TACTILE AND AUDIBLE EFFECTS OF TRANSVERSE RUMBLE STRIPS ON TWO-LANE RURAL HIGHWAY

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ABSTRACT

Rural highways in Thailand experience high rate of motor vehicle related accidents. This rate is increasing each year. Main causes of accident involve aggressive driving such as tailgating and speeding, drowsiness, and intoxication. Transverse rumble strips (TRSs) have been used to alert inattentive drivers by providing tactile and audible warning. However, proper magnitude of noise and vibration produced by the rumble strips has been limitedly studied. In general, excessively high level of noise and vibration can cause nuisance to people in communities located along the rural highway. On the other hand, subordinate tactile and audible warning produced by the rumble strips may not be notified by inattentive drivers.

This study was aimed to investigate tactile and audible warning produced by different configuration of rumble strips installed on two-lane highway. The eighteen different patterns of rumble strips with different thickness, width of each strips, and gap between strips, were examined. The rumble strips were tested with a test vehicle, which was a pickup truck, at different speeds. It was found that as speed of vehicles passing over the TRSs increase, the roadside sound and in-vehicle sound also increase. On the other hand, changes in in-vehicle vibration decrease as vehicle speed increase. Considering the thickness of TRSs, thicker TRSs caused bigger change in in-vehicle sound and in-vehicle vibration. The DOR's configuration TRSs seem to provide adequate in-vehicle sound difference and in-vehicle vibration difference for driver to be clearly notified. In comparison with Department of Rural Roads's (DOR) configuration TRSs, the TRSs with 25 cm-gap (W10G25T0.5) seems to be more efficient in terms of speed reduction and making bigger change in in-vehicle vibration.

Keywords: Rumble strips, Tactile and audible effects

INTRODUCTION

Highways in Thailand experience high rate of motor vehicle related accidents. This rate is increasing each year. Based on the statistics from the Royal Thai Police (RTP, 2009), main causes of accidents involve aggressive driving such as tailgating and speeding, drowsiness and intoxication.

Rumble strips may consist of four types; milled, rolled, formed, and raised. (FHWA, 2006). It can also be classified by location and purpose of installation; shoulder, centerline, and transverse rumble strips (TRSs). Shoulder and centerline rumble strips were proved to be effective in run-off road crushes and head-on crushes prevention, respectively (Griffith, M.S., 1999; Hanley, K.E. 2000; Outcalt, W., 2001a; Delaware Department of Transportation, 2003). Several studies have suggested that TRSs are effective in speed reduction (Cynecki, 1993; Meyer, E., 2000; Zech, W. 2005). In Thailand, shoulder rumble strips are not widely used due to the disruption of motorcyclist traveling on the road shoulder. Centerline rumble strips are also barely implemented. Only transverse rumble strips (TRSs) are extensively used in Thailand. TRSs may be classified in to two types : movable and permanent rumble strips. Both of them have been used for different purposes. Moveable rumble strips are used for work zone and removed after finishing the roadwork. Permanent TRSs installed on two-lane highway are often used to notify drivers of imminent changes in driving conditions, for example; approaching to stop-controlled intersections, approaching to sharp horizontal curves, as well as travelling on extended basic road segments by providing tactile and audible warning.

The thermoplastic raised TRSs are implemented by the Department of Rural Roads (DOR), Thailand (Figure 1). It consists of three sets, 40 meter apart; each set consists of 10 strips with, 10 cm.-widths, 40 cm.-gaps, and 0.5 cm.-thicknesses. However, the magnitude of sound and vibration produced by the rumble strips has been limitedly studied. In general, excessively high level of sound and vibration may cause nuisance to residences along the rural highway. On the other hand, subordinate tactile and audible warning produced by the rumble strips may not be able to alert drivers. There is a lack of guidance with regard to required sound level or change in sound level generated by TRSs to alert driver of errant vehicles. Watts (Watts, 1977) was found that rumble strips producing sound 4 dB(A) increases above the ambient noise is adequate to be recognized by drivers. Outcalt (Outcalt, 2001b) has reported that sound level increases by 3 dB(A) and 6 dB(A), is considered as barely noticeable and clearly noticeable, respectively, as perceived by normal human ear.

In order to warn the drivers effectively, in-vehicle sound should be increased by at least 6 dB(A), while the vehicle is passing over the rumble strips. However, extreme noise may cause disturbance to residents living along the roadway.

The purposes of this study were to examine the audible and tactile effects as well as its speed reduction effectiveness, produced by TRSs with DOR’s configuration. The TRSs with different configurations were also examined and compared.

Figure 1. Transverse Rumble Strips on a Two-lane Rural Road

RESEARCH APPROACH

The experiment was conducted at a section of two-lane asphaltic concrete surface highway, route No. PT3006 Klong 8, Patumthani, in suburban of Bangkok, Thailand. The lane width and shoulder width are 3.0 m. and 1.0 m., respectively. During the experiment, the weather condition was sunny and the pavement surface was dry. The posted speed is 80 km/hr. Eighteen configurations of TRSs were examined (Table 1). Figure 2 shows installation of transverse rumble strips. Thickness of rumble strips was measured using a vernire. The test vehicle was a Pickup car (2005 TOYOTA Vigo extra-cab) with tire size 215/65R16 and a pressure of 210 kPa and a passenger inside. In this study, pickup car was used due to an extensive use of this type of vehicle in the study area, which is accounted for over 70 percent.

In-vehicle sound and vibration levels were recorded. A sound meter with accuracy of ±0.1 dB(A) with "A Weighting" mode was used. A vibration meter, Hand-Held Vibration meter 908, with overall accuracy of ±5% was used for vibration measurement. The vibration level was measured as vibration velocity, which was calculated as vibration decibel (VdB). The sound level was also measured on the roadside at the right of way, 12 meter from the centreline, perpendicular to the road where TRSs located. Figure 3 shows set-up of in-vehicle sound, vibration, and speed measurement.

The test car was tested at different speed of 50, 70, and 90 km/hr, three times of each speed and each TRSs configurations. The sound and vibration of different specific conditions were an average value. Speeds of general vehicles before and after installation of TRSs were measured with speed gun with an accuracy of ±0.16 km/hr. The speeds were measured at angle less than 7 degree and cosine correction was applied. Table 2 shows parameter collected.

Table 1. TRSs configurations tested

No. of Strips per set	Strip Width (cm)	Strip Thickness (cm)	Gap between strips (cm)
10	10	0.3	25, 40, 50, 70, 90
10	10	0.5	25, 40, 50, 70, 90
10	10	0.7	25, 40, 50, 70, 90
10	20	0.7	40, 60, 80

Figure 2 Installation of TRSs


Figure 3 In-vehicle sound, vibration, and speed measurements

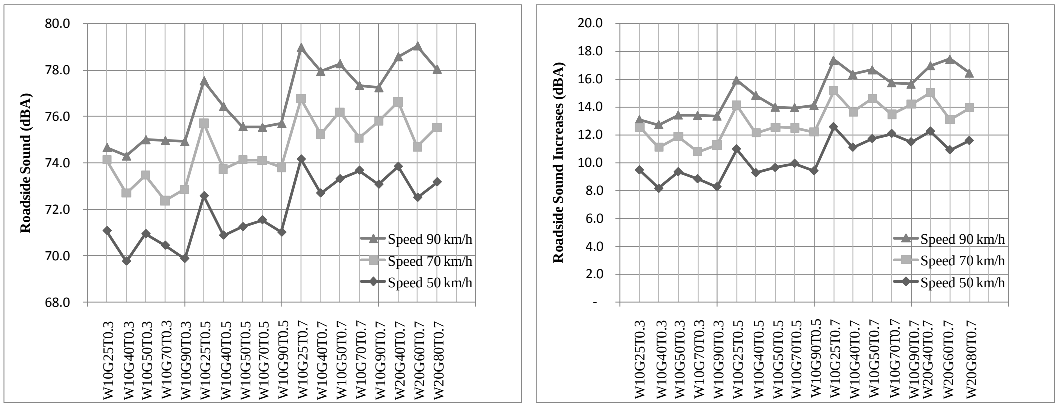
Table 2. Parameter Collected

Vehicle	Speed(km/hr)	Parameter Collected (Before and after installation)	
		In-vehicle	Roadside
Test Vehicle	50,70,90	Sound level Vibration level	Sound
General Vehicles	As collected	N/A	Speed

RESULTS AND DISCUSSION

Roadside Sound

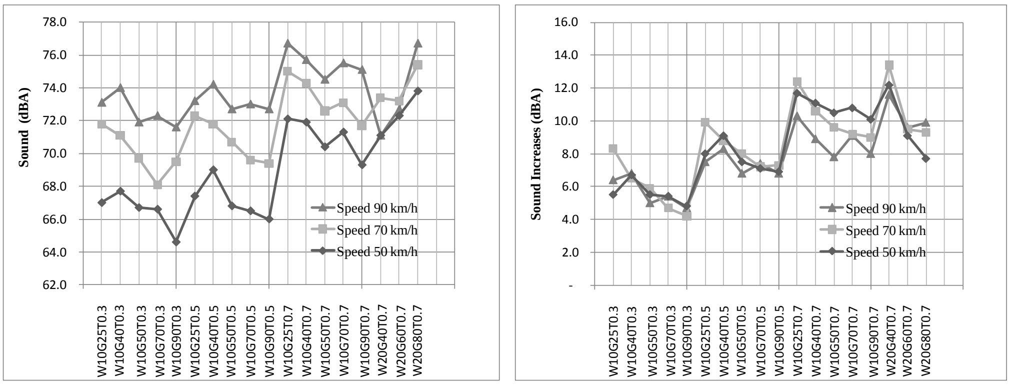
From Figure 4a, it clearly shows that increasing vehicle speed causes an increase in roadside sound level. Likewise, changes in sound level increase with rising of vehicle speeds. This is true for all TRSs configurations tested as shown in Figure 4b. The change in sound level is the sound differences when vehicle passing normal pavement and pavement with TRSs. Considering the thickness of TRSs, it was found that thicker TRSs cause higher sound level and bigger change in sound level. The lowest level of sound changes equals 8.2 dB(A), for TRSs with 10 cm-width, 40 cm-gap, and 0.3 cm-thickness (W10G40T0.3) at vehicle speed of 50 km/h. From Figure 6b, the highest level of sound changes equals 17.4 dB(A), for TRSs with 10 cm-width, 25 cm-gap, and 0.7 cm-thickness (W10G25T0.7) and with 20 cm-width, 60 cm-gap, and 0.7 cm-thickness (W20G60T0.7) at vehicle speed of 90 km/h. On average, it can by said that using 0.7 cm-thickness TRSs cause changes in sound level by 2 dB(A) and 3 dB(A), higher than those with 0.5 cm and 0.3 cm-thickness, respectively. As can be seen in Figure 4a, it can be noticed that, roadside sound level produced by DOR's configuration TRSs (W10G40T0.5) range from 70.9 to 76.4 dB(A) at speed from 50 to 90 km/hr, which are additional 9.3 to 14.8 dB(A) over sound level produced by traffic on normal pavement.



Note: (W=width (cm), G=Gap (cm), T=thickness(cm))
a) Sound Level b) Sound Level Increases
Figure 4 Roadside sound level and change in roadside sound level

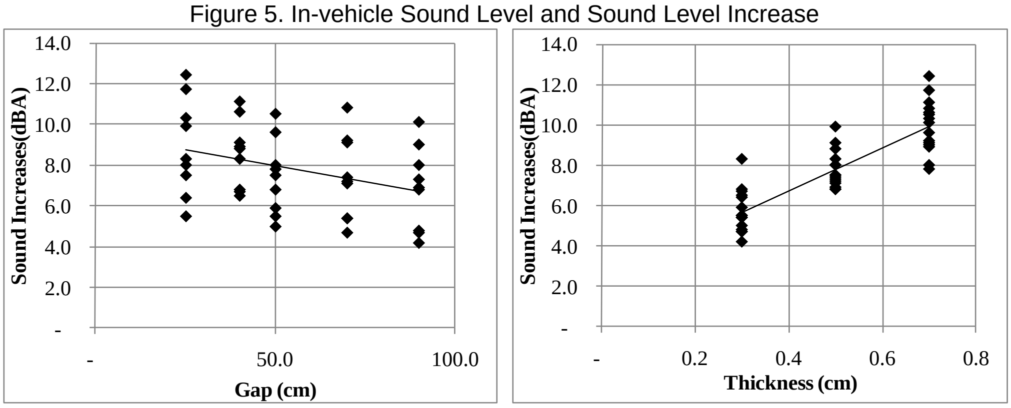
Average sound levels inside the test vehicle, before installation of the rumble strips, were measured and recorded at the test spot. It was found that average in-vehicle sound level on normal pavement at vehicle speeds 50, 70, and 90 km/hr equal 60.1, 63.3 and 66.4 dB(A), respectively. It is believed that in-vehicle sound is generated from two sources; engine and interaction between road surface and tires. As shown in Figure 5a, as expected, sound level increases as vehicle speed increases. However, the degree of sound increases is lower at higher speed (Figure 5b). Figure 5b also shows that in-vehicle sound produced by DOR's configuration TRSs (W10G40T0.5) range from 69.0 to 74.2 dB(A) at speed from 50 to 90 km/hr, which are additional 8.3 to 9.1 dB(A) over in-vehicle sound level produced by vehicle on normal pavement. As suggested by Watts (Watts, 1977), these in-vehicle sound levels are greater than 6.0 dB(A), which are adequate for driver to be clearly noticed. From Figure 5b, the TRSs with 0.5 cm and 0.7 cm-thickness cause in-vehicle sound level difference exceeding 6.0 dB(A) at vehicles speed 50 to 90 km/hr. For the TRSs with 0.3 cm-thickness, only the one with 10 cm-width and 40 cm-gap cause in-vehicle sound level difference above 6.0 dB(A).

Figure 6a shows that, increasing changes in sound level tends to be lower as TRSs gap increasing. On the other hand, increasing thickness causes bigger changes in sound level (Figure 6b). Paired t-test was performed to test if in-vehicle sounds after installation of TRSs are significantly greater than those before installation of TRSs for each rumble strips configurations and vehicle speed. It was found that for all TRSs configurations and vehicle speeds, in-vehicle sound levels produced by the test vehicle on TRSs are significantly higher than those on normal pavement (p-value < 0.001).



a) Sound Level b) Sound Level Increase

Figure 5. In-vehicle Sound Level and Sound Level Increase



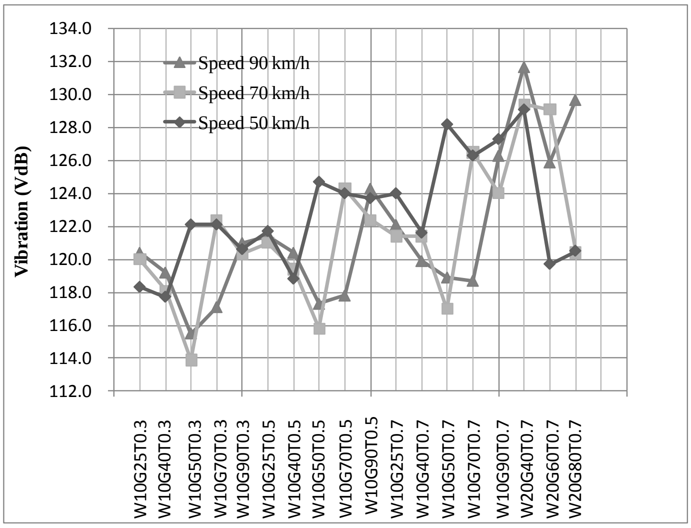
a) Sound level increases at various TRSs Gap b) Sound level increases at various TRSs thickness

Figure 6. Sound level increases for different TRSs gap and thickness

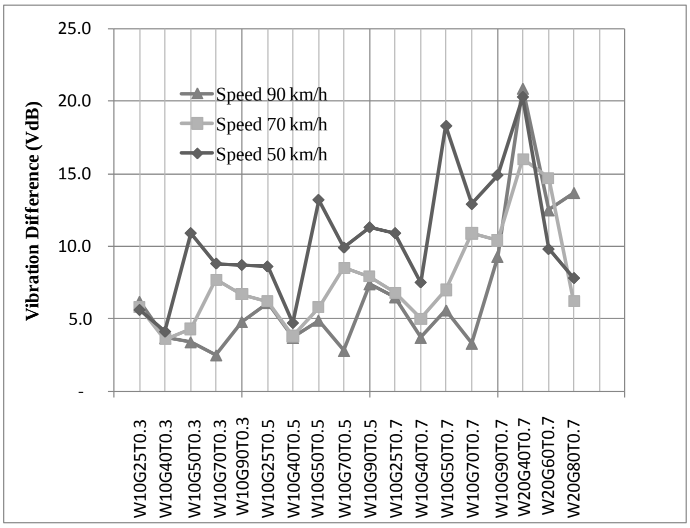
In-vehicle Vibration

From Figure 7a, it can be seen that driving with high speed over rumble strips tends to produce lower tactile effects than driving with lower speed, as expected. The in-vehicle vibration ranges from 113.9 to 131.7 VdB. The thicker TRSs tend to produce higher vibration. As shown in Figure 7b, increasing changes in in-vehicle vibration tend to be lower as vehicle speed increases. However, it can be noted that if low speed vehicle produces too high in-vehicle vibration, drivers may try to accelerate to reduce tactile effects. The vibration increase by 2.5 to 20.3 VdB. Figure 8a shows vague relationship between TRSs gap and change in vibration level. On the other hand, increasing thickness causes higher changes in vibration level.

Paired t-test was performed to test; if in-vehicle vibration after and before installation is greater significantly for each TRSs configurations and vehicle speed. It was found that for all rumble strips configurations and vehicle speeds, in-vehicle vibration are significantly higher than those with no rumble strips (p-value < 0.001).

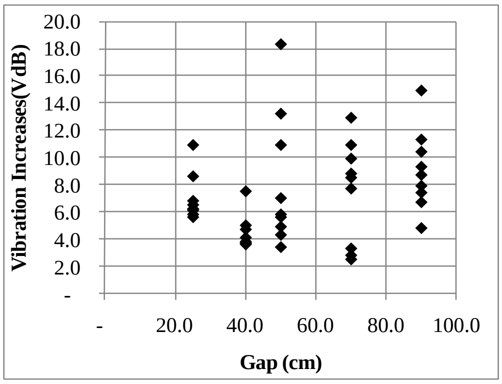


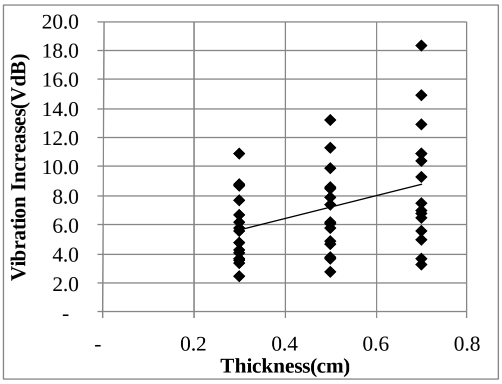
a) In-vehicle vibration



b) In-vehicle vibration increases

Figure 7. In-vehicle vibration at different vehicle speed





a) Vibration Increases at Various TRSs Gap b) Vibration Increases at Various TRSs Thickness

Figure 8. In-vehicle Vibration Increases

In order to select the suitable TRSs, configurations that produce low roadside sound level and cause high in-vehicle sound and vibration were carefully considered, especially for high speed vehicles. This is due to the fact that high speed vehicles are prone to cause accident than those with low speed. According to field test results, it was found that the TRSs with thickness of 0.7 cm might be inappropriate since it produces high increasing changes in roadside sound and too high tactile effect for low speed vehicles. Furthermore, by inspection during field experiment, it may cause uncomfortable for motorcyclists to ride over and loss control of their motorcycle. While TRSs with 0.3 cm thickness produced too low in-vehicle sound difference (about 4-6 dB(A)), hence, TRSs with 0.5 cm thickness was used for further investigation. It was observed that among TRSs with 0.5 cm thickness beside the DOR's configuration TRSs (W10G40T0.5), TRSs with 25 cm-gap show high in-vehicle sound level with low deviation of in-vehicle vibration at different vehicle speed. Therefore, two patterns with different gap of TRSs were further investigated; the TRSs with 10 cm-width, 25 cm-gap and 0.5 cm-thickness, and DOR's configuration TRSs (W10G40T0.5).

Applications of TRSs, Speed Before and After Installation of TRSs

Two configurations of TRSs were further investigated for speed reduction effectiveness. Each configuration consists of three sets of rumble strips with gap of 40 m. and each set consists of 10 strips, each strip has 10 cm width, 25 cm-gap, and 0.5 cm thickness, for first configuration and 40 cm-thickness for second configuration. The vehicle speeds were measured at five stations (Figure 9) before and after installation of TRSs. In estimating percent time spent following, the Highway Capacity Manual (HCM) utilizes the percentage of vehicles with headways less than 3 seconds as a surrogate measure of percentage of vehicles travelling in platoon (TRB, 2000). In order to remove the effect of platooning and increase the effectiveness of speed collected with speed gun, only speeds associated with time headway 5 second or greater were considered.

It was found that for the TRSs with 25 cm.-gaps (configuration 1 or W10G25T0.5), the 85th percentile speeds decrease by 1.60 to 4.14 km/hr, and mean vehicle speeds at station 2, 3, 4, and 5 were significantly reduced at 95 percent confidence level (Table 3). For TRSs configuration 2 (W10G40T0.5), the 85th percentile speed decrease by 0.01 to 3.03 km/hr and mean vehicle speeds were reduced significantly at station 4 and 5 only, at 95 percent confidence level (Table 4). According to this, it can be said that TRSs configuration 1 provides higher in-vehicle vibration differences than configuration 2 TRSs as shown in Figure 7. However, when considered only vehicles having speed greater than 80 km/hr, speed reduced significantly only at station 4 and 5, for configuration 1 TRSs and at station 5 for configuration 2 TRSs. This may be because high speed vehicles cause lower in-vehicle vibration than low speed vehicles. The high speed vehicles reduced their speed only when ran over or passed the last set of TRSs. It can be mentioned that the TRSs with 25 cm-gap is slightly more efficient in terms of speed reduction, as compared with the TRSs with 40 cm-gap, but it caused higher roadside sound differences about 1-2 dB(A).

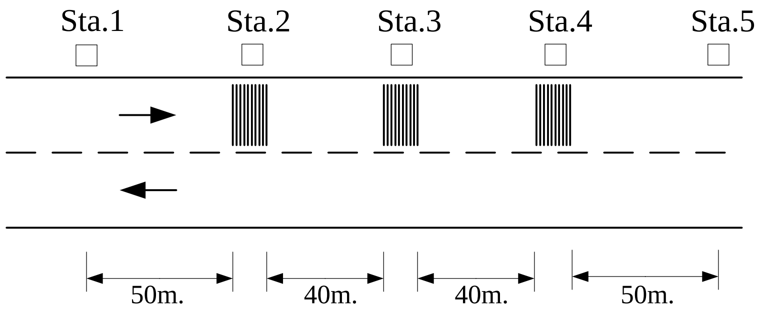


Figure 9. Speed measurement locations

Table 3. TRSs with 10 cm width, 25 cm gap, 0.5 cm thickness (W10G25T0.5) (General vehicles)

Station	N		Mean		SD.		85th Percentile		t-Value	p-value
	Before	After	Before	After	Before	After	Before	After		
1	129	173	74.35	72.28	13.50	12.51	88.04	85.54	1.360	0.087
2	129	173	74.73	72.12	13.29	12.61	87.46	85.86	1.723	0.043
3	129	173	74.81	70.85	13.05	13.05	87.54	84.10	2.611	0.005
4	129	173	74.40	69.29	12.98	13.84	86.48	82.50	3.288	0.001
5	129	173	73.97	67.96	13.01	14.13	86.38	82.24	3.829	<0.001

Table 4. TRSs with 10 cm width, 40 cm gap, 0.5 cm thickness (W10G40T0.5) (General vehicles)

Station	N		Mean		SD.		85th Percentile		t-Value	p-value
	Before	After	Before	After	Before	After	Before	After		
1	129	91	74.35	72.41	13.50	16.29	88.04	87.50	0.929	0.177
2	129	91	74.73	72.82	13.29	15.83	87.46	87.45	0.944	0.173
3	129	91	74.81	72.01	13.05	15.62	87.54	87.40	1.399	0.082
4	129	91	74.40	69.77	12.98	15.27	86.48	85.00	2.354	0.010
5	129	91	73.97	67.59	13.01	14.97	86.38	83.35	3.283	0.001

CONCLUSIONS AND RECOMMENDATIONS

As speed of vehicles passing over the TRSs increased, roadside sound and in-vehicle sound also increased. On the other hand, changes in in-vehicle vibration decreased as vehicle speed increased. Considering the thickness of TRSs, thicker TRSs caused higher change in in-vehicle sound and higher change in in-vehicle vibration.

The DOR's configuration TRSs (W10G40T0.5) seem to cause adequate in-vehicle sound difference and in-vehicle vibration difference for driver to be clearly notified. In comparison with DOR's configuration TRSs, the TRSs with 25 cm-gap (W10G25T0.5 or configuration 1) seem to be more efficient in terms of speed reduction and bigger change in in-vehicle vibration. However, it is likely to create higher roadside sound difference by about 1-2 dB(A). The use of current configuration of TRSs by DOR may be appropriate whereas roadside sound is of a significant concern. The uses of configuration 1 TRSs (W10G25T0.5) may be implemented if the speed reduction is more concerns. It may be noted that the results are based exclusively on specific vehicle type, conditions, and loads tested. In the next efforts, investigating their effectiveness on other vehicle types, conditions, and loads, as well as other road segments will be conducted.

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