Impulsivity of Noise due to Single Lightweight Vehicles Transit on Transverse Rumble Strip

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Abstract. Transverse Rumble Strips (TRS) acts as safety device that alert inattentive drivers from potential dangers. However, the noise produced due to TRS was reported as noise annoyance among the nearby residents lived adjacent to roadways. Thus, this paper investigates the impulsivity characteristic of noise due to single lightweight vehicles transit on TRS. The objectives of this study are to determine the increase of sound level and to evaluate the impulsivity of noise. Two TRS profiles namely middle overlapped (MO) and middle layer overlapped (MLO) were selected. Three types of single lightweight vehicles which include hatchback, sedan and multipurpose (MPV) were tested at speed of 30, 50 and 70km/h. The sound level was measured using sound level meter (SLM). Noise indices such as L_{Aeq}, L_{AIeqT}, L_{AImax}, L_{AFmax} and L_{ASmax} were obtained from the measurement. This study considered the differences of $L_{AImax} - L_{AFmax} >$ 2dBA, $L_{AFmax} - L_{Aeq} \geq$ 10dBA, $L_{AIeqT} - L_{Aeq} \geq$ 2dBA and $L_{AImax} - L_{ASmax} >$ 6dBA to evaluate the impulsivity of noise. It was found that TRS increased the sound level by at most of 6dBA. Furthermore, all single lightweight vehicles transit on TRS show significant impulsive characteristic. These results proved that TRS produce significant impact to the nearby residents.

1 Introduction

Transverse rumble strip (TRS) is one of the configurations of rumble strip installed on roadways apart from centreline rumble strip (CRS) and shoulder rumble strip (SRS). In Malaysia, TRS is commonly installed with various types of profiles such as middle overlapped, middle layer overlapped and raised rumble strip. It is usually installed at residential or urban area, which acts as one of the countermeasures in reducing traffic accident [1]. It alerts the inattentive and distracted drivers from potential dangers by transmitting sound and vibration through a vehicle. The sound and vibration will produce once the vehicle's tire interacts with the TRS surface. Installation of TRS helps to reduce accidents at pedestrian crosswalks, head-on collision, run off road crashes, fatal crashes and other potential accidents [2-6].

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Several complaints were made by the nearby residents who lived adjacent to the roadways regarding the rumble strips noise annoyance. Thus, attempts had been made to find the extent of increase sound level, L_{Aeq} toward the noise annoyance incur by the rumble strip installations. In the case of CRS, a study reported that noise produced is a trade-off from the safety as it was 60dBA at distance of 60m away from roadway [7]. Furthermore, it was also found that noise produced is enough to be noticed by a normal human at a distance up to 45m away from the CRS [8]. On the other hand, TRS has increased noise level by 7dBA at a distance of 15m [9]. Besides that, installation of TRS at residential areas may generate noticeable noise that can be detected by the nearby residents as much as 4.5 dBA at 70km/h [10].

Beside the increase in sound level, most guidelines suggest the extent of impulsive characteristic of sound in order to examine the extent of noise annoyance. In Malaysia, Department of Environment (DOE) provides a penalty of 5dBA to the measured equivalent continuous A-weighted sound pressure level, L_{Aeq} for estimating annoyance [11]. However, impulsive characteristic of noise produced by the TRS application is very limited. Impulsive characteristic of noise annoys the nearby residents more than the normal continuous noise. It is also must be included in the guidelines by the local authority. Therefore, this study was conducted to investigate the impulsivity characteristic of noise due to single lightweight vehicles transit on TRS by determining the increase of sound level and evaluating the impulsivity of noise.

2 Methodology

2.1 Sound level due to single lightweight vehicles

In this study, middle overlapped (MO) and middle layer overlapped (MLO) were selected. The details of both TRS types were shown in Table 1. The TRS and road surfaces at the selected sites were in good and dry conditions. Both roadways at two sites are straight as required by the ISO 13325 [12]. Meanwhile, Table 2 shows the three types of selected test vehicle such as hatchback (Axia), sedan (Saga) and multipurpose (Alza). These vehicles were selected because they are typical cars used on the roadways in Malaysia. The same test vehicles were used throughout the measurement for both TRS types in order to avoid the effect of vehicle type and road condition [13]. All single vehicles were drove over both TRS types at running speeds of 30, 50 and 70km/h. These running speeds were tested as required by the PWD guideline [14].

A Type 1 Pulsar Model 33 sound level meter (SLM) was used to measure the sound level due these single lightweight vehicles transit on the TRS. The SLM was calibrated prior and after measurement using Model 105 acoustic calibrator in order to avoid reading error. It was set up at 1.5m above the ground level and 7.5m away from the middle of nearest travel lane as shown in Fig. 1. Each site has two measurement points where the distance between Point 1 and Point 2 is 300m which is sufficient for noise dissipation [15]. The measurement was repeated three times for each running speed in order to obtain the average value. The single vehicle test was conducted using controlled pass-by, a method derived from coast-by method [12]. This method can directly measure the tire-pavement noise due to single vehicle in free flowing and at constant vehicle speed.

Table 1. TRS profile types.

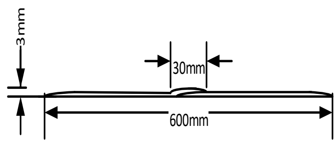
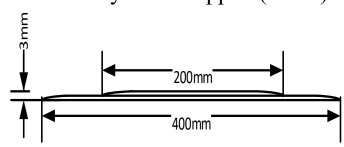
Types of TRS profiles	Middle overlapped (MO) 	Middle layer overlapped (MLO) 
Thickness, mm	3	3
Width, mm	600	400
Spacing, mm	2350	2450
Length, mm	3350	2800
Number of strip	33	30

Table 2. Details of test vehicle.

Types of test vehicle	Hatchback 	Sedan 	Multipurpose 
Model	Perodua Axia	Proton Saga	Perodua Alza
Year	2016	2013	2007
Weight, kg	840	1017	1145
Displacement, cc	1.0	1.3	1.5
Tire Size	175/50 R14	195/55 R15	185/55 R15

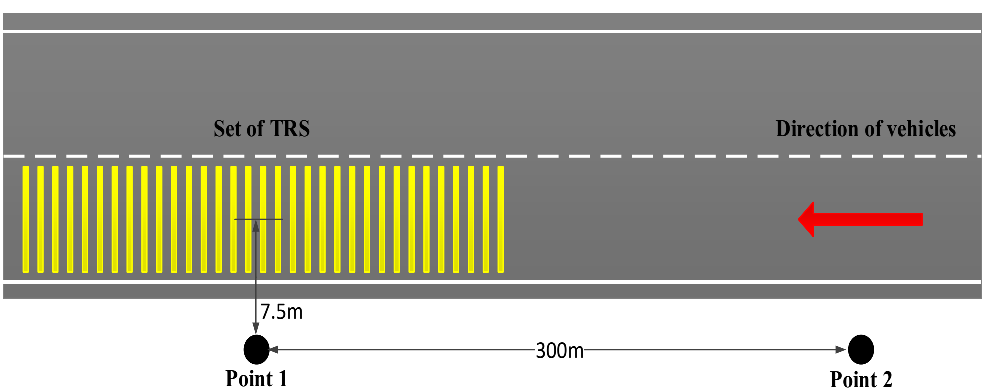


Fig. 1. Measurement layout.

2.2 Impulsivity due to single lightweight vehicles

The impulsive characteristic of noise was detected objectively using the following methods. The first one is by comparing the A-weighted maximum noise level between fast response (L_{AFmax}) with the equivalent A-weighted sound pressure level (L_{Aeq}), difference value of ≥10dB [16]. Besides that, the difference between A-weighted impulse sound pressure level, determined with time-weighting characteristic I (L_{AIeqT}), averaged over the same time interval and L_{Aeq} also can detect the impulsivity. A difference value of ≥2dB would indicate an impulsive characteristic [17]. Meanwhile, the third method is by comparing L_{AFmax} and A-weighted maximum impulse response (L_{AImax}) with >2dB difference value [18]. The last method is by comparing A-weighted, slow, maximum sound level (L_{ASmax}) with L_{AImax}. If the difference is ≥6dB, impulsive characteristic occurs [19].

3 Results and discussions

3.1 Sound level due to single lightweight vehicles

In this study, sound levels due to all types of single lightweight vehicles driven through both types of TRS were recorded by the SLM at Point 1. Fig. 2 to Fig. 7 shows the sound level (L_{Aeq}) versus time history of hatchback, sedan and MPV driven through MO and MLO and its differences with baseline (roadside sound level without TRS). The peak noise levels were shown at 6th second when the vehicle was directly in front of SLM at Point 1. The L_{Aeq} values produced due to single vehicles driven through roadways with and without TRS were presented using solid and dotted lines respectively. It can be observed that MO has significant lower sound level increment with peak level of 2.4dBA (hatchback) as compared to MLO with peak level of 6.6dBA (MPV). Besides that, hatchback and sedan which has lower engine power recorded lower sound level increment as compared to MPV.

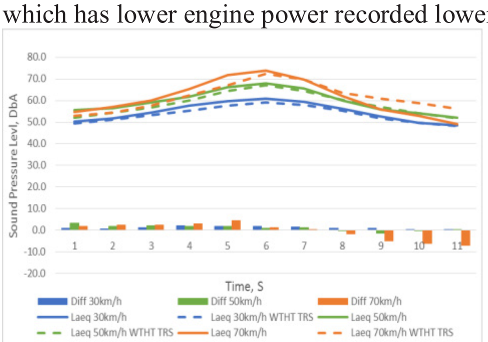


Fig. 2. L_{Aeq} vs. time using hatchback at MO.

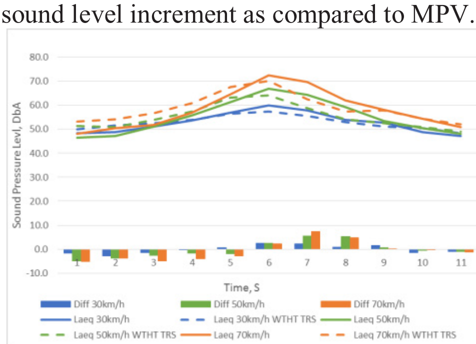


Fig. 3. L_{Aeq} vs. time using hatchback at MLO.

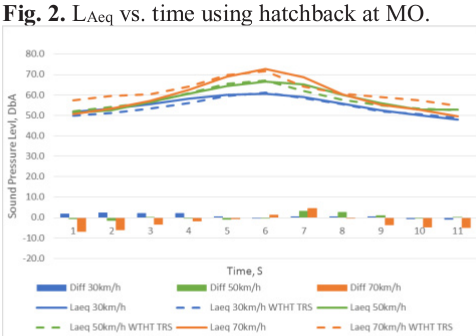


Fig. 4. L_{Aeq} vs. time using sedan at MO.

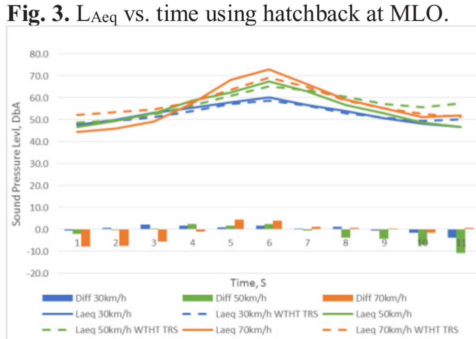


Fig. 5. L_{Aeq} vs. time using sedan at MLO.

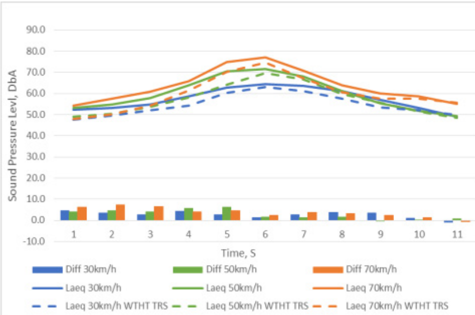


Fig. 6. L_{Aeq} vs. time using MPV at MO.

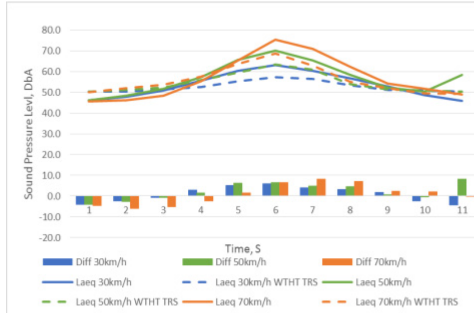


Fig. 7. L_{Aeq} vs. time using MPV at MLO.

Fig. 8 shows the relationship of average increment of L_{Aeq} and vehicle speeds for all vehicle types driven through MO and MLO. It is noted that the average increment of L_{Aeq} values for vehicles driven through MLO are higher than MO. It can be seen that only hatchback driven through both TRS types not recorded any increment for all vehicle speeds. At speeds of 30 and 50km/h, the increments are very low or the same where the values are below 3dBA. However, sedan at speed of 70 km/h and MPV at all three speeds driven through both TRS types recorded increment over 6dBA. There are no significant increments for low power engine vehicles such as hatchback and sedan which can be annoyance to the nearby residents. It shows that the overall average increment of L_{Aeq} values do not give significant impact when measured with L_{Aeq} only.

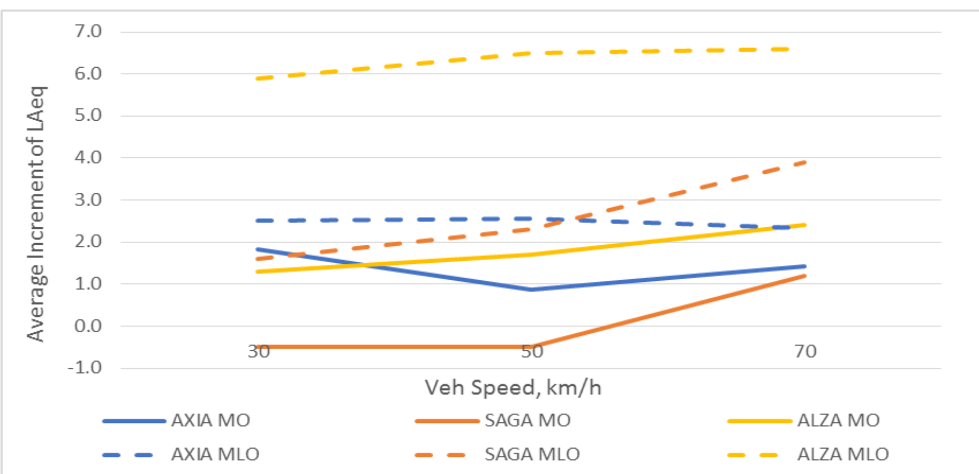


Fig. 8. Average increment of LAeq values versus vehicle speeds.

Other noise indices related to peak L_{Aeq} such as L_{AFmax}, L_{AImax}, L_{AIeqT} and L_{ASmax} were also evaluated. The values were compared with baseline of normal road (L_{AFmaxw}, L_{AImaxw}, L_{AIeqTw} and LA_{Smaxw}) as in Table 3. Some of the values are characterized by an increment for all vehicle speeds. However, most of the values shows the increment at speed of 30 to 50km/h whereas decrement at speed of 50 to 70km/h. This may be due to the values at higher speed were influenced by the sound produced by the power engine of the testing vehicles. Other than that, the values for all noise indices show decrement as compared to baseline at speed of 30km/h. There are also values decrement for hatchback and sedan at noise indices of L_{AFmax}, L_{AImax} and L_{ASmax} as compared to MPV. This can be assumed that the TRS act as a sound damper when vehicles are moving at low speed and power engines.

Table 3. Noise indices.

Vehicle types	TRS types	Speed, km/h	L_{Aeq}	L_{AFmax}	L_{AImax}	L_{AIeq}	L_{ASmax}	L_{Aeq}- L_{Aeqw}	L_{AFmax}- L_{AFmax}	L_{AImax}- L_{AImaxw}	L_{AIeq}- L_{AIeqw}	L_{ASmax}- L_{ASmax}
			dBA									
Hatchback	MO	30	59.9	81.8	84.2	61.4	74.6	2.5	-2.9	-1.0	3.2	-7.8
	MLO		61.0	73.6	77.4	61.8	68.7	1.8	-3.7	-3.5	1.9	-6.1
	MO	50	66.7	83.5	85.2	68.6	79.4	2.5	0.9	2.0	3.2	1.3
	MLO		68.1	86.0	87.3	69.1	83.9	0.9	7.3	6.4	1.2	9.6
	MO	70	72.3	80.2	81.8	74.2	75.1	2.3	4.9	5.3	3.1	2.8
	MLO		73.9	75.3	77.5	75.6	73.1	1.5	-9.3	-9.4	2.6	-5.1
Sedan	MO	30	60.3	81.8	84.2	61.1	74.6	1.6	-3.8	-2.5	1.9	-7.8
	MLO		60.6	74.7	78.6	61.4	69.0	-0.5	-11.6	-9.0	-0.7	-14.3
	MO	50	67.6	83.6	85.2	69.3	80.6	2.3	1.0	2.0	3.5	2.5
	MLO		66.6	86.0	87.3	67.5	83.9	-0.5	7.3	6.4	-1.1	9.6
	MO	70	73.1	82.3	85.5	75.6	75.3	3.9	4.3	6.2	5.9	0.7
	MLO		72.7	75.4	77.5	73.8	73.3	1.2	-9.2	-9.4	-0.3	-4.9
MPV	MO	30	63.1	77.1	79.7	64.3	71.8	5.9	-2.8	-0.9	6.6	-5.4
	MLO		64.5	83.6	84.4	65.3	81.4	1.3	14.3	13.5	1.5	14.4
	MO	50	70.0	77.7	81.3	71.5	69.7	6.5	1.1	3.1	7.5	-2.2
	MLO		71.5	78.6	80.3	72.6	76.3	1.7	5.1	6.2	2.1	4.5
	MO	70	75.2	76.9	78.6	76.6	74.0	6.5	-2.2	-2.1	7.2	0.5
	MLO		77.0	88.4	90.1	78.6	84.8	2.4	-8.1	-7.2	2.6	-8.0

3.2 Impulsivity due to single lightweight vehicles

Fig. 9 to Fig. 12 shows that impulsive characteristics exist for all types of vehicles driven through both TRS types at different running speeds. Based on Fig. 9, most of lightweight vehicles transit on both TRS at lower speed recorded difference values > 2dBA for L_{AImax} –

L_{AFmax}. Similar results were also recorded for $L_{AFmax} - L_{Aeq} \geq 10dBA$ as in Fig. 10. Meanwhile, for $L_{AIeqT} - L_{Aeq}$, most of the vehicles recorded values of < 2dBA except for sedan driven through MLO at speed of 70km/h which show no significant impulsivity. However, for $L_{AImax} - L_{ASmax}$, most of the vehicles at different speed driven through both TRS types show impulsivity of > 6dBA. As compared to hatchback and sedan, MPV shows less impulsivity for both TRS types at higher speed. In overall, all single lightweight vehicles transit on TRS show significant impulsive characteristic.

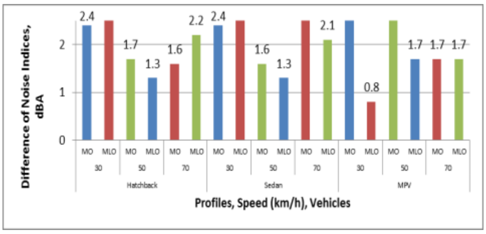


Fig. 9. $L_{AImax} - L_{AFmax}$

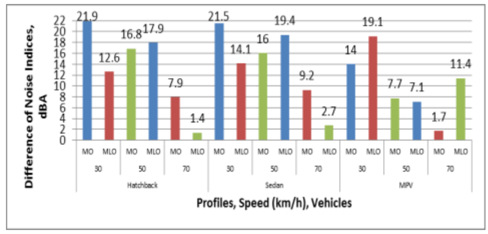


Fig. 10. $L_{AFmax} - L_{Aeq} \geq 10dBA$

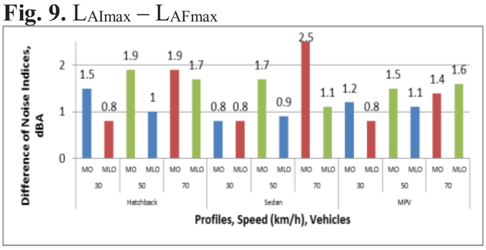


Fig. 11. $L_{AIeqT} - L_{Aeq}$

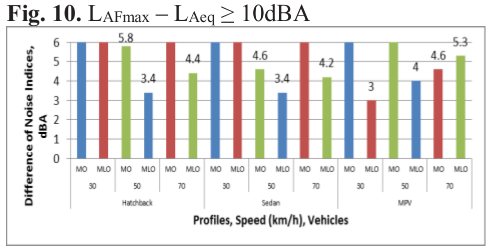


Fig. 12. $L_{AImax} - L_{ASmax}$

4 Conclusions

In conclusion, this study has investigated the impulsivity characteristic of noise due to hatchback, sedan and MPV transit on MO and MLO at speeds of 30, 50 and 70km/h. It was found that MO has significant lower sound level increment with peak level of 2.4dBA (hatchback) as compared to MLO with peak level of 6.6dBA (MPV). Besides that, hatchback and sedan has lower engine power recorded lower sound level increment as compared to MPV. Overall average increment of L_{Aeq} values does not give significant impact when measured with L_{Aeq} only. Based on other noise indices such as L_{AFmax}, L_{AImax}, L_{AIeqT} and L_{ASmax}, it can be assumed that the TRS act as a sound damper when vehicles are moving at low speed and power engines. Finally, all single lightweight vehicles transit on TRS show significant impulsive characteristic, which may affect the nearby residents.

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