

Research Article

## Safety Factor Analysis on the Stability of Slopes and Embankments from Volcanic Ash Stabilization Using Plaxis 2D

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### Abstract

Slope stability analysis has a very important role in civil construction planning, especially in road infrastructure. Slope stability is a crucial aspect in highway construction and maintenance, especially in landslide-prone areas. The level of slope stability is known by calculating and analyzing the value of the safety factor. The safety factor is the ratio between the strength of the slope material and the force acting on the slope. By understanding the safety factors, it can be determined whether the slope is safe to pass on or needs to be repaired. This study aims to analyze the value of safety factors from the slope reviewed using the finite element method to the help of Plaxis 2D software. Case studies were carried out on slopes in sharp bends that often occur in Lamreh, Mesjid Raya District, Aceh Besar Regency. The analysis was carried out on three different conditions, namely the initial condition due to self-weight, the condition due to traffic load, and the condition with soil reinforcement resulting from the stabilization of the volcanic ash mixture. The results obtained in this study were the value of safety factors in three different conditions. In the initial condition due to the weight itself, a safety factor value of 1.068 was obtained, and in the condition due to traffic load, a safety factor value of 1.069 was obtained. After soil reinforcement was carried out with the stabilization method of volcanic ash mixture as much as 15.1%, a safety factor value of 1,582 was obtained. The value of safety factors in the initial condition and due to traffic load from the analysis results showed that the slope was still in a labile state and prone to landslides. After soil reinforcement with volcanic ash stabilization, the safety factor value increased significantly and met the minimum required criteria, which is greater than 1.25. This indicates that the slope becomes more stable and the potential for landslides is lower.

**Keywords:** Landslide; Plaxis 2d; Safety Factor; Slope Stability; Volcanic Ash Stabilization

### Introduction

Slope stability is one of the important elements in civil and geotechnical engineering, especially in the context of infrastructure development such as roads in hilly areas. In the process of developing transportation infrastructure, sometimes roads are found that pass through hilly and sloped areas with less supportive soil conditions. Unstable slopes can cause a variety of

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problems, including accidents that could potentially threaten the safety of road users. The slopes need to be reviewed in order to be able to bear the heavy load of vehicles passing through the main road. In Indonesia, many cases of accidents occur due to landslides or slope collapses, especially in areas with high rainfall and complex geological conditions. This situation can lead to a decrease in slope safety which affects the occurrence of landslides that threaten road infrastructure [1].

The trigger for landslides or land movements is more caused by the ability of human resources to ignore natural factors such as topography, land vegetation, and climate which are very closely related to balance disturbances called storie index factors [2]. The possibility of landslides is always present on every type of slope. Landslides occur because the driving force is greater than the opposing force derived from the shear force of the ground along the landslide plane [3]. The stability of the slope is greatly influenced by aspects such as the condition of the soil, the shape of the slope, and the load that must be beared. Therefore, an in-depth analysis of the factors affecting slope stability is essential to ensure the safety of road users. The purpose of the slope stability analysis here is to calculate the value of the safety factor of the field with the potential for collapse [4]. The safety factor value is used to identify slope stability which is defined as a comparison between the shear strength of the soil and the shear stress acting on the soil mass [5]. In general, the SF safety factor value of  $\geq 1.25$  is a normal design to provide an estimate of safety factors in slope stability analysis [6]. The relationship between the safety factor value and the intensity of the landslide is shown in **Table 1**.

**Table 1.** The relationship between safety factor values and landslide probability

Value of Safety Factors	Possible Landslides
SF < 1.07	Landslides occur frequently (labile slopes)
1.07 < SF < 1.25	Landslides have occurred (critical slope)
SF > 1.25	Landslides are rare (relatively stable slopes)

Source : Bowles J.E [7]

If the slope has the possibility of landslides, then slope reinforcement will be carried out according to field conditions. The feasibility of the reinforcement carried out is based on the value of the safety factor generated after the reinforcement of the slope. The safety factor criteria for the analysis of slope stability after reinforcement are based on the evaluation of the cost and impact of slope failure on the level of uncertainty in the analyzed conditions, in accordance with those specified by SNI 8460:2017 [8]. Criteria The value of safety factors after slope reinforcement as shown in **Table 2**.

**Table 2.** Safety factor value after reinforcement

Costs and Consequences of Slope Failure	Uncertainty Levels Analysis Conditions	
	Low	High
The cost of repairs is proportional to the additional cost of designing a more conservative slope	1.25	1.5
The cost of repairs outweighs the additional cost of designing a more conservative slope	1.5	2

Source : SNI 8460:2017 [8]

There are several methods in conducting safety factor analysis on slope stability, one of which is by using the finite element method to study the deformation or change in shape of the slope being reviewed. The finite element method is a numerical technique that constructs mathematical equations in various ways and series of algebraic equations by involving values at separate points in the section being studied. In the finite element method, the analyzed area is divided into several elements [9]. The use of this method to analyze slope stability requires high concentration and long calculations to obtain accurate results, so the analysis is better performed with geotechnical software.

Among the various slope stability analysis software available, Plaxis 2D is one that applies the principles of the finite element method to slope stability analysis. The advantage of this software is its ability to provide more results compared to others; In addition to being able to calculate the value of safety factors, the output of Plaxis 2D also includes deformation, effective stress, strain, pore water value, and direction of soil movement [10]. One of the models used in Plaxis 2D programming is the Mohr-Coulomb model. The parameters required for the Mohr-Coulomb model are soil volume weight ( $\gamma$ ), cohesion ( $c$ ), shear angle ( $\phi$ ), young modulus constant ( $E$ ), Poisson ratio ( $\nu$ ) and permeability coefficient ( $k$ ) [11].

Analysis of the value of safety factors on slope stability was also carried out on conditions after slope reinforcement with soil stabilization. Stabilization methods can be physical, mechanical, or chemical [12]. Chemical stabilization is a way to improve the properties of native soils through mixing the soil with certain materials that can improve soil characteristics to conform to the standards set by planners [13]. Based on the opinions of Munirwansyah and Munirwan, the advantages of stabilization include increasing land density; the addition of active soil material that increases the shear strength of the soil; the addition of materials to trigger natural and chemical changes in the soil; decrease in groundwater levels; and poor quality soil binding [14].

In this study, the slope reinforcement was carried out using the soil stabilization method with a mixture of volcanic ash. The use of soil stabilization methods with a mixture of volcanic ash as slope reinforcement in this study is because there is still relatively little research related to slope stability with this reinforcement method, where most studies related to volcanic ash stabilization focus more on improving the mechanical properties of the soil. Volcanic ash, as a result of volcanic activity, has unique physical and chemical characteristics, such as the ability to improve soil cohesion and reduce permeability. The use of volcanic ash as a soil stabilization material offers the potential to improve slope stability. The addition of volcanic ash also affects the value of the soil shear strength parameters, so it is hoped that the addition of volcanic ash as a soil stabilization material can increase the value of the safety factor on slope stability [15].

In the previous study, Suwandi and Munirwansyah conducted a comparative analysis of the shear strength test resulting from the stabilization of the soft clay of Paya Tumpi and other quarries with Burni Telong volcanic ash as much as 15.1%. The results of the study showed that the addition of volcanic ash to the three soil samples was able to increase the cohesion value ( $c$ ) and shear angle ( $\phi$ ) of the original soil conditions [16]. Based on the results of previous research, the initial hypothesis of this study is that the soil stabilization method with a mixture of volcanic ash is a reinforcement method that can increase the safety factor value of the slope reviewed to more than 1.5. The purpose of this study is to analyze the value of safety factors on slope stability in existing slope conditions, traffic load conditions, and after using slope reinforcement with the volcanic ash soil stabilization method. The benefit of this study is to know the effectiveness of reinforcement used on the slope which is reviewed based on the value of the safety factor produced.

## Methods and Materials

The study was conducted on hilly roadsides. The location of the study is a sharp bend that is often located in Lamreh, Mesjid Raya District, Aceh Besar Regency. The study location and field conditions are shown in **Figure 1** and **Figure 2**.



**Figure 1.** Study location of research location



**Figure 2.** Cracks in the study site

In this study, there are two categories of data used, namely primary data and secondary data. The primary data in this study is information obtained directly from the source in the field in the form of high measurement results in the field, location identification with the aim of observing the situation of the study site and taking existing photos for observation and analysis as well as taking coordinate points from mapping.

Meanwhile, the secondary data used in this study are information obtained from sources such as articles and scientific journals relevant to this study, as well as data obtained from fellow research teams of the professor's research scheme (PP) who conducted the study in the same location. The data obtained from fellow research teams are data from testing the physical properties and mechanical properties of the original soil and soil from the stabilization of the volcanic ash mixture, while the data obtained from related references are traffic load data and study location maps.

The reinforcement method carried out in this study is to replace the soil as large as the landslide field that occurred, according to the output displayed in the total displacement after analysis of the conditions due to traffic loads. The landfill soil used is soil from the study site that has been stabilized with a mixture of volcanic ash. There are several stages carried out in this study, namely:

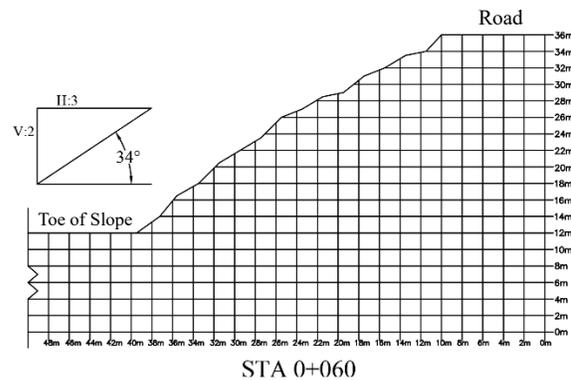
- a- Preparation stage: at this stage, information and literature searches are carried out related to the study topic to be carried out.
- b- Data collection stage: at this stage, field data collection and supporting references for the study are carried out. Some of the data that are important for this study are slope geometry data in the field, soil physical properties data, soil mechanical properties data, and test results data after soil is mixed with volcanic ash.
- c- Analysis and data processing stage: After the soil *properties* and slope geometry data are obtained, data processing and analysis are carried out with the help of Plaxis 2D. Analysis is carried out in three conditions, namely in the initial condition due to self-weight, due to traffic load, and after reinforcement.
- d- Discussion stage: Present an explanation containing solutions and summaries based on the findings of the study in an organized and thorough manner. From this explanation, conclusions will be drawn that answer the formulation of the problem from the study conducted.

The soil parameters used for soil parameter data input in the Plaxis 2D program are based on laboratory test results obtained from previous studies conducted with data samples from the same location. The parameter data used for the analysis is shown in **Table 3**.

**Table 3.** Soil parameter data used in the analysis

Parameter	Units	Natural Land	Mixed Soil
		Clayey Sand	Volcanic Ash Clayey Sand
$\gamma_{unsat}$	kN/m <sup>3</sup>	14.81	15.30
$\gamma_{sat}$	kN/m <sup>3</sup>	18.93	19.13
E	kN/m <sup>2</sup>	30000	30000
v	-	0.3	0.3
Kx	m/day	0.0001	0.0001
Ky	m/day	0.0001	0.0001
C	kN/m <sup>2</sup>	3.33	21.86
$\phi$	(°)	32.3	40.3

The cross section of the slope in this study was designed using the Autocad application as shown in **Figure 3**. Slope elevation data is obtained from the Google Earth application and based on measurements in the field.



**Figure 3.** Cross section design

The analysis process carried out in the Plaxis 2D software requires several stages to get the desired output, namely:

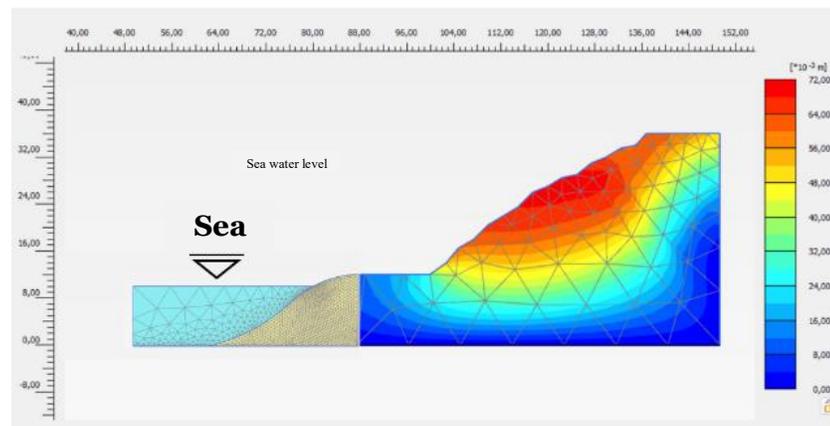
1. **Plaxis Input**  
In this first stage, modeling was carried out on the application to match the original conditions in the field. Some of the data entered are soil geometry, soil properties in each layer, and the load that occurs.
2. **Plaxis Calculation**  
After entering all the data required for Plaxis 2D to analyze, the next step is to perform calculations from existing modeling.
3. **Plaxis Output**  
After performing the calculation, Plaxis 2D will display the output of the calculation results. The result of the calculation can be numbers, drawings, and curves.

## Results

After the calculation using Plaxis 2D, the value of the safety factor and total displacement on the slope being reviewed was obtained to determine the probability of landslides that occurred in each condition.

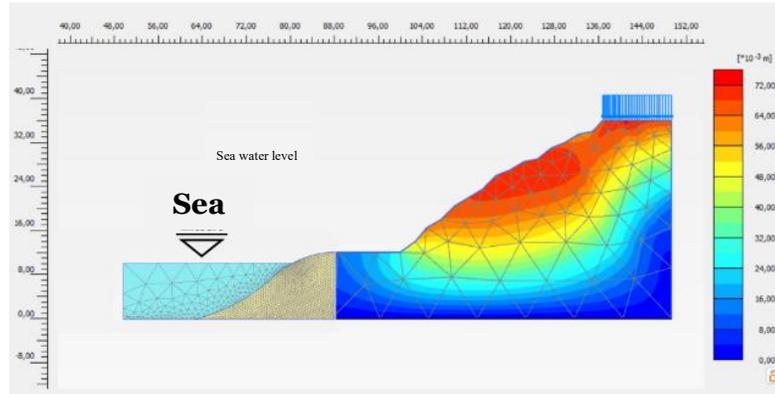
Total displacement refers to the displacement or movement of soil that occurs in response to certain environmental loads and conditions. According to the Plaxis 2D/3D User Manual published by Bentley System, deformation visualization uses a color gradient to show the amount of displacement in the Plaxis output. Red, orange, or yellow colors indicate the greatest deformation and areas with extreme drops in the soil. Green or yellow indicates moderate deformation and transition areas between stable and critical zones. While the blue color indicates small or almost zero deformation and a stable ground area.

The results of the analysis showed that there was a shift in the existing condition of the slope due to its own weight, where the color visualization was dominated by red, orange and yellow. It can be concluded that slopes under existing conditions have a high probability of extreme deformation. The total displacement result of the Plaxis output under the existing condition is 0.06938 m, and the color visualization is as shown in **Figure 4**.



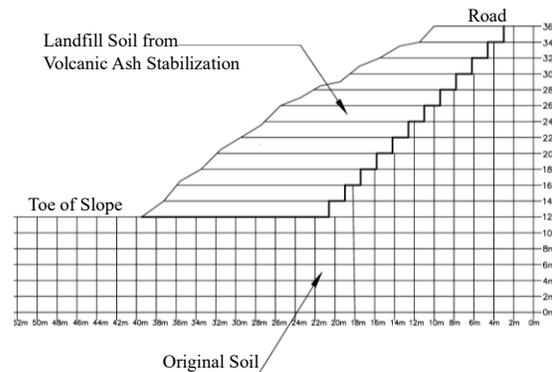
**Figure 4.** Total displacement in existing conditions

The results of the analysis showed that there was soil deformation on the slope due to the heavy traffic load, where the color visualization was dominated by red, orange and yellow. It can be concluded that slopes in conditions due to traffic loads have a high probability of extreme deformation occurring. The total displacement result of the Plaxis output under traffic load conditions is 0.07348 m, and the color visualization is as shown in **Figure 5**.



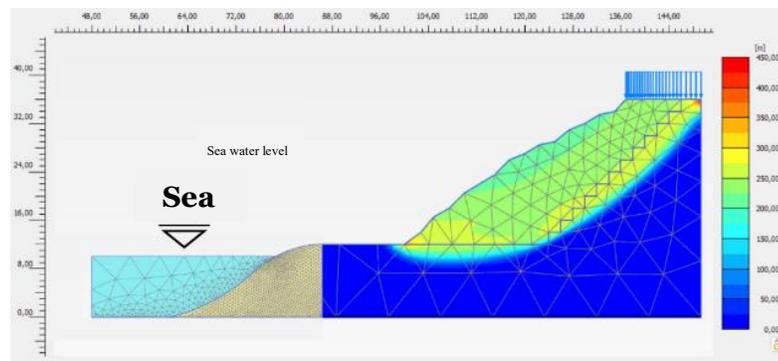
**Figure 5.** Total displacement in conditions due to traffic load

From the Plaxis output, the safety factor value in the existing condition is 1.068 and in the condition due to traffic load is 1.069. The results of the remodeling of the slope geometry as shown in **Figure 6**.



**Figure 6.** Remodeling of the geometry of the soil layer on the slope

After analyzing the slope stability with reinforcement, a safety factor value of 1.582 and a total displacement of 0.04445 m from the Plaxis output were obtained. The results of the analysis showed that the landslide field was previously dominated by red, orange, and yellow colors, after soil reinforcement with volcanic ash stabilization changed to green and blue. It can be concluded that the slope in the condition after reinforcement has a small chance of deformation. Color visualization of the analysis results as shown in **Figure 7**.



**Figure 7.** Total displacement in post-reinforcement conditions

The recapitulation of the value of safety factors and total displacement that occurred in the three conditions is shown in **Table 4**.

**Table 4.** Recapitulation of analysis results

<b>Analysis Conditions</b>	<b>Value of Safety Factors</b>	<b>Total Displacement</b>
Existing	1.068	0.06938 m
Load Consequences Traffic	1.069	0.07348 m
After Reinforcement	1.582	0.04445 m

## Discussion

The results of the slope stability analysis in the first two conditions, namely existing conditions and conditions due to traffic loads, obtained a safety factor value of less than 1.07, which indicates that the slopes in both conditions have a high probability of landslides and indicate that the slope under review is a labile slope. From the results of the analysis on Plaxis, the total displacement value in the existing condition was also 0.06938 m, and 0.07348 m in the condition due to traffic load. The output of the total displacement displays a visualization of the deformation dominated by red, orange, and yellow colors. These results indicate that the slope in both conditions has the possibility of extreme deformation in the area displayed by the Plaxis output.

Based on the value of the safety factor and total displacement resulting from the calculation using Plaxis 2D, it can be concluded that the shear strength of the soil on the slope is lower than the shear stress borne by the soil mass, so soil reinforcement is needed to increase the shear strength capacity of the soil on the slope. In this study, the slope reinforcement was carried out in the form of soil replacement in the landslide field that occurred, with new landfill soil as a result of stabilization of the volcanic ash mixture.

The results of the slope stability analysis in the conditions after soil reinforcement were carried out obtained a safety factor value that increased far from the previous two conditions, where the value of the safety factor produced was more than 1.5 and indicated that the slope in the condition after slope reinforcement using the soil stabilization method with a mixture of volcanic ash had a low probability of landslides. This also indicates that the slope that was previously in a labile condition has turned into a relatively stable slope. The total displacement displayed in the conditions after the ground reinforcement also showed a change, where the total displacement value produced after reinforcement was 0.0445 m, and the visualization of the deformation in the landslide field, which was previously dominated by red, orange, and yellow, changed to green and blue. The change in the visualization of deformation indicates that slopes that previously had the possibility of extreme deformation are now slopes that have a low probability of deformation and have a stable soil area.

Based on the safety factor value and total displacement resulting from the calculation using Plaxis 2D in the condition after soil reinforcement with the volcanic ash mixture stabilization method, it can be concluded that the shear strength of the soil increases after reinforcement and is higher than the shear stress borne by the soil mass either due to its own weight or due to traffic loads. This is because the volcanic ash used as a stabilizing material has unique physical and chemical characteristics, namely increasing the cohesion and shear strength of the stabilized soil. The increase in the shear strength and soil cohesion values resulting from the stabilization of the volcanic ash mixture is also evident from the related thesis research conducted by Suwandi and Munirwansyah [15], where the results of the study show that the cohesion values ( $c$ ) and shear angle ( $\varphi$ ) of the three soil samples studied were successfully increased through the addition of volcanic ash compared to the original condition.

## Conclusion

From the results of the analysis and discussion displayed, the conclusion obtained is that the soil stabilization method with a mixture of volcanic ash can increase the value of safety factors on the slopes under review, so that it can be used as a consideration for the government to use the stabilization method of volcanic ash mixture as a slope reinforcement in areas prone to landslides. In the first condition, namely the existing condition of the slope due to its own weight, the calculation resulted in a safety factor value of 1.068; and in the second analysis, namely the existing condition of the slope due to a traffic load of 15 kN/m<sup>2</sup>, the output of the calculation produced a safety factor value of 1.069; And in the last analysis, namely the condition after strengthening the results of volcanic ash stabilization, the output of the calculation produced a safety factor value of 1.582. After conducting the study, some suggestions that can be given are that the next study still has the opportunity to be improved by making changes to the type of soil reinforcement used, such as applying reinforcement from different stabilization methods, exploring variations in soil parameters, and testing various other analysis methods to determine the effect of soil parameter changes on the value of safety factors on slope stability. Further studies can be analyzed using other programs such as Geoslope, Slope-W, and Midas GTX NX.

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## Conflict of Interest

The authors declare no conflicts of interest

## Author Contribution Statement

**Munirwansyah:** Conceptualization, Methodology, Investigation, Validation, Reviewing, Supervision. **Devi Sundary:** Writing-Original draft preparation, Reviewing and Editing. **Thaariq Ziad Mardhatillah:** Data curation, Visualization, Investigation, Software.

## Data Availability Statement

The data used to support the findings of this study are included within the article.

## Ethics Approval

Not required

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