# slope stability

*by* Abul Fida Ismaili

# Slope Stability Analysis on Railroad Line in Lahat Lubuk Linggau, South Sumatra

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**Abstract**

The Lahat Lubuklinggau railroad line is a strategic railroad line in the DIVRE III area of South Sumatra. Several incidents have occurred there in recent years. The incidents indicate the condition of the railroad at Lahat Lubuklinggau crossing is prone to landslides and subsidence areas, which can disrupt rail traffic. Consequently, it results in the inconvenience of train travel, which threatens the safety of rail traffic if not immediately get comprehensive repair. This study aims to analyze the vulnerability of slopes in the Lahat-Lubuklinggau railroad area using the GEO5 program to determine the slope safety number, which shows the stability of the slopes. GEO5 programs are designed to perform deformation and stability analysis in geotechnical engineering. The analytical methods used include Bishop, Fellenius, Spencer, and Janbu. After modeling and analyzing slopes using the GEO5 program, the soil reinforcement increased the safety factors according to SNI 8460:2017. With the use of slope reinforcement, the increased value of the safety factor supports the operation of train travel in the Lahat Lubuklinggau South Sumatra.

**Keywords:** Landslide; Railroad; Subsidence; Sumatera; Train.

## I. Introduction

The Lahat – Lubuklinggau railroad line is a strategic railroad line in the DIVRE III area of South Sumatra. Bearing in mind that the basic foundation for a safe and smooth train operation is to operate infrastructure production assets that meet the following requirements:

A. *Safe in Construction*;
B. *Safe in Position*;
C. *Built-in Safety*.
D. *Environment Friendly*.

The increase in the Lahat-Lubuklinggau railroad line will make the Lahat-Lubuklinggau railroad cross more uniform with other railroad lines in South Sumatra. Previously, the Lahat-Lubuklinggau route had an axle pressure of 14 tons. In comparison, the other track had an axle pressure of 18 tons, so the increase in traffic is expected to improve the quality of rail infrastructure on the Lahat-Lubuklinggau cross and then have a positive impact on the development of railroads in South Sumatra, especially from reducing travel time and making train journeys more comfortable.

The incident that has occurred in recent years shows that the condition of the railroad on the Lahat-Lubuklinggau crossing is in an area prone to landslides and subsidence, which can disrupt rail traffic. If it is not immediately repaired thoroughly, it results in the inconvenience of train travel and threatens train traffic safety. Landslides and subsidence can be studied from two mechanisms: the movement of soil or rock masses due to geological processes (primary disasters) or landslides caused by triggering factors such as rain and erosion. These two disasters can be predicted based on measuring parameters widely studied in disaster studies.

A landslide is the movement of material in the form of rock or soil through the inclined plane surface is called the slope. Rock or soil that has undergone landslides down the cliff in the direction of the slope [1]. In contrast, the cause of the subsidence is thought to be due to the compression of natural alluvial deposits, building loading, soil backfill, and water extraction of land beyond its capabilities (Safe Yield) [2]. The triggers for landslides are natural factors and human factors. The hydrological and meteorological disasters known as hydrometeorological disasters are mostly the result of global climate change, which is not directly related to the geological structure of an area. However, hydrometeorological disasters will affect the occurrence of landslides as secondary disasters.

This study aims to analyze the vulnerability of slopes on the Lahat-Lubuklinggau railroad line using the GEO5 program. GEO5 is a program designed to perform deformation and stability analysis in geotechnical engineering. The analytical method used is Bishop, Fellenius, Spencer, and Janbu to determine the slope safety rate, which will later show the slope stability in the area.

## II. METHOD

### *A. Research Object and Location*

This study analyzes slope conditions and then provides alternative soil reinforcement around the Lahat-Lubuklinggau railroad, South Sumatra, at the points of STA 435+650/850, STA 436+1/2, STA 444+350/450, and STA 490+870.

### *B. Data Collecting Techniques*

There are two sources of data used in this study, namely:

1. Primary data
   The researchers collected primary data directly from the field as basic data. Data related to primary data include the results of field surveys and sonder tests, as well as sampling from the field.
2. Secondary data
   The researchers obtained secondary data from written information or related documents, such as data on disaster and landslide hazards, train travel operations, and earthquake data.

### *C. Research Data Processing*

The process of processing research data includes taking soil sonder data and soil samples and then continuing with research in the laboratory, including measuring soil physical properties, making test objects, and direct shear testing. The test results or the obtained soil parameters will be analyzed for slope stabilization using the GEO5 program to obtain the results of the slope stabilization analysis at the research site. In processing research data, the researchers apply the following steps:

1. Safety factor analysis
   The safety factor is used to identify slope stability, defined as the ratio of the shear strength of the soil to the shear stress acting on the soil mass.
2. Slope modeling
   At this stage, a combination of soil layers is carried out according to the results of the soil investigation data and the modeled slope angle. The shear angle ($\phi$) is obtained in different soil layers.
3. Use of GEO5
   In using the GEO5 program, proper slope angle modeling is required. This modeling is carried out to obtain slope stability from the actual conditions in the field. The data needed include soil parameters and seismic data.

### *D. Design Criteria*

Based on SNI 8460-2017, slope stability analysis is carried out to find out several reviews, including the following:

1. Provide an overview of the stability of the artificial slope,
2. Provide an evaluation of the potential for landslides from existing slopes,
3. Analyzing landslides that have occurred,
4. Provide the possibility of redesigning slopes that have landslides and planning preventive measures if necessary,
5. Assessing the effects of unexpected loads such as earthquakes and traffic loads.

Important aspects of natural slope stability are:

1. Geological conditions,
2. Topographical conditions,
3. Slope condition,
4. Types of soil layers,
5. Shear strength,
6. Subsurface water flow,
7. Weathering speed,
8. Traffic disturbance.

Factors that cause instability of natural slopes include the following.

1. Changes in slope profile due to additional loads at the top or reduced strength at the bottom.
2. An increase in groundwater pressure results in decreased shear resistance in non-cohesive soils or expansion in cohesive soils. Groundwater pressure can increase when the soil becomes saturated due to rain, seepage, or surface runoff.

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3. Decrease in soil or rock shear strength caused by weathering, mineralogy changes, and fractures.
4. Earthquakes, explosions, or pile driving cause vibrations.

The safety factor is referenced to determine whether the slope belongs to safe or unsafe conditions [3].

TABLE I. SAFETY FACTOR VALUE FOR SOIL SLOPE

| NO | Costs and consequences of slope failure | NO EARTHQUAKE Uncertainty level analysis conditions | | EARTHQUAKE |
|---|---|---|---|---|
| | | Low[a] | High[b] | |
| 1 | The repair costs outweigh the additional costs of designing a more conservative slope | 1.25 | 1.5 | 1.00 |
| 2 | The repair costs outweigh the additional costs of designing a more conservative slope | 1.5 | 2,0 or more | 1.00 |

[a] The level of uncertainty in the analysis conditions is categorized as low, if the geological conditions can be understood, the soil conditions are uniform, the soil investigation is consistent, complete and logical to the conditions in the field.
[b] The level of uncertainty in the analysis conditions is categorized as high, if the geological conditions are very complex, the soil conditions vary, and the soil investigation is inconsistent and unreliable.

*Source: SNI 8460:2017*

## III. RESULT AND DISCUSSION

The analysis of this study begins with knowing the soil parameters used and modeling existing slopes and slope reinforcement in the GEO5 program without or with earthquake loads.

### A. *Research Location STA 435+650/850*

1. Soil Parameter

The drilling point is located around the Gunung Gajah tunnel. N-SPT drilling test using an automatic hammer. Drilling is carried out to a depth of 15 meters with a Ground Water Level (MAT) of 7.5 meters (point A) and 0.5 meters (point B) from the ground. Soil classification obtained clay at a depth of 0-3 meters and stone at a depth of 3-15 meters. Hard soil is found at a depth of 3-4 meters with an average N-SPT value of 58 (point A) and 62.34 (point B). At a depth of up to 3 meters, the casing is installed for drilling and sampling for laboratory testing. UDS samples each drilling hole with varying depths between 1-2 meters. From laboratory testing, it is known that the average Gs value from the test results is 2.42, the water content (w) is 34.32% on average, the average dry density is 1.34 gr/cm$^3$, the average void ratio (e) is 0.98, the average plasticity index of 35.52% with the soil classification obtained is CH-OH. Based on triaxial testing, the average cohesiveness value is 0.2 kg/cm$^2$, and the average internal shear angle is 26.37°.

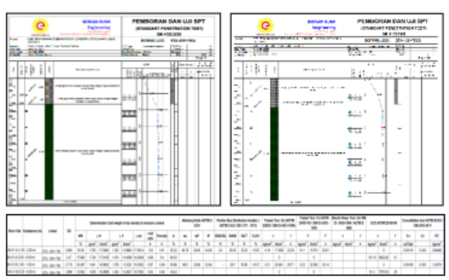

Figure 1. N-SPT Drill Results and laboratory test results at STA 435+650/850

2. Seismic Data

Based on the 2017 Indonesia Earthquake Source and Hazard Map issued by the PUPR Research and Development Center, the Peak Ground Acceleration (PGA) value for work locations at STA 435+650/850 is 0.446g.

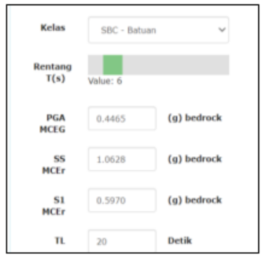


Figure 2. PGA at STA 435+650/850

3. Result of Slope Analysis in Existing Conditions
   - Slope modeling under existing conditions without earthquake loads
     The results of the analysis using the GEO5 program for landslide-prone areas in existing conditions without earthquake loads at STA 435+650/850 showed that the value of the safety factor (SF) obtained for the area was 1.13 with the Bishop method, 1.08 with the Fellenius method, 1.15 with the Spencer method, and 1.16 with the Janbu method did not meet the safe conditions according to SNI 8460:2017.

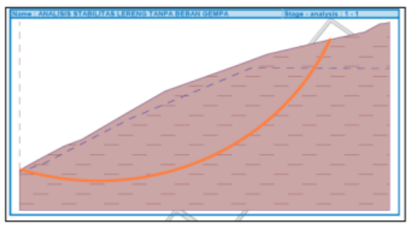

Figure 3. Modeling results using GEO5 for existing conditions without earthquake loads at STA 435+650/850.

| Slope stability verification (all methods) | | |
|---|---|---|
| Bishop : | FS = 1.13 < 1.25 | NOT ACCEPTABLE |
| Fellenius / Petterson : | FS = 1.08 < 1.25 | NOT ACCEPTABLE |
| Spencer : | FS = 1.15 < 1.25 | NOT ACCEPTABLE |
| Janbu : | FS = 1.16 < 1.25 | NOT ACCEPTABLE |
| Morgenstern-Price : | | The solution has not been found. |

Figure 4. The results of the safety factor analysis in modeling using GEO5 for existing conditions with earthquake loads at STA 435+650/850.

   - Slope modeling in existing conditions with earthquake loads
     The results of the analysis using GEO5 for landslide-prone areas in existing conditions with earthquake loads at STA 435+650/850 showed that the value of the safety factor (SF) obtained was 0.73 with the Bishop method and 0.69 with the Fellenius method so that it did not meet the safe conditions according to SNI 8460:2017.

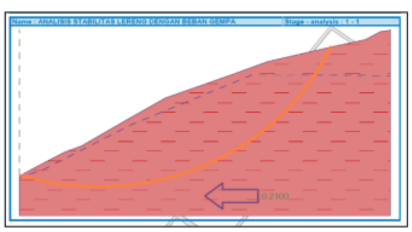

Figure 5. Modeling results using GEO5 for existing conditions with earthquake loads at STA 435+650/850.

| Slope stability verification (all methods) | |
|---|---|
| Bishop : | FS = 0.73 < 1.00 NOT ACCEPTABLE |
| Fellenius / Petterson : | FS = 0.69 < 1.00 NOT ACCEPTABLE |
| Spencer : | The solution has not been found. |
| Janbu : | The solution has not been found. |
| Morgenstern-Price : | The solution has not been found. |

Figure 6. The results of the safety factor analysis in modeling using GEO5 for existing conditions with earthquake loads at STA 435+650/850.

4. Results of Slope Stabilization Analysis With Reinforcement

The reinforcement specifications used in the reinforcement analysis at the STA 435+650/850 point are using Soil Nailing with the TerraNail brand of Fully Threaded TerraNail type, which has a diameter of 22 mm and a distance between nails of 1 meter. The soil nailing component consists of a bearing plate, grout, and shotcrete. The bearing plate is made of steel plate measuring 150x150x8 mm. The grout material uses type 1 cement with added plasticizer to improve workability. Shotcrete or spray concrete has a typical thickness of 10 cm and is equipped with 1 layer of M8 wire mesh (8 mm size). Shotcrete is required to have a compressive strength of fc' 15 MPa. Reinforcement analysis can be seen in the modeling using GEO5.

- Modeling of slope reinforcement without earthquake loads
  The analysis of slope reinforcement using GEO5 for landslide-prone areas without earthquake loads at STA 435+650/850 showed that the value of the safety factor (SF) obtained was 2,14 with the Bishop method so that it met the safe conditions according to SNI 8460:2017.

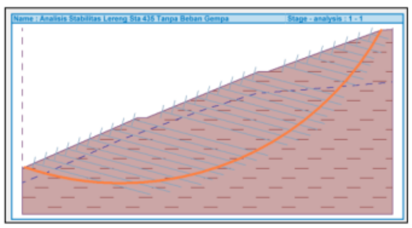

Figure 7. Slope reinforcement modeling results with soil nailing on GEO5 without earthquake loads at STA 435+650/850

| Slope stability verification (Bishop) | | |
|---|---|---|
| Sum of active forces : | $F_a$ = | 1247.39 kN/m |
| Sum of passive forces : | $F_p$ = | 2668.40 kN/m |
| Sliding moment : | $M_a$ = | 40003.91 kNm/m |
| Resisting moment : | $M_p$ = | 85575.64 kNm/m |
| Factor of safety = 2.14 > 1.25 | | |
| Slope stability ACCEPTABLE | | |

Figure 8. The results of the safety factor analysis on slope reinforcement modeling with soil nailing on GEO5 without earthquake loads at STA 435+650/850

- Modeling of slope reinforcement with earthquake loads
  The analysis of slope reinforcement using GEO5 for landslide-prone areas with earthquake loads at STA 435+650/850 shows that the value of the safety factor (SF) obtained is 1.29 with the Bishop method, so it meets safe conditions according to SNI 8460:2017.

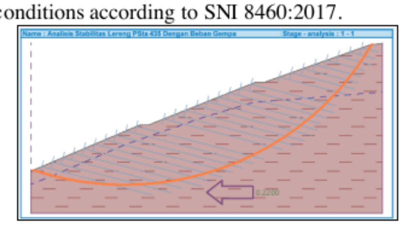

Figure 9. The results of soil nailing reinforcement modeling on slopes using GEO5 with earthquake loads at STA 435+650/850.

**Slope stability verification (Bishop)**
Sum of active forces : $F_a$ = 1968.13 kN/m
Sum of passive forces : $F_p$ = 2531.48 kN/m
Sliding moment : $M_a$ = 63117.98 kNm/m
Resisting moment : $M_p$ = 81184.71 kNm/m
Factor of safety = 1.29 > 1.00
Slope stability ACCEPTABLE

Figure 10. The results of the safety factor analysis on slope reinforcement modeling using soil nailing on GEO5 with earthquake loads on STA 435+650/850

*B. Research Location STA 436+1/2*

1. Soil Parameter

N-SPT drilling is carried out to a depth of 15 meters with a Ground Water Level (MAT) height of 0.5 meters (points A and B) from the ground. Soil classification obtained clay at a depth of 0-2.5 meters and stone at a depth of 2.5-15 meters. Hard soil is found at a depth of 6-8 meters with an average N-SPT value of 66.515. At a depth of up to 2.5 meters, the casing is installed for drilling and sampling for laboratory testing. From laboratory testing, it is known that the average Gs value from the test results is 2.64, the water content (w) is 23.46% on average, the average dry density is 1.41 gr/cm3, the average void ratio (e) is 0.87, the average plasticity index is 27.29%. Based on triaxial testing, the average cohesiveness value is 0.195 kg/cm2, and the average internal shear angle is 31.345°.

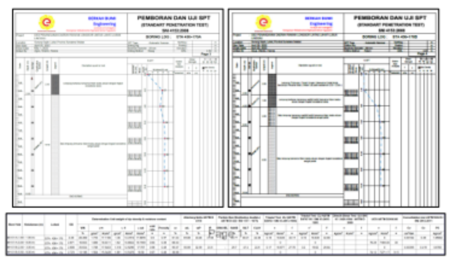

Figure 11. N-SPT Drill Results and laboratory test results at STA 436+1/2

2. Seismic Data

Based on the 2017 Indonesia Earthquake Source and Hazard Map issued by the PUPR Research and Development Center, the PGA value for work locations at STA 436+1/2 is 0.397.

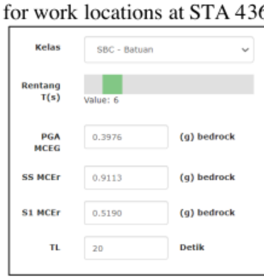


Figure 12. PGA at STA 436+1/2

3. Result of Slope Analysis in Existing Conditions
   - Slope modeling under existing conditions without earthquake loads
     The analysis results using GEO5 for landslide-prone areas in existing conditions without earthquake loads at STA 436+1/2 show that the value of the safety factor (SF) obtained for the area is 1.08 with the Fellenius method meeting the safe conditions according to SNI 8460:2017.

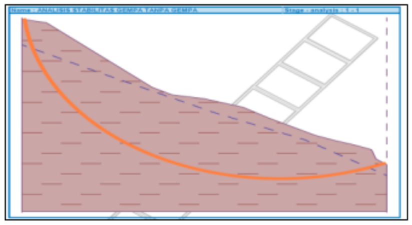

Figure 13. Modeling results using GEO5 for existing conditions without earthquake loads at STA 436+1/2.

**Slope stability verification (Fellenius / Petterson)**
Sum of active forces : $F_a$ = 960.55 kN/m
Sum of passive forces : $F_p$ = 1253.50 kN/m
Sliding moment : $M_a$ = 18269.69 kNm/m
Resisting moment : $M_p$ = 23841.66 kNm/m
Factor of safety = 1.30 > 1.25
Slope stability ACCEPTABLE

Figure 14. The results of the safety factor analysis in modeling using GEO5 for existing conditions with earthquake loads at STA 436+1/2.

- Slope modeling in existing conditions with earthquake loads
  The analysis results using GEO5 for landslide-prone areas in existing conditions with earthquake loads at STA 436+1/2 show that the value of the safety factor (SF) obtained is 0.85 with the Fellenius method; it does not meet the safe conditions according to SNI 8460:2017.

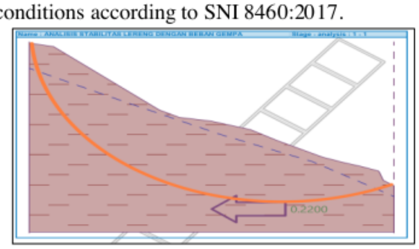


Figure 15. Modeling results using GEO5 for existing conditions with earthquake loads at STA 436+1/2.

**Slope stability verification (Fellenius / Petterson)**
Sum of active forces : $F_a$ = 1401.57 kN/m
Sum of passive forces : $F_p$ = 1187.96 kN/m
Sliding moment : $M_a$ = 26013.05 kNm/m
Resisting moment : $M_p$ = 22048.47 kNm/m
Factor of safety = 0.85 < 1.00
Slope stability NOT ACCEPTABLE

Figure 16. The results of the safety factor analysis in modeling using GEO5 for existing conditions with earthquake loads at STA 436+1/2.

4. Results of Slope Stabilization Analysis With Reinforcement

The reinforcement specifications used in the reinforcement analysis at the STA 436+1/2 point use soil Nailing with the TerraNail brand of Fully Threaded TerraNail type, which has a diameter of 22 mm and a distance between nails of 1 m. The soil nailing component consists of a bearing plate, grout, and shotcrete. The bearing plate is made of steel plate measuring 150x150x8 mm. The grout material uses type 1 cement with added plasticizer to improve workability. Shotcrete or spray concrete has a typical thickness of 10 cm and is equipped with 1 layer of M8 wire mesh (8 mm size). Shotcrete is required to have a compressive strength of fc' 15 MPa. Reinforcement analysis can be seen in the modeling using GEO5.

- Modeling of slope reinforcement without earthquake loads
  The results of the analysis of slope reinforcement using soil nailing on GEO5 for landslide-prone areas without earthquake loads at STA 436+1/2 show that the value of the safety factor (SF) obtained is 2.17 with the Bishop method so that it meets the safe conditions according to SNI 8460: 2017.

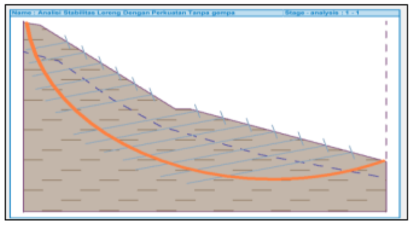

Figure 17. Slope reinforcement modeling results with soil nailing on GEO5 without earthquake loads at STA 436+1/2.

**Slope stability verification (Bishop)**

| | | | |
|---|---|---|---|
| Sum of active forces : | $F_a$ = | 786.23 | kN/m |
| Sum of passive forces : | $F_p$ = | 1702.85 | kN/m |
| Sliding moment : | $M_a$ = | 13680.34 | kNm/m |
| Resisting moment : | $M_p$ = | 29629.52 | kNm/m |

Factor of safety = 2.17 > 1.25
Slope stability ACCEPTABLE

Figure 18. The results of the safety factor analysis on slope reinforcement modeling with soil nailing on GEO5 without earthquake loads at STA STA 436+1/2.

- Modeling of slope reinforcement with earthquake loads
  The results of the analysis of slope reinforcement using soil nailing on GEO5 for landslide-prone areas with earthquake loads at STA 436+1/2 show that the value of the safety factor (SF) obtained is 1.52 with the Bishop method so that it meets safe conditions according to SNI 8460:2017.

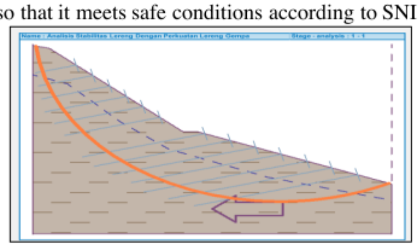

Figure 19. The results of soil nailing reinforcement modeling on slopes using GEO5 with earthquake loads at STA 436+1/2.

**Slope stability verification (Bishop)**

| | | | |
|---|---|---|---|
| Sum of active forces : | $F_a$ = | 1066.41 | kN/m |
| Sum of passive forces : | $F_p$ = | 1622.59 | kN/m |
| Sliding moment : | $M_a$ = | 18555.48 | kNm/m |
| Resisting moment : | $M_p$ = | 28233.00 | kNm/m |

Factor of safety = 1.52 > 1.00
Slope stability ACCEPTABLE

Figure 20. The results of the safety factor analysis on slope reinforcement modeling using soil nailing at GEO5 with earthquake loads on STA 436+1/2.

### *C. Research Location STA 444+350/450*

1. Soil Parameter

The N-SPT drilling test uses an automatic hammer with a borehole diameter of 89 mm. Drilling is carried out to a depth of 15 meters with a Ground Water Level (MAT) of 0.5 meters above the ground. Soil classification obtained fine sand at a depth of 0-6 meters and sand mixed with very dense clay at a depth of 6-15 meters. Hard soil is found at a depth of 8-15 meters with an average N-SPT value of 63.23. At a depth of up to 6 meters, the casing is installed for drilling and sampling for laboratory testing. UDS samples each drilling hole with varying depths between 1-6 meters. From laboratory testing, it is known that the average Gs value from the test results is 2.67, the water content (w) is 24,53% on average, the average dry density is 1.50 gr/cm3, the average void ratio (e) is 0.79, the average plasticity index is 32,87%. Based on triaxial testing, the average cohesiveness value is 0,22 kg/cm2, and the average internal shear angle is 34,13°.

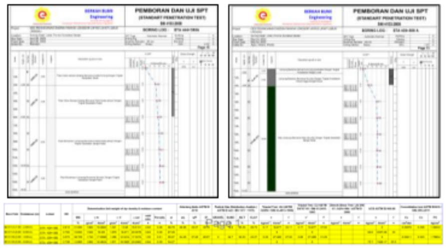

Figure 21. N-SPT Drill Results and laboratory test results at STA 444+350/450

2. Seismic Data

Based on the 2017 Indonesia Earthquake Source and Hazard Map issued by the PUPR Research and Development Center, the PGA value for work locations at STA 436+1/2 is 0.397.

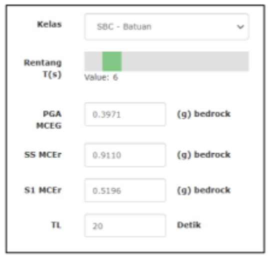


Figure 22. PGA at STA 444+350/450

3. Result of Slope Analysis in Existing Conditions
   - Slope modeling under existing conditions without earthquake loads
     The analysis results using GEO5 for landslide-prone areas in existing conditions without earthquake loads at STA 436+1/2 show that the value of the safety factor (SF) obtained for the area is 1.30 with the Fellenius method meeting the safe conditions according to SNI 8460:2017.

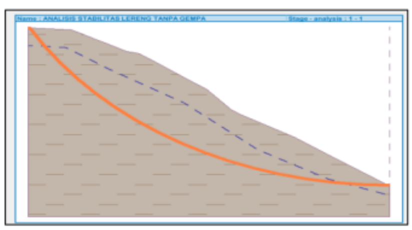

Figure 23. Modeling results using GEO5 for existing conditions without earthquake loads at 444+350/450.

**Slope stability verification (Bishop)**
Sum of active forces : $F_a$ = 3181.12 kN/m
Sum of passive forces : $F_p$ = 4139.31 kN/m
Sliding moment : $M_a$ = 155047.79 kNm/m
Resisting moment : $M_p$ = 201750.01 kNm/m
Factor of safety = 1.30 > 1.25
Slope stability ACCEPTABLE

Figure 24. The results of the safety factor analysis in modeling using GEO5 for existing conditions with earthquake loads at STA 444+350/450.

   - Slope modeling in existing conditions with earthquake loads
     The analysis results using GEO5 for landslide-prone areas in existing conditions with earthquake loads at STA 436+1/2 show that the value of the safety factor (SF) obtained is 0.91 with the Fellenius method, so it does not meet the safe conditions according to SNI 8460:2017.

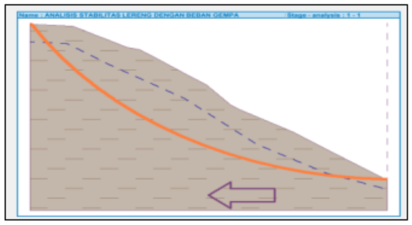

Figure 25. Modeling results using GEO5 for existing conditions with earthquake loads at STA 444+350/450.

**Slope stability verification (Bishop)**
Sum of active forces : $F_a$ = 3979.16 kN/m
Sum of passive forces : $F_p$ = 3601.94 kN/m
Sliding moment : $M_a$ = 206239.80 kNm/m
Resisting moment : $M_p$ = 186688.72 kNm/m
Factor of safety = 0.91 < 1.00
Slope stability NOT ACCEPTABLE

Figure 26. The results of the safety factor analysis in modeling using GEO5 for existing conditions with earthquake loads at STA 444+350/450.

4. Results of Slope Stabilization Analysis With Reinforcement

The reinforcement specifications used in the reinforcement analysis at the STA 436+1/2 point use soil Nailing with the TerraNail brand of Fully Threaded TerraNail type, which has a diameter of 22 mm and a distance between nails of 1 m. The soil nailing component consists of a bearing plate, grout, and shotcrete. The bearing plate is made of steel plate measuring 150x150x8 mm. The grout material uses type 1 cement with added plasticizer to improve workability. Shotcrete or spray concrete has a typical thickness of 10 cm and is equipped with 1 layer of M8 wire mesh (8 mm size). Shotcrete is required to have a compressive strength of fc' 15 MPa. Reinforcement analysis can be seen in the modeling using GEO5.

- Modeling of slope reinforcement without earthquake loads
  The results of the analysis of slope reinforcement using soil nailing on GEO5 for landslide-prone areas without earthquake loads at STA 444+350/450 show that the value of the safety factor (SF) obtained is 1,74 with the Bishop method so that it meets the safe conditions according to SNI 8460: 2017.

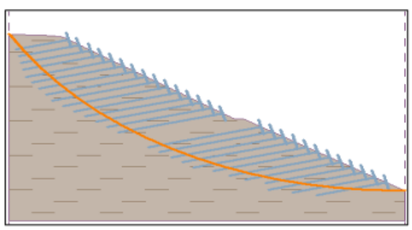

Figure 27. Slope reinforcement modeling results with soil nailing on GEO5 without earthquake loads at STA 444+350/450.

**Slope stability verification (Bishop)**
Sum of active forces : $F_a$ = 2978.04 kN/m
Sum of passive forces : $F_p$ = 5176.63 kN/m
Sliding moment : $M_a$ = 145149.50 kNm/m
Resisting moment : $M_p$ = 252309.01 kNm/m
Factor of safety = 1.74 > 1.25
Slope stability ACCEPTABLE

Figure 28. The results of the safety factor analysis on slope reinforcement modeling with soil nailing on GEO5 without earthquake loads at STA 444+350/450.

- Modeling of slope reinforcement with earthquake loads
  The results of the analysis of slope reinforcement using soil nailing on GEO5 for landslide-prone areas with earthquake loads at STA 444+350/450, the results show that the value of the safety factor (SF) obtained is 1.52 with the Bishop method so that it meets safe conditions according to SNI 8460:2017.

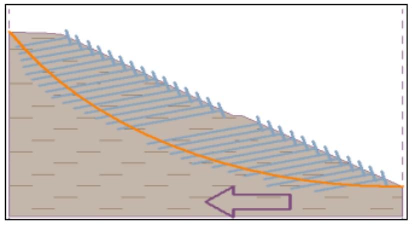

Figure 29. The results of soil nailing reinforcement modeling on slopes using GEO5 with earthquake loads at STA 444+350/450.

**Slope stability verification (Bishop)**
Sum of active forces : $F_a$ = 1066.41 kN/m
Sum of passive forces : $F_p$ = 1622.59 kN/m
Sliding moment : $M_a$ = 18555.48 kNm/m
Resisting moment : $M_p$ = 28233.00 kNm/m
Factor of safety = 1.52 > 1.00
Slope stability ACCEPTABLE

Figure 30. The results of the safety factor analysis on slope reinforcement modeling using soil nailing at GEO5 with earthquake loads on STA 444+350/450.

*D. Research Location STA 490+870*

1. Soil Parameter

The N-SPT drilling test uses an automatic hammer with a borehole diameter of 89 mm. Drilling was carried out to a depth of 15 meters with a Ground Water Level (GWL) of 2.5 meters above the ground. Soil classification obtained clay (clay) at 0-16 m. Hard soil is found at a depth of 16 meters with an average N-SPT value of 63 cm. At a depth of up to 12 meters, the casing is installed for drilling and sampling for laboratory testing. UDS sampled each drilling hole with varying depths between 1-1.5 m and 7-7.5 m. From laboratory testing, it is known that the average Gs value from the test results is 2.6, the water content (w) is 30.50% on average, the average dry density is 1.37 gr/cm3, and the void ratio (e) is average. The average is 0.91; the average plasticity index is 17.62%. Based on triaxial testing, the average cohesiveness value is 0.2 kg/cm2, and the average internal shear angle is 31.77°.

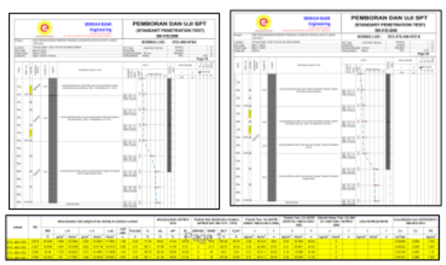

Figure 31. N-SPT Drill Results and laboratory test results at STA 490+870.

2. Seismic Data

Based on the 2017 Indonesia Earthquake Source and Hazard Map issued by the PUPR Research and Development Center, the PGA value for the work location at STA 490+870 is 0.463g.

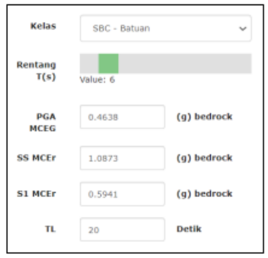


Figure 32. PGA at STA 490+870

3. Result of Slope Analysis in Existing Conditions
   - Slope modeling under existing conditions without earthquake loads
     The analysis results using GEO5 for landslide-prone areas in existing conditions without earthquake loads at STA 490+870 show that the value of the safety factor (SF) obtained for the area is 1.75, with the Bishop method meeting the safe conditions according to SNI 8460:2017.

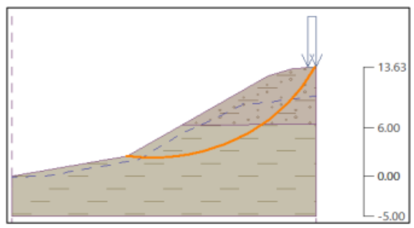


Figure 33. Modeling results using GEO5 for existing conditions without earthquake loads at 490+870.

**Slope stability verification (Bishop)**
Sum of active forces : $F_a$ = 700.13 kN/m
Sum of passive forces : $F_p$ = 1224.10 kN/m
Sliding moment : $M_a$ = 14086.68 kNm/m
Resisting moment : $M_p$ = 24628.94 kNm/m
Factor of safety = 1.75 > 1.25
Slope stability ACCEPTABLE

Figure 34. The results of the safety factor analysis in modeling using GEO5 for existing conditions with earthquake loads at STA 490+870.

   - Slope modeling in existing conditions with earthquake loads
     The analysis results using GEO5 for landslide-prone areas in existing conditions with earthquake loads at STA 490+870 show that the value of the safety factor (SF) obtained is 1.18 with the Bishop method, so it meets safe conditions according to SNI 8460:2017.

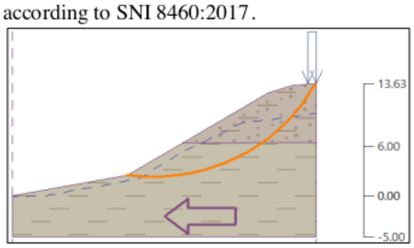


Figure 35. Modeling results using GEO5 for existing conditions with earthquake loads at STA 490+870.

**Slope stability verification (Bishop)**
Sum of active forces : $F_a$ = 962.52 kN/m
Sum of passive forces : $F_p$ = 1139.25 kN/m
Sliding moment : $M_a$ = 19365.85 kNm/m
Resisting moment : $M_p$ = 22921.76 kNm/m
Factor of safety = 1.18 > 1.00
Slope stability ACCEPTABLE

Figure 36. The results of the safety factor analysis in modeling using GEO5 for existing conditions with earthquake loads at STA 490+870.

4. Results of Slope Stabilization Analysis With Reinforcement

The point of STA 490+870 is an area prone to subsidence, so retaining wall reinforcement is used with a specification of 2.90 meters high, 1.50 meters wide for the foundation, and 0.30 meters for the upper wall.

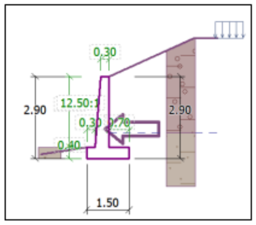


Figure 37. The results of the safety factor analysis on slope reinforcement modeling using retaining walls at GEO5 without earthquake loads at STA 490+870.

- Modeling of slope reinforcement without earthquake loads

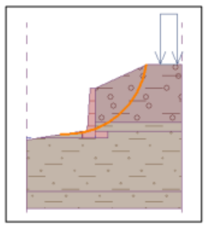

Figure 38. Slope reinforcement modeling results with soil nailing on GEO5 without earthquake loads at STA 444+350/450.

| **Slope stability verification (Bishop)** | | | |
|---|---|---|---|
| Sum of active forces : | $F_a$ = | 260.38 | kN/m |
| Sum of passive forces : | $F_p$ = | 433.24 | kN/m |
| Sliding moment : | $M_a$ = | 1656.02 | kNm/m |
| Resisting moment : | $M_p$ = | 2755.38 | kNm/m |
| Factor of safety = 1.66 > 1.50 | | | |
| Slope stability ACCEPTABLE | | | |

Figure 39. The results of the safety factor analysis on slope reinforcement modeling using retaining walls at GEO5 without earthquake loads at STA 490+870.

- Modeling of slope reinforcement with earthquake loads
  The analysis of slope reinforcement using retaining walls at GEO5 for landslide-prone areas with earthquake loads at STA 490+870 shows that the value of the safety factor (SF) obtained is 1.52 with the Bishop method so that it meets safe conditions according to SNI 8460:2017.

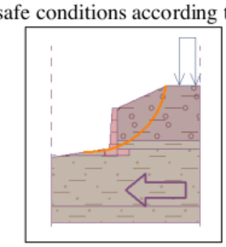

Figure 40. The results of modeling the reinforcement of retaining walls on slopes using GEO5 with earthquake loads at STA 490+870.

**Slope stability verification (Bishop)**

| | | | |
|---|---|---|---|
| Sum of active forces : | $F_a$ = | 535.93 | kN/m |
| Sum of passive forces : | $F_p$ = | 665.10 | kN/m |
| Sliding moment : | $M_a$ = | 5975.66 | kNm/m |
| Resisting moment : | $M_p$ = | 7415.84 | kNm/m |

Factor of safety = 1.24 > 1.10
Slope stability ACCEPTABLE

Figure 41. The results of the safety factor analysis on slope reinforcement modeling using retaining walls at GEO5 with earthquake loads at STA 490+870.

## IV. Conclusion

After modeling and analyzing slopes using the GEO5 program, the results showed that soil nailing reinforcement was used at STA 435+650/850, STA 436+1/2, STA 444+350/450, and retaining walls at STA STA 490+870 proved to increase the safety value. Factors, especially at the STA point where the existing conditions do not meet the safety requirements according to SNI 8460:2017. With the use of slope reinforcement that can increase the value of the safety factor, it can support the operation of train travel on the Lahat-Lubuklinggau South Sumatra line that is safe and comfortable following the basic foundation for rail operational business activities.

## References

[1] Supriyono, P. (2014) *Seri Pendidikan Pengurangan Risiko Bencana Tanah Longsor*. 1st edn. Yogyakarta: ANDI.

[2] Holtz, R.D dan Schuster, R.L. 1996. *Stabilization of Soil Slopes (In Landslides Investigation and Mitigation)*. National Academy Press. Washington DC.

[3] Indonesia, S. N., & Nasional, B. S. (2017). *Persyaratan perancangan geoteknik*.

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