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Evaluation of Ground Vibration Resulting from a Heavy Vehicle Passing Over Transverse Rumble Strips: A Case Study in Kluang Road FT050

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ABSTRACT

The transverse rumble strip (TRS) is one of the methods used to improve the driver's alertness to its driving and reduce their speed. However, the presence of a TRS causes unevenness on the road surface and may result in ground vibration when heavy vehicles passes it. This ground vibration may cause discomfort to the people living adjacent to the road. Therefore, there is a need to evaluate the level of ground vibration resulting from heavy vehicles passing over TRS especially on typical federal road in Malaysia which contains high percentage of fast-moving heavy vehicles. Ground vibration assessment study was conducted at federal road of Kluang-Batu Pahat Road (FT050) by using existing heavy vehicles in the traffic stream as study samples. ICP accelerometer and computer software Dewesoft7 have been used to measure and analyse the level of vibration generated. The results indicate heavy vehicles at a speed of 50 km/h, 33 km/h and 24km/h generate ground vibration level of 1.24 mm/s, 2.30 mm/s and 0.76 mm/s respectively. Other factors such as the weight of the heavy vehicles may involve in ground vibration generation mechanism as the results shown that there was no direct correlation between vehicle speed and level of ground vibration. All the generated ground vibration levels were found to be within the allowable limit set by Department of Environment Malaysia (DOE) standard guidelines.

Keywords: Ground vibration; transverse rumble strip; heavy vehicle; road safety

INTRODUCTION

Transverse rumble strips (TRS) (Figure 1) are widely used in Malaysia. It is a group of perpendicular lines across the road and is arranged parallel to the traffic flow. Through the combination of vibration, noise and visual stimuli, TRS function is to reduce vehicle speed and enhance driver alertness on the dangers ahead (Bahar et al. 2005). TRS has found to be effective in its role to reduce vehicle speed and accidents (Liu et al. 2011; Yang et al. 2016).

However, the presence of TRS on road leads to unevenness on the surface of the road. This may result in ground vibration when heavy vehicles pass over it. This vibration is feared to cause discomfort to residents who are living adjacent to the road. Therefore, there is a need to evaluate what factors contribute to the ground vibration levels.

FIGURE 1. Typical transverse rumble strips in Kluang-Batu Pahat Road FT050

To address this question, two objectives have been developed in which to evaluate the relationship between the speed of the heavy vehicles and the level of ground vibration that will be generated when they pass over the

TRS. Next is, to assess whether the generated ground vibration level has potential to disturb local residents who live nearby. The level of vibration was then collected in peak particle velocity with unit mm/s on three axes, x, y and z. The value of peak particle from data collection is compared to the guidelines from the Department of Environment (DOE) Malaysia to determine whether it is within the DOE allowable limit (DOE 2007).

GROUND VIBRATION FROM HEAVY VEHICLES

Ground vibration can be a severe concern for nearby neighbors of a transit system route or maintenance facility, causing buildings to shake and hearing rumbling sounds (Hanson et al. 2012). The effects of ground vibration include feelable movement of the building floors, the rattling of windows, shaking of items on shelves or hanging on walls, and rumbling sounds. In extreme cases, the vibration can cause damage to buildings. Annoyance from vibration often occurs when the vibration exceeds the threshold of perception by only a small margin (Sica et al. 2014).

The main factors influencing the vibration levels caused by traffic are shown in Table 1. These factors include its sources, transmission path, and receiver. One study evaluates the ground vibration levels generated from heavy vehicles passing over speed hump. It found that the higher the speed of the vehicle, the higher ground vibration level produced by the vehicles and it also depends on the weight of a vehicle (Fozi et al. 2019).

TABLE 1. Factor affecting vibration

Sources	Transmission path	Receiver
1. Surface condition	1. Distance	1. Building parameter
2. Vehicle parameter	2. Soil/ground absorption	2. Receiver location
3. Vehicle speed	3. Ground topography	

Source: Blekhman and Kremer (2017)

TABLE 2. Recommended limit by DOE (DOE, 2007)

Receiving Land Use Category	Day Time 7.00 am -10.00 pm	Night Time 10.00 pm -7.00 am
Vibration Sensitive Areas	Curve 1	Curve 1
Residential	Curve 8 to Curve 16	Curve 4
Commercials, Business	Curve 16 to Curve 20	Curve 16 to Curve 20
Industrial	Curve 32	Curve 32

Ground vibration occurs due to the interaction between dynamic forces generated by a vehicle's tires on the highways and road surface roughness. Typically, road surface unevenness can cause dynamic force which is 15% greater than static force (Hanson et al. 2004). In the context of TRS application, the TRS across the road that functions to increase the driver's sensitivity are taken into account as one of the sources of vibration. Furthermore, the speed of the vehicle moving through this uneven road with the presence of a transverse rumble strip will result in varying vibration results. With the combined mass of the vehicle and the speed of the vehicle, the resulting ground vibration is at a high amplitude that it can have a significant impact on the people around it (Blekhman & Kremer 2017).

Malaysian Department of Environment has come up with standard guidelines that set the allowable limit of ground vibration level as shown in Table 2 and Figure 2. The ground vibration limit depends on the vibration frequency, time and land category. When the vibration level exceeds this allowable limit, it may cause annoyance to local residents.

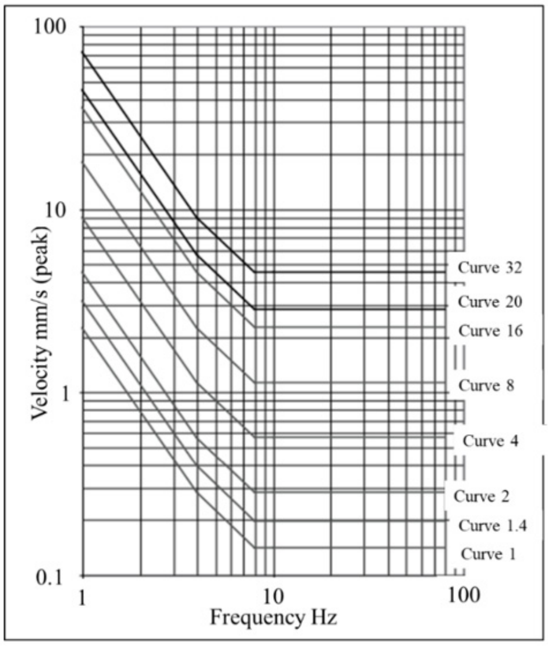


FIGURE 2. Limit of vibration on z-axis (DOE 2007)

METHODOLOGY

EQUIPMENT AND SOFTWARE

ICP accelerometer works as a vibration sensor. Each generated vibration will be measured before being sent to the data acquisition unit. The vibration was measured in peak particle velocity (PPV) in unit of mm/s. The vibration is sensed through the piezoelectric effect as an electric charge proportional to the force applied to it. The following features further characterize the ICP accelerometer: 1) The voltage sensitivity is fixed, regardless of the type or length of the cable, 2) Long cable can be used to transmit signals in any environment with virtually no loss in terms of signal quality, 3) Low noise, voltage output signal corresponding to readings of the recorder, 4) Able to read the vibration level through three different axes. That is the x-axes, y-axes, and z-axes. Figure 3 illustrated the installation setup of the ICP accelerometer and Figure 4 shows the on-site installation.

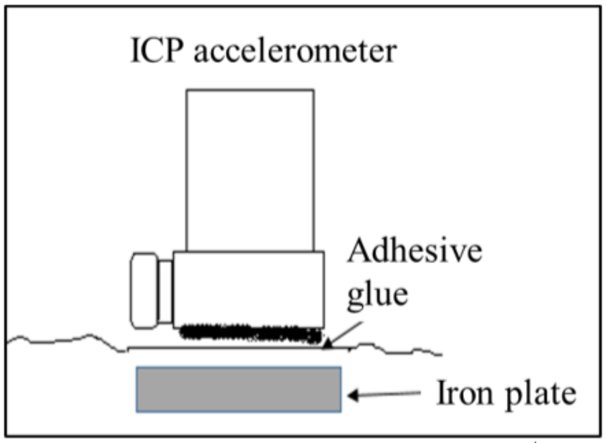


FIGURE 3. ICP acceleration installation

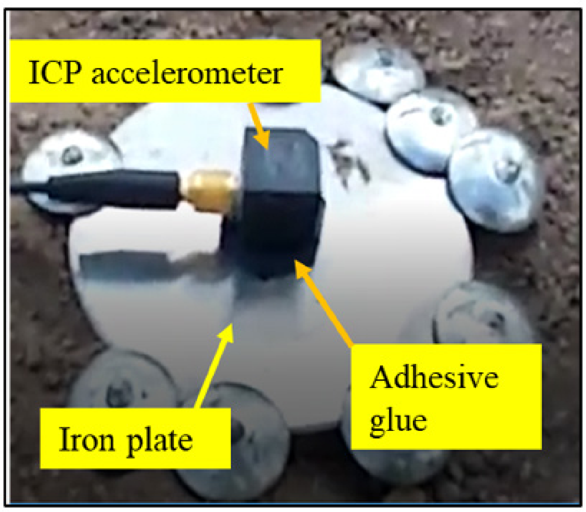


FIGURE 4. ICP acceleration on site

Dewesoft7 is the computer software for analyzing and storing data that were retrieved from the ICP accelerometer. The software could analyze and read the PPV value of the three different axes, the x-axes, the y-axes, and the z-axes.

Data acquisition is used as an intermediate medium between ICP accelerometer and Dewesoft7 computer software. This data acquisition unit works to store as much data as it can record in the data per second. Therefore, the 500Hz frequency has been set in this study as the value is the lowest value that can be applied. This data acquisition unit also has three different channels, which are channel 0, channel one, and channel two, which each represent the z-axis, y-axis, and x-axis, respectively.

A LiDAR gun (Figure 5) is a speed detection device used by law enforcement for traffic control. LiDAR is an acronym for light detection and ranging. Laser Technology's design process for speed equipment is driven by the demands of real-world needs with more vehicles on the road than ever before and multi-lane highways everywhere, enforcing the speed limit accurately and efficiently is an absolute must. In this study, this equipment has been used to measure the speed of a heavy vehicle that passes the transverse rumble strip. LiDAR speed gun transmits the laser to the rear of the vehicles and then processes the signal that will be received by using the microprocessor. The data received were in speed parameter in a unit km/h.

FIGURE 5. Uses of LiDAR speed gun to measure the speed

DATA COLLECTION PROCEDURE

The measurement set up was following traffic noise measurement study as stated in ISO 11819- 1:2001 (ISO 2001). The ICP accelerometer was set up at distance of 7.5 m from the travel lane as shown in Figure 6. For every selected heavy vehicle, the speed was recorded by LiDAR gun and class of vehicle was recorded manually. The generated ground vibration level in PPV was recorded. The data collections were conducted during day time and in good weather.

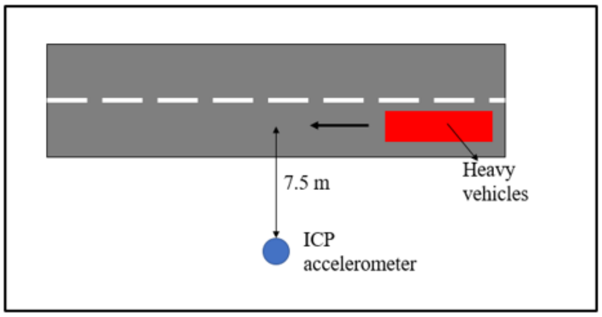


FIGURE 6. Data collection layout

The ground vibration that generated from heavy vehicles crossing the TRS were propagated to surroundings in every direction. The resulting vibrations are different due to several factors, which were the mass of the vehicle and the speed of the vehicles. Therefore, the vibration sensor was installed in the middle of the TRS set to get the average PPV. Figure 7 shows the sample of display data in Dewesoft7 software.

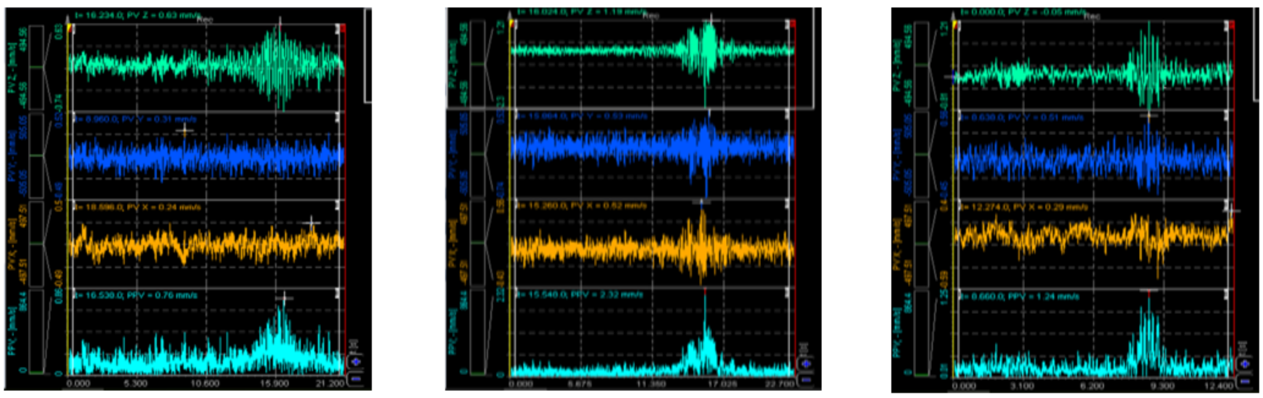
RESULTS AND DISCUSSIONS

The results of data collection are shown in Table 3, and the values of the PPV were then used to evaluate either the resulting vibration level exceeds the limit in terms of human comfort issued by the Department of Environment (DOE).

Results from Table 3 show that heavy vehicles at a speed of 50 km/h generated ground vibration level of 1.24 mm/s. Meanwhile, at the speed of 33 km/h, the ground velocity of 2.30 mm/s has been recorded. At a speed of 24 km/h, the ground vibration velocity is 0.76 mm/s. Ground vibration levels that peak at 33 km/h compares to lower and high speeds may be due to effect of weight of the vehicles, which were might be heavier for the vehicles at 33 km/h.

EVALUATION LEVEL OF VIBRATION TOWARDS HUMAN COMFORT

DOE guidelines were used to estimate the comfort level of residents living nearby the TRS. For this study, the graph



(a) Speed - 24 km/h PPV - 0.76 mm/s

(b) Speed - 33 km/h PPV - 2.30 mm/s

(c) Speed - 50 km/h PPV - 1.24 mm/s

FIGURE 7 . The time domain graph of peak particle velocity (PPV)

TABLE 3. The recorded vibration level data

No.	Type of vehicles	Speed(km/h)	Peak particle velocity (mm/s)	Class of vehicles
1	Lorry 1 ton	38	0.60	Class 2
2	Lorry 1 ton	48	0.45	Class 2
3	Lorry 1 ton	46	1.20	Class 2
4	Lorry 1 ton	40	1.11	Class 2
5	Lorry 1 ton	24	0.76	Class 2
6	Lorry 6 tyres	46	0.88	Class 3
7	Lorry 6 tyres	27	1.36	Class 3
8	Lorry 6 tyres	42	1.32	Class 3
9	Lorry 6 tyres	50	1.24	Class 3

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10	Lorry 6 tyres	45	1.01	Class 3
11	Lorry 6 tyres	45	1.24	Class 3
12	Lorry 10 tyres	44	1.02	Class 3
13	Lorry 10 tyres	49	1.14	Class 3
14	Lorry container	42	1.56	Class 3
15	Lorry container	33	2.30	Class 3
16	Lorry container	35	1.96	Class 3
17	Bus	44	1.12	Class 5
18	Bus	42	0.88	Class 5

TABLE 4. Data from the study

Data no.	Type of vehicles	Velocity Z-axis (mm/s)
1.	Lorry 1 ton	0.56
2.	Lorry 1 ton	0.41
3.	Lorry 1 ton	1.18
4.	Lorry 1 ton	1.11
5.	Lorry 1 ton	0.63
6.	Lorry 6 tyre	0.85
7.	Lorry 6 tyre	1.10
8.	Lorry 6 tyre	1.31
9.	Lorry 6 tyre	1.21
10.	Lorry 6 tyre	0.99
11.	Lorry 6 tyre	1.23
12.	Lorry 10 tyre	0.93
13.	Lorry 10 tyre	1.13
14.	Lorry container	1.57
15.	Lorry container	1.17
16.	Lorry container	1.68
17.	Bus	1.08
18.	Bus	0.88

z-axis for the peak velocity had been referred. According to the guidelines provided by the DOE, the separation is carried out in accordance with the x-axis, y-axis, and z-axis. Based on this study, all z-axis data has greater values than other axes. Therefore, only z-axis comparisons are taken into account in this study. The z-axis readings are shown in Table 4. In the case study locations, there were two categories of receiving land use that were involved, which is 1) residential and 2) commercial.

Based on Table 2 and Figure 2, as for residential, it involves curve 8 to curve 16, which gives value in the range 1.1 mm/s to 2.2 mm/s. As for commercial buildings, it requires curve 16 to curve 20, which provides the range with a value of the velocity at 2.2 mm/s to 3.0 mm/s. Based on this result, the velocity z-axis on the data collection is still within the allowable limit.

CONCLUSION

Every heavy vehicle crossing the TRS produces ground vibration either at high or low levels. Ground vibration from the vehicles should be identified and measured to determine whether it is capable to disturb the comfort of people in its surroundings. The resulting vibrations are different due to several factors, which were the mass of the vehicle and the speed of the vehicles. The results show that heavy vehicles at a speed of 50 km/h result in a ground vibration level of 1.24 mm/s. Meanwhile, at the speed of 33 km/h, the ground velocity of 2.30 mm/s has been recorded. At a speed of 24 km/h, the ground vibration velocity is 0.76 mm/s. Ground vibration levels peak at 33 km/h compared to lower and high speeds may be due to the floating effect. This study also found that the level of ground vibration produced is not exceeding the limit set by the Department of Environment (DOE) Malaysia.

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DECLARATION OF COMPETING INTEREST

None.

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