The study on length and diameter ratio of nail as preliminary design for slope stabilization

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Abstract. Soil nailing technology has been widely applied in practice for reinforced slope. The number of studies for the effective design of nail-reinforced slopes has also increased. However, most of the previous study was focused on a safety factor of the slope; the ratio of length and diameter itself has likely never been studied before. The aim of this study is to relate the length and diameter ratio of the nail with the safety factor of the 20 m height of sand slope in the various angle of friction and steepness of the slope. Simplified Bishop method was utilized to analyze the safety factor of the slope. This study is using data simulation to calculate the safety factor of the slope with soil nailing reinforcement. The results indicate that safety factor of slope stability increases with the increase of length and diameter ratio of the nail. At any angle of friction and steepness of the slope, certain effective length and diameter ratio was obtained. These results may be considered as a preliminary design for slope stabilization.

1. Introduction

Indonesia has a diverse geological structure and topographic condition. One form of the topographic condition is the slopes that can be found in the hilly areas. The common issues in slope stability are the prevention of landslides in slope. The National Board for Disaster Management (BNPB) noted that there were 364 landslides occurred in Indonesia between the period of January – Mei 2017. These disaster resulted not less than 180 casualties of people and 1800 property damage. Based on these data, there should be an alternatives way to reduce the danger of the landslides. Slope reinforcement is one of the alternative to stabilize the slope that is prone to landslides. One method of slope improvement that has been widely applied is soil nailing.

Soil nailing is one of the technique to stabilize the slope with passive inclusions or reinforcements by steel-bar known as soil nails. The inclusions can be fully bonded (grouted nails) or simply driven into the ground. The nails act to limit the soil deformations near the exposed face and transfer the stress to a more stable zone behind the wall.

As soil nailing technology is increasingly applied to reinforce slopes, the number of studies on the effective design of nail-reinforced slope has also increased. The effective design depends on the impact of soil and nail parameter to the stability level of the reinforced slopes, which should be based on a failure behavior and reinforcement mechanisms. The study about the effect of nail parameter such as nail spacing (Sᵥ and Sₕ) [1], nail length (L) [2], nail inclination angle (θ) [3], nail diameter (d) [4], and...
number of nail \((n)\) [5] to the safety factor have been conducted in recent years. The effect of soil parameters such as slope steepness \((\beta)\) [1], the angle of internal friction \((\phi)\) [6], soil cohesion \((c)\) [7], and unit weight \((\gamma_b)\) [8] to the safety factor of the slope have also been developed. However, most of the previous study were only focused on the exact parameter impact to the safety factor of the slope; The ratio of this parameter have likely never been studied before.

The purpose of this research was to determine the effective design of soil nailing parameter using the length and diameter ratio \((L/d)\). The properties of the slope were a 20 m height of sand slope in a various angle of friction and steepness of the slope. Data simulation was conducted to determine the impact of length and diameter ratio to the safety factor of the slope.

2. Method

2.1. Soil and nail parameter

The soil and nail parameter that used in this study are based on the previous study and references about nail reinforcement in sand slope [9], [10], [11]. Table 1 shows the soil and nail parameter that used in this study. The length and diameter ratio of nail range from 0 – 700 with the interval of 50 for every diameter that been used in data simulation. The yield stress of the soil nail bar is 517 MPa based on the standard of nail dimensions (ASTM A615 Grade 75).

| Soil parameter       | Data input | Nail parameter       | Data input |
|----------------------|------------|----------------------|------------|
| Unit Weight (kN/m³)  | 16         | Nail diameter (mm)   | 19, 22, 25, 29, 32 |
| Soil cohesion (kPa)  | 0          | Bor diameter (m)     | 0,2        |
| Angle of internal friction \((^\circ)\) | 30, 35, 40 | Nail Spacing (m)     | 1.5 and 2 |
| Slope height (m)     | 20         | Nail inclination \((^\circ)\) | 15         |
| Angle of the slope \((^\circ)\) | 45, 60, 90 | Bond skin friction (kN/m²) | 140         |

2.2. Data simulation

Data simulation was conducted to determine the safety factor of the slope based on the impact of the length and diameter ratio. Simplified Bishop Method [12] were utilized in data simulation before and after the soil nailing reinforcement model using Equation 1 and Equation 2 in a computer program. The stability of the slope is determine based on the Bowles safety factor classification [13] that shown in Table 2. The total variations analyzed in this study were 585 variations based on the length and diameter ratio and various condition of soil and nail parameter.

\[
FS_{b} = \frac{\sum \left[ c \cdot b_i + W_i(l-r) \cdot \tan \phi \left( \frac{1}{\cos \alpha_i \tan \phi \tan \alpha_i \tan \phi \tan \alpha_i - \tan \phi} \right) \right]}{\sum W \sin \alpha_i} \tag{1}
\]

\[
FS_{bf} = \frac{\sum \left[ c \cdot b_i + W_i(l-r) \cdot \tan \phi \left( \frac{1}{\cos \alpha_i \tan \phi \tan \alpha_i \tan \phi \tan \alpha_i - \tan \phi} \right) \right]}{\sum W \sin \alpha_i \cdot T_n \cos \left( \alpha_i + \lambda \right)} \tag{2}
\]

| Safety factor | Slope condition |
|---------------|-----------------|
| SF ≥ 1,25     | Stable          |
| 1,07 ≤ SF ≤ 1,25 | Critical       |
| SF ≤ 1,07     | Unstable        |
3. Results and discussion

3.1 Safety factor of the slope before reinforcement

The model of the existing slopes (without reinforcement) is described based on the soil parameter in Table 1. Figure 1 shows the example of data simulation on 60º existing slopes using a computer program. The result of critical safety factor on this slope variation is 0.349.

![Figure 1](image1.png)

Figure 1. Critical safety factor result on the 226th slope variation ($\beta = 60^0$, $\phi = 30^0$, no reinforcement)

3.2 Safety factor of the slope after reinforcement

The model of the soil nailing reinforcement on the existing slope is described in the program based on the nail parameter in Table 1 and the length and diameter ratio of nail parameter. Figure 2 shows the example of data simulation on 60º reinforced slope using a computer program. The result of safety factor on this slope variation is 1.429. This result indicates that the implementation of soil nails are improved the safety factor of the slope.

![Figure 2](image2.png)

Figure 2. Critical safety factor result on the 290th slope variation ($\beta = 60^0$, $\phi = 30^0$, $d = 32$ mm, $L/d = 600$)

3.3 Impact of length and diameter ratio of nail (L/d) on the safety factor of 45º of slope steepness

The safety factor of 45º slope reinforcement using soil nailing are calculated using a computer program. The length and diameter ratio of the nail (L/d) that have been used in this variation are 0 – 700 with the interval of 50. The safety factor result based on the length and diameter ratio of the nail from 45º of
slope steepness is shown in Figure 3 – Figure 5. The average increase of safety factor on the 45° slope is shown in table 3. The effective value of L/d from the 45° of slope reinforcement using the soil nails are 600 – 650.

**Figure 3.** Impact of length and diameter ratio of nail on the safety factor of 45° loose sand slope ($\beta = 45^\circ$, $\phi = 30^\circ$)

**Figure 4.** Impact of length and diameter ratio of nail on the safety factor of 45° medium sand slope ($\beta = 45^\circ$, $\phi = 35^\circ$)
Figure 5. Impact of length and diameter ratio of nail on the safety factor of 45° dense sand slope $(\beta = 45^\circ, \phi = 40^\circ)$

Table 3. Impact of L/d parameter to average increase of safety factor on the 45° slope

| Nail diameter | Average increase of safety factor based on L/d |
|---------------|---------------------------------------------|
| 19 mm         | ± 4.36%                                     |
| 22 mm         | ± 5.15%                                     |
| 25 mm         | ± 5.90%                                     |
| 27 mm         | ± 6.56%                                     |
| 32 mm         | ± 7.28%                                     |

3.4 Impact of length and diameter ratio of nail on the safety factor of 60° of slope steepness
The length and diameter ratio of the nail (L/d) that have been used in 60° of slope reinforcement using soil nailing are 0 – 600 with the interval of 50. The safety factor result based on the length and diameter ratio of the nail from 60° of slope steepness is shown in Figure 6 – Figure 8. The average increase of safety factor on the 60° slope is shown in table 4. The effective value of L/d from the 60°of slope reinforcement using the soil nails are 450 – 550.
**Figure 6.** Impact of length and diameter ratio of nail on the safety factor of 60° loose sand slope 
($\beta = 60^\circ$, $\phi = 30^\circ$)

**Figure 7.** Impact of length and diameter ratio of nail on the safety factor of 60° medium sand slope 
($\beta = 60^\circ$, $\phi = 35^\circ$)
3.5 Impact of length and diameter ratio of nail on the safety factor of 90° slope

The length and diameter ratio of the nail (L/d) that have been used in 60° of slope reinforcement using soil nailing are 0 – 500 with the interval of 50. The safety factor result based on the length and diameter ratio of the nail from 60° of slope steepness is shown in Figure 9 – Figure 11. The average increase of safety factor on the 60° slope is shown in table 5. The effective value of L/d from the 60° of slope reinforcement using the soil nails are 400 – 450.

Table 4. Impact of L/d parameter to average increase of safety factor on the 60° slope

| Nail diameter | Average increase of safety factor based on L/d |
|---------------|-----------------------------------------------|
| 19 mm         | ± 6.94 %                                      |
| 22 mm         | ± 8.06 %                                      |
| 25 mm         | ± 9.27 %                                      |
| 27 mm         | ± 10.35 %                                     |
| 32 mm         | ± 11.71 %                                     |

Figure 8. Impact of length and diameter ratio of nail on the safety factor of 60° dense sand slope ($\beta = 60^\circ$, $\varphi = 40^\circ$)
Figure 9. Impact of length and diameter ratio of nail on the safety factor of 90° loose sand slope
\( (\beta = 90^\circ, \phi = 30^\circ) \)

Figure 10. Impact of length and diameter ratio of nail on the safety factor of 90° medium sand slope
\( (\beta = 90^\circ, \phi = 35^\circ) \)
Figure 11. Impact of length and diameter ratio of nail on the safety factor of 90° dense sand slope (β = 60°, φ = 40°)

Table 5. Impact of L/d parameter to average increase of safety factor on the 90° slope

| Nail diameter | Average increase of safety factor based on L/d |  
|---------------|-----------------------------------------------|
| 19 mm         | ± 14.12 %                                     |
| 22 mm         | ± 15.87 %                                     |
| 25 mm         | ± 18.41 %                                     |
| 27 mm         | ± 19.96 %                                     |
| 32 mm         | ± 22.02 %                                     |

4. Conclusion

The result indicates that safety factor of the slope is increases with the increase of L/d value to the effective value of L/d. If the length of the nail passes the effective value of L/d, the safety factor of the slope does not change significantly. The effective value of L/d range from 400 – 650 based on the steepness of the slope. The average increase of slope safety factor also increases with the increase of nail diameter. It indicates that the larger diameter of the nail is more effective to apply in soil nailing reinforcement. However, the use of an efficient nail diameter size is still adjusted to the needs of slope safety factor based on the density and steepness of the slope.

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