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2	Identitas Pelaksana		
	a.Nama Tim	:	F Alami and L Afriani
	b. Nama Pengusul	:	Dr.Ir. Lusmeilia Afriani, D.E.A.
	c. NIP	:	196505101993032008
	d. Pangkat/Golongan	:	Pembina Tk I/IVB
	e. Jabatan Fungsional	:	Lektor Kepala
	f. Fakultas/Program Study	:	Teknik Sipil
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Dekan Fakultas Teknik
Universitas Lampung

Prof. Dr.Drs. Suharno, M.Sc
NIP. 196207171987031002

Penulis

Dr.Ir.Lusmeilia Afriani, D.E.A
NIP.196505101993032008

Menyetujui
Ketua LP2M
Universitas Lampung

Dr.Ir.Lusmeilia Afriani, D.E.A
NIP.196505101993032008

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Vibration problem due to railway loading

F Alami[1,2], and L Afriani [1]

[1] Faculty of Engineering, University of Lampung, Bandar Lampung, Indonesia
[2] Postgraduated Student of Study Program of Environmental Science, University of Lampung, Bandar Lampung, Indonesia

E-mail: fikri.alami@eng.unila.ac.id

Abstract. Train is one of transportation mode is increasingly polular in Indonesia nowdays, although in developed countries this transportation has long been a very advanced mode of mass transportation. Problems due to railroad tracks adjacent to densely populated settlements cannot be avoided. Problems such as noise levels can interfere with the health and comfort of the environment, vibrations in the surrounding environment due to passing trains cause some damage to civilian buildings such as residents' houses and high rise buildings as well. This field study shows the potential problem due to mass train loading (Babaranjang) in Bandar Lampung.

1. Introduction

Railways in Indonesia in the last decade have grown very rapidly. Starting from the many renovations at several existing train stations, to the construction of several new train tracks. One of them is the construction of LRT (light rapid transit) type trains in several big cities, such as Jakarta, Bandung and Palembang. In addition to this development having a positive impact, there are also negative impacts that arise such as noise, vibration, adverse effect on sleep and physical dicomfort [1]. This condition will greatly affect the health of the people living around the railroad tracks. Noise is a sound or noise that is unwanted and can interfere with the health and comfort of the environment which is expressed in decibels (dB). If the noise is on the threshold greater than 85 db it can be annoying. Vibration is a motion back and forth around equilibrium. Equilibrium here means the state in which an object is at rest if there is no force acting on it. Vibrations that exceed the allowable threshold will have a vascular and neurological effect, and cause changes in blood pressure.

Vibration in buildings is influenced by several parameters such as the interaction between building and foundation, type or type of foundation and geotechnical parameters [2]. In general, a stiff foundation will produce a greater natural frequency dynamic response than a flexible foundation. The vibrations from the ground support beneath the building due to trains can make building occupants uncomfortable or disturbed. These vibrations come from rail transit systems, road traffic, construction in the field and also industrial factories [2][3][4]. This study of vibration problems becomes interesting to research because of the environmental impact it causes on the surrounding environment [5][6][7]. Table 1 below is the threshold for rail vibration speed at several required building types in Indonesia. A proposed safe level for serious structure damage is very high: 50 mm/s peak particle velocity. Nevertheless, much lower levels may be relevant for damage to old and historic building as low as 2 mm/s.

Table 1. Threshold for the speed of rail vibration in several types of buildings

Class	Type of Buildings	Peak Velocity (mm/second)
1	Designations and ancient buildings that have high historical value	2
2	Buildings with existing damage, visible damage to the walls	5
3	The building is in good technical condition, there are minor damages such as: cracked plaster	10
4	Strong buildings, for example: industrial buildings made of concrete or steel	10-40

Figure 1 showed that when a train passes near the building it causes vibrations which are transferred to the rail system and transmitted to the sleeper and then to the ballast. The waves that are emitted can be in the form of body waves and surface waves. If a body wave encounters a hard ground surface below it, it will be turned back towards the surface and will arrive at the adjacent building. While surface waves will propagate through the ground surface and arrive at the nearest building as shown in Figure 1 below. When arriving at the building, these waves will propagate vertically through the vertical elements of the building such as columns and then will be transferred to horizontal components such as beams and plates. The vibrations that occur in this building can be felt by residents of the building.

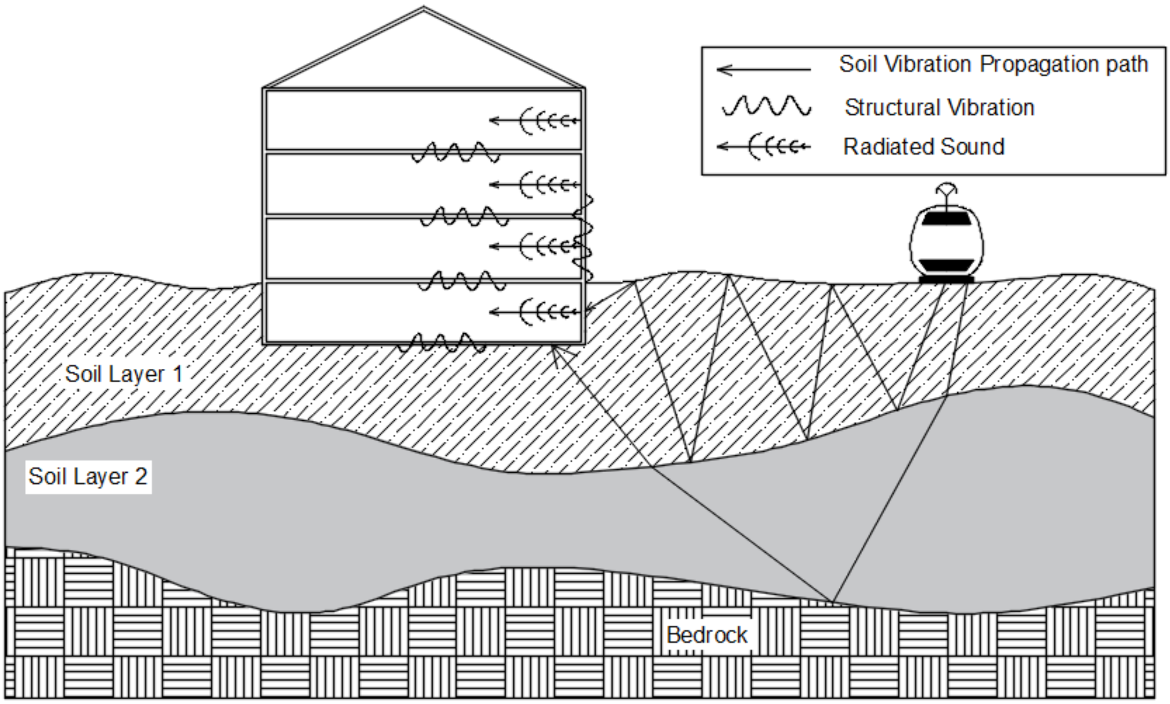

Figure 1. Vibration from train transferred to buildings [8]

Several researchers found the way to control and predict of ground-borne noise and vibration [9][10]. First method was to use of floating slab trackbeds, which proven to be effective at reducing vibration at frequency above the resoncance frerequency of its system. The second method is to modify design of transic car bogies such that the wheel/rail forces are reduced [9]. Different method was using a novel additional anti-vibration sleeper track (AAST) to reduce low-frequency vibration (40-80 Hz) [8]. By controlling sleeper spcacing and track support stiffeness, vibration of subgrade could be controled as well.

This field experimental study aims to learnd and investigate the problem mentioned above especially vibration due to train passing through densely populated settlement. So that potential problems such as damage on buildings nearby train tracks and uncomfortable noises can be anticipated.

2. Method

This was an experimental study which conducted on site at railway track nearby city of Bandar Lampung. The location was at Hos Cokroaminoto street, Rawa Laut, central Tanjungkarang, Bandar Lampung as showed on the map in Figure 2. Data was collected at railway track only about 10 meter away from railway closing doors as shown in Figure 3 using two accelerometer sensors. These sensors read acceleration in three directions. Direction of X was along with railway track, Y-direction was perpendicular to the railway track and vertical Z-direction to the ground below. The sensors was conneted to portable Labquest 2 through bluetooth channel and data was stored there during recording.

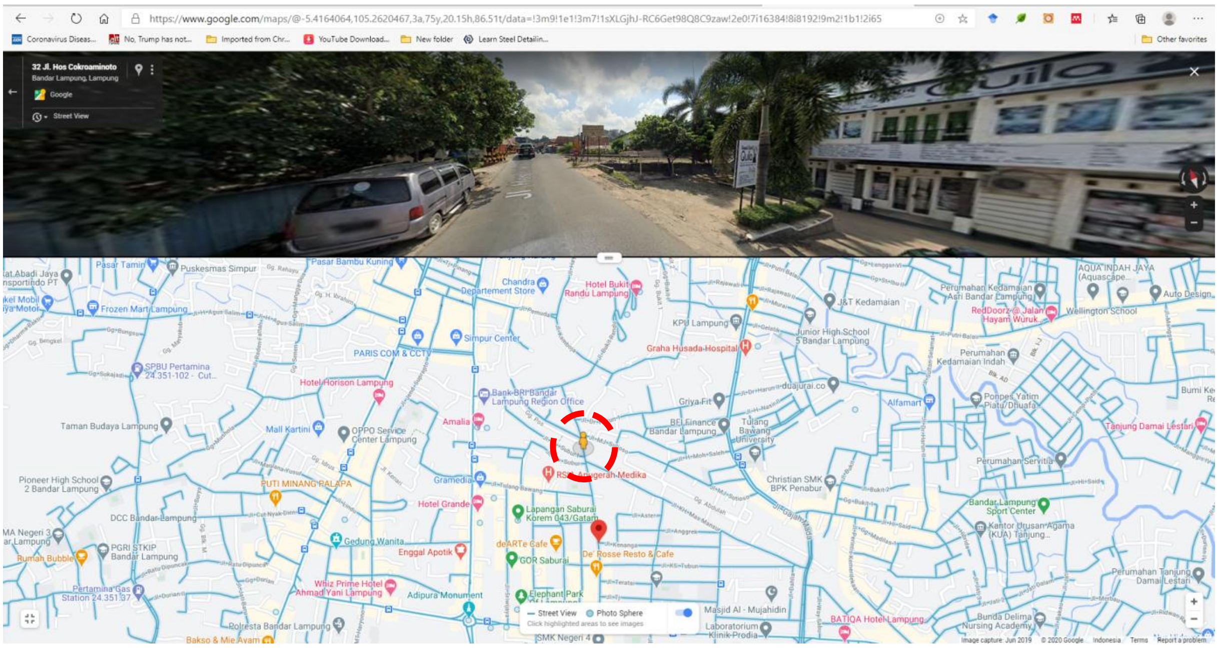

Figure 2. Location of field test in Bandar Lampung city

Figure 3. Accelerometer sensors was located at sleeper on left picture and another one on the ground.

Scheme of sensors application and geometry cross section of railway track and surroundings was depicted at Figure 4. There is wall seperated resident houses and rail only 6 meter distance in between.

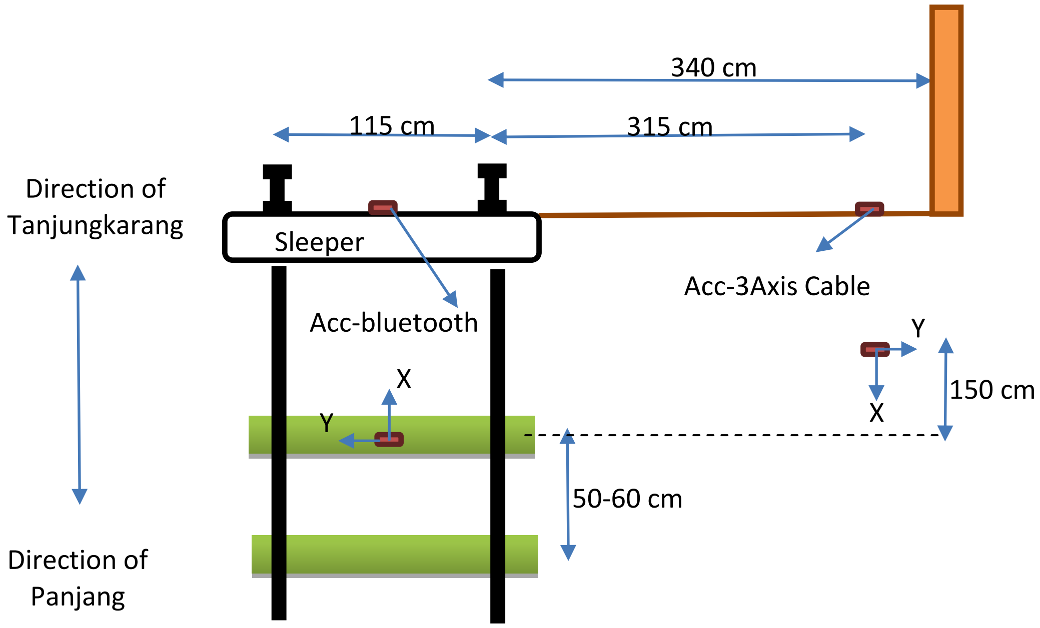

Figure 4. Sensors application on sleeper and ground

The output of data record was acceleration in three directions, X, Y and Z at the sleeper and gound. Time-domain graphs display the changes in a signal over a span of time were recorded using portable Labquest 2. Frequency domain analysis and Fourier transforms was used to change time-domain acceleration to frequency domain as showed in equation (1). The results came out in form of relationship between frequency and amplitude.

Time domain S(t) ↔ Frequency domain S(ω)

$$S(t) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{+\infty} S(\omega) sin\omega t.\,d\omega \leftrightarrow S(\omega) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{+\infty} S(t) sin\omega t.\,dt \quad (1)$$

(this gives S(t) if we know $S(\omega)$) (this gives $S(\omega)$ if we know $S(t)$)

3. Results and Discussion

Three direction accelerations were recorded during the train passing through location of study. Train came from Tanjungkarang to Panjang with 60 carriages that brough coal. It was aproximately 120 tonnes of coal in every caarriage. Three graphs showing relationship between acceleration and time were depicted in Figure 5 to 7 respectively. Those readings obtained from sensor on sleeper. Then Figure 8 to 10 showed reading acceleration in X, Y and Z direction on ground respectively.

Figure 5 to 7 showed when train approaching the sensors on sleeper, accelerations in X, Y and Z direction were small which were ±0.17 m/s^2, -0.18 m/s^2 and -0.26 m/s^2 respectively. At the same time, sensor on the ground showed acceleration in X, Y and Z direction were smaller which were 0.028 m/s^2, -0.036 m/s^2 and -0.077 m/s^2 respectively. These two values, acceleration in X and Y are below 0.5% G (or 0.04905 m/s^2) which allowed for peak acceleration of residence. However acceleration in Z direction exceeded the recomended acceleration limit which gives uncomfortable impact for people in the buildings.

Then when train passing through the sensor on sleeper the accelerations increased rapidly to -17.88 m/s^2 , 12.75 m/s^2 and 20.32 m/s^2 (see table 1). The accelerations on the ground increased to values of -0.26 m/s^2, 0.48 m/s^2 and 0.37 m/s^2 respectively. This vibration could have more effect not only to the people inside the building but to the building its self. Building structure would have damages for long time services of trains.

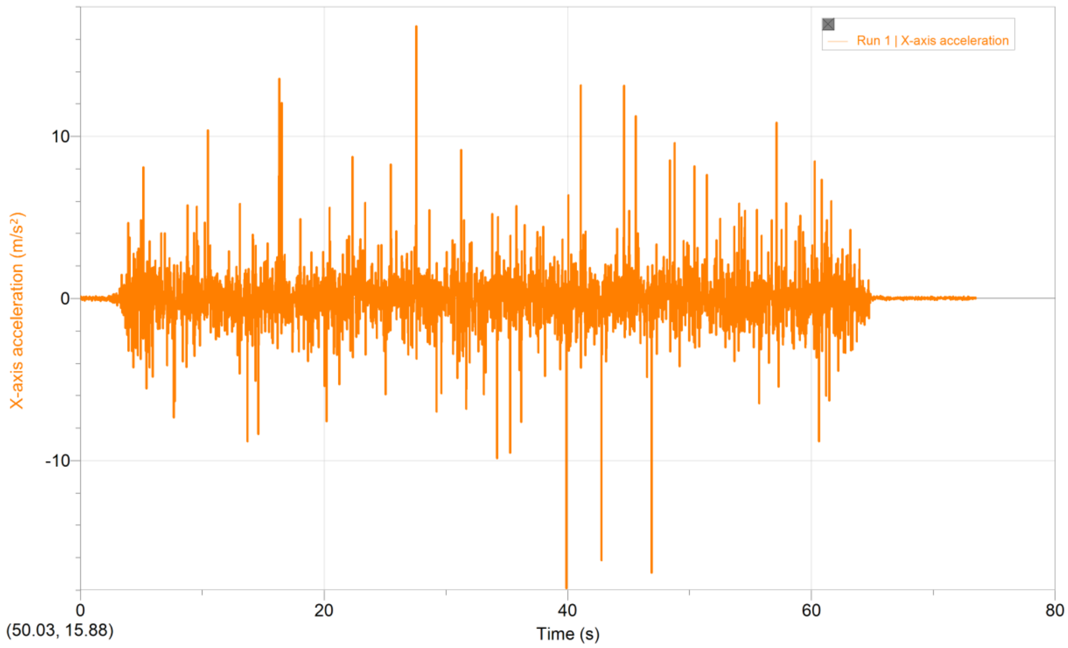

Figure 5. Acceleration in X-direction on sleeper due to train laoding of 60 carriages contained coal

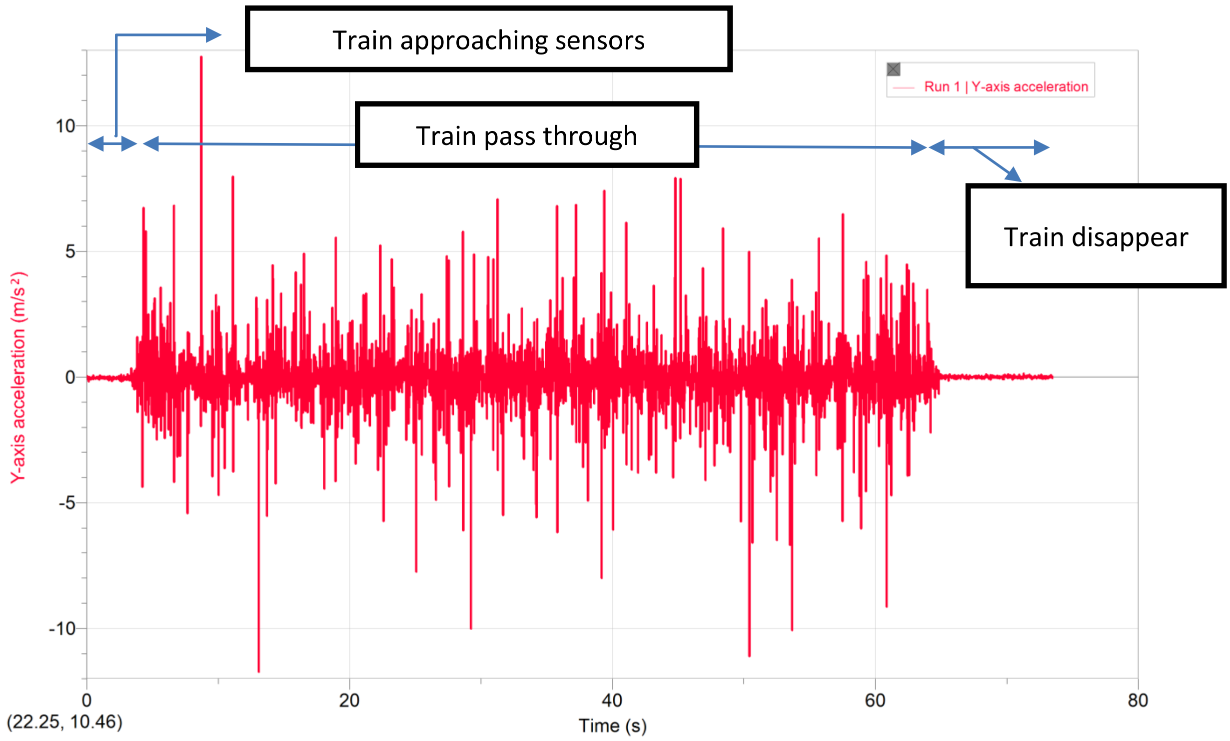

Figure 6. Acceleration in Y-direction on sleeper due to train laoding of 60 carriages contained coal

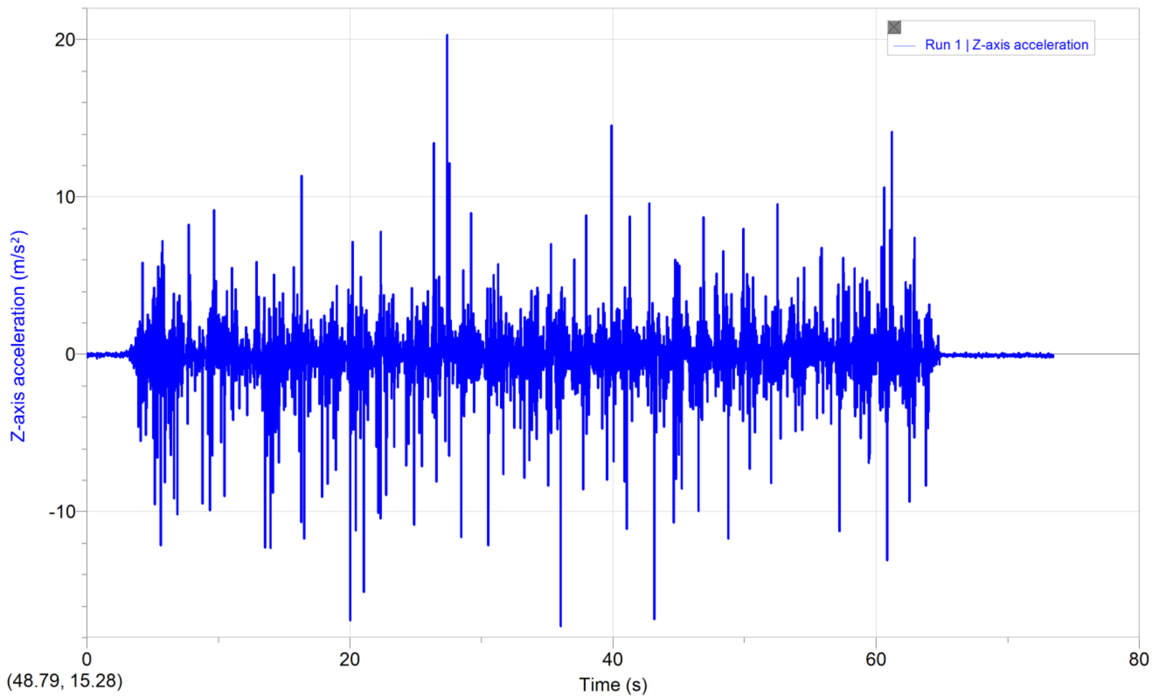

Figure 7. Acceleration in Z-direction on sleeper due to train laoding of 60 carriages contained coal

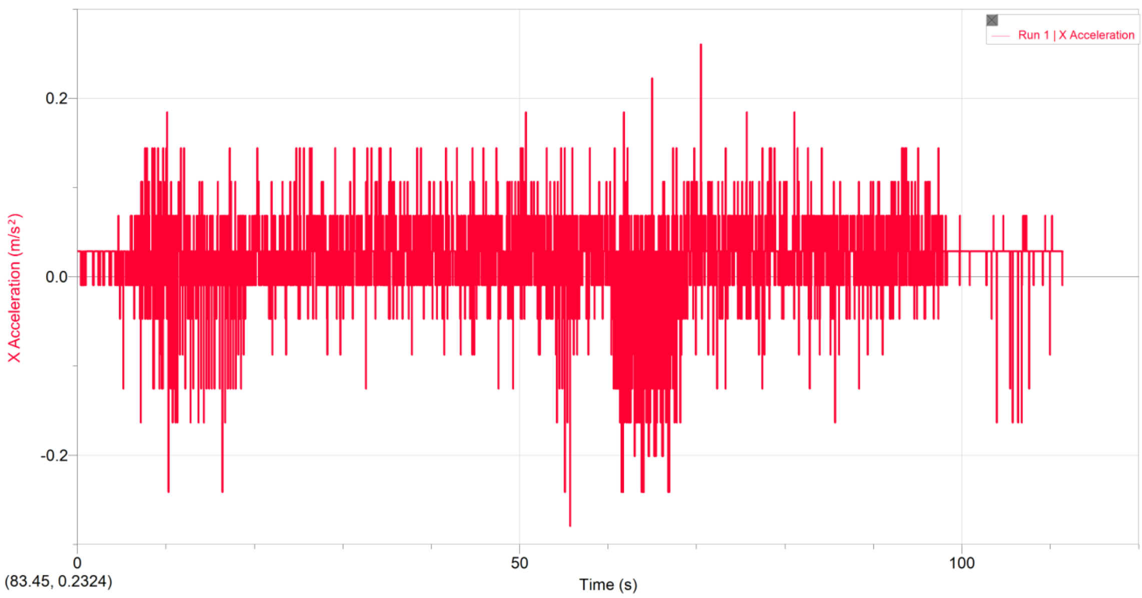

Figure 8. Acceleration in X-direction on ground due to train laoding of 60 carriages contained coal

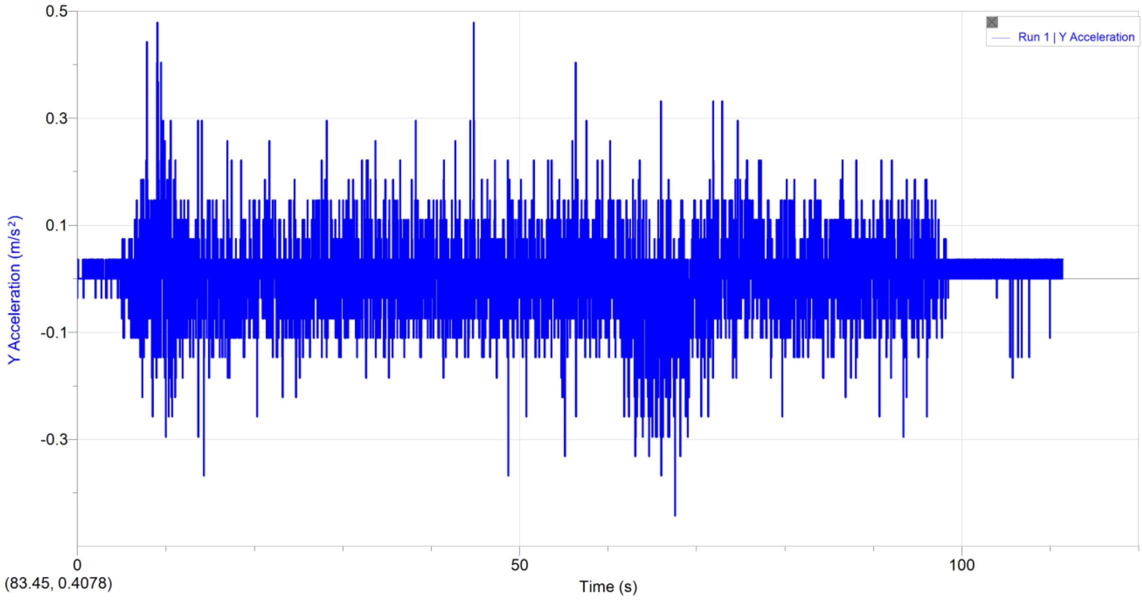

Figure 9. Acceleration in Y-direction on ground due to train laoding of 60 carriages contained coal

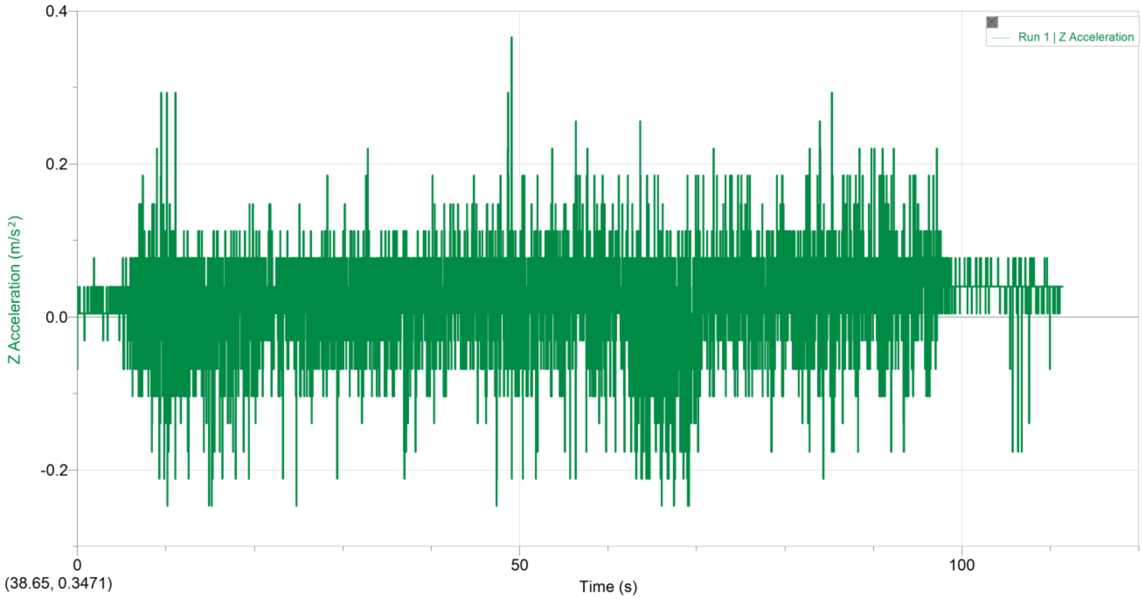

Figure 10. Acceleration in X-direction on ground due to train laoding of 60 carriages contained coal

Table 2 showed the summary of vibration analysis for train passing through two sensors which were located on sleeper and on the ground. The variables analyzed consisted of frequency, periode, peak amplitude and peak acceleration of data. This vibration is transmitted through the ground and may reach the foundation of a bulding [11]. The vibration trasmitted through the building structures. This ground-borne vibration is accociated with a frequency range of roughly between 1 and 100 Hz [11]. Results in Table 2 showed the obtained frequency between 0.28 Hz and 22.46 Hz for sleeper and 0.01 Hz and 20.02 Hz for ground were in this recommended range. However, acceleration was other variable which associated with human comfortable [12,13].

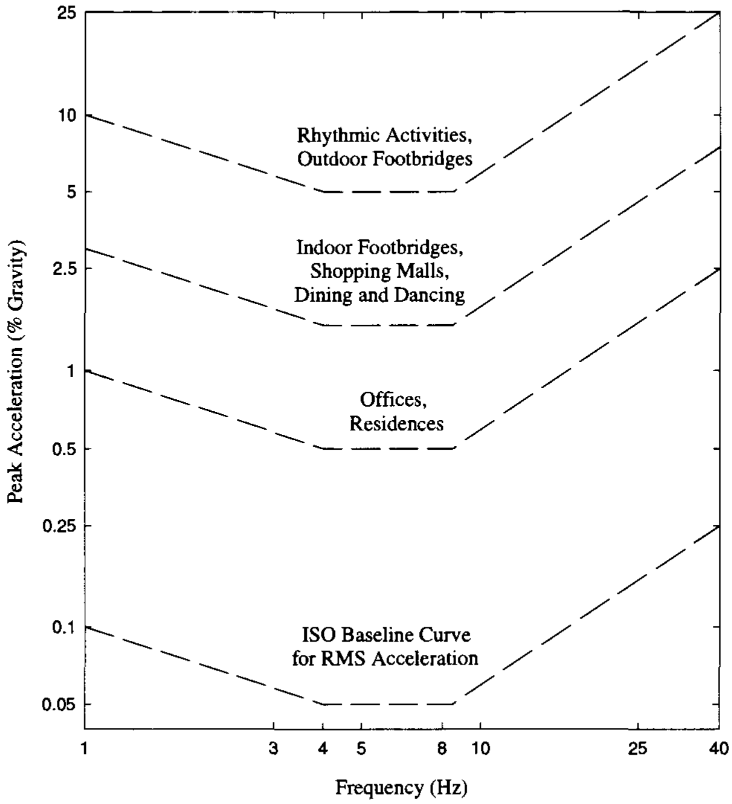

Figure 11. Recommendation acceleration peak for human comfort due to vibration [12,13].

As showed in Table 2, acceleration in X, Y and Z directions on the sleepers were much higher compared with accelerations on the ground in the same directions. Acceleration on sleeper could reach almost two time of gravity acceleration. The maximum one was 20.32 m/s^2 which was 2.07 G (G = 9.81 m/s^2). However, when this vibration propageted to the ground, these values reduced between 0.26 m/s^2 and 0.48 m/s^2. For building appliaction (offices and residences) the recommended peak acceleration in vertical direction (Z-direction) was 0.5% G (0.0495 m/s^2) as showed in Figure 11. The vertical acceleration (0.37 m/s^2) on the gound obtained from the sensor was 7.54 times greated than recommended value. This was potential problem for houses and buildings near the train track.

Table 2. Summary of vibration analysis for train passing through the sensors on sleeper and gound.

variable analysed	acceleration direction on Sleeper			acceleration direction on ground		
	X-direction	Y-direction	Z-direction	X-direction	Y-direction	Z-direction
Frequency (Hz)	0.28	22.46	21.00	0.01	16.38	20.02
Periode (s)	3.57	0.04	0.05	100.00	0.06	0.05
Peak Amlitude (mm)	6.00	4.10	5.00	0.26	0.23	0.20
Acceleration (+) (m/s^2)	16.80	12.75	20.32	0.26	0.48	0.37
Acceleration (-) (m/s^2)	-17.88	-11.73	-17.3	-0.28	-0.44	-0.25

4. Conclusions

Potential problem due to railway loading that carry tonnes of coal and pass through densely populated settlements will effect comfortable people in the residence and buildings elements as well. Potential damages of structure element of buildings/ houses due to train loading are able to identify using vibration sensors. The dynamics response which associated with ground-borne vibration, showed the obtained frequency between 0.28 Hz and 22.46 Hz for sleeper and 0.01 Hz and 20.02 Hz for ground were in the recommended range. However, vertical acceleration response on the ground still had valued much greater than recommended value for human comfort for buildings application.

Propagation of vibration decreased from railway track as distance increased. By keeping a distance from railroad tracks, it will reduce the problems that arise due to vibration.

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