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Ground Vibration Analysis of Railroad Dynamic Loads on Rail Structure

Rini Kusumawardani[1, a)], Mufita Aulia Zelin[1, b)], Arief Kusbiantoro[2, c)]

[1]*Civil Engineering Department, Faculty of Engineering, Universitas Negeri Semarang*
[2]*Department of Construction Engineering, National Yunlin University of Science and Technology,Taiwan*

[a)]rini.kusumawardani@mail.unnes.ac.id
[b)] mufitazelin@gmail.com
[c)] D10610213@yuntech.edu.tw

Abstract. The railroad structure consists of rail steel, sleepers, fastening, ballast, sub-ballast and subgrade. The load of the passing train at a certain speed can produce vibrations channeled through the train wheels to the railway steel to be forwarded to the sleepers then to the ballast and distributed to the subgrade. The amount of vibration caused by the train can be seen from the value of the acceleration, amplitude and frequency of the vibration. In this study, the accelerometer sensor was used to detect the magnitude of the vibration acceleration. The vibration acceleration data was then processed using Geopsy software to obtain the value of natural frequency and vibration amplitude using the HVSR (Horizontal to Vertical Spectral Ratio) method. The value of acceleration due to railroad vibration of 0.14 g - 0.64 g with a position placed 1.5 m sensor from the edge of the rail. The biggest vibration acceleration is 0.26 g x direction, 0.39 y direction and 0.29 z direction caused by Maharani trains that pass at a speed of 65 km / h and a load of 728 tons. The natural frequency of vibration obtained value 2.4077 Hz - 5.392 Hz. The highest natural frequency was caused when the Maharani train, which was 5.392 Hz. Train speed and load affected the vibration of the rail structure. The acceleration of vibration increased when the train speed and load increased.

Keywords: Rail structure, Speed, Load, Vibration, Train, Acceleration, Natural frequency.

INTRODUCTION

Railway is a means for train travel. Railroad construction consists of components such as steel rails, bearings, fastening, ballasts, sub-ballasts and layers of foundation and subgrade. Passing train can cause vibration and damage to the area around the rail and railroad structure. The development of transportation technology has resulted in an increase in vehicle speed resulting in greater vibrations [1]. Vibration caused by the passing train was received as a Rayleigh wave with a frequency range of 0.5-80 Hz. The magnitude of the vibration increases in proportion to the increase in train speed [1]. When the train passes the railway, it produces vibration that is measured in the form of acceleration and frequency of waves. When the wheels of a train pass through rails and sleepers, it will cause a frequency whose magnitude is affected by the speed of the train [2]. The ground vibration is also affected by the train's load. The acceleration of ground particle vibration caused by trucks is 0.0012-0.0045 m / s^2, by motorcycle is 0.0002-0.0005 m / s^2, and by car is 0,0006 - 0,00085 m/s^2. Trucks cause the most vibration due to their heavy loads when passing sensors [3]. In this study, a seismic monitoring device based on the accelerometer sensor was used to detect the magnitude of the acceleration caused the passing trains. The sensor was placed on the ground with a position in the middle of the railroad with a distance of 1.5 meters from the edge of the ballast. The data was in the form of acceleration of vibration which was then processed using Geopsy software to obtain the value of natural frequency and amplitude using the HVSR (Horizontal to Vertical Spectral Ratio) method. Natural frequency is the dominant frequency of a system when experiencing vibrations without damping. The natural frequency value can be used as a guideline whether the structure experiences resonance or not. A structure can experience a resonance if the load frequency received by the structure is close to or equal to its natural frequency value [4].

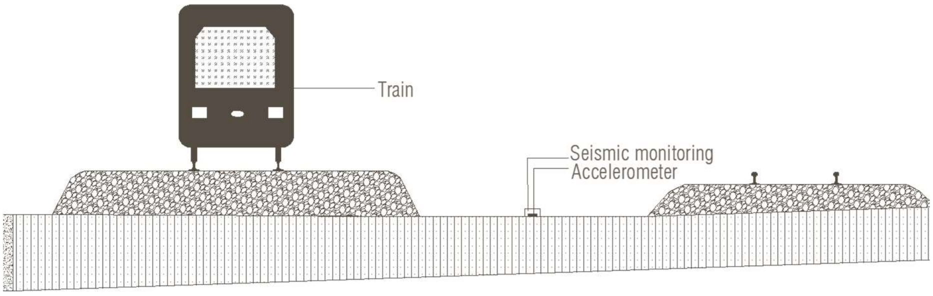
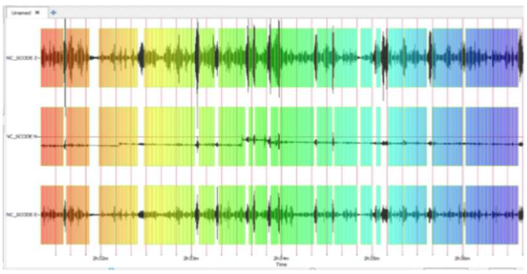


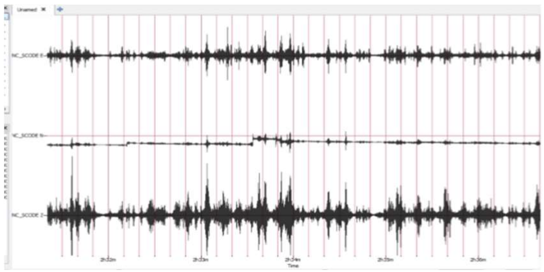
FIGURE 1. The illustration of equipment at the site

Horizontal to Vertical Spectral Ratio (HVSR)

Natural vibrations are vibrations that occur continuously due to the presence of vibration sources such as earthquakes, traffic, machinery and other activities [5]. Measuring the amount of vibration is performed by using the accelerometer sensor which is then be processed using Geopsy software with the HVSR method. The HVSR method is a method based on the assumption that the horizontal and vertical spectrum ratio of surface vibrations is a displacement function [6].

The HVSR method uses three-way wave components two horizontal components and one vertical component. The results of the HVSR method are natural frequency and amplification [7]. The HVSR method compares the spectrum ratio of the horizontal component of micro tremor signal to its vertical component [8].





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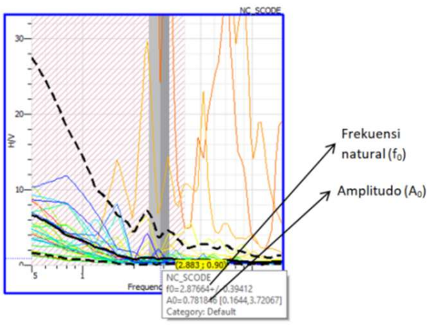


(c)

FIGURE 2. Display in the Geopsy software (a) Graph of vibration acceleration; (b) Graph of vibration acceleration after signal selection; (c) Graph of the relationship of natural frequencies and H / V.

Natural Frequency (F_0)

Natural frequency is the dominant frequency found in a system when it receives triggering vibrations without damping. If the frequency when vibrating is equal or close to the natural frequency of the system, a large and dangerous resonance and oscillation will be obtained [4][9].

The natural frequency value can be used as a guideline whether a structure experiences resonance or not. A structure can experience a resonance if the load frequency received by the structure is close to or equal to its natural frequency value [4]. Daryono [5] states that an area that has a low natural frequency, is very vulnerable to the dangers of vibration or waves with a long period.

METHODOLOGY

The study was conducted on the railroad section of the Brumbung KM 12 + 815. The KM 12 + 815 rail is located at the pile location with two rail lines with a width of 14 meters. The equipment used is a set of acceleration sensor-based seismic monitoring tools that are placed in the middle of the rail line.

FIGURE 4. Site location

(a) (b)

FIGURE 3. (a) Position of the equipment at the research site; (b) Direction x of the equipment facing east.

The sensor is then connected to a recorder that has been connected to a laptop to record vibrations caused by trains using Geodas software.

FIGURE 4. The Sensor is connected to the recorder that already connected to the laptop.

The data obtained from the research will be processed using Geopsy software to obtain the natural frequency value of the rail structure due to the vibration of the train.

RESULTS AND DISCUSSION

Rail Structure Specifications

Based on the technical specification of the rail component of PT. KAI (Persero) is obtained the following data;

TABLE 1. Rail Component Specifications Data

No	Component	Material	Modulus of Elasticity (kg / cm ^{2})	Information
1	Rail	UIC 54	2.1 x 10 ^{6}	The UIC 54 rail uses 900A / 1100 material with a length of 12-25 meters.
2	Fastening	E-Clip Pandrol	-	Pandrol E-clip fastening is able to withstand 600 kgf force.
3	Sleepers	Concrete and wood	-	Concrete sleepers are used on ordinary tracks and wooden sleepers are used on tracks on the bridge.
4	Ballast	Aggregate	-	Ballast materials typically use sharp angled aggregates measuring 2-6 cm with a thickness between 29-59 cm and 1-1.4 meters wide from the side of the railway steel rail.
5	Subgrade	The subgrade at the study site is silt.	-	

Train Speed and Load

Train load is calculated based on axle load, locomotive load and hopper load. Axle loads are taken up to 18 tonnes, a locomotive load of 90 tonnes and a load of carriages for a maximum of 54 tonnes and the carriage loads for passenger trains is maximum of 40 tonnes. There are 1 carriage trains and 2 passenger trains in this study. The load on trains varies depending on the type and number of train series. The data of the trains load crossing the rail are as follows:

TABLE 2. Train load

No	Types of Train	Number of Train series	Load (Ton)
1	Freight train	1 locomotive, 15 carriages	1170
2	Kalijaga train	1 locomotive, 8 train	554
3	Maharani train	1 locomotive, 11 train	728

The train speed data crossing the sensor are as follows:

TABLE 3. Train speed

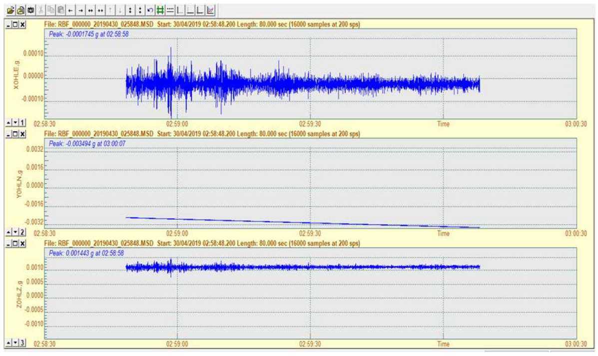
No	Types of Train	Speed , v (km/h)
1	Freight train	21.25
2	Kalijaga train	37
3	Maharani train	65

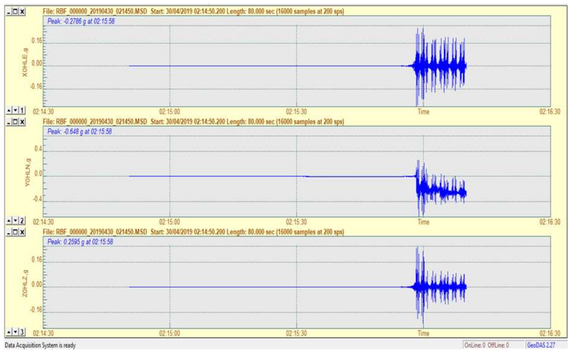
Vibrations Acceleration

The vibrations obtained as vibration acceleration data in three directions which are x direction, y direction and z direction. X direction indicates the direction of east, y direction shows west and z direction indicates vertical direction. Here are the vibration acceleration data due to the train passing:

TABLE 4. Acceleration data of trains moving

No	Types of Train	Speed , v (km/h)	Max Acceleration,a (g)		
			X direction	Y direction	Z direction
1	Freight train	21.25	0.27	0.64	0.26
2	Kalijaga train	37	0.14	0.27	0.15
3	Maharani train	65	0.26	0.39	0.29





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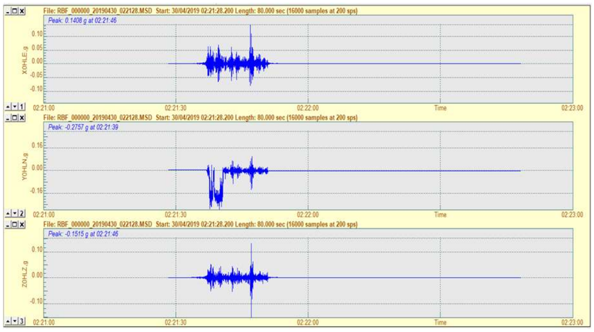
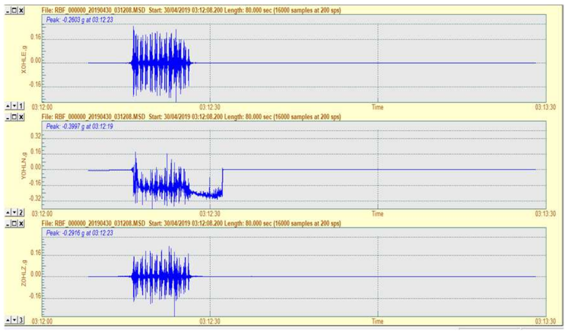




(c) (d)

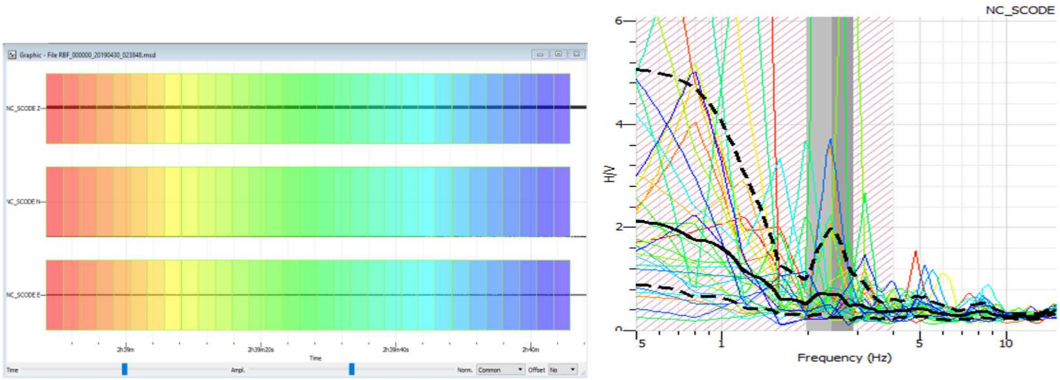
FIGURE 5. Acceleration of vibrations recorded by Geodas software (a) when there are no trains passing; (b) when the freight train passes; (c) when the Kalijaga train passes; (d) when the Maharani train passes.

Based on table 1.4, the vibration acceleration values for freight trains are 0.27 x, 0.64 y and 0.26 z. For Kalijaga trains, the value of vibration acceleration is 0.14 in the x direction, 0.27 in the y direction and 0.15 in the z direction. For Maharani train, vibration acceleration is 0.26 x direction, 0.39 y direction and 0.29 z direction. The maximum vibration velocity of the freight train 0.64 g occurring in the y direction where in Figure 1.5 (b) it occurs in the initial seconds when the freight train locomotive passes the sensor placement point. The freight train has a greater load than the Kalijaga and Maharani trains, which results in significant acceleration vibrations in the rail structure. Maharani train causes great vibrations also because Maharani train has high speed when passing.

Natural Frequency

Based on the results of the study, the data were then processed using Geopsy software to obtain the value of natural frequency, amplification and frequency, when the rail structure received the load of a passing train. Based on the results of data processing using geopsy software and HVSR processing method, the natural frequency and amplification values were obtained, as follows:

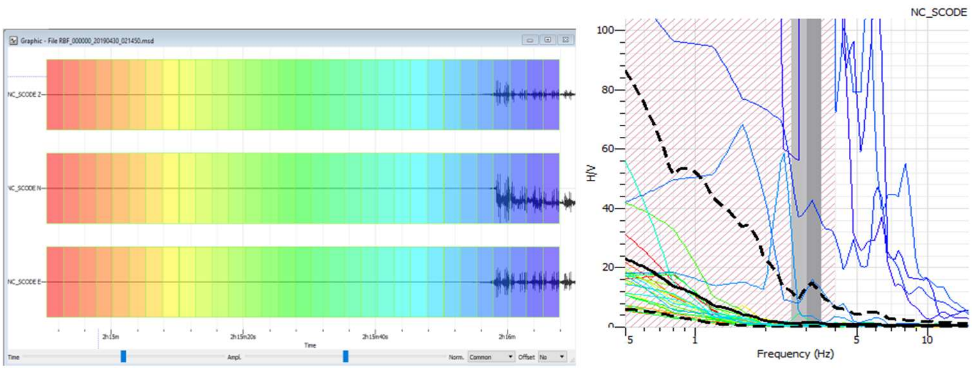
1. There are no trains that cross the research point.
   When there were no trains passing the tracks, the vibrations recorded on the seismic monitoring device were vibrations due to wind and other micro seismic vibrations around the device. The maximum vibration acceleration when there is no train passing was very small that was 0,0001745 g in the x direction, 0.00349 g in the y direction and 0.00144 g in the z direction. In figure 1.6 (b), we obtained natural frequency value (f_0) of 2.4077 and 0.6995 amplification



(a) (b)

FIGURE 6. (a) Display of the vibration signal in the Geopsy software; (b) Graph of the relationship of natural frequencies with H / V

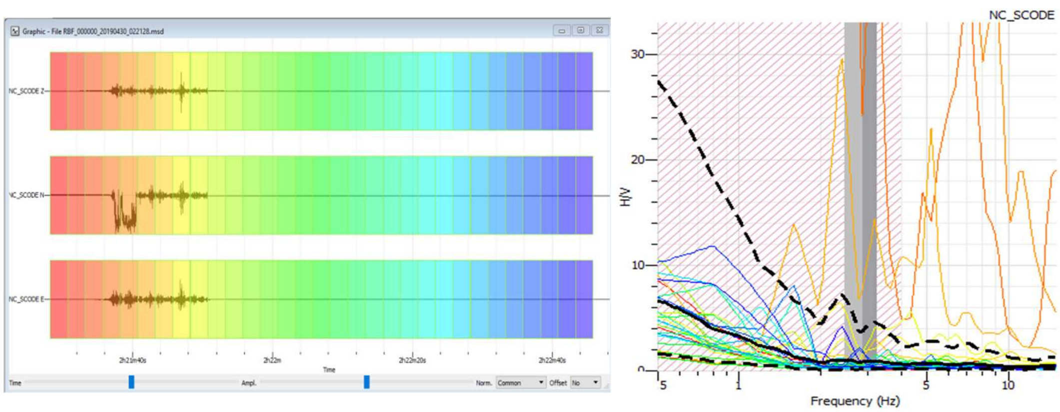
2. When freight train 1 passed
   When the freight train passed with a speed of 21.25 km / h, it caused a maximum vibration acceleration of 0.2786 g in the x direction, 0.648 g in the y direction and 0.2595 g in the z direction. The data were then processed using Geopsy software and produced 3.042 Hz natural frequency and 1.577 amplification.



(a) (b)

FIGURE 7. (a) Display of the vibration signal in the Geopsy software; (b) Graph of the relationship of natural frequencies with H / V

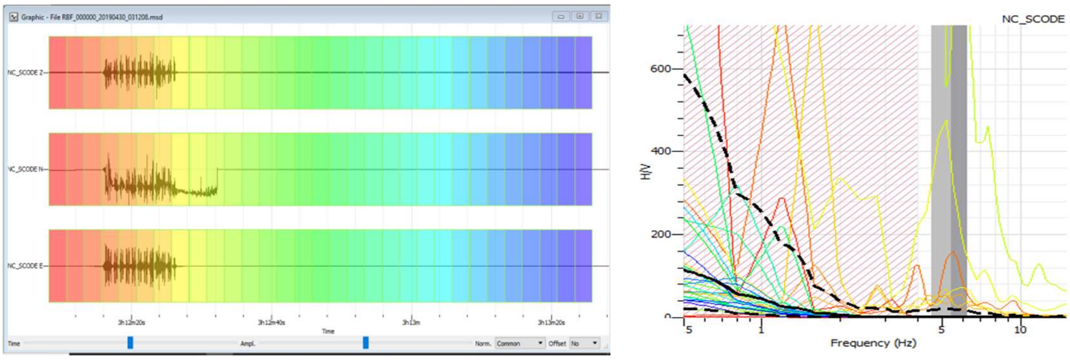
3. When the Kalijaga train passed
   The Kalijaga passenger train passed at a speed of 37 km / h resulting in vibrations with a maximum acceleration of 0.1408 g in the x direction, 0.2757 g in the y direction and 0.1515 g in the z direction with a natural frequency of 2.876 Hz and an amplification of 1,782.



(a) (b)

FIGURE 8. (a) Display of the vibration signal in the Geopsy software; (b) Graph of the relationship of natural frequencies with H / V

4. When the Maharani train passed
Maharani trains pass at the highest speed of 65 km / h resulting in vibrations with a maximum acceleration of 0.2603 g in the x direction, 0.3997 in the y direction and 0.2916 in the z direction. The natural frequency is 5.392 Hz and the amplification is 1.983.



(a) (b)

FIGURE 9. (a) Display of the vibration signal in the Geopsy software; (b) Graph of the relationship of natural frequencies with H / V

Based on data processing using Geopsy software, for structures without trains passing, natural frequency values was 2.4077 Hz and amplitude was 0.6995. On the other hand, the structure, when the freight train passed, caused a frequency of 3.042 Hz and an amplitude of 1.577. When the Kalijaga passenger train passed the railway, it caused a frequency of 2.876 Hz and an amplitude of 0.782 Hz. The structure, when the Maharani passenger train passed the rails, resulted in a frequency of 5.392 and an amplitude of 1.983. From the frequency results, freight trains, Kalijaga passenger trains and Maharani trains had higher frequencies than the natural frequency of the structure. In addition, the frequency of the three trains was almost close to the natural frequency of the structure. Therefore, it can allow dangerous resonances for the rail structure to occur. When the Maharani train passed, it caused the highest amplitude of 1.983. Maharani trains had the highest possibility of causing rail structure damage due to high amplitude. This is influenced by the speed of the Maharani train which is relatively higher than the freight train and Kalijaga.

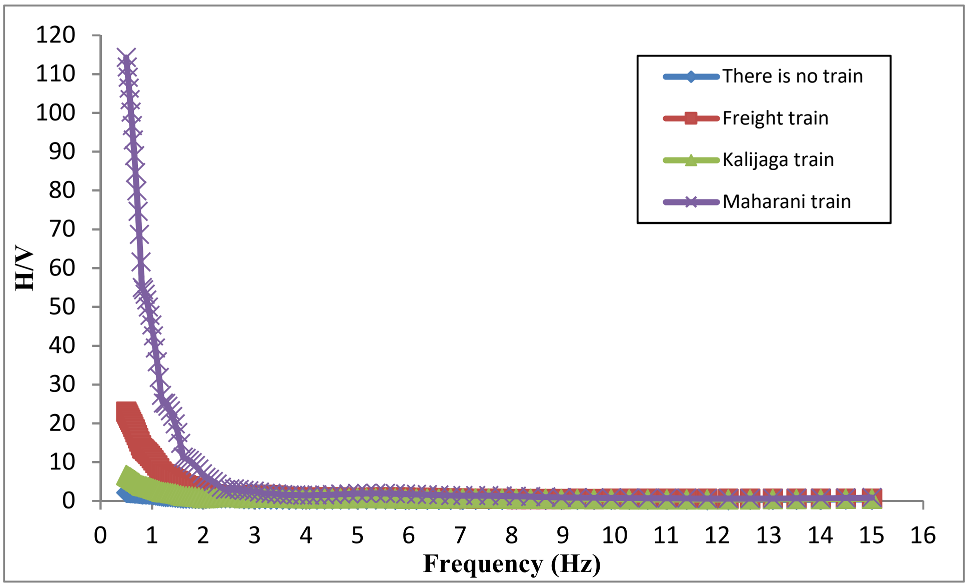
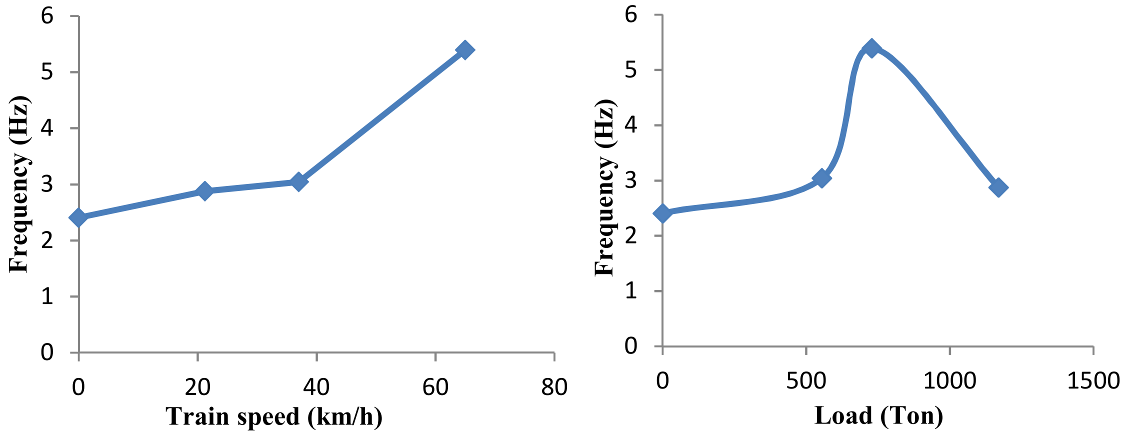


FIGURE 10. Graph of the relationship of natural frequencies with H / V in terms of the type of train passing the railway

The magnitude of the natural frequency value is also influenced by the magnitude of the acceleration of vibration that occurs. The following table 1.5 and graphs the relationship of acceleration and frequency.

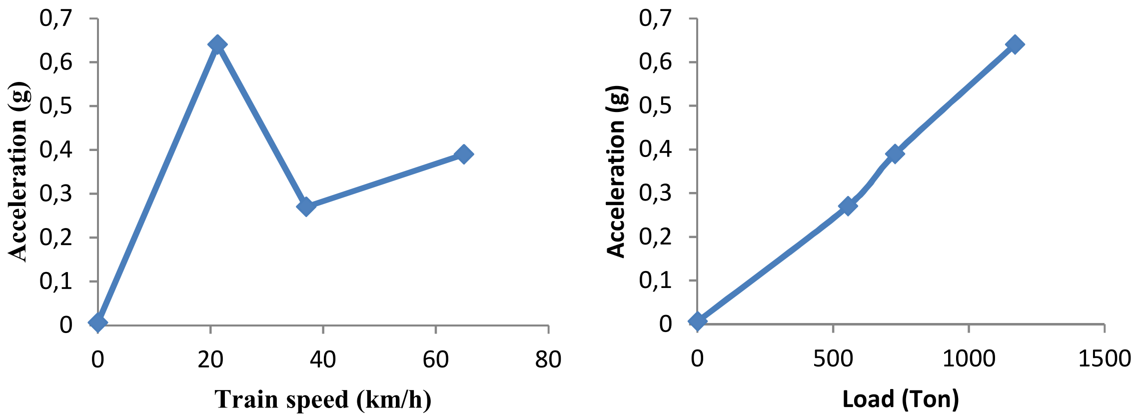
TABLE 5. The vibration acceleration and the natural frequency data

No	Type of Train	Speed, v (km/h)	Loading (Ton)	Acceleration,a (g)	Frequency (Hz)
1	Unloaded train	0	0	0.00633	2.4077
2	Freight train	21.25	1170	0.64	2.876
3	Kalijaga train	37	554	0.27	3.042
4	Maharani train	65	728	0.39	5.392



(a) (b)

FIGURE 11. (a) The graph of natural frequency and train speed; (b) The graph of natural frequency and loads.



(a) (b)

FIGURE 12. (a) Graph of relationship between natural frequency and train speed; (b) Graph of the relationship of natural frequency and load.

Based on Figure 12 (a), it is found that trains that passed with greater speed could produce a high natural frequency as well. In figure (b), train load also affected the natural frequency magnitude. The freight train had the heaviest load of 1170 tons. However, its natural frequency is still smaller than the Maharani train with a load of 728 tons. This is because the speed of the freight train is lower than the speed of the Maharani train. Figure 12 (a) and (b) show the relationship between train speed and train load with the acceleration of vibration. The Maharani train passed at the highest speed but the acceleration due to the vibration of the Maharani train is still below the freight train. This is because the freight train has a greater load than the Maharani train.

CONCLUSION

Based on the results of research and data processing, it can be found that vibrations due to freight trains resulted in acceleration of 0.27 g in the x direction, 0.64 g in the y direction and 0.26 g in the z direction with a natural frequency of 2.876 Hz. for the Kalijaga train, the vibration acceleration is 0.14 g in the x direction, 0.27 in the y direction and 0.15 g in the z direction with a natural frequency of 3.042 Hz. In addition, the Maharani train which passed at the highest speed among the three other trains caused vibrations with an acceleration of 0.26 g in x direction, 0.39 in the y direction and 0.29 in the z direction with a natural frequency of 5.392 Hz. the value of vibration acceleration was affected by the train's load and speed. Trains with heavy loads and high speeds could produce great vibrations to the rail structure. The natural frequency of the rail structure without any passing trains is 2.4077 Hz. The natural frequency when there is vibration due to train's load is still not close to the natural frequency value of the structure. Therefore, the condition of the rail structure is safe when receiving vibrations due to the passing train load.

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