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ANALYSIS OF LANDSLIDE HANDLING WITH MINI PILE REINFORCEMENT USING PLAXIS SOFTWARE ON THE "X" TOLL ROAD PROJECT

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Abstrak

Jalan Tol Semarang-Demak menghadapi masalah geoteknik akibat kondisi geologi yang meliputi daerah perbukitan dan cekungan, dengan batuan dasar seperti batu lempung, serpih, dan lignit yang rentan menjadi bidang perlemahan. Terjadi longsoran di lokasi Jalan Tol Semarang-Demak antara Sta. 1+250 dan Sta. 2+715, meskipun telah dilakukan berbagai macam cara pekerjaan timbunan yang tidak sepenuhnya berhasil, oleh karena itu menyebabkan terjadinya kerusakan. Analisis menunjukkan perbedaan yaitu antara faktor keamanan teoritis dan kondisi longsoran aktual, memerlukan teknologi perkuatan lereng seperti mini pile yang efektif menghambat pergeseran tanah. Mini pile, berupa beton bertulang dengan panjang 7 hingga 10 meter dan jarak antar pile 2 meter, ditambah penggunaan geotekstil, dianalisis menggunakan program Plaxis 2D menunjukkan peningkatan faktor keamanan. Meskipun ada sedikit perbedaan antara model perkuatan, kombinasi mini pile dan geotekstil terbukti efektif, terutama jika ditempatkan pada lapisan tanah keras atau melewati tanah lunak pada kedalaman 7 meter dari permukaan, mengatasi beban timbunan di lokasi tersebut.

Keywords:
Geotextiles;
Loam;
Mini Pile;
Reinforcement;
Landslide

Abstract

The Semarang-Demak Toll Road faces geotechnical problems due to geological conditions that include hilly areas and basins, with bedrock such as claystone, shale, and lignite that are prone to weakening. A landslide occurred at the Semarang-Demak Toll Road site between Sta. 1+250 and Sta. 2+715, despite various methods of embankment work that were not entirely successful, therefore causing damage. The analysis showed a discrepancy between the theoretical factor of safety and the actual landslide condition, requiring slope reinforcement technology such as mini piles that effectively inhibit soil movement. Mini piles, in the form of reinforced concrete with a length of 7 to 10 meters and a spacing of

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2 meters between piles, plus the use of geotextiles, analyzed using the Plaxis 2D program showed an increase in the factor of safety. Although there were slight differences between the reinforcement models, the combination of mini piles and geotextiles proved effective, especially when placed in hard soil layers or over soft soil at a depth of 7 meters from the surface, overcoming the embankment loads at the site.

1. INTRODUCTION

A landslide is a type of mass movement of soil, rock, or a combination of both that slides down or away from a slope due to loss of stability of the soil or rock that forms the slope. Human development activities can also trigger the acceleration of landslides. Semarang - Demak Toll Road is located on the North Coast of Java which has a soil type of alluvium. The main materials in this area are clay and silt which have a fairly low bearing capacity. This causes the Semarang - Demak Toll Road to be built with Slab on Pile construction. Of course, in addition to the influence of Rob Flood and the phenomenon of land subsidence. Geotechnical problems encountered at the Semarang-Demak Toll Road site, between Sta. 1+250 and Sta. 2+715, is the occurrence of landslides. Despite soil backfilling, the results were not entirely satisfactory, causing damage to the area. This damage included subsidence and cracking of the soil, as well as the occurrence of landslides at a considerable depth of the subgrade, which resulted in damage to the box culvert structure above (the box culvert became broken and shifted). To improve and ensure the future stability of the structures (both the box culvert and the high ground embankment), a geotechnical engineering solution is required which includes the application of slope reinforcement technology. This is done by installing reinforcing materials (mini piles) into the ground, passing through the potentially landslide-prone soil layer. To address the failures that have occurred, it is necessary to re-evaluate the physical and mechanical characteristics, including conducting a back analysis of the problem to find the conditions under which the failure started. Slope stability analysis must be able to reflect the actual field conditions so that the results are close to the real situation, which will make it easier to design the handling strategy. One method that can be used for this is by using Plaxis software. This study aims to obtain technical advice in dealing with landslides at Sta. 1+250 - Sta. 2+715. Furthermore, this study also aims to identify the value of the factor of safety after construction is completed, focusing on the depth of the mini pile of 7 meters and 10 meters.

A. Landslide

Defines landslide as a natural event in which there is a movement of land masses aiming to reach a new equilibrium. This movement is triggered by an external disturbance that results in a decrease in soil bearing capacity and an increase in soil stress. Overall, the main causative factors of landslides are a decrease in the value of soil shear strength parameter and an increase in soil pressure. The decrease in soil shear strength parameters is generally caused by an increase in water content in the soil and a decrease in cohesion between soil particles (Suryolelono, 2002). Avalanches can occur on many types of slopes, caused by loads from the soil itself, along with the significant impact of groundwater infiltration, as well as other external forces affecting the slope. (Craig, 1989)states that the forces of gravity and water infiltration often trigger instability on natural slopes, as well as on slopes formed through excavation, and also on earthen embankment and dam slopes.

There are three main types of landslides as depicted in Figure 1, which include :

1) Rotational slips are defined as a type of avalanche in which the failure or collapse surface forms a circular arc or a non-circular curve.
2) Translational slips usually occur when there is a layer of soil that lies at a fairly shallow depth below the surface of the slope.
3) Compound slips this usually takes place when adjoining soil layers lie at a greater depth, often caused by the collapse of material that includes curved and plane-shaped pieces.

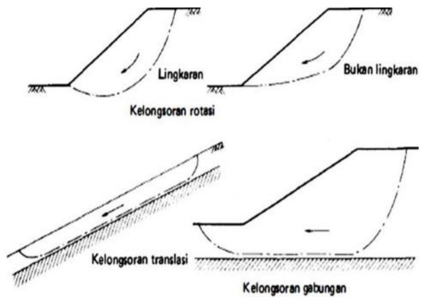

Fig. 1. Types of Slope Collapse (Craig, 1989)

B. Soil Reinforcement with Mini Pile

One effective way to increase soil strength and address road derailment and slope stability issues is to utilize vertical piles that function similarly to a pile system. Alternatively, these can be replaced with mini piles, which are small piles made of concrete or long steel pipes that can be connected to each other. This is done because the length of the pile needs to be longer than the deepest area of settlement. In this context, they act as foundation piles used to strengthen slope stability (Rusdianyah, 2016). Mini pile foundations can be categorized based on the materials used, the method by which the piles transfer loads, and the installation techniques, among other factors :

1. Mini pile foundation based on material type and structural characteristics
   Mini piles can be grouped into several classifications according to (Bowles, 1991), including :
   a) Wooden Mini Pile
   b) Concrete Mini Pile
   c) Steel Mini Pile
   d) Composite Mini Pile
2. Mini pile foundation based on installation method
   Mini pile foundations can be classified based on their installation method into two main categories, namely :
   a) Prefabricated Mini Pile
      Precast mini piles are mini piles that are molded and cast inside a concrete reference (formwork), then after it is strong enough, it is lifted and plugged. This precast mini pile according to the installation method consists of :
      - Pounding method
      - Vibrating method
      - Method of planting
   b) Cast In Place Pile
      Cast in place pile is according to the technique of excavation consists of several ways, namely :
      1) How to penetrate the base
      2) How to dig

C.. Geotekstil

Geotextiles are sheet-shaped materials made from polymeric textiles, are water permeable, and can consist of non-woven materials. Geotextiles, which can be non-woven, knitted or woven, are used in contact with soil or other materials in civil engineering projects. The role of geotextiles as reinforcement is similar to that of reinforcement in reinforced concrete (Darmiyanti, L., *et al*, 2023). Similarly, soil can withstand compressive loads but is not strong against tension. Geotextiles overcome this weakness of the soil against tension. They can be installed under layers made on top of soft soil, used in the construction of retaining structures, as well as in the reinforcement of road surface layers.

D. Reverse Analysis

Reverse analysis is performed to obtain the geotechnical parameters or mechanical characteristics of the rock at the time of the avalanche, while the information needed is the mechanical characteristics for design. Several methods are available to perform back analysis, including :

1) Using a direct trial-and-error method to match the input data with the observed behavior.
2) Performing sensitivity evaluation on each variable.
3) Perform probability evaluation on two interconnected variables.
4) Apply advanced probability techniques to analyze multiple parameters simultaneously.

Reverse analysis can be applied to calculate the shear strength with a factor of safety of 1.0 at the time of failure. Such an analytical model, built from failure experience, is considered more accurate than analytical models based on laboratory test data and assumptions of ideal groundwater conditions. To carry out the back analysis, trial and error method can be used on the available soil parameters.

E. Plaxis Software

Plaxis is a finite element software designed for deformation and stability analysis in two dimensions in geotechnical engineering. Since soils are composed of multiple phases, special methodologies are required to analyze hydrostatic and non-hydrostatic stresses in the soil. While modeling the soil material is important, much of the work involves modeling the structure and the interaction between the structure and the soil'

F. Mohr-Coloumb Parameters In Plaxis

The parameters applied in the Mohr-Coulomb model are as follows :

1) Poisson's ratio (v) is defined as the ratio between axial strain and lateral strain. Bowles emphasized through various reviews that determining the Poisson's Ratio value directly is a very complex task.
2) Young's Modulus (E) describes the value of soil elasticity, which is calculated from the ratio between the stress experienced and the strain that occurs.
3) The soil volume weight (γ), when the soil sample is in a water-saturated condition, where the pores are completely filled with water, is referred to as saturated soil volume weight (γ_{sat}). If the soil sample is not water-saturated, this condition is expressed as unsaturated soil volume weight (γ_{unsat}).
4) Cohesion (c) is a value that arises because of the bond between soil particles. The formula used to determine the cohesion value is explained as follows :
   $C_u = \frac{1}{2} q_u$
   dengan,
   C_u : cohesion (in undrained state)
   q_u : unconfined compressive strength
5) Shear Angle (φ)
   Shear angle refers to the angle formed when two or more soil particles slide. The value of the shear angle can be obtained through triaxial testing.
6) Sudut Dilatansi (ψ)
   In clay soils, the value of ψ = 0, the dilatancy angle for sand soils depends on their density and shear angle, generally 30. In most cases the value of ψ = 0, for shear angle values less than 30.
7) Permeabilitas (*k*)
   Permeability is the characteristic of a porous material that allows liquids such as water or oil to seep and flow through its porous cavities.

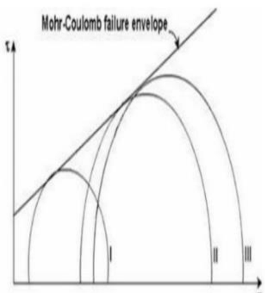

Fig. 2. Mohr Coloumb Collapse

The Mohr-Coulomb failure criterion is represented by an equation that describes a straight line (failure envelope), with the general form of the equation as follows :

$$\tau = c' + \sigma \tan \varnothing'$$

dengan τ = shear stress; c = cohesion; σ = normal stress; ∅ = internal friction angle.

G. Evaluation of Soil Investigation

Based on the sondir tests conducted in the Sta. 1+250 and Sta. 2+715, it was found that the subgrade at both locations consisted of soft clay with depths varying from 4 meters to 6 meters from the subgrade surface. Problems encountered in the field include the occurrence of shifts or landslides in the soil embankment when the soil filling process for the formation of the road body reaches the final stage or finish grade. The height of the embankment ranges from 4 meters to 9 meters, plus the original soil condition is soft clay. The location is on a slope with a steep slope, plus the presence of water flow from springs or surrounding areas that make the soil more moist or wet. This condition results in a decrease in the value of the soil shear parameter, which leads to the instability of the embankment soil.

2. METHODS

A. Research Location

This research was conducted on the Semarang - Demak Toll Road Construction Project, the location of the research point was at STA 1+250 - 2+715, as shown in Figure 3.

Fig. 3. Research Location

B. Research Flow Chart

In general, the research stages in the technical study of landslides in the construction of the Semarang - Demak Toll Road STA 1+250 - 2+715 can be seen in Figure 4.

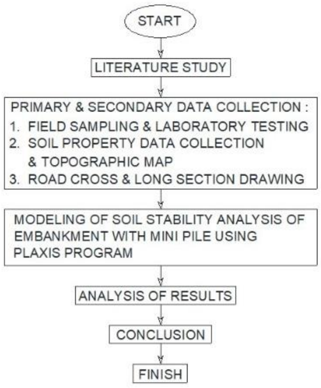

Fig. 4 Research Flow Chart

C. Permodelan Stabilitas Tanah Timbunan dengan Program Plaxis

To overcome the landslide between Sta. 1+250 and Sta. 2+715, a technical analysis based on available soil parameters and modeling using Plaxis software was conducted to generate conclusions and suggestions regarding this issue. To optimize the results, the steps and modeling in this analysis are limited to certain conditions as described below :

1) The analysis was carried out in reverse to determine the parameters corresponding to the situation when the leakage occurred.
2) The use of mini piles as reinforcement, consisting of 10 pieces with a length of 5 meters and 12 pieces with a length of 8 meters, with each mini pile spaced 2 meters apart from each other.
3) The analysis will be run in three stages: first without reinforcement, second with reinforcement using mini piles, and third with a combination of mini pile and geotextile reinforcement.

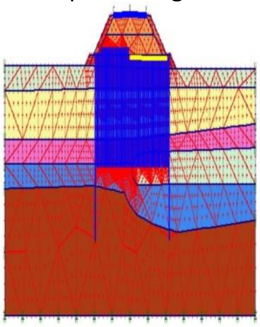

Fig. 4 Research Flow Chart

D. Analisis Balik

To address the landslide problem, soil testing was conducted at the site using the boring test method at four locations, as shown in the cross section drawing. However, in the reverse analysis conducted, only three locations were referenced because the landslide was already in progress. This back-analysis aims to determine the soil parameters that were relevant at the time of the landslide. Based on the analysis, the soil parameters applicable at the time of the landslide were identified, as shown in Figure 5.

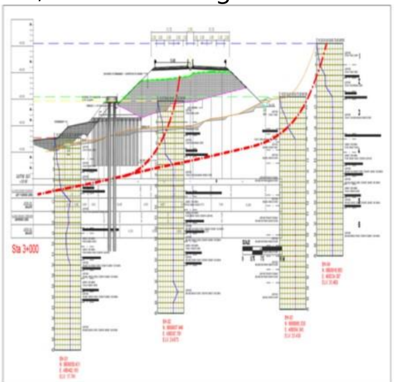

Fig. 5 Soil Investigation Point

3. RESULT AND DISCUSSION

A. Result of Landslide Condition Assessment

To address the landslide, several steps were taken, including conducting a technical study on local geological conditions and field survey results. From this study, the cause of the landslide in the Balikpapan – Samarinda Toll road segment from Sta. 1+250 to Sta. 2+715 were identified as follows :

1) The geology of the site consists of a basin with bedrock such as claystone, shale and lignite, which creates a potential 10º dipping weakening plane, as shown in Figure 6.
2) The overburden is made of volcanic deposits with unfavorable properties, including a tendency to weather quickly, be porous, and break easily.
3) Debris from previous landslides was not fully cleared from the site.
4) Problems with underground and surface water and natural waterways that were not effectively managed or anticipated.
5) At the bottom of the embankment on the left side (where the left side is lower than the right side), there are swampy areas and soft soil.
6) The fill is 6-10 meters above the original ground level.

B. Analisis Timbunan Tanah Asli

The results of the field soil investigation and technical studies involving modeling using the Plaxis Program resulted in the following findings :

Fig. 6 Old Landslide Point

Tabel 1. Data Parameter Tanah

Parameters	Name	Layer 1 Emb	Layer 2 Softclay	Layer Subgrade	Units
Model	Model	MC	MC	MC	-
Type of behavior	Type	UD	UD	UD	-
Soil Weight Unsaturated	γ_{unsat}	17	15	16	kN/M^3
Soil Wieght Saturated	γ_{sat}	18.5	16	17.5	kN/M^3
Young's Modulus	E_{ref}	149 00	199 0	14000	kN/M^2
Cohession	c	30	30	40	kN/M^2
Friction Angle	φ	20	5	20	º
Poisson Ratio	v	0.2	0.2	0.2	-

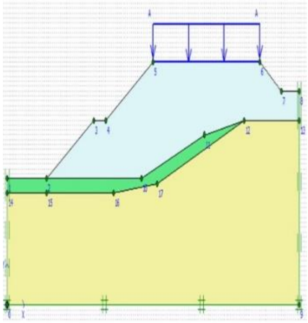

Fig. 7 Plaxis Modeling without Reinforcement

From the analysis results using Plaxis software without the application of reinforcement (as shown in Figure 7) on the landslide condition before reinforcement, the purpose was to determine the soil parameters through back analysis. The figure shows the landslide condition corresponding to the field situation, where the landslide occurred when the backfilling process had reached the final level.

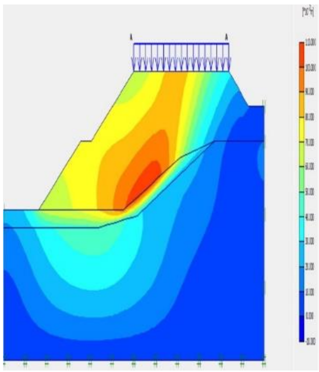

Fig. 8 Total Displacement = 108 m

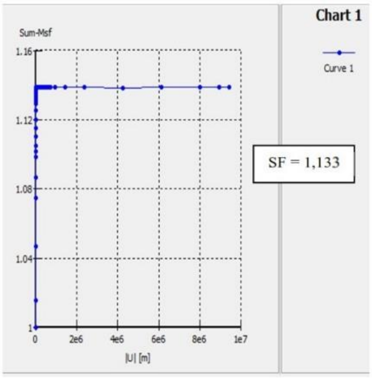

Fig. 9 Safety Factor Curve

From the analysis conducted, a total displacement of 0.108 meters (shown in Figure 8) and a Factor of Safety of 1.133 (shown in Figure 9) were recorded, indicating that the condition of the embankment on site was quite critical from a design perspective. There was a landslide at the project site, which warranted further research into its cause. Based on field observations, the landslide may have occurred due to uncontrolled embankment soil moisture during the backfilling and compaction process, suboptimal compaction, the influence of rainwater, and the presence of water from other sources. In addition, after the compaction process, the backfill soil was not protected from exposure to sunlight and rainwater.

C. Perkuatan Dengan Mini Pile

Sebagai solusi alternatif untuk mengatasi longsoran, mini pile yang digunakan terbuat dari beton bertulang dengan panjang 7 meter dan 10 meter, ditempatkan dengan jarak satu sama lain sebesar 1 meter. Karakteristik dari mini pile tersebut dijelaskan dalam Tabel 2 berikut :

Tabel 2. Data Parameter Tanah

Parameters	***Name***	***Layer 1***	***Units***
Type of behavior	Type	Elastoplastic	-
Normal Stiffness	*EA*	8.71×10^6	kN/m
Flexural Rigidity	*EI*	2.32×10^4	kNm^2/m
Equivalent Thickness	*d*	0.20	M

Poisson Ratio	*v*	0.1	-
Momen Crack	*Mp*	17.23	kNm/m
Allowable Axial Load	*Np*	550	kN/m
Weight	*w*	1.21	kN

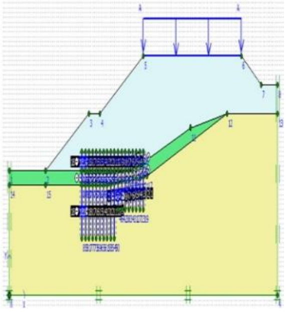

Fig. 10 Modeling With Mini Pile Reinforcement

Figure 10 illustrates a plaxis model that has been reinforced with mini piles. The mini piles are installed in the hard soil layer or across the soft soil layer at a depth of 8 meters from the ground surface. There are 11 mini piles with a length of 8 meters for the lower layer and 7 mini piles with a length of 5 meters for the upper layer, with a distance of 2 meter between each mini pile.

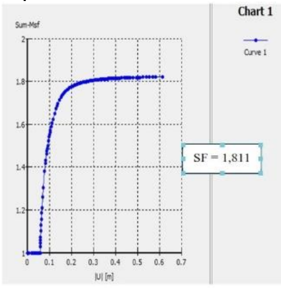

Fig. 11 Total Displacements 0,085 m

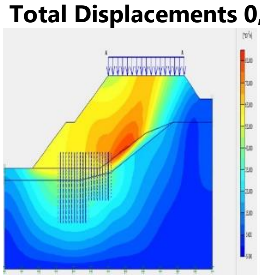

Fig. 12 Safety Factor Curve for Mini Pile Reinforcement

Berdasarkan analisis yang menggunakan metode perkuatan dengan mini pile, ditemukan total pergeseran sebesar 0,085 meter (lihat Gambar 11). Ini menunjukkan peningkatan pergeseran sebesar 0,021 meter dibandingkan dengan kondisi tanpa perkuatan (lihat Gambar 4.3). Sementara itu, Faktor Keamanan (Safety Factor) untuk kasus dengan perkuatan menggunakan mini pile mencapai 1,811 (lihat Gambar 12), menunjukkan peningkatan sebesar 0,682 jika dibandingkan dengan Faktor Keamanan tanpa perkuatan (lihat Gambar 9). Temuan ini menegaskan efektivitas lokasi pemasangan perkuatan, terutama ketika pemasangan dilakukan menembus lapisan tanah keras atau melintasi tanah lunak pada kedalaman 6 meter dari permukaan tanah. Keefektifan ini berkaitan dengan adanya beban timbunan setinggi 4-8 meter dari tanah asli di lokasi, sesuai dengan analisis desain untuk penanganan longsor yang direferensikan pada SNI 8460 : 2017.

Based on the results of the analysis with mini pile reinforcement, the total displacement is 0.085 m (Figure 11), there is a displacement change of 0.021 m when compared to without reinforcement (Figure 8) while the safety factor for reinforcement with mini pile = 1.811 (Figure 12) there is an increase of 0.682 compared to SF without reinforcement (Figure 9). This shows that the reinforcement installation position is very effective when embedded in hard soil layers or passing through soft soil at a depth of 6 m from the ground surface, this is due to the presence of embankment loads with a height of 4-8 m from the original soil at that location according to the analysis of avalanche handling design (SNI 8460: 2017).

D. Perkuatan Dengan Mini Pile Dan Geotextile

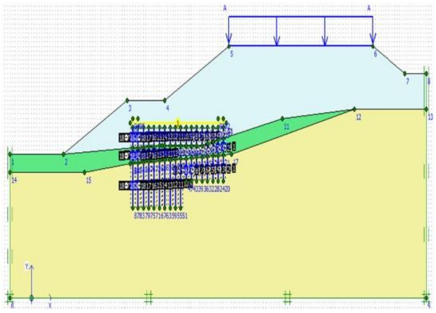

Fig. 13 Modeling with Mini pile & Geotextile Reinforcement

Figure 13 shows the modeling results using Plaxis that have been reinforced with the use of mini piles and additional geotextiles. The mini piles are installed on the left side, precisely through the hard soil layer or through the soft soil at a depth of 6 meters from the ground surface. There are nine mini piles with a length of 8 meters for the lower layer and seven mini piles with a length of 5 meters for the upper layer, with a distance of 2 meters between mini piles.

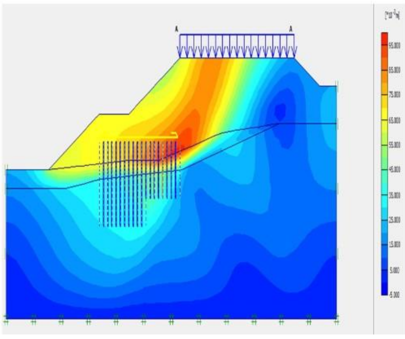

Fig. 14 Total Displacements 0,082 m

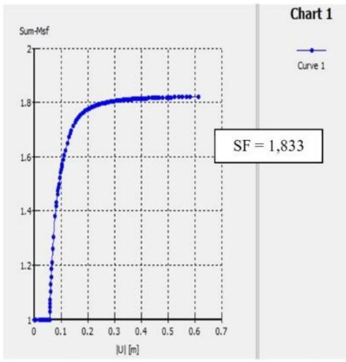

Fig. 15 Safety Factor Curve for Mini Pile Reinforcement & Geotextile

The analysis results displayed in Figure 14 show that with the use of minipile and geotextile reinforcement, the total displacement achieved was 0.082 meters. This represents an increase in displacement of 0.001 meters compared to the use of minipiles alone (as shown in Figure 11). Meanwhile, the Safety Factor for the combined reinforcement using minipiles and geotextiles was 1.833 (Figure 15), indicating an increase of 0.022 compared to the use of minipiles alone (Figure 11). Details of the differences in Safety Factor values and displacements achieved from this analysis can be seen in Table 3.

This indicates that the difference in results between the application of reinforcement with minipiles alone and the combination of minipiles & geotextiles is not very significant. This is evidenced by the small shift difference between the two reinforcement methods, which is only 0.002 meters (with the shift in the application of minipiles alone being 0.084 meters and in the combination of minipiles & geotextiles being 0.082 meters). The application of this reinforcement proved to be very effective or beneficial when carried out on hard soil layers or when crossing soft soil at a depth of 6 meters from the ground surface. This effectiveness is due to the presence of embankment loads whose height ranges from 6-10 meters from the original soil at that location, in accordance with the design analysis for handling landslides based on SNI 8460: 2017.

Table 3. Recapitulation of Safe Figures Analyzed with 10 kN Load

Modeling	Safety Factor	Displacement
No Reinforcement (Stockpiled Soil)	1,128	0,107 m

Reinforcement with Mini Pile	Model 1	1,811	0,082 m
Reinforcement with Mini Pile and Geotextile	Model 2	1,801	0,081 m

Table 4. Type of Geotextile Used

Geotextile Type	Tensile strength kN/m	Elongation
Woven Geotextile	50	5

4. CONCLUSION

Based on the analysis and discussion that has been carried out, the conclusions obtained show that the Safety Factor (SF) value obtained is 1.127 to 1.717. For safety in the field, an SF of more than 1.30 is required. In this case, reinforcement using mini piles with lengths of 7 meters (9 pieces) and 8 meters (9 pieces), which have a distance between mini piles of 2 meters, shows that in model 1, the safe SF value obtained is 1.713, which is greater than the SF allowed in the field. Meanwhile, if the reinforcement is carried out using 7 meters (9 pieces) and 8 meters (9 pieces) long mini piles, and equipped with a geotextile layer (model 2) on top, an SF of 1.717 is obtained with a total displacement of 0.082 meters. Mini piles should be embedded in hard soil layers or pass through soft soil at a depth of 6 meters from the ground surface, so it is recommended to use mini piles with a length of 8 meters and 7 meters. For landslide management, reinforcement with mini piles and woven geotextile layers are used. The causes of landslides in the field are mainly suboptimal implementation factors and the influence of weather and rainwater trapped flowing into the embankment area.

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