



# A parametric study of soil nailed slope for the multiple soil type under static and pseudo static condition using software

Vipul R.OD,<sup>1</sup> Dr. N.H. Joshi<sup>2</sup>, Mrs. Kajal S. Vachhani<sup>3</sup>

M.E Research Scholar, Department of Applied Mechanics, The Maharaja Sayajirao University of Baroda, Vadodara Gujarat, India

Associate Professor, Department of Applied mechanics, The Maharaja Sayajirao University of Baroda, Vadodara , Gujarat, India

**ABSTRACT:** The study investigates soil slope failures under static, dynamic, and rapid drawdown loading conditions. Soil nails are employed at inclinations of 10°, 15°, 20°, and 25° relative to the horizontal, subjected to tensile stresses. This reinforcement is applied in a homogeneous soil slope under dynamic loading, assuming a planar failure surface at the slope toe. Analytical methods are utilized to calculate the global factor of safety, considering both resisting forces from the soil nails and driving forces induced by the loading conditions. The study explores the impact of various factors such as nail inclination angle, combinations of horizontal and vertical seismic acceleration coefficients, and soil friction angle on the factor of safety. Findings indicate that the factor of safety decreases with higher seismic acceleration coefficients and greater inclination angles of the soil nails. Design charts derived from the proposed method offer practical tools for analyzing and designing reinforced soil slopes under seismic conditions.

## 1INTRODUCTION

When designing and building different geotechnical constructions, such as embankments, earth dams, and excavations, soil slope stability is a crucial consideration. Slope failures or man-made structures such as embankments and dams have caused substantial losses in terms of property and human lives in the past. Numerous loading scenarios, such as dynamic loading, fast drawdown, static loading, and even vehicle loads acting as point loads, might cause these problems. It is crucial to properly analyse these situations since they have the potential to cause landslides and other slope failures, which can be catastrophic and devastate the environment. Slender components called as soil nails or reinforcing bars have become widely used in a technique for strengthening soil slopes, retaining walls, and excavations in recent years. These soil nails are exposed to tensile stresses caused by the deformation of retained materials during excavation operations. Typically, they are installed at inclinations between 10° and 25° with the horizontal. Hard to stiff fine-grained soils, such as stiff clay, clayey silts, silty clays, sandy clays, and their mixtures, respond best to soil nailing. Dense to extremely dense granular soils with some apparent cohesiveness might also benefit from it. The idea behind soil nailing is to increase the stability of the soil mass by transferring loads to the earth through these inserted nails. This method has been useful in guarding against slope collapses and guaranteeing the longevity and safety of geotechnical constructions in a range of loads and environmental scenarios.

Limit equilibrium, finite element, and limit analysis techniques have all been put forth by various scholars for the stability analysis of reinforced soil slopes in seismic and static circumstances. The design and construction approach of nailed soil slopes in static conditions was the subject of canonical work by Sheahan and Ho (2003), Chu and Yin (2005), and Fan and Jiun (2008). Using horizontal slices, Shohola et al. (2001) examined the reinforced soil slope under pseudo-static conditions while taking into account a polylinear failure surface. The pseudo-dynamic method was employed by Nimbalkar et al. (2006) to assess the seismic stability of a

reinforced soil wall. The horizontal slice approach was employed by Choudhury and Modi (2008) to compute seismic displacement and conduct a stability analysis on soil slopes that are either reinforced or unreinforced. Additionally, Yin and Su (2006), Pradhan et al. (2006), Su et al. (2007), and Su et al. (2008) have conducted studies on the interaction between nails and soil.

### Numerical Model

This paper presents the stability analysis for a nailing slope in both static and seismic situations. The slope has a  $50^\circ$  slope angle and a 10-meter height.

### Slope/w modeling for pseudo static analysis

To determine the slope's stability in the event of a certain PGA earthquake, more analysis is done. Seismic loading is taken into account in pseudo-static analysis using both vertical and horizontal seismic coefficients of earthquake. Pseudo-static analysis is comparable to static analysis in terms of slope modeling and material assignment. Once the slope model is completed, the magnitudes of the earthquake's horizontal and vertical seismic coefficients are provided as input. Seismic coefficients of  $k_h = 0.13$  and  $k_v = 0.065$  are taken into consideration for the analysis in this study. The main outcomes of the pseudo-static analysis are the failure slip circle and the factor of safety (FOS).

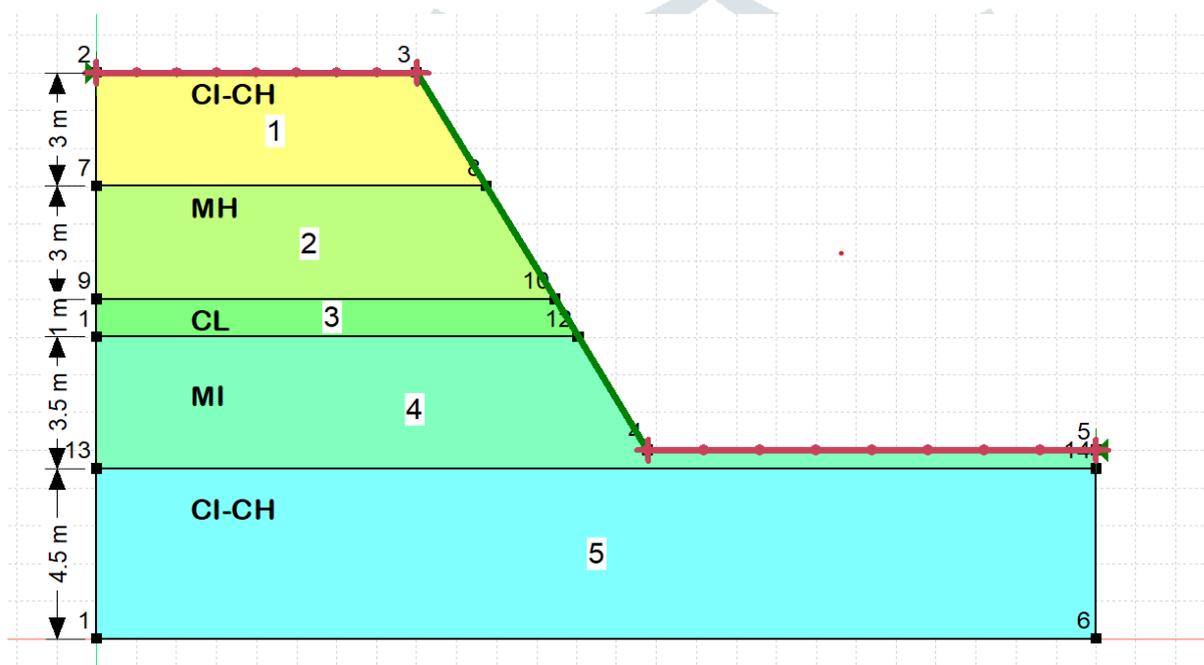


Figure 2.1: Software Model multiple layer

### Constitutive Modelling

The coordinate system included in the SLOPE/w is used to simulate the slope at various slope angles and heights. After the slope regions have been identified, materials of slope are defined and allocated to the various regions. Reinforcement can be added using the SLOPE/w module in the form of piles, anchors, nails, and geosynthetics. In this analysis, the nail element option is employed. Table 2 provides a summary of the nail qualities considered in the analysis. By supplying the slip surface's range along the ground surface, the slip surface is replicated. The entry-exit option is employed in this study to approximate the slip surface's range. SLOPE/w offers many limit equilibrium techniques for the problem's analysis. Bishop's simplified approach is taken into consideration when analyzing stability.

Table 3.1: Optimum nail details used in the analysis

| Property           | Symbol    | (change) Values       |
|--------------------|-----------|-----------------------|
| Yield strength     | $f_y$     | 415 N/mm <sup>2</sup> |
| Nail diameter      | D         | 16mm                  |
| Nail length        | L         | 0.8H                  |
| Nail inclination   | $\Lambda$ | 25°                   |
| Horizontal spacing | $S_h$     | 1.5m                  |
| Vertical spacing   | $S_v$     | 1.5m                  |

## INPUT PARAMETER FOR NUMERICAL ANALYSIS

Table 4.1 lists the specific soil characteristics that were used for the SLOPE/W modules. Figure 2.1 mentions the vertical incision that was simulated using the GeoStudio software.

Table 4.1: Soil properties – multiple soil layer

| SLOPE/W             |  |                   |                        |
|---------------------|--|-------------------|------------------------|
| Layer (m)           | Unit wt. $\gamma$ , [KN/m <sup>3</sup> ] | Cohesion C, [KPa] | Friction angle, $\Phi$ |
| 1 <sup>nd</sup> 3   | 14.7                                     | 15                | 23                     |
| 2 <sup>nd</sup> 3   | 14.7                                     | 8                 | 26                     |
| 3 <sup>nd</sup> 1   | 15.1                                     | 8                 | 26                     |
| 4 <sup>nd</sup> 3.5 | 16.4                                     | 6                 | 27                     |
| 5 <sup>nd</sup> 4.5 | 16                                       | 12                | 24                     |

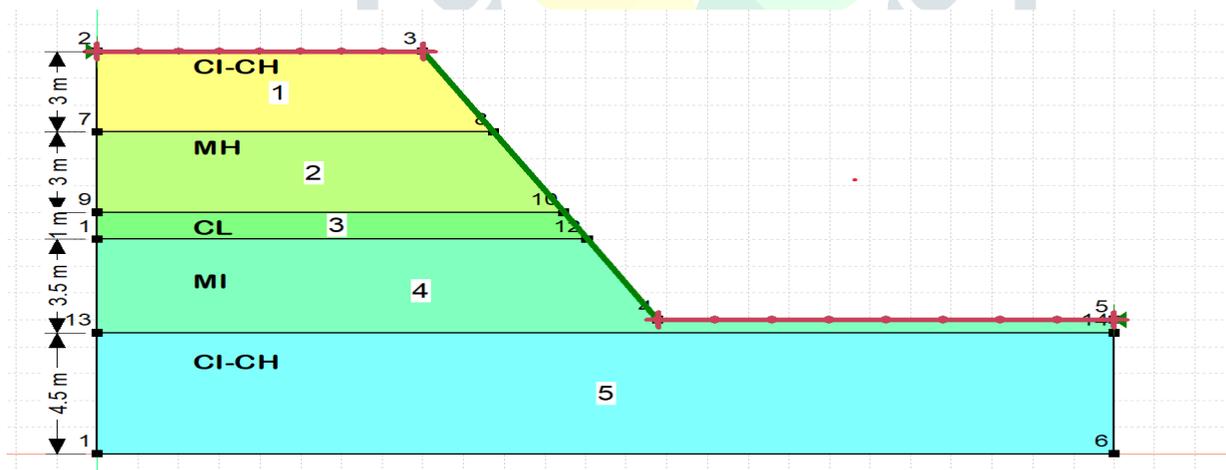
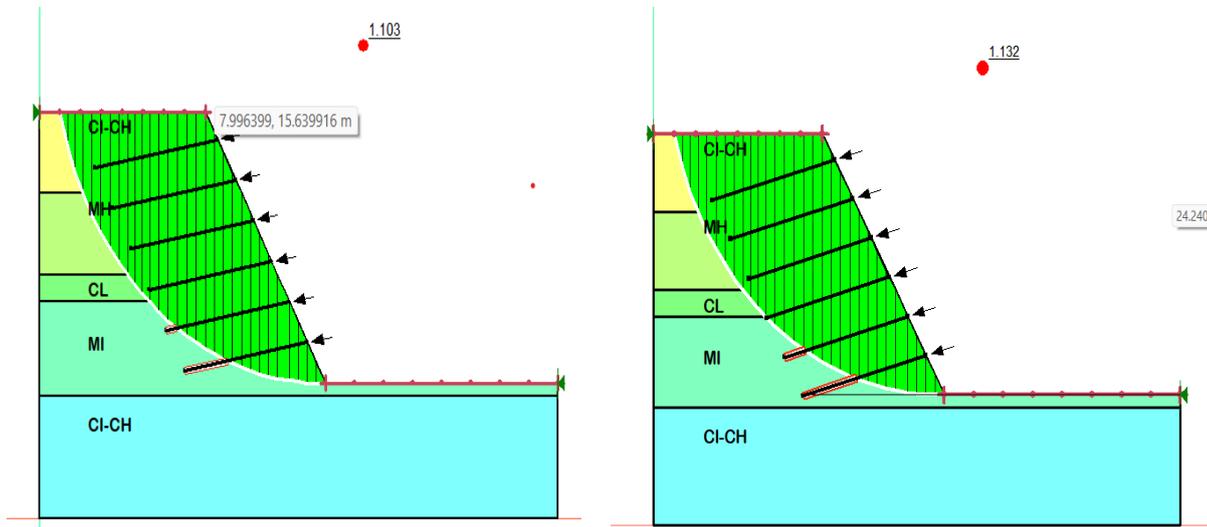


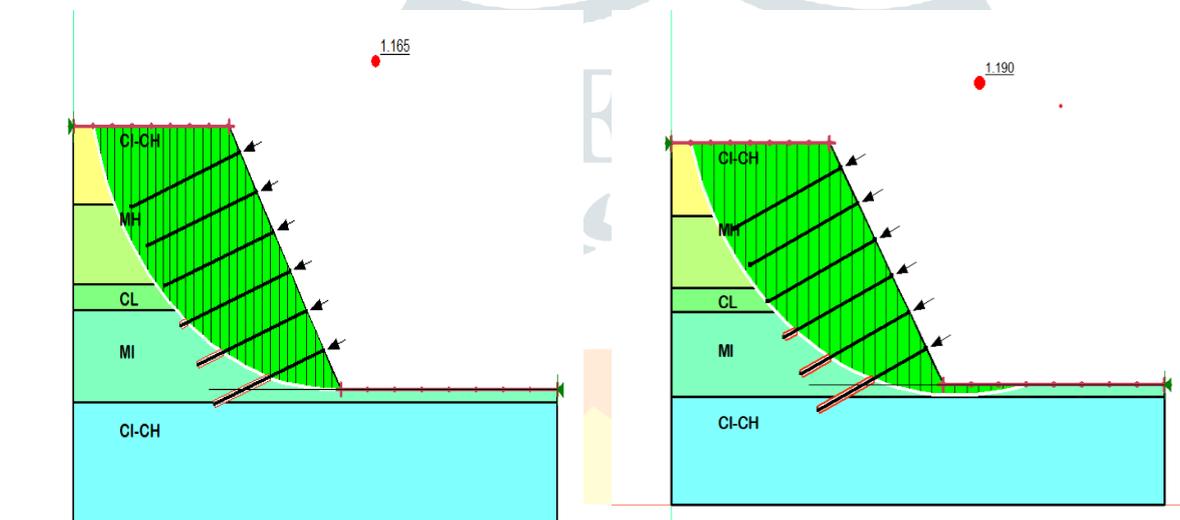
Figure 4.2: Software Model multiple layer  
Numerical Study

The following graph 5.15, from (a) to (e), which are provided below, the effect of the seismic coefficient on FOS is depicted for all nails inserted at different inclination angles and nail lengths. Nail spacing is between 1.5 m and 2 m, nail inclination is between 10° and 25°, nail diameter is 16 mm, and drill hole diameter is 100 mm. The range of nail lengths taken into consideration for this analysis is from 6 m to 7.5 m. For 1.5 m and 2 m nail spacing, separate analyses were conducted. It was observed from the analysis that the safety factor for the vertical cut reduced as the value of the horizontal seismic coefficient rose. All nails that were put at different inclination angles and with different nail lengths and 1.5 m and 2 m nail spacing displayed a similar trend.



(a) 6m Nail inclination angle 10°

(b) 6m Nail inclination angle 15°



(c) 6m Nail inclination angle 20°

(d) 6m Nail inclination angle 20°

Figure (a to d): 6 m Nail length installed at various inclination angles ranging from 10° to 25°  
Various Seismic coefficients kh=0.1to0.4

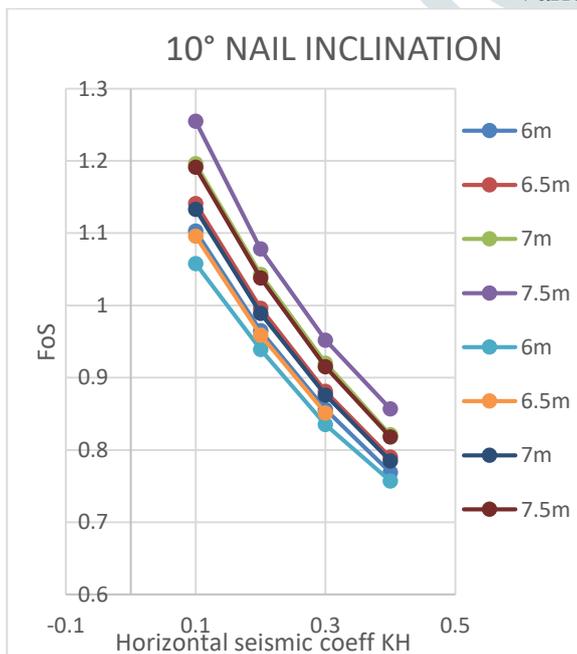
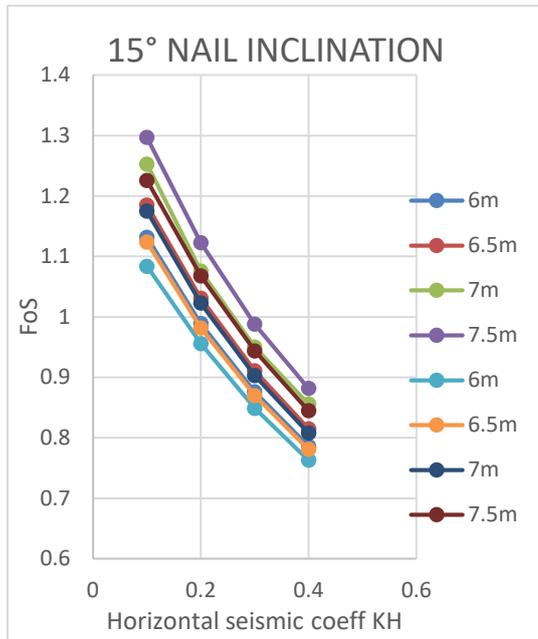


Table : Factor of safety at different seismic coefficients - 10° nail inclination Multiple soil layers

| Nail length                  | 10 Seismic coefficients |       |       |       |
|------------------------------|-------------------------|-------|-------|-------|
|                              | 0.1                     | 0.2   | 0.3   | 0.4   |
| <i>For 1.5m nail spacing</i> |                         |       |       |       |
| <b>6</b>                     | 1.103                   | 0.965 | 0.856 | 0.769 |
| <b>6.5</b>                   | 1.141                   | 0.996 | 0.881 | 0.79  |
| <b>7</b>                     | 1.196                   | 1.043 | 0.92  | 0.821 |
| <b>7.5</b>                   | 1.255                   | 1.078 | 0.952 | 0.857 |
| <b>For 2 m nail spacing:</b> |                         |       |       |       |
| <b>6</b>                     | 1.058                   | 0.939 | 0.835 | 0.757 |
| <b>6.5</b>                   | 1.096                   | 0.959 | 0.851 | 0.765 |
| <b>7</b>                     | 1.133                   | 0.989 | 0.876 | 0.785 |
| <b>7.5</b>                   | 1.191                   | 1.038 | 0.915 | 0.818 |

FOS v/s Kh - 10° nail inclination

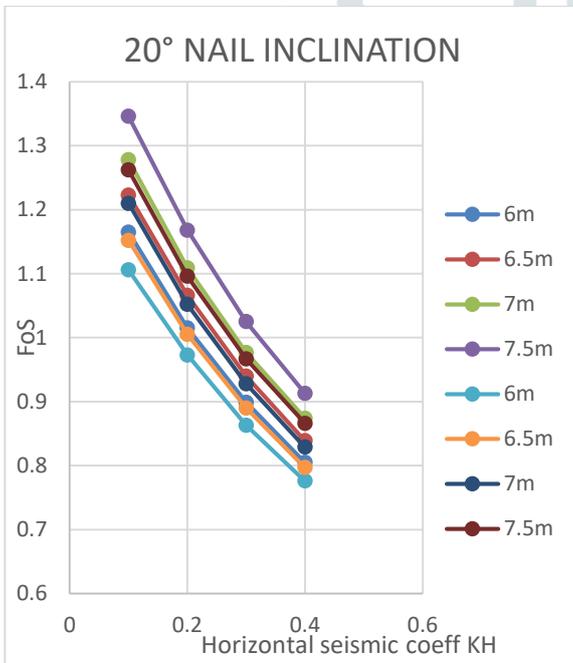


FOS v/s Kh - 15° nail inclination

Figure (a & b): FOS v/s Seismic coefficient ( $K_h$ ) for soil type: multiple soil layer

Table 5.2: Factor of safety at different seismic coefficients - 15° nail inclination Multiple soil layers

| Nail length                  | 15 Seismic coefficients |       |       |       |
|------------------------------|-------------------------|-------|-------|-------|
|                              | 0.1                     | 0.2   | 0.3   | 0.4   |
| <i>For 1.5m nail spacing</i> |                         |       |       |       |
| <b>6</b>                     | 1.132                   | 0.989 | 0.876 | 0.786 |
| <b>6.5</b>                   | 1.185                   | 1.031 | 0.911 | 0.815 |
| <b>7</b>                     | 1.253                   | 1.076 | 0.95  | 0.856 |
| <b>7.5</b>                   | 1.297                   | 1.123 | 0.988 | 0.882 |
| <b>For 2 m nail spacing:</b> |                         |       |       |       |
| <b>6</b>                     | 1.084                   | 0.956 | 0.849 | 0.763 |
| <b>6.5</b>                   | 1.124                   | 0.982 | 0.87  | 0.781 |
| <b>7</b>                     | 1.175                   | 1.023 | 0.903 | 0.808 |
| <b>7.5</b>                   | 1.226                   | 1.068 | 0.944 | 0.845 |



FOS v/s Kh - 20° nail inclination

Table : Factor of safety at different seismic coefficients - 20° nail inclination Multiple soil layers

| Nail length                  | 20 Seismic coefficients |       |       |       |
|------------------------------|-------------------------|-------|-------|-------|
|                              | 0.1                     | 0.2   | 0.3   | 0.4   |
| <i>For 1.5m nail spacing</i> |                         |       |       |       |
| <b>6</b>                     | 1.165                   | 1.015 | 0.899 | 0.805 |
| <b>6.5</b>                   | 1.223                   | 1.066 | 0.94  | 0.839 |
| <b>7</b>                     | 1.278                   | 1.109 | 0.977 | 0.874 |
| <b>7.5</b>                   | 1.346                   | 1.168 | 1.025 | 0.913 |
| <b>For 2 m nail spacing:</b> |                         |       |       |       |
| <b>6</b>                     | 1.106                   | 0.973 | 0.863 | 0.776 |
| <b>6.5</b>                   | 1.152                   | 1.005 | 0.89  | 0.797 |
| <b>7</b>                     | 1.21                    | 1.052 | 0.928 | 0.829 |
| <b>7.5</b>                   | 1.262                   | 1.096 | 0.967 | 0.866 |

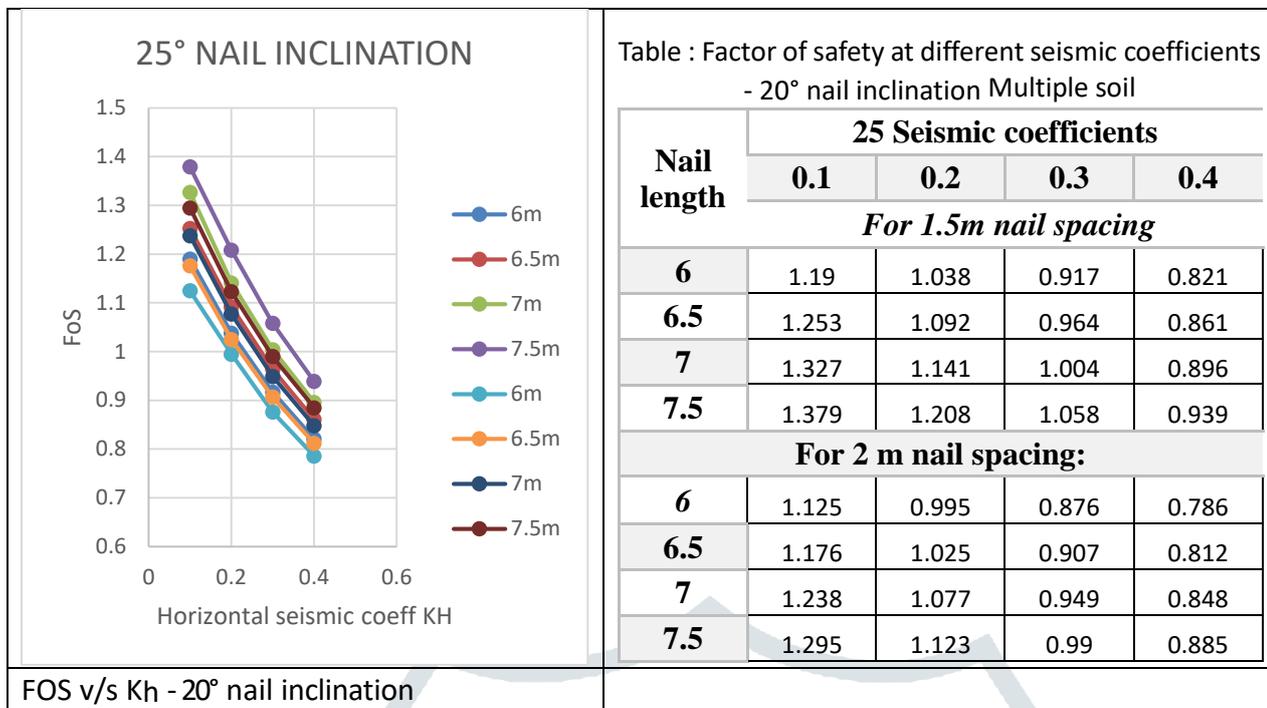


Figure (c & d): FOS v/s Seismic coefficient ( $K_h$ ) for soil type: multiple soil layer

## CONCLUSION

the Multiple Soil Layer, the initial FOS was 1.054, which increased to 1.557 after the installation of nails under comparable conditions.

Moreover, the study examined the influence of seismic coefficients ( $K_h$ ) ranging from 0.1 to 0.5 on the FOS of soil nailed walls. It was found that increasing  $K_h$  generally decreased the safety factor across all soil types considered. This underscores the importance of accounting for seismic conditions in the design and reinforcement of slope stability measures.

In the case of *Multiple soil layers*, increasing the seismic coefficient from 0.1 to 0.4 significantly affected the soil-nailed wall's factor of safety. The factor of safety specifically dropped by 61% when a 1.5 m nail spacing was taken into account. The factor of safety also reduced by 63% with a 2 m nail spacing.

The factor of safety for each of the soil types described increased significantly as a result of the installation of nails. To accomplish the necessary improvement in stability and factor of safety for each soil condition, the precise parameters of nail length, nail inclination angle, and nail size were chosen.

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