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Effect of Ground Vibration to Slope Stability, Case Study Landslide on The Mouth of Railway Tunnel, Gunung Gajah Village, Lahat District

Moamar Aprilian Ghadafi[1,*], Muhammad Taufik Toha[2], Dedi Setiabudidaya[3]

[1] *Mining Engineering, Faculty of Engineering, Sriwijaya University, Palembang 30319*
[2] *Mining Engineering, Faculty of Engineering, Sriwijaya University, Palembang 30319*
[3] *Physics, Faculty of Mathematics and Natural Science, Sriwijaya University, Palembang 30319*

Abstract

Slope stability around railway tunnel in Gunung Gajah Village, Lahat District needs to be analysed due to landslide which occurred on January, 23th 2016. That analysis needs to be done so that the railway transportation system can run safely. The purposes of this research are: to find out the factors that cause slope instability, to find out peak acceleration caused by railway traffic and earthquakes and its effects to the safety factor of slope, and determine stabilization method in order to prevent the occurrence of further landslide. The research activities include surveying, sampling, laboratory testing and analyzing slope stability using pseudo-static approach. Based on research result, the main factors that cause slope instability are morphology, structural geology, and ground vibration caused by earthquakes. Ground vibration are correlated to the slope instability. It shows that the higher of peak acceleration the lower of safety factor of slope. To prevent the occurrence of further landslide around research area, stabilization method should be applied in accordance with the conditions in that area such as building a retaining wall to increase safety factor of slope, building draining channels to reduce run off and performing shotcrete in the wall of landslide in order to avoid weathering.

Keywords: ground vibration, slope stability, stabilization method

Abstrak (Indonesian)

Kestabilan lereng di sekitar terowongan kereta api di Kelurahan Gunung Gajah, Kabupaten Lahat perlu dianalisis sehubungan dengan terjadinya longsoran di lokasi tersebut pada tanggal 23 Januari 2016. Analisis tersebut perlu dilakukan agar sistem transportasi kereta api dapat berjalan dengan aman dan lancar. Tujuan penelitian yaitu mengetahui faktor - faktor yang mempengaruhi lereng menjadi tidak stabil, mengetahui percepatan puncak getaran tanah dan pengaruhnya terhadap kestabilan lereng, dan menentukan metode stabilisasi lereng untuk mencegah terjadinya longsoran selanjutnya. Kegiatan penelitian meliputi kegiatan survei, pengambilan sampel, uji laboratorium, dan analisis kestabilan lereng menggunakan pendekatan psedostatik. Berdasarkan hasil penelitian, faktor utama yang menyebabkan lereng tidak stabil adalah morfologi, struktur geologi, dan getaran tanah akibat gempa bumi. Getaran tanah akibat gempa bumi dan lalu lintas kereta api berbanding lurus terhadap ketidakstabilan lereng. Hal ini menunjukkan bahwa semakin besar nilai nilai percepatan puncak getaran tanah maka semakin kecil nilai faktor keamanan suatu lereng. Untuk mencegah terjadinya longsoran selanjutnya maka metode stabilisasi perlu diterapkan sesuai dengan kondisi-kondisi di lokasi tersebut. Metode stabilisasi yang dapat diterapkan, yaitu membangun dinding penahan (*retaining wall*) untuk menaikkan nilai faktor keamanan lereng, saluran drainase untuk mengurangi jumlah air limpasan dan melakukan penyemenan (shotcrete) pada dinding bekas longsoran untuk menghindari pelapukan.

Katakunci: getaran tanah, kestabilan lereng, metode stabilisasi

1. Introduction

On January 23th, 2016 a landslide has occurred at the mouth of the railway tunnel in Gunung Gajah Village, Lahat District. At the time of the landslide occurred, fortunately, there was no train passing and the railway track could be cleared immediately from landslide. Landslide covering the railway track could be very dangerous if there was a train passing though the tunnel and could cause injuries and fatalities.

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*Corresponding Author: moamar.ghadafi@gmail.com

Generally, the landslides are caused by several parameters such as geological structure, hydrogeology, geotechnical, land use, and ground vibration due to earthquake activity and rail traffic. Landslides are more common occurred in the areas which have weak structures with slope of 35°. These structures greatly affect rock strength because they are weak areas in the rock or at least they are water seeps and this will accelerate weathering and generally the weak plane becomes a landslide. Next hydrology will cause a high degree of weathering. Hydrology affects the strength value of the material and decreases the effective normal pressure and resistance to shear strength. Then the physical properties of the soil or rock that affect the stability of the slope is the density (γ), while the mechanical properties are shear strength expressed by the cohesion (c) and internal friction angle (ϕ). Shear strength is a force that serves as a force to resist or resist the force of cause of sliding. Last but not least, ground vibration can contribute to the occurrence of landslide because the dynamic load from the ground vibration can increase the shear stress on the slope and increase the soil pore pressure so that the shear stress increases and the shear strength retaining the slope decreases.

Considering the impact that can be caused by landslide so the analysis of the parameters that affect a landslide, especially the variables of ground vibration around the railway track of Gunung Gajah Village is important to do in order to anticipate the possibility of landslides elsewhere.

2. Experimental Section

This research was conducted around the mouth of railway tunnel, Gunung Gajah Village, Lahat District, South Sumatera (Figure 1).

The data which were needed in this research consist of secondary data and primary data. The secondary data were collected from departments/agencies, journals and literature like DEM SRTM, history of landslide and earthquake in Lahat District and Indonesian earthquake zone map. The primary data were collected through field surveys like land use survey, soil sampling, laboratory testing, measurement of strike and dip of rock layers and geological structure, measurement of slope geometry and measurement of peak ground acceleration (PGA) due to rail traffic.

The data of physical characteristics and mechanical characteristics, peak ground acceleration and earthquake were used for slope stability analysis, limit equilibrium and pseudo static method. Moreover, slope stability modeling will also be analyzed using Slide Program. After that, the determination of the stabilization method was carried out in which the selection was adjusted to the slope conditions and the type of collapse.

Figure 1. Research Location

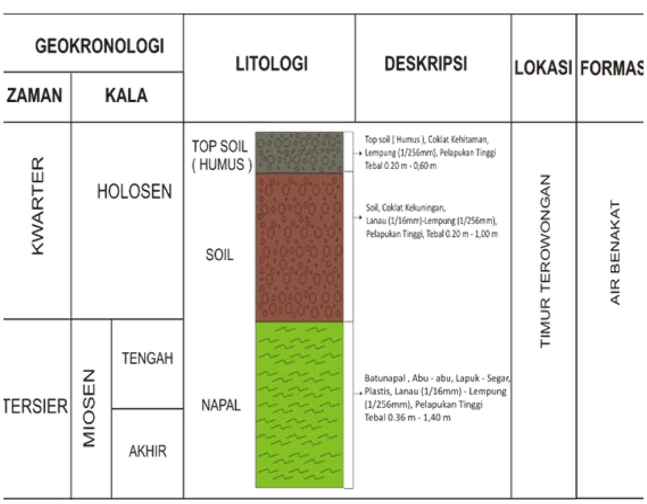

Figure 2. Lithology on Research Area

3. Results and Discussion

Observation and analysis of parameters causing slope instability consist of geology, hydrogeology, geotechnical condition, ground vibration, land use and morphology.

3.1. Geology

Lithology on research area consist of two types of material which are top soil/soil and marl. Based on observations on research area with a number of drill holes as many as 7 points, test pits as many as 7 points and trenches as many as 6 points, the depth of top soil ranged from 0.20 m to 1.00 meters and the depth of marl ranged from 0.36 m (weathered) to more than 1.40 m (Figure 2).

Based on observations and measurements of the rock structure layers through the wall of landslide on research area and test pit data, the orientation of the rock structure layers, strike trending East-West N 100°E and dip ranged from 20° to 30° (Figure 3).

The orientation of rock structure layers that have same direction to the slope which is unfavorable slope in the mouth of railway tunnel have high potential to cause landslide (Figure 4).

3.2. Hydrogeology

Based on observations of the lithology of research area, the potential of groundwater was found in top soil and soil layer at a depth of 0.10 m - 1.00 m. That value can be changed at anytime due to crack in soil layers and the amount of rainfall.

3.3. Geotechnical condition

Based on laboratory testing, top soil have the average value of density of 17,65 kN/m3, the average value of cohesion of 22,5 kN/m^2, and the average value of internal friction angle of 18° while marl have the average value of density of 22,06 kN/m^3, the average value of cohesion of 29,7 kN/m^2, and the average value of internal friction angle of 22°. The geotechnical data can be seen in the table 1.

Figure 3. Orientation of Rock Outcrop

Figure 4. Unfavorable slope on Research Area

3.4. Land Use

Land use around research area do not have a significant influence on the slope instability as the condition is still natural.

3.5. Morphology

Based on the observations of the morphology of landslide and the surrounding area, slope geometry measurement results obtained of 25° - 40° and a slope height of 10-20 m.

3.6. Ground Vibration

The ground vibration that appears on research area can be from earthquakes and rail traffic. The peak ground acceleration due to earthquake can be determined using Indonesian earthquake zone map 2010. Based on the interpretation of that map, the research area has a range of peak acceleration values between 0,2 to 0,3 g. Ground vibration due to rail traffic comes from two types of rails, which are fuel carrier rail and passenger rail. Based on the measurement result, the average of peak ground acceleration due to fuel carrier rail traffic is 0.025 g while the average value of peak ground acceleration due to passenger rail traffic is 0.026 g.

Slope Stability Analysis

Slope stability analysis is conducted to determine safety factor of slope whether the slope is stable or not. If the slope is not stable then slope is not safe and landslide can be occured immediately.

In modeling the slope and analyzing the stability of the slope by using Slide program, some data are needed like density, cohesion, internal friction angle, and slope geometry in which the height of slope is 16 meters, the width of slope is 35 meters and slope angle is 27°. The slope model can be seen in the figure 5.

In addition to analyzing the slope stability based on slope geometry data and physical and mechanical properties, slope stability analysis was also done using variation of groundwater level and seismic load. This needs to be done because of the possibility of increasing ground water level due to rainfall precipitation into the soil layer through the pores of the soil or crack and earthquake activity. For variation of ground water level, there are three conditions, water-saturated condition (ground water level is 2 meters below ground level), water-half saturated condition (ground water level is

Table 1. Geotechnical Data

Layer	Statistical Parameter	Density	Cohession	Internal Friction Angle
		kN/m3	kN/m2	°
Top Soil	Average	17,65	22,5	18
Marl	Average	22,06	29,7	22

8 meters below ground level) and water-unsaturated condition. For variation of seismic load, the data used is seismic coefficient which is obtained from the formula kh = 0,5 x PGA (Hyness-Griffin and Franklin, 1984) on research area, 0,10 – 0,15.

Based on slope analysis result, for water-saturated condition, the safety factor varied form 1,64 to 1,86. The result for water-half saturated condition, the safety factor varied form 1,84 to 2,05 and The result for water-unsaturated condition, the safety factor varied form 2,00 to 2,30. In general, the slope can be said to be safe because the average value of the safety factor is above 1.5. All result of slope stability analysis can be seen on table 2.

For slope stability that considers the seismic load value (pseudo static analysis), the result for water-saturated condition varied from 1,11 to 1,29. The result for water-half saturated condition varied from 1,25 to 1,42 and the result for water-unsaturated condition varied from 1,45 to 1,61. In general, with seismic load condition, the slope can be said to be unsafe and landslide can be occured immediately because the average value of the safety factor is under 1.5. All result of slope stability analysis with seismic load can be seen on table 3.

Those results of slope stability analysis showed that ground vibration caused earthquakes are correlated to the slope instability. It shows that the higher of peak acceleration the lower of safety factor of slope.

The Proposed Stabilization Method

To prevent the occurrence of the landslides around research area, stabilization method should be applied in accordance with the conditions in that area such as:

1. Build a retaining wall to increase the safety factor of the slope, considering that that is natural slope whose age of slopes is unlimited.

2. Build the drains to reduce run off on research area.

3. Perform cementing (shotcrete) in the wall of landslide in order

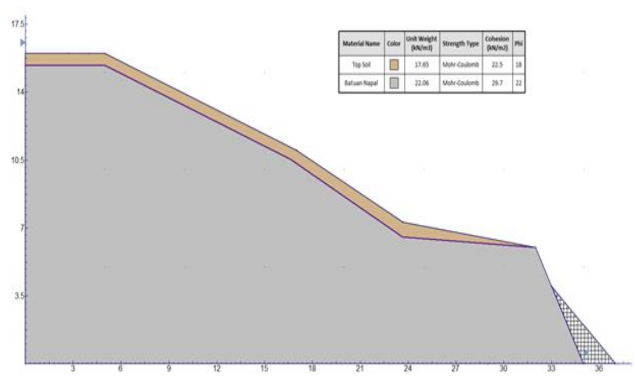

Figure 5. Slope Mode

Table 3. The Result of Slope Stability Analysis with Seismic Load

Method	*Minimum SF*
Water-saturated condition (ground water level is 3 meters below ground level)	
Ordinary/Fellenius	1,74
Bishop Simplified	1,86
Janbu Simplified	1,64
GLE/Morgenstren-Price	1,86
Water-half saturated condition (ground water level is 8 meters below ground level)	
Ordinary/Fellenius	1,89
Bishop Simplified	2,05
Janbu Simplified	1,84
GLE/Morgenstren-Price	2,05
water-unsaturated condition	
Ordinary/Fellenius	2,16
Bishop Simplified	2,30
Janbu Simplified	2,00
GLE/Morgenstren-Price	2,30

Table 2. The Result of Slope Stability Analysis

Method	Minimum SF with seismic load	Minimum SF with seismic load
	(0,10 g)	(0,15 g)
Water-saturated condition (ground water level is 3 meters below ground level)		
Ordinary/Fellenius	1,35	1,21
Bishop Simplified	1,44	1,29
Janbu Simplified	1,25	1,11
GLE/Morgenstren-Price	1,44	1,29
Water-half saturated condition (ground water level is 8 meters below ground level)		
Ordinary/Fellenius	1,46	1,34
Bishop Simplified	1,59	1,42
Janbu Simplified	1,40	1,25
GLE/Morgenstren-Price	1,58	1,42
water-unsaturated condition		
Ordinary/Fellenius	1,68	1,51
Bishop Simplified	1,79	1,61
Janbu Simplified	1,62	1,45
GLE/Morgenstren-Price	1,79	1,61

to avoid weathering.

4. Conclusion

Based on research result, the main factors that cause slope instability are morphology, structural geology, and ground vibration caused by earthquakes. Ground vibration caused by railway traffic and earthquakes are correlated to the slope instability. It shows that the higher of peak acceleration the lower of safety factor of slope.

To prevent the occurrence of further landslide around research area, stabilization method should be applied in accordance with the conditions in that area such as building a retaining wall to increase safety factor of slope, draining channels to reduce run off and performing shotcrete in the wall of landslide in order to avoid weathering.

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