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Natural Frequency Analysis Using Raspberry Shake 4D on the Diponegoro Education Dam

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ABSTRACT

The Diponegoro Dam is an educational dam that is used for many activities. The vibration of the dam is important to monitoring for mitigation assessment. This mitigation research uses a passive method, Horizontal Vertical Spectral Ratio (HVSR), and spectrum methods. The HVSR method obtains natural frequencies (f0) and amplification, spectrum method to obtain vibration frequencies. The data that has been recorded via an accelerometer 3 component. The research data contains of 9 primary data taken using an accelerometer, which used the Raspberry Shake 4D. This study aims to determine the distribution of the natural frequency and the resonance values. The research results are natural frequency values of 0,50 to 50,0 Hz and resonance values of 1.8 to 2.7 mm/s2. The amplitude resonance on line 1 from 1,8 to 2,7 mm/s2 and on line 2 ranges from 1,8 to 2,7 mm/s2. Line 1 and line 2 resonance values do not show any resonance. The direction of particle movement shows the dominant horizontal direction (northeast-southwest). The water flow and failing water on the Diponegoro dam drain system cause vibration on the dam. The Diponegoro dam is in good condition.

Keywords: natural frequency, dam, Raspberry Shake 4D

INTRODUCTION

A tool that is often used for monitoring dam behavior in Indonesia is an accelerometer. The accelerometer was used to monitor the dynamic response of dams. An accelerometer is a type of seismometer used to record mechanical vibrations [1]. These seismic monitors measure seismic vibrations and are often used in large dams in Indonesia. The results of the study are expected to provide input for information and minimize damage to the dam. Some things that affect damage to dams are earthquakes. These geological conditions are not considered, cracks in the dam body due to differences in the decline of the dam body pile with the pedestal hill, damage caused by clogged drainage systems, landslides on the slopes of the dam, and water overflowing to the top of the dam due to insufficient water storage capacity [2].

Microtremor data collection for building structures is carried out at each level of the building if the building has several levels, using a three-component seismometer, namely the horizontal component in the north-south direction, the east-west component, and the vertical component. Data collection on measurements is attempted to be carried out near the center of the building mass or close to the wall of the research building. SESAME suggests a measurement duration for each point between 10 to 15 minutes. The acquisition distance with the soil structure is sought to be close and at the same geological conditions. To date, there is no reference describing the minimum distance measurement parameters in building structures [3].

Natural frequency values can be known through HVSR processing, which is one method of knowing the nature of the subsurface structure of the study area without causing interference with the structure. The main parameters resulting from the HVSR method are the dominant frequency and amplification which is the peak value of the HVSR curve [4]. The floor spectra ratio (FSR) method is a method used for the evaluation of building strength caused by seismic vibrations and development characteristics can be done by recording microtremor records. The main parameters of the floor spectra ratio (FSR) processing results are the frequency and amplitude values of the vibration source. From the results of the frequency and amplitude floor spectra ratio (FSR) and the natural frequency of soil and amplitude obtained from the HVSR method, building resonance values will be obtained at each research point [5]. The resonance occurs when the frequency of the force is equal to or close to the natural frequency of the system (the natural frequency of the building), then the system will oscillate with an amplitude much greater than the amplitude of the force [6]. Analysis of particle movement provides an overview of the direction of motion of particles in the study area so that it can be expected to help researchers in determining the movement of particle direction. The use of particle motion has been carried out to examine the direction of particle movement on the Soekarno Hatta Bridge in Malang City [7].

The tool used for data acquisition at the dam in this study is Raspberry Shake 4D which has 1 geophone component and 3 accelerometer components (vertical, north-south, and east-west) that can record natural frequencies on the dam and can be moved according to the research point. Raspberry shake device can serve for dynamic identification of structural systems before and after extreme events such as earthquakes, this tool is also able to calculate the degree of damage to infrastructure conditions. High vibrations in the infrastructure are well recorded, ensuring that low-quality MEMS data can still capture structural characteristics due to the high signal-to-noise ratio [8]. This study aimed to find out the natural frequency value, to find out the resonance value in the dam structure, and the condition of the dam.

MATERIALS & METHODS

Microtremor in Building

SESAME suggests a measurement duration for each point between 10 to 15 minutes. The acquisition distance with the soil structure is sought to be close and at the same geological conditions. Until now there has been no reference explaining the parameters of the minimum distance measurement in building structures [3].

Amplification

Seismic wave amplification is the magnification of seismic waves that occur due to the impact of contrast differences between layers. If the impedance contrast value for both layers is low, the amplification value is also low, and vice versa. The amplification value can increase if the rock has deformed (weathering, folding, or faulting) causing changes in the physical properties of the rock. In rocks of the same type, the amplification value can vary depending on the degree of deformation and weathering in the rock [9]. The magnitude of amplification factors into several categories in Table 1 [10].

Table 1. Classification A_0

Zone	Classification	A_0 Value
1	Low	$A_0 < 3$
2	Medium	$3 \leq A_0 < 6$
3	High	$6 \leq A_0 < 9$
4	Very High	$A_0 \geq 9$

Natural Frequency

Natural frequency is the frequency that often appears, so it is often called the dominant frequency of rocks in the region because the frequency dominates other frequencies such as frequencies caused by human activities. Natural frequency values in an area can provide information about the characteristics of rocks in that area. The results of the analysis obtained from HVSR processing describe the natural frequency of rocks from the area studied. The frequency range generally observed in microtremors is between 0,5 to 2,0 Hz and microtremors with small frequencies can reach 0,2 Hz [5].

Horizontal to Vertical Spectral Ratio (HVSR)

The HVSR method was the relationship between the ratio of horizontal and vertical components to the ellipticity curve in Rayleigh waves. The HVSR (Horizontal to Vertical Spectral Ratio) method is a geophysical method that makes a correlation between the spectrum of horizontal components to the vertical components of microwave tremors [7]. The initial concept of HVSR was to assume Microtremor is dominated by shear waves and ignores surface waves (Rayleigh waves). HVSR is considered the same as the transfer function between wave vibrations in sediments and bedrock. The HVSR method is based on the trapping of shear wave vibrations (SH waves) in the sedimentary medium above the bedrock. It can be interpreted that SH waves play a very important role in the HVSR curve. The HVSR method is usually used in three-component passive seismic, namely the north-south component, the east-west component, and the vertical component. The use of microtremor to date is widely applied to determine the basic frequency resonance of buildings and soil structures below. The main parameters resulting from HVSR processing are natural frequency and amplification. The purpose of this step is to get an idea of the geological characteristics in the study area [12].

Floor spectra Ratio (FSR)

The FSR method is a method used to identify frequencies coming to a building and the resonances that exhibit the characteristics of the building to vibration. The floor spectra ratio (FSR) method is a standard method for evaluating building resistance to seismic vibrations and building characteristics that can be done by recording microtremor records [13].

Resonance

Each object has a natural frequency whose value depends on its shape, composition, and size. If the natural frequency of an object is equal to the frequency of another source, there will be a resonance or amplitude of the wave, then the object is said to be resonant with the frequency source [14]. When a structure is shaken by vibration, the frequency of the structure's vibration and the shaking vibration propagate together. The reaction structure will be related to the natural frequency and the shaking frequency, but the effect will be smaller if the frequency of the ground vibration has a greater or lesser value [15].

Particle Motion

The results of particle movement analysis show the direction of motion of particles in the study area so that it can be used to assist related parties in mapping building areas that are not good. The processing data is a particle movement graph that shows the direction of horizontal and vertical particle movement in the object due to vibrations or waves propagating through the medium. Particle motion analysis can be applied to buildings as well as to the ground [16]. The use of particle motion examined the direction of particle movement on the dam [17,18].

Research Area

This research was carried out at the Diponegoro University dam with the distribution of measurement points mapped in Figure 1. The vibration acquisition points are in the North-South and East-West direction. The measurement point is above the dam wall where the vibration response will be studied. Knowing the direction of dominant vibrations in a dam is very important. By knowing the direction of vibration and how much force there is every day, the strength of the dam wall can be determined.

Figure 1. Survey area and the position acquisition

The data obtained on the Raspberry Shake 4D tool is in the form of mini-seed data. This data can be directly processed using Geopsy software without making any changes. Geopsy software will process the data into a frequency spectrum, H/V curve, and particle motion graph. The results obtained from H/V processing are the frequency (f_0), period, and amplitude values at each acquisition point. In determining frequency and amplification, you need to pay attention to the smoothing type. Inappropriate selection will produce unexpected frequency output. The recommended smoothing is Kohno and Ohmaci, which will produce an output suitable for the low-frequency domain. The results of H/V processing are in the form of an H/V curve. H/V curve analysis produces the natural frequency of the soil (ft), which is useful for calculating resonance values.

The results of spectrum data processing are the frequency values of each component (EW component, NS component, and vertical component), amplitude, and the average value of the three components. The smoothing type used is Kohno and Ohmachi. The resulting frequency value is the building frequency value (f_b), one of the variables for calculating the resonance value.

The resonance value is obtained by calculating the natural frequency value of the soil (f_t) and the building frequency value (f_b). Resonance values are calculated using Microsoft software. Using the resonance vulnerability level classification table, identify resonance values that indicate building vulnerability. Particle motion processing by combining the frequencies of the three components (EW component, NS component, and vertical component), the recommended filter is Cosin taper and the signal filter uses band-pass. This filter makes it easier to select frequencies that will be processed into particle motion graphics. Particle motion processing produces horizontal and vertical particle graphics. Particle motion is used to determine the direction of movement of particles in the research area and to determine the strength of the dam when vibrations or waves propagate through the dam. Figure 2 is the research flow.

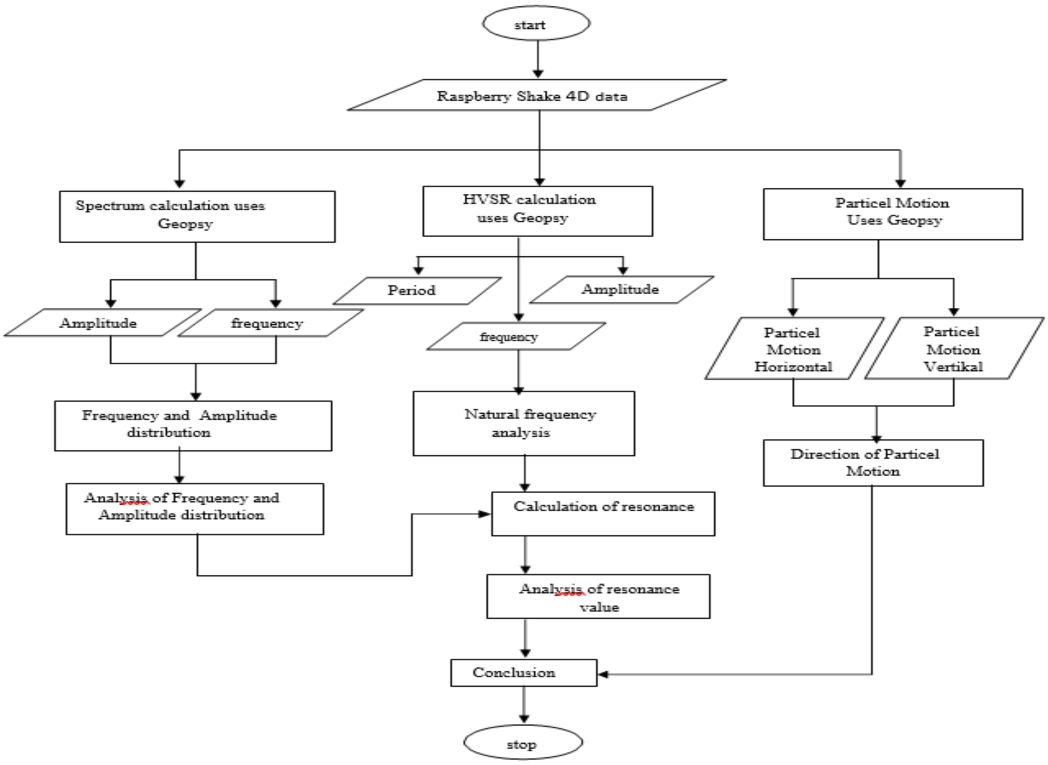


Figure 2. Research flowchart

RESULT

Natural frequency and amplification are obtained through HVSR curve analysis. Natural frequency values have benefits for structural planning, because if the natural frequency value of the building structure is equal to the frequency value coming from outside the area, then when there is a shock in the structure, it will cause resonance. The resonance will amplitude the vibration of the earth, and will eventually cause damage to the building above it when the vibration occurs. The distribution of natural frequency values in dams ranges from those shown in Table 2. The natural frequency value obtained at the whole point ranges from 0,60 to 1,0 Hz.

Table 2. Natural frequency values

Point	f_0
D1	0,60
D2	0,74
D3	0,86
D4	0,78
D5	0,66
L1	0,71
L2	0,96
L3	1,00
L4	0,71

Amplification

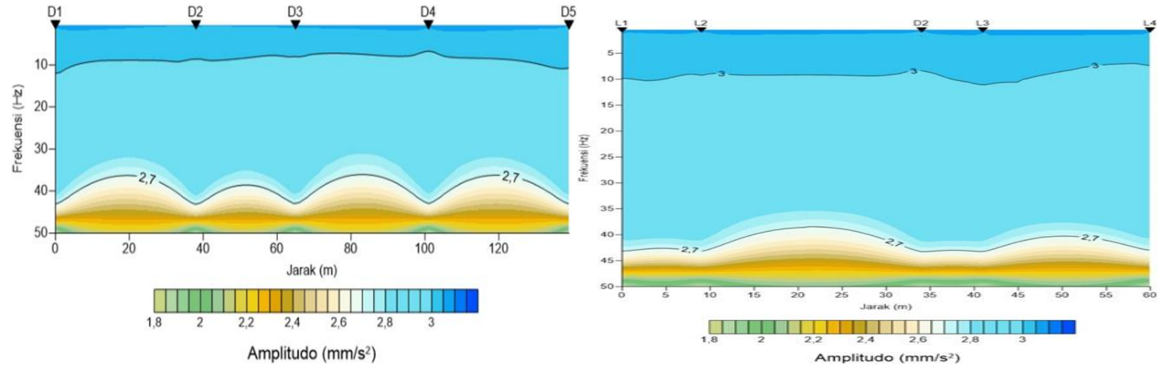
Very noticeable differences between the layers through which seismic waves pass can result in wave magnification, known as amplification. Amplification of seismic waves will occur when propagating from another medium that is softer than the previous medium through which it passes. The acquisition results in the dam obtained the distribution of amplification values (A_0). The amplification distribution values are shown in Table 3. The amplification value in the turbidity of the research point according to Table 1, shown in Table 3 shows the level of vulnerability 1. All amplification values in the measurement area are low [2].

Table 3. Classification of amplification vulnerability levels

Point	A_0	Vulnerability level	Low/Medium/High
D1	2,5	1	Low
D2	2,2	1	Low
D3	2,5	1	Low
D4	2,6	1	Low
D5	2,4	1	Low
L1	2,5	1	Low
L2	2,5	1	Low
L3	2,4	1	Low
L4	2,4	1	Low

FSR spectrum

The frequency value and amplitude can be seen in Figure 3 at the point in the dam has amplitude values at each frequency ranging from 1.8 to 3.1 mm/s^2. The amplitude value on line 2 ranges from 1,8 to 3,1 mm/s^2. There are amplitude values as low as 1,8 to 2,7 mm/s^2 between frequencies 38 to 50,0 Hz and amplitudes as large as 3,0 to 3,1 mm/s^2 between frequencies 0,50 to 1,5 Hz as shown in Figure 3.



a. b,

Figure. 3. Spectrum modeling, a. Line 1 b. Line 2

HVSR

The HVSR value distribution shown in Figure 4, shows that from a frequency of 0,50 to 50,0 Hz there is an amplitude of 1,8 to 2,7 mm/s^2.

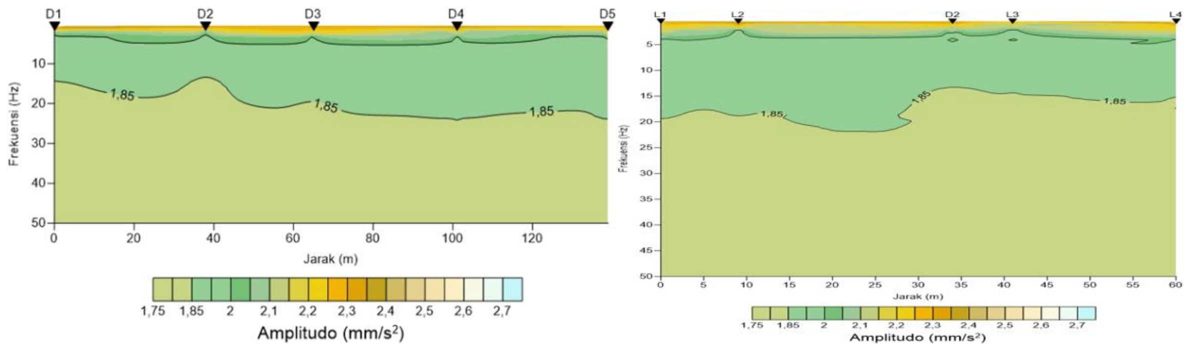
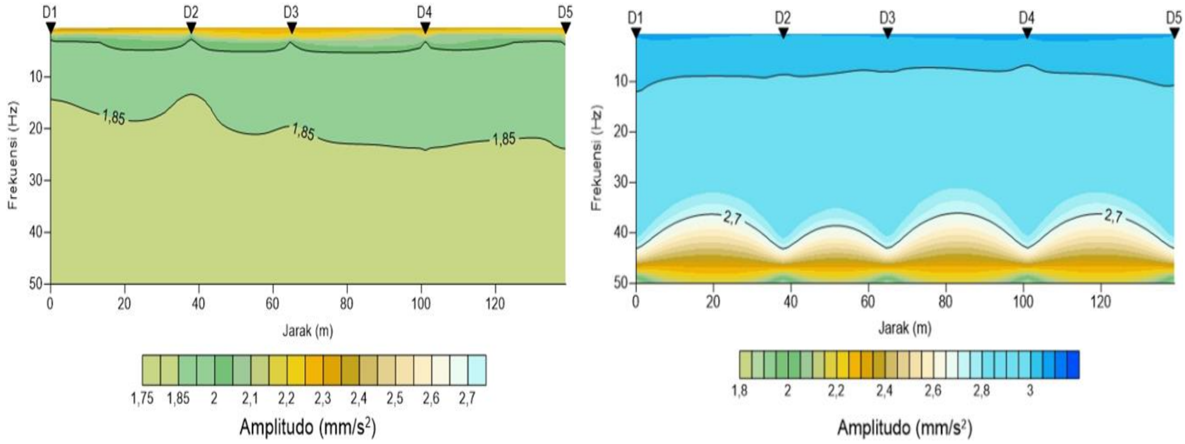


Figure 4. HVSR value distribution, a. Line 1 b. Line 2

Resonance

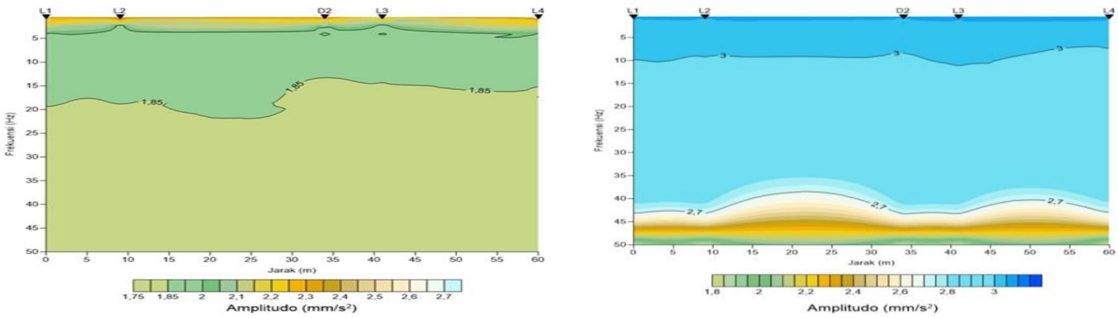
Modeling of the spectrum and H/V on line 1 as shown in Figure 5 shows that the resonance value on line 1 is not found because the frequency and amplitude values of the H/V contour and the spectrum do not show the similarity in each frequency distribution.



a. b.

Figure 5. Line 1 model, a. HVSR model b. Spectrum model

Analysis of spectral modeling and H/V line 2 shown in Figure 6 shows the resonance values in line 2.



a. b.

Figure 6. Line 2 model, a HVSR model b Spectrum model

The amplitude value of the dam structure ranges from 2,2 to 2,6 mm/s^2 and the peak amplitude value of the vibrating source ranges from 3,0 to 3,1 mm/s^2. The resonance value is based on a comparison of the peak amplitude value of the dam structure and the vibration source, shown in Table 4.

Table 4. The resonance value

Point	Amplitude of dam structure (mm/s^2)	Amplitude of vibration source (mm/s^2)	Meaning of comparison
D1	2,5	3,1	No resonance
D2	2,2	3,1	No resonance
D3	2,5	3,1	No resonance
D4	2,6	3,1	No resonance
D5	2,4	3,0	No resonance
L1	2,5	3,1	No resonance
L2	2,5	3,1	No resonance
L3	2,4	3,1	No resonance
L4	2,4	3,1	No resonance

Particle motion

All points show graphs of horizontal and vertical particle movements that almost form ovals, line 1 and line 2 which total 9 points on the dam body, namely points D1, D2, D3, D4, and D5. And those around the dam, namely points L1, L2, L3, and L4 have the direction of horizontal particle movement that is relatively the same, which ranges from 29° to 47° from the north, vertical particle movement also shows relatively the same particle movement, which ranges from 60° to 86° from above shown in Figure 7. The red color indicates the direction in which the particles move.

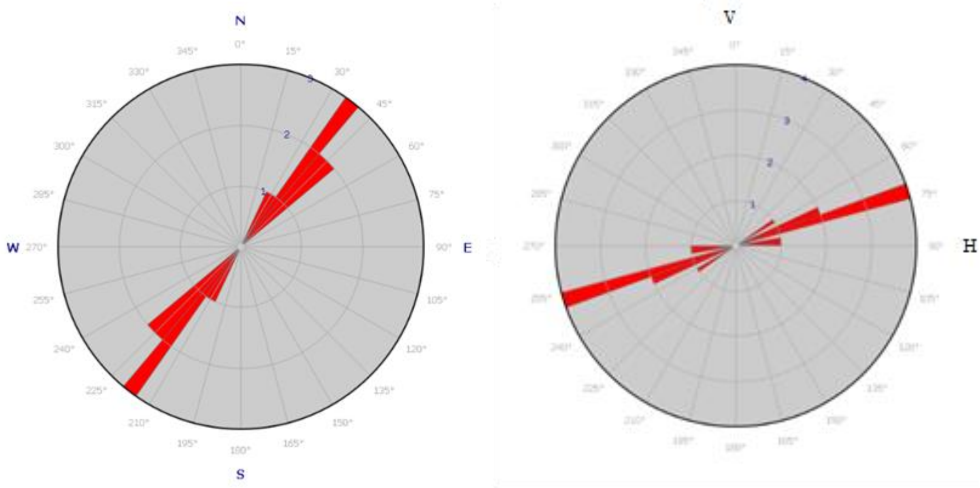


Figure 7. Horizontal and vertical particle motion graphics

DISCUSSION

The differences between the layers through which seismic waves pass can result in wave magnification, known as amplification. Amplification of seismic waves will occur when propagating from another medium that is softer than the previous medium through which it passes. The acquisition results in the dam obtained the distribution of amplification values (A_0). The amplification distribution values are shown in Table 3. The amplification value in the turbidity of the research area is low [2]. The geological structure of the dam area does not show a structure that is susceptible to vibration.

The frequency and amplitude values at each point in the dam or line 1 are relatively the same, which means that the thickness of the rocks and the dam are the same. There is an amplitude value of at least 1,8 to 2,7 mm/s^2 between frequencies 37 to 50,0 Hz and a maximum amplitude value of 3,0 to 3,1 mm/s^2 between frequencies 0,50 to 1,7 Hz. The amplitude value on line 2 ranges from 1,8 to 3,1 mm/s^2. There are amplitude values as low as 1,8 to 2,7 mm/s^2 between frequencies 38 to 50,0 Hz and amplitudes as large as 3,0 to 3,1 mm/s^2 between frequencies 0,50 to 1,5 Hz as shown in Figure 3. The dam structure has good conditions because there is no difference in frequency and amplitude that is high.

HVSR value on line 1, a frequency of 0,50 to 50,0 Hz and an amplitude of 1,8 to 2,7 mm/s^2. The largest amplitude values are at 2,0 to 2,7 mm/s^2 at frequencies of 0,50 to 5,0 Hz and the smallest amplitude values are 1,8 to 1,9 mm/s^2 at frequencies of 13 to 50,0 Hz. HVSR value on line 2, a frequency of 0,50 to 50,0 Hz there is an amplitude of 1,8 to 2,7 mm/s^2. The largest amplitude values are at frequencies of 0,50 to 4,0 Hz with amplitude values of 2,0 to 2,7 mm/s^2 and the smallest amplitude values of 1,8 to 1,9 mm/s^2 are at frequencies of 13 to 50,0 Hz. HVSR is considered the same as the transfer function between wave vibrations in sediments and bedrock. the result determines there is no resonance between the dam structure and the soil structures below.

In the model of the spectrum and H/V on lines 1 and 2 as shown in Figure 5, the resonance value on line 1 is not found because the frequency and amplitude values of the H/V contour and the spectrum do not show the similarity in each frequency distribution. Analysis of spectral modeling and H/V line 2 shows that the resonance is not found, because the frequency and amplitude values of the H/V contour and spectrum do not show similarities in each frequency distribution

The particle motion results of the comparison show that the peak amplitude value of the dam structure and the peak amplitude value of the vibration source of each measurement point namely points D1, D2, D3, D4, D5, L1, L2, L3, and L4 obtained different results, so the resonance at all measurement points was not found because there was no similarity between the peak amplitude value of the dam structure and the peak value of the incoming vibration amplitude shown. The direction of horizontal particle movement is relatively the same, which ranges from 29° to 47° from the north, vertical particle movement also shows relatively the same particle movement, which ranges from 60° to 86°. The source of vibration is caused by the flow of water falling out through the reservoir drain, this is evidenced by the direction of horizontal particle movement towards the northeast which leads to the flow of water disposal of the Diponegoro education reservoir.

CONCLUSION

The natural frequency value profile of line 1 shows a natural frequency value of 0,5 to 50,0 Hz with an amplitude of 1,8 to 2,7 mm/s^2. The largest amplitude values are at 2,0 to 2,7 mm/s^2 at frequencies of 0,50 to 5,0 Hz and the smallest amplitude values are 1,8 to 1,9 mm/s^2 at frequencies 13 to 50,0 Hz. The natural frequency value profile of line 2 shows a natural value of 0,5 to 50,0 Hz, and there is an amplitude of 1,8 to 2,7 mm/s^2. The largest amplitude values are at frequencies of 0,50 to 4,0 Hz with amplitude values of 2,0 to 2,7 mm/s^2 and the smallest amplitude values of 1,8 to 1,9 mm/s^2 are at frequencies of 13 to 50,0 Hz. The resonance profiles of line 1 and line 2 do not show any resonance in each frequency distribution. Resonance is not found at the entire measurement point. The resonance value must be known whether it is present or absent because the resonance value will affect the structure of the building. The absence of resonance values proves that the condition of the building structure is in good condition.

Declaration by Authors

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