Eduvest – Journal of Universal Studies
Volume 6 Number 7, July, 2026
p- ISSN 2775-3735- e-ISSN 2775-3727

Evaluation of the Effectiveness of Soil Nailing Configurations on Slope Stability as an Alternative for Slope Reinforcement in Deep Excavations Case Study of the Rengat–Pekanbaru Toll Road, Pekanbaru Ring Road Section, STA 205+600

Rully Finaliyah Santoso*, Trihanyndio Rendy Satrya, Ria Asih Aryani Soemitro
Institut Teknologi Sepuluh Nopember, Indonesia
Email: santosorully@gmail.com* , trendysatrya@its.ac.id, ria@ce.its.ac.id

Keywords
Soil Nailing; Slope Stability; Deep Digging; Safety Factor; Clay Soil

Abstract
This study evaluated the effectiveness of soil nailing configurations for slope stability as an alternative slope reinforcement method in deep excavations along the Rengat–Pekanbaru Toll Road, Pekanbaru Ring Road Section, Sta 205+600. Limited right-of-way (ROW) conditions required the construction of steeper slopes, necessitating a reinforcement system to maintain slope stability. The analysis was conducted using geotechnical investigation data, including laboratory test results, borehole data, and project-specific geotechnical parameters. The evaluated variations included soil nail length and installation angle, with assessments performed for global stability and internal stability under long-term service conditions (static conditions) and earthquake loading conditions (pseudostatic conditions). The results showed that increasing soil nail length improved the factor of safety (FS) values for both global and internal stability. The highest global stability FS value was achieved with a 19 m soil nail length, while internal stability against pullout resistance increased as soil nail length increased and the installation angle became steeper. Under pseudostatic conditions, soil nailing reinforcement did not provide a significant improvement in global stability for clay soils; however, it continued to enhance internal stability. Based on technical evaluation and cost-efficiency considerations, the 15 m soil nail length with a 30° installation angle was identified as the most effective configuration, as it provided an optimal improvement in safety factors while maintaining more economical construction costs.

INTRODUCTION

Toll roads in Indonesia play an important role in supporting economic activities by facilitating community mobility and serving as interregional transportation links across five major islands: Java, Sumatra, Kalimantan, Sulawesi, and Bali (Anas n.d.; Hariyanto et al. 2024; Rahmadana et al. 2025; Verico et al. 2024). PT Hutama Karya (Persero) received a government mandate to operate the Trans-Sumatra Toll Road (Jalan Tol Trans Sumatera [JTTS]), which extends from Bakauheni to Banda Aceh with a total length of 2,819 km. The Rengat–Pekanbaru Toll Road, specifically the Pekanbaru Junction Section–Pekanbaru Interchange (IC) Bypass, is one segment of the 30.57 km JTTS network located in Riau Province, covering areas within Kampar Regency and Pekanbaru City (Hidir et al. 2025).

The STA 205+600 location represents a toll road design section involving a 20 m deep excavation. Based on field conditions, the local community required frontage road access along the toll road alignment because the existing access route was disrupted by the toll road construction. Furthermore, the limited width of available land required adjustments to the excavation slope design to accommodate the frontage road. The limited right-of-way (ROW) availability within the toll road corridor became a major design constraint, requiring the excavation slope to be constructed at a relatively steep inclination. An ideal slope configuration of 1V:2H could not be applied because it would require a larger land area than available. Therefore, additional reinforcement measures were required to maintain slope stability under steep excavation conditions (Li et al. 2020; C. Lin et al. 2020; P. Lin et al. 2015; Ma et al. 2017; Tian et al. 2021).

Soil nailing is considered an effective slope reinforcement method for projects with limited working areas because it can improve slope stability under steep excavation conditions. According to the Directorate General of Highways (2022), soil nail installation angles generally range from 10° to 20° relative to the horizontal plane of the slope. Soil nailing has also demonstrated the ability to resist potential slope failures under extreme conditions involving saturated groundwater levels (Riogilang et al., 2014).

Several factors influence the factor of safety (FS) of soil nailing systems, including soil nail inclination angle, nail bar length, and the number of nail bars and reinforcement rows (Imbar et al., 2019; Budiharjo et al., 2020). A soil nailing system consists of several components, including nail bars connected to a facing system, bearing plates, and locking nuts that transfer soil pressure to the reinforcement elements. Nail bars are commonly constructed using steel reinforcement bars with a minimum diameter of 25 mm and protected against corrosion through measures such as epoxy coating or galvanization (Lazarte et al. 2015; Marwane et al. 2024; Reza et al. 2018; Wang et al. 2024).

Previous studies have demonstrated that soil nailing configurations significantly influence slope stability performance. Tian, Zhu, and Zhang (2022) found that the transverse shear resistance of soil nails contributed approximately 30%–50% improvement in the factor of safety for clay slopes. Bahramipour et al. (2025) reported that a 10° nail inclination from the horizontal plane provided an optimal balance between tensile and shear forces, reducing deformation and increasing the factor of safety to 1.52. They also found that increasing nail length improved stability, although the improvement decreased beyond a certain threshold. Ramayanti, Faris, and Hardiyatmo (2024) investigated the effects of soil nailing parameters under seismic loading conditions and found that increasing soil nail length improved the factor of safety and reduced displacement, whereas increasing horizontal and vertical spacing reduced stability. Pinuji et al. (2024) applied soil nailing for railway track protection in organic clay soil conditions and found that a design with a 29 mm diameter nail, a 20° slope inclination, and a 9 m nail length achieved a factor of safety of 1.548, demonstrating the effectiveness of soil nailing in clay soils. Research on pseudostatic seismic behavior (2022) showed that soil nails installed at angles between 10° and 15° produced lower displacement and higher safety factors, while increasing nail length reduced lateral deformation and improved stability. Nuradrina (2024) analyzed slope stability reinforced with soil nailing using PLAXIS software on clay soils in Yogyakarta, Indonesia, and found that a 20° nail inclination produced the highest factor of safety, whereas earthquake loading reduced the factor of safety by approximately 0.4 points. A numerical study on staged excavation response (2025) revealed that an increase in groundwater table depth improved stability, while increasing excavation stages reduced stability. Yanto (2024) investigated bamboo as an alternative soil nailing material for basement construction and found that bamboo could substitute steel reinforcement, achieving a factor of safety value of 4.271, which exceeded the required value of 2.

This study aimed to analyze the deep excavation slope conditions at STA 205+600 of the Rengat–Pekanbaru Toll Road, Pekanbaru Bypass Section, using laboratory investigation data, borehole logs, and supporting project data obtained from Hutama Karya Infrastruktur. The analysis evaluated the influence of soil nailing configurations on slope stability and identified the most effective soil nailing configuration for deep excavation slope reinforcement in plastic clay soil conditions at the study location.

The purpose of this study was to evaluate the existing design of the Trans-Sumatra Toll Road construction project at the Rengat–Pekanbaru Toll Road, Pekanbaru Ring Road Section, and develop alternative reinforcement planning. Theoretically, this study contributes to geotechnical engineering knowledge by improving understanding of soil nailing behavior in deep excavations involving medium to stiff clay soils and by providing empirical validation of finite element method (FEM) analysis using PLAXIS 2D software for slope stability evaluation under tropical soil conditions. Practically, this study provides recommendations for infrastructure planners and contractors in selecting effective and efficient soil nailing configurations by considering technical performance and cost efficiency. The findings also provide guidance for similar slope reinforcement projects in areas with limited right-of-way availability and high rainfall intensity. From a policy perspective, the findings may support the development of more comprehensive geotechnical design standards for deep excavation projects on toll road infrastructure in Indonesia, particularly in regions with challenging soil conditions and seismic activity. These objectives were addressed through three research questions: (1) How do soil nailing configuration parameters, including nail length and installation angle, affect global and internal stability of excavated slopes? (2) How do long-term stability conditions and pseudostatic conditions influence the factor of safety of excavated slopes reinforced with soil nailing? and (3) What soil nailing configuration provides the most effective and efficient improvement in global stability and internal slope stability?

METHOD

Flow Chart

A research flowchart was used to illustrate the sequence of activities conducted in this study. The research procedure consisted of problem identification, primary and secondary data collection, analysis of existing slope stability conditions, and design of soil nailing reinforcement.

The analysis was conducted using the finite element method (FEM) with PLAXIS 2D software. The FEM analysis involved modeling the slope geometry and soil nailing reinforcement system. The analysis results were evaluated based on the factor of safety (FS) for global and internal slope stability under static and pseudostatic conditions using various soil nail length and installation angle configurations. The FS values obtained from each configuration were compared to determine the most effective and efficient soil nailing design and to evaluate the influence of nail length and installation angle on global and internal slope stability performance under different loading conditions.

Data Collection Methods

Soil Data

Soil data is needed to obtain accurate information related to soil characteristics and parameters to later be used in analyzing slope stability and the effect of installing soil nailing reinforcement so that a good level of calculation accuracy is obtained. The soil data used in the analysis is field soil data from the BS – 56 bore log to determine the soil parameters. Based on the results of the core box of soil properties obtained information on the soil layer at the research site in the form of cohesion soil. This type of soil tends to be less stable and more susceptible to saturated conditions, considering the fairly high level of rainfall in Riau Province. The soil data used is in the form of boring log data and laboratory test results data, but while still comparing the visuals and existing conditions in the field for further interpretation from various literature to be used in determining the parameters to be used. The N-SPT test data on the log form is shown in Figure 3.5 and the results of the soil data interpretation are shown in Table 3.1

Data Analysis Methods

In this study, data analysis of soil behavior and structure will be carried out, including soil nailing using FEM-based methods with Plaxis 2D software. The calculation steps with Plaxis 2D for soil nailing involve:

1. Modeling the geometry and properties of the soil: The initial step is to model the geometry of the slope and determine the properties of the soil that are relevant for analysis. Plaxis 2D allows users to enter geometric and soil properties information in high detail.
2. Soil nails setup: Soil nails are added to the model, with specifications that match the desired design. Plaxis 2D allows the user to determine the position, length, diameter, and other mechanical characteristics of the soil nails.
3. Soil nails modeling uses the type of geogrids material where this reinforcement application is influenced by two factors, namely internal and external factors.
4. Numerical analysis with FEM: Plaxis 2D uses the Finite element method (FEM) to perform numerical analysis. It involves breaking down the analysis domain into small elements, where each element is treated as a connected system. FEM is used to calculate the distribution of stress, deformation, and other responses in soils and structures.
5. Evaluation of the results: After the analysis is complete, the results are evaluated to determine the safety factors of the slope and the behavior of the soil nails. Plaxis 2D allows users to visualize the results of the analysis in the form of graphs and tables, as well as to identify areas that require special attention in reinforcement design.

RESULTS AND DISCUSSION

Numerical Analysis Before Reinforcement

After obtaining the soil parameters at the previous calculation stage, then modeling was carried out using Plaxis 2D to analyze the stability of the slope with and 2:1 to determine the value of the Safety Factor (SF) of the slope.

Earthquake Factors

The effect of earthquake load is taken into account if the excavated slope or embankment is planned to be built near a residential area or built with criteria of strategic importance, namely with the condition that it must not collapse or disconnect the transportation lane. The minimum safety factor required for analysis using a pseudostatic model is greater than 1.1 (SF >1.1) using the seismic coefficient obtained from the acceleration of the peak on the surface (PGA) with the determination of the site class and the amplification factor after the planned earthquake occurs. At this stage, the determination of earthquake factors at the research site is carried out.

Determination of Soil Site Grade

The determination of the design response spectrum should be determined based on the site classification using the criteria in Table 1. To get the value of the site class, it is necessary to obtain an average value of N

for each soil layer.

Table 1. Site Class Calculation Results based on NSPT

Depth	N	di/N
2	6	0.33
4	10	0.20
6	11	0.18
8	14	0.14
10	16	0.13

12	18	0.11
14	20	0.10
16	28	0.07
18	32	0.06
20	24	0.08
22	30	0.07
24	33	0.06
26	47	0.04
28	66	0.03
30	55	0.04
32	61	0.03
34	65	0.03
Total		1.71
Navg		19.87

Based on the table above, the value of N = 19.87 is obtained until the value of N is in the range of 15 < N < 50, then the class of the site at the research location is SD (Tanah Moderate).

Table 2. Site classification

Site Class	**v¯s (m/sec)**	**N¯ or N¯ch**	**s¯u (kPa)**
SA *(hard rock)*	>1500	N/A	N/A
SB *(rock)*	750 to 1500	N/A	N/A
SC *(very dense soil and soft rock)*	350 to 750	>50	≥ 100
SD *(stiff soil)*	175 to 350	15 to 50	50 to 100
SE *(soft soil)*	<175	<15	<50
	Or any soil profile containing more than 3 m of soil with the following characteristics: 1. Plasticity Index, PI > 20, 2. Moisture Content, w≥ 40%, 3. Undrained shear strength, s_u < 25 kPa		
SF *(soils requiring site-specific geotechnical investigation and dynamic response analysis)*	Any soil layer profile that has one or more of the following characteristics: - Vulnerable to potential failure or collapse under seismic loading, such as liquefiable soils, quick highly sensitive clays, weakly cemented soils - Highly organic clays and/or peat (thickness H > 3m)		

Source : Modification of SNI 8467:2017

Determination of Peak Ground Acceleration

After obtaining the classification of the soil site class, then a check was carried out on the earthquake map, peak acceleration and response spectrum in the bedrock. The location of the research is in the Elementary Soil Site Class and based on the 2017 Indonesian earthquake map is in the range of PGAMCEG or PGAM values of 0.1 – 0.2.

The PGAM value used was 0.17 obtained from the value on the earthquake acceleration graph in the soil site class, then the FPGA value was interpolated based on the PGAM value. The acceleration value of the surface top soil was obtained at 0.24g. The calculation of horizontal seismic coefficient (Kh) is described as follows

$$K_h = 0,5\frac{a_d}{g}$$

Kh = 0.5 x 0.24 = 0.122

Based on SNI Geotechnical Design Requirements (8460:2017) Vertical seismic coefficient (kv) = 0.

Soil Data Input

In this study, soil data analysis was selected with a modeling type using the Hardening Soil Model (HSM) because it is more suitable for use in deep excavation analysis and considering the soil layer of the research site is clay-type which is elasto-plastic with a medium to stiff consistency so that the function of soil tension is very influential in the analysis of slope stability and depends on the undrained condition for the short term and the drained condition for the long term. Soil modeling using Mohr Coulomb was not chosen because it was not realistic for soil conditions at the research site where in Mohr Coulomb modeling the modulus of soil elasticity was considered constant. The following recapitulation of soil data to be input into the Plaxis 2D application can be seen in Table 3.

Table 3. 2D Plaxis Soil Data Input Recapitulation

Depth		N SPT	Soil Type	Consistency	gsat (kN/m³)	gunsat (kN/m³)	v	Cu (kPa)	Drained Shear Strength:			Deformasi Undrained		
m	m								c' kPa	ϕ' °	Eu kPa	E50 kPa	Eoed kPa	Eur kPa
0	4	6	Clayey Silt	Medium	18	17	0.3	30	3.0	23.2	7500	5250	5250	15750
4	10	12	Clayey Silt	Stiff	19	18	0.3	60	6.0	27.5	48000	33600	33600	100800
10	22	23	Clayey Silt	V stiff	20	19	1.3	115	11.5	30.0	92000	64400	64400	193200
22	28	37	Clayey Silt	Hard	21	20	2.3	185	18.5	30.0	148000	103600	103600	310800
28	34	60	Clayey Silt	Hard	21	20	3.3	300	30.0	30.0	240000	168000	168000	504000

Source : Author

In the modeling data input on Plaxis 2D, the value of the soil shear strength parameter as the input data on the drainage type was selected undrained for modeling during the construction period until the initial service and the drainage type was selected drained for modeling during the long-term service life and during pseudostatic conditions. The following is an example of soil parameter input in Plaxis 2D shown in Figures 1 and 2.

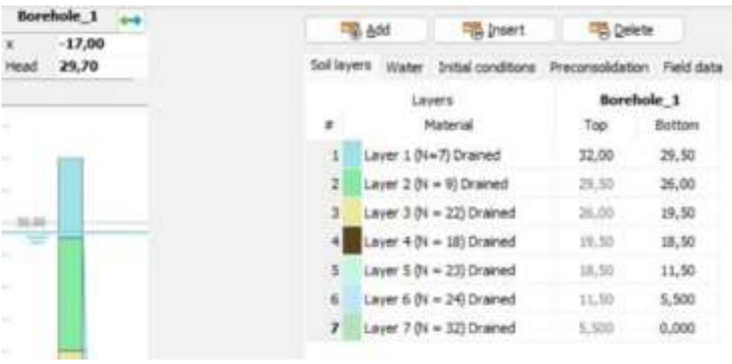

Figure 1. Soil layer on undrained 2D Plaxis Modeling
Source: Author

Figure 2. Soil layer on undrained 2D Plaxis Modeling
Source: Author

Cross Section Geometric Input

At this stage, data input is carried out on the actual condition of the soil layer before excavation work is carried out. Then the cross section image is input to simulate the stages of slope excavation from the 1st excavation to the 4th excavation and the road body.

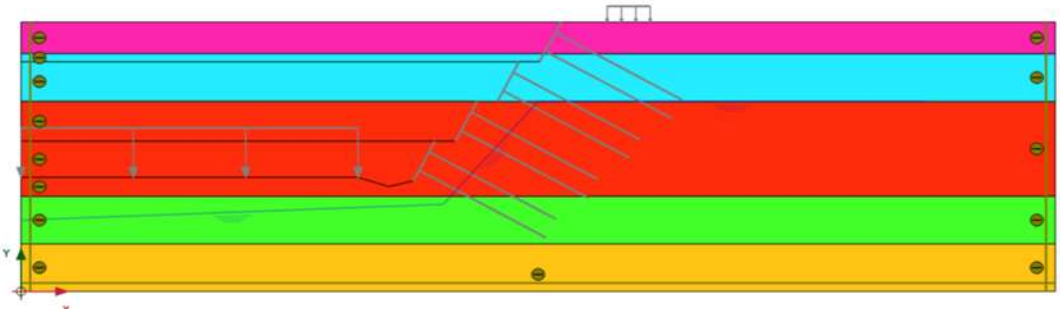

Figure 3. Soil Stratigraphy of the Mainroad STA. 205+600
Source: Author

Mesh

A mesh is dividing each segment of the soil into small elements to allow numerical computation of the response of a soil or reinforcement structure to the load it poses. PLAXIS 2D allows for multiple levels of mesh roughness (mesh refinement). Smoother meshes have more accurate results, but require longer computational time. In this model, the roughness level of medium mesh is used.

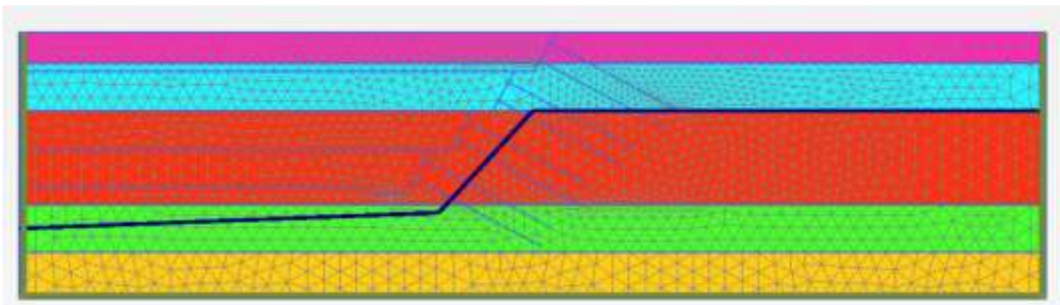

Figure 4. 2D Plaxis Mesh Output
Source: Author

Groundwater Level Input

The groundwater level is modeled in saturated conditions by assuming that the groundwater level is close to the surface of the excavated slope. The position of this groundwater table is carried out at the flow condition stage shown in Figure 5. According to the log drill data on BS-57, the groundwater level is at an elevation of – 2.30 meters from the ground level.

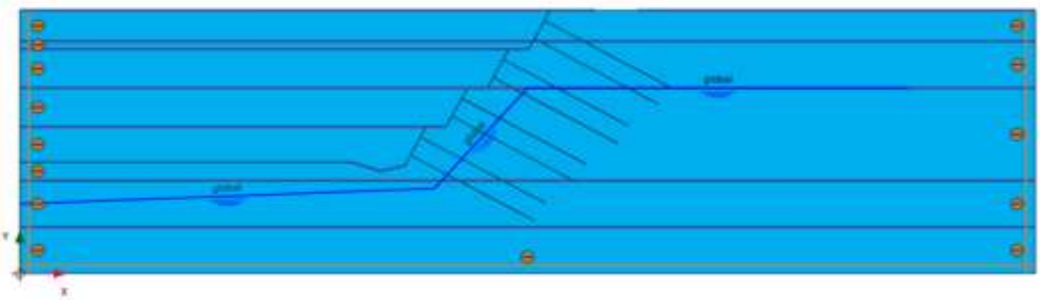

Figure 5. Groundwater Position of the Mainroad STA. 205+600
Source: Author

Earthquake Load

The earthquake load is input into the Plaxis 2D application in the explorer – pseudostatic model section shown in Figure 6. The value of the earthquake coefficient used according to the analysis in the subchapter of soil parameters is Kh = 0.122.

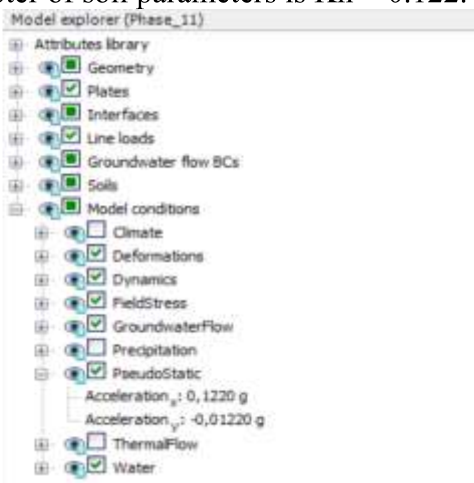

Figure 6. Horizontal seismic coefficient input
Source: Author

Stage Construction and Calculation

At this stage, excavation analysis is carried out starting from the initial condition before the work is carried out. The excavation work was carried out in 4 (four) stages until it reached the finish grade (FG) elevation. In each phase, an analysis was carried out on the value of the safety factor (SF) of the excavation slope from the 1st excavation stage to the initial service stage, in addition to modeling with earthquake factors during the initial service period. The analysis of the excavation construction stage to the initial service life was carried out in undrained conditions. The analysis of earthquake conditions is carried out under undrained conditions because the earthquake load is a cyclic load so that the soil is considered to be in a saturated condition where water is considered to be incapable of dissipating properly. Furthermore, in the last phase, an analysis was carried out on the value of slope safety factors (SF) in long-term service conditions with drained conditions.

Figure 7. Construction Internship
Source: Author

After all phases have been formed, the last stage is calculation. The calculation process takes a few minutes to complete. Next, the safety factor (SF) and the slipping field that occurred on the slope were checked.

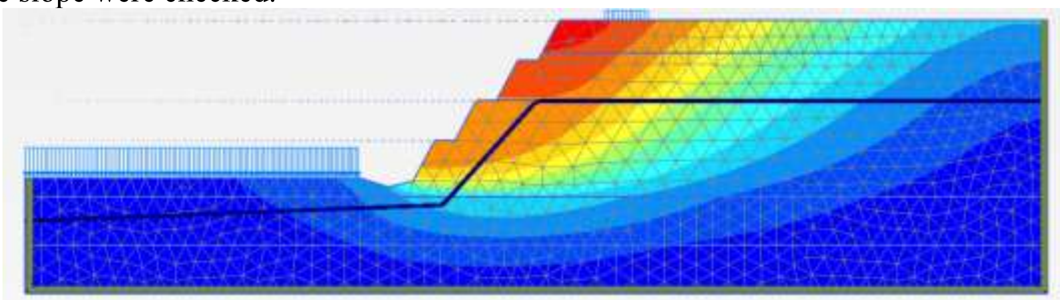

Figure 8. Slope Long Term Slip Field 2:1 Without Reinforcement

Slope Stability Analysis Results Before Reinforcement

After analysis using Plaxis 2D, the value of the slope safety factor for the slope excavation slope was obtained. The 2:1 slope design obtained results that met the planning criteria, namely a minimum SF of 1.3 for the short term, a minimum SF of 1.5 for the long term, and a minimum SF of 1.1 for the pseudostatic modeled earthquake load conditions. The slope SF value for slope slope 2:1 can be seen in Table 4 with an illustration of SF fluctuations in Figure 9.

Table 4. Recapitulation of SF Values for Slope Slope 2 : 1

1	Excavation 1	2,27	1,3	OK
2	Excavation 2	1,79	1,3	OK
3	Excavation 3	1,79	1,3	OK
4	Excavation 4	1,49	1,3	OK
5	Long-Term Service	1,44	1,5	Not OK
6	Earthquake	1,22	1,1	OK

Source : Author

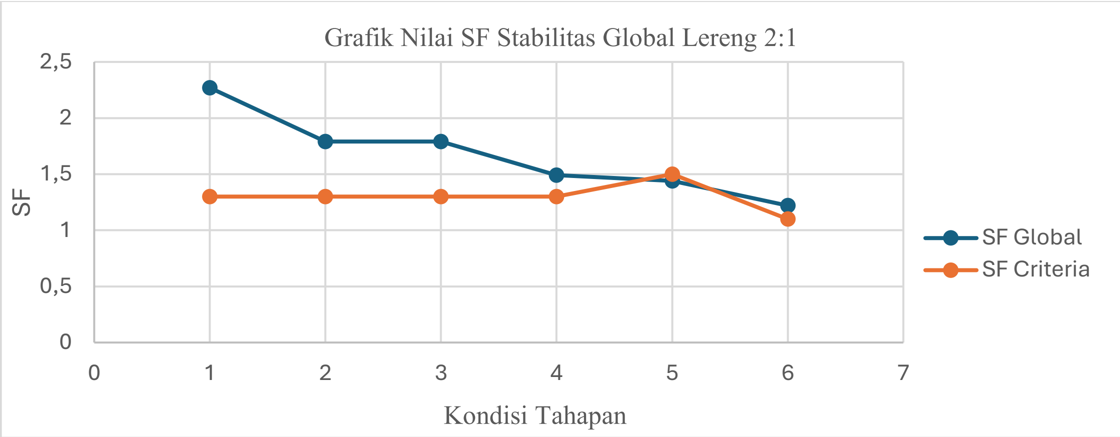

Figure 9 Comparison chart of SF excavation slopes 2 : 1
Source: Author

Based on the evaluation of the SF value in table 5.4 by adding the residents' frontage roads, the SF value on the slope of 2:1 was obtained in the condition of Long-Term Service that did not meet the SF value of the criteria. From these results, modeling was then selected using soil nailing for slopes with a slope of 2:1 to determine the effect of length and installation angle on the global and internal stability of the slope under static conditions and dynamic conditions of pseudostatic models.

Planning Variations of Soil Nailing & Shortcrete Reinforcement

The planned reinforcement is soil nailing and shortcrete. The cohesive soil consistency that is medium – very stiff is the right soil condition for soil nailing reinforcement because the effect of bond strength is very significant. So that soil nailing is more effective to avoid unplug failure. In addition, soil nailing has been widely applied as slope reinforcement so that the implementation method is easy to apply. Soil nailing planning In this modeling, soil nailing is modeled as a plate element. Soil and nail interactions utilize an elastoplastic approach to capture deformation and stress distribution along the nail. The modeling was carried out in two-dimensional (2D) conditions assuming homogeneous and isotropic slopes. Data on soil nailing and shortcrete reinforcement are shown in Figure 5.10 and Figure 5.11.

Soil Nailing - Plate Model			
Eeq	=	23340711.1	kPa
Diameter lubang	=	0.15	m
Luas lubang	=	0.017671	m2
Momen Inersia	=	0.000025	m4
Axial Stiffness	=	274976.3	kN/m
Bending Stiffness	=	386.7	kNm
Tebal Ekuivalen	=	0.130	

Figure 10. Soil naling plate model
Source: Author

Shortcrete - Plate Model

w	=	24 kN/m/m
fc'	=	28 MPa
Tebal	=	0.1 m
E	=	24870 MPa
	=	24870062.32 kPa
EA	=	2487006.232 kN/m
I	=	0.0000833 m4
EI	=	2072.5 kNm2/m
v	=	0.2

Figure 11. Shortcrete plate model
Source: Author

In soil nailing design, design variations include slope slope, ground nail length, and nailing angle to the horizontal plane. Soil nailing is designed to have a length embedded in the passive zone of the slope to increase the shear strength against avalanches and increase the nail-pulling capacity against the resulting pulling force. The active zone and passive zone in this study are represented in Figure 12.

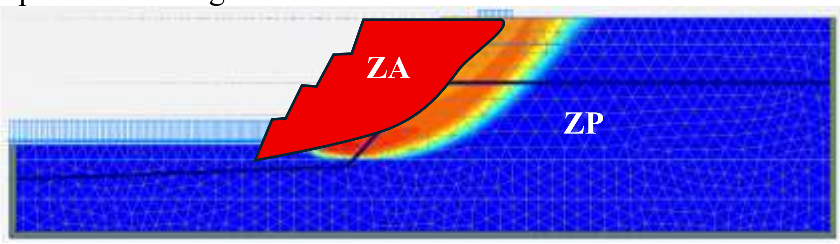

Figure 12. Active zone and passive zone of slope slope 2:1
Source: Author

Taking into account the active zone and the passive zone of the slope, the soil nailing configuration planned for reinforcement is found in Table

Table 5. Variations of soil nailing

Variations	Slope (V:H)	Nailing Length	Nailing Angle
1	2 :1	15 m	10 ^{of}
2	2 :1	15 m	20 ^{of}
3	2 :1	15 m	30 ^{of}
4	2 :1	17 m	10 ^{of}
5	2 :1	17 m	20 ^{of}
6	2 :1	17 m	30 ^{of}
7	2 :1	19 m	10 ^{of}
8	2 :1	19 m	20 ^{of}
9	2 :1	19 m	30 ^{of}

Numerical Analysis Results After Reinforcement

Soil nailing reinforcement is planned to be calculated internally first to avoid unplug failure and tensile failure, after which an evaluation of global stability is carried out.

Analysis of soil nailing reinforcement retraction resistance

The internal stability analysis aims to ensure that the interaction between soil nailing and soil mass makes a sufficient contribution to maintaining slope stability. The pull resistance formed in the part of the nail located behind the slip plane contributes to the overall stability.

Internal stability analysis is carried out by conducting an inspection of the holding of the unscrewing that occurs so that the value of the safety factor against the retraction and. The soil nailing pull force was obtained based on analysis using the numerical method on Plaxis 2D. In this study, the nails were named with sequence numbers 1 – 8 which were sequential from the upper slope to the lower slope after the final excavation. An example of calculation for nail 1 with a length of 17 meters with an angle of 30° under conditions is described as follows:

a.1 Calculation of Lp value (Length of the nail behind the slip plane)

Nails in the active zone shown in Figure 5.12 do not provide retraction resistance, because this zone interacts with the nails and soil masses relatively moving together so that the value of the bond strength is very small so that it is considered not to have an effect on the bond which affects the retraction resistance.

The strength of the nail bond with the ground will appear when the nail movement occurs. The soil zone that provides the strength of the nail bond is the zone behind the slip plane or the passive zone. Nail 1 with a length of 17 meters and an installation angle of 30o has an Lp value of 9.41 meters. This means that only 55.35% of the total nail length contributes to the retraction resistance.

a.2 Calculation of bond strength value (q_u)

Nail 1 has an Lp value of 9.41 meters. This Lp value is dominant in stiff silty clay soils, so based on the strong correlation of bond and soil type in Table 2.11, with conservative considerations, the value of soil-nail bond strength (q_u) is taken to be the lower limit of 96.6 kPa

a.3 Calculation of the value of the ultimate revocation detention (Rpo)

Niali Rpo is calculated based on equation 15 which is described as follows

$$
\begin{aligned}
Rpo &= \pi \cdot qu. D \cdot LP \\
&= \pi \times (96.6) \times (0.15) \times (9.41) \\
&= 428 \text{ kN}
\end{aligned}
$$

a.4 Calculation of maximum retractable force value (Fp)

The pull force was obtained from the results of numerical modeling using Plaxis 2D, on nail 1 for the installation of nails 17 meters long and the installation angle of 30^{o} the maximum force that occurred on the nail was 76.5 kN,

a.6 Calculation of FKpo niali (Safety number against failure to retract)

$$
\begin{aligned}
Fkpo &= Rpo / Fp \\
&= 428 / 76.5 \\
&= 5.6 > 2 \text{ (OK)}
\end{aligned}
$$

It was obtained that the FK_{po} value met the design criteria in static conditions. Typical calculations are performed for nails at any depth, any soil-nailing configuration, under static and dynamic conditions

The recapitulation of the calculation results is found in Table 5.7 and Table 5.8 Based on this table, the results for all soil nailing configurations meet the design criteria of FK_{po}

Table 6. FKpo recapitulation under static conditions

No	Tahapan	Kriteria	Statis								
			15 M			17 M			19 M		
			10	20	30	10	20	30	10	20	30
1	Medium Clayey Silt	1,5	3.91	4.04	4.41	5.01	5.13	5.60	6.11	6.22	6.79
2	Stiff Clayey Silt	1,5	2.64	2.53	2.68	3.37	3.22	3.39	4.10	3.91	4.11
3	Stiff Clayey Silt	1,5	2.36	2.99	3.02	3.29	4.01	3.97	4.22	5.03	4.92
4	Very Stiff Clayey Silt	1,5	2.43	2.56	2.74	3.26	3.32	3.49	4.09	4.08	4.24
5	Very Stiff Clayey Silt	1,5	2.59	2.79	2.78	3.61	3.69	3.58	4.63	4.59	4.37
6	Very Stiff Clayey Silt	1,5	2.55	2.57	2.49	3.33	3.24	3.09	4.11	3.91	3.69
7	Very Stiff Clayey Silt	1,5	4.07	4.04	3.79	5.21	4.96	4.55	6.35	5.88	5.31
8	Very Stiff Clayey Silt	1,5	4.71	4.16	5.10	5.54	4.83	5.88	6.37	5.50	6.65

Source : Author

Figure 13. SF or FKpo 10o angle nail variations 19 m, 17 m, and 15 m long

Source : Author

Figure 14. SF or FKpo 20o angle nail variations 19 m, 17 m, and 15 m long

Source : Author

Figure 15. SF or FKpo 30o angle nail variations 19 m, 17 m, and 15 m long

Source : Author

Based on Table 6 and Figure 13 – Figure 15, the internal stability to the failure of the retract was evaluated against the influence of length, angular influence and soil material influence. In static conditions, nails with a length of 19 meters provide an increase in FK_{po} values that are higher and more stable in nails 1 – 8 compared to 17 meters and 15 meters in length. The effect of the angle on static conditions shows that the result of the nail installation angle of 20^{o} provides an increase in the value of FK_{po} gives an increase in the value of FK_{po} is more stable and higher than the nail installation angle of 10^{o} and 30o for all length variations. Furthermore, the influence of soil material on the static condition of nails 5 – 6 has a FK_{po} value that tends to decrease, this is due to the high but strong pull force of soil-nail bonds in very stiff clay soil is lower than very stiff clay soil.

Table 7. FK Recapitulation$_{night}$ in dynamic conditions

No.	Stages	Criteria	Dynamic								
			15M			17M			19M		
			10	20	30	10	20	30	10	20	30
1	Medium Clayey Silt	1.5	3.11	3.22	3.18	3.99	4.08	4.04	4.86	4.95	4.90
2	Stiff Clayey Silt	1.5	2.44	2.23	2.09	3.11	2.83	2.64	3.78	3.43	3.20
3	Stiff Clayey Silt	1.5	1.88	2.33	2.20	2.62	3.12	2.89	3.36	3.92	3.58
4	Very Stiff Clayey Silt	1.5	1.90	2.00	2.00	2.56	2.60	2.55	3.21	3.19	3.09
5	Very Stiff Clayey Silt	1.5	1.82	1.90	1.83	2.53	2.51	2.35	3.25	3.12	2.88
6	Very Stiff Clayey Silt	1.5	1.86	1.98	1.82	2.43	2.49	2.26	3.00	3.00	2.69
7	Very Stiff Clayey Silt	1.5	1.82	1.87	1.81	2.33	2.30	2.17	2.85	2.72	2.54
8	Very Stiff Clayey Silt	1.5	2.43	1.82	4.28	2.86	2.11	4.94	3.29	2.41	5.59

Source : Author

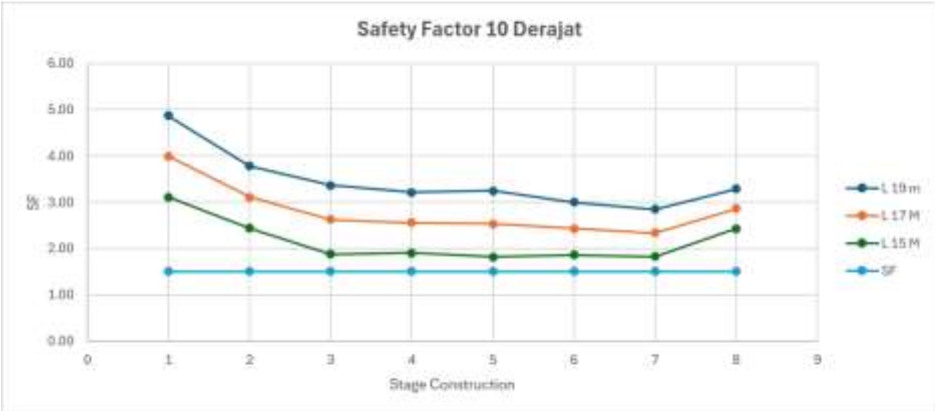

Figure 16. SF or FKpo pseudostatic variation of 10o angle nails 19 m, 17 m, and 15 m

Source : Author

Figure 17. SF or FKpo pseudostatic variation of 20o angle nails 19 m, 17 m, and 15 m

Source : Author

Figure 18. SF or FKpo Pseudostatic variation of 30o angle nails 19 m, 17 m and 15 m

Source : Author

Based on Table 7 and Figure 16 – Figure 18, the analysis of the internal stability of the retract resistance in the pseudostatic condition of the 19-meter nail length had an increase in the FKpo value with the highest results in all variations of the 17-meter and 15-meter nails. The effect of the nail on pseudostatic loading conditions with 20o and 30o mounting angles gives a more stable FKpo result than a 10o mounting angle. The influence of soil material on the condition of pseudostatic loading of clay soil provides the weakest retraction resistance so that nails 6 – 7 that get a high dynamic pull force have a low FKpo value but still meet the design criteria.

Analysis of soil nailing reinforcement tensile resistance

The tensile strength of soil nailing is highly dependent on the tensile strength of the material used, for example steel or other materials. Analysis of the strength of the nailing material based on parameters such as permissible tensile tension and nail cross-sectional area. The calculation of tensile strength and tensile safety factor was calculated according to equations 17 and 18. An example of the tensile resistance calculation on the 1st nail with a length of 17 meters for a 10o installation angle with static conditions is described as follows:

<u>b.1 Calculation of nominal cross-sectional area (An)</u>

The nominal cross-sectional area calculated is the area of the nail, based on Figure 5.12 and Figure 5.13 the nail diameter is 32 mm. then the calculation of An is described as follows

An = 1/4. π. D2

= 1/4 x π x $(32/1000)^2$

= 0.0008 m2

<u>b.2 Calculation of tensile safety factor (FKts)</u>

The tensile force on the 1st nail for a length of 26 meters with an installation angle of 100 in static conditions was obtained a value of 96.6 kN. then the calculation of FKts is described as follows

Tmax

FKts = Ace

Sigh.

96,6

= 0.0008

400

= 239.06 > 1.5 (OK)

It was obtained that the FKts value met the design criteria under static conditions. Typical calculations are performed for nails at any depth, any soil-nailing configuration, under both static and dynamic conditions.

It was obtained that the FKts value met the design criteria under static conditions. Typical calculations are performed for nails at any depth, any soil-nailing configuration, under static and dynamic conditions

The recapitulation of the results of the tensile resistance calculation is found in Table 5.9. Based on the table, the results for all soil nailing configurations meet the FKts design criteria

Table 8. Recapitulation of FKts of static and dynamic conditions

	22 M						20 M						18M					
	Static			Pseuodostatic			Static			Pseuodostatic			Static			Pseuodostatic		
Nails Number	10	20	30	10	20	30	10	20	30	10	20	30	10	20	30	10	20	30
1	292,57	383,90	220,64	630,40	777,43	655,27	242,96	318,81	183,23	509,29	628,08	529,38	216,40	283,95	163,20	457,42	564,10	475,46
2	337,58	374,57	239,57	652,78	725,52	618,59	280,82	311,60	199,29	538,06	598,02	509,88	262,83	291,63	186,52	464,70	516,48	440,36
3	288,62	319,55	293,04	501,40	527,51	528,44	277,07	306,76	281,31	449,69	473,10	473,94	265,61	294,07	269,67	412,43	433,90	434,67
4	327,32	309,08	307,55	474,05	503,27	495,80	312,25	294,84	293,39	437,00	463,94	457,06	291,58	275,33	273,97	405,59	430,59	424,20
5	386,39	364,00	359,96	519,43	571,96	563,26	378,48	356,56	352,60	487,91	537,26	529,08	347,68	327,54	323,91	449,35	494,80	487,27
6	479,64	523,16	359,34	675,48	793,91	764,69	475,49	518,63	356,23	636,54	748,15	720,61	471,87	514,69	353,52	620,46	729,25	702,41
7	285,70	400,06	414,98	463,79	597,45	621,70	272,95	382,21	396,47	429,58	553,38	575,84	252,10	353,02	366,18	406,49	523,64	544,89
8	308,89	445,76	410,01	493,32	633,51	614,55	295,56	426,52	392,32	468,17	601,21	583,22	273,14	394,16	362,55	432,29	555,14	538,52
9	421,82	516,01	477,46	608,33	709,05	714,95	408,57	499,80	462,46	583,23	679,79	685,46	396,92	485,55	449,28	562,67	655,83	661,29
10	532,49	614,55	622,32	772,15	850,17	945,60	518,61	598,54	606,11	744,48	819,71	911,72	512,31	591,27	598,74	699,81	770,53	857,02
11	323,91	417,16	441,72	491,45	618,28	684,49	311,80	401,57	425,21	484,50	609,53	674,80	305,44	393,38	416,54	459,46	578,03	639,93
12	359,03	454,77	475,60	537,46	661,18	716,20	351,75	445,56	465,96	548,14	674,31	730,43	337,29	427,23	446,80	509,06	626,24	678,36
13	416,85	521,92	559,53	635,38	777,43	868,82	410,40	513,85	550,88	671,63	821,79	918,39	391,67	490,39	525,73	601,07	735,46	821,91
14	533,11	637,55	740,75	857,63	1043,83	1294,07	531,01	635,05	737,84	881,32	1072,66	1329,81	512,22	612,57	711,73	821,49	999,84	1239,53
15	250,86	327,32	404,42	521,92	767,49	946,23	263,80	344,21	425,28	562,48	827,13	1019,76	246,64	321,83	397,62	510,08	750,08	924,77
16	287,10	341,00	398,51	569,17	729,87	870,38	313,20	372,01	434,74	649,62	833,04	993,40	282,34	335,34	391,90	565,79	725,55	865,22
17	336,65	402,55	468,76	668,02	792,04	907,68	348,16	416,31	484,79	659,88	782,40	896,63	340,15	406,73	473,63	624,66	740,64	848,77
18	413,12	557,35	666,46	797,64	1210,76	1464,10	428,24	577,75	690,86	838,09	1272,16	1538,35	354,67	478,50	572,17	730,65	1109,08	1341,15

Source : Author

Global Sstability Analysis of Slope after Soil Nailing Reinforcement

At this stage, an analysis was carried out on the variation in the length of the nailing and the angle of installation of the nailing in accordance with the variation that had been determined An analysis was carried out on the internal stability and global stability of the static and pseudostatic conditions of the slope to determine the nailing behavior of the excavated slope. One example of the variation carried out by modeling is the length of the nailing 17 meters with a nailing installation angle of 30^0. The soil layer is modeled with Hardening Soil and drainage type Undrained model materials.There is an assumed load of 10 kPa on the upper side of the excavated slope bordering the ROW fence as input data for the residents' road frontage. The 1st excavation consists of one excavation trap that has a slope geometry with a total depth of 4 meters with the condition that the slope surface has been protected using shorcrete and the installation of 2 rows of nailing on the slope. The slope stability at excavation stage 1 after reinforcement has an SF value of 3.2. At the excavation stage, the analysis used is the total stress analysis for cohesive soil because groundwater is still not fully dissipated, so the shear strength must be modeled as the total shear strength in undrained conditions. The results of the excavation of the slope from the beginning to the end can be seen from the image x – x nail 17 m installation angle 30o for a slope of 2:1.

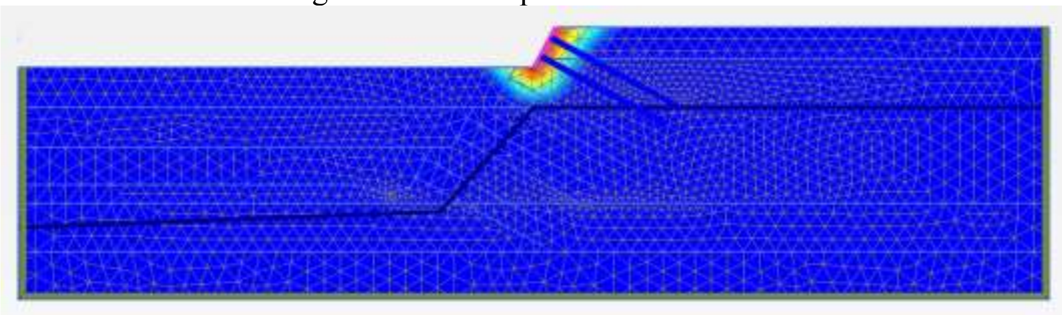

Figure 19 Excavation Modeling 1 Nail 17 m angle 10o, SF= 3.2

Source: Author

The next stage is the 2nd excavation which has a slope geometry with a total depth of 9.00 meters with the condition that the slope surface has been protected using shorcrete and the installation of 4 additional nailing rows on the 2nd slope excavation. The slope stability at excavation stage 2 after reinforcement had an SF value of 3.03. Numerical modeling of these conditions is shown in Figure 20.

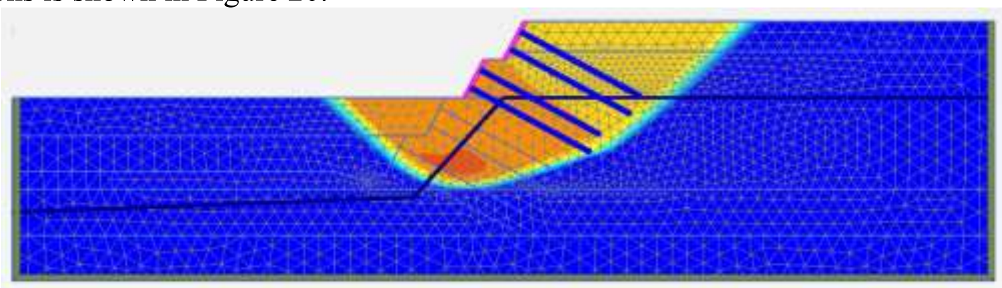

Figure 20. Excavation Modeling 2 Nail 17 m angle 30o, SF = 3.03

Source : Author

The next stage is the 3rd excavation which has a slope geometry with a total depth of 14.00 meters with the condition that the slope surface has been protected using shorcrete and the installation of 4 additional nailing rows on the 3rd slope excavation. The slope stability at excavation stage 3 after reinforcement has an SF value of 2.24. Numerical modeling of these conditions is shown in Figure 5.21.

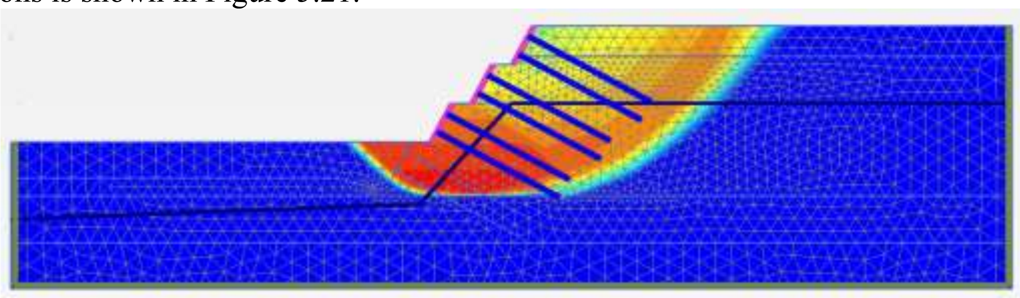

Figure 21. Excavation modeling 3 nails 17 m angle 30o, SF = 2.24

Source : Author

The 4th excavation which has a slope geometry with a total depth of 19.00 meters with the condition that the slope surface has been protected using shorcrete and the installation of 4 additional nailing rows on the 4th slope excavation. The slope stability at excavation stage 4 after reinforcement had an SF value of 2.18. Numerical modeling of these conditions is shown in Figure 5.24.

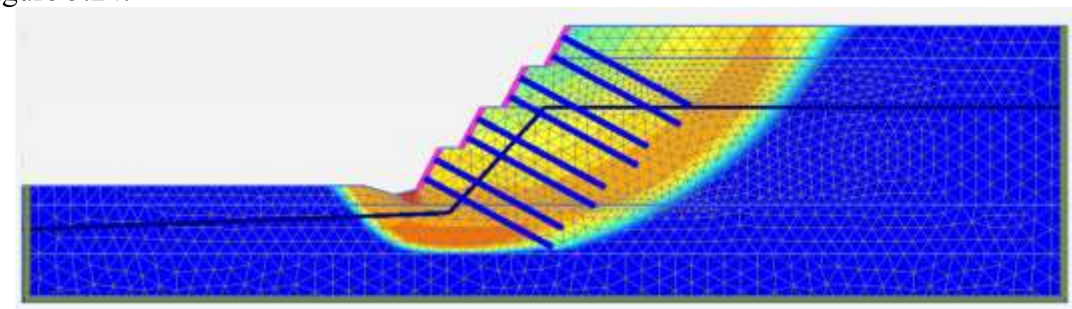

Figure 22. Excavation modeling 4 nails 17 m angle 30o, SF = 2.18
Source : Author

The next stage is modeling for long-term service conditions. The modeling is with a soil layer modeled with a hardening soil type drained model. This is because the groundwater level has been dissipated so that the soil that has been analyzed must be modeled effective stress analysis, namely by modeling the soil with its effective shear strength in drained conditions. The slope stability at the Long-term service stage after reinforcement has an SF value of 2.31. Numerical modeling of these conditions is shown in Figure 5.23. Slope stability at the long-term service stage.

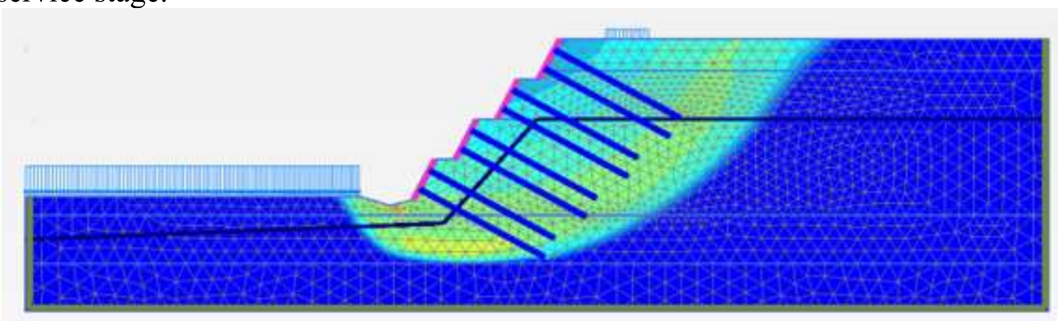

Figure 23. Modeling long-term serve nail 17 m angle 30o, SF = 2.31
Source : Author

The last stage is modeling for earthquake treatment conditions using pseudostatic methods. In earthquake conditions, the cyclic load that occurs on the soil makes the behavior of the soil undrained because when the load of an earthquake occurs, water does not have time to experience the process of water dissipation, so the analysis used is a total stress analysis of the undrained type. The slope stability at the stage of treating the earthquake load after percutaneous had a SF value of 1.68. This value meets the design criteria for soil nailing reinforcement in earthquake conditions, with a minimum SF value of 1.1. Numerical modeling of these conditions is shown in Figure 5.24.

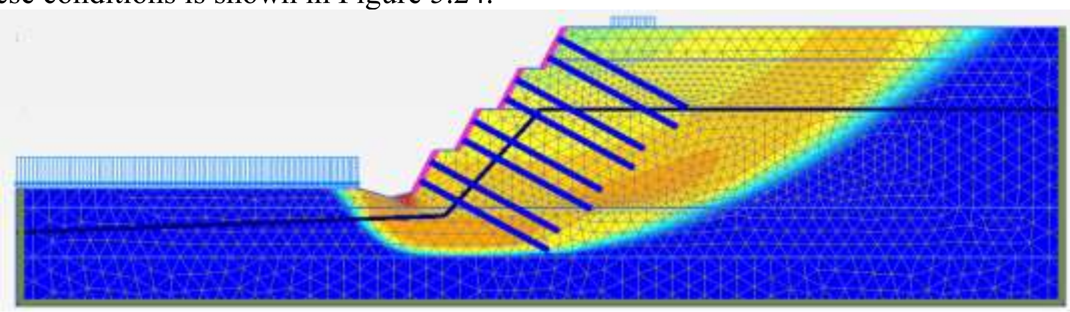

Figure 24. Modeling handle earthquake nail 17 m angle 30o, SF = 1.68
Source : Author

Analysis of the global stability of the excavated slope after soil nailing reinforcement is typically performed using 2D Plaxis for each nail variation. Subsequently, the recapitulation of the results of the global stability analysis is contained in Table 9.

Table 9. Global Stability SF Value Recapitulation

No.	Stages	Criteria	Without Reinforcement	15 M			17 M			19 M		
				10	20	30	10	20	30	10	20	30
1	Excavation 1	1 M	2.27	3.69	3.50	3.23	3.85	3.50	3.20	3.93	3.42	3.14
2	Excavation 2	1.3	1.79	2.91	2.97	2.99	2.95	3.00	3.03	2.98	3.04	3.13
3	Excavation 3	1.3	1.79	1.98	2.02	2.10	1.99	2.07	2.24	2.01	2.14	2.47
4	Excavation 4	1.3	1.49	1.59	1.98	2.10	1.67	2.07	2.18	1.77	2.13	2.32
7	Long-Term Service	1.5	1.44	2.01	2.18	2.31	2.06	2.27	2.37	2.11	2.33	2.49
8	Earthquake	1.1	1.22	1.26	1.53	1.64	1.29	1.61	1.68	1.35	1.64	1.75

Based on Table 9, the results of the interpretation are obtained, namely that at the same length, the angle variation of 30o provides a significant increase in the global SF value. In addition, the value of SF Global at the initial excavation stage to the initial service life decreased significantly due to the loss of normal force of the excavated soil mass resulting in a reduction in the resistance moment to the thrust moment. Furthermore, the highest effectiveness on the review of the influence of length on static conditions, the increase in the global SF value in the condition without reinforcement is the nail with a length of 30 meters experiences an increase in the global SF value. The effect of the angle with the highest global SF value increase effectiveness on static conditions was the nail with a mounting angle of 30o, followed by a mounting angle of 200, and a mounting angle of 100 against the non-reinforcement condition. Meanwhile, in earthquake conditions, the use of nails did not have a significant effect on angles 200 and 100, but at the angle of installation 300

Cost Evaluation of Soil Nailing & Shortcrete Reinforcement Alternatives

The cost of implementing the work is calculated by multiplying the volume of each work by the predetermined unit price. The calculation of the volume of work is based on the drawings of the available implementation plan. Meanwhile, the unit price of work is taken from the Work Unit Price Analysis contained in the contract for the construction of the Rengat – Pekanbaru Toll Road Project Pekanbaru Ring Section, which refers to the General Specifications of Freeways and Toll Roads in 2020. The unit price used is the price that applies at the project site, namely the Rengat – Pekanbaru Toll Road Project area of the Pekanbaru Ring Road Section in Pekanbaru City, Riau Province. Full details of the calculation can be seen in Table 5.10.

Table 5.10 Cost Comparison Table on MR STA 205+600 Cross Section

Variation	Work Item	Volume	Unit	Unit Price	Price	% Increase
Long Soil Nailing 15	Soil Nailing	30	m'	Rp. 1,245,410.00	Rp. 37,362,300.00	**100.00%**
	Shortcrete	26	m2	Rp. 1,248,500.00	Rp. 32,461,000.00	
					Rp. 69,823,300.00	
Long Soil Nailing 15/17/19	Soil Nailing	34	m'	Rp. 1,245,410.00	Rp. 42,343,940.00	**107.13%**
	Shortcrete	26	m2	Rp. 1,248,500.00	Rp. 32,461,000.00	
					Rp. 74,804,940.00	
Long Soil Nailing 19	Soil Nailing	38	m'	Rp. 1,245,410.00	Rp. 47,325,580.00	**114.27%**
	Shortcrete	26	m2	Rp. 1,248,500.00	Rp. 32,461,000.00	
					Rp. 79,786,580.00	

Table 10 is a calculation based on the Cross Section Mainroad STA figure. 205+600 with 3 variations of soil nailing length. It can be concluded that the increase in the 2nd variation of the addition of 2 meters of soil nailing length increased the cost by 7.13%, while for the 3rd variation the addition of 3 meters of soil nailing length increased the cost by 14.27%.

In conclusion, the most effective and efficient soil nailing configuration in improving global stability and internal stability of the slope is using a variation of **15 meters of soil nailing length and a slope angle of 30º**. looking at the efficiency and factor of global and internal stability of the large slope.

CONCLUSION

This study was conducted on the Rengat–Pekanbaru Toll Road, Pekanbaru Ring Road Section, at the main road location of STA 205+600. The study evaluated the effectiveness of soil nailing configurations for slope stability as an alternative reinforcement method for deep excavation slopes. The investigated parameters included the effects of soil nail length and installation angle on the internal and global stability of the slope. Based on the analysis and evaluation results, several conclusions were obtained.

The factor of safety (FS) for global slope stability increased with increasing soil nail length and installation angle. The highest improvement in global stability compared with the unreinforced condition was achieved using a 19 m soil nail length. The FS for internal stability against soil nail pullout resistance increased as soil nail length increased, while smaller installation angles provided improved pullout resistance performance. Overall, the tensile resistance capacity met the required FS criteria for all variations of soil nail lengths and installation angles.

The increase in global stability FS was significant under static loading conditions; however, under earthquake (pseudostatic) conditions, soil nailing reinforcement did not provide a significant improvement in global stability for slopes consisting of clay soils. Conversely, the internal stability FS against soil nail pullout resistance increased with longer soil nails and smaller installation angles under both static and pseudostatic loading conditions. For medium-consistency clay soils with relatively weak bonding characteristics, soil nailing proved effective in improving slope stability performance in terms of both internal and global stability.

Based on technical evaluation and cost-efficiency analysis, the soil nailing configuration with a 15 m nail length and a 30° installation angle provided the most effective and economical performance. This configuration achieved a significant increase in FS compared with the initial unreinforced condition while maintaining efficient construction requirements, making it the recommended configuration for implementation at the study location.

REFERENCES

Anas, T. (n.d.). *Massive infrastructure development and its impact on Indonesia's economy.*

Bahramipour, O., Moezzi, R., Jalali, F. M., Khaksar, R. Y., & Gheibi, M. (2025). Parametric evaluation of soil nail configurations for sustainable excavation stability using finite element analysis. *Inventions, 10*(4), 45. https://doi.org/10.3390/inventions10040045

Budiharjo, L. A. S., Mahardika, D. C., Whayuni, M., & Karlinasari, R. (2020). Pengaruh jumlah pemasangan *soil nailing* terhadap peningkatan faktor keamanan lereng. *G-SMART: Jurnal Teknik Sipil Unika Soegijapranata Semarang, 4*(2).

Hariyanto, A. D., Graha, D. T. R., & Afrianto, F. (2024). Regional economic agglomeration and Trans-Sumatra toll road development: A network and spatial review. *Journal of Infrastructure Policy and Management, 7*(1), 75–96.

Hidir, A., Yusuf, Y., & Syafrizal, S. (2025). Sociological analysis of Pekanbaru-Kampar agglomeration's response to infrastructure development: A structural and functional analysis. *Jurnal Riset Teknologi Pencegahan Pencemaran Industri, 16*(2), 123–135.

Imbar, E. R. B., Mandagi, A. T., & Rondonuwu, S. G. (2019). Analisis stabilitas lereng dengan perkuatan *soil nailing* menggunakan program Slope/W dan Geostructural. *Jurnal Tekno,* *17*(72), 59–64.

Lazarte, C. A., Robinson, H., Gómez, J., Baxter, A., Cadden, A., & Berg, R. R. (2015). *Geotechnical engineering circular No. 7: Soil nail walls—Reference manual*. Federal Highway Administration.

Li, Q., et al. (2020). Field investigation and numerical study of a siltstone slope instability induced by excavation and rainfall. *Landslides, 17*(6), 1485–1499.

Lin, C., et al. (2020). Reinforcement effects and safety monitoring index for high steep slopes: A case study in China. *Engineering Geology, 279*, 105861. https://doi.org/10.1016/j.enggeo.2020.105861

Lin, P., et al. (2015). Cracking, stability and slope reinforcement analysis relating to the Jinping Dam based on a geomechanical model test. *Arabian Journal of Geosciences, 8*(7), 4393–4410. https://doi.org/10.1007/s12517-014-1518-3

Ma, K., et al. (2017). Stability analysis and reinforcement evaluation of high-steep rock slope by microseismic monitoring. *Engineering Geology, 218*, 22–38. https://doi.org/10.1016/j.enggeo.2017.01.008

Marwane, H., et al. (2024). Soil nailing for slope stabilization: An overview. *Interactions, 246*(1), 14.

Pinuji, I., Dewi, P., Puspitasari, A., & Widiastuti, S. (2024). Soil nailing application for railways track safety on slope area. *Journal of Physics: Conference Series, 2916*(1), 012015. https://doi.org/10.1088/1742-6596/2916/1/012015

Rahmadana, M. F., & Putra, I. M. (2025). Community dynamics towards the existence of toll roads in Indonesia: A literature and spatial study. *Frontiers in Built Environment, 11*, 1515186. https://doi.org/10.3389/fbuil.2025.1515186

Ramayanti, A., Faris, F., & Hardiyatmo, H. C. (2024). Effect of parametric soil nailing under seismic behavior. *Inersia: Jurnal Teknik Sipil dan Arsitektur, 20*(2). https://doi.org/10.21831/inersia.v20i2.74144

Reza, A., et al. (2018). Review on corrosive behavior and possible protective measures for reinforcing bars. *International Journal of Engineering & Technology*.

Riogilang, H., Pontororing, C., & Mekel, A. (2014). *Soil nailing* dan *anchor* sebagai solusi aplikatif penahan tanah untuk potensi longsor di Sta 7+250 ruas jalan Manado–Tomohon. *Jurnal Ilmiah Media Engineering, 4*(2), 119–126.

Tian, K., Zhu, H., & Zhang, C. (2022). Influence of transverse shear resistance of soil nails on slope stability. *Journal of Engineering Geology, 30*(5), 1744–1752. https://doi.org/10.13544/j.cnki.jeg.2022-0459

Tian, X., Song, Z., & Zhang, Y. (2021). Monitoring and reinforcement of landslide induced by tunnel excavation: A case study from Xiamaixi Tunnel. *Tunnelling and Underground Space Technology, 110*, 103796. https://doi.org/10.1016/j.tust.2021.103796

Verico, K., Wibowo, H., & Yudhistira, M. H. (2024). *Infrastructure for inclusive economic development* (Vol. 2): *Case studies of accelerated projects*. Economic Research Institute for ASEAN and East Asia & Ministry of Finance.

Wang, J., et al. (2024). Research on corrosion protection of ground anchors and soil nails based on European and American standards. In *International Conference on Hydraulic and Civil Engineering & Engineering Safety and Disaster Prevention Forum* (pp. 212–226). Springer.

Yanto, F. H. (2024). Safety factor investigation based on finite element analysis in basement design using bamboo soil nailing. *IOP Conference Series: Earth and Environmental Science, 1314*(1), 012091.