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Frequency and Amplification for Assessing site Effects and PVS in the Padang City Railway

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ABSTRACT

The train uses a special line in the form of railroad tracks that produce vibrations during movement. This study aims to determine the type of soil layer and the peak particle velocity due to the train around the Padang City train line. The acquisition was carried out at 8 points with a recording duration of 65 minutes using three geophone components. Microtremor data was analyzed using horizontal to vertical spectral ratio (HVSR) method. The results show that the research area has a type of surface layer of soil is sediment with a thickness of 30 meters or more. This is indicated by the dominant frequency value ranging from 0.64 Hz – 1.67 Hz. The research area has an amplification value ranging from 0.85 to 1.29. The train vibration has a dominant frequency ranging from 2.20 Hz – 13.54 Hz and an amplification of 1.11 – 1.82. The particle velocity values obtained from the PVS values ranged from 0.1605 mm/s – 0.7592 mm/s. The research area can be categorized as safe from train vibrations because of the low amplification value and the PVS value which is below the safe limit (<3 mm/s) according to SNI 7571:2010.

1. INTRODUCTION

The train is a more effective mode of transportation than others because it can save energy and be efficient (Koller et al., 2012; Santos et al., 2016, 2017). In Indonesia, the first railway network was constructed in Semarang city in 1867 by the Dutch colonial government (Muhajir et al., 2020). Despite the benefits, issues related to rail implementation and operation should be considered, such as vibration and noise (Santos et al., 2017). The vibration of the train is the result of the irregularity of the surface of the wheels and rails due to the rise and fall of the axle above the bearing which is then transmitted to the ground (Connolly et al., 2016). Train noise consists of rolling noise, drive-system noise, and structure noise (Asmussen et al., 2008; Koller et al., 2012).

Susceptibility to vibration is not only felt through earthquakes but also by small vibrations called microtremors (Siska et al., 2020). Microtremor is a low-amplitude vibration (0.1 micron - 1 micron for the amplitude displacement 0.001 cm/s – 0.01 cm/s for the amplitude velocity) that comes from natural or man-made phenomena, such as wind, ocean waves, or vibrations from vehicles that can describe geological conditions near the surface (Haerudin et al., 2020; Kafadar, 2020; Nelson, 2019; Susilo & Wiyono, 2012). Microtremor analysis provides information on the dynamic properties of site characteristics such as dominant frequency, amplification, and soil susceptibility (Kafadar, 2020; Nakamura, 1989; Shankar et al., 2021; Yaghmaei-Sabegh & Rupakhety, 2020). One method for analyzing microtremor is the horizontal to vertical spectral ratio (HVSR) method (Kafadar, 2020; Nakamura, 1989; Nelson, 2019; Susilo & Wiyono, 2012).

The HVSR method was introduced by Nogoshi and Igarashi (1971) and later developed by Nakamura (1989). Since its introduction, the application of the HVSR method has increased in research worldwide (Ahn et al., 2021; Maghami et al., 2021; Zavala et al., 2021). The HVSR method has the advantage that it does not contain source effects (noise) on the power spectrum density and does not depend on the availability of adjacent hard rock sites (Kumar et al., 2021). HVSR analysis can be used to determine the resonant frequency (Zhu et al., 2020), estimate sedimentary layers (Guo et al., 2021; Irham et al., 2021; Kumar et al., 2021), relevant information regarding seismic response and local stratigraphy (Syarah & Pohan, 2022; Trevisani et al., 2021).

In addition to the HVSR method, train vibrations can be analyzed using peak particle velocity (PPV). If the frequency of train vibration exceeds the permitted threshold according to SNI 7571:2010, then the vibration can damage buildings around the railway line. PPV is the maximum velocity of particle movement which is used as the damage criterion (Herbut et al., 2020; Syarah & Pohan, 2022; Zeng et al., 2021). The PPV value of a wave propagating in 3 directions of propagation can be determined by finding the peak vector sum (PVS) value. PVS is the root value of squaring the resultant PPV for the north-south, east-west, and vertical components (Tripathy et al., 2016).

The use of rail transportation in Indonesia has been implemented in several areas on the islands of Java and Sumatra. One of the areas on the island of Sumatra that uses rail transportation is Padang, West Sumatra. The construction of rail infrastructure that passes through residential buildings allows problems. This problem is because the train vibration transmitted to the ground will cause vibrations on the floor and walls of the building, as well as the generation of reradiated noise (Alves Costa et al., 2012; López-Mendoza et al., 2020; Santos et al., 2016). The Padang City railway line is a line that passes through residential buildings. This study aims to determine the type of soil layer and the peak particle velocity due to the train around the Padang City train line.Microtremor analysis is needed to mitigate train vibrations on buildings around the railroad track.

2. METHOD

The study was conducted along the Padang City railway with 8 data acquisition points as shown in Figure 1. The coordinates of the data points are presented in Table 1. Microtremor data retrieval was carried out for 65 minutes per data acquisition point with a distance of 1 km between data acquisition points.

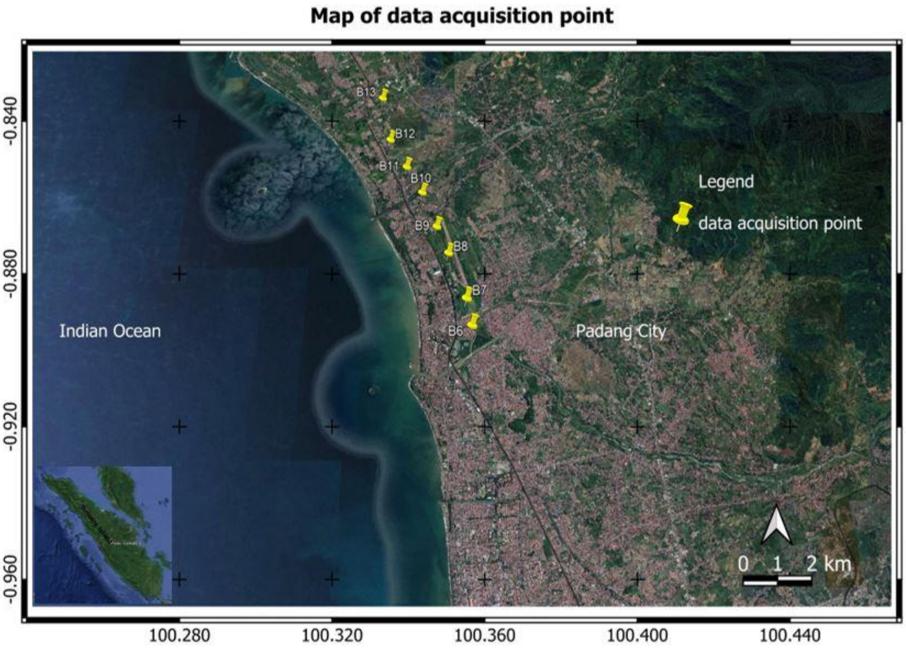


Figure 1. Research sites.

Table 1 Data acquisition point coordinates

No.	Data Acquisition	Latitude (Degree)	Longitude (Degree)
1.	B6	-0.895318	100.355748
2.	B7	-0.888835	100.354503
3.	B8	-0.877344	100.350077
4.	B9	-0.870483	100.347103
5.	B10	-0.861304	100.343264
6.	B11	-0.854198	100.339071
7.	B12	-0.846356	100.334545
8.	B13	-0.833853	100.331957

Measurement of microtremor data was obtained from three geophone signals with components in the horizontal north-south, horizontal east-west, and vertical directions as shown in Figure 2. Data collection was carried out in areas with little external noise. After the data was obtained, it was then analyzed using the HVSR method. The basic concept of the HVSR method is to compare the ratio between the Fourier spectrum of the horizontal component to the vertical component (Nakamura, 1989; Susilo & Wiyono, 2012). Mathematically it can be formulated as Equation 1.

$$HVSR = \frac{\sqrt{S_{NS}^{\ 2} + S_{EW}^{\ 2}}}{S_V} \tag{1}$$

where S_{NS} is the spectrum of the north-south horizontal component, S_{EW} the spectrum of the east-west horizontal component, and S_{V} the spectrum of the vertical component.

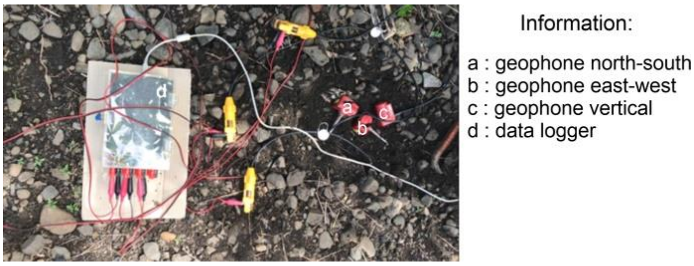


Figure 2. Position of the tool when data acquisition.

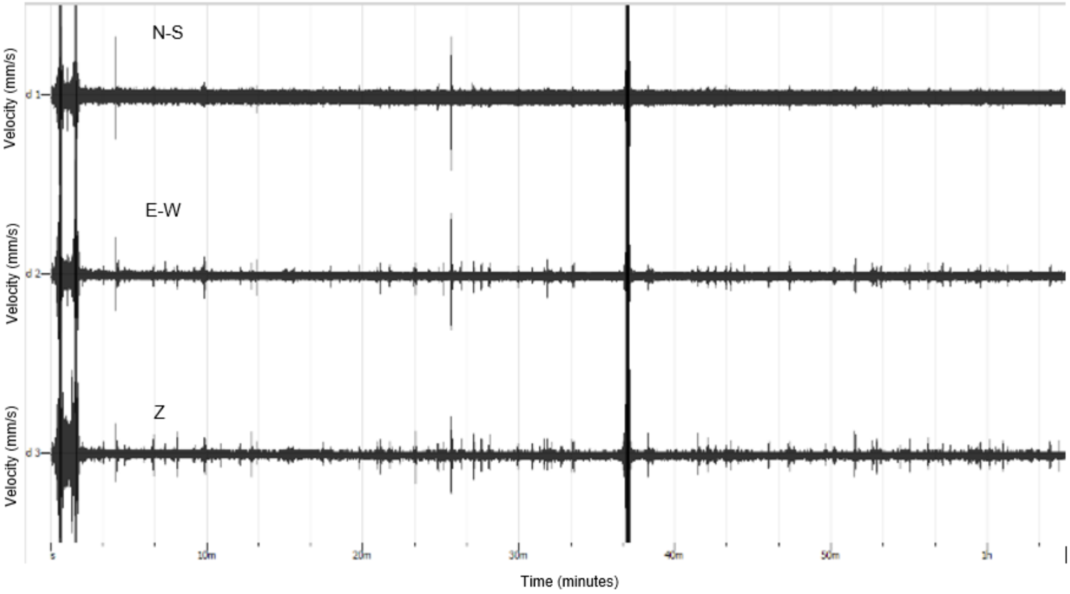


Figure 3. Three components of geophone microtremor signal.

Determination of the level of mechanical vibration due to the train is analyzed by finding the PVS value. The PVS value is formulated as Equation 2.

$$PVS = \sqrt{PPV_{NS}{}^{2} + PPV_{EW}{}^{2} + PPV_{V}{}^{2}} \tag{2}$$

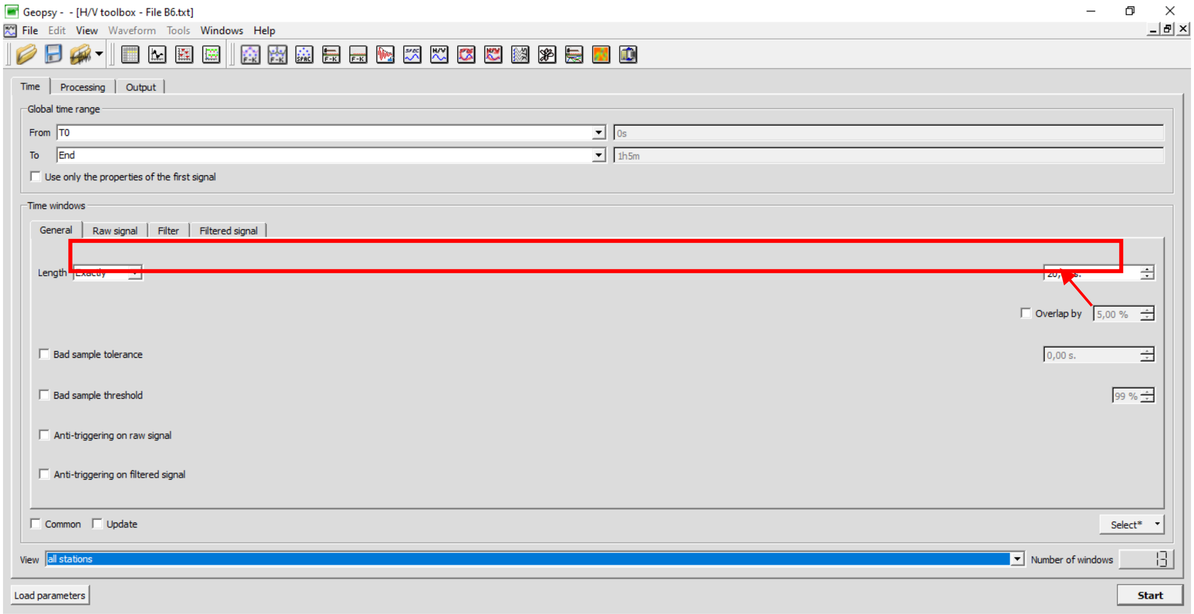
where PPV_{NS} is the peak particle velocity in the north-south direction, PPV_{EW} the peak particle velocity in the east-west direction, and PPV_{V} the peak particle velocity in the vertical direction.

In this study, microtremor data was obtained from vibrations around the geophone. The recorded vibrations are caused by train vibrations, vehicle movement, plant movement due to wind, and pedestrian movement. The vibrations captured by the geophone will be converted into digital data by the data logger and displayed on the laptop.

Microtremor studies using the HVSR method have been carried out by many researchers, such as Singh et al., (2020), Tian et al., (2020) and Azzara et al., (2021). The recording of the microtremor signal can be seen in Figure 3. It can be seen the microtremor signal with three geophone components in a north-south, east-west, and vertical direction (sequentially from top to bottom). The horizontal axis of the signal record shows the recording time (second) and the vertical axis shows the signal amplitude (centimeters). Data processing is carried with the signal selection rules referring to the provisions proposed by (Sesame, 2004), mathematically it can be formulated as Equation 3.

$$f_0 > 10 / l_w \tag{3}$$

where f_0 is the dominant frequency and l_w is the window length (see Figure 4 and Figure 5).



From T0 0s
To End 1h5m
☐ Use only the properties of the first signal
Length Exactly 20,
☐ Overlap by 5,00 %
☐ Bad sample tolerance 0,00 s.
☐ Bad sample threshold 99 %
☐ Anti-triggering on raw signal
☐ Anti-triggering on filtered signal
☐ Common ☐ Update
View all stations
Number of windows 13

Figure 4. H/V toolbox Screenshot.

The first step taken to prove whether the data processing results can be trusted (according to SESAME requirements) is to test Equation 3 with the values obtained. For the example, we will use Data Acquisition Point B6 (stationary signal). We use the length window $l_w = 20$ (Figure 4).

After that, we select the window from the graphic and we get 13 windows (Figure 5) and click Start on H/V toolbox. The HVSR curve will appear and show the dominant frequency and amplification value (Figure 6). After selecting the window for all data points, the dominant frequency and amplification values are obtained. The frequency value analysis was compared with Table 2 to determine the type of soil layer (Iswanto et al., 2019) and the amplification was compared with Table 3 (Arifin et al., 2014).

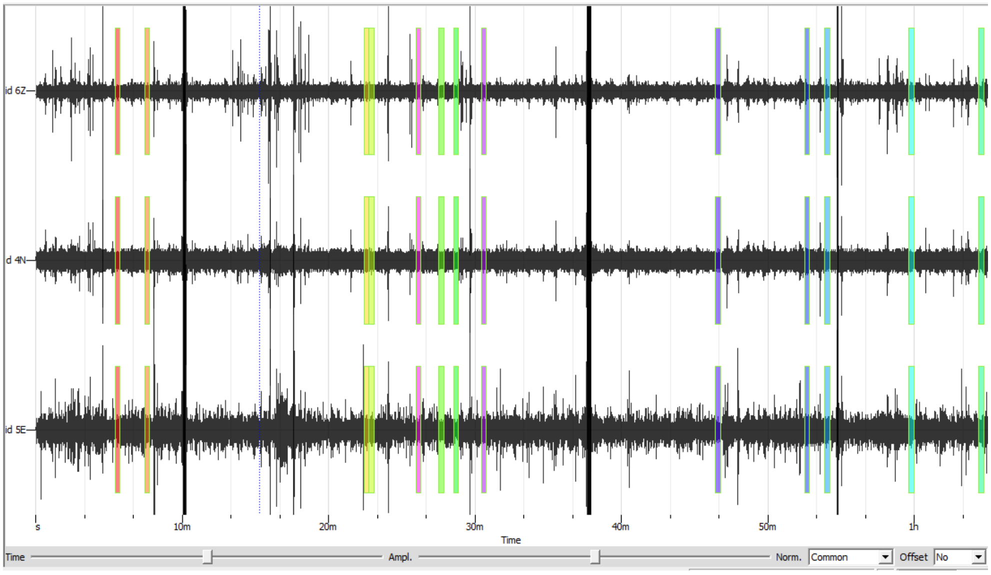


Figure 5. Graphic examples with 13 windows

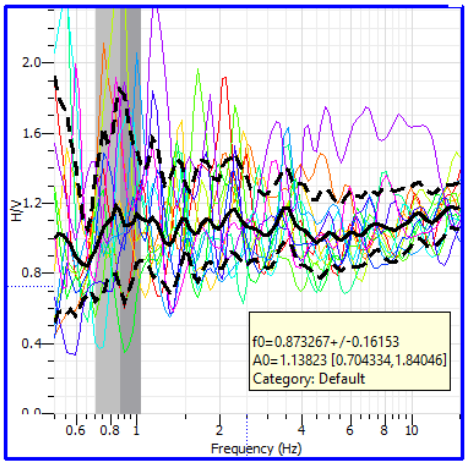


Figure 6. H/V result examples

Table 2 Types of soil classification based on dominant frequency by Kanai

Type of soil	**Dominant Frequency, f_0 (Hz)**	**Classification by Kanai**	**Description**
Type IV	6.667-20	Tertiary rock or older. Consists of hard sandy rocks, gravel, etc.	The thickness of the surface sediment is very thin, dominated by hard rock.
Type III	4-10	Alluvial rock with a thickness of 5 meters. Consists of hard sandy rocks, gravel, etc.	The thickness of the surface sediment is in the medium category, which is 5-10 meters.
Type II	2.5-4	Alluvial rock with a thickness of >5 meters. Consists of sandy gravel, sandy hard clay, loam, etc.	The thickness of the surface sediment is in the thick category, about 10-30 meters.
Type I	<2.5	Alluvial rock formed from delta sedimentation, topsoil, mud, etc. With a depth of 30 meters or more.	The thickness of the surface sediment is very thick.

PVS data processing begins with finding the first derivative of the displacement function so that the PPV value is obtained. The PPV value is the peak particle velocity value for data with one direction of propagation. If the data used has three directions of propagation (north-south, east-west, and vertical), then the PVS value is used. After obtaining the PVS value of all data acquisition points, it will be compared with SNI 7571:2010.

Table 3 Amplification value classification (Arifin et al., 2014)

Classification	Amplification Factor (A_0)
Low	$A_0 < 3$
Medium	$3 \leq A_0 < 6$
High	$6 \leq A_0 < 9$
Very high	$A_0 > 9$

3. RESULTS AND DISCUSSION

Based on the data processing that has been carried out, the discussion in this study is divided into 3 important points, namely stationary signals, train vibration signals, and PVS due to train vibrations. Stationary signals are used to determine the local characteristics of the research area, namely the type of soil layer and the wave amplification factor. The train vibration signal is used to determine whether a resonance event occurs or not, while the PVS value is used to determine the level of mechanical vibration of buildings around the railroad track. Values for stationary signals are listed in Table 4.

Table 4 Dominant frequency value and stationary signal amplification

Data Acquisition Point	**Dominant Frequency, f_0 (Hz)**	**Amplification (A_0)**	**Description**
B6	0.87 ± 0.16	1.14	Soil Type I, namely soft soil (f_0<2.5) with very thick surface sediment thickness (>30m) and low amplification
B7	1.67 ± 0.34	1.01	
B8	1.01 ± 0.21	0.9	
B9	0.64 ± 0.07	0.86	
B10	0.72 ± 0.14	1.29	
B11	1.12 ± 0.22	1.22	
B12	0.7 ± 0.10	1.03	
B13	0.66 ± 0.07	0.85	

Based on Table 4, all soils in the study area, including Type I soils, have characteristics consisting of alluvial rock formed from delta sedimentation, topsoil or clay, mud, and others with a depth of 30 meters or more (see Table 2). An area that has a low dominant frequency value means that the sediment deposits in that area are getting thicker (Kumar et al., 2021). The distribution of the dominant frequency values for the stationary signal can be seen in Figure 7.

Based on Figure 7 it can be seen that all data acquisition points have dominant frequencies with values that are not much different, namely 0.64 Hz - 1.67 Hz or < 2 Hz (purple area). The dominant frequency value obtained is in accordance with research conducted by (Susilanto et al., 2016) with the dominant frequency value between 0.5 Hz - 0.9 Hz for the Koto Tangah District, North Padang District, and East Padang District. From this value, it can be seen that the dominant frequency value of the study area is below < 2.5 Hz, which means it has a very thick surface sediment layer (>30 meters) (Iswanto et al., 2019). In addition, the dominant frequency value obtained also corresponds to information from the Padang geological map (Kastowo et al., 1996) which states that the study area has a surface sediment layer with a thickness of >30 meters. The next discussion is about train vibration signals. The results of processing the train vibration signal data can be seen in Table 5.

Based on Table 5, it can be seen that the lowest dominant frequency value is at point B11 with a value of 2.20 Hz which is marked by a purple area (Figure 8). The amplification of waves caused by the train is relatively low (Arifin et al., 2014) so it is not dangerous for buildings around the railway line. Region B11 has a low dominant frequency value of the stationary signal, namely 1.12 ± 0.22 Hz and the frequency value due to train vibration is 2.20 Hz ± 0.51 Hz. If the waves have the same frequency, resonance will occur which can cause damage to the structure of the soil and buildings above it, and determination of the danger level of mechanical vibration due to trains can be known from the PVS value. PVS values are attached in Table 6.

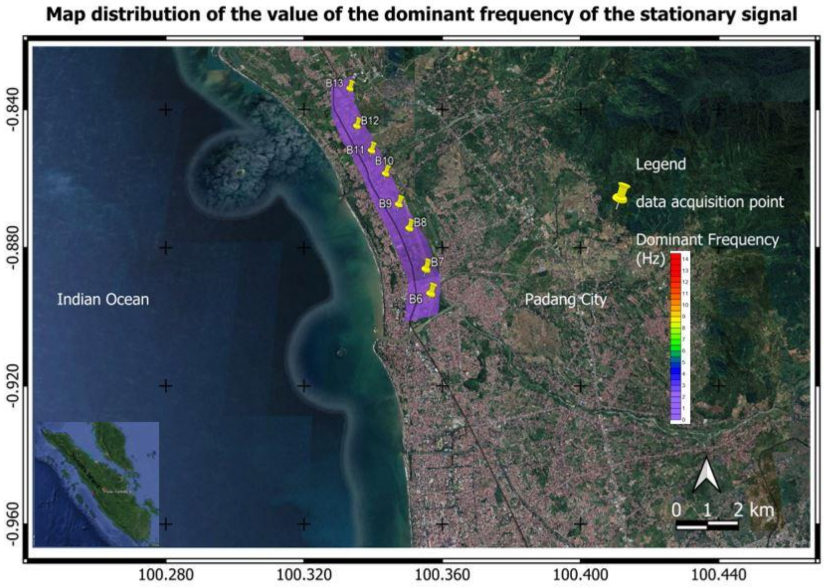


Figure 7. Distribution of the value of the dominant frequency of the stationary signal

Table 5 Value of dominant frequency and amplification of train vibration signal

Data Acquisition Point	Dominant Frequency, f_0 (Hz)	Amplification (A_0)	Description
B6	10.76 ± 1.72	1.59	Safe
B7	13.54 ± 0.54	1.75	Safe
B8	12.99 ± 1.23	1.16	Safe
B9	3.32 ± 0.60	1.82	Safe
B10	2.51 ± 0.47	1.24	Safe
B11	2.20 ± 0.51	1.11	Safe
B12	9.64 ± 0.98	1.48	Safe
B13	6.35 ± 1.07	1.15	Safe

Table 6 Data acquisition point *PVS* value

Data Acquisition Point	Train vibration frequency (Hz)	*PVS* (mm/s)	*PVS* safe limit for house building (mm/s)	Description
B6	10.76	0.2901	3	Safe
B7	13.54	0.2750		Safe
B8	12.99	0.1605		Safe
B9	3.32	0.5820		Safe
B10	2.51	0.2948		Safe
B11	2.20	0.7592		Safe
B12	9.64	0.2933		Safe
B13	6.35	0.4339		Safe

From Table 6 it can be seen that the highest value of PVS is at point B11 with a value of 0.7592 mm/s and the lowest value is at point B8 with a value of 0.1605 mm/s. Overall, the level of mechanical vibration due to the train on buildings around the railway line is still in a safe condition

(<3 mm/s). This is indicated by the PVS value caused by the train being still below the safe limit according to SNI 7571:2010.

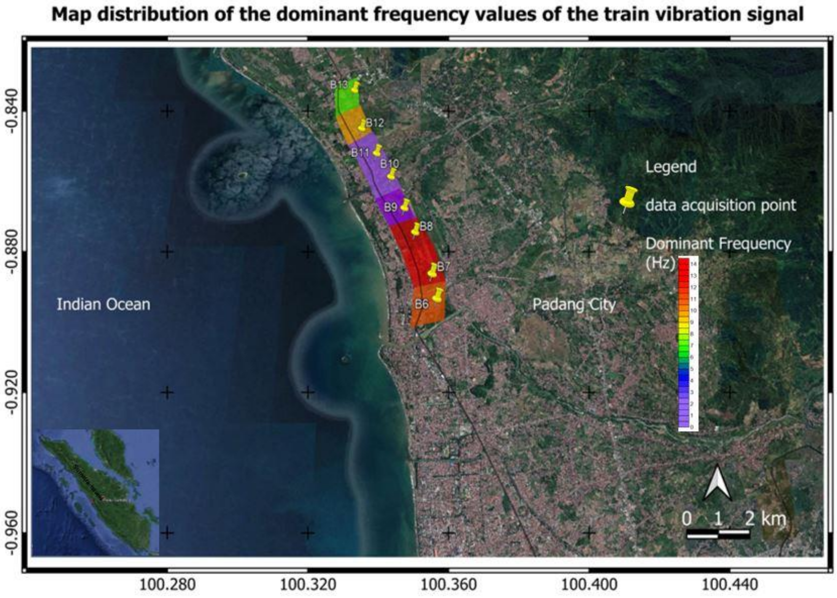


Figure 8. The distribution of the dominant frequency values of the train vibration signal

4. CONCLUSION

From this research, it can be concluded that the research area is included in the safe category against train vibrations. This is indicated by the low amplification value due to train vibrations ranging from 1.11 – 1.82. The amplification value due to train vibration is included in the low category, which is smaller than 3. In addition. based on the *PVS* value due to train vibration in the study area. the *PVS* value ranges from 0.1605 mm/s – 0.7592 mm/s. The *PVS* value due to train vibration is still below the safe limit allowed for community houses along the railway line, which is 3 mm/s. When viewed from the type of soil classification,the local geological characteristics of the study area has a type of surface layer of soil is sediment with a thickness of 30 meters or more. This is indicated by the low value of the dominant frequency of the stationary signal, which ranges from 0.64 Hz – 1.67 Hz. This condition must be considered by the community who will carry out development due to the thick layer of surface sediment in the area. A thick layer of surface sediment interprets that the area is prone to vibration.

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