Journal of Ecohumanism
2025
Volume: 4, No: 2, pp. 1262 – 1272
ISSN: 2752-6798 (Print) | ISSN 2752-6801 (Online)
https://ecohumanism.co.uk/joe/ecohumanism
DOI: https://doi.org/10.62754/joe.v4i2.6460

Modeling of Soil Nailing Configuration towards the Slope Height Due to the Land Sliding Safety

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Abstract

This research intends to investigate the effective height for installing the soil nailing in the vertical direction of slope height. One of the effective retaining wall methods and much be used in Indonesia is by using soil nailing. The methodology consists of the usage of finite element by using the Plaxis software. The variable that is researched is the effective height of soil nailing which the configuration model of vertical direction follows the simulation. The research is conducted on 5 models as follows: the effective height of nailing is the same as slope height (Ha); then the effective height of nailing is the same as ¾ Hn; 2/3 Hn; ½ H; 1/3 H; and ¼ H. Based on the numerical simulation, the result shows that the effective height of soil nailing configuration in the vertical direction is 1/3 of slope height. The simulation result is effective enough to produce the safety value (SF) is 1.62 (> 1.5) and giving the lowest deformation value as follows: δ = 0.02318 m (< 0.005 H = 0.09 m). The research result is hoped can give a recommendation to the determination of effective height in design of soil nailing for retaining wall.

Keywords: *soil nailing, effective height, slope, landslide, safety.*

Introduction

One of the methods for effective retaining wall and much be used in Indonesia is by using soil nailing. Initially, soil nailing is used for artificial retaining wall like earthen wall excavation, so SNI 8460 (SNI 8460, 2017) as well as FHWA 007 (FHWA GEC 007, 2015) still recommends the steps system of wall construction for sail nailing from top to down (top-down construction). In accordance with the steps of this construction, it is clear that if all height of soil wall will be given the soil nailing retaining. In real, nowadays there are many soils nailing retaining that are used for handling the landslide in the natural slope which needs the construction step from bottom to top (bottom-up construction). If the height of natural slope is not too high (< 15 m), the usage of soil nailing in all of slope height is still possible. However, if the height of natural slope is high enough or very high (> 15 m), the usage of soil nailing in all of slope height will cause many doubts, mainly from the financial aspect as well as the technical aspect. The SNI 8460 has not given the requirement about the height of soil nailing for natural slope with high category, so for the design of landslide handling in the slope that uses the soil nailing, often appears the question about is the soil nailing safe if it is installed in all of slope height?

Soil nailing is a passive retaining wall system (SNI 8460, 2017), it means that nail bar that has been planted in the ground, is not given the pre-stress power. This retaining system mainly consists of a number of nail bars that are installed in the ground by drilling or pressuring, and the slope surface wall is as reinforced concrete. The nail bar is installed with tilt angle closes to horizontal. However, in the slope surface part there is the nail head that will be connected with shot Crete through the bearing plate that is placed on the top of the wall and fastening bolt. When there happens the slope deformation, so it will cause the soil pressure in the surface wall that the pull power can be continued to the nail bar. The longer nail bar will cause the higher value of safety factor; however, the design of retaining wall will become non-economic. SNI 8460 gives rule that the length of nail bar should be taken between 0.6 H until 1.2 H, where H is the slope height. The length of nail bar < 0.6 H usually does not fulfill the stability to sliding. On the contrary,

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if the length of nail bars > 1.2 H, it shows besides being wasteful that the soil in the site location is too soft and it is not suitable by using the design of soil nailing.

Some researchers have carried out to determine the effectiveness of nail bar length in increasing the safety factor of slope. In numerical research that discussed about the length of nail bar with the length variation of 5.9 m, 6.1 m, 6.3 m, and 6,5 m; it turns out there is known that the getting longer the nail bar will increase the safety factor although the increasing is not significant (Simorangkir and Suhendra, 2020; Yakin et.al, 2022; Salamah et.al, 2020; Prabowo and Jatmika, 2019; Ega et.al). The best slope of nail bar is slope that cause the pull power in the nail bar can work aligned and in located in the neutral line as of nail bar. SNI 8460-2017 gives the rule that the slope of nail bar should be taken between 10° until 20°. The installing of nail bar slope which is less than 10° must be avoided because it will cause the formation of pore in grouting that is the end it will decrease the pull capacity of nail bar. On the contrary, the slope of nail bar which is more 20° will cause the nail bar is not effective hold the lateral force. In research about the nail bar slope with the slope variation of 10°, 15°, 20°, it turns out that the conclusion is the nail bar slope of 15° has given the highest safety factor that is 2.195 (Tarakashima and Zhafirah; Beatrix et.al; Pangestu and Marzuko, 2018. In an experiment that modelled the influence of earthquake in the slope which is retained by nailing (Hanif et.al, 2017; Budiharjo et.al; Wang et.al, 2010; Syuhada et.al, 2020) mentioned that the nailing retaining can hold the dynamic acceleration as the earthquake response, so the slope deformation can be significantly decreased and hold the slope deformation in the retaining effect zone of soil nailing. The slope landslide due to earthquake in the middle and low parts of slope [15], there is the identification that soil nailing is not necessarily installed in all of slope height. It is also known that the longer nailing with close distance can increase the slope stability and decrease the happening of slope deformation. However, the condition of slope soil that is saturated will cause the slope soil is still experiencing moving (Tarakashima and Zhafirah; Wang et.al, 2010; Zhao et.al, 2020; Riogilang et.al, 2014; Zhang and Ding, 2019), so it becomes not effective and efficient if the soil nailing is installed in all of slope surface.

This research intends to investigate the effective height for soil nailing installing in vertical direction, remembering that some previous researchers mentioned that the installing of soil nailing in all of slope height is not necessarily effective mainly with the condition of slope is saturated and experiences earthquake.

Materials and Methods

Study Location and Methodology

This research is conducted on the landslide point in Km 234+600 on the road section Jalan Sisu-Snopy-Papua Barat Province. On the landslide point, there are 2 sides of upper slope that is facing each other as presented in Figure 1. In rainy season, the right side of upper slope more often experiences land sliding that causes the debris is collapsed on the road section so it is functional. Data of soil parameter is obtained based on the result of SPT test and laboratory test and the result is presented in Table 1. However, the parameter data of soil nailing is based on the best parameter that is obtained from the previous research that is presented in Table 2. The slope modelling in analysis is in accordance with the real condition which the geometry data of slope cross section is obtained based on the topography survey as presented in Figure 2.

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Figure 1. Photography of Slope in Km. 234+600 Road Section of Sisu – Snopy Papua Barat Province

The research method is carried out by using finite element method with the Plaxis software. Variable that is researched is effective height of soil nailing which the vertical direction of configuration model to carry out the simulation as presented in Figure 3 until 6.

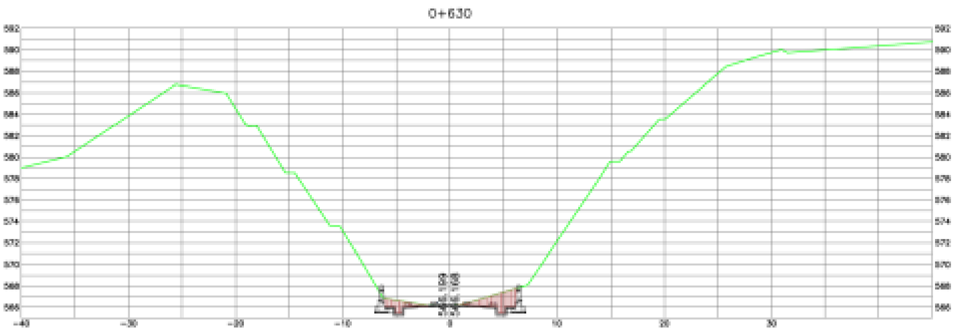

Figure 2. Long Section Existing Location

Experiment Model Design of Numerical Simulation for Effective Height

The experiment model design of numerical simulation for effective height is as follows: 1) Model-1 (Figure 3): the effective height of nailing is the same as slope height (Ha); 2) Model-2 (Figure 4): the effective height of nailing is the same as ¾ H_n; 3) Model-3 (Figure 5): the effective height of nailing is the same as 2/3 H_n; 4) Model-4 (Figure 6): the effective height of nailing is the same as ½ H; 5) Model-5 (Figure 7): the effective height of nailing is the same as 1/3 H; 6) Model-6 (Figure 8): the effective height of nailing is the same as ¼ H.

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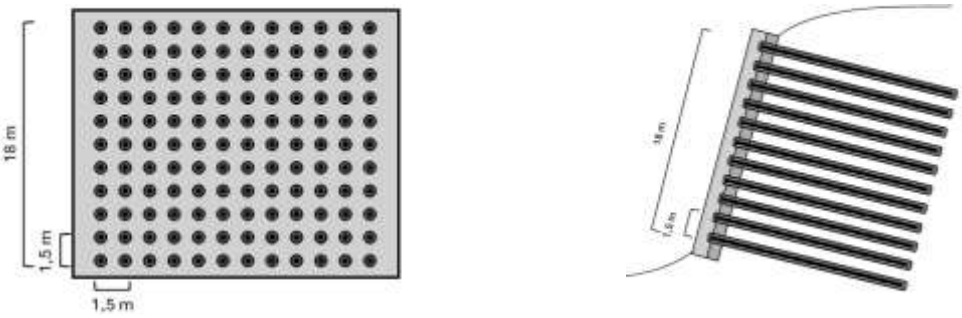

Figure 3. Model 1: Effective Height of Nailing = Slope Height (H_n)

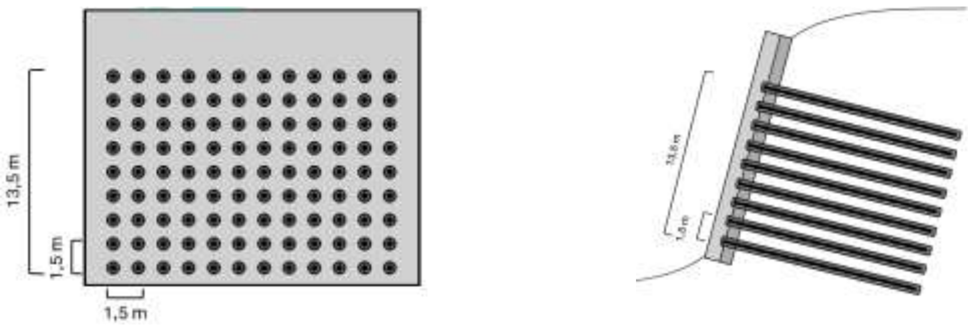

Figure 4. Model 2: Effective Height of Nailing = ¾ H_n

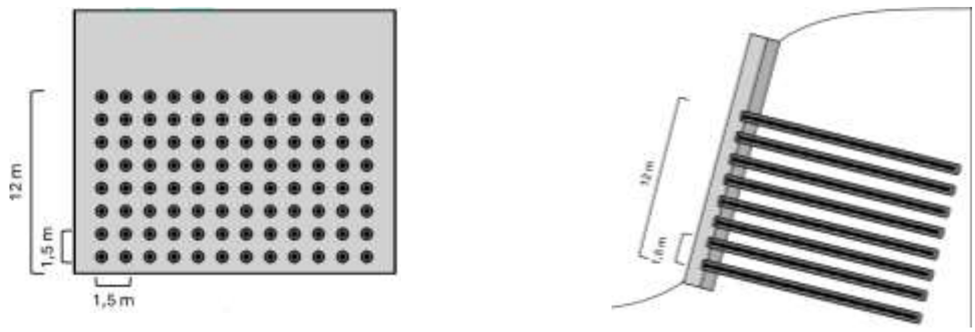

Figure 5. Model 3: Effective Height of Nailing = 2/3 H_n

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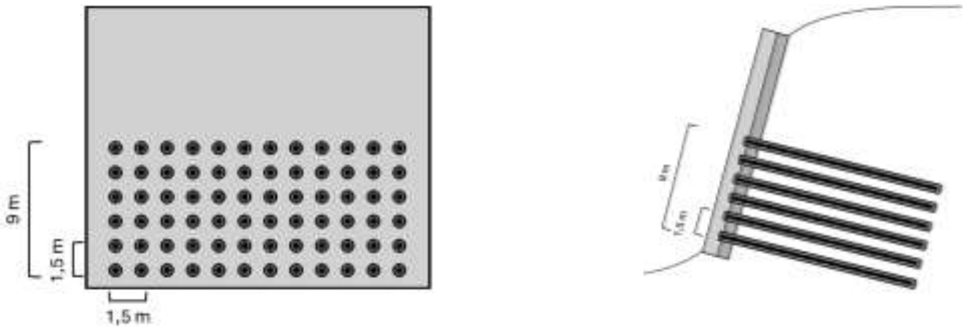

Figure 6. Model 4. Effective Height of Nailing = ½ H_n

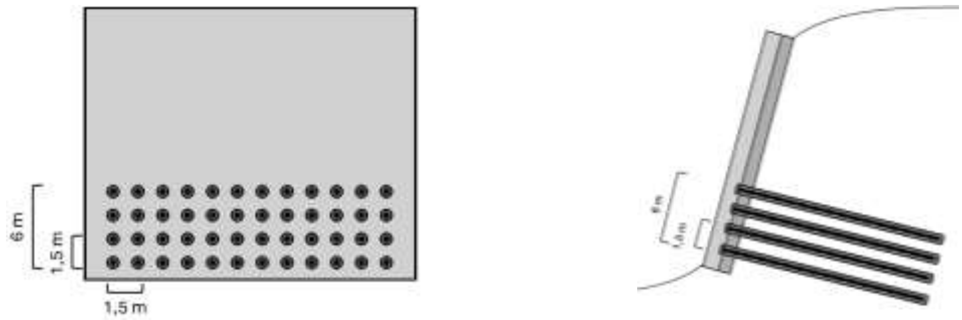

Figure 7. Model 5: Effective Height of Nailing = 1/3 H_n

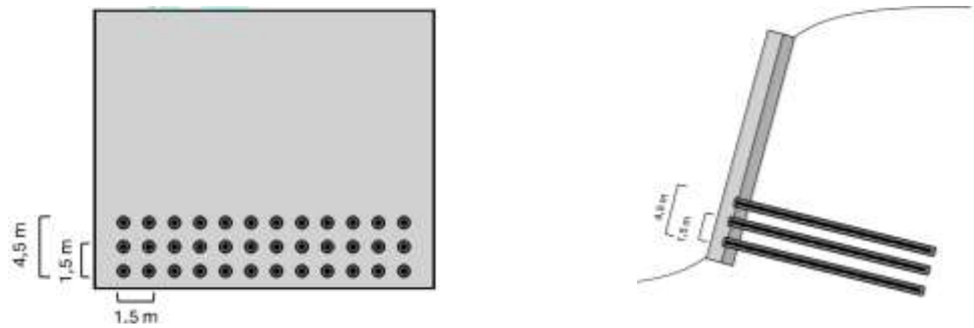

Figure 8. Model 6: Effective Height of Nailing = ¼ H_n

Data of soil parameter is presented in Table 1 and data of soil nailing parameter is presented in Table 2.

Table 1. Data of Soil Parameter

Soil Layer	Type	Soil	Elv	N_{SPT}	γ	c'	φ'	Su	τ	Eu	E50'
		Model		avg				6xN_{SPT}	c'+σtanφ'		
			m		kN/m³	kPa	°	kPa	kPa		kPa
Hard Clay	Undrained A	MC	-6	60	18	40.0	20	360.0	171	108000	86400
Stiff Clay	Undrained A	MC	-6	8	18	25	20	48.0	42	14400	11520

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Table 2. Data of Soil Nailing Data

Parameter	Value	Unit
Distance of Nailing	1.5	m
Diameter	0.15	m
Slope	15	deg
Length	20	m
D iron- Soil Nailing	0.025	m
Spec of Grout Concrete	25	Mpa
D Shotcrete	3	m
D grouting	0.15	m

In order to know the slope behaviour that experiences earthquake with water saturated condition, there is formerly modelled the slope condition without soil nailing reinforcement. The behaviour that is mainly observed is how big the deformation if the slope without reinforcement experiences the earthquake and in water saturated condition.

The next stage is to carry out the modelling of slope reinforcement by using soil nailing. The reason of selecting this reinforcement is because the soil nailing is more used for increasing the slope stability, the installing is fast, easy, and economic. The scenario that will be given for testing the hypothesis in the beginning is by giving the reinforcement from slope foot until the height is a quarter of slope height, the next scenario is the height is until one third of slope height, and the highest is three-quarter of slope height.

From the four scenarios, there will be carried out the modelling iteration with the variable is reinforcement height of slope foot. If in the initial scenario (the reinforcement until a quarter of slope height from slope foot) happens the deformation more than 10 cm, so the slope will be assumed collapsed (break down) and so on until the deformation is less than 10 cm.

After every stage has been carried out, so it will be concluded from the ratio between the deformation and pore water pressure in the slope that is reinforced and unreinforced in the earthquake condition, the graph of slope dynamic safety factor can be made, and the next research can be suggested.

If there has been known the effective height that is produced, then there is carried out the simulation of slope shape change by re-slopping that is to divide the slope height into some trap for finding the optimal design.

Results and Discussion

The numerical simulation is started by modelling the existing condition based on the available data and the result is presented in Figure 9. Because the critical slope is seen in the right side, so for the effectiveness of numerical simulation then it is carried out the modelling only in the right side of slope.

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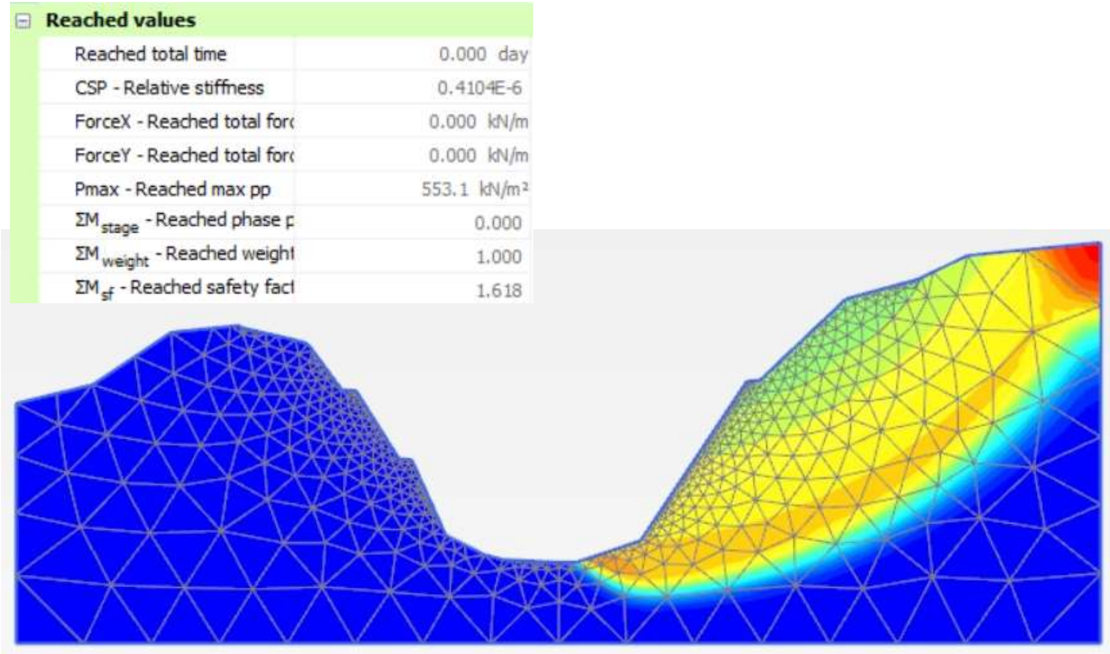

Figure 9. Existing Condition Modeling

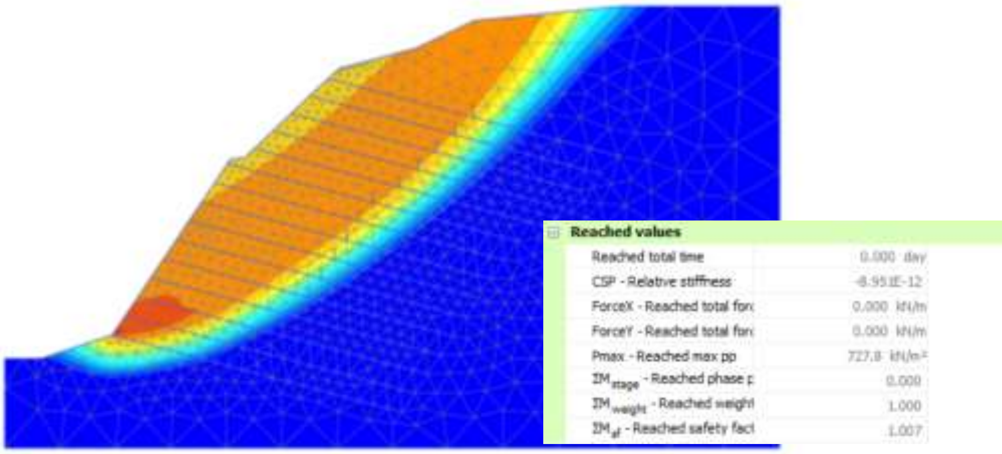

Figure 10. Numerical Simulation Result of Existing Condition Modelling (SF = 1.007)

Based on the result of numerical simulation in Figure 10, the existing slope is seen critic because it has the safety factor (SF) = 1.007 (< 1.5), so it is needed the retaining by using soil nailing. The relative stiffness is -8.951×10^{-6}, the reached total force for X = 0 kN/m and for Y = 0 kN/m. However, the reached max pp: P_{max} = 727.8 kN/m², the reached phase F: EM_{stage} = 0, the reached weight: EM_{weight} = 1, and the reached safety factor: EM_{sf} = 1.007. Then, with the same parameter, the result of numerical simulation is retained by using soil nailing and it can be seen in Figure 11 until 16 which shows that by retaining with soil nailing can produce safety factor (SF) more than 1.5.

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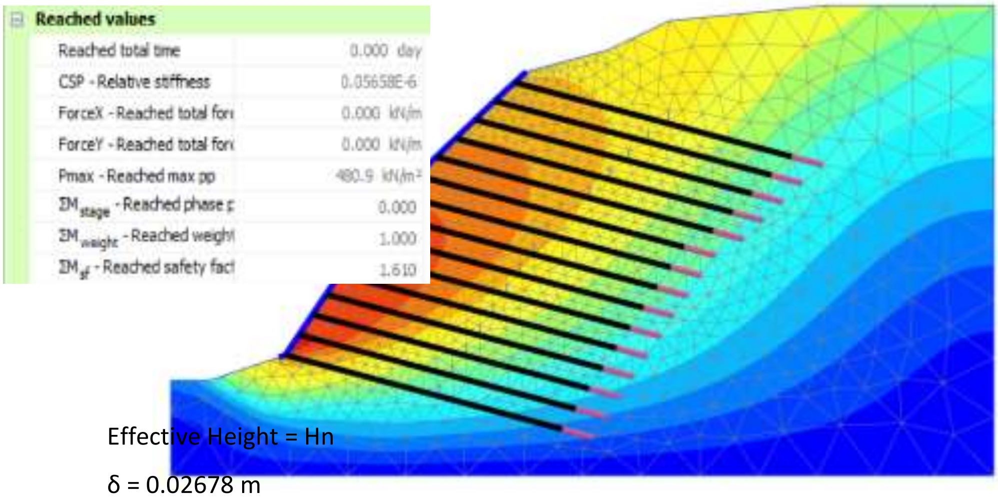

Figure 11. Numerical Simulation Result of Model-1 (SF = 1.61)

Based on the result of numerical simulation in Figure 11, the existing slope is seen non-critic because it has the safety factor (SF) = 1.610 (>1.5). The relative stiffness is 0.0568x10^{-6}, the reached total force for X = 0 kN/m and for Y = 0 kN/m. However, the reached max pp: P_{max} = 480.9 kN/m^2, the reached phase F: EM_{stage} = 0, the reached weight: EM_{weight} = 1, and the reached safety factor: EM_{sf} = 1.610.

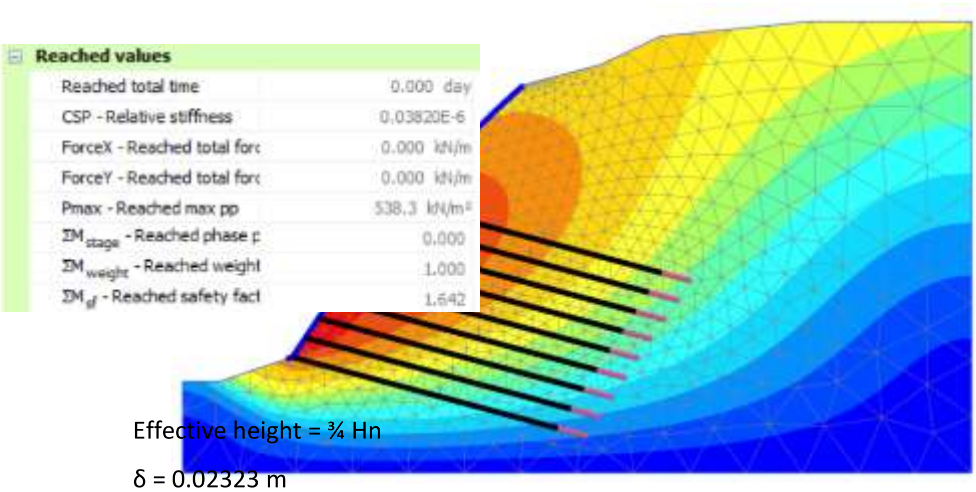

Figure 12. Numerical Simulation Result of Model-2 (SF = 1.64)

Based on the result of numerical simulation in Figure 12, the existing slope is seen non-critic because it has the safety factor (SF) = 1.642 (>1.5). The relative stiffness is 0.0382x10^{-6}, the reached total force for X = 0 kN/m and for Y = 0 kN/m. However, the reached max pp: P_{max} = 538.3 kN/m^2, the reached phase F: EM_{stage} = 0, the reached weight: EM_{weight} = 1, and the reached safety factor: EM_{sf} = 1.642.

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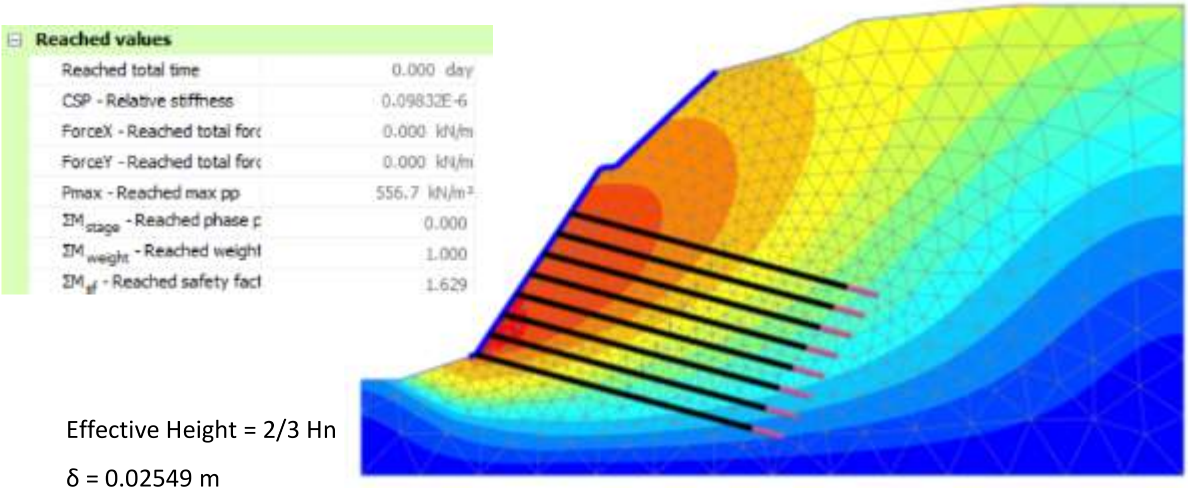

Figure 13. Numerical Simulation Result of Model-3 (SF = 1.63)

Based on the result of numerical simulation in Figure 13, the existing slope is seen non-critic because it has the safety factor (SF) = 1.629 (>1.5). The relative stiffness is 0.09832 x10^{-6}, the reached total force for X = 0 kN/m and for Y = 0 kN/m. However, the reached max pp: P_{max} = 556.7 kN/m², the reached phase F: EM_{stage} = 0, the reached weight: EM_{weight} = 1, and the reached safety factor: EM_{sf} = 1.629.

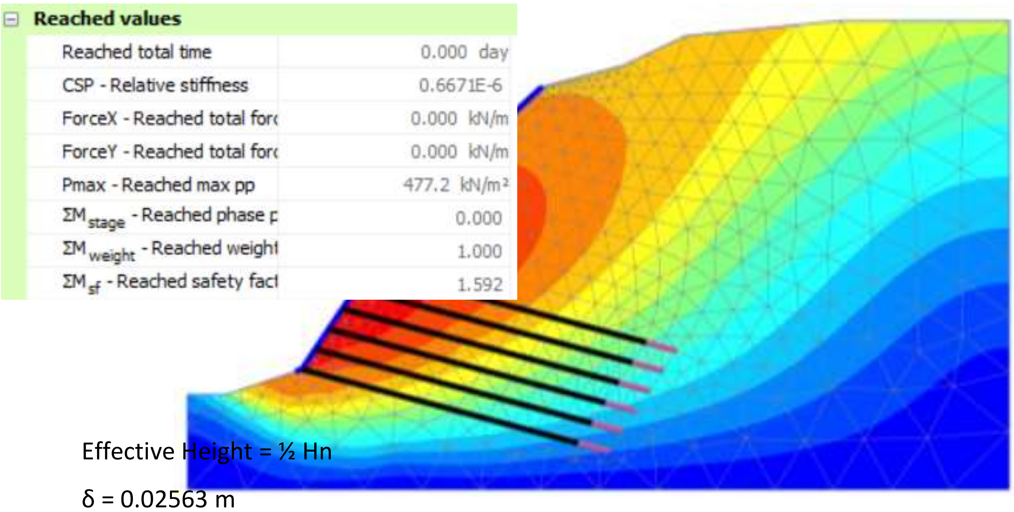

Figure 14. Numerical Simulation Result of Model-4 (SF = 1.59)

Based on the result of numerical simulation in Figure 11, the existing slope is seen non-critic because it has the safety factor (SF) = 1.592 (>1.5). The relative stiffness is 0.6671x10^{-6}, the reached total force for X = 0 kN/m and for Y = 0 kN/m. However, the reached max pp: P_{max} = 477.2 kN/m², the reached phase F: EM_{stage} = 0, the reached weight: EM_{weight} = 1, and the reached safety factor: EM_{sf} = 1.592.

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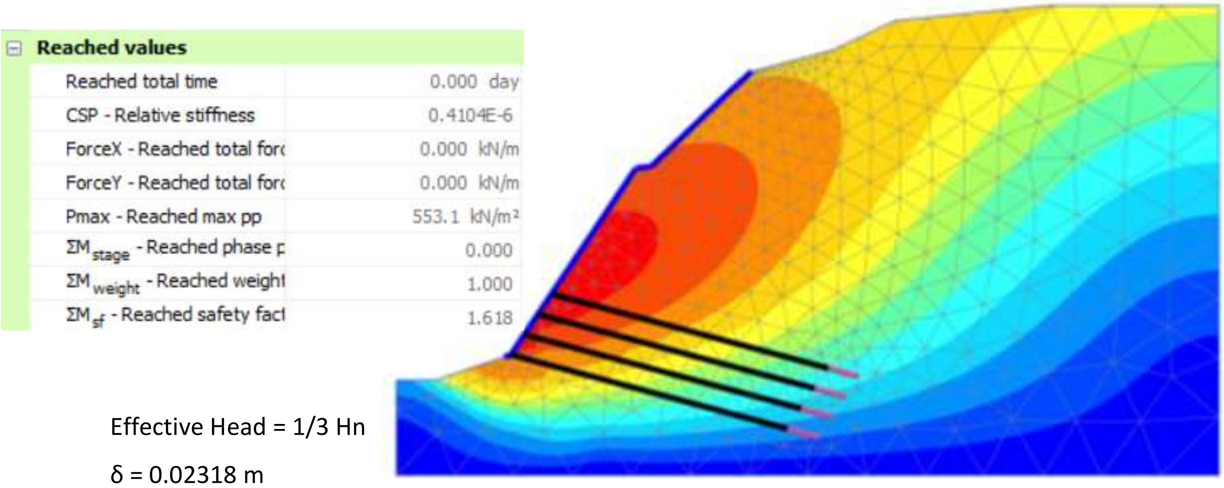

Figure 15. Numerical Simulation Result of Model-5 (SF = 1.62)

Based on the result of numerical simulation in Figure 15, the existing slope is seen non-critic because it has the safety factor (SF) = 1.618 (>1.5). The relative stiffness is $0.410x10^{-6}$, the reached total force for X = 0 kN/m and for Y = 0 kN/m. However, the reached max pp: P_{max} = 553.1 kN/m², the reached phase F: EM_{stage} = 0, the reached weight: EM_{weight} = 1, and the reached safety factor: EM_{sf} = 1.618.

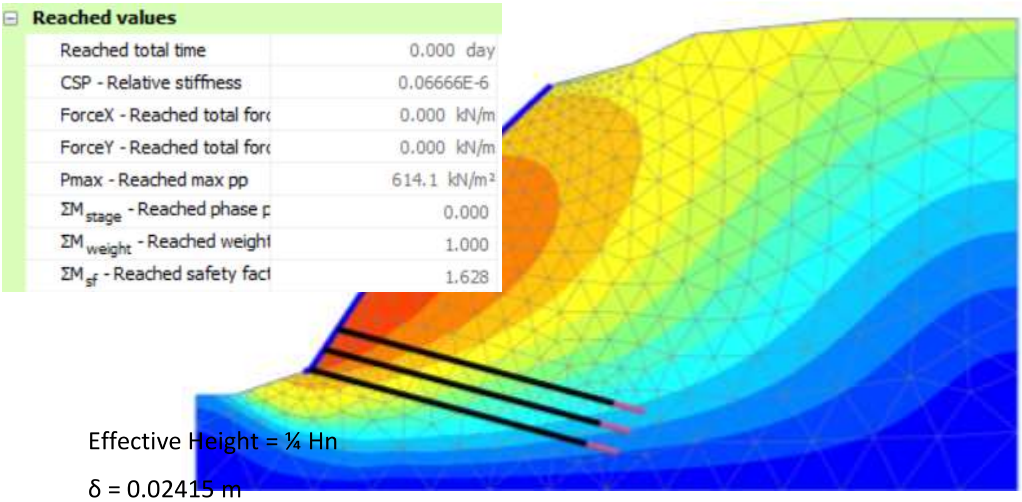

Figure 16. Numerical Simulation Result of Model-6 (SF = 1.63)

Based on the result of numerical simulation in Figure 16, the existing slope is seen non-critic because it has the safety factor (SF) = 1.610 (>1.5). The relative stiffness is $0.06666 x10^{-6}$, the reached total force for X = 0 kN/m and for Y = 0 kN/m. However, the reached max pp: P_{max} = 614.1 kN/m², the reached phase F: EM_{stage} = 0, the reached weight: EM_{weight} = 1, and the reached safety factor: EM_{sf} = 1.628.

Conclusion

One of the methods for effective retaining wall and much be used in Indonesia is by using soil nailing. This research intends to investigate the effective height for installing the soil nailing in the vertical direction of slope height. The variable that is researched is the effective height of soil nailing which the configuration model of vertical direction follows the simulation. One of the methods for producing the effective slope retaining and to be more used in Indonesia is by using soil nailing. This research is conducted on 5 models as follows: the effective height of nailing is the same as slope height (Ha); then the effective height of nailing is the same as ¾ H_n**;** 2/3 H_n; ½ H; 1/3 H; and ¼ H. The research is carried out by using finite element

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method that uses the Plaxis software for the numerical simulation. Variable that is researched is the effective height of soil nailing which the vertical direction of configuration model follows the simulation. Based on the numerical simulation, the result shows that the effective height of soil nailing configuration in the vertical direction is 1/3 of slope height. The simulation result is effective enough to produce the safety value (SF) is 1.62 (> 1.5) and giving the lowest deformation value as follows: δ = 0.02318 m (< 0.005 H = 0.09 m).

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