

## THE LANDSLIDES MECHANISM ON THE SLOPES OF MOUNT RINJANI DUE TO THE JULY 2018 LOMBOK EARTHQUAKE

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**Abstract:** The Lombok earthquake that occurred in succession, which began at the end of July 2018, triggered landslides on several slopes on Mount Rinjani. The vibrations caused by the earthquake make the slopes unstable due to a decrease in the normal force as a component of the frictional force that binds the deposited material on the mountain slopes. The standard power is one factor that influences the friction force as a material binding to resist landslides. Under ordinary conditions, the average pressure depends on mass, gravity, and the slope's slope. During an earthquake, the normal force can be significantly reduced, causing landslides to occur. The slope stability angle shows the maximum slope angle susceptible to landslides due to an earthquake shock. The greater the peak ground acceleration (PGA) due to an earthquake, will have a landslide effect at a smaller tilt angle. The means that a significant shock due to an earthquake on a slope will be able to launch a landslide on a gentle slope, whereas a small shock can only slide a steep slope with a large angle. From the calculation of slope stability, which depends on the static friction coefficient, and PGA, which depends on the earthquake magnitude and the distance of the earthquake source from the slopes of Mount Rinjani, it gives a maximum value of 61.90 and a minimum value of 45.760.

**Keywords:** *Landslide, Rinjani, Lombok Earthquake*

### INTRODUCTION

Earthquakes do not cause many casualties, but it is the second danger that causes many lives. Secondary hazards can be in the form of landslides, tsunamis, or collapsing of buildings that are not resistant to shocks.

The Lombok earthquake that occurred in succession, which started at the end of July 2018 until the end of 2018 has caused many casualties and property. Two hundred nine people were victims of this earthquake, while the damage to buildings and infrastructure was estimated at 300 billion rupiahs. The earthquake has also triggered land cracks and landslides in several places on the slopes of Mount Rinjani. Figure 1. shows debris due to a landslide on the slope of Rinjani Mountain.

The vibrations that occur during an earthquake can trigger landslides, as the results of research that previous researchers have conducted. A probabilistic model has been created by linking seismic parameters and geological, geotechnical, and geo-morphological information to assess the spot's potential. Trials of this method in southern Italy have shown promising results for the zoning of landslide-prone areas [1]. Rainfall information and earthquake parameters have been used as the trigger variables for landslides [2].



Figure 1. Debris due to landslide on the slope of Rinjani Mountain

Geological data and laboratory tests data have been used in research to determine the trigger mechanism for the Chiufufengershan landslide that occurred during the Chi-Chi earthquake in 1999. This research indicates that an earthquake with a magnitude of 3.3 can trigger landslides in areas that are quite stable with a safety factor. 1.77 [3]. Mapping the landslides that occurred around the epicenter of the Avaj earthquake that occurred on June 22, 2002, showed that most of the landslides that occurred were in landslide-prone areas [4].

Earthquakes can also trigger liquefaction in wet areas with high groundwater content. Areas prone to liquefaction in Bengkulu province have been examined using the Horizontal to Vertical

Seismic Ratio (HVSR). This method succeeds in mapping liquefaction-prone areas [5]. The HVSR is also used to detect earthquake-prone zones in Tanjung, North Lombok [6]. Some other research conducted slope characterization to determine the potential for landslides and undertake mitigation efforts. A simple Coulomb friction model was used in this study to assess slope stability [7]. The velocity of the moving body also weakens frictional force [8]. The granular mechanism of the landslide has been investigated in other research [9]. Dynamic friction of landslides in a wide area has been performed to understand the landslide mechanism [11].

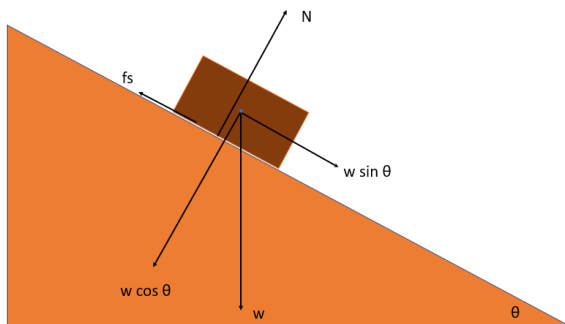


Figure 1. Model of rock in stable condition which is on an inclined plane.

Figure 1 shows a rock model in stable condition which is on an inclined plane. The weight of the object can be broken down into the force pushing towards the plane with a magnitude of  $w \sin \theta$ , and the force towards the normal plane of  $w \cos \theta$ . The resistance force which prevents the object from slipping towards the slope is the friction force. The amount of friction force on the object depends on the static friction coefficient between the object and the slope plane and the normal force as shown in equation (1).

$$f_s = \mu_s N \quad (1)$$

In stable conditions, the value of  $f_s$  is greater than the value of  $w \sin \theta$ . In critical conditions with a value of  $f_s$  equal to  $w \sin \theta$ , rock material can slip with a little additional force on  $w \sin \theta$  or a reduction in force at  $f_s$ . The addition of the sliding force, namely  $w \sin \theta$ , is not easy to occur for physical or geological reasons. Reduction of the force  $f_s$  occurs when the normal force decreases. Frictional force also depends on moisture of soil, moderate moisture will strengthen frictional force, but in extreme moisture, excess of water will weaken the force [11-12].

The normal force is the product of the static friction coefficient and the normal force. A reduction in the normal force can occur if the total acceleration towards the normal value decreases. The vibrations

that occur due to the earthquake can reduce the normal force as a result of fluctuations in total acceleration.

The decrease of normal force can be written as equation (2) [13].

$$N' = N - m \cdot a_p \quad (2)$$

$N$  is a normal force in the steady condition.  $N'$  is a normal force in shaking conditions due to earthquakes. The decreasing normal force is  $m \cdot a_p$ , where  $m$  is mass over sliding plane and  $a_p$  is the acceleration due to earthquake shaking.

## RESEARCH METHODS

The vibrations that occur due to the earthquake make the slopes unstable due to a decrease in normal forces. The normal force is one factor that influences the friction force as a material binding to resist landslides. Under ordinary conditions, the normal pressure depends on mass, gravity, and the slope's slope. In the event of an earthquake, the normal force can be significantly reduced, triggering landslides.

Normal force fluctuation due to vibration can be formulated as:

$$N' = w \cos \theta \pm m a_p$$

$$N' = m g \cos \theta \pm m a_p$$

$$N'_{\max} = m (g \cos \theta + a_p) \quad (3)$$

$$N'_{\min} = m (g \cos \theta - a_p) \quad (4)$$

$N'_{\max}$  is maximum normal force produced by earthquake shaking, and  $N'_{\min}$  is the minimum one. This normal force is a component of the frictional force that binds the deposited material on the slopes of the mountain. A decrease in the value of the normal force will also decrease the amount of friction force so that the gravitational force towards the slope is greater than the friction force. This unbalance forces make movement of mass over sliding plane. The minimum friction force due to earthquake movement can be written as:

$$f_s = \mu_s N'_{\min} \\ f_s = \mu_s m (g \cos \theta - a_p) \quad (5)$$

As a result of this event, the slopes become unstable and landslides occur. In this condition the force-force equation in the direction of the slope changes to:

$$\Sigma F = mg \sin \theta - \mu_s m (g \cos \theta - a_p) \quad (6)$$

Landslide will be occurred when  $\Sigma F$  has positive value that means:

$$mg \sin \theta > \mu_s m (g \cos \theta - a_p) \quad (7)$$

Solution of equation 7 trigonometrically will result as shown in equation 8.

$$\theta > \{ \arctan (a_p^2 \mu_s^6 g^{-2}) \} / 2 \quad (8)$$

Value of  $a_p$  in equation 6 is taken from peak ground acceleration that depend on earthquake magnitude and distance from hypocenter of earthquake as shown in equation (9).

$$PGA = (5/\sqrt{7}) 10^{0.61.M - (1.66 + 3.6/R) \log R + (0.167 - 1.83/R)} \quad (9)$$

Unit of PGA must be in  $cm/s^2$ , magnitude must be in Richter, and R is in km.

The Seismic data record is taken from USGS. There are five major earthquake taken from July Lombok earthquake. Value of  $\mu_s$  from Rinjani slope has been taken in Physics Laboratory, University of Mataram [14].

## RESULTS AND DISCUSSION

The Seismic data record on July Lombok earthquake is taken from United States Geological Survey (USGS). There are five major earthquake taken from the earthquake. Table 1 shows the major earthquake, including magnitude, latitude, longitude, and depth of hypocentre.

Table 1. Major 2018 Lombok Earthquake

Date	Time (UTC)	Lat	Long	Depth (km)	Magnitude (R)
19-8-18	14:56:27	-8.28	116.71	10	7.0
5-8-18	11:46:37	-8.39	116.48	28	6.8
19-8-18	4:10:22	-8.24	116.66	10	6.5
9-8-18	5:25:32	-8.36	116.22	12	6.2
29-7-18	1:50:32	-8.22	116.46	10	5.7

Peak ground acceleration of the major earthquake computed with equation (9), shown in table 2.

Table.2 Stability angle due to earthquake

Magnitude (R)	Space (km)	PGA ( $cm/s^2$ )	$\Theta$ (degree)
7	34.34	1474.68	45.76
6.8	10.79	578.73	50.025
6.5	32.13	814.65	47.54
6.2	28.42	556.28	50.43
5.7	23.71	297.69	61.95

The PGA value combined with the static friction coefficient value is then used to calculate the angle of slope stability. This slope stability value is the maximum angle of the slope which is still able to withstand earthquake shocks. This angle value is calculated using equation 8.

The value of the static friction coefficient used is based on research that has been conducted before [14], with a maximum value of 1.6.

In the first column the earthquake magnitude 7 on the Richter scale from a distance of 34.33 km will give an acceleration shock of  $1474.68 \text{ cm/s}^2$ , so that the slope on Mount Rinjani with an angle greater than  $45.76^\circ$  will experience landslides. In column 5, it can be seen that a magnitude with a scale of 5.7 on the Richter scale at a distance of 23.71 km will provide a shock acceleration of  $297.69 \text{ cm/s}^2$ , which will cause landslides on the slopes of Rinjani with a slope angle of above 61.94 degrees.

## CONCLUSION

The slope stability angle shows the maximum slope angle that is susceptible to landslides due to an earthquake shock. The greater the acceleration (PGA) due to an earthquake will have a landslide effect at a smaller tilt angle. This means that a significant shock due to an earthquake on a slope will launch a landslide in a gentle slope, whereas a small shock can only slide a steep slope with a large angle. The slope stability calculation, which is dependent on the static friction coefficient, and PGA, which depends on the earthquake magnitude and the distance on the slopes of Mount Rinjani, gives a maximum value of 61.90 and a minimum value of 45.760.

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