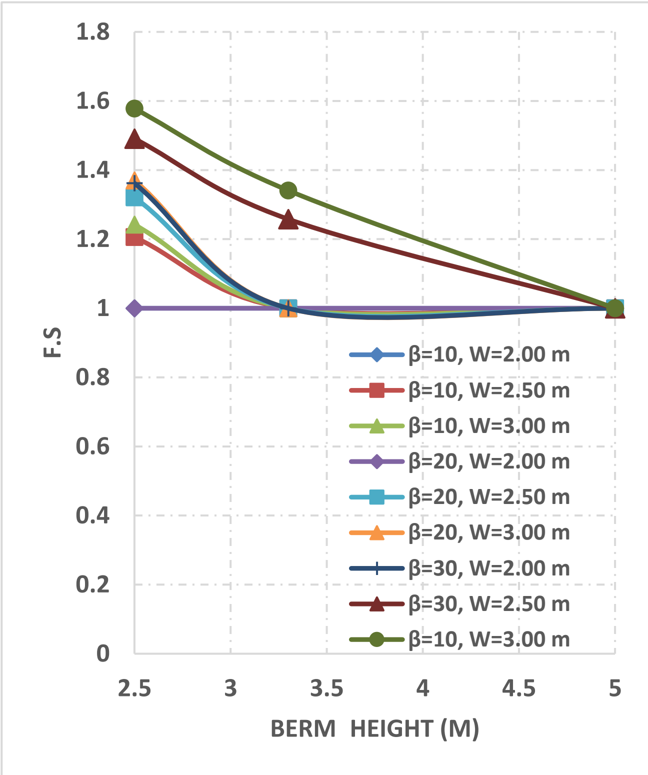

Fig (48): Relation between F.S and berm height (H) for soil (1)

Effect of Berm Inclination (B)

Altering the inclination angle affects the distribution of forces acting on the slope. A steeper angle increases the gravitational force acting downhill, potentially reducing stability and decreasing the safety factor. Conversely, a shallower angle can distribute the load more evenly, enhancing stability and increasing the safety factor.

Steeper berm inclination angles can increase the likelihood of sliding along the slope. This can lead to decreased safety factors, as the resisting forces may be insufficient to counteract the increased driving forces. Conversely, a shallower angle can improve resistance to sliding, contributing to higher safety factors. Shallower angles may be more feasible to construct and maintain, leading to higher safety factors due to better construction quality and stability.

Figure. 49 and Fig. 50 present the relation between berm inclination(β) and safety factor for soil (1) and soil (2), respectively. From these figures it can be observed that slope stability increases with the increase in berm slope angle (B). It is observed that increasing in slope inclination angle (β) is effective in soil (1) and (2). Hence, it can be inferred that slope inclination (β) has more effect on slope stabilization compared with berm width.

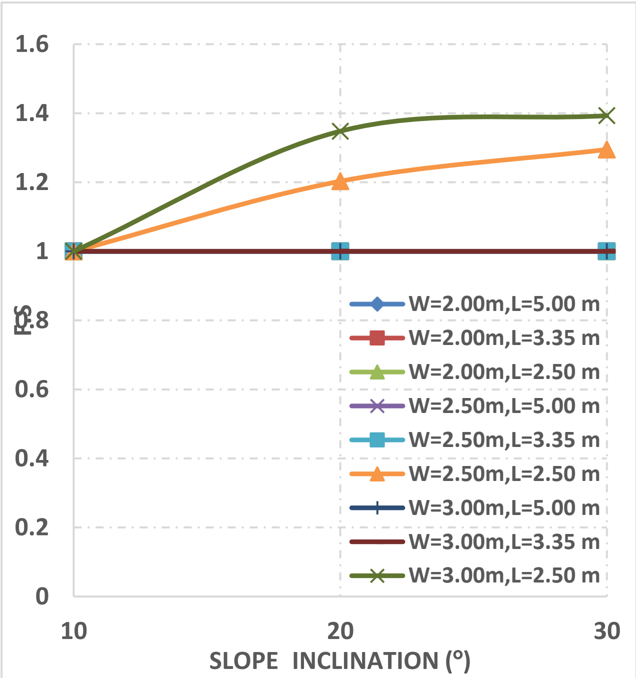

Fig (49): Relation between F.S and slope inclination for soil (1) (β =20 °)

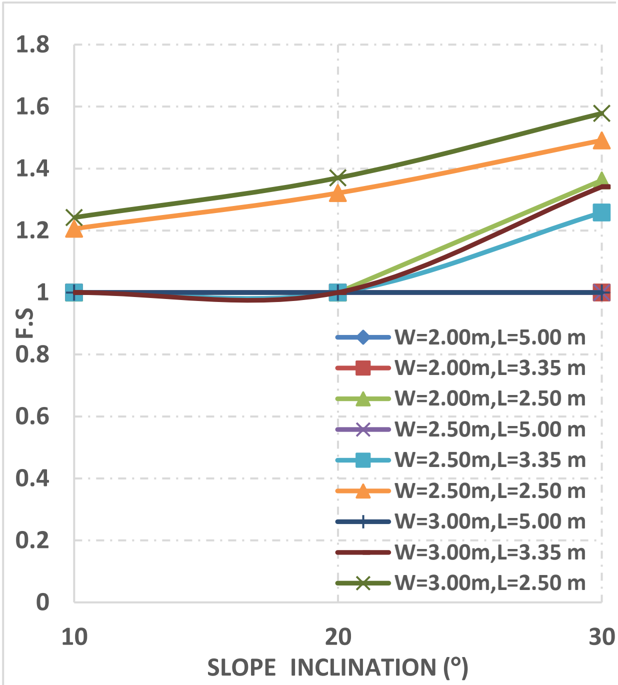

Fig (50): Relation between F.S and slope inclination for soil (1) (β =30 °)

Conclusions

Based on the results of the carried out numerical study, it is concluded that:

- Soil nailing and berming technique are two approaches that used for slope stability. There are some variables that affect and increase safety factor such as Nail length as when nail length to wall height ratio increases the safety factor increase as a result of greater length in the passive zone of slope.

- Changing in nail inclination angle (I) from 10 ° to 20 ° can be affect the safety factor with a negligible effect. Spacing between nails has a significant effect on the stability of slopes as when the spacing between nails increase the area served by nails is increased as a result the safety factor decrease the max spacing between nails range from 2.00 to 3.00 m depend on the soil types. Slope angle of slope (β) when change from 10° to 20° that lead to decrease the forces on nailing system and that lead to increase safety factor.

- In case of using berming technique, when increase the berm width, the safety factor increases. Another crucial factor is called berm height, when berm height decrease, it lead to increase the safety factor due to berm divide the overall slope into multiple small slopes which reduces the driving forces and increasing the resisting forces. When the slope of berm (B) change from 10° to 30 that lead to increase safety factor.

- The choice between soil nailing and berm as shown in table (2) should be decided based on a comprehensive assessment of site-specific conditions, project requirements, and stake-holder objectives. Factors such as slope geometry, soil characteristics, environmental consid-erations, construction feasibility, and budget constraints should all be taken into account when selecting the most proper stabilization technique.

Table (2): The Comparison between soil nailing and berm

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Soil Nailing</td><td colspan="2">Berm Stabilization</td></tr>
<tr><td>Soil (1)</td><td>Soil (2)</td><td>Soil (1)</td><td>Soil (2)</td></tr>
<tr><td rowspan="2">Safety Factor</td><td>B=10°</td><td>F.O. S=1.49</td><td>F.O. S=1.82</td><td>Failure occurred</td><td>Failure occurred</td></tr>
<tr><td>B=20°</td><td>F.O. S=1.53</td><td>F.O. S=1.85</td><td>F.O. S=1.27</td><td>F.O. S=1.38</td></tr>
<tr><td colspan="2">Stability and Performance</td><td colspan="4">Both soil nailing and berm stabilization techniques are capable of providing effective slope stabilization. Soil nailing offers superior resistance against sliding and can accommodate a wider range of slope geometries. However, berms provide better erosion control and may be more suitable for certain site conditions.</td></tr>
<tr><td colspan="2">Versatility and Adaptability</td><td colspan="2">Soil nailing is more versatile and adaptable to various soil types and ground conditions</td><td colspan="2">berm construction may be challenging</td></tr>
<tr><td colspan="2">Cost and Construction</td><td colspan="2">soil nailing may offer advantages in terms of construction speed and flexibility.</td><td colspan="2">berm is generally more cost-effective and re-quires less specialized equipment</td></tr>
</table>

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