Assessment of Community Noise Annoyance due to Transverse Rumble Strips Installation at Residential Areas

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Abstract. Transverse rumble strips (TRS) acts as a traffic calming device to alert inattentive drivers, however, inappropriate design may generate excessive noise level which cause annoyance among the nearby residents. This study attempts to assess community noise annoyance by investigating current TRS designs and characteristics, measuring roadside noise level and traffic characteristics and evaluating noise annoyance due to TRS installation. Middle overlapped (MO), middle layer overlapped (MLO) and raised rumbler (RR) TRS profile types were selected. Noise indices such as A-weighted equivalent continuous sound pressure level ($L_{Aeq}$), sound level exceeding 10% ($L_{10}$) and 90% ($L_{90}$) of specified time were measured using sound level meter (SLM) based on ISO 11819 - 1: 2001 Acoustics: Measurement of the influence of road surfaces on traffic noise - Part 1: statistical pass-by (SPB) method. Traffic characteristics such as volume and speed were also measured. Then, community noise annoyance was evaluated in terms of $L_{Aeq}$ changes, noise limit comparison by the Department of Environment (DOE) and traffic noise index (TNI) calculation. It was found that there are various TRS profile types with the thickness of only 3mm. Regardless the types, TRS installation has increased the roadside noise level of about 7dBA and exceeded permissible noise limits.

1. Introduction
Traffic calming device helps in reducing unsafe driving practices among the drivers which may cause road traffic accident. Transverse rumble strips (TRS) among other traffic calming devices is a set of transverse strips purposely installed on roadways which considered visual, sound and vibration effects. This is to ensure the driver aware on the upcoming hazards on the roadways [1-2]. It is also known as transverse bars, transverse strips, log strips, speed breakers, in-lane, or travel way rumble strips due its installation’s location which is perpendicular to the traffic flows or vehicle directions. Besides, according to national guidelines, it is also known as yellow transverse bars due to its common colour. In Malaysia, TRS is widely installed at sensitive areas, especially residential, schools and hospitals by the respected local authorities. The TRS installation has been practiced worldwide by many countries such as the United Kingdom (UK) [3], United States of America (USA) [4], China [5], Thailand [6], Korea [7], Italy [8] and Australia [9]. There are several varieties of installation in regard of its configurations, profiles, dimensions and colours. For local TRS installation, it should be installed according to the national TRS guidelines to ensure uniform TRS designs all over the country [10-12].
In terms of colour, yellow coloured TRS is mostly installed in Malaysia [2] and other countries such as the United Kingdom (UK) [3] and China [5]. Besides, colour plays an important role to assist the driver’s alertness on upcoming hazards through visual effect and to avoid the possible unsafe situation on the roadways. According to the road safety facility manual, yellow colour is mainly suggested for TRS installation with the purpose of colour uniformity as a safety signal to the road users [11]. Apart from colour, material is also an important physical characteristic of TRS where thermoplastic, the most common TRS material which known for its durability and cost-saving advantages over elastoplastic, preformed plastic, concrete or asphalt [2-3, 13-14]. For local practice as suggested in the national guidelines, most TRSs are installed uniformly across entire country using thermoplastic material [10-12]. This material is used together with the reflective materials such as glass and microcrystalline ceramic beads to improve visibility and retro reflectivity especially during night-time and raining condition.

On the other hand, the available TRS guidelines lack on detailed explanation of TRS profile. In actual practice, the local authorities and road engineers are responsible on the selection of TRS profile and dimension. For some cases where different TRS profiles generate different sound levels which may cause noise annoyance especially to the residents who live adjacent to the roadways [15]. Due to excessive TRS noise generation, several noise complaints were lodged to the local authorities [16-17]. Furthermore, it is not locally happened but widely spread all over other countries [18-19]. In our local scope, the pioneer TRS study reported that installation of TRS generate noticeable sound level change of as much as 14 dBA [16]. Then, another recent study also highlighted sound level changes of 4 to 6 dBA due to TRS installation [2]. However, there are still few studies on roadside TRS noise have been conducted especially in our local context. Therefore, this study aims to assess community noise annoyance due to TRS installation at residential areas.

2. Methodology
This study was conducted in three main stages based on objectives of the study. The following sections present the details of each stage.

2.1. Investigation of current TRS designs and characteristics
In order to investigate the profile, thickness, width, spacing, length and strip number of TRS, visual investigation and on-site measurement were carried out at the first stage. This study was conducted at three selected residential areas located in Johor state, installed with different TRS profile types as sampling site. The selection criteria include good TRS surface’s condition, located near to residential areas at 70 m away minimum from the nearest traffic light to ensure a consistent traffic flow [20-21]. Besides, the selected roadways must be in a good pavement condition, flat and straight topography. These criteria must be considered to avoid bias of measurement readings. In determining the type and measuring the thickness of selected TRS profile, Barton comb profilometer (BCP) as in figure 1 was used in this study. Both TRS and road surfaces were cleaned off using a brush prior to the measurement to ensure smooth surfaces which required for the measurement reading and TRS profile pattern. The BCP was pressed down on both surfaces to obtain the TRS thickness and profile using BCP teeth. Apart from that, measuring tape was also used in this study to measure TRS width, spacing and length as shown in figure 2.

![Figure 1. Barton comb profilometer.](image1)

![Figure 2. Measuring tape.](image2)
2.2. Measurement of roadside noise level and traffic characteristics due to TRS installation

A-weightage frequency weighting was used in measuring all required data in representing sound in decibel to suit human ear’s sensitivity. Figure 3 shows Type 1 Pulsar Model 33 data logging sound level meter (SLM) and acoustic calibrator, Model 105 - Class 1 with calibration value of 94 dB ± 1 dB @ 1 kHz in compliance with the International Regulations and Codes of Practice. The measurement procedures were conducted for 15 hours (daytime) based on ISO 11819 - 1: 2001 Acoustics: Measurement of the influence of road surfaces on traffic noise - Part 1: statistical pass-by (SPB) method [2, 22]. SLM was installed on a tripod at 1.5 m above ground level, 7.5 m and 3.5 m away from the middle of nearest travel lane and any obstacles, respectively as shown in figure 4 [22, 23]. Point 1 and Point 2 represent with and without TRS, respectively. To avoid the effect of TRS noise, the distance between these points should be greater than 100 m [2, 24]. Meanwhile, wind speed and air temperature were measured using anemometer as in figure 5 must be below 5 m/s and 5 °C to 40 °C, respectively to avoid reading bias [22, 25].

![Figure 3. Sound level meter.](image)

![Figure 4. Measurement layout.](image)

![Figure 5. Anemometer.](image)

In this study, traffic volume and vehicle speed in the units of vehicle per hour (veh/h) and kilometre/hour (km/h), respectively were also measured among other contributing factors of higher traffic noise level [19]. All required traffic data was measured using MetroCount (MC5600) Series Vehicle Classifier System, an automatic traffic counter (ATC) which basically consists of a data recorder and two pneumatic tubes. The tubes were secured in parallel with nails and steal cleats on the flat pavement surface at one-metre spacing perpendicularly across the roadways. The tubes ends were connected to the data recorder and tightly tied to secure the air sensor within the tube. In avoiding any loss or damage, the instrument was kept in a safety box secured with steel chain and padlock which positioned at the roadside. One week measurement was conducted which focused on three days (Monday to Wednesday) within the middle of the week. Besides, the start and end days of the week were excluded in order to avoid different traffic behaviours such as vehicle speed and traffic volume.

2.3. Evaluation of noise annoyance due to TRS installation

The difference between with and without TRS measured noise levels were first evaluated. Basically, 3 dBA, 5 dBA and 10 dBA changes were considered just discernible, clearly discernible and perceived as a doubling or halving of volume, respectively [26]. Besides, the noise levels were also compared with $L_{90} + 10$ dB and 60 dBA permissible limits under Schedule 2 and Schedule 4 in the DOE guidelines [23]. In this study, all selected sampling sites are located at the roadside within 7.5 m from the middle of nearest lane. These limits are applicable for daytime noise exposure as the roadside noise measurements were conducted for 15-hour starting from 7 a.m. to 10 p.m. excluding night-time. Both $L_{Aeq}$ and $L_{90}$ values obtained from this study were compared with these permissible noise limits. Then, the noise annoyance was also evaluated using TNI as in equation (1) [16]. TNI values should not exceed 74 dBA to avoid annoyance among the nearby residents.

$$TNI = 4(L_{10} - L_{90}) + L_{90} - 30$$  \hspace{1cm} (1)
where, $TNI$ is traffic noise index, $L_{10}$ and $L_{90}$ are sound levels exceeding 10% and 90% of specified measurement time, respectively, and 30 is the constant value.

3. Results and discussions
The following sub-sections present the finding of this study.

3.1. Current TRS designs and characteristics
Generally, the selection of TRS profile type is dependent on the judgment of local authorities where middle overlapped (MO), middle layer overlapped (MLO) and raised rumbler (RR) are common profile types. First two profile types were mostly found around Johor Bahru and Iskandar Puteri City Councils, Pasir Gudang and Kulai Municipal Councils. Meanwhile, RR profile was usually installed in Batu Pahat, Muar and Pontian Municipal Councils. Table 1 summarizes the designs and characteristics of MO, MLO and RR. The MO and MLO profiles are located under Iskandar Puteri city council territory, whereas RR is located under Batu Pahat municipal council. The optimum thickness for all TRS profile is 3 mm as suggested by previous study [2]. Meanwhile, the width, spacing, length and TRS strip number were between 400 to 600 mm, 2.35 to 2.50 m, 2.80 to 3.35 m and 20 to 33 strips, respectively.

| TRS profile | MO | MLO | RR |
|-------------|----|-----|----|
| Thickness (mm) | 3  | 3   | 3  |
| Width (mm) | 600 | 400 | 500 |
| Spacing (mm) | 2350 | 2450 | 2500 |
| Length (mm) | 3350 | 2800 | 3000 |
| Strip number | 33 | 30  | 20  |

### Table 1. TRS designs and characteristics.

Actual configuration

3.2. Roadside noise level due to TRS installation
Based on the measurement, 15-hour roadside noise levels at three residential areas are in range of 60 dBA to 75 dBA as shown in figure 6. Sites installed with RR and without MLO recorded the highest and lowest noise levels, respectively. All sampling sites recorded noise level increment during morning and evening peak hours where RR generated the highest $L_{Aeq}$ for both with and without TRS followed by MO and MLO. All readings due to TRS were higher than without TRS for all profiles indicates that regardless profile types, TRS installation has increased the actual roadside noise level. Similar to the previous studies, it was found that the average $L_{Aeq}$ of this study at residential area was 70 dBA [27]. Meanwhile, average $L_{Aeq}$ values of 69.1 dBA and 71.4 dBA were recorded at two different schools located in Johor [28]. Apart from TRS installation, vehicle speed and traffic volume play important factor in affecting roadside noise level.

3.3. Traffic Volume and Vehicle Speed
Among the sampling sites, MO recorded the highest average traffic volume of 1124 veh/h followed by MLO and RR of 398 veh/h and 491 veh/h, respectively as shown in figure 7. With traffic volume of more than double than the other two sites, MO is the busiest roadway. Meanwhile, figure 8 shows that RR recorded the highest vehicle speed which exceeded the posted speed limit of 60 km/h. Thus, there is significant difference of speed between Site 3: RR with Site 1: MO and Site 2: MLO.
Figure 6. 15-hour roadside noise level.

Figure 7. Traffic volume.

Figure 8. Vehicle speed.

3.4. $L_{Aeq}$ Changes
Figure 9 shows that $L_{Aeq}$ changes during peak hours were higher as compared to non-peak hours for all TRS profiles. The highest and lowest $L_{Aeq}$ changes of 6.7 dBA and 0.8 dBA were recorded by MLO and RR, respectively. It also was found that RR shows insignificant changes of less than 3 dBA while MO records discernible changes especially during peak hours except for several periods of 11.00 to 12.00 a.m. and 19.00 to 20.00 p.m. On the other hand, MLO exceeded the limit during evening peak hours starting from 17.00 to 20.00 p.m. with the highest reading of 6.7 dBA recorded clearly discernible changes. This finding is in agreement with previous studies of $L_{Aeq}$ changes due to multiple vehicles transited over raised TRS [2, 26] but less than 14 dBA [16-17].
3.5. Permissible Noise Limits Comparison
Based on figure 10, it was also found that all sampling sites have exceeded the permissible $L_{Aeq}$ limit of 60 dBA. On top of that, RR recorded the highest noise level of 74 dBA with maximum reading during morning peak hours while the noise level at the roadway without RR is 71.9 dBA. MO with the readings range from 69.9 to 74 dBA followed after the RR readings. Based on the measurement, except for several higher readings during peak hours, MLO recorded the lowest noise level. Average $L_{Aeq}$ for all readings were found exceeded the permissible value of $L_{90} + 10$ dBA where RR shows the highest difference as presented in figure 11. It is highly potential to cause TRS roadside noise annoyance among the nearby residents. Furthermore, traffic noise exposure at suburban residential areas exceeded the permissible noise exposure limit of 60 dBA as reported by a recent study [27]. Thus, TRS roadside noise may worsen the actual traffic noise condition.

![Figure 9. 15-hour roadside noise level.](image)

![Figure 10. Comparison of $L_{Aeq}$ with a permissible limit of 60 dBA.](image)

![Figure 11. Comparison of average $L_{Aeq}$ with $L_{90} + 10$ dBA.](image)
3.6. Traffic Noise Index

Apart from previous assessment methods, TRS roadside noise was further assessed by using TNI as in figure 12. All sites were found exceeded the TNI value of 74 dBA where RR recorder the highest roadside noise levels for both with and without TRS of 117.5 dBA and 114.7 dBA, respectively. Previous TRS studies were also reported higher values [16-17]. Apart from that, the measured TNI value was obviously violated the specified TNI limit as reported by another related study [28]. Discernible reading of calculated value and the limit showed that it has tendency to cause traffic noise annoyance to the adjacent resident. The highest recorded value at RR may be due to high average speed at the sampling site. On top of that, previous studies have also supported that high vehicle speed caused higher TNI value of roadside noise level [29-30]. In this study, TNI values with and without MLO are lower than MO where MLO recorded the lowest values of 77.4 dBA and 78 dBA for both with and without, respectively.

![Figure 12. Traffic noise index.](image)

4. Conclusions

All in all, MO, MLO and RR with 3 mm thickness are three most common TRS profiles installed on roadways in Malaysia, especially Johor state. They are usually yellow coloured thermoplastic strips which have variety of width, spacing, length and strip number. Basically, the design varies among the districts or states due to the judgement of local authorities on detailed TRS characteristics. This study found that TRS installation at residential areas has significantly increased the roadside noise level by approximately 7 dBA due to MLO installation. It was clearly perceptible to adjacent residents, which resulted in noise complaint. Other than that, all measured roadside noise levels have exceeded the permissible noise limits. It shows that roadside noise exposure due to TRS installation have affect the nearby residents in terms of noise annoyance. Therefore, this study may assist related authorities in selecting suitable TRS profile for future TRS installation on roadways.

5. References

[1] Datta T K, Gates T J and Savolainen P T 2012 Impact of Non-Freeway Rumble Strips - Phase 1 Final Report ORBP No. OR09084A (Michigan: Michigan Department of Transportation) pp 1
[2] Othman M H 2016 Performance and Modelling of Transverse Rumble Strips on Noise and Vibration Stimuli PhD Thesis (Johor Bahru: Universiti Teknologi Malaysia) pp 2
[3] Webster D C and Layfield R E 1993 An assessment of Rumble Strips and Rumble Areas TRL Report No. TRL-PR-33 (Berkshire: Traffic and Transport Resource Centre) pp 1
[4] Yang L, Zhou H, Zhu L and Qu H 2016 Operational effects of transverse rumble strips on approaches to high-speed intersections, Transp. Res. Rec. 2602 78–87
[5] Liu P, Huang J, Wang W and Xu C 2011 Effects of transverse rumble strips on safety of pedestrian crosswalks on rural roads in China, Accid. Anal. and Prev. 43(6) 1947–1954
[6] Thanasupsin K, Kulso K, Nilkhet M and Srisurapanon V 2011 Effectiveness of thermoplastic transverse rumble strips on a two-lane rural highway, Jour. of the East. Asia Soc. for Transp. Stud. 9 1812–1822

[7] Lee J J, An D S, Lim J K, Kwon S A, Son H J and Eo M S 2013 Fundamental study of traffic noise characteristic due to change transverse rumble strip shape, Adv. Mat. Res. 723 113–120

[8] Sabato A and Niezrecki C 2016 Rumble strips noise emission effects on urban road traffic, Proc. National Conf. on Noise Control Engineering: Revolution in Noise Control (Rhode Island)

[9] Mainroads Western Australia 2017 Guideline Rumble Strips (Australia: The Government of Western Australia) pp 7

[10] Public Works Department 2014 Manual Fasiliti Keselamatan Jalan (Kuala Lumpur: Public Works Department Malaysia) pp 265

[11] Highway Planning Unit 2002 Traffic Calming Guidelines (Malaysia: Ministry of Works) pp 16

[12] Road Engineering Association of Malaysia 2004 Guidelines on Traffic Control and Management Devices Part 4 Pavement Marking and Delineation (Kuala Lumpur: Road Engineering Association of Malaysia) pp 10

[13] Lopez C A 2004 Pavement Marking Handbook (Texas: Texas Department of Transportation) pp 16

[14] Maryland State Highway Administration 2014 Guidelines for Application of Rumble Strips and Rumble Stripes (Maryland: State Highway Administration) pp 20

[15] Boruff D 2019 Rumble Strips and Rumble Stripes Design Memorandum No. 19-01 (Indiana: Indiana Department of Transportation) pp 8

[16] Haron Z, Othman M H, Yahya K, Yaacob H, Hainin M R and Mohd Yusof M B 2012 Noise produced by transverse rumble strips: A case study on rural roadways, IOSR Jour. of Mech.l and Civ. Eng. 1(5) 12–16

[17] Haron Z, Othman M H, Yahya K, Hainin M R and Yaacob H 2013 The effect of application of transverse rumble strips on traffic noise levels, Res. Jour. of Chem. and Env. 17(2) 13–18

[18] Clarkin M 2010 Rumble strips near roundabout to be removed Retrieved on March 2, 2020 from http://archive.fo/WOXUu

[19] Terhaar E and Braslau D 2015 Rumble Strip Noise Evaluation Final Report No. MN/RC 2015-07 (Minnesota: Minnesota Department of Transportation) pp 1

[20] Aziz S Q, Lulusi, Asaari F A H, Ramli N A, Hamidi A A, Mojiri A and Umar M 2012 Assessment of traffic noise pollution in Bukit Mertajam, Malaysia and Erbil City, Iraq, Caspian Jour. of App. Sci. Res. 1(3) 1–11

[21] Suheerth G, Munilakshmi N and Anilkumarreddy C 2017 Mathematical modeling for the prediction of road traffic noise levels in Tirupati Town, Int. Jour. of Eng. Dev. and Res. 5(2) 2091–2098

[22] BSI 2001 BS EN ISO 11819-1: 2001 Acoustics-Measurement of the Influence of Road Surfaces on Traffic Noise (Brussels: BSI) pp 10

[23] Department of Environment 2007 The Planning Guidelines for Environmental Noise Limits and Control. (Kuala Lumpur: Ministry of Natural Resources and Environment Malaysia) pp 16

[24] Bahar G and Parkhill M 2005 Synthesis of Practices for the Implementation of Centerline Rumble Strips Proc. Annual Conf. of the Transp. Assoc. of Canada (Alberta)

[25] Pimentel R L, Melo R A De and Rolim I A 2014 Estimation of increases in noise levels due to installation of transverse rumble strips on urban roads, App. Acous. 76 453–461

[26] Darbyshire J L and Young J D 2013 An investigation of sound levels on intensive care units with reference to the WHO guidelines, Critical Care 17 1–8

[27] Abdul Matalib N H, Mashros N, Aminudin E, Zakaria R, Haron Z, Abd Talib M H and Abdul Hamid A R 2018 Disturbance of traffic noise: evaluation on the effects and management on road corridors IOP Conference Series: Earth and Environmental Science. 143 1–9

[28] Hashim M, Misran H F, Yazid S, Nasir N and Che Ngah M S Y 2014 Traffic noise analysis in the school environment in Batu Pahat town, Johor, Malaysia, Geografi 2(2) 66–79

[29] Jamrah A, Al-Omari A and Sharabi R 2006 Evaluation of traffic noise pollution in Amman, Jordan, Env. Mon. and Ass. 120 499–525
[30] Marathe P D 2012 Traffic noise pollution, *IJED* 9(1) 63–68

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