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Investigation on Effectiveness of Rumble Strip Designs to Alert Run-off-road Vehicles on Expressways

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Abstract: Safety is one of the key functional factors of a road network and is especially incorporated in the design of highway geometry. Road designs should not only ensure safe vehicular operations such as providing sufficient visibility and skid resistance, roadway characteristics should make provisions to reduce the severity and probability of road crashes. Road signs, road markings, signal lights, etc., are installed to ensure provision of necessary guidance to the drivers to operate their vehicles in a safe manner. Road furniture, such as median barriers, ensures that the severity of crashes is minimized. Similarly, installation of rumble strips along the roadway edge has been proven as an effective countermeasure against run-off-road crashes on highways. The vibration and the noise generated when the tyre traverses over the rumble strips act as an alert to the drivers to help them manoeuvre the vehicle back to the lane safely. This study aims to explore various rumble strip designs and arrangements to identify an optimal design which would provide sufficient noise level while being cost effective so that it could be implemented on expressways in Sri Lanka.

Keywords: Rumble Strip, Noise, Expressway, Road Safety Countermeasure

1. Introduction

Road safety is a major issue in Sri Lanka, with approximately 3000 fatalities per annum due to road accidents occurring over the past 5 years [1]. While the road safety levels have remained largely poor over the period in the national roads, the safety performance of the expressway network has been satisfactory. With the expansion of the expressway network, currently at 313 km, and the increasing traffic volume on these roads, the risk of road crashes is likely to be increased.

The causal factors resulting in road crashes are broadly categorized as human, environmental and vehicle-related [2, 3]. Human factors are known to be a causal factor in 90% of all road crashes. Among them, fatigue, distracted driving, driving under the influence of alcohol, excessive speed and negligence are the main causes. Similar factors are also relevant to expressway accidents [4, 5]. However, this does notalleviate the responsibility of the road agencies to provide a safe road environment for road users as well as to ensure the damage is minimized in the event of a road crash.

According to the accident records for Colombo-Katunayake Expressway and Southern Expressway for the year 2019 obtained from the Expressway Operation Maintenance & Management Division (EOM&M Division) of the Road Development Authority (RDA), the number of accidents due to various reasons can be categorized as shown in Table 1.

Accordingly, on the Southern Expressway, 19 % of the roadway accidents have been caused due to fatigue or drowsiness, and on the Colombo-Katunayake Expressway the accidents have dropped down to 15%. The trip length on Colombo-Katunayake Expressway is less when compared to Southern Expressway. Therefore, the lower trip length can be related to the number of accidents caused due to drowsiness and fatigue.

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The number and severity of the roadway departure crashes can be reduced by introducing countermeasures such as roadway widening, delineation, applying high friction surface treatment, breakaway supports and slope flattening. Most of the countermeasures are costly and applied only in high priority locations.

Installation of centre line rumble strips to reduce head-on and opposing-direction sideswipe crashes and edge line and shoulder rumble strips to reduce single-vehicle run-off-road crashes are identified as effective low-cost countermeasures in reducing Run-off-the Road (ROR) crashes [6].

Table 1 - No. of Accidents Occurred During the Year 2019

Accident Cause	**Southern Expressway**		**Colombo - Katunayake Expressway**	
	No.of accidents	**% of the total no. of accidents**	**No.of accidents**	**% of the total no.of accidents**
Animal Crossing	167	15.48	12	6.35
Obstacle	105	9.73	32	16.93
Vehicle Defect	127	11.77	10	5.29
Negligence/ Carelessness	298	27.62	70	37.04
Drowsiness/ Fatigue	206	19.09	29	15.34
Overtaking	73	6.77	8	4.23
Sudden stopping/ Break	24	2.22	2	1.06
Weather Condition	26	2.41	21	11.11
No data	41	3.80	0	0.00
Other	12	1.11	5	2.65
Total	1079		189	

Rumble strips are designed aiming to reduce the number and severity of ROR crashes which occur due to driver performance errors such as distraction, drowsiness, fatigue or inattention. Rumble strips consist of either raised or grooved patterns, installed perpendicular to the travel, and produce noise and vibration, alarming drivers when the vehicle tires are passing on. Rumble strips can be categorized as transverse rumble strips, shoulder rumble strips, and centreline rumble strips based on their installed location. Further, rumble strips can be categorized as milled rumble strips, raised rumble strips, rolled in rumble strips and formed rumble strips based on the construction material and procedure [7].

The effectiveness of installing rumble strips in reducing the number and severity of ROR crashes was evaluated in many studies [8, 9]. Shoulder rumble strips installed along 1783 miles of two-lane rural highway in Idaho reduced the ROR crashes by 14% [10]. Furthermore, the study revealed shoulder rumble strips are more effective on roads with relatively moderate curvature. Sun & Rahman [11] investigated the impact of centreline and shoulder rumble strips on two-lane highways in Louisiana along 1593miles. The results indicated a significant reduction of fatal and severe injury crashes, which are 34% for rural two-lane and 45% for urban two-lane highways.

Pennsylvania Turnpike Commission developed an innovative rumble-strip called Sonic Nap Alert Pattern (SNAP) as a countermeasure to reduce the large number of ROR crashes. In 1986, 57% of the crashes along the Pennsylvania Turnpike were ROR crashes [12]. SNAP is a narrow, continuous, rumble strip installed on the shoulder. After the installation of SNAP, ROR crashes per month along the Pennsylvania Turnpike reduced by 70% [13].

Crash modification factors (CMF) can be considered as measures of the safety effectiveness of a particular treatment to compute the estimated crashes with treatment as shown in Equation 1 [14].

$$EC_{\text{with treatment}} = CMF \times EC_{\text{without treatment}} \ldots (1)$$

where, EC is Estimated Crashes; CMF is the Crash Modification Factor

A Crash Modification Factor (CMF) less than 1.0 indicates that treatment has the potential to reduce crashes. A CMF for total crashes for installing edge line or shoulder rumble strips on Rural Highways should lie between 0.78-0.9 [14].

2. Evaluation of Rumble Strip Designs: Criteria for Effectiveness Evaluation, Existing Practices, and Limitations

2.1 Evaluation of Rumble Strip Designs

According to NCHRP 641, the following three noise level increases from ambient in-vehicle noise levels have been identified as effective noise level increments for rumble strips to alert the drowsy drivers.

- 3 dBA – minimum design value,
- 6 dBA – desirable design value, and
- 15 dBA – maximum design value.

2.2 Existing Practices and their Limitations

Rumble strips are milled or raised patterns on the roadway that provide noticeable noise and a physical vibration which alerts the drowsy and inattentive drivers.

When the existing practices are considered, milled strips can be identified as the most common method used. Raised strips are not promoted in cold weather countries because they create problems for the snow removal and vehicles that are used for maintenance. If the raised strips are constructed in those countries, they get damaged during the operation of the snow removal. Therefore, most cold-weather countries construct rumbles strips with indentations.

The above type of rumble strips with an indentation does not suit Sri Lanka due to various reasons. Sri Lanka is a tropical country and experiences rain throughout the year. When the milled strips or strips with indentations are constructed due to rainwater, the strips may get filled with water which may result in long term pavement structural deterioration due to water infiltration. During the operation of the expressway, the milled strips get filled with dust and frequent maintenance is required for the proper functioning of the rumble strips.

2.3 Design Alternative

Due to the above reasons, the authors studied an alternative method to suit the local conditions (Sri Lankan conditions). The outline pattern was selected as a set of rumble strips(indentation) spaced at every 1′ (300 mm) in the direction of vehicle travel, 16″ wide (405 mm), 4″ long (100 mm) and 0.5″ in depth (12 mm) as based on the study carried out at the Pennsylvania Turnpike [15].

The above type of rumble strips with an indentation does not suit Sri Lanka as described above;hence, it was decided to carry out rumble strips as raised rumble strips marked with thermoplastic road marking material instead of indentation into the asphalt surface. Accordingly, 4 types of patterns were selected for Trial 1.

Once the initial 4 patterns were tested in Trial 1, the gap and the thicknesses were varied and another 6 patterns were tested in Trial 2. Figure 1 shows the rumble strip design.

3. Research Methodology

The following steps were carried out to study the suitable rumble strip pattern for the Sonic Nap Alert Pattern (SNAP).

3.1 Installation of the Ruble Strips

3.1.1 Initial Pattern

The initial pattern has been identified as follows.

Thickness of the Strip = 6 mm
Width of the Strip = 100 mm
Clear gap between 2 consecutive Markings = 200 mm

3.1.2 Trial 1 - Patterns

Based on the Initial pattern, 1st trial has been carried out with the 4 different pattern types as shown in Table 2.

Table 2 - Trial 1 Patterns

Pattern Type – Trial 1	The thickness of the Strip (mm)	Width of the Strip (mm)	The clear gap between two consecutive Markings (mm)
6-100	6	200	100
8-100	8	200	100
6-200	6	100	200
12-100	12	200	100

Above 4 pattern types were installed at 300 mm away from the edge line to a length of 405 mm.

Figure 2 shows the shoulder rumble strips installed on the Expressway.

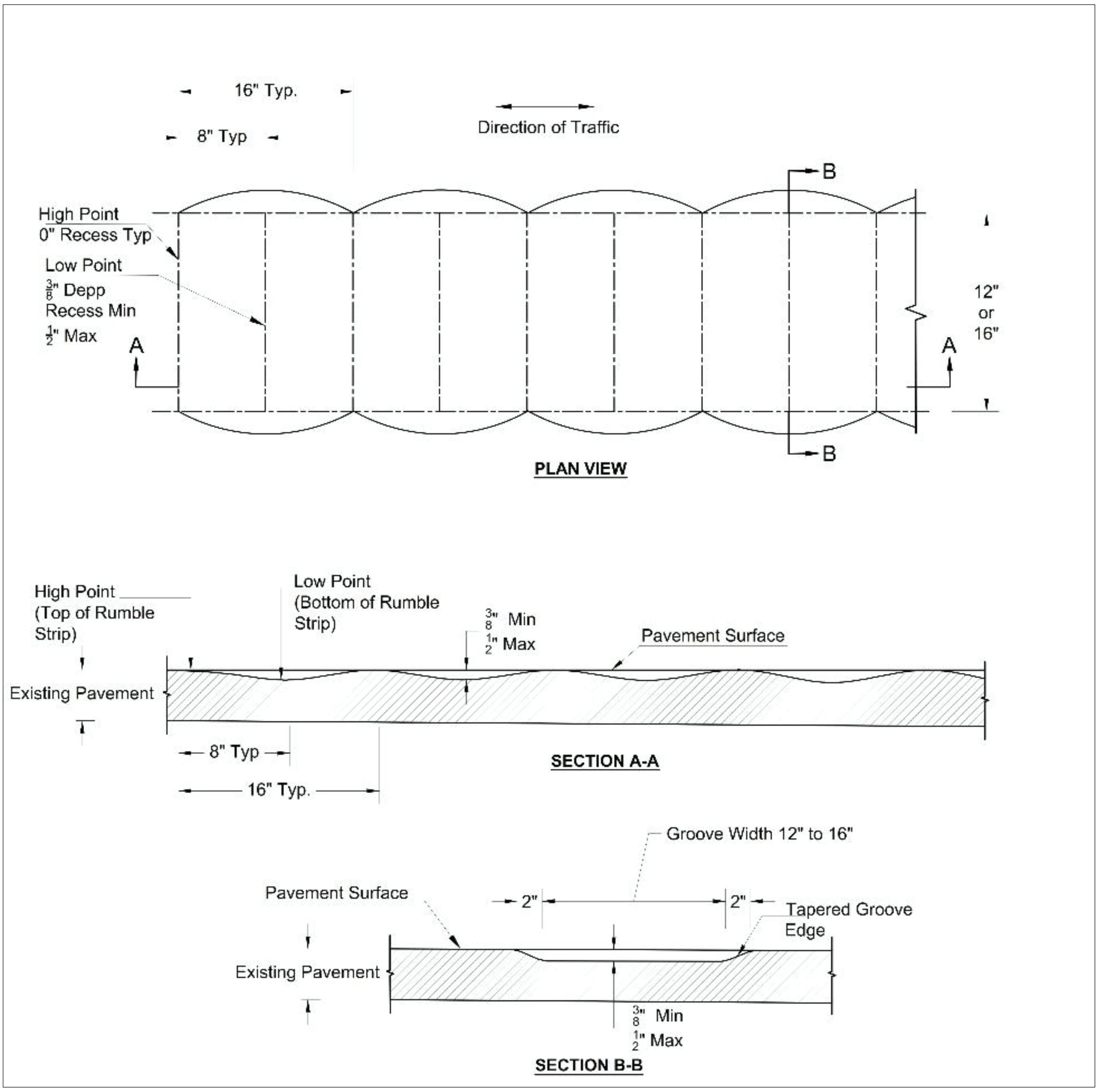

Figure 1 - Rumble Strip Design

Figure 2 - Shoulder Rumble Strips Installed on the Central Expressway (CH 39+600 LHS)

3.1.3 Trial 2 – Patterns

The pattern type 6-200 was identified as the most appropriate pattern based on Trial 1 where the results are shown in the next section.

Six further patterns were designed based on pattern type 6-200, for Trial 2 testing.

Trial 2 included 6 patterns with a clear gap of 200 mm, 300 mm, and 400 mm with strip thickness of 4 mm and 6 mm, altogether 6 designs. These 6 pattern types were installed 100 mm away from the edge line to the length of 405 mm as shown in Figure 3. The gap between the edge line and rumble strip has been reduced from 300 mm to 100 mm to increase the recoverable time of the errant vehicle.

Construction Cost

The costs for the construction of different pattern types are indicated in Table 3. The construction cost was obtained from the actual cost proposals submitted by the relevant contractor at the Central Expressway Section 2.

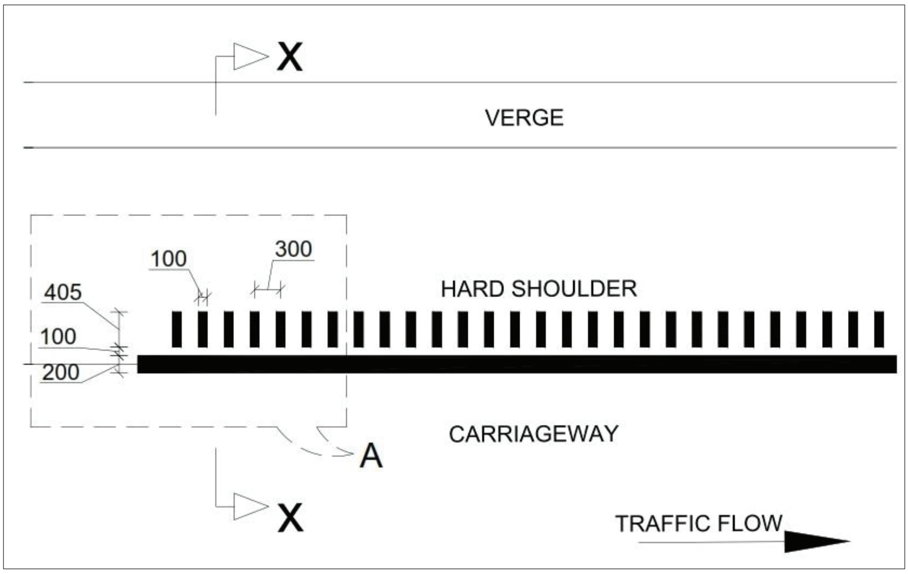

Figure 3 - SNAP Marking – Shoulder Rumble Strip Plan

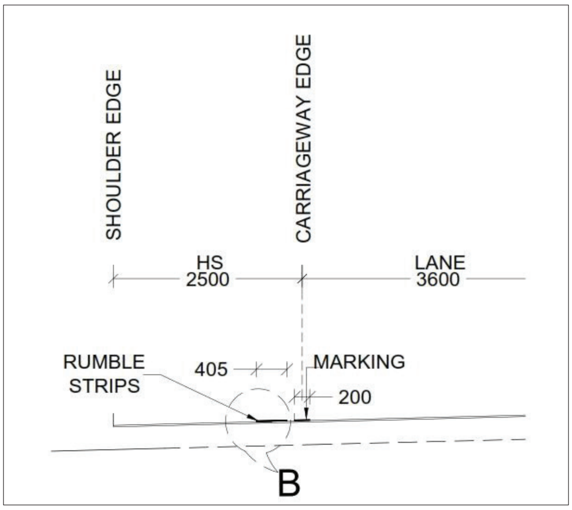

Figure 4 - SNAP Marking – Shoulder Rumble Strip
Section X-X

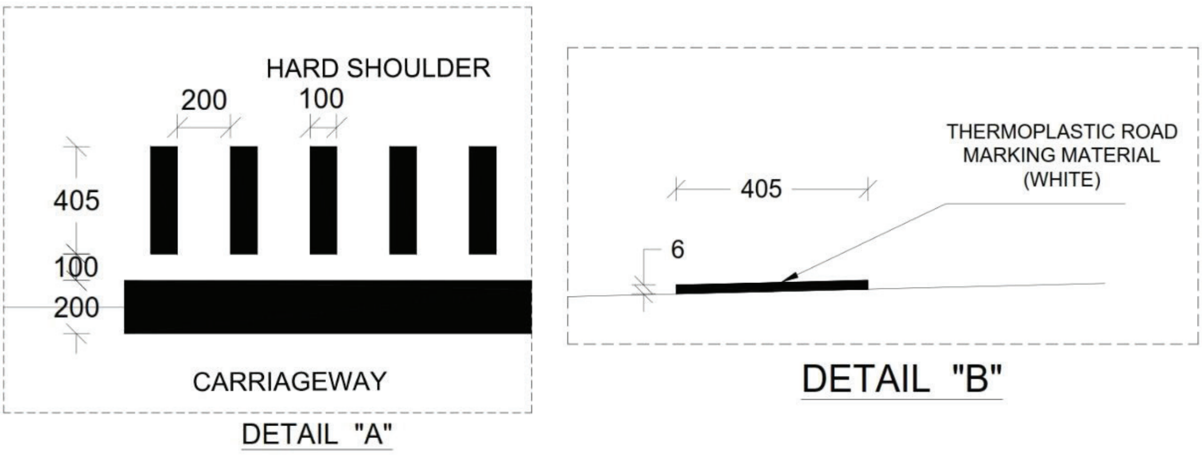

Figure 5 – Close View of the Rumble Strip Design

Table 3 – Construction Cost of Different Patterns of SNAP

Pattern Type	2(6-200)	2(6-300)	2(6-400)	2(4-200)	2(4-300)	2(4-400)
Cost per sq.m (LKR)	10,056.00	10,056.00	10,056.00	6,200.00	6,200.00	6,200.00
Cost per 1km (LKR)	2,715,120.00	2,036,340.00	1,629,072.00	1,674,000.00	1,255,500.00	1,004,400.00
Percentage of cost reduction, in comparison to pattern 6-200	0%	25%	40%	38%	54%	63%

3.2 Testing

To evaluate the performance of the two trials, noise level and vibration were measured with the help of the Services Division of Industrial Testing Institute, Sri Lanka (ITI), operating different types of vehicles and varying the speed over each marked pattern.

3.2.1 Details of the Vehicles

Table 4 summarizes the vehicles used for the testing of the SNAP.

Table 4 - Vehicles Used to Test SNAP

Vehicle type	Vehicle Model	Tyre size	Operation condition
Trial 1			
4X4 Double Cab	Toyota Hilux	265/6SR17/1 125	All doors& windows closed, AC[1] turned on
Car	Toyota Prius	195/6SR/15	
Ten Wheel	Tata Daewoo	1000/20	
Bus	Ashok Leyland	900/20	All doors & windows are open
Trial 2			
Car	Toyota Allion	215/4SZR17	All doors & windows closed, AC[1]turned on
Bus	Mitsubishi Rosa	700R-16	
4X4 Double Cab	Toyota Hilux	P-265/6SR17	
Ten Wheel	Tata Daewoo	12/R22.5	

[1]Air Conditioning

3.2.2 Methods of Sound Measurement

The sound level meter was mounted on the front passenger seat in such a way as to place the microphone at a height of the driver's ear. The equivalent continuous sound pressure level (LAeq, T) was measured for short periods (T) under FAST selection mode and 'A' frequency weighted scale using a Modular Precision Sound Level Analyser Type 2270, Enhanced Sound Analysis Software BZ 7202 version 2, Brüle & Kjaer.

The above meter was calibrated before the measurements against an acoustic calibrator B & K Type 4231, traceable to the primary standard maintained at Brüel & Kjær; Calibration Laboratory, Denmark. Certificate No. CDK 1808300.

Vibration

Three accelerometer sensors were mounted on the steering using permanent magnets. The sensors were mounted in such a way to obtain vibration in three perpendicular directions X, Y & Z (Longitudinal, Transverse and Vertical). The Pulse Multi-Channel Analyser, Bruel & Kjaer (B&K) Type 3160-A-042, Model LAN-XI with Pulse Lab shop software version 19.0 was used to measure the vibration.

The above meter was calibrated before the measurements against vibration exciter Brüel & Kjaer type 4294, traceable to the primary standard maintained at Brüel & Kjær, The Calibration Laboratory, Denmark. Certificate No. CDK 1702917.

The background measurements (i.e., sound and vibration) were measured by running a vehicle over the left lane of the expressway) have been taken for both sound and vibration as the 1st step for each speed, respectively.

Vehicle Speed

The testing was carried out for the different speeds of 70 kmph, 80 kmph and 100 kmph for each of the above vehicles over each rumble strip pattern.

4. Results

Table 5 and Table 6 summarize the noise level and vibration level results obtained from Trial 1 and Trial 2.

Table 5 – Noise and Vibration Level Measurements: Trial 1

Vehicle Type	Vehicle speed (km/h)		Pattern Type				
			1(6-100)	1(8-100)	1(6-200)	1(12-100)	Background
Toyota Prius Car Tyre size - 195/6SR/15	70	Noise level*	83	80	80	67	66
		Vibration Level**	46.2	49.4	63.3	68.6	31.1
	80	Noise level	68	68	75	66	68
		Vibration Level	44.6	48.3	42.6	58.1	30.0
	100	Noise level	71	69	77	68	67
		Vibration Level	56.6	47.5	63.8	56.4	34.2
Toyota Hilux Double Cab Tyre size - 265/6SR17/1125	70	Noise level	70	68	69	64	63
		Vibration Level	39.7	59.5	62.2	54.6	38.0
	80	Noise level	69	73	72	63	63
		Vibration Level	39.0	64.0	62.3	47.0	38.6
	100	Noise level	67	73	72	63	66
		Vibration Level	56.7	61.2	68.1	62.2	39.7
Ashok Leyland Bus Tyre size - 265/6SR17/1125	80	Noise level	88 (average overall types)				80
		Vibration Level	-				
Tata DaewooTen Wheel Tyre size -1000/20	70	Noise level	78 (average overall types)				69
		Vibration Level	-				
	80	Noise level	79 (average overall types)				70
		Vibration Level	-				

Table 6 - Noise and Vibration Level Measurements: Trial 2

Vehicle Type	Vehicle speed (km/h)		Pattern Type						
			2(6-200)	2(6-300)	2(6-400)	2(4-200)	2(4-300)	2(4-400)	Background
Toyota Allion car Tyre size - 265/4SZR17	70	Noise level*	76.0	74.0	75.0	75.0	74.0	73.0	64.0
		Vibration Level**	43.0	51.5	52.1	77.7	47.4	53.2	25.9
	80	Noise level	77.0	78.0	80.0	75.0	72.0	76.0	66.0
		Vibration Level	45.9	48.7	56.9	47.6	31.7	54.3	29.0
	100	Noise level	81.0	81.0	78.0	78.0	76.0	77.0	69.0
		Vibration Level	54.5	50.6	59.7	53.4	46.9	48.1	29.5
Toyota Hilux 4 wheel Double Cab Tyre size - 265/6SR17	70	Noise level	70.0	69.0	71.0	64.0	67.0	64.0	62.0
		Vibration Level	31.6	49.3	46.7	29.7	39.8	32.3	26.4
	80	Noise level	69.0	69.0	70.0	64.0	68.0	70.0	63.0
		Vibration Level	38.7	44.3	58.0	38.8	32.6	37.1	24.4
	100	Noise level	75.0	72.0	72.0	73.0	73.0	74.0	67.0
		Vibration Level	32.3	47.6	42.6	38.7	37.7	37.0	24.4
Mitsubishi Rosa Bus Tyre size – 700/R-16	70	Noise level	80.0	77.0	82.0	79.0	86.0	79.0	76.0
		Vibration Level	104.1	96.6	-	115.5	157.2	117.5	99.4
	80	Noise level	88.0	85.0	81.0	84.0	84.0	85.0	79.0
		Vibration Level	102.5	152.5	152.5	125.9	134.0	166.4	103.3
	100	Noise level	84.0	88.0	83.0	82.0	85.0	80.0	79.0
		Vibration Level	123.7	133.7	118.7	164.3	130.1	130.1	90.9
Tata Daewoo Ten Wheel Tyre size - 12/R225	70	Noise level	75.0	76.0	79.0	70.0	71.0	73.0	70.0
		Vibration Level	131.8	106.1	133.3	99.0	106.6	119.5	95.2
	80	Noise level	78.0	75.0	76.0	76.0	73.0	76.0	72.0
		Vibration Level	127.5	131.1	134.4	154.8	138.8	151.4	101.9
	100	Noise level	80.0	79.0	78.0	79.0	78.0	78.0	77.0
		Vibration Level	154.9	124.0	109.4	116.8	116.4	114.7	-

*Measured noise level (L AeqT) dB(A)
** Maximum peak value in velocity mode (mm/sec.)

5. Analysis

Based on the results obtained from Trial 1, the noise level differences related to each vehicle type, pattern and speed were graphed as indicated in Figure 6. The following observations were identified based on the Trial 1 results.

- The observed noise level differences related to pattern type 1(6-200) for all speeds and vehicles lie above the minimum noticeable noise difference (3 dB).
- Pattern type 1(12-100) has shown the poorest performance, where the observed noise difference is less than the minimum noticeable noise difference (3 dB).
- When the car was travelling at a speed of 70 km/h along the pattern type 1(6-100), the observed noise level difference was 17 dB which is greater than the maximum allowable noise level difference (15 dB).
- Some noise level differences observed for pattern type 1(6-100), pattern type 1(8-100) and pattern type 1(12-100) lie below the minimum noticeable noise difference (3 dB).

Based on the above observation, pattern type 1(6-200) was selected as the appropriate pattern type for further investigation.

Figure 7 and Figure 8 indicate the results of Trial - 2 done for strip thickness of 4 mm and 6 mm, respectively.

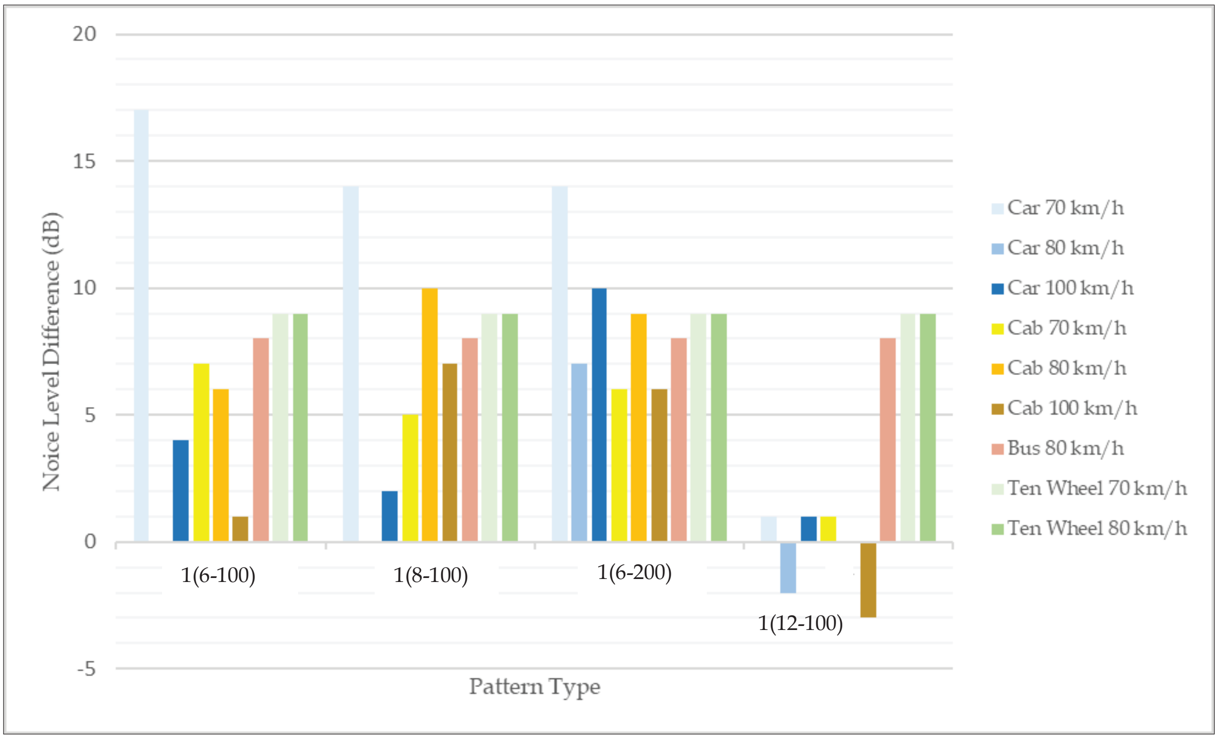

Figure 6 – Noise Level Difference Vs Pattern Type with Speed: Trial 1

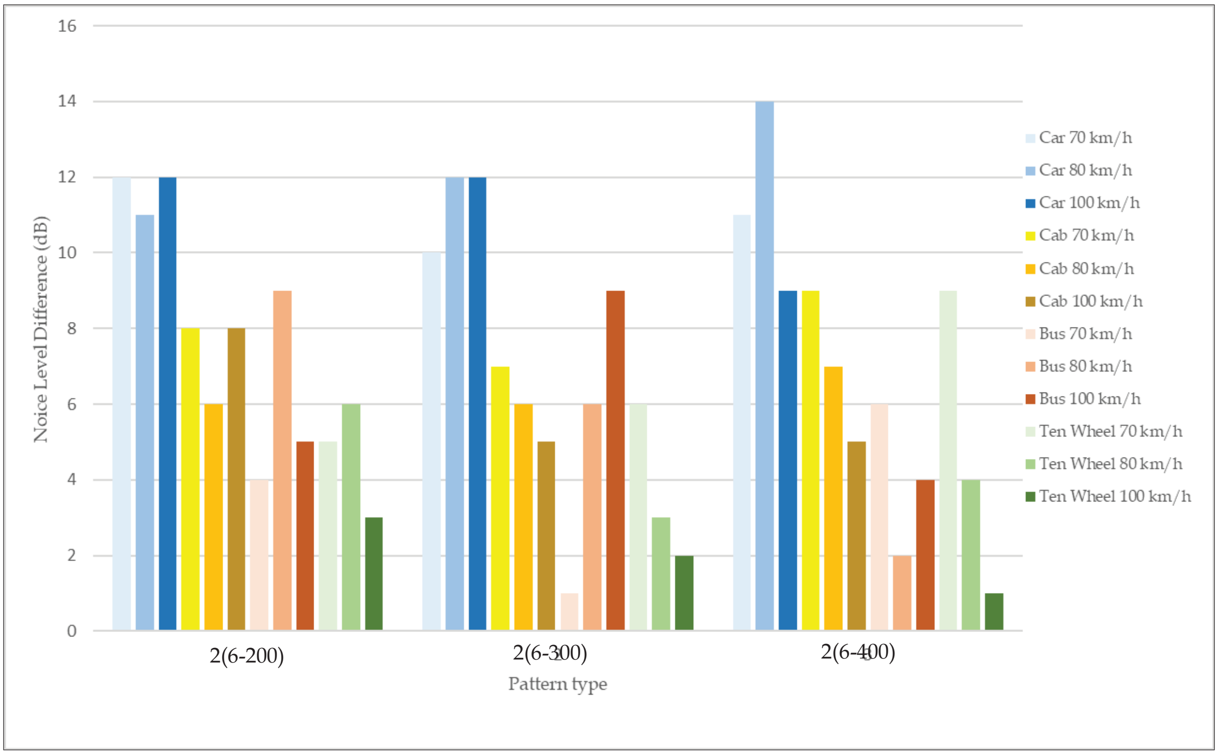

Figure 7 - Noise Level Difference Vs Pattern Type with Speed (6 mm strip thickness): Trial 2

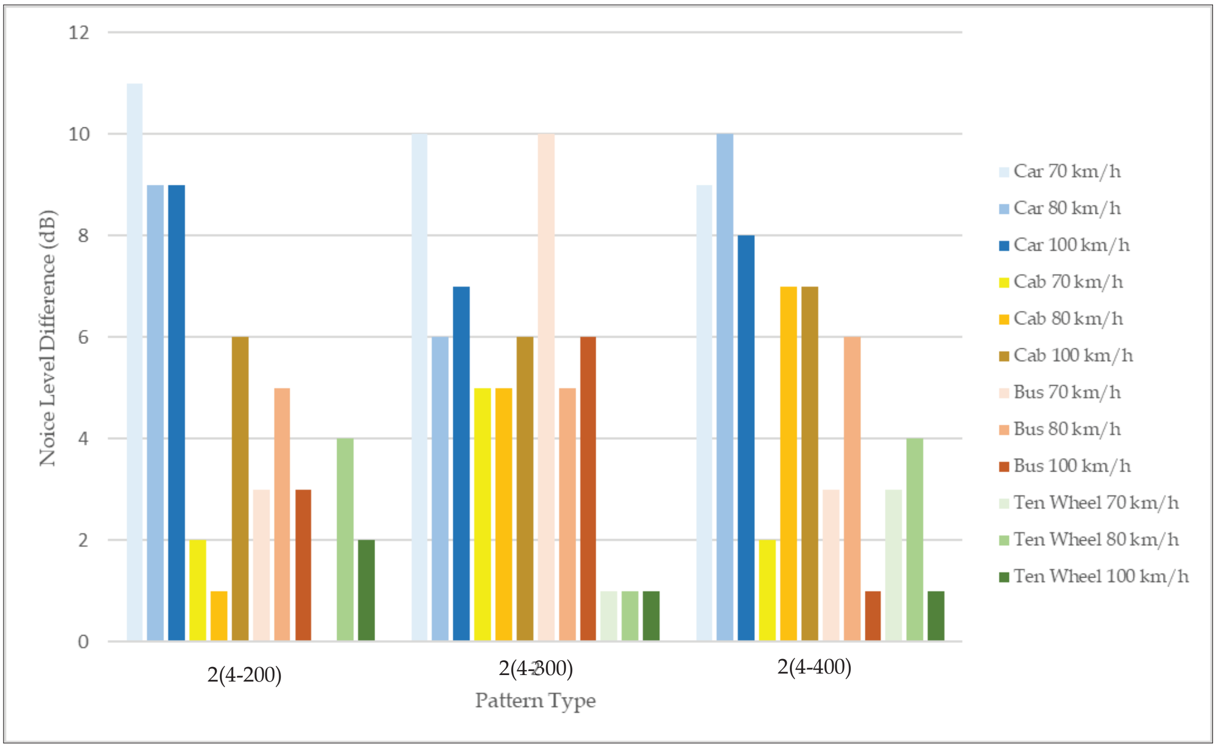

Figure 8 - Noise Level Difference Vs Pattern Type with Speed (4 mm strip thickness): Trial 2

Results of Trial 2 suggests, a spacing of 300mm and 400 mm can be recommended to achieve the desired noise difference for cars, pick-up trucks and buses. However, the desirable noise increase levels were not achieved consistently for trials done with multi-axle vehicles.

Figure 9 shows the noise level difference range for each pattern type of Trial 2. From Figure 9, patterns of noise level differences that lie above the 6 dB (threshold value) can be taken into further consideration.

The construction cost for each pattern type is illustrated in Figure 10.

Based on the cost, the cost-effective ratios have been calculated and indicated in Table 7.

The cost with noise level difference is illustrated in Figure 11.

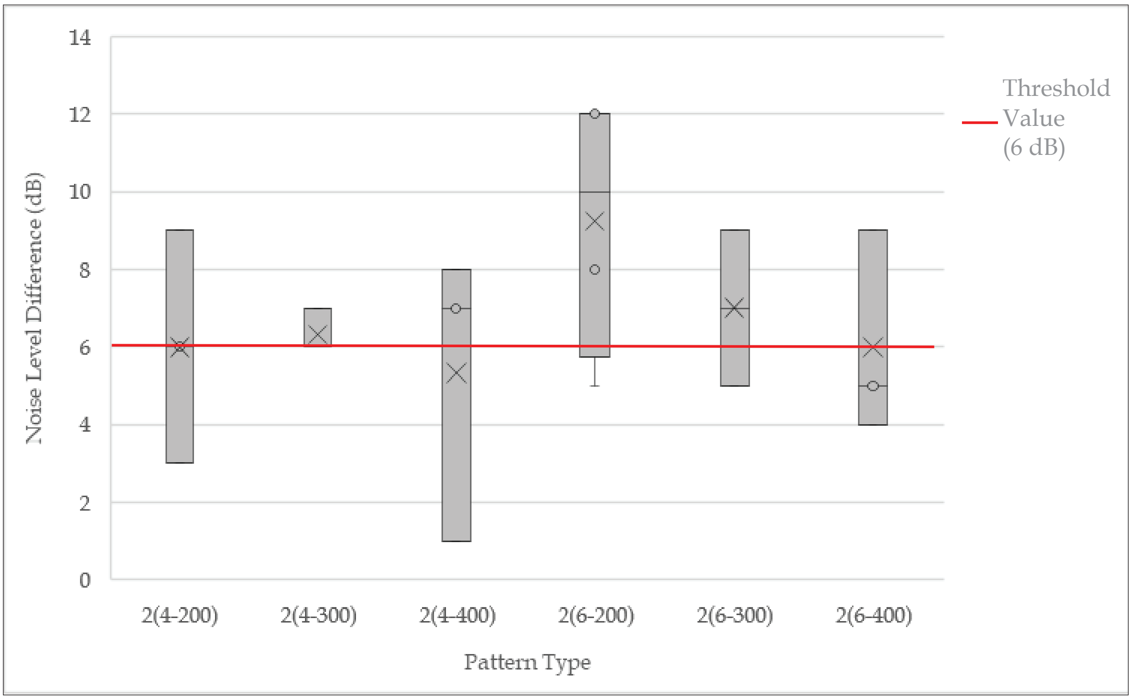

Figure 9 – Noise Level Difference Range for Each Pattern Type

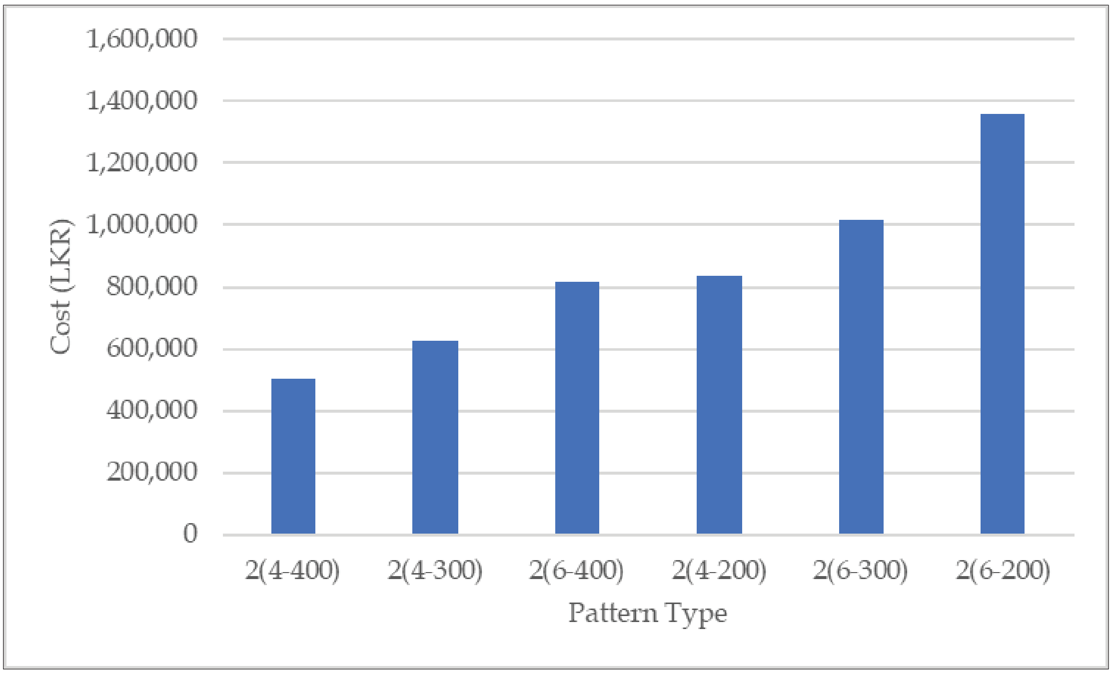

Figure 10 – Variation of Construction Cost with Pattern Types

Table 7 – Cost-Effective Ratios

Vehicle type	Speed	Pattern type	Noise difference	Cost	Cost per linear km (mn)	Noise diff/cost
Car	100	2(6-200)	12	1,357,560	1.36	8.84
	100	2(6-300)	12	1,018,170	1.02	11.79
	100	2(6-400)	9	814,536	0.81	11.05
	100	2(4-200)	9	837,000	0.84	10.75
	100	2(4-300)	7	627,750	0.63	11.15
	100	2(4-400)	8	502,200	0.50	15.93
Bus	100	2(6-200)	5	1,357,560	1.36	3.68
	100	2(6-300)	9	1,018,170	1.02	8.84
	100	2(6-400)	4	814,536	0.81	4.91
	100	2(4-200)	3	837,000	0.84	3.58
	100	2(4-300)	6	627,750	0.63	9.56
	100	2(4-400)	1	502,200	0.50	1.99
Double Cab	100	2(6-200)	8	1,357,560	1.36	5.89
	100	2(6-300)	5	1,018,170	1.02	4.91
	100	2(6-400)	5	814,536	0.81	6.14
	100	2(4-200)	6	837,000	0.84	7.17
	100	2(4-300)	6	627,750	0.63	9.56
	100	2(4-400)	7	502,200	0.50	13.94

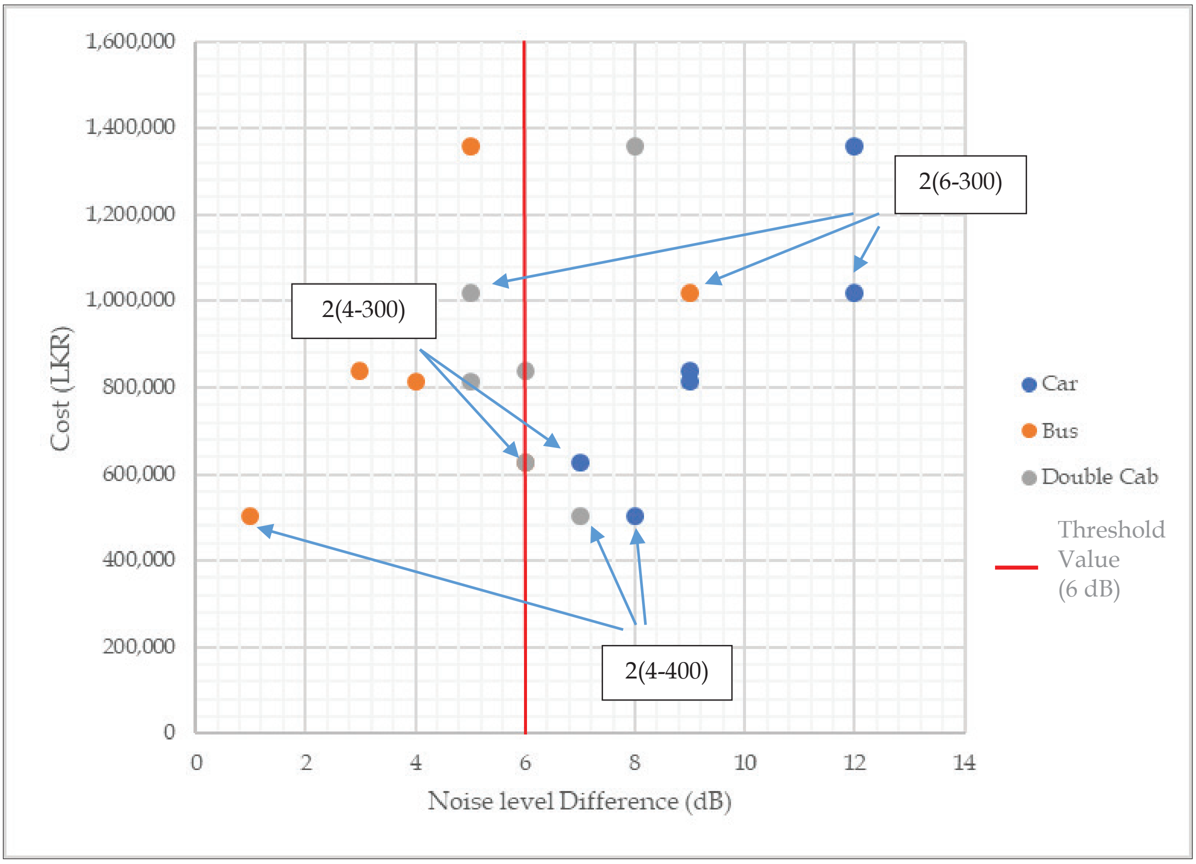

Figure 11 – Cost and Noise Comparison for Different Rumble Strip Patterns and Vehicle Types

Design patterns that confirm the threshold value of 6 dB and above with minimum cost requirements can be taken as acceptable design patterns from Figure 11.

Analysis of Table 7 and Figure 11 emphasises that, although pattern 2 (4-400) complies with minimum cost requirements, the noise level difference of one vehicle type is not above the threshold value. Therefore, SNAP pattern 2 (4-400) cannot be considered an optimum design.

Noise level differences of all three vehicle types are similar to or above the threshold value in design pattern 2(4-300) and the required cost is comparatively low.

In the remaining patterns, 2(4-200), 2(6-400), 2(6-300) and 2(6-200), noise level differences of vehicle types are not confirmed to the minimum noise level difference requirement.

This elaborates that the SNAP with 4 mm thickness and 300 mm clear spacing can be selected as the optimum pattern which can be installed as a SNAP.

6. Conclusion

SNAP (Sonic Nap Alert Pattern) on the outer shoulders of the expressway is useful as a safety measure to alert drowsy and inattentive drivers who drift to the left side of the road on the expressway and to avoid ROR crashes. This research was carried out to find a cost-effective design alternative for the indentation SNAP which most cold-weather countries use but not suitable for use in the Sri Lankan context.

The researchers used Thermoplastic Road marking material to make SNAP to achieve the sound variation required to alert the drowsy divers. Two trials have been carried out to identify the most effective pattern by giving due consideration to the threshold value of 6dB and their installation cost as well. To evaluate the performance of 10trial patterns (4 Nos of Trial 1 and 6 Nos of Trial 2), noise level and vibration were measured by running different types of vehicles and varying the speed over each marked pattern.

Pattern type 1(6-200)) was identified as the most suitable pattern from Trial 1. Similarly, pattern type 2(4-300) was identified as the optimum pattern from Trial 2 and selected for the implementation.

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