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Analysis of Vibration Patterns on Slopes Due to Vehicles On Landslides Using The Microtremor Method, Tomilito District, North Gorontalo

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Abstract. This study aims to determine the graphic patterns of vibration on slopes caused by vehicles, and graphic designs can be observed based on the time and frequency domains. The research data were recorded using a movable type TDL 303 S (three components) with six measurement points in Tomilito District. The recorded data were processed using the Geopsy software. The data analysis was used is HVSR analysis. HVSR research has produced time- and frequency-domain graph patterns. Based on the data analysis, in the design of the time-domain graph, locations close to the road have interference/noise caused by the vehicle amplitudes. This area does not exist, and the frequency-domain graph has natural frequency values and amplification at the peak of the H/V curve. In each morning time curve, the frequency in the range of 18-37 Hz experiences an increase in amplitude. By contrast, the amplitude did not increase significantly.

1 Introduction

The Gorontalo area was once an active, ancient volcanic caldera. The cessation of volcanic activity in the Gorontalo area was caused by the formation of an active Gorontalo fault, accompanied by rock deformation and local defects [1]. Local faults affect rock weathering and form vertical topographical grooves, such that the rocks experience fragmentation and have the potential for landslides. In particular, Tomilito District is a hilly area with many slopes of different heights. Thus, they are prone to landslides. .

The hilly area in Tomilito District is frequently covered by vehicles. Landslide/soil movement is the process of mass movement of rock or soil due to gravity, a movement that occurs because of controlling factors and triggers that are natural or non-natural, one of which is vibration on slopes caused by vehicles. The mechanism carried out by moving vehicles, such as sedans and trucks, produces vibrations on the slopes, also called dynamic forces, related to the trajectory and weight of the vehicle. Vibration on the slopes of the road has a vibration frequency that varies depending on the weight and vehicles that cross it [2].

Based on the results of direct observations and data located at the Gorontalo Province land transportation management office, commonly referred to as BPTD, Tomilito District is an area that has activities that are pretty busy being traversed by vehicles, both light vehicles (LV), heavy vehicles (HV), and public vehicles (UM).

Table 1. Number of Vehicles

Day/Date of Peak	Hour Survey	Number of Vehicles (Vehicles/Hour)		
		LV	HV	UM
Wednesday 03/12/2021	Cluster Time 1 (06.00-10.00)	86	92	19
	Cluster Time 2 (11.00-14.00)	59	42	6
	Cluster Time 3 (15.00-18.00)	91	67	15
Thursday 04/12/2021	Cluster Time 1 (06.00-10.00)	102	75	16
	Cluster Time 2 (11.00-14.00)	65	58	11
	Cluster Time 3 (15.00-18.00)	98	64	18

(Source: BPTD Gorontalo, 2022)

1.1 Basic Theory

1.1.1 Understanding Landslides

Landslides are formed by the movement or destruction of rock, soil, or mixed materials that shift down or out of the slope [3]. Landslides begin with the absorption of water into the ground, which adds weight to the soil. If the water penetrating the soil acts as an impermeable shear plane, the soil becomes slippery, and the weathered soil above it bends to follow the slope and eventually exit the slope [4]

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1.1.2 Seismic

Wave seismic waves are a time-dependent phenomenon, so we need to calculate the effect of momentum by applying Newton's laws. Seismic waves are elastic waves that propagate within the Earth. Seismic waves can be classified into two groups: body and surface waves. Body waves propagate in the body of the medium, which means that they can also propagate on the surface of the medium [5].

1.1.3 Vibration Vehicle

Vibration releases energy that causes particle vibrations in all directions [6]. Vibration due to highway traffic is caused by changes in ground pressure through tires when the vehicle is moving. The vehicle model, load, road grade, and other factors affect the vibration [7]. On the ground, one source of mechanical vibration is vibration caused by vehicles [8].

2 Methods and Data Analysis

Processing data using the microtremor method to determine graphic patterns by comparing slopes near the road and slopes far from the road to see vibration behaviour on vehicle slopes using the microtremor method two times, namely morning and evening time. This time is the rush hour of the vehicle. Data processing was done using *geopsy* [9]. The raw data obtained from measurements in the field are in the form of three signal components as a function of time [10]. The following is a display of the raw data resulting from the data collection process that will be analyzed:

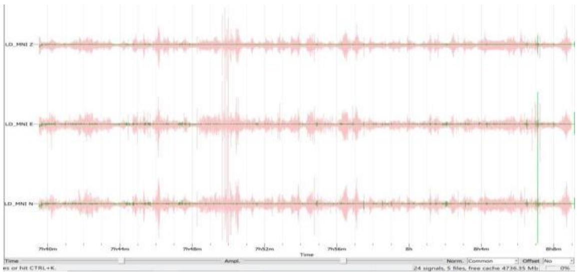

Fig 1. Combined initial data for location 1 and location 5 (green: location 5 and red: location 1) measurements on a seismogram

Figure 1 shows the result of data collection in the field, where the green color is an area that is not traversed by vehicles, whereas the red color is an area that is often passed by vehicles. The difference from the seismogram is that there are more surface waves or noise in the window, the red window, and the green window. After that, a Fourier FFT on each signal component picked using sampling from human activity. Then, the H/V curve is obtained to determine the graphic pattern of vibration on the slope of the vehicle, as shown in Figure 2.

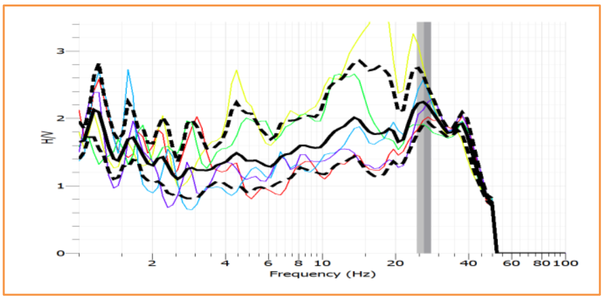

Fig 2. H/V Curve Geopsy Software

1.1.4 Relationship between Seismic Waves and Vehicle Vibration

The vibration is the process of energy release according to [6]. This release of energy causes particle vibrations in all the directions. Seismic waves are elastic waves that propagate on the Earth. Some seismic waves propagate through the Earth's interior, called body waves, and propagate through the Earth's surface, which are called surface waves [11]. Seismic noise can be grouped into two sources: natural noise and seismic noise. Natural noise occurs because of tectonic earthquakes, volcanic earthquakes, and rockfalls. Both sources are caused by humans and are commonly called noise [12].

3 Results and Discussion

Based on research results in the field, the data obtained are passive seismic data, where the vibration conditions on the slopes are suitable for natural occurrences that produce the HVSR [13]. The unbroken line in the middle is the average value generated by the FFT of all H/V ratio values, whereas the colored lines are the H/V curves of each window [14]. The following is the vibration signal on the slope owing to vehicles in the time and frequency domains.

A. Location 1 Passed by Vehicles

1. **Results of Vibration Measurements on Slopes Due to Truck Vehicles (08.00-11.01 WITA)**

a. Time Domain

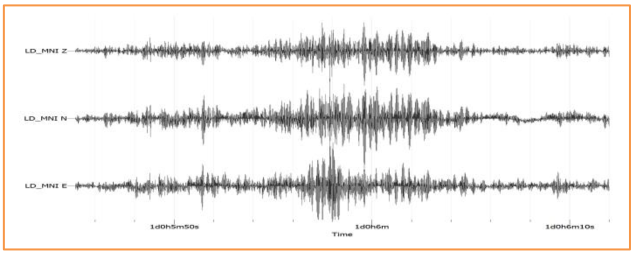

Fig 3. Vibration Signals on Slopes Due to Truck Vehicles

Based on Figure 3, the horizontal vibration signal has a larger wavelength than the vertical direction signal (Z), where the horizontal vibration signal has a wavelength of Horizontal N (north–south) greater than Horizontal E (east–west).

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b. Frequency Domain

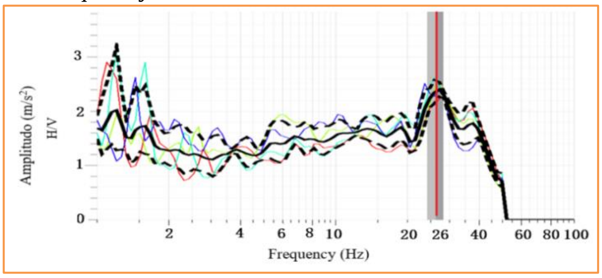

Fig 4. Curve *HVSR* Truck Vehicle

Based on Figure 4, the x-axis represents the frequency and the y-axis represents the amplitude. It can be seen on the x-axis, where the frequency is 26 Hz, there is an increase in amplitude, while on the y-axis, the vibration amplitude on the slope for the frequency on the curve does not change significantly for each color, but it can be seen that the x-axis has increased at the beginning.

2. Results of Vibration Measurements on Slopes Due to Sedan Vehicles (08.00-11.01 WITA)

a. Time Domain

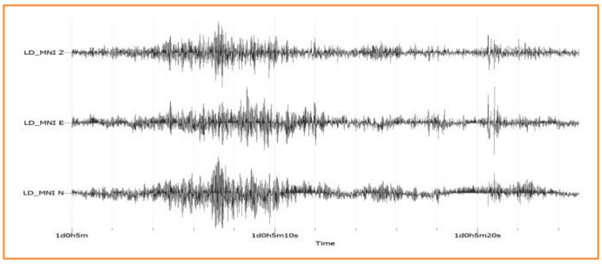

Fig 5. Vibration Signals on Slopes Due to Sedan Vehicles

Based on Figure 5, the vertical vibration signal is smaller than the horizontal signal, where the horizontal signal N (north–south) vibration is longer than the horizontal vibration E (east–west).

b. Frequency Domain

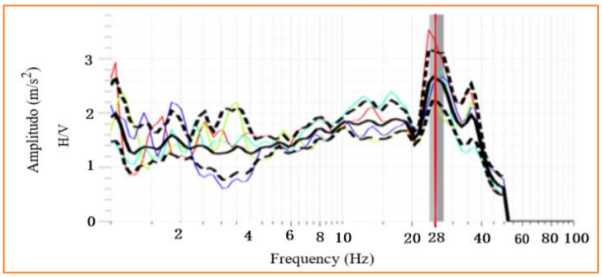

Fig 6. HVSR Curve Obtained from The Geopsy Data Processing of The H/V Characteristics

Based on Figure 6, the x-axis, namely the frequency of 28 Hz, increases the amplitude, while the y-axis is the amplitude of the frequency on the curve, which does not experience a significant change at every color.

3. Results of Vibration Measurements on Slopes Due to Motorcycle Vehicles (08.00-11.01 WITA)

a. Time Domain

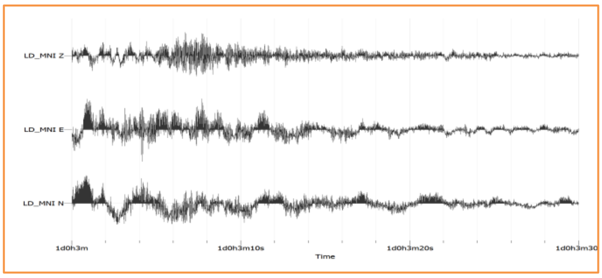

Fig 7. Vibration Signals on Slopes Due to Motorcycle Vehicles

Based on Figure 7, the horizontal vibration signal has a longer wavelength than the vertical vibration signal. However, the horizontal vibration signal is E (*east-west*), and N (north-south) has a difference in the initial arrival, where the horizontal E (*east-west*) has a longer wavelength.

b. Frequency Domain

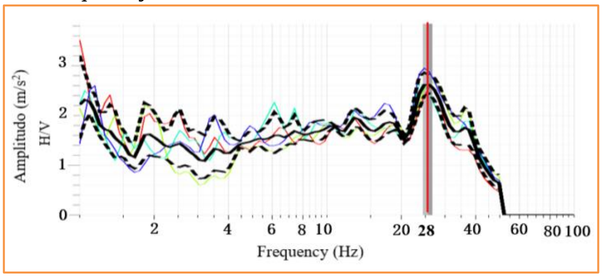

Fig 8. Curve *HVSR* for Sedan Cars Obtained from Geopsy Data Processing of The H/V Characteristics

Based on Figure 8, the amplitude increases on the x-axis, where the 28 Hz frequency increases, whereas the y-axis does not change significantly.

B. Location 2 (Passed by Vehicles)

1. Results of Vibration Measurements on Slopes Due to Trucks (08.00-11.01 WITA)

a. Time Domain

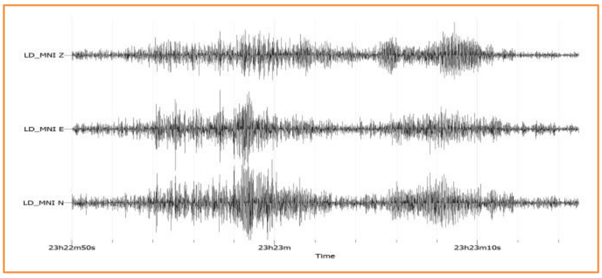

Fig 9. Vibration Signals on Slopes Due to Trucks

Based on Figure 9, the horizontal vibration signal has a longer wavelength than the vertical signal, and it can be observed that the horizontal vibration signal N (north–south) has a longer wavelength than the horizontal vibration signal E (east–west).

b. Frequency Domain

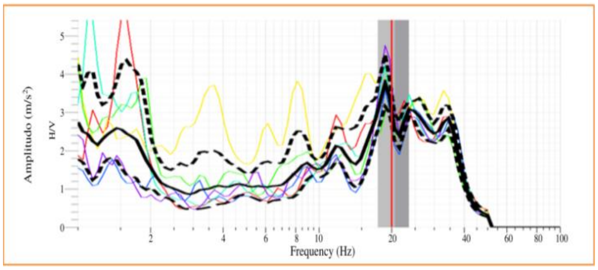

Fig 10. Curve *HVSR* Truck Vehicle

Based on the x-axis in Figure 10, at a frequency of 20 Hz, there is a significant increase in the amplitude, whereas the y-axis amplitude for the frequency on the curve changes to red, green, and yellow.

2. Results of Vibration Measurements on Slopes Due to Sedan Vehicles (08.00-11.01 WITA)

a. Time Domain

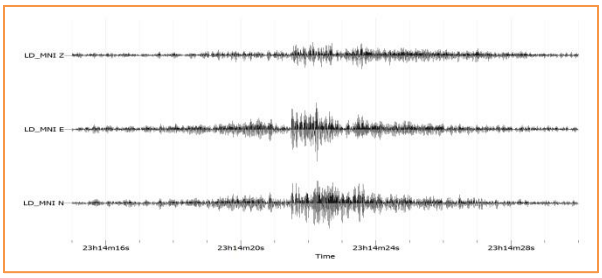

Fig 11. Vibration Signals on Slopes Due to Sedan Vehicles

As shown in Figure 11, the horizontal vibration signal has a longer wavelength than the vertical vibration signal, where the horizontal vibration signal N (north–south) is greater than the horizontal E (east–west).

b. Frequency Domain

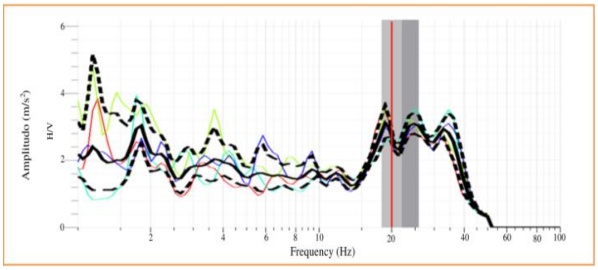

Fig12. Curve *HVSR* Sedan Car Vehicle

Based on Figure 12, the amplitude increases on the x-axis. In contrast, the y-axis, namely the amplitude, experiences a change in frequency at the beginning of the curve for each colour representing the signal.

3. Results of Vibration Measurements on Slopes Due to Motorcycle Vehicles (08.00-11.01 WITA)

a. Time Domain

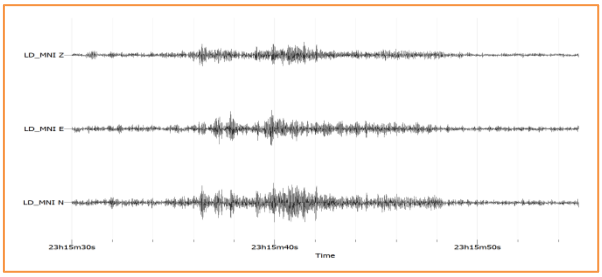

Figure 13. Vibration Signals on Slopes Due to Motorcycle Vehicles

Based on Figure 13, the horizontal vibration signal is greater than the vertical vibration signal, and the horizontal vibration signal E (east–west) is smaller than the horizontal vibration signal N (north–south).

b. Frequency Domain

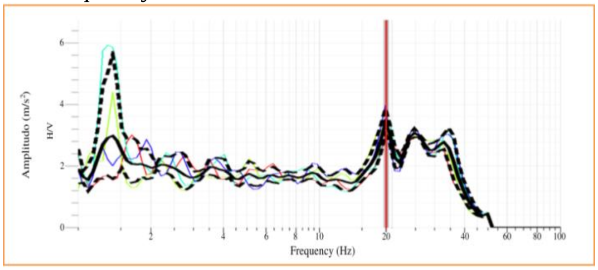

Fig 14. Curve *HVSR* Motorcycle Vehicle

Based on the x-axis in Figure 14, the frequency of 20 Hz has increased in amplitude, while the amplitude has changed in green and turquoise, where it has changed in frequency beginning the H/V curve of each color represents the signal.

C. Location 3 (Near Road)

1. Results of Vibration Measurements on Slopes Due to Trucks (08.00-11.01 WITA)

a. Time Domain

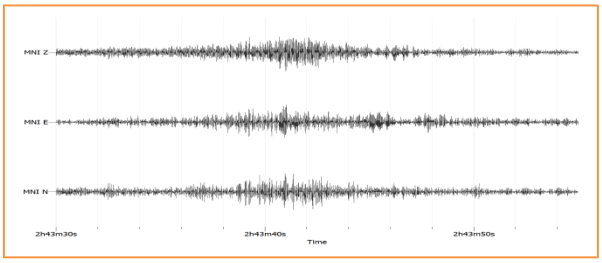

Fig15. Vibration Signals on Slopes Due to Trucks

As shown in Figure 15, the vertical vibration signal has a longer wavelength than the vibration signals on the E (east–west) and N (north–south) horizontal slopes.

b. Frequency Domain

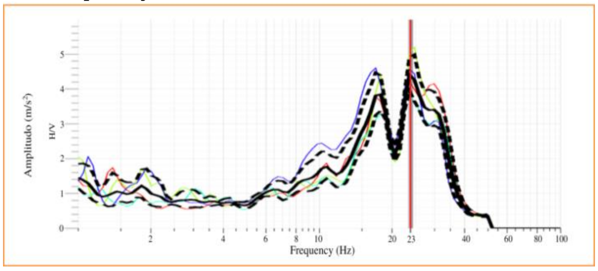

Fig 16. Curve *HVSR* for Truck Vehicles Obtained from Geopsy Data Processing of H/V Characteristics

As shown in Figure 16, the x-axis frequency of 23 Hz increased in amplitude, while the amplitude did not change significantly.

2. Results of Vibration Measurements on Slopes Due to Sedan Vehicles (08.00-11.01 WITA)

a. Time Domain

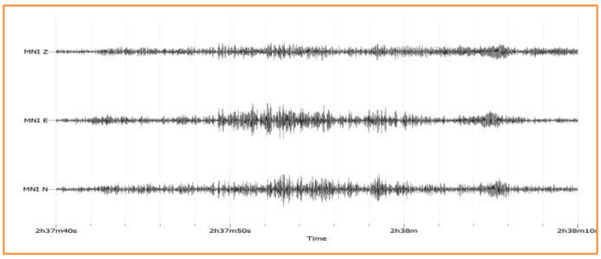

Fig 17. Vibration Signals on Slopes Due to Sedan Vehicles

Based on Figure 17, the vibration signal due to vehicles has a longer wavelength in horizontal vibration than in vertical vibration, where the horizontal vibration is greater on horizontal E (east–west) than on horizontal N (north–south).

b. Frequency Domain

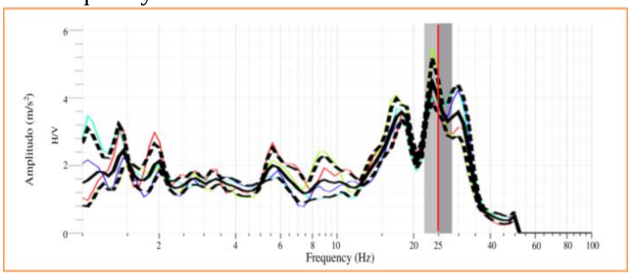

Fig 18. Curve *HVSR* Sedan Car Vehicle

As shown in Figure 18, the amplitude increases on the x-axis at 25 Hz, whereas on the y-axis, the amplitude does not experience a significant change.

3. Results of Vibration Measurements on Slopes Due to Motorcycle Vehicles (08.00-11.01 WITA)

a. Time Domain

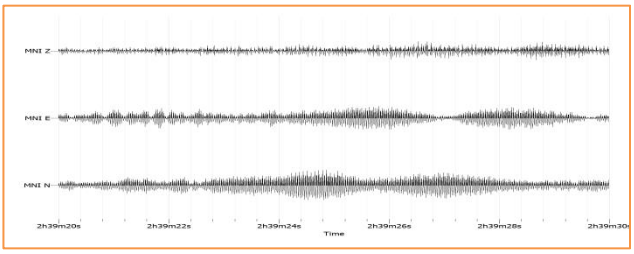

Fig 19. Vibration Signals on Slopes Due to Motorcycle Vehicles

Based on Figure 19, the vibration signal on slopes due to vehicles is small, where the wavelength of vertical vibrations is small compared to the wavelength in horizontal vibrations, where the horizontal N (north–south) is more significant than E (east–west).

b. Frequency Domain

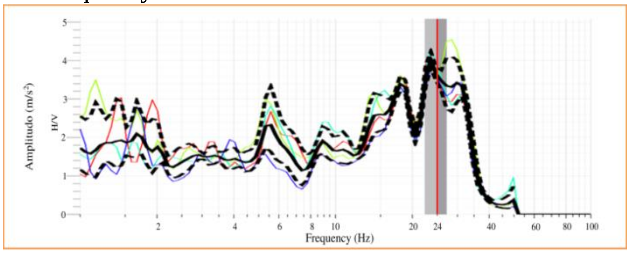

Fig 20. Curve *HVSR* Motorcycle Vehicle

Based on Figure 20, the amplitude increases on the x-axis at 24 Hz, whereas the amplitude y-axis changes to green and red at the start of the frequency.

D. Location 4 Near Road

1. Results of Vibration Measurements on Slopes Due to Truck Vehicles (08.00-11.01 WITA)

a. Time Domain

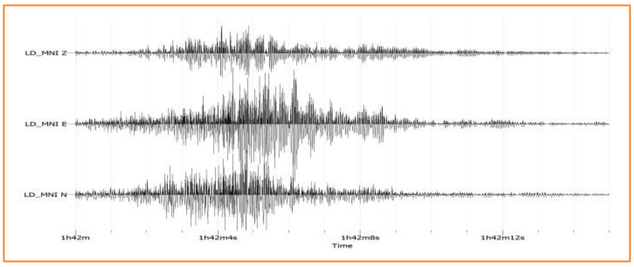

Fig 21. Vibration Signals on Slopes Due to Truck Vehicles

Based on Figure 21, the vibration signal on the slopes caused by the vehicles is small. The wavelength of vibrations on vertical slopes is compared with the wavelength in the horizontal vibration, where the horizontal E (east–west) is longer than the horizontal N (north–south) wavelength.

b. Frequency Domain

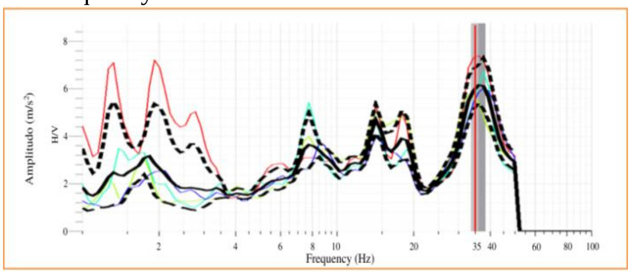

Fig 22. Curve HVSR for Truck Vehicles Obtained from Geopsy Data Processing of H/V Characteristics

As shown in Figure 22, the amplitude increases on the x-axis, whereas the y-axis amplitude changes in frequency at the beginning of the red signal, where the signal is more significant than the other signals.

2. Results of Vibration Measurements on Slopes Due to Car Vehicles (08.00-11.01 WITA)

a. Time Domain

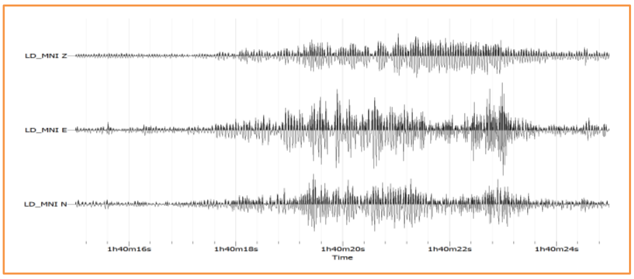

Fig 23. Vibration Signals on Slopes Due to Car Vehicles

Based on Figure 23, the vibration signal due to vehicles has a small wavelength in vertical vibration compared to the wavelength in horizontal vibration, where Horizontal E (east–west) has a longer wavelength than Horizontal N (north–south).

b. Frequency Domain

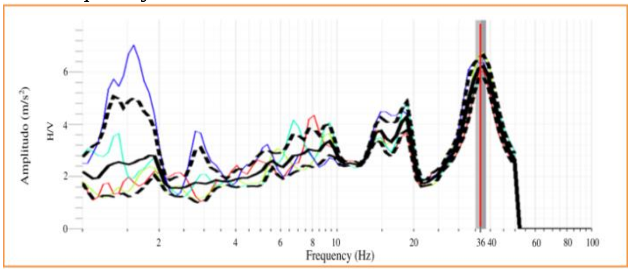

Fig 24. Curve *HVSR* Sedan Car Vehicle

Based on the x-axis in Figure 24, the frequency of 36 Hz increased in amplitude, while the y-axis experienced a change in frequency beginning of the blue signal, where the signal was larger than the other signals.

3. Results of Vibration Measurements on Slopes Due to Motorbike Vehicles (08.00-11.01 WITA)

a. Time Domain

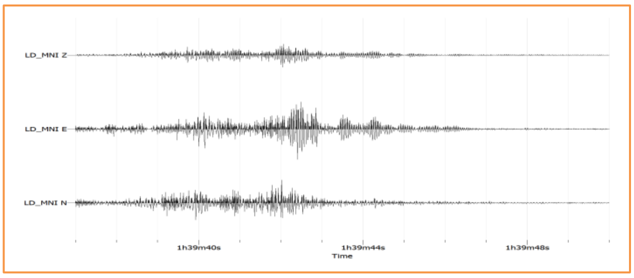

Fig 25. Vibration Signals on Slopes Due to Motorcycle Vehicles

Based on Figure 25, the vibration signal on slopes due to vehicles is a tiny wavelength in vibrations on vertical slopes compared to the long waves in horizontal vibrations, where Horizontal E (east-west) has a longer wavelength than Horizontal N (north-south).

b. Frequency Domain

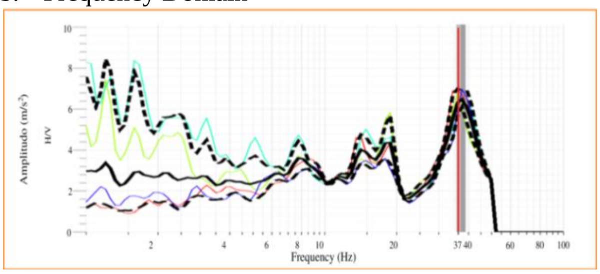

Fig 26. Curve *HVSR* Motorcycle Vehicle

Based on Figure 26, the amplitude increases along the x-axis, whereas the y-axis experiences a frequency change at the beginning of the signal on the H/V curve.

Morning H/V curve Far from the Road (07.32-08.47)

E. Location 5 Far from the Road There has not yet been a landslide

a. Time Domain

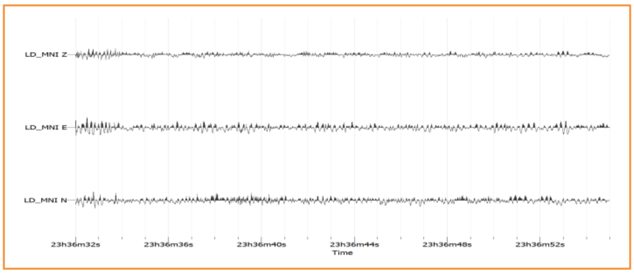

Fig 27. Signal No Noise Interference (Far from the Road)

Based on Figure 27, the signal does not experience interference or noise because it is far from the road, so there is no noise at all.

b. Frequency Domain

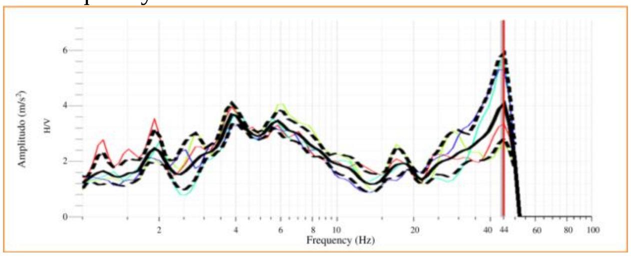

Fig 28. Curve *HVSR* From Geopsy Data Processing H/V Characteristics

As shown in Figure 28, the x-axis of the 44 Hz frequency increased in amplitude, while the y-axis of amplitude did not change significantly.

F. Location 6 Landslides

a. Time Domain

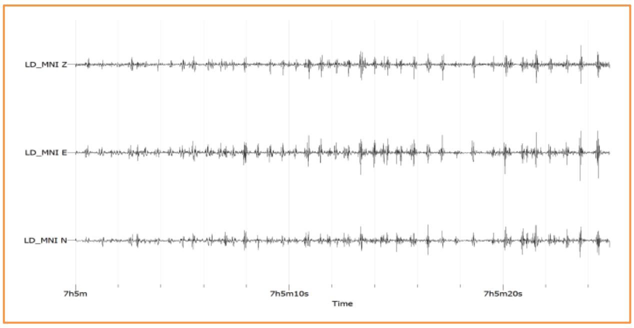

Fig 29. No Noise Interference Signal (Far from the Road)

As shown in Figure 29, the signal does not experience interference or noise because the area is far from the road; therefore, there is no noise.

b. Frequency Domain

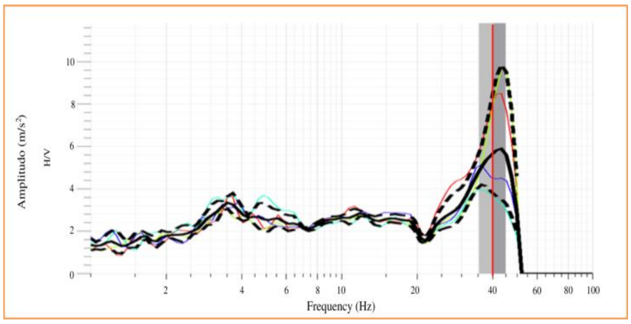

Fig 30. Curve *HVSR* Geopsy Data Processing of H/V Characteristics

Based on Figure 30, the x-axis of the 40 Hz frequency increased in amplitude, while the y-axis of amplitude did not change significantly.

The graphic patterns analyzed to explain the behavior of the vibration on the slopes of vehicles against landslides are the time domain and the frequency domain, as follows:

a. Time Domain

The time-domain location that is close to the road has interference (noise), resulting in many amplitudes being responded to by the slope, while areas far from the road are not affected by interference (noise) so that the amplitudes in the area are not there and slopes do not receive noise.

b. Frequency Domain

The frequency domain can be seen as the value of natural frequency and amplification at the peak of the H/V curve; in each morning time curve, the frequency with a range of 18-37 Hz experiences an increase in amplitude, while the amplitude does not experience a significant increase. It can also be seen that the frequency and amplitude values on the H/V curve in areas where landslides have occurred are higher than those that have not yet occurred. According to Gazali et al. (2018), the analytical results of HVSR reflect the dynamic characteristics of the local area. Areas that have experienced landslides have a significantly different response from the surrounding areas, where the landslide area has a very high HVSR curve. This is because the thick soft layer was eroded, causing the bedrock to be closer to the surface.

Based on the time and frequency domains, it is explained that the graphical pattern of vehicle vibration behavior of various types of vehicles in the research location consists of locations that are passed by vehicles, and locations that are not passed by vehicles that are divided into two zones, namely the avalanche zone and no landslide.

The exciting thing about the purpose of this study is that in the landslide area that is passed by vehicles, the natural frequency value is lower between amplitudes 4-6 for truck vehicles, while the natural frequency value is higher between 2-3 amplitudes for motorcycle types. This indicates that the greater the load, the lower the natural frequency value. This is evidenced by Jumini (2015). The greater the mass load, the smaller is the frequency value, where the frequency is inversely proportional to the mass load. The time and frequency domains explain that the graphic pattern of vehicle vibration behavior of various vehicles in the research location consists of locations that are passed by vehicles and locations that are not passed by vehicles, which are divided into two zones: the avalanche zone and no landslide.

Interestingly, the natural frequency value in areas not passed by vehicles, especially landslide areas, was higher than that in landslide areas that passed by vehicles. This was caused by the natural frequency value of an area is influenced by the thickness of the weathered layer (H) and subsurface velocity (Vs); areas with thick sediment layers tend to have natural frequency values obtained from the peak horizontal axis H/V curve [15].

4 Conclusion

It can be seen from the pattern of the time-domain graph that locations that are close to the road have interference/noise so that there are many amplitudes resulting from vehicles, while locations that are far from the road on the graph do not have interference/noise from vehicles so that the amplitudes in that area are very small. The frequency domain graph has natural frequency values and amplification at the peak of the H/V curve, where in each morning time curve, the frequency in the range of 18-37 Hz experiences an increase in amplitude. In contrast, the amplitude does not experience a significant increase.

5 Acknowledgments

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