Vibration Analysis on a Railway Bridge Structure

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Abstract The railway bridge would be vibrating when a series of train passed on it. The movement a train triggers a noise to the bridge structure which is generated by the combination of small-scales undulation between wheel of train, railway and bridge railway contact surfaces. Nowadays, railway researches focused on dynamic behaviour of railway track when the train passed on it. This study discusses the dynamic behaviour of railway bridges vibrations caused by train traffic load in terms of three axis direction (x, y and z direction). A field investigation was conducted by applied a series of accelerometers to find out the value of frequency natural and amplitude. The tools are placed on the beam at a half span and at a third span. The results were compared between passengers train and carriage train. During unloaded condition, the range of frequency natural is 0.78–3.73 Hz and amplitude is in between 1.82 and 1.89. When the train passes by, the range of frequency natural is in between 1.03 and 5.77 Hz and amplitude 1.70–4.

Keywords Vibration analysis · Railway bridge · HVSR

1 Introduction

The occurrence of earth noise ambient could be triggering through many ways by several independent sources. Since it caused the noise to environmental then probably could affect the frequency band of natural frequency itself. The oceanic and large-scale meteorological could generated the frequencies below 1 Hz. For frequency above 1 Hz are dominated by traffic vibration and environmental natural sources [1].

By using the ambient noise with frequency band below 1 Hz could help to get better understanding about relationship between the earth, oceans and atmosphere.

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Normally, the range of ambient noise frequency is in between 1 and 20 Hz and it commonly known by microtremor analysis. This method is quite powerful in order to provide a low-cost and non-invasive exploration when the geotechnical information data is difficult to obtain [2]. Many studies were applied of microtremor measurements results to determine several parameter vibrations such as frequency of fundamental resonant, unconsolidated shallow sediment thickness and shear wave velocity. This parameter could be used to predict the ground motion local amplification during the earthquake and could be said it has an important role for seismic hazard assessment [3, 4]. A seismic microzonation maps could be built by referring to this parameter. Nowdays, the ground motion amplification could be reach by comparing the observed data during earthquake and amplification pattern modelled by microtremor measurements and this method widely used by many researchers in the world [5–8].

The responses of the railway bridge when the train passed on it is one of crucial aspect in the point of view bridge structure railway capacity support the dynamic loading. Lorieux [9] revealed the train speed induced the dynamic behavior of bridge particularly the amplitude and frequency. They are having a positive correlation; the increasing of train speed will be increase the amplitude of dynamic behavior of a railway bridge and rails. Rigid railway bridge and tracks have non-elastic behaviour, therefore when vibrations occur, the ballast particle displacement is often irreversible and the accumulation of these minor displacements results in settlements and degradation of the track itself. The complexity of the structural response of train load and speed based on the interaction of parts of the track-railway bridge system which is consist of rails, sleepers, ballast, girders and foundations. Each elements of the bridge has its own behavior with different characteristics. Due to the non-linear differences of each element, it is very difficult to predict the distribution of stresses and vibrations of each element. The aims of this article to revealed the dynamics behavior of railway bridge by using microtremor methods to understand the dynamic properties of railway bridge.

2 Materials and Methods

In this work is using the HSVR (Horizontal to Vertical Spectral Ratio) which could be used as indicator the subsurface structure which shows the relationship between the Fourier spectrum ratios of the horizontal component microtemor signal to its vertical component. This method utilized three direction components which consist of two horizontal components and one vertical component. The results of the HSVR method are natural frequency and amplification [10] could be used to determine the maximum value of vibration acceleration, amplitude and natural frequency.

The type of railway bridges is closed frame bridge which could be seen in Fig. 1. A railway bridge in Semarang city is chosen as appropriate model for this study. This railway bridge is fully composed by steel material and constructed over the river which cross cut the east of Semarang city, Central Java province, Indonesia.

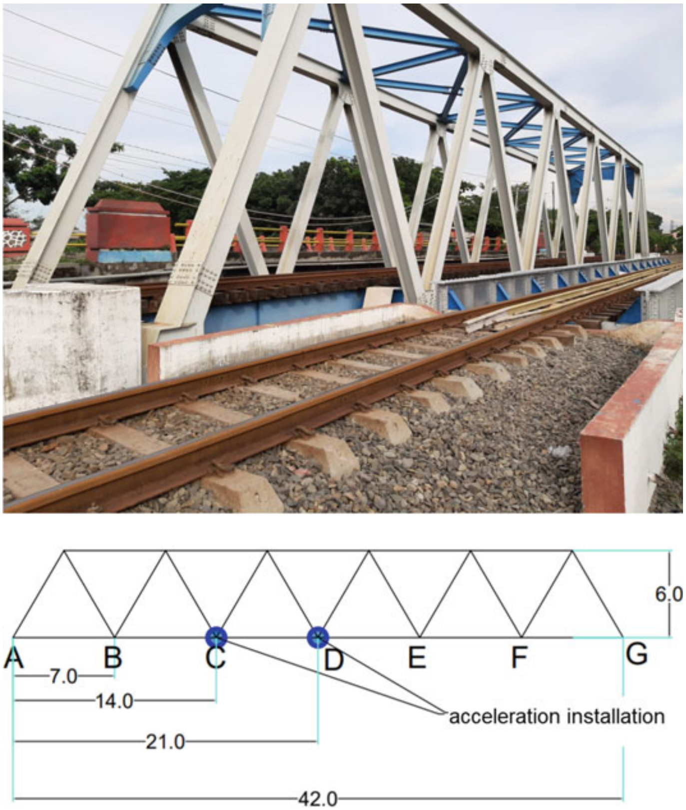

Fig. 1 Railway bridge and acceleration installation

The measurements length and width of railway bridge during the field investigation are 42 m and 5.13 m respectively and the support is identified as roll at both side.

A set of sensor was installed in several parts of the span bridge frame which could be seen in Fig. 2. The vibration data due to passing train known as a microtremor. The sensor collected the data of frequency and time during unloaded bridge and when the train passed. Data collections were conducted in two techniques, firstly, the data was taken when the bridge was passed by train and secondly, the data was collected when the bridge was unloaded state. The two sensors were located in the mid of span and the third of span. The total of data collection was 12 on which 7 were taken when the train passing by and the other when the bridge was unloaded. Data collection was performed by applying by sensor and using GEOPSY software to analyse signals from the acceleration data recording [11].

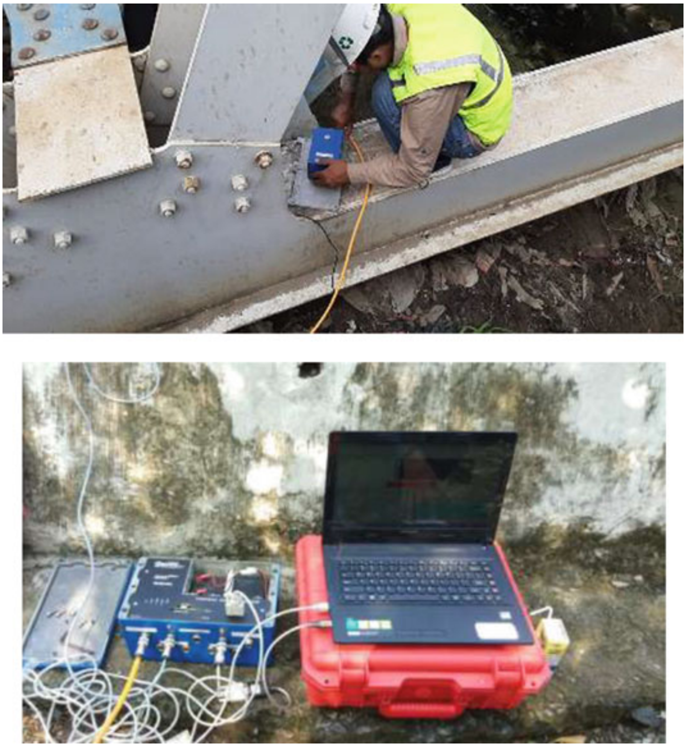

Fig. 2 Sensor installation and a set of measurements

3 Results and Conclusion

According to the technical field and the data analysis using Geopsy program, it obtained natural frequencies of the bridge, vibration maximum, vertical displacement, and amplitude. Further, the data of result analysis obtained from the program was presented in the form of figure and table and then analyzed.

3.1 Train Characteristic as a Load

The natural frequency of railway was obtained from HVSR curve for the data of the bridge taken while train passing by with the assumption that loads passing it were at maximum. Figure 3 illustrated HVSR curve of the bridge while Agro Anggrek train passed. There were two HVSR curves obtained during field investigation, while the train passed and while the bridge was unloaded. Based on Fig. 3, it was obtained that the natural frequency value of bridge was 5.5 Hz.

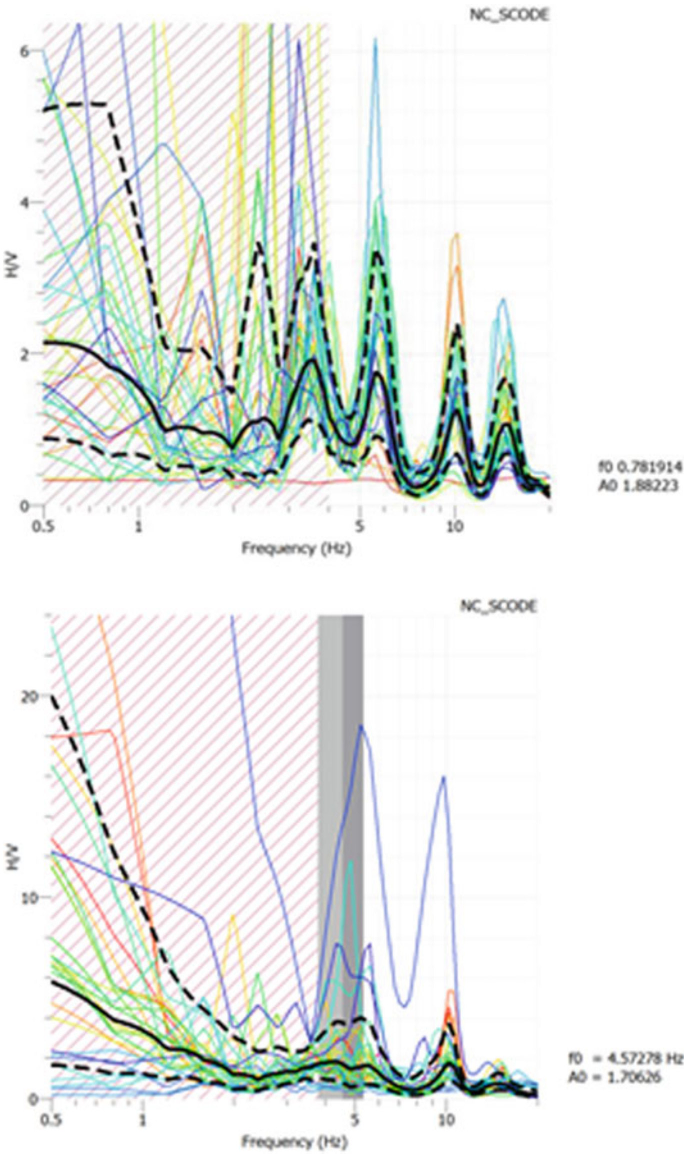

Fig. 3 H/V graphic when unloaded condition (**a**) and Maharani train passed (**b**)

3.2 The Natural Frequency

The natural frequency of railway was obtained from HVSR curve for the data of the bridge taken while train passing by with the assumption that loads passing it were at maximum. When the railway in the condition of unloaded, the measurement recorded

Table 1 Measurement result

Train name	Weight (tons)	Acceleration (g)			Velocity (km/h)	f (Hz)	A
		X	Y	Z			
No train		0.003751	0.00145	0.00385		0.78	1.88
Maharani	902	0.57	0.827	1.896	72.42	4.572	1.706
Freight train	2250	0.754	**1.017**	1.787	51.5	1.03	2.6
Kedung Sepur	264	0.345	0.427	0.838	56.33	5.66	3.88
Argo Anggrek	612	**0.815**	0.724	**1.903**	78.86	5.5	4.14

For the maximum value for each direction is indicated by bold number

the natural frequency and amplitude are 0.78 Hz and 1.88. Figure 3 illustrated the comparison of HVSR curve when the bridge conditions are unloaded and with a train passed on it. Based on Fig. 3, it was obtained that the natural frequency value of bridge was 5.5 Hz. Moreover, we could be seen the curve while the bridge is unloaded, the initial frequency natural (f_n) is 0.78 Hz. The detail of natural frequency (f) and amplification (A) of each train in the study site could be seen in Table 1.

3.3 Acceleration and Velocity

The data related to acceleration was obtained by using sensor equipment which connected to a seismic monitoring recorder. Thus, the raw data from sensor was processed by Geopsy software to determine the parameters of natural frequency, amplification and frequency with two difference condition (unloaded and loaded by dynamic load of train passed). When the bridge structure does not have loads passing on it, the vibrations that occur come from earth/microseismic vibrations, vibrations due to wind and surroundings. The maximum acceleration of vibration when there is no train passing is very small, namely 0.003751 g in the x direction (east–west), 0.001450 g in the y direction (north–south) and 0.00835 g in the z direction. The natural frequency and an amplitude value is 0.78 Hz and 1.88, respectively.

While the Maharani train passes at a speed of 72.42 km/h, it causes a maximum acceleration of 0.570 g in the x direction, 0.827 g in the y direction and 1.896 g in the z direction, with a natural frequency value of 4.572 Hz and an amplification of 1.706. At moment the freight train get through at a speed of 51.50 km/h causes vibrations with a maximum acceleration of 0.754 g in the x direction, 1.017 g in the y direction and 1.787 g in the z direction.

The natural frequency is 1.03 Hz and the amplification is 2.60. In time the Kedung Sepur passenger train passing at a speed of 56.33 km/h causes vibrations with a maximum acceleration of 0.345 g in the x direction, 0.427 in the y direction and

0.838 in the z direction, has the natural frequency 5.66 Hz and the amplification 3.88. Furthermore the Argo Anggrek passenger train passes with the highest speed of 78.86 km/h causing vibrations with a maximum acceleration of 0.815 g in the x direction, 0.724 y direction and 1.903 z direction, possesses the natural frequency 5.5 Hz and the amplification 4.14.

3.4 Conclusion

Based on the research results, the acceleration of vibration is influenced by the load and speed of the train. The highest vibration acceleration in Y direction occurred when the freight train with a load of 2250 tons and with a speed of 51.5 km/h passed, which was 0.754 m/s^2 in the x direction, 1.017 m/s^2 in the y direction and 1.787 m/s^2 in the z direction. Meanwhile, the highest vibration acceleration in X and Z direction occurred when the Argo Anggrek train with a load of 612 tons and with a speed of 75.64 km/h passed, which was 1.35 m/s^2 in the x direction, 1.63 m/s^2 in the y direction and 1.31 m/s^2 in the z direction.

From data processing using Geopsy software, the natural frequency of the structure is 0.78 Hz and an amplitude of 1.88. Meanwhile, the value of the natural frequency when the train passes is 1.03–5.77 Hz and the amplitude is 1.70–4.14. The greatest frequency value occurs when the Argo Anggrek train passes at a speed of 78.86 km/h which produces a natural frequency of 5.50 Hz and an amplitude of 4.14.

For further research, data collection samples should be reproduced so that more accurate results are representative of the bridge conditions. Especially if you want to get the bridge shape mode data, which is really needed if you want to do a finite update of the model.

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