(e)ISSN 2656-8896 (p)ISSN 2656-890X
Journal of Infrastructure and Facility Asset Management – Vol. 7, Special Issue 2, January 2025

Alternative Planning Slope Reinforcement on Roadway Case Study: Landslide on Tabone-Polewali Road Sectionkm 168+790 To 168+820

Ismi Istiqamah[1,a], Mohamad Khoiri[2,b], Mahendra Andiek Maulana[3,c] & Bambang S. Razak[4,d]

[1]Graduate Student of Civil Engineering of ITS
[2]Civil Engineering Dept. ITS, Surabaya, Indonesia
[3]Civil Engineering Dept. ITS, Surabaya, Indonesia
[4]National Road Construction Agency (BPJN) Sulbar, Mamuju

Correspondent : [a]ismiiistiqamah@gmail.com

ABSTRACT

The Tabone-Polewali road section is a national road in the West Sulawesi Province that connects the Polewali Mandar Regency and Mamasa Regency. The terrain along this section consists of fairly steep slopes. In 2021, landslides occurred at several points along the Tabone-Polewali road, one of which happened at KM 168+790 to 168+820 during heavy rain. The cause of the landslides is estimated to be water flowing from the upper slope to the lower slope without effective water runoff management. No measures have been taken at this location, making it still hazardous for road users.

There are several alternative designs for permanent mitigation, including bored. Slope stability existing analysis and reinforcement stability analysis were conducted using the Finite Element Method (FEM).

The results obtained from this study show that the Safety Factor for the existing condition is 0,99, which indicates that a landslide has occurred. The Safety Factor for the alternative design using bored piles is 1.256 where this has met the minimum safety factor value requirements.

Keywords : slope stability, landslides, bored pile

INTRODUCTION

The Tabone-Polewali road section is one of the national roads under the authority of the Directorate General of Highways through the West Sulawesi BPJN with a length of 71.88 km connecting Polewali Mandar Regency and Mamasa Regency. The existing condition of the section before the landslide was a rigid road with a width of 6.0 meters and a road shoulder width without pavement of 5.0 meters on both sides. In 2021, landslides occurred at several points on the Tabone-Polewali road section, one of which was at KM 168+790-KM-168+820 when heavy rain conditions caused the road shoulder on the left side of the road to be eroded by 2.5 meters and the road body to be 1.0 meters wide.

There has been no handling done to overcome the condition, either temporary handling or permanent handling. Therefore, in 2023, BPJN West Sulawesi has contracted the Malabo-Tabone-Polewali Road Preservation package which has planned permanent handling at the landslide location. Permanent handling is in the form of installing geotextiles and selected embankments in areas that have been eroded by landslides.

(e)ISSN 2656-8896 (p)ISSN 2656-890X
Journal of Infrastructure and Facility Asset Management – Vol. 7, Special Issue 2, January 2025

Figure 1. Landslide location, Tabone-Polewali Road Section KM 168+790 to 168+820, Mamasa Regency, West Celebes

The cause of the landslide is due to water flowing from the upper slope to the lower slope through the road body without any effective water runoff management on the section. The soil under the road pavement experiences a decrease in soil bearing capacity due to increased pore water pressure, resulting in landslides.

To overcome the landslides that have occurred and prevent subsequent landslides on the slope, construction is needed to withstand the landslide load. This study provides alternative slope reinforcement that can be used as a solution to overcome landslides on the Tabone-Polewali road section KM 168 + 790 to 168 + 820.

LITERATURE REVIEW

Safety Factor

Slope stability or Safety Factor of a slope is defined as the ratio of actual soil strength required to prevent failure (Bishop, 1995). There are two methods that are often used to determine the safety factor value, namely the Limit Equilibrium Method (LEM) and the Finite Element Method (FEM).

According to Liong and Herman (2012) LEM is a method that uses the principle of force balance. This analysis method first assumes the landslide plane that occurs. There are two assumptions of the landslide plane, namely the circular landslide plane and the assumed non-circular landslide plane. This analysis method assumes a landslide plane that occurs with the assumption that slope failure will occur at a point along the failure surface. The shear strength required to maintain limit equilibrium is compared to the shear strength of the soil. FEM method does not make assumptions about the landslide plane. The safety factor is sought by finding the weak plane in the soil layer structure. The safety factor is obtained by gradually reducing the cohesion value (c) and the friction angle in the soil (ϕ) until the soil collapses (Liong and Herman, 2012).

According to Bowles (1989), slope stability is classified based on the Safety Factor (SF) value as follows:

1. SF >= 1.25 : the slope is stable (safe)
2. SF = 1.07 - 1.25 : Landslides have occurred (critical slope)
3. SF < 1.07 : Landslides occur frequently (unstable slope)

Bored Pile

According to Atikah et al., (2017) bored piles with small or large diameters can be used as retaining walls. Bored piles are installed into the ground by digging the ground first, then filled with reinforcement and poured with concrete. Bored Piles are installed to a certain depth through the hard soil layer to withstand ground movements that will landslide. The depth of the bored pile must exceed the potential landslide area.

Indrawahyuni et al., (2012), slope reinforcement using piles can significantly increase the bearing capacity of the soil. Piles are effective in holding back soil movement so that it does not move freely towards the slope surface. The length and diameter of the pile play an important role in increasing the bearing capacity of the slope, the longer the pile and the larger the diameter of the pile, the greater the bearing capacity that occurs.

Calculation of Foundation Bearing Capacity Using the Luciano Decourt Method (1982):

$$Q_L = Q_P + Q_S \quad \dots (1)$$

With:

Q_L= Maximum soil bearing capacity at the foundation
Q_P= Ultimate resistance at the base of the foundation
Q_S= Ultimate resistance due to lateral adhesion

$$Q_P = q_P.A_P = (N_P.K).A_p \quad \dots (2)$$

Where:

NP= Average SPT price around 4B above to 4B below the foundation (B=foundation diameter)
K = Soil characteristic coefficient:
12 t/m^2= 117.7 kPa for clay
20 t/m^2= 196 kPa for clayey silt
25 t/m^2= 245 kPa for sandy silt
40 t/m^2= 392 kPa for sand
A_P= Pile base cross-sectional area
q_P= Stress at the tip pole

$$Q_S = q_S.A_S = \left(\frac{N_S}{3} + 1\right).A_S \quad \dots (3)$$

Where:

q_S= Stress due to lateral bonding (t/m^2)

N_S= Average value along the length of the embedded pole with limits: 3<N<50
A_S= Perimeter x Length of immersed pole (area of pole cover)

Embankment

Embankment is a selected soil material used to achieve stability on slopes or embankments. According to the 2018 General Specifications, selected embankments must be used to increase the bearing capacity of the base soil in the supporting layer on soft soil that has a field CBR value of <2.5% which cannot be increased by compaction or stabilization and if necessary, excavation is provided. Selected embankments can be used for slope stabilization or embankment widening work. Based on the Geotechnical 4 Design and Construction guidelines, the following are the design parameters for embankment materials in the Java, Sumatra, Kalimantan, and Eastern Indonesian Islands regions:

Table 1. Parameter of Embankment

Parameter	Unit	Geographic Area	
		A	B
Content Weight	kN/m^3	18	20
Undrained Shear Strength (Cu)	kN/m^2	100	100
Effective Stress Parameters			
Cohesion (C)		10	5
Friction		35	30

Description:
A: Java Region
B: Sumatra, Kalimantan, East Indonesian Islands Region

Slope Stability Analysis

The method used in analyzing existing slope landslides is the Limit Equilibrium Method (LEM) with the Geo5 and Finite Element Method (FEM) assisted programs with the Plaxis 2D assistance programs. Meanwhile, to analyze slope reinforcement using the FEM method with the Plaxis 2D assisted program. The data input in both auxiliary programs are almost the same but the parameters in Plaxis 2D are more complex. The output of the analysis in both auxiliary programs is the safety factor values, where the minimum requirement for the safety factor value is 1.25.

RESEARCH METHOD

After collecting the secondary data (DED and rainfall data) and primary data (undisturbed soil samples and soil properties) needed, geometric modeling was carried out on both analysis methods to analyze the stability of the existing slope. The parameters input were the results of testing properties at depths of 1, 3, and 5 meters, while at depths > 5 meters using parameters from the correlation results of the SPT values. The results obtained from the two methods used were that the safety factor value did not meet the minimum requirement of 1,25. Therefore, slope reinforcement is needed using bored piles to meet the safety factor value of more than 1,25.

DATA COLLECTION

Secondary data is collected from Balai Pelaksanaan Jalan Nasional Sulawesi Barat (BPJN Sulbar) based on soil investigation at KM 168+790 to 168+820 in October 2024 Meanwhile, primary data is obtained by taking undisturbed data samples which are then tested for soil properties. The data is used as input parameters in the Geo5 auxiliary program as shown in table 2.

Table 2. Input Parameters For Existing Slope Conditions

Parameter	**Sat.**	**Depth 0,0-2,0 m**	**Depth 2,0 – 4,0 m**	**Depth 4,0 – 6,0 m**	**Depth 6,0 – 8,0 m**	**Depth 8,0 – 10 m**	**Depth 10 – 12 m**	**Depth 12 – 30 m**
Unit Weight	kN/m^3	16,10	16,50	16,90	17,20	18,00	18,50	19,30
Stress State		Effective						
Angle of Internal Friction	(^{o})	5,00	5,00	5,00	5,00	5,00	5,00	10,00
Cohesion (C)	kPa	12,27	43,85	60,00	90,00	100,00	110,00	130,00
Saturated unit weight	kN/m^3	16,40	17,02	17,20	17,40	18,30	19,00	20,00

RESEARCH ANALYSIS

Slope Stability Analysis Before Landslide

Parameter data obtained from the results of soil property testing and SPT value correlation as shown in Table 2. Based on these data, modeling was carried out in the Geo5 support program so that a safety factor value of 2.94 > 1,25 was obtained, which means safe and stable, where these results are contrary to what happened in the field. Therefore, a back calculation was carried out.

Back Calculation

Based on the results of the slope stability analysis above using the Geo5 assistance program, the safety factor value was obtained at 2.94 with a standard analysis type that adjusts to existing landslide conditions. This means that the slope is stable and safe from landslides because Safety Factor > 1.25 and is contrary to what happened in the field. Landslides occur when heavy rain occurs which causes progressive landslides, so re-modeling is carried out with the assumption that the cohesion value (C) decreases due to the soil being saturated with water. Based on the results of the Unconfined Compressive Strength re-test with water-saturated conditions, the cohesion value (C) was reduced by 60% at a depth of 2.00 - 4.00 meters from the initial test results. The reduction in cohesion value by 60% was carried out at a depth of 0.00 - 12.00 m while at a depth of 12.00 - 30.00 m it was reduced to 35% with the assumption that at a depth of 12.00 - 30.00 m (the lowest layer) it was not saturated due to rainwater because it was in the deepest layer. So, if it is re-inputted with these conditions, the modeling results will be as shown below.

Table 3. Input Parameters for Existing Slope Conditions After Back Calculation

Parameter	**Sat.**	**Depth 0,0-2,0 m**	**Depth 2,0 – 4,0 m**	**Depth 4,0 – 6,0 m**	**Depth 6,0 – 8,0 m**	**Depth 8,0 – 10 m**	**Depth 10 – 12 m**	**Depth 12 – 30 m**
Unit Weight	kN/m^3	16,10	16,50	16,90	17,20	18,00	18,50	19,50
Stress State		Effective						
Angle of Internal Friction	(^{o})	5,00	5,00	5,00	5,00	5,00	5,00	10,00
Cohesion (C)	kPa	8,00	17,00	23,00	27,00	30,00	40,00	65,00
Saturated unit weight	kN/m^3	16,40	17,00	17,20	17,50	18,30	19,00	20,00

Based on the results of the slope stability analysis above, the safety factor (SF) value in the Geo5 auxiliary program is 1,05 and in the Plaxis 2D auxiliary program is 0,99. This indicates that the slope has collapsed. Because the slope conditions have a safety factor below the minimum requirements, namely <1,25 and the resulting landslide area in the worst conditions is close to the conditions in the field, the safety factor value becomes the safety factor value after back calculation.

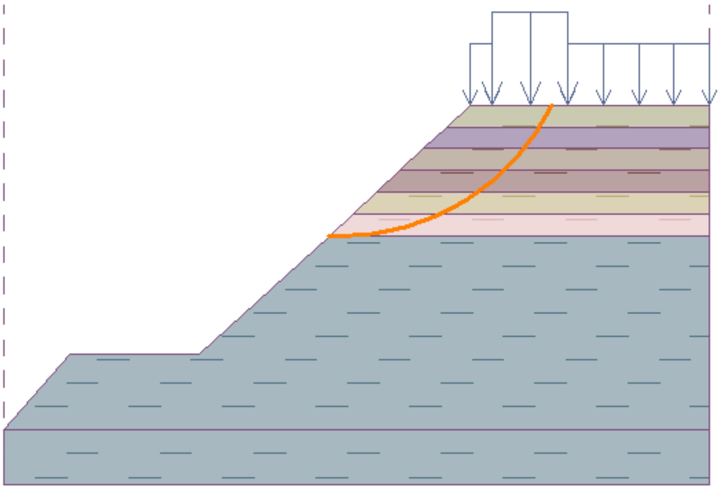


Figure 1. Results of Slope Stability Analysis Using Geo5 Assistance Program

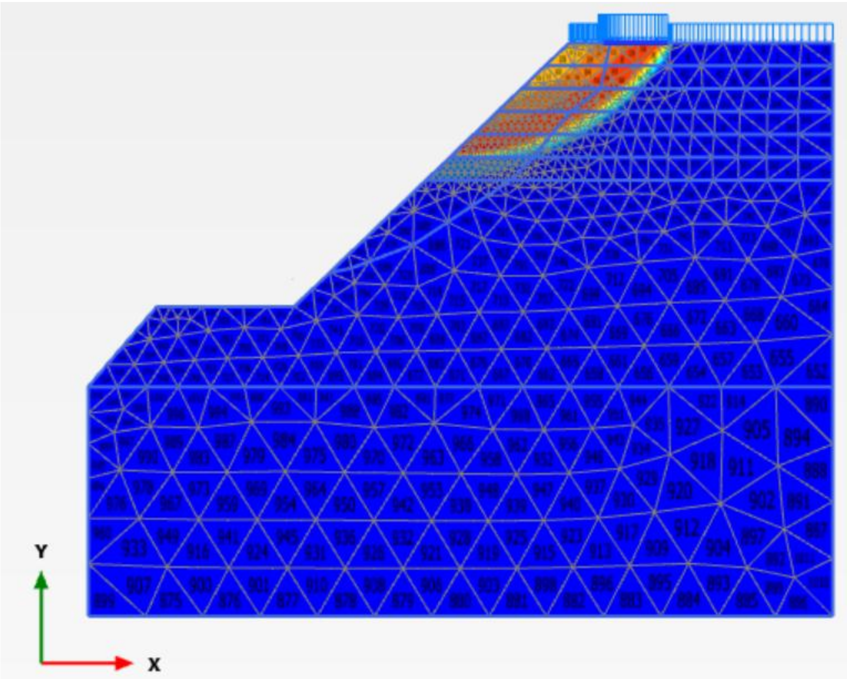


Figure 2. Results of Slope Stability Analysis Using Plaxis 2D Assistance Program

Slope Reinforcement Analysis with Bored Piles

Based on the results of the existing slope reinforcement analysis using both the Limit Equilibrium Method and the Finite Element Method, the SF value <1,25 is obtained, which does not meet the requirements for slope stability. Therefore, it is necessary to make improvements or add reinforcement to the slope to meet the minimum safety factor value of >1,25. Therefore, an alternative reinforcement analysis was made in the form of slope reinforcement.

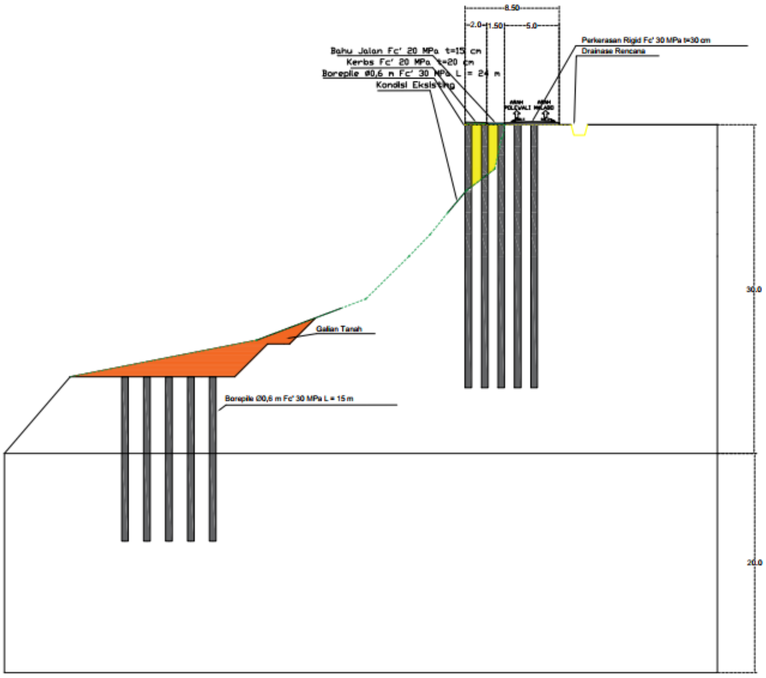


Figure 3. Slope Reinforcement Planning Design with Bored Pile Quality F'c 30 MPa, Diameter 0.60 m, and Length 24 m

Slope reinforcement analysis of bored piles and selected embankments using the Finite Element Method with the Plaxis 2D assistance program, the calculation of input parameter requirements in Plaxis 2D is as follows:

1. Analysis of Foundation Bearing Capacity Calculation

   Analysis of the calculation of pile bearing capacity based on the NSPT correlation with the Luciano Dacourt formula in 1982. An example of a calculation at a depth of 24 meters with a bored pile diameter of 0.60 m is as follows:

$$QL = Qp + Qs \qquad \dots (4)$$

Calculation of Ultimate Resistance at the base of the foundation:

$$Qp = qp.Ap = (Np.K).Ap \qquad \dots (5)$$

$$Qp = 60\,.\,117.7\,.\,0.28$$

$$Qp = 203.66\ ton$$

Calculation of Ultimate Resistance due to lateral attachment:

$$Qs = qs.As = \left(\frac{Ns}{3} + 1\right).As \qquad \dots (6)$$

$$Qs = 774.40\ ton$$

$$Q_L = 203{,}66 + 774.40$$

$$Q_L = 978.06\ ton$$

Calculation of Skin Resistance on L= 24 m bored pile:

$$T_{Skin} = \frac{Qs}{10}.9.81 \qquad \dots (7)$$

$$T_{Skin} = \frac{774{,}40}{10}.9.81$$

$$T_{Skin} = 759.68\ kN/m$$

(e)ISSN 2656-8896 (p)ISSN 2656-890X
Journal of Infrastructure and Facility Asset Management – Vol. 7, Special Issue 2, January 2025

Base Resistance Calculation on L= 24 m bored pile:

$$F_{Max} = Qp.9{,}81 \quad \ldots (8)$$

$$F_{Max} = 203.66\,.\,9.81$$

$$F_{Max} = 1{,}997.90\ kN$$

Table 4. Example of Input Parameters for Embedded Beam for Bored Pile D=0.60 m and f'c 30 MPa and L=24 m

Parameter	Symbol	Unit	*Bored Pile* f'c 30, d= 0,60 m, L=14 m
Modulus of elasticity	E	kN/m^2	26,019,858.20
Material weight	γ	kN/m^3	24,53
Pile type	Pile type		Predefined
Predefined pile type	Predifined pile type		Massive circular pile
Diameter	Diameter	m	0.60
Spacing	$L_{spacing}$	m	2.00
Axial skin resistance			Linier
Skin resistance	$T_{skin, start, max}$	kN/m	372.44
	$T_{skin, end, max}$	kN/m	372.44
Lateral skin resistance			
Base resistance	F max	kN	1,997.90
Interface stiffness factor			Default values

2. Plate Requirement Calculation Analysis

Analysis of plate input parameters such as bulk density, modulus of elasticity. An example of calculation on the road shoulder f'c 20 MPa with a width of 1,5 m and a thickness of 0,15 m.
Concrete Content Weight f'c 20 MPa= 24,53 kN/m3
Calculation of Concrete Elasticity:

$$E = 4700.\sqrt{fc'} \quad \ldots (9)$$

$$E = 4700.\sqrt{20}$$

$$E = 21.019{,}04\ MPa = 21.019.038{,}99\ kN/m2$$

$$EI = E.h3.\frac{b}{12} \quad \ldots (10)$$

$$EI = 21.019.038{,}99\,.\,0{,}15^2.1{,}5/12$$

$$EI = 8.867\ kN/m$$

$$EA = E.b.h \quad \ldots (11)$$

$$EA = 21.019.038{,}99\,.1{,}5.0{,}15$$

$$EA = 4.729.284\ kN/m$$

Table 5. Plate Parameter Input Recapitulation

Parameter	**Symbol**	**Unit**	**Rigid Pavement**	**Kerbs**	**Road Side**
			f'c 30 MPa	**f'c 20 MPa**	**f'c 20 Mpa**
General					
Material type			Elastic	Elastic	Elastic
Unit Weight	γ_{unsat}	kN/m^2	7,36	4,91	3,68
Parameter					
Isotropic			yes	yes	yes
Axial Stiffness	EA_1	kN/m	38.614.440,30	8.407.615,60	4.729.283,77
Flexural stiffness	EI	kN/m^2/m	289.608,30	28.025,39	8.867,41
Poisson's ratio	$v_{(nu)}$		0,15	0,15	0,15

3. Results of Slope Stability Analysis with Bored Pile Reinforcement

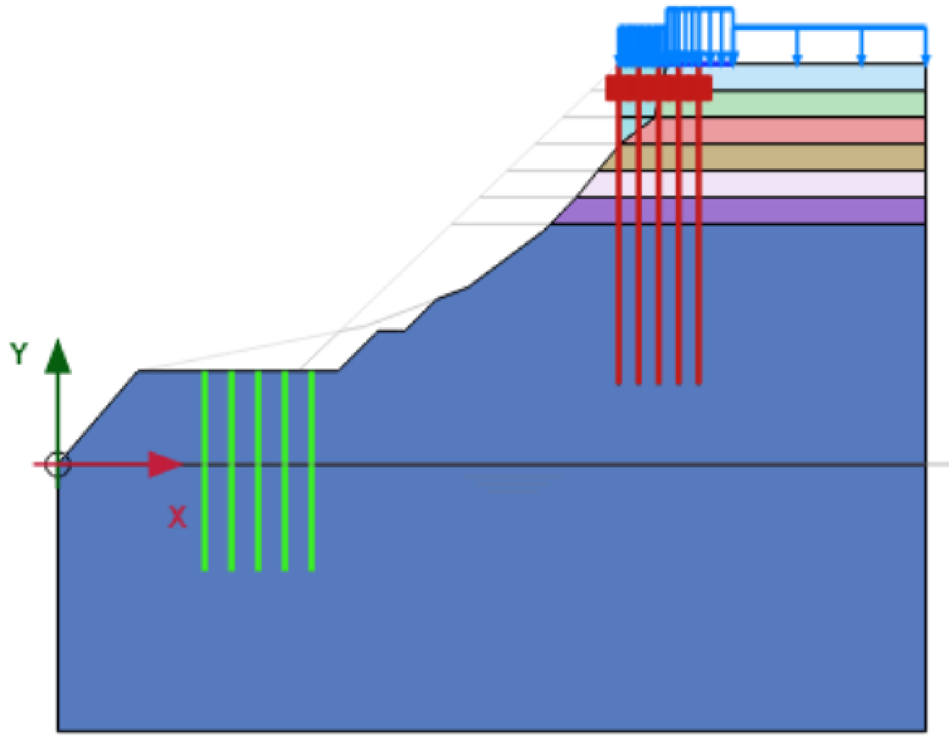


Figure 4. Bored Pile Reinforcement Structure and Selected Embankment Materials in Plaxis 2D Assistance Program

(e)ISSN 2656-8896 (p)ISSN 2656-890X
Journal of Infrastructure and Facility Asset Management – Vol. 7, Special Issue 2, January 2025

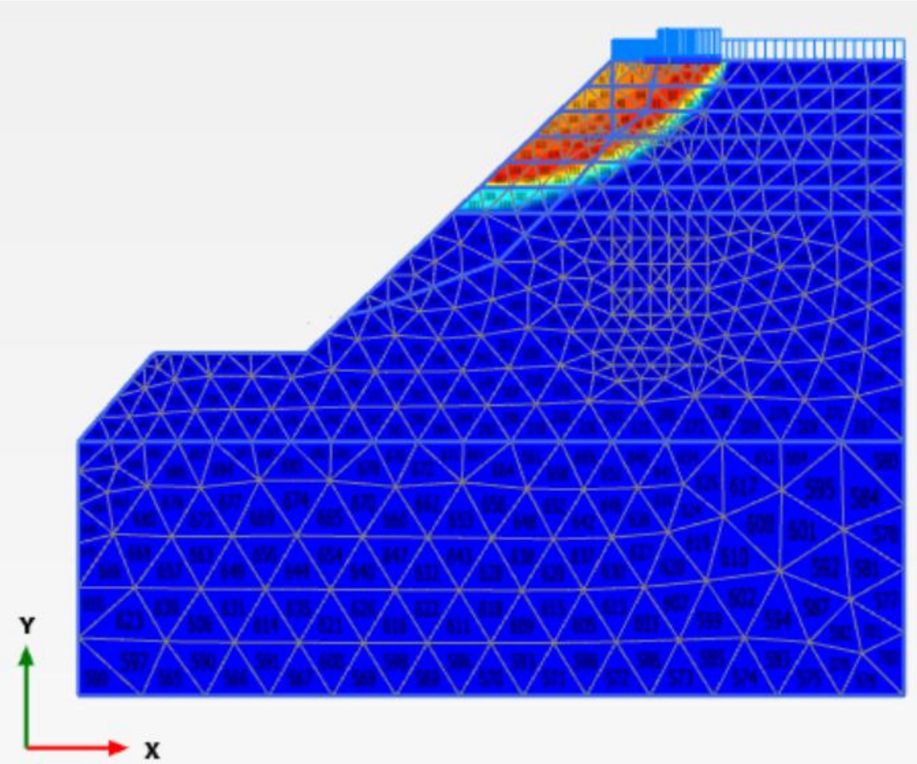


Figure 5. Landslide Area Condition and Total Displacement Before Reinforcement

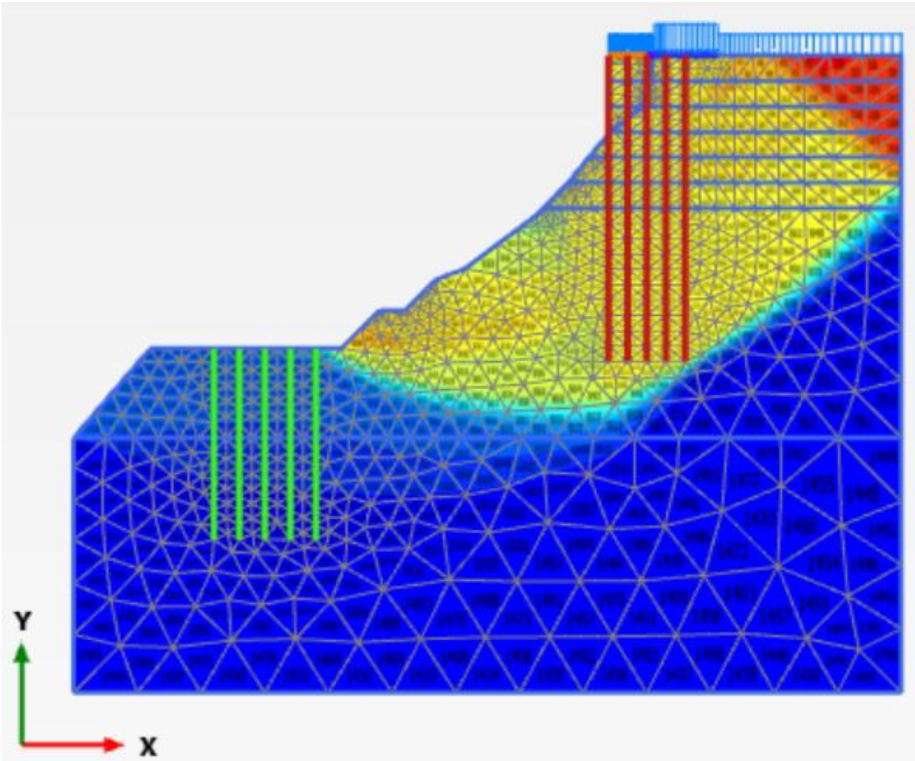
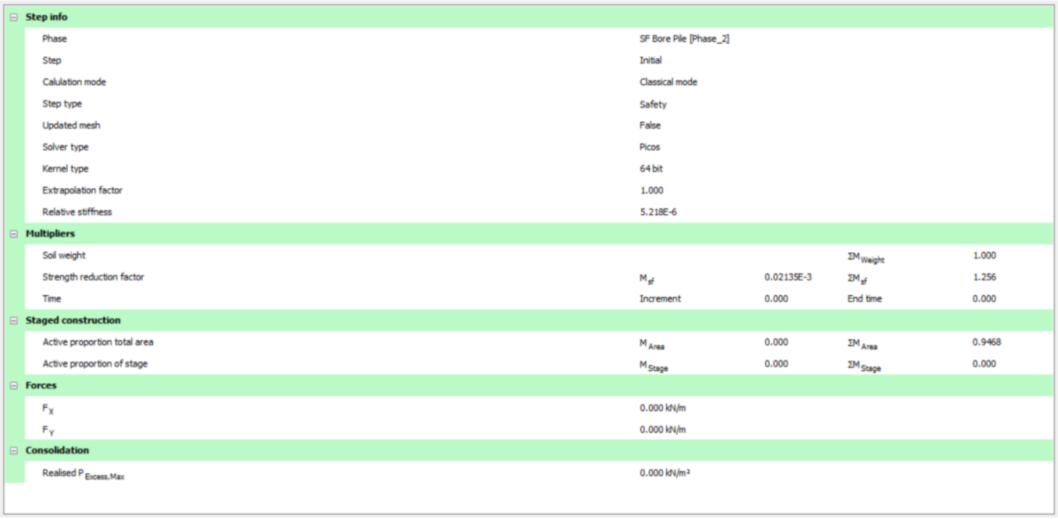


Figure 6. Landslide Area Condition and Total Displacement After Reinforcement

(e)ISSN 2656-8896 (p)ISSN 2656-890X
Journal of Infrastructure and Facility Asset Management – Vol. 7, Special Issue 2, January 2025



Step info				
Phase	SF Bore Pile [Phase_2]			
Step	Initial			
Calulation mode	Classical mode			
Step type	Safety			
Updated mesh	False			
Solver type	Picos			
Kernel type	64 bit			
Extrapolation factor	1.000			
Relative stiffness	5.218E-6			
Multipliers				
Soil weight			ΣM_{Weight}	1.000
Strength reduction factor	M_{sf}	0.02135E-3	ΣM_{sf}	1.256
Time	Increment	0.000	End time	0.000
Staged construction				
Active proportion total area	M_{Area}	0.000	ΣM_{Area}	0.9468
Active proportion of stage	M_{Stage}	0.000	ΣM_{Stage}	0.000
Forces				
F_X	0.000 kN/m			
F_Y	0.000 kN/m			
Consolidation				
Realised $P_{Excess,Max}$	0.000 kN/m²			

Figure 7. Results of Slope Stability Analysis Calculations with Plaxis 2D Assistance Program

Reinforcement analysis was conducted using bored piles under the road body, but after the analysis, there were no variations that met the minimum requirements for the Safety Factor value set, which was > 1.25, so reinforcement modifications were carried out by adding bored pile reinforcement at the foot of the slope using the Plaxis 2D assistance program. After the results of the slope stability analysis with bored pile reinforcement with the Plaxis 2D assistance program, the analysis results were obtained in the form of a safety factor. An analysis was carried out on several variations in the length and distance of the bored pile installation on the bored pile located directly under the road body so that the following safety factor results were obtained:

Table 6. Recapitulation of Bored Pile Reinforcement Analysis Results

Depth	Variety D=0,6 m					
(m)	**Number of Poles**	**Safety Factor**	**Number of Poles**	**Safety Factor**	**Number of Poles**	**Safety Factor**
14	5	1.079	6	1.088	7	1.095
16	5	1.095	6	1.104	7	1.112
18	5	1.149	6	1.154	7	1.165
20	5	1.158	6	1.163	7	1.170
24	5	1.256	6	1.264	7	1.273

Based on the analysis recapitulation table above, the most efficient variation is obtained at a diameter of 0.6 m, a bored pile length of 24 m, and the number of transverse piles of 5 (five) units with the analysis results in the form of a Safety Factor of 1,256 where the Safety Factor value is > 1,25.

CONCLUSIONS

Based on the result of slope stability analysis on Tabone – Polewali Road KM 168+790 to 168+820 using Geo5 and Plaxis 2D, it can be concluded that:

1. Based on the results of the analysis of the stability of the existing slope using the Geo5 auxiliary program, the Safety Factor value was obtained at 2.94, so a retest was carried out on the undrained cohesion value assuming the soil was submerged in water and a

decrease in soil strength of up to 60% was obtained. A reanalysis was carried out on the new soil parameter values using the Geo5 auxiliary program, the Safety Factor value was obtained at 1,05 and using the Plaxis 2D auxiliary program, the Safety Factor value was obtained at 0,99, where both did not meet the requirements of Safety Factor > 1.25.
2. Reinforcement using bored piles and selected embankments, the most efficient Safety Factor value was obtained at the variation of bored pile length of 24 m, diameter of 0.6 m, and the number of transverse piles of 5 (five) with a Safety Factor value of 1.256 > 1.25.

REFERENCES

[1] Badan Standarisasi Nasional. (2017). *SNI 8460:2017 Persyaratan Perancangan Geoteknik*. Jakarta, DKI Jakarta, Indonesia.
[2] Bowles, J. E. (1989). *Sifat-sifat Fisis dan Geoteknis Tanah.* PT. Erlangga. Jakarta.
[3] BPJN Sulawesi Barat. (2022). *Detail Engineering Design Paket Preservasi Jalan Malabo-Tabone-Polewali.* Mamuju.
[4] Das, B. M. (1995). *Mekanika Tanah Prinsip-prinsip Rekayasa Geoteknis (N. Endah & I. B. Mochtar).* Penerbit Erlangga. Surabaya.
[5] Das, B. M. (2010). *Principle Of Geothecnic Engineering Advanced Soil Mechanics, Seventh Edition.* Cengage Learning. Stamford, USA.
[6] G. Wright, S., Duncan, J. & L. Brandon, T. (2014). *Soil Strength and Slope Stability* (Second Edition ed.). John Wiley & Sons, Inc. Hoboken, New Jersey.
[7] Indonesia, S. N. (2017). *SNI 8460 Persyaratan Perancangan Geoteknik.* Badan Standarisasi Nasional. Jakarta.
[8] Liong, G. T., & Herman, D. J. (2012). *Analisa Stabilitas Lereng Limit Equilibrium vs Finite Element Method*. HATTI-PIT-XVI-2012. HATTI. Jakarta.
[9] Terzaghi, K., & Peck, R. B. (1967). *Soil Mechanics in Engineering Practice 2nd Edition.* John Wiley & Sons Inc. New York.
[10] Wahyudi, H. (1999). *Daya Dukung Pondasi Dalam.* Institut Teknologi Sepuluh Nopember. Surabaya.