The Effect of Application of Transverse Rumble Strips on Traffic Noise Levels

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Abstract
Transverse rumble strips (TRS) are widely used by local authorities to reduce vehicle speed and to alert the driver of road conditions ahead. This study investigated the application and effects of installation of TRS on the roadway to the traffic noise climate condition. The evaluations were carried out through changes in noise levels and changes in traffic noise index (TNI) which indicate the dissatisfaction. The samplings were performed at a road installed with two types of TRS which has most noise complaints, located at a highway that passes through a rural area of South Malaysia. Results show that TRS increase the sound level indices $L_{Aeq}$, $L_{10}$, $L_{90}$ significantly and also increase the TNI values. All TNI values exceed the value intended for planning purposes. Therefore, engineers should compromise the environmental effects and the role of TRS as a tool in safety aspect.

Keywords: Transverse rumble strips, traffic safety, pavement markings, noise pollution, traffic noise, traffic noise index, annoyance response.

Introduction
Noise from traffic has become a major pollution experienced by the world's population. The problem becomes worse when homes, clinics, schools and shops are built close to the road without buffer zones or adequate soundproofing. Traffic noise is a combination of all of the sound produced by vehicle in the street. The generation of noise particularly light vehicles is caused by aerodynamic power, vehicle power units and tire/road interactions. The problem is compounded by speeding drivers which cause the tire-pavement interaction as the dominant noise source. Doubling the speed increases traffic noise level as much as 3 dB(A). High traffic noise level can cause annoyance and affect not only cognitive function (learning and understanding) but also cardiovascular disease and adverse effects on mental health. In addition, a recent study in Denmark found that road noise is potentially increasing the risk of stroke. Currently there is a widespread use of TRS as a road safety tool because of its relatively low cost. TRS attract the attention of the driver through the generation of noise and vibration in the vehicle when the vehicle passes through it. TRS can be constructed by grooving pavement surface or installing the raised strips made of thermoplastic material. Grooved TRS have been found to increase noise level between 6-8 dB(A) when measured at 3m from the edge of the roadway. Furthermore, over half of the rumble strip conditions produced changes in the exterior noise greater than 4 decibels. The majority of sound created by grooved type dissipated at approximately 100m. Additionally, noise pollution from groove type produces a pattern of impulsive noise which can cause higher levels of disturbance.

In Asian countries, the use of thermoplastic TRS is very popular, but only little research has been conducted on the effect of thermoplastic TRS installation on traffic noise levels. This is important as it can be used as guidance by the engineers. Therefore, this study was conducted to investigate the changing phenomenon of noise level for a road installed with two types of TRS. Traffic noise level generated by both types of TRS was assessed and interference effects on the population were evaluated using the empirical formula of the TNI.

Material and Methods
Figure 1 shows the sampling site which is located at a highway that passes through rural area of South Malaysia. Initially, saw blade pattern called the raise-inverted (RI) type of TRS were installed in Skudai-Pontian highway (Figure 2a). Due to massive noise complaints from residents, the road was resurfaced in May 2011, at two thirds the length of the RI. As a replacement, new TRS with the same width but different profiles, identified as middle overlapped (MO), with a thickness of 5 mm were installed in the remaining 2/3 of the length (Figure 2b). This leads to a combination of TRS patterns where each strip contains a mixture of RI and MO (RI-MO). Thus, it was found that only left tire hits the MO, while right tire hits the RI.

A sound level meter was used to measure the traffic noise level between 2 points (Figure 3). Point 1 is located in the middle of a set of TRS. At this location, readings were taken twice i.e. one due to installation of RI (before resurfacing) and second due to the effect of RI-MO installation (after resurfacing). At point 2 measurements were carried out 300 m from point 1 to avoid the effect of RI. This position is sufficient because it is larger than the 100 m. At point 2, the pavement was not resurfaced so the measurement is taken only once. Sound level meter was installed at 1.5m height from the ground and 5m away from the road shoulder to represent the actual position of the premises in the village near the road.

To maintain precision of data collection, the sound level was calibrated before and after measurements. The measured noise index was $L_{Aeq}$ (1minute) for 1 hour taken from...
09:00 am to 10:00 am (1st cycle) and 10:00 am to 11:00 am (2nd cycle) during weekdays. 1-hour measurement period can represent the characteristics of real traffic. $L_{Aeq}$ is the constant noise level that expends the same amount of energy as a fluctuating level over the same time period. Further, $L_{10}$, $L_{50}$, $L_{90}$ were obtained using the cumulative frequency of acquired noise level data for 1 hour. $L_{10}$, $L_{50}$ and $L_{90}$ represent the noise level exceeding 10%, 50% and 90% of their time. $L_{10}$ showed the upper end of the level range caused by a vehicle pass-by. This vehicle-pass by can be considered to behave as point sources i.e. its corresponding peak noise level decreases by 6 dB/doubling distance. $L_{90}$ forms the background or the noise of the overall flow of vehicles and acts as a line source that can decrease of only 3 dB per doubling of distance.

Although the noise level obtained is a combination of all noise sources (traffic from two lanes), the effect of RI installation can be found by evaluating the differences in sound level indices between the road with RI (Point 1) and without TRS (Point 2). Further, the differences in sound level indices between road with RI and RI-MO were obtained to determine the effect of installation of RI-MO. The sound level difference is vital as it can relate the human ear perception. The increase in sound pressure level by 3 dB is barely detectable by the human ear, which is similar to doubling the sound source, while an increase of 10 dB is perceived by the human ear as a double the sound. According to the Federal Highway Administration (FHWA) :2000- The Low Cost Treatment for Horizontal Curve Safety, for a residential area, if the increase of sound pressure level is of 10 dBA and $L_{10}$ above 70 dBA, a noise impact will occur and a countermeasure will be necessary to correct this impact.

The TRS installation effects can be measured using the TNI through the following expression:

$$TNI = 4(L_{10} - L_{90}) + (L_{90} - 30)$$

TNI equivalent to 74 dB(A) corresponds to the 3% dissatisfaction and this value is the recommended level for planning purposes to determine the optimum distance to the houses from the road.

The counts of number of vehicles that crossed the point of measurement from either direction on the road were also recorded concurrently with the noise level. This is because halving the traffic volume can reduce traffic noise by 3 dBA. Vehicles travelling the roads were divided into two categories on the basis of their size and engine capacity: light vehicles (motor cycle, medium vehicles, car, taxi, van) and heavy vehicles (bus and trailer). The average speed of vehicles was calculated by recording the time of vehicles passing over a known distance of 25 m.

Results and Discussion

The effects on traffic noise levels: The number of vehicles/hour for the first and second measurement cycle showed that the volume of traffic for one hour is nearly constant with an average of 1405 vehicle/hour and more than half of them travel on the TRS. The amount of vehicles travelling along/ across the lane with TRS was also higher than the smooth lane. It was also found that more than 90% of total vehicles travelling the road are light vehicles and hence becoming a significant contributor to the sound source. Average speed of vehicles is 65 km/h. $L_{Aeq}$ (1 minute) recorded at the point 1 and 2 is shown in Figure 4. The noise level of road without TRS fluctuates over time, from 40 dB (A) to 67 dB (A) and the fluctuations were more pronounced with the road installed with RI ranging from 44 to 82 dB (A). The fluctuation was even higher for road installed with RI-MO i.e. 31 to 95 dB (A) (Figure 4).

Roads with the installation of TRS showed higher traffic noise levels and this can be attributed to by the interaction mechanism between the tire and TRS. Generation of noise due to tire and pavement interaction mechanism has been reported earlier. The interaction of tires and TRS has similarities to the interaction between tire and road surface. Thus, when vehicle moves through TRS, there are four important mechanisms that play a major role in producing sound. They are the effects of tread, texture effects, the effect of running and the air pumping as depicted in Figure 5. Interaction between the tires block of tread and TRS cause radial and tangential vibration in the tire designs and belt and then spread to the sidewalk. Also, the interaction of surface texture and TRS on the tires has the same mechanism of tread blocks effect mechanism. Running deflection will lead to tire/belt vibration while air pumping displaced air into or out of the cavity between the tread and TRS profile.

The frequency distribution of noise level with the road installed with RI, RI-MO and without TRS for cycle 1 and cycle 2 was constructed (Figure 6). $L_{Aeq}$, $L_{10}$, $L_{50}$ and $L_{90}$ of each measurement cycle are shown in figure 7 while the average $L_{Aeq}$, $L_{10}$, $L_{50}$ and $L_{90}$ and their change are shown in table 1. For 10% of the measurement time, sound pressure level increases from 62 (without TRS) to 78 dB(A) (with RI) and additional sound pressure levels as much as 6 dB(A) (with RI-MO). Thus, both TRS increased $L_{10}$ exceed 70 that would give adverse impact and need a proper countermeasure. Taking into account the reduction of 6 dB(A)/doubling distance, one must be at a distance of greater than 10m from the road shoulder to perceive $L_{10}$ value less than 70 dB(A) for the road installed with the RI and greater than 20m for road installed with RI-MO.

Table 1 shows the road installed with RI increases $L_{10}$ of 14 dB (A) or 26% (more than 10 dB (A)), which produces twice the loudness. This increase is higher than that reported by Finley and Miles who found that the TRS with a grooved surface generate additional external sound 13% higher than the highest noise level measured on the smooth road. This is the reason people had complained and asked for help from the authorities to remove the RI. While the $L_{10}$ results from the installation of RI-MO increased to 84 dB (A) or an
increase of 6 dB (A) or 8% and the increase can be perceived by the human ear. For 90% of the measurement time, the noise level increases as much as 9 dB(A) with the installation of RI, however, the replacement with RI-MO reduced the level as much as 7 dB(A). The decrease was caused by the interaction between left tire with RI and the interaction between the left tires and the new pavement. This means that with the installation of RI-MO, the value of $L_{Aeq}$ is similar with the sound level due to the installation of RI obtained at 20m from the road shoulder. Thus, installation of RI-MO would make people feel less annoyance because 90% of the time they are exposed to levels above 45 dB (A).

For $L_{Aeq}$ noise index, the road installed with RI yielded 14 dB (A) or 26% higher than the road without TRS. This was another reason for the complaints made by resident for removal of RI. When the road was resurfaced and installed with RI-MO, an additional increased of $L_{Aeq}$ by 1 dB (A) was obtained but the increase cannot be detected by human ear. This makes resident in Kampung Batu still perceive the same noise problem as before, during the RI existence. The important finding is that the installation of TRS causes Kampung Batu’s $L_{Aeq}$ value similar to that reported for cities around the world in Jordan, Italy, Brazil and Greece8,13,14. Therefore, it should be noted that the noise levels generated by road containing the TRS are not considered acceptable and noise buffers can be used to enable conversation easy to be understood and phone’s usage is not disturbed.

**Effects of TRS on TNI:** Traffic noise index (TNI) shown in table 2 shows that the road with the installation of TRS increases the dissatisfaction. Roads with the installation of RI increased 42 per cent of the value of TNI obtained from road without TRS. With the values obtained exceeded the suggested value of 74 dB(A), it indicates that the dissatisfaction from social survey would be greater than 3%15 and is not encouraged in the planning of any street. This has become evident why people have complained to the local authority or district public works department (PWD) for the removal of the RI while the installation of roads and RI-MO enhance TNI value of 36% from that of road with RI. Thus, installation of RI-MO did not improve the traffic noise situation in the study area. Analysis used equation 1 and the assumption of reduction of $L_{10}$ by 6dB (A) / doubling distance, to obtain the standard requirements TNI = 74. TRS should not be used within 100m of residential areas. This is actually less than the recommendations made by the Transportation Association of Canada16 which is 200m from any dwelling house.

**Conclusion**

Transverse rumble strips (TRS) are widely used by local authorities to reduce vehicle speed and sensitivity to the driver of any structural changes on the road. This study evaluated the effect of the TRS installation on traffic noise climate. The evaluation was carried out through changes in noise levels indices and the change of TNI to indicate the dissatisfaction. Compared to road without TRS, both types of TRS increased equivalent noise level and noise level indices significantly. The first type of RI increased $L_{Aeq}$, $L_{10}$ by 14, 9, 16 and 16 dB (A). Replacement with the second type of RI-MO further increased the $L_{Aeq}$ and $L_{10}$ of 14 dB (A) and 6 dB (A), respectively, but reduced $L_{Aeq}$ of 7 dB (A). TNI values were also increased with TRS installation. Both values exceeded the suggested value for planning purposes by 74 dB (A) for dissatisfaction of 3% of the social survey. Therefore, engineers should juggle between the effect of TRS installation on environmental noise and the role of TRS as safety equipment.

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Figure 2: Profiles of RI (before resurfacing) and mixed RI-MO (after resurfacing)

Figure 3: Measurement layout

Figure 4: Fluctuation of traffic noise level

Figure 5: Tire/TRS interactions that result in excessive noise
Figure 6: Comparison of the cumulative distribution for noise level due to installation RI, RI-MO and without TRS

Figure 7: $L_{index}$ due to installation RI, RI-MO and without TRS for each cycle

Table 1
Comparison of statistical index

<table>
<thead>
<tr>
<th>Average $L_{index}$</th>
<th>Without TRS (dB(A))</th>
<th>With RI (dB(A))</th>
<th>With mixed RI-MO (dB(A))</th>
<th>Change in level with RI relative to without TRS</th>
<th>Change in level with mixed RI-MO relative to RI</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>dB(A)</td>
<td>%</td>
<td>dB(A)</td>
<td>%</td>
<td>dB(A)</td>
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<td>$L_{max}$</td>
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<td>$L_{10}$</td>
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<td>$L_{Aeq}$</td>
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<td>74</td>
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Table 2
TNI values due to RI and mixed RI-MO

<table>
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<tr>
<th>Condition</th>
<th>TNI (dB(A))</th>
<th>Percentage of increment relative to TNI without TRS</th>
<th>Percentage of increment relative to TNI with RI</th>
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<tbody>
<tr>
<td>With installation of RI</td>
<td>126</td>
<td>42</td>
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<tr>
<td>With installation of RI-MO</td>
<td>171</td>
<td>92</td>
<td>36</td>
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<tr>
<td>Without TRS</td>
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References


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