E-ISSN: 2528-388X
P-ISSN: 0213-762X

INERSIA
Vol.20, No.2, December 2024

# Effect of Parametric Soil Nailing under Seismic Behavior

Anggie Ramayanti, Fikri Faris*, Hary Christady Hardiyatmo

Department of Civil and Environment Engineering, Universitas Gadjah Mada, Yogyakarta, 55281, Indonesia

Keywords:
Slope stability
Slope failure
Dynamic
Slope reinforcement
Finite element method

ABSTRACT

The Wonogiri region has hilly contours that make the area vulnerable to slope failure. Treatment of slope failure can be done by several methods, such as geometry changes, controlling drainage and creating structures for stability such as soil nailing. Soil nailing has proven useful as a slope reinforcement with several advantages such as low cost and fast implementation. This study aims to see the effect of the parametric behavior of soil nailing on the displacement and axial force of the nail bar under earthquake conditions. First, soil nails are modeled in the finite element method with variations in length, horizontal distance, and vertical distance between nails by applying pseudo-static load based on the history of the largest earthquake that have occurred at the research location, then displacement and axial forces on the nail bar are checked. The modeling shown that increasing the length increases the safety factor, reduces the displacement of the soil nailing wall, and reduces the axial force on the nail bar, as it increases the length of the nail behind the landslide plane and increases the friction between the nail and the soil which resists excessive displacement of the soil surface. Meanwhile, increasing the horizontal and vertical spacing reduces the safety factor, increases the displacement of the soil nailing wall, and reduces the axial force on the nail bar, due to the increased friction between the nail and the soil. Vertical nail spacing variation has more effect on safety factor, displacement, and axial force than horizontal nail spacing variation.



## 1. Introduction

Central Java, especially the Wonogiri region, has hilly contours that makes this area vulnerable to slope stability failure. Slope stability is influenced by environmental factors such as rain, soil geology, human activities, and vibrations such as earthquakes [1]. To overcome the problem of slope instability, it can be solved by changing the slope geometry [2], adjusting the groundwater level such as making drainage [3], and making retaining structures, such as retaining wall [4], sheet pile [5], anchor [6], soil nailing [7], and geotextile [8].

Soil nailing was chosen because it has advantages such as relatively cheaper costs than concrete gravity walls and anchor walls and relatively fast installation. In its implementation, soil nailing does not require a large work area because it uses smaller tools, so it does not interfere with traffic on site and is easy to mobilize, unlike soldier pile walls or drilled shafts. Furthermore, soil nailing is also flexible to changes in movement and has satisfactory performance during earthquake [9].

In designing soil nailing, it is necessary to consider several nail bar parameters that affect slope stability, such as nail bar inclination [10], nail bar spacing, nail bar length [11], nail bar stiffness [12] dan wall thickness [13]. The treatment with soil nailing has been proven to increase the value of the slope safety factor by reducing the deformation that occurs on the slope, especially in earthquake conditions [7]. During an earthquake, the driving force will increase and reduce the slope resisting force and the equivalent force of the nails, affecting the global stability of the slope.

Stability analysis of soil nailing walls can be performed using the limit equilibrium method (LEM) [14], finite difference method (FDM) [15], or finite element method (FEM), which is then tested in the laboratory to see the deformation pattern that occurs [16], or by measuring the amount of deformation directly in the field with strain gauges on the surface wall [17]. The results show that the numerical analysis can represent the deformation conditions satisfactorily.

An example of slope failure treatment using soil nailing is observed in the Giriwoyo-Glonggong road section, considering the influence of major earthquakes that

*Corresponding author.
E-mail: fikri.faris@ugm.ac.id
http://dx.doi.org/10.21831/inersia.v20i2.74144
Received March 21st 2024; Revised November 24th 2024; Accepted November 26th 2024
Available online 15th December 2024

occurred around the Giriwoyo area, this research aims to explore the parametric study of soil nailing on the seismic behavior of the Giriwoyo road section using finite element method. The parametric that will be studied are the effect of the length, horizontal distance, and vertical distance of the nail bar on the safety factor, displacement, and axial force of the nail bar.

## 2. Research Methods

This research is located on the slope of the Giriwoyo-Glonggong road section, Wonogiri district, Central Java Province, with a slope height of 18 meters as show in Figure 1.

### 2.1 Finite Element Model

The geometry of the 18-meter-high slope with inclination 72˚ used in the finite element modeling can be seen in Figure 2. In this modeling using Mohr-Coulomb soil model parameters can be seen in Table 1 and the reinforcement used is soil nailing with parameters can be seen in Table 2.

In RS2 modeling, the Shear Strength Reduction method is used to determine the safety factor for the slope. Shear strength reduction method is a repeated process with different values of strength reduction factor (SRF) until the model becomes do not converged and show the critical SRF or safety factor [18].

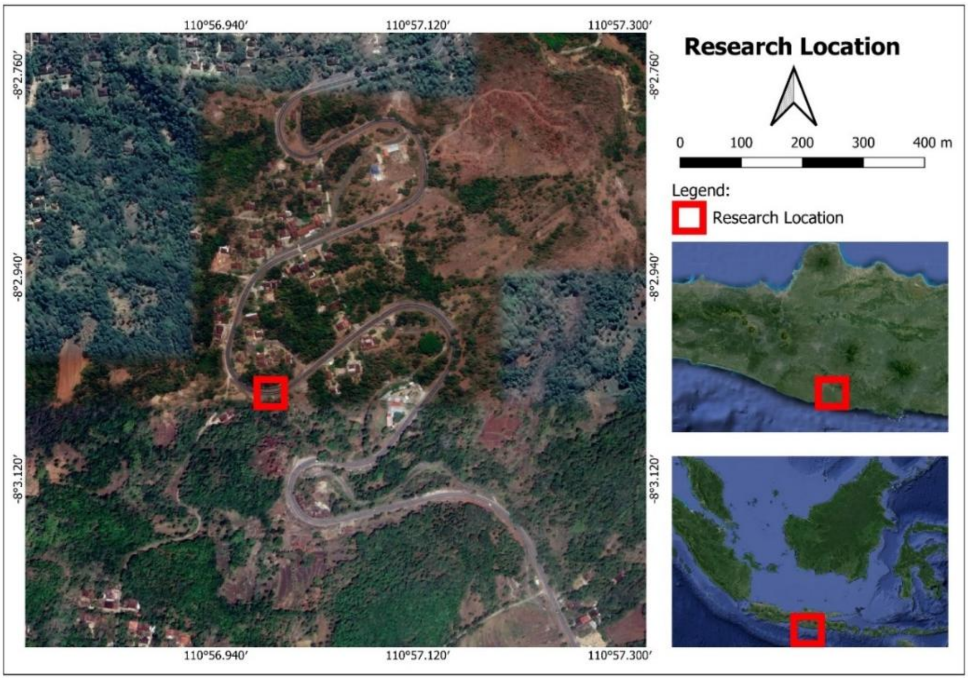



**Figure 1.** Study area

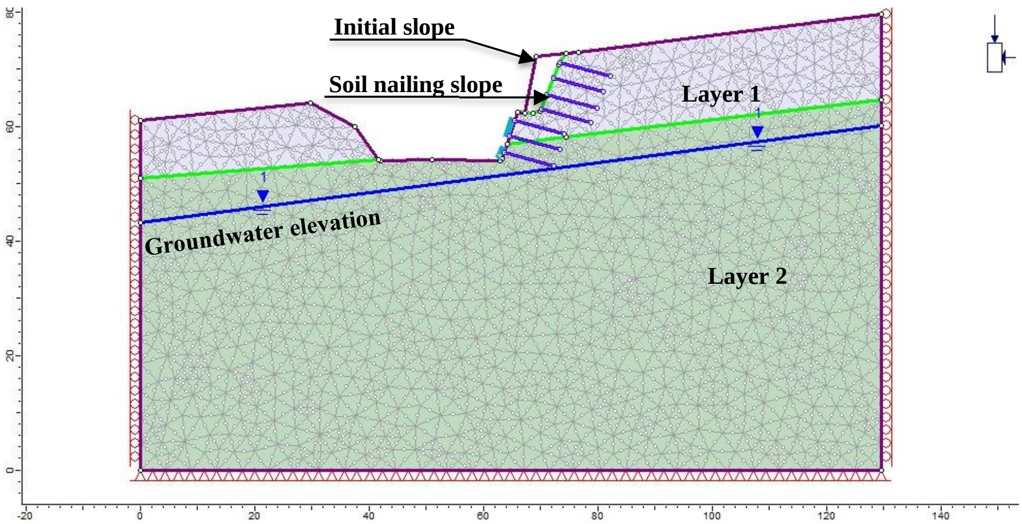



**Figure 2.** Geometry and meshing of the finite element model

**Table 1.** Soil parameter

| Parameter | Layer 1 | Layer 2 |
|---|---|---|
| Soil type | Clayey-sandy | Sand and silt |
| Unit weight, $\gamma$ (kN/m$^3$) | 18 | 19 |
| Poisson's ratio, $\upsilon$ | 0.35 | 0.4 |
| Modulus elasticity, $E$ (kPa) | $60 \times 10^3$ | $108 \times 10^3$ |
| Friction angle, $\phi$ (°) | 23 | 40 |
| Cohesion, $c$ (kPa) | 32 | 8 |

**Table 2.** Parameter soil nailing

| Parameter | Value |
|---|---|
| Diameter of nail bar (mm) | 32 |
| Tensile capacity (kN) | 430 |
| Nail modulus (kPa) | $2.10^8$ |
| Inclination (˚) | 15 |
| Model | Fully bonded |
| Grout fc' (kg/cm$^2$) | 250 |

### 2.3 Earthquake Analysis

Earthquake analysis was conducted to obtain the value of Peak Ground Acceleration that would be used in modeling. The first step in determining Peak Ground Acceleration was to determine the reference earthquake from earthquake records that have occurred around the location with a maximum distance of 100 km with a minimum Mw of 5, which can be seen in Figure 3 then would be recapitulated the 5 largest earthquakes that have ever occurred as show in Table 3.

Based on the Table 3 can be seen that the earthquake with the largest magnitude was caused by the Opak fault with a magnitude of 6.3 and a distance of 58.3 km from the research location based on latitude and longitude coordinates. From this reference earthquake data, a ground motion search was conducted from the PEER NGA West website [19], by inputting the magnitude, distance, and fault type values.

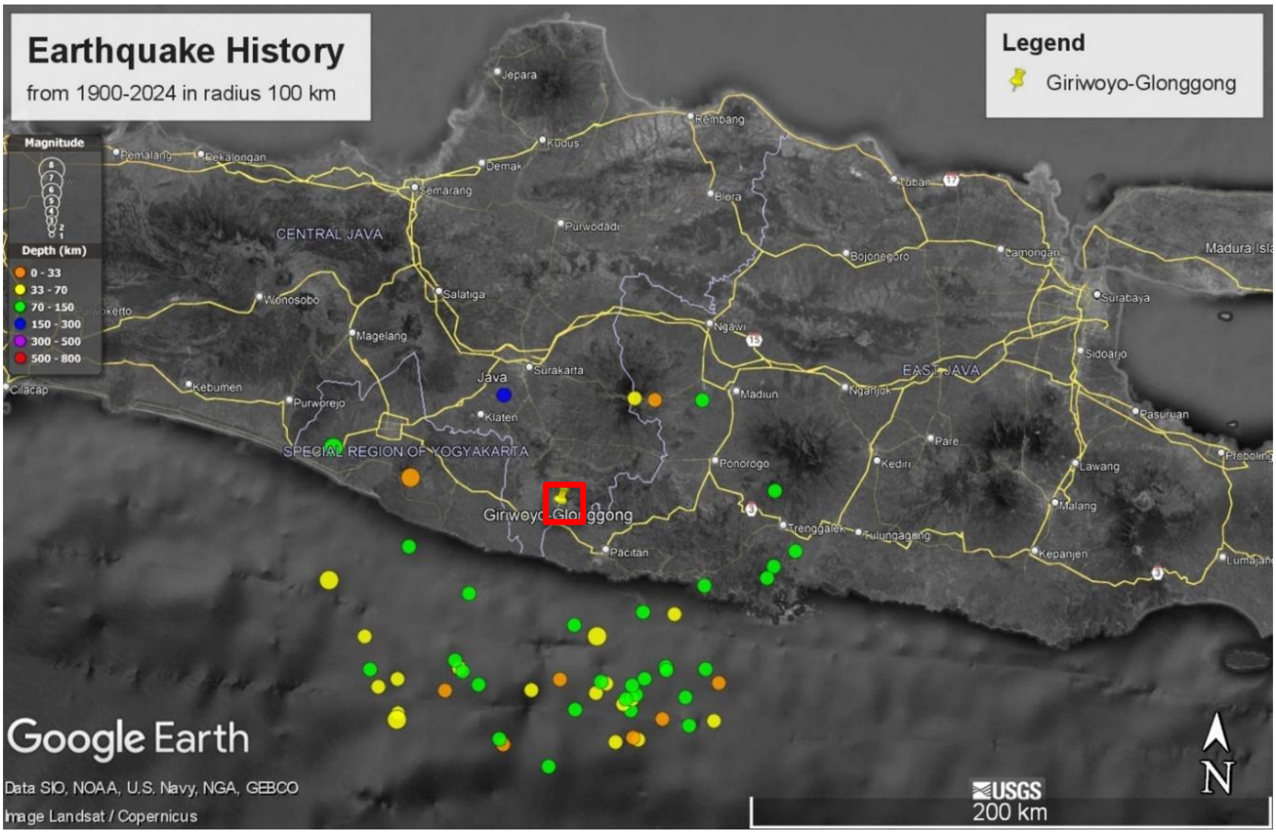



**Figure 3.** Earthquake history [20]

**Table 3.** Largest earthquake history

| Years | Latitude | Longitude | Depth (km) | $M_w$ | Location |
|---|---|---|---|---|---|
| 2006-05-26 | -7.961 | 110.446 | 12.5 | 6.30 | 10 km E of Pundong, Indonesia |
| 1992-06-09 | -8.474 | 111.100 | 63.9 | 6.10 | 65 km S of Jatiroto, Indonesia |
| 1957-10-12 | -8.317 | 110.178 | 50.0 | 6.04 | 42 km SSW of Bambanglipuro, Indonesia |
| 2003-07-19 | -8.682 | 111.227 | 56.2 | 5.90 | 85 km SW of Trenggalek, Indonesia |
| 1965-11-23 | -8.666 | 111.103 | 55.0 | 5.76 | 86 km S of Jatiroto, Indonesia |

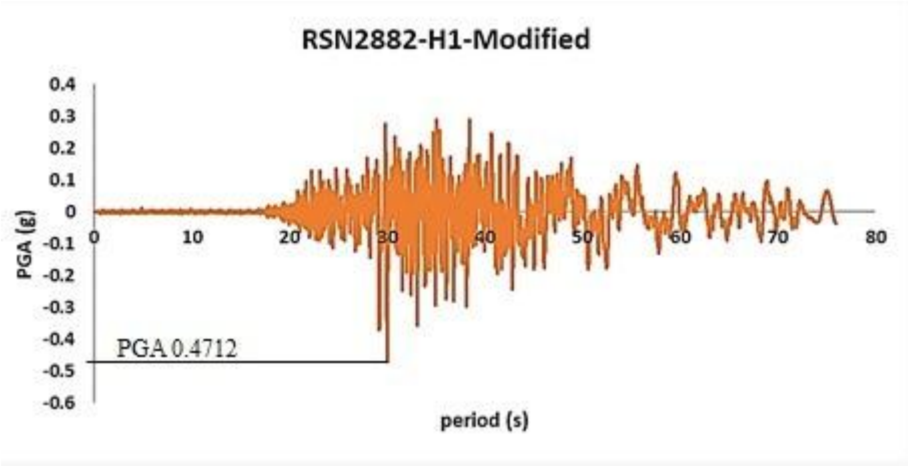



**Figure 4.** Modified ground motion

Then the ground motion modification was carried out with a minimum of 11 pairs of ground motions [21]. Then from the 11 pairs of ground motions, the movement with the largest PGA was selected, namely the PGA of the Chi-Chi earthquake in 1999 with the movement code RSN-2882-H1 with a PGA value of 0.4712 which can be seen in Figure 4.

The PGA value used is the maximum value of PGA on the surface, so it is necessary to multiply the field coefficient [22], from the N-SPT value it is obtained that the review location is included in the SC class area and PGA 0.4712, so that the $F_{PGA}$ value is 1.0, the PGA value on the surface ($PGA_M$) can be determined by multiple of $F_{PGA}$ and PGA. Where $PGA_M$ is the surface PGA value, $F_{PGA}$ is the field coefficient value for a 7% probability in 75 years and PGA is the PGA value in the bedrock. Therefore, a $PGA_M$ value of 0.4712 g was used. If soil deformation of 1-2 inches is allowed, the $PGA_M$ value is reduced by 50%, resulting in a seismic coefficient of 0.2356 g in the pseudo-static modeling. In this modeling, only horizontal pseudo-static forces are used, while vertical pseudo-static forces are ignored because the upper structural elements already have proper resistance [23].

## 3. Results

In this study, the results obtained are the effect of nail bar length and nail bar spacing on the SRF, displacement, and axial force on the nail bar.

### 3.1 Effect of nail bar length (L)

In modeling the effect of nail bar length, modeling was carried out with a length variation of 8 meters, 9 meters, 10 meters, 11 meters, and 12 meters, with a horizontal and vertical distance of 2 meters. From the modeling, the results can be seen in Table 4. For nails with a length of 8 meters, the SRF is 0.97 with an axial force of 400.221 kN, while for nails with a length of 12 meters, the SRF is 1.06 with an axial force of 340.995 kN.

**Table 4.** Results of nail bar length variation

| Nail bar length (L) (m) | SRF | Max. Hor. Disp. (m) | Max. Axial Force (kN) |
|---|---|---|---|
| 8 | 0.97 | 0.2948 | 400.221 |
| 9 | 1.01 | 0.2818 | 395.358 |
| 10 | 1.03 | 0.2794 | 366.944 |
| 11 | 1.05 | 0.2775 | 347.303 |
| 12 | 1.06 | 0.2765 | 340.995 |

Based on the graph of the relationship between SRF and nail bar length, it can be seen that the increase in nail bar length affects the SRF of the slope, where the longer nail bar, the more SRF value will increase, which can be seen in Figure 5.

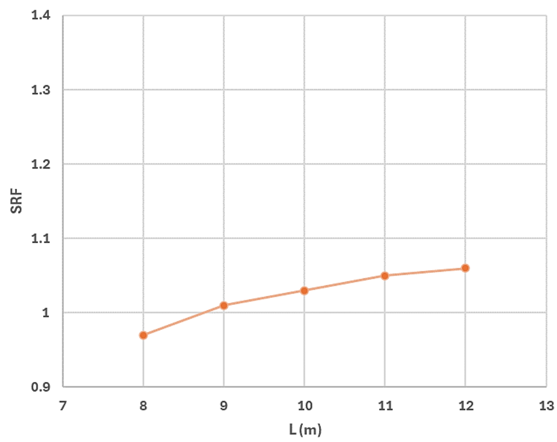



**Figure 5.** Effect of nail bar length (L) to SRF

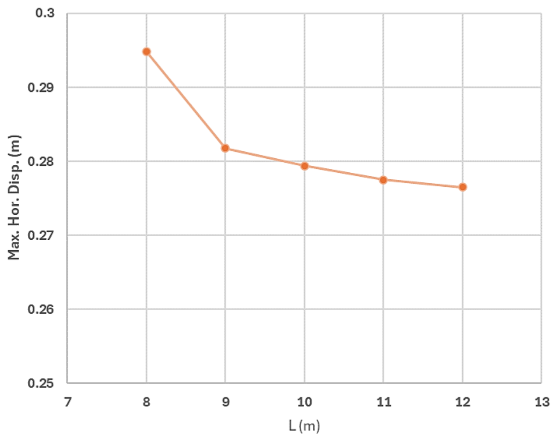



**Figure 6.** Effect of nail bar length (L) to maximum horizontal displacement

In opposition to the SRF, increasing the length of the nail bar reduces the amount of displacement that occurs on the slope, as can be seen in Figure 6.

In addition to reducing the displacement that occurs, increasing the length of the nail bar also reduces the axial force on the nail bar which can be seen in Figure 7. The observed increase in nail length can be attributed to a corresponding increase in nail length behind the slip surface that binds the soil mass to the soil behind it.

In Figure 8, show an increase in the length of the nail bar results in an enlargement of the slip area, which is caused by an increase in the normal stress. The increase of normal stress leads to an increase in friction, which can be useful in increasing the pull-out capacity in resisting the pull-out force that occurs on the nail bar [24]. The transferred force is then applied to the soil behind the slip surface, reducing the axial force acting on the nail and consequently decreasing the deformation in the soil nail wall, thereby increasing the stability of the slope [12]. This increase in stability is characterized by an increase in the SRF value.

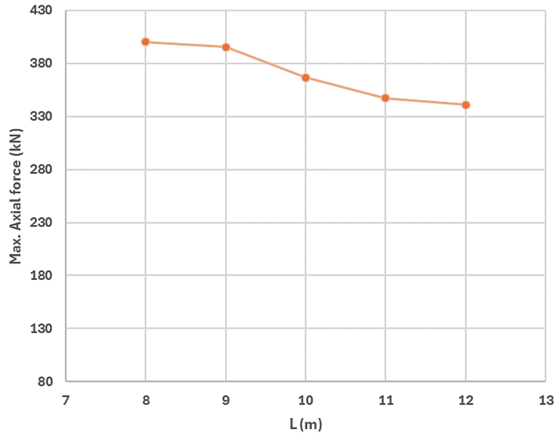
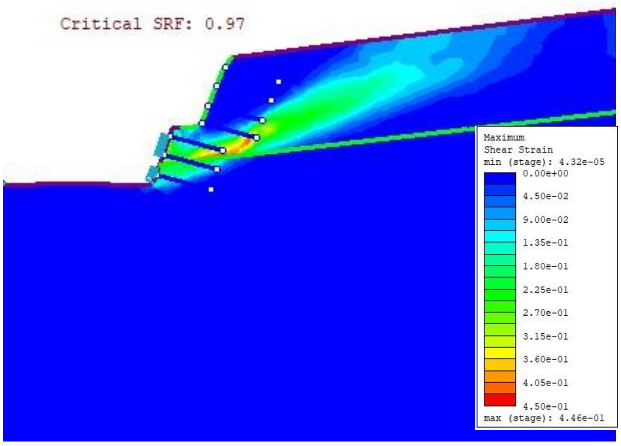
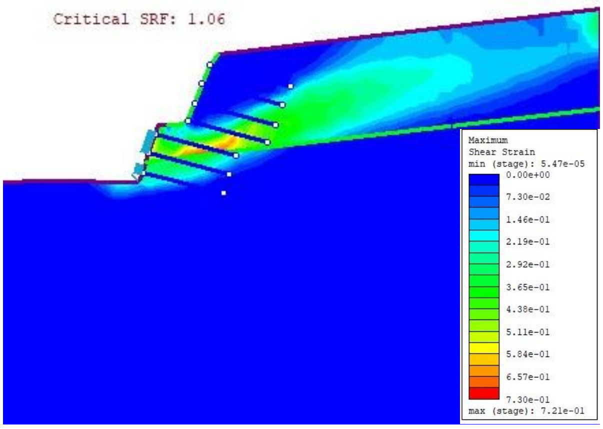



**Figure 7.** Effect of nail bar length (L) to axial force




(a)




(b)

**Figure 8.** Effect of nail bar length on slip surface (a) L = 8m, (b) L = 12m

### 3.2 Effect of nail bar horizontal distance ($S_h$)

In modeling the effect of the horizontal distance of the nail bar, modeling was carried out with variations of 8 meters, 9 meters, 10 meters, 11 meters, and 12 meters with horizontal distance variations of 0.5 meters, 1 meter, 1.5 meters, and 2 meters with the results show in Table 5, where in nails with a length of 12 meters and a distance of 0.5 meters, the SRF obtained reached 1.29 with an axial force of 117.9610 kN under pseudo-static conditions, while in nails with a length of 8 meters and a distance of 2 meters, the SRF obtained was 0.97 with an axial force of 400.2210 kN.

The graph of the relationship between horizontal distance and SRF shows that the horizontal distance between nail bars affects the stability of the slope, it can be seen from Figure 9 that the greater the horizontal distance between nail bars, the value of the SRF will decrease. However, it can be seen that nails with a length of 12 meters with a horizontal distance of 1 meter are less effective because they produce a less significant increase in SRF.

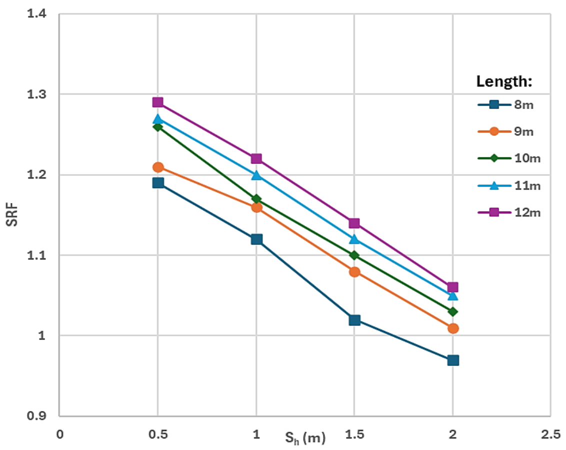



**Figure 9.** Effect of nail bar horizontal distance ($S_h$) to SRF

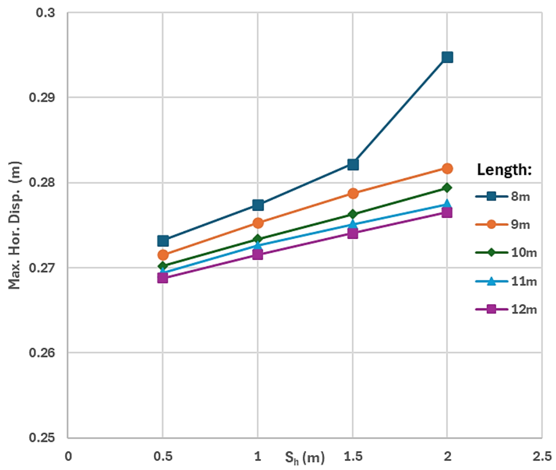



**Figure 10.** Effect of nail bar horizontal distance ($S_h$) to maximum horizontal displacement

An increase in the horizontal distance will result in a reduction in the number of nails working on the slope. This phenomenon has a direct impact on the overall stability of the slope, as it reduces the binding factor, which subsequently diminishes the friction zone that is formed between the nail and the ground [12].

In addition to affecting the SRF, the horizontal distance also affects the horizontal displacement that occurs on the slope, but in contrast to the SRF, the addition of horizontal distance increases the displacement that occurs on the soil nailing wall as shown in Figure 10.

**Table 5.** Results of nail bar horizontal distance variation

| Length (L)(m) | $S_h$ (m) | SRF | Max. Hor. Disp. (m) | Max. Axial Force (kN) |
|---|---|---|---|---|
| 8 | | 0.97 | 0.2948 | 400.2210 |
| 9 | | 1.01 | 0.2818 | 395.3580 |
| 10 | 2 | 1.03 | 0.2794 | 366.9440 |
| 11 | | 1.05 | 0.2775 | 347.3030 |
| 12 | | 1.06 | 0.2765 | 340.9950 |
| 8 | | 1.02 | 0.2822 | 370.3070 |
| 9 | | 1.08 | 0.2788 | 306.1810 |
| 10 | 1.5 | 1.1 | 0.2763 | 300.9950 |
| 11 | | 1.12 | 0.2751 | 271.5090 |
| 12 | | 1.14 | 0.2741 | 265.8760 |
| 8 | | 1.12 | 0.2774 | 290.2840 |
| 9 | | 1.16 | 0.2753 | 283.6085 |
| 10 | 1 | 1.17 | 0.2734 | 276.9330 |
| 11 | | 1.2 | 0.2726 | 200.5760 |
| 12 | | 1.22 | 0.2716 | 186.8190 |
| 8 | | 1.19 | 0.2732 | 253.7530 |
| 9 | | 1.21 | 0.2716 | 214.9520 |
| 10 | 0.5 | 1.26 | 0.2702 | 172.4680 |
| 11 | | 1.27 | 0.2694 | 144.2640 |
| 12 | | 1.29 | 0.2688 | 117.9610 |

The variation of horizontal distance between nail bars also affects the axial force on the nail bar as can be seen in Figure 11, with the increase of horizontal distance between nail bars, the axial force increases, this is because the increase of horizontal distance reduces the pull-out capacity of the nail by increasing the pull-out force resulting in greater axial force, which affects the displacement in front of the soil nailing wall, this then reduces the SRF. It can be seen from the graph that for nails with a length of 9 meters and 10 meters, the change in horizontal distance from 1.5 meters to 1 meter does not result in a significant reduction in axial force and is therefore less effective, but the change in horizontal distance from 1 meter to 0.5 meter results in a significant reduction in axial force.

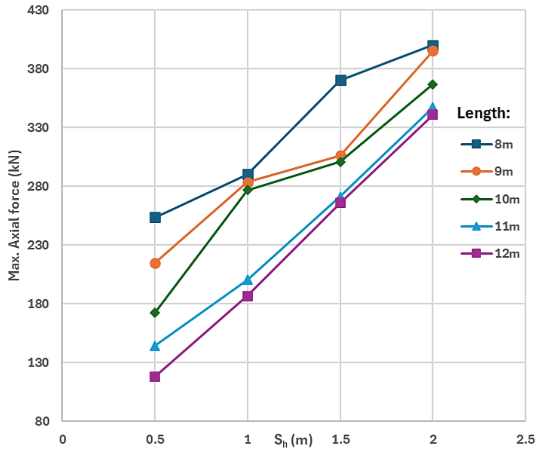



**Figure 11.** Effect of nail bar horizontal distance ($S_h$) to axial force

### 3.3 Effect of nail bar vertical distance ($S_v$)

In modeling the vertical distance of the nail bar, modeling is made with a vertical distance of 0.5 meters, 1 meter, 1.5 meters, 2 meters with a nail bar length of 8 meters, 9 meters, 10 meters, 11 meters, and 12 meters with the results show in Figure 12. Effect of nail bar vertical distance (Sv) to SRF

**Table *6***, at a length of 8 meters with a vertical distance of 2 meters, the SRF is 1.39 with an axial force of 185.371 kN, while at a length of 12 meters with a vertical distance of 0.5, the SRF is 1.82 with an axial force of 85.204 kN.

The graph of the relationship between vertical distance and SRF can show that the change in vertical distance affects the SRF value of the soil nailing wall, which can be seen in Figure 12. It is concluded that the decrease in the vertical distance of the nail bar will increase the SRF on the slope. It can be seen that the change in vertical distance from 2 meters to 1.5 meters results in a significant SRF.

From the graph of the relationship between vertical distance and SRF and the graph of the relationship between horizontal distance and SRF, it can be seen that changes in vertical distance have more effect than changes in horizontal distance [14].

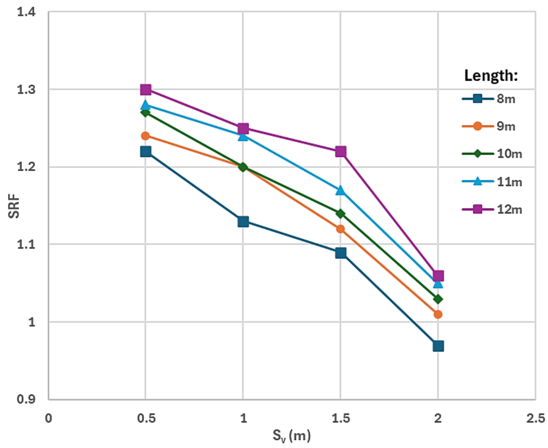



**Figure 12.** Effect of nail bar vertical distance ($S_v$) to SRF

**Table 6.** Results of nail bar vertical distance variation

| Length (L)(m) | $S_v$ (m) | SRF | Max. Hor. Disp. (m) | Max. Axial Force (kN) |
|---|---|---|---|---|
| 8 | | 0.97 | 0.2948 | 400.2210 |
| 9 | | 1.01 | 0.2818 | 395.3580 |
| 10 | 2 | 1.03 | 0.2794 | 366.9440 |
| 11 | | 1.05 | 0.2775 | 347.3030 |
| 12 | | 1.06 | 0.2765 | 340.9950 |
| 8 | | 1.09 | 0.2761 | 281.1520 |
| 9 | | 1.12 | 0.2748 | 244.3040 |
| 10 | 1.5 | 1.14 | 0.2738 | 236.0420 |
| 11 | | 1.17 | 0.2728 | 227.7800 |
| 12 | | 1.22 | 0.2717 | 188.6110 |
| 8 | | 1.13 | 0.2736 | 266.2030 |
| 9 | | 1.2 | 0.2722 | 242.9580 |
| 10 | 1 | 1.2 | 0.2712 | 219.7130 |
| 11 | | 1.24 | 0.2702 | 207.0440 |
| 12 | | 1.25 | 0.2694 | 184.0720 |
| 8 | | 1.22 | 0.2707 | 248.0190 |
| 9 | | 1.24 | 0.2696 | 238.6030 |
| 10 | 0.5 | 1.27 | 0.2686 | 217.1500 |
| 11 | | 1.28 | 0.2677 | 184.1410 |
| 12 | | 1.3 | 0.2670 | 141.5210 |

Vertical spacing also affects the maximum horizontal displacement of the soil nailing wall. Increasing the vertical distance between nails will increase the horizontal displacement that occurs in the soil nailing wall, as can be seen in Figure 13.

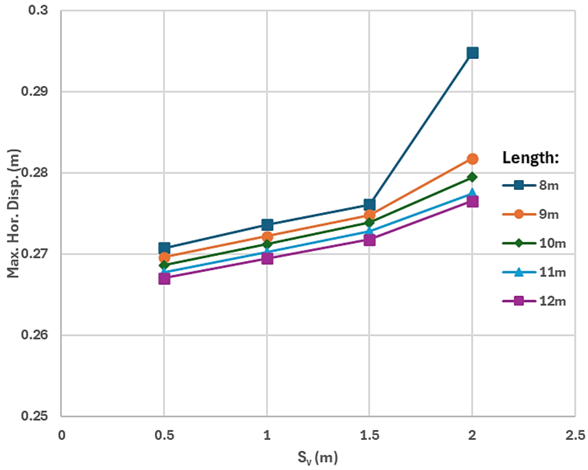



**Figure 13.** Effect of nail bar vertical distance ($S_v$) to maximum horizontal displacement

In addition to affecting the SRF and displacement, variations in vertical spacing also affect the axial force on the nail bar, as show in Figure 14, where the greater the vertical distance between nail bars, the greater the axial force on the nail bar. This is because the increase in distance will reduce the ultimate pulling capacity, thus increasing the displacement that occurs in the nail bar wall. The graph shows that the change in vertical distance from 1.5 meters to 1 meter does not produce a significant axial force.

An increase in vertical distance is indicative of a reduction in the number of nails installed on the slope, which in turn results in a reduction in the friction zone between the nails and the ground. This reduction in friction affects the magnitude of the force that holds the soil mass.

The vertical distance is a more influential factor than the horizontal distance, given that the height of the slope has a significant impact on the stability of the slope. It can be demonstrated that a reduction in distance can indeed enhance the stability of a slope. However, the selection of the distance must be carefully considered from an economic and practical perspective. The goal of this process is to select a distance that maintains stability and is both cost-effective and straightforward to implement in the field [10].

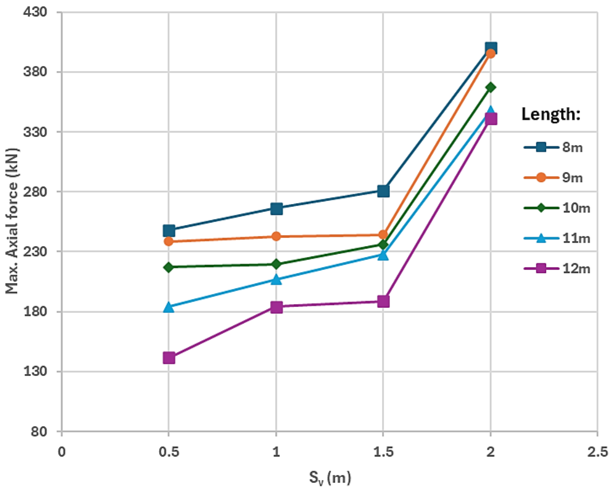



**Figure 14.** Effect of nail bar vertical distance ($S_v$) to axial force

### 3.4 Effect of Elevation to Displacement

Figure 15 shows that the maximum horizontal displacement is at the top of the soil nailing wall in pseudo-static conditions. Figure 16 displays the relationship between maximum horizontal displacement and depth. This graph uses soil nailing with a length of 9 meters, vertical distance and horizontal distance is 2 meters, the results show that the maximum horizontal displacement occurs at elevation 2 meter above the surface of slope with the maximum horizontal displacement obtained is 0.28 meters.

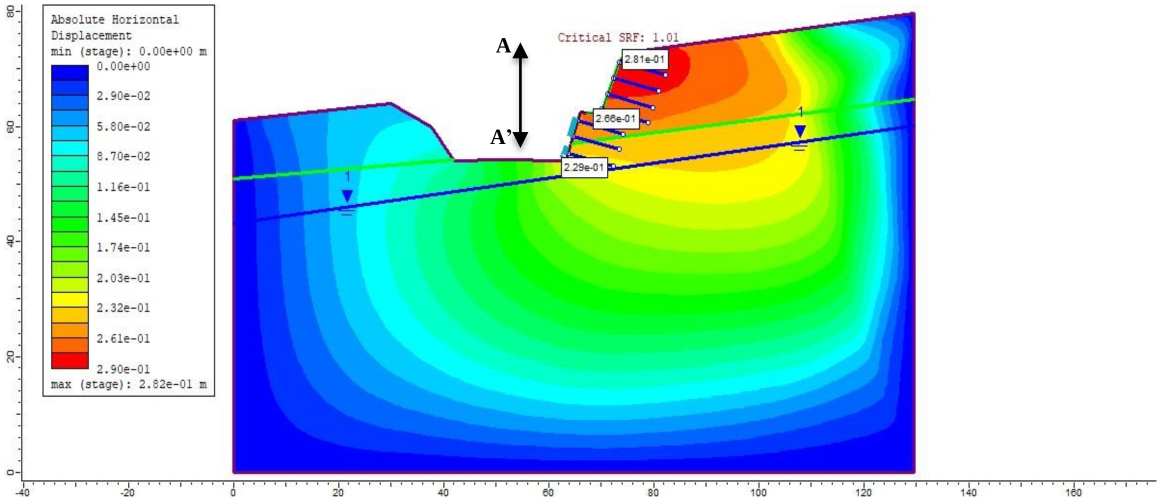


**Figure 15.** Displacement on pseudo-static condition

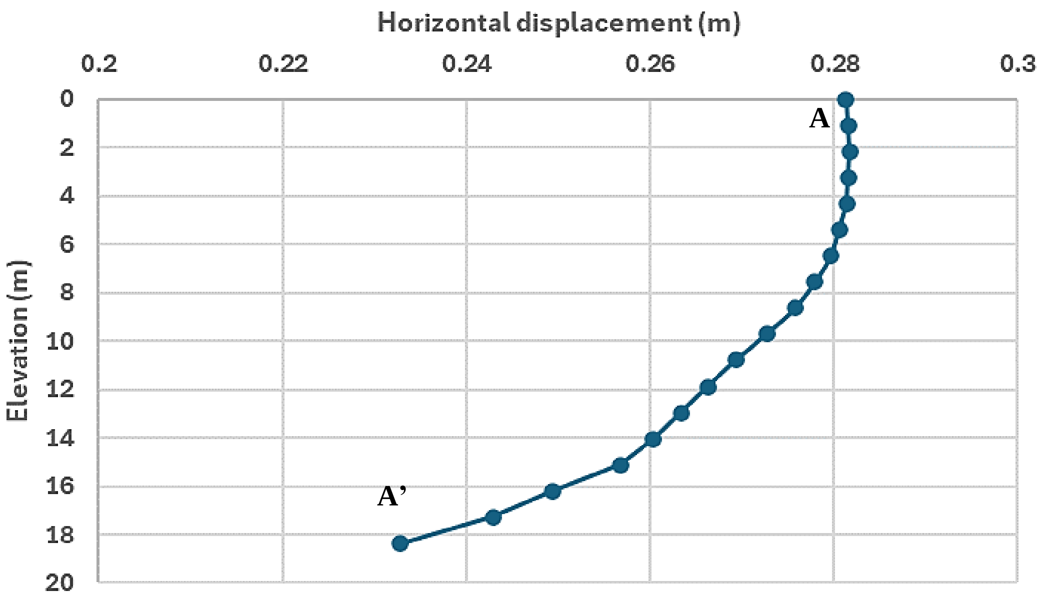



**Figure 16.** Effect of elevation to displacement

## 4. Conclusions

This research examines the modeling of slopes treated with soil nails, with a particular focus on slopes with a height of 18 meters. Keeping consistent variables, such as angle, diameter, and type of soil nails, this study investigated the impact of varying the nail bar length, horizontal spacing, and vertical spacing on the Strength Reduction Factor (SRF), maximum horizontal displacement of the soil nail wall, and maximum axial force experienced by the nail bar. The results showed that increasing the nail bar length increased the SRF, reduced the displacement of the soil nail wall, and reduced the axial force on the nail bar. This is due to the increased length of the nail behind the slip surface and the increased friction between the nail and the soil, which reduces excessive ground surface displacement. In contrast, increasing horizontal and vertical spacing has the opposite effect, with increased spacing indicating a reduced number of nail bars on the slope, leading to reduced SRF, increased soil nail wall displacement, and increased axial force on the nail bar due to a reduction in the friction zone. This study shows that vertical spacing between nails exerts a more significant influence on slope stability than horizontal spacing. This observation is consistent with the findings of previous research in this area.

**Acknowledgements**

The researcher would like to thank the National Road Implementation Center of Central Java - DI Yogyakarta, Bina Marga, Ministry of Public Works and Housing for providing the data.

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