Evaluation of Milled Centerline Rumble Strip Patterns

Recently, several states and Canadian provinces have begun experimenting with centerline rumble strips. Modeled after shoulder rumble strips, centerline rumble strips are placed in the center of the roadway between opposing lanes of traffic to alert drivers that they have crossed over into the path of oncoming traffic. At the current time there does not appear to be a standard for the patterns and dimensions of the centerline rumble strips being installed. Therefore, this research attempts to determine the optimal pattern and dimensions for installation on Kansas highways based on decibel levels and steering wheel vibration generated by traveling over the rumble strips. Twelve patterns were generated based on the installations of other states and these were installed at an isolated location for testing. Seven vehicles of various sizes negotiated these rumble strips at varying speeds and the decibel levels at the driver's location, as well as steering wheel vibration, were recorded and analyzed. From this data, two patterns were selected for further testing in an actual highway setting in Kansas in 2003.

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The purpose of rumble strips is to provide motorists with an audible and tactile warning that their vehicle is approaching a decision point of critical importance to safety or that their vehicle has partially or completely left the road. Rumble strips can be installed either on the traveled surface of the roadway or the roadway shoulder. Rumble strips placed on the traveled surface are warning devices intended to alert drivers to the possible need to take some action (Harwood 1993).

Vehicles veering out of their travel lane are the cause of nearly 20% of all vehicle crashes in the United States, and nearly 40% of the fatalities occurring on US highways are attributed to them (Pilutti and Ulsoy 1998). In rural areas, where there is generally less stimuli (vehicles and others) to keep the driver's attention, these accidents account for more than 60% of highway fatalities (Suzman 1999). Not only do these accidents claim lives, they come with a societal cost of $80 billion annually as well (Griffith 2000). Clearly there is a need for an effective method of keeping inattentive drivers in their lane. A variety of methods have been used to do so, including shoulder rumble strips, which have been installed extensively on American and Canadian highways for decades, and have been shown to effectively reduce run-off-the-road (ROR) crashes by as much as 65 to 70% (Johnson 2000). However, until recently, little has been done to prevent drivers from crossing over the highway centerline, where the results of drifting out of the travel lane can be even more dramatic because of the possibility of a head-on collision.

According to a 1990 national study, head-on collisions were the cause of approximately 40% of all fatal multi-vehicle accidents (Alexander and Garder 1995). This same study showed that over 86% of fatal head-on collisions on two-lane highways were not caused by a driver attempting to pass anoth-

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er vehicle, but rather "typically either by entering a curve at too high a speed or by drifting across the road after falling asleep or being inattentive" (Alexander et al. 1995). Preliminary testing has shown that centerline rumble strips are an effective method of reducing these crossover accidents (Perrillo 1998), but more extensive testing is needed to determine the true extent of their effectiveness.

Modeled after shoulder rumble strips, centerline rumble strips are placed between opposing lanes of traffic in "no passing" zones to alert drivers that they have crossed over into the path of oncoming traffic. The purpose of this research is to evaluate 12 different patterns and dimensions for milled centerline rumble strips based on vehicle interior noise level, steering wheel vibration level and exterior noise level.

METHODOLOGY

The Kansas State University (KSU) research team, consisting of the authors of this paper with the support of the Kansas Department of Transportation (KDOT), initiated the research on centerline rumble strips in the fall of 1999. Initially, a phone survey was conducted in the fall of 1999 of the DOTs of various states with centerline rumble strips in place. The states involved in this survey were Colorado, Arizona, California, Pennsylvania, Oregon, and Washington. Its purpose was to accumulate and analyze data regarding the types and dimensions of centerline rumble strips being installed in these locations and any problems or concerns they raised. This was followed by a more formal survey that was sent to all 50 states and all Canadian provinces. This survey was written to address the following questions:

- Are centerline rumble strips in use?
- How were they constructed (milled or rolled)?
- What are their dimensions (width, length, depth)?
- What pattern type was chosen?
- Are they located in all zones or only in double yellow 'no passing' zones?
- How long have they been in use?
- Has any data been gathered?
- What type of research was conducted on that data?
- What were the results?

This survey produced 23 responses. Florida, Michigan, South Dakota, New Hampshire, Virginia, North Carolina, Missouri, Illinois, New York, Indiana, Texas, Wisconsin, Utah, and Nova Scotia, Canada, all were either considering installations or asked for additional information and results. California, Oregon, Massachusetts, Washington, Arizona, Colorado, Connecticut, Pennsylvania, and Alberta, Canada, responded that they had centerline rumbles strips installed at various locations. This information can be seen in Table 1.

After compiling and analyzing the results of these surveys, it became apparent that there was no standard in the types and dimensions of rumble strips being used and tested. Members of the KSU Centerline Rumble Strip Evaluation Team then drafted a proposal for centerline rumble strip testing in the state of Kansas. This proposal called for the evaluation of three different patterns which are: (1) continuous 12 inches on center (spacing between center of rumble strips), (2) continuous 24 inches on center; and (3) alternating 12 & 24 inches on center consisting of four different widths each (5", 8", 12", and 16"), for a total of 12 test patterns (see Figures 1, 3, and 5). Decibel (dB) and steering wheel vibration levels would then be recorded at the driver's position during a series of tests at various speeds utilizing multiple vehicle types. This testing would attempt to validate an optimum pattern for centerline rumble strip installations in the State of Kansas.

Table 1: Milled Centerline Rumble Strips by US States and Canadian Province

State	Width	Length	Depth	Center	All Zones or No Pass Only	Comments
California	6.5"	16"	0.5"	Continuous 24"	No Pass Only	Used with raised thermoplastic striping and reflectors
Washington	6.5"	16"	0.5"	Continuous 12"	No Pass Only	Markings installed over strips
	6.5"	16"	0.5"	Continuous 24"	No Pass Only	Markings installed over strips
Oregon	7"	16"	0.63"	Continuous 12"	No Pass Only	Used with 4' median
Arizona	6.5"	12"	0.5"	Continuous 12"	All Zones	Markings installed over strips
	6.5"	8"	0.5"	Continuous 12"	All Zones	Narrower to reduce residential noise
	6.5"	5"	0.5"	Continuous 12"	All Zones	Narrower to reduce residential noise
Massachusetts	6.5"	18"	0.5"	Continuous 12"	No Pass Only	Markings installed over strips
Pennsylvania	6.5"	30"	0.5"	Alternating 24 & 48"	No Pass Only	Across centerlines - 12' lanes
	6.5"	16" each	0.5"	Alternating 24 & 48"	No Pass Only	Outside centerlines - 12' lanes
	6.5"	16"	0.5"	Alternating 24 & 48"	No Pass Only	Between centerlines - 12' lanes
	6.5"	18"	0.5"	Alternating 24 & 48"	No Pass Only	Across centerlines - 11' lanes
	6.5"	10" each	0.5"	Alternating 24 & 48"	No Pass Only	Outside centerlines - 11' lanes
	6.5"	12"	0.5"	Alternating 24 & 48"	No Pass Only	Between centerlines - 11' lanes
Colorado	6.5"	12"	0.5"	Continuous 12"	All Zones	Markings installed over strips
Connecticut	6.5"	16"	0.5"	Continuous 12"	No Pass Only	Markings installed over strips
Alberta, Canada	6.5"	12"	0.5"	Continuous 12"	All Zones	Markings installed over strips

Note:
Width - represents dimension parallel to travel surface
Length - represents dimension perpendicular to travel surface
Depth – represents dimension downward (cut) from the top of the surface
Center - spacing between center of strips (see Figures 1, 3 and 5)

Figure 1: Kansas Blueprint of Continuous 12 Inches on Center Pattern

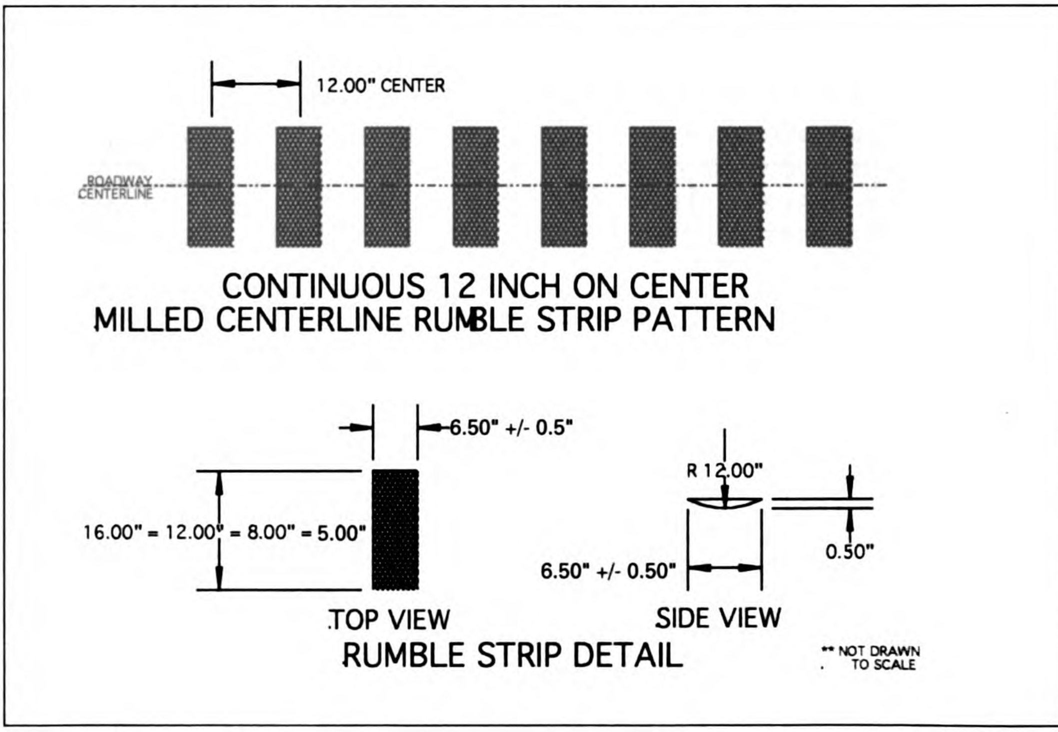

Figure 2: Installed Continuous 12 Inches on Center/ 16 Inches Long

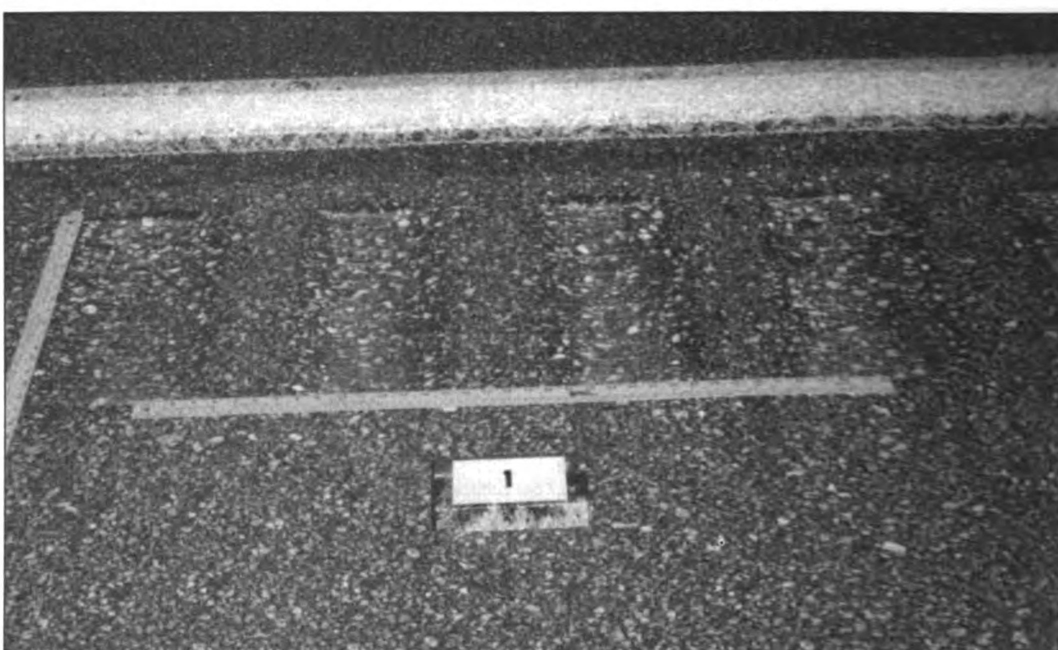

Figure 3: Kansas Blueprint of Continuous 24 Inches on Center Pattern

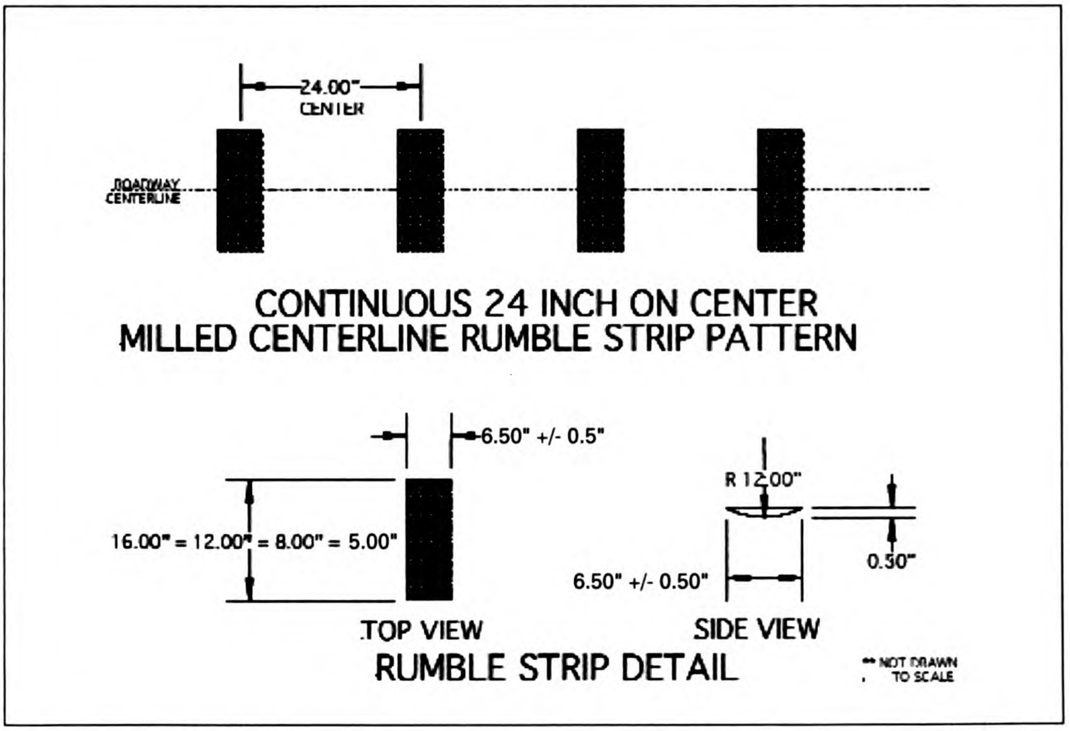

Figure 4: Installed Continuous 24 Inches on Center / 16 Inches Long

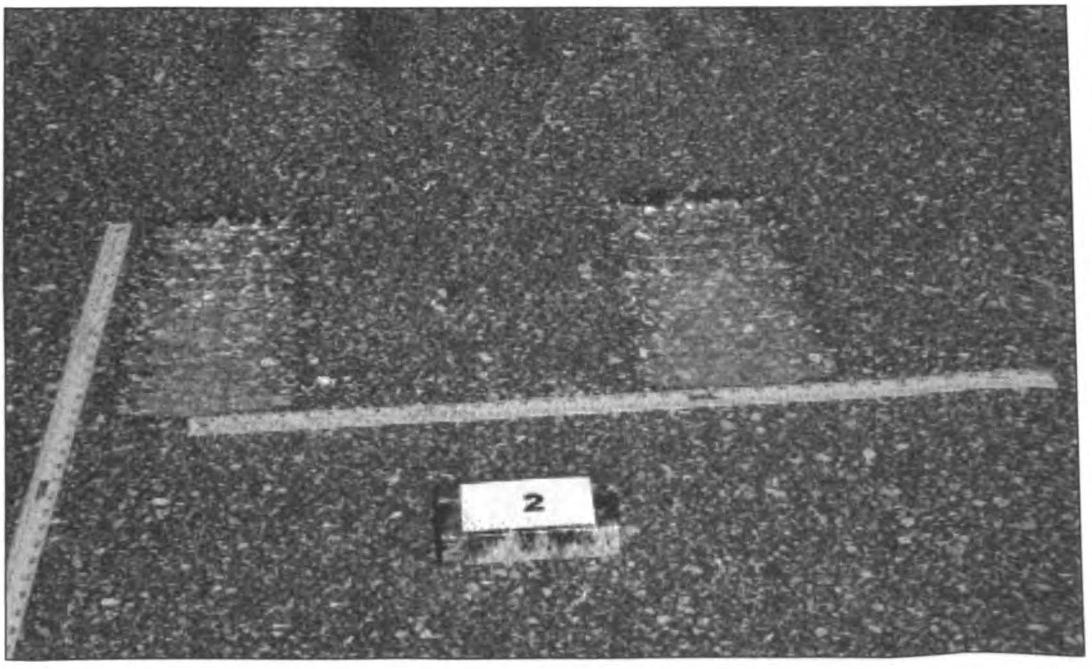

Figure 5: Kansas Blueprint of Alternating 12 and 24 Inches on Center Pattern

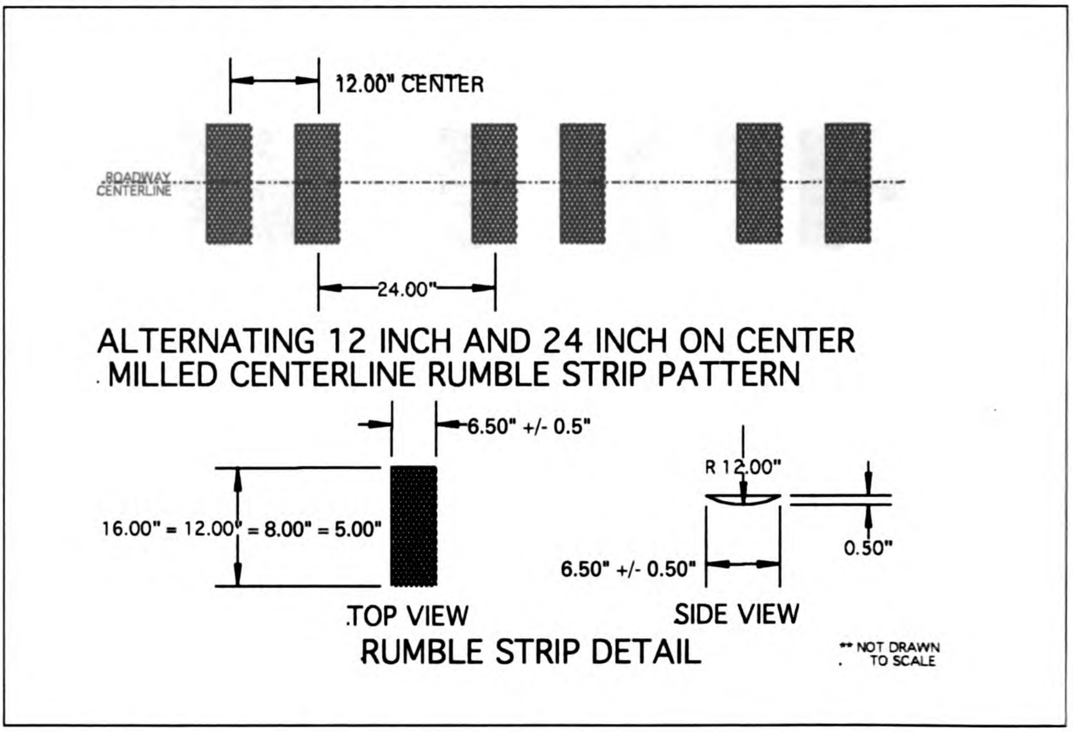

Figure 6: Installed Alternating 12 and 24 Inches on Center / 16 Inches Long

FIELD TESTS

The Kansas centerline rumble strip test patterns were installed in May 2000 by Dustrol Inc. of Towanda, Kansas, on the southbound lane of Interstate 135, approximately eight miles south of Salina, Kansas (see Figures 2, 4, and 6). The rumble strips were installed in such a way that the general driving public would not contact them under normal driving circumstances (installed in the emergency lane several feet from the intended driving lanes).

This particular location was chosen as the initial test site because this section of pavement was scheduled to be resurfaced in 2001. The shoulder surface is asphalt. The 12 test pattern sections were arranged as follows:

Section 01: Continuous 12 inches on center / 16 inches long
Section 02: Continuous 24 inches on center / 16 inches long
Section 03: Alternating 12 and 24 inches on center / 16 inches long

Section 04: Continuous 12 inches on center / 12 inches long
Section 05: Continuous 24 inches on center / 12 inches long
Section 06: Alternating 12 and 24 inches on center / 12 inches long

Section 07: Continuous 12 inches on center / 8 inches long
Section 08: Continuous 24 inches on center / 8 inches long
Section 09: Alternating 12 and 24 inches on center / 8 inches long

Section 10: Continuous 12 inches on center / 5 inches long
Section 11: Continuous 24 inches on center / 5 inches long
Section 12: Alternating 12 and 24 inches on center / 5 inches long

Section 01 is oriented as the northernmost pattern, and Section 12 the southernmost. Each test pattern section is approximately 1/4 mile in length with 200 feet between test sections. The cutting spindle on the milling machine used had a 12-inch milling radius and the depth of cut was 0.5 inch on all patterns.

Testing was conducted over the course of several visits to the test site throughout the summer and fall of 2000. Weather variability is not believed to have had an effect on vehicle testing, as each occasion was dry, with moderate to warm temperatures and moderate to strong wind gusts. On each occasion, KDOT erected a highway work zone that blocked the traffic lane adjacent to the test strips, so that highway traffic would not become a factor in the testing and to help insure the safety of the testers.

The vehicle tests were conducted using seven vehicles which represent a wide spectrum of the vehicles currently in operation on Kansas highways. The seven vehicles consisted of the following: two large trucks (a 1996 International Harvester 4900 DT 466 dump truck and a 1995 Ford L8000 dump truck), a full-size pickup truck (1991 Chevrolet 2500), a full-size passenger car (1993 Pontiac Bonneville), a compact passenger car (1994 Ford Escort Wagon), a minivan (1995 Ford Aerostar), and a sport utility vehicle (1997 Jeep Cherokee). All of these vehicles were in good operating condition at the time of testing.[1] The vehicles negotiated the rumble strips in such a manner that the driver's side wheels made contact with the rumble strips. This was necessary because it is the driver's side wheels that would contact the centerline rumble strips in an actual highway installation. Because of the close proximity of the rumble strips to the delineating poles, it was necessary during testing to negotiate the patterns in reverse numerical order, so that test Section 12 was the first section encountered during each vehicle trial, and Section 01 the last.

INTERIOR NOISE LEVEL TEST

Testing at this site consisted of both interior noise level testing and steering wheel vibration testing. These were tested because sound and touch are the two senses that the rumble strips alert when the driver's visual senses become impaired (falling asleep, becoming distracted, etc.).

Interior noise level testing was conducted by measuring the noise levels generated by the rumble strips as the vehicles passed over each test section. The data was recorded using a Quest Technologies Model Q-300 dosimeter, with a remote microphone clipped to the driver's collar just below the right ear. This meter operates at 32 samples per second, and displays the highest decibel reading taken during any one-second period. The readings were taken using Monitoring Setting A, which boosts high-level frequencies and more closely represents what the human ear actually hears. While the tests were conducted, the climate control system, radio, and any other noise-producing sources were turned off, and the windows were rolled up, to eliminate as much background noise as possible. A video camera was used to record the noise levels on the dosimeter as the vehicles passed over the test strips. This data was then transcribed from the videotape, analyzed to locate the proper test strip intervals, and then entered into Microsoft Excel for evaluation. Each vehicle negotiated the rumble strips at 60 mph. This speed was chosen because it is the current speed limit on many of the rural, two-lane highways in Kansas.

RESULTS OF INTERIOR NOISE TEST

The decibel level mean and standard deviation for each vehicle over each test section at 60 mph was calculated and is displayed in Table 2.[2] The data was then analyzed for trends. Trends were examined by pattern type and by rumble strip length. While there appears to be many inconsistencies in the results, the results do show a trend in pattern type by examining the Grand Mean in Table 2. Among all of the vehicles tested, the continuous 12-inch on center pattern (test Sections 1-87.18 dB, 4-89.29 dB, 7-89.11 dB, and 10-88.24 dB) generally produced the highest mean decibel levels, followed by the alternating 12- and 24-inch on center pattern (test Sections 3-86.92 dB, 6-87.34 dB, 9-86.68 dB, and 12-82.71 dB). The continuous 24-inch on center pattern (test Sections 2-85.59 dB, 5-85.29 dB, 8-84.69 dB, and 11-83.36 dB) produced the lowest mean decibel levels. Further analysis shows that over a given distance, the continuous 12-inch on center pattern has the greatest number of rumble strip indentations, followed by the alternating 12- and 24-inch on center pattern, and finally the continuous 24- inch on center pattern, which has the fewest indentations. Thus, it can be inferred that patterns with higher densities of rumble strip indentations produce higher average decibel levels. As for trends in decibel levels due to rumble strip length, it does appear that the longer rumble strips do generally produce higher average decibel levels, but there is no consistency among the longer lengths. This could be explained as a result of the vehicle tires not remaining in full contact with the shorter rumble strip patterns.

STEERING WHEEL VIBRATION TEST

Steering wheel vibration testing was conducted by measuring the vibration levels in the steering wheel of each vehicle that was generated by the rumble strips as the vehicles passed over each test section at 60 mph. The data was recorded using a MicroDAQ Model SA-600 accelerometer, which was firmly attached to the steering wheel of the vehicle by duct tape. This accelerometer simultaneously samples and internally records the peak acceleration levels on all three axes (X, Y, and Z) at a rate of four readings per second. The accelerometer was

Table 2: Decibel Level Mean and Standard Deviation at Driver's Position – 60 mph

	Pattern Tested											
Vehicle	**P12**	**P11**	**P10**	**P9**	**P8**	**P7**	**P6**	**P5**	**P4**	**P3**	**P2**	**P1**
1996 IH 4900 DT 466	—	—	92.24	92.84	91.47	93.41	93.35	92.23	94.12	92.94	92.16	91.23
Dump Truck (GW=75,000)	—	—	0.852	0.490	0.482	0.546	0.346	0.494	0.429	0.373	0.685	0.316
1995 Ford L8000	—	88.21	92.31	90.54	90.03	92.01	91.43	90.48	92.73	91.07	90.73	91.34
Dump Truck (GW=48,000)	—	0.445	0.950	0.283	0.433	0.456	0.592	0.440	0.465	0.587	0.263	0.915
1991 Chevrolet 2500	—	—	85.29	84.11	81.44	88.77	84.18	82.68	87.47	83.77	82.86	83.50
Pickup Truck	—	—	1.117	0.753	0.614	1.242	0.896	0.572	0.796	0.452	0.845	1.194
1993 Pontiac Bonneville	82.86	79.01	83.32	83.75	79.46	83.59	84.65	79.61	84.24	83.48	80.01	82.89
Full-Size Passenger Car	1.053	0.703	0.786	0.459	0.371	0.970	0.374	0.150	0.274	0.179	0.312	0.568
1994 Ford Escort Wagon	—	85.60	88.42	88.62	87.75	89.74	87.44	86.57	89.97	87.76	86.22	87.34
Compact Passenger Car	—	0.390	0.990	0.083	0.465	0.483	0.238	0.083	0.430	0.508	0.351	0.711
1995 Ford Aerostar	82.56	80.62	87.83	84.09	82.83	89.49	86.12	84.97	87.77	85.59	85.89	88.33
Minivan	1.255	1.083	0.437	0.604	0.851	0.692	0.668	0.530	0.600	0.612	0.904	1.146
1997 Jeep Cherokee	—	—	—	82.82	79.87	86.76	84.22	80.48	88.65	83.80	81.24	85.63
SUV	—	—	—	0.563	0.725	0.683	1.014	0.419	0.338	0.544	0.821	0.676
GRAND MEAN	**82.71**	**83.36**	**88.24**	**86.68**	**84.69**	**89.11**	**87.34**	**85.29**	**89.28**	**86.92**	**85.59**	**87.18**

Note:
— Indicates that the test results were inconclusive
For each vehicle the first row of numbers is the mean and the second row is the standard deviation
P12 = Section 12.........P1 = Section 01

controlled by MicroDAQ proprietary software by a laptop computer. This data stored after each vehicle trial was then downloaded directly to Microsoft Excel for analysis. During testing, the drivers were instructed to maintain as minimal contact with the steering wheel as safely as possible, so that the dampening effects caused by touching the steering wheel would be minimized.

RESULTS OF STEERING WHEEL VIBRATION TEST

Once the data from each vehicle trial was downloaded into Microsoft Excel for analysis, the data from each of the three axes (X, Y, and Z) had to be combined into a single resultant vector to show the overall vibration effect in the steering wheel. This was accomplished using the following mathematical formula:

(1) Resultant Vector = Square root $(X^2 + Y^2 + Z^2)$

X – Vibration along the x-axis
Y - Vibration along the y-axis
Z – Vibration along the z-axis

The resultant average vibration level and standard deviation for each vehicle and rumble strip pattern can be seen in Table 3. These resultant means and standard deviations were then averaged by pattern type and the GRAND MEAN (for each pattern) is shown in the last row in Table 3.

In analyzing the vibration data, there was a considerable amount of unexplained variability and inconsistency in the data. In the case of the 1996 IH 4900 DT 466 Dump Truck, it was simply impossible to distinguish the individual test patterns, some of which we attributed to the vehicle's suspension. However, the results for the remaining vehicles do show some consistencies. The alternating 12- and 24-inch on center pattern produced the highest mean vibration levels in two of the six remaining vehicles (the 1996 IH 4900 DT 466 Dump Truck removed from analysis) and the second highest average levels in the other four. Conversely, the continuous 24-inch on center pattern had none of the highest vibration levels, and only produced the second highest in two of the six. Thus, the highest overall vibration was produced by the alternating 12- and 24-inch on center pattern (see Table 3; GRAND MEAN), followed by the continuous 12-inch on center pattern. The lowest mean was produced by the continuous 24-inch on center pattern. For details, see Table 3.

DISCUSSION

Several difficulties arose during testing that were previously unforeseen, yet have had a significant impact on the validity of the data. First, it became obvious that the drivers, especially those in the large trucks, were having a difficult time positioning and maintaining the wheels directly on the 5-inch long strips. This is the reason that Table 2 does not have values for some of the vehicles for test patterns 10, 11, and 12. After reviewing the data and observing the numerous gaps in the data, both the members of the KSU Centerline Rumble Strip Evaluation Team and the members of KDOT unanimously decided to eliminate the 5-inch long rumble strip patterns from further evaluation, as they are simply too narrow to gain valid test data given the testing being used. Another unforeseen situation during interior noise testing was rattles and noises in several of the vehicles, especially the pickup truck. As the vehicles traveled squarely on each pattern, whatever was causing the rattles in the interior would occasionally begin to resonate, increasing the readings by as much as 5 to 10 decibels. Finally, both the dosimeter and the accelerometer that were used were not specifically designed for this type of testing. In the case of the dosimeter, rather than dis-

Table 3: Steering Wheel Vibration G-Forces Mean and Standard Deviation – 60mph

	Pattern Tested								
Vehicle	**P9**	**P8**	**P7**	**P6**	**P5**	**P4**	**P3**	**P2**	**P1**
1996 IH 4900 DT 466 Dump Truck (GW=75,000)	— —	— —	— —	— —	— —	— —	— —	— —	— —
1995 Ford L8000 Dump Truck (GW=48,000)	1.44 0.178	1.24 0.146	1.30 0.194	1.56 0.167	1.14 0.149	1.31 0.197	1.46 0.198	1.23 0.149	1.35 0.232
1991 Chevrolet 2500 Pickup Truck	1.42 0.372	1.09 0.093	1.93 0.402	1.51 0.245	1.26 0.141	2.05 0.255	1.68 0.293	1.38 0.204	1.69 0.459
1993 Pontiac Bonneville Full-Size Passenger Car	1.35 0.420	1.14 0.206	1.97 0.249	1.25 0.166	1.24 0.133	1.44 0.269	1.21 0.240	1.44 0.112	1.69 0.373
1994 Ford Escort Wagon Compact Passenger Car	1.47 0.139	1.06 0.145	1.14 0.139	1.25 0.186	1.32 0.129	1.19 0.154	1.45 0.203	1.33 0.106	1.34 0.138
1995 Ford Aerostar Minivan	1.42 0.353	1.37 0.201	1.52 0.327	1.68 0.184	1.34 0.191	1.47 0.223	1.69 0.272	1.43 0.220	1.59 0.310
1997 Jeep Cherokee SUV	1.64 0.265	1.34 0.183	1.49 0.302	2.31 0.229	1.85 0.391	1.93 0.185	2.33 0.364	1.60 0.322	1.73 0.396
GRAND MEAN	**1.46**	**1.21**	**1.56**	**1.59**	**1.36**	**1.57**	**1.64**	**1.40**	**1.57**

Note:
— Indicates that the test results were inconclusive
For each vehicle the first row of numbers is the mean and the second row is the standard deviation

play instantaneous measurements, an internal algorithm gives a reading based on both the current measurement and previous measurements. Using the readings recorded immediately after the test strip was encountered would have artificially lowered the mean decibel level. Thus, each of the 12 test sections for each of the vehicle trials had to be analyzed individually, so that the proper testing interval could be used in the statistical evaluations. The accelerometer was designed to monitor long-term vibration levels during cargo shipment. Its measuring and recording capability of only four readings per second was far lower than the capability that would have resulted in accurate steering wheel vibration levels because the actual number of oscillations was much higher.

CONCLUSION

The literature review revealed that shoulder rumble strips have been used since the 1950s by most state Departments of Transportation to successfully reduce the number of run-off-the-road accidents. However, the use of centerline rumble strips as an effective accident-prevention tool has only recently gained attention, and relatively little information concerning their effectiveness has been published. The surveys found that only a handful of states and Canadian provinces have installed centerline rumble strips, and most that have installed them have only done so recently on a limited basis for testing. They also revealed that little testing has been completed on the effectiveness of these installations. Furthermore, they showed that there is no standard that has been established for centerline rumble strip installations.

The initial Kansas testing of 12 different rumble strip patterns comprised interior decibel level testing and steering wheel vibration testing conducted over the course of several visits to the test site throughout the summer and fall of 2000. The road tests were conducted using seven vehicles, which represent a wide spectrum of the vehicles currently in operation on Kansas highways. While the vehicles negotiated the different rumble strip patterns (the driver's side wheels made contact with the rumble strips) the interior decibel levels and the steering wheel vibration levels were recorded. Based on the results of these tests, two patterns were chosen for further testing in an actual highway setting, pattern 4 (continuous 12-inch on center, 12-inch long) and pattern 6 (alternating 12- and 24-inch on center, 12- inch long). Pattern 4 produced the highest noise level with the mean of 89.29 dB and had one of the highest vibration levels (1.57). The overall highest vibration levels were produced by the alternating patterns and pattern 6 was chosen based on the scores from the noise (mean of 87.34 dB) and vibration (1.59) tests. While the tests were conducted, the climate control system, radio, and any other noise-producing sources were turned off, and the windows were rolled up, to eliminate as much background noise as possible. According to Konz and Johnson (2000) for detection of auditory signal, the sound level should exceed the background noise by 8 to 12 dB. Since a vehicle with the windows up and radio off has a typical noise level of 70 dB (Konz and Johnson 2000) we chose the patterns with the highest noise level (89.29 dB, pattern 4 and 87.34 dB, pattern 6). For this reason the authors feel the test patterns with the highest noise and vibration levels should be considered for further testing. A section of each pattern will be installed on Kansas highways in two different locations, one rural and one urban. Further testing will be conducted throughout 2003.

Endnotes

1. Although tires affect the transmission of noise, the study did not collect tire information for the vehicles used in the field test.
2. The sample size was too small to permit testing the means for statistical significance.

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