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Analysis of Seismic Vulnerability Index on Slope Stability in Landslide-Prone Areas of Tomilito District, North Gorontalo Regency

Meilan Demulawa[1*], Irsan[2]

[1,2]Jurusan Fisika, Fakultas Matematika dan Ilmu Pengetahuan Alam, Universitas Negeri Gorontalo

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Abstract
This study analyzes the seismic vulnerability index to slope stability in landslide-prone areas, Tomilito District, North Gorontalo Regency. The results of the study indicate that the seismic vulnerability index in this area is in the low category, which is at a vulnerable level (0.2246-1.047736) where if vibrations occur, the surface soil layer level does not experience deformation or changes in the soil so that it is safe from the influence of shaking reinforcement.

Keywords: *Seismic Vulnerability Index*

(*) Corresponding Author: meilan.demulawa@ung.ac.id

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INTRODUCTION

The Tomilito area is a low hilly area, and highlands spread at an altitude of 0-1800 meters above sea level; the topography is dominated by a slope of 15-400 (60-70%). The main geological structural conditions are faults that can potentially cause tectonic movements, causing landslides (BPP, 2017). Landslides are the movement of soil or rock masses, or both, down or out of a slope due to disturbances in the stability of the soil or rocks that make up the slope (Priyono, 2015). Landslides are formed by moving or destroying rocks, soil, or mixed materials, shifting down or out of the slope. Landslides begin with the infiltration of water into the soil, adding weight to the soil. If the water penetrates the soil and acts as a watertight shear plane, the soil becomes slippery, and the weathering above it will bend along the slope and eventually out of the slope (Dalimunthe & Hamid, 2018).

Geographically, Tomilito District is a highland area with the lowest altitude (300 m) above sea level. The slip plane in Tomilito District shows that the upper layer has a lower resistivity; this layer is a top soil layer in the form of clay sand and gravel sand. The lower layer has a higher resistivity value estimated to be andesite igneous rock (Akbar et al., 2021). If the soil is loaded, it will result in shear stress; if the shear stress reaches the limit value, the soil mass will deform and tend to collapse. This collapse may result in the foundation expanding movement/shifting of the retaining wall or landslides of the soil embankment. Shear failure in the soil results from relative motion between the grains of the soil mass, so the shear strength of the soil is determined to measure the ability of the soil to withstand pressure without collapsing (Chr et al., 2020).

THEORETICAL BASIS

Seismic Vulnerability Index

The seismic vulnerability index (Kg) is an index that describes the level of vulnerability of the surface soil layer to deformation during an earthquake. This study will look at the seismic vulnerability to vehicle vibrations on slopes around the road (Febriani et al., 2013). The high and low seismic vulnerability index by amplification and frequency factors so that the relationship can be expressed in the following equation:

$$K_g = \frac{A0^2}{f_0}$$

Where :

Kg = Seismic vulnerability index

A_0 = Amplification

f = Natural frequency

High vulnerability index levels are generally found in areas with high amplification and low natural frequencies. This occurs because the surface sediment layer is relatively thick and covers the bedrock (Simanjuntak et al., 2017). The following Table 1 is the classification of seismic vulnerability index values:

Table 1. Classification of Seismic Vulnerability Index Values

Zone	Classification	Seismic Vulnerability Value
1	Low	Kg< 3
2	Medium	3 ≤ Kg< 6
3	High	>6

Several previous research results have shown a positive correlation between the distribution of Kg values and damage due to earthquakes, where a high Kg means that the area is prone to damage, meaning that the rocks there are composed of soft rocks. Conversely, a low Kg implies that the area is safe from harm (Febriani et al., 2013).

Landslide Causing Factors

Many factors affect slope stability that results in landslides, such as geological and hydrographic conditions, topography, climate, and weather changes. In principle, landslides occur when the driving force on the slope is greater than the retaining force, and the strength of the rock and soil density generally influence the retaining force. The driving force is influenced by the size of the slope angle, water, load, and density of the rock soil (Widiastari et al., 2021). Several factors cause landslides, including:

a. Rainfall

Rainfall can indirectly affect slope stability and the condition of pore water in the slope-forming material. In soil conditions with high conductivity, the water will flow into deeper soil and cause the groundwater level to rise. The heavier the rain, the more the water in it will increase in discharge and volume, the capacity and infiltration reach a minimum, and most of the pores are filled with water or the soil is in a saturated condition; this is what can cause landslides (Khoiriyah et al., 2016).

b. Slope Gradient

A steep slope or cliff will increase the driving force. Steep slopes are formed due to river water, springs, seawater, and wind erosion. The slope of the slope affects the flow and erosion. Most slope angles that cause landslides are 1800 if the end of the slope is steep and the landslide plane is flat (Indrasmoro, 2013).

c. Soil Type

The less-dense soil type is clay or clay with a thickness of more than 2.5 m from a slope angle of more than 220 (Indrasmoro, 2013). This soil type has the potential for landslides, especially when it rains. In addition, this soil is very susceptible to soil movement because it becomes soft when exposed to water and breaks when the air is too hot, making it easy for water to pass through (Arsyad et al., 2018).

d. Weathered Rock

Less intense rocks are generally volcanic deposits and sand-sized sediments, and a mixture of gravel, sand, and clay is generally less strong. These rocks will quickly become soil if they undergo a weathering process and are generally susceptible to landslides if they are on steep slopes (Arsyad et al., 2018)

e. Type of Land Use

Landslides often occur in rice field land use areas, plantations, and where there is standing water on steep slopes. Rice field land has roots that are not strong enough to bind soil particles and make the soil soft and saturated with water so that landslides easily occur, while for plantation areas, the cause is because the tree roots cannot penetrate deep landslide areas and generally occur in old landslide areas (Naryanto et al., 2019).

f. Vibration

Earthquakes, explosions, engine vibrations, and vehicle traffic vibrations usually cause the vibrations that occur. The effects are that the house's soil, road body, floor, and walls become cracked (Nugraha et al., 2020).

g. Additional Load

The presence of additional loads, such as building loads on slopes and vehicles, will increase the driving force of landslides, especially around bends in the road in valley areas. The result is frequent land subsidence and cracks directed towards the valley (Bokko et al., 2019).

h. Erosion

Erosion is often carried out by river water towards the cliff. In addition, due to deforestation around river bends, the cliff will become steep (Debataraja & Pardede, 2020).

i. Presence of Embankment Material on the Cliff

For the development and expansion of residential land, cliffs are generally cut, and valleys are filled. The embankment in the valley has yet to be perfectly compacted like the original soil below it. Land subsidence will occur when it rains, followed by soil cracks (Bokko et al., 2019).

RESEARCH METHOD

The measurement data is raw microtremor data from time-domain ground vibration signals analyzed using geopsy. Analysis of vibration patterns in geopsy contains three components of the microtremor signal, namely the North-South (N.S.) horizontal component, the East-West (E.W.) horizontal component, the last is the Vertical (V) component, and to determine the effects of vehicle vibrations, namely by looking at the frequency, amplification, and seismic vulnerability parameters. The seismic vulnerability index (Kg) is based on the comparison of the square of the amplification value (Ao) with the natural frequency (fo) of the peak of the H/V curve (Nur & Hartantyo, 2021); here are the stages of data analysis:

1. Input data (microtremor recording files converted into mini-seeds) into geopsy.
2. Signal windowing: the signal will be divided into several boxes (windows). Window selection can be done manually or automatically. This selection (windowing) separates the tremor signal from transient events (specific sources such as footsteps and passing vehicles and others that are considered noise). 3. Fourier transformation on each component to obtain the Fourier spectrum on each window (Mufida et al., 2013).

RESULTS AND DISCUSSION

Low seismic vulnerability index values are obtained in areas with low amplification values (A0) and high natural frequency values (f0). Based on the data obtained in Table 2, the seismic vulnerability index (kg) produced by the natural frequency and soil amplification values, the data obtained does not pass filtering because what will be analyzed is the effect of noise with a sampling frequency of 1-100Hz. Table 1 is as follows:

Table 2. Seismic Vulnerability Index (Kg)

	Seismic vulnerability index (Kg)		**Classification**	
Location	Morning	Afternoon	Morning	Afternoon
L	0,2665	0,329684	Low	Low
Ll	0,2246	0,355718	Low	Low
Lll	0,7970	0,988226	Low	Low
lV	1,0156	0,989888	Low	Low
V	0,4819	0,5308	Low	Low
Vl	0,4972	1,047736	Low	Low

Based on Table 2, the seismic vulnerability index value (Kg) shows that Tomilito District has a low value; it can be seen in the seismic vulnerability value table that the area is at a vulnerability (0.2246-1.047736) where if vibrations occur, the surface soil layer level does not experience deformation or changes in the soil so that it is safe from the influence of shaking. According to (Maimun et al., 2020), the low seismic vulnerability index value (Kg) is caused by geological conditions in areas composed of andesite or breccia rock material on the surface. This kind of hard rock physically has a meager shear-strain value if an earthquake occurs, so locally, this location is relatively safe from earthquake shocks.

CONCLUSION

This study analyzes the seismic vulnerability index to slope stability in landslide-prone areas, Tomilito District, North Gorontalo Regency. The results of the study indicate that the seismic vulnerability index in this area is in the low category; it can be seen that it is vulnerable (0.329684-1.047736) where if vibrations occur, the surface soil layer level does not experience deformation or changes in the soil so that it is safe from the influence of shaking reinforcement.

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