MIDWEST SMART WORK ZONE DEPLOYMENT INITIATIVE

MwSWZDI

FHWA POOLED FUND STUDY

Report Title

Report Date: 2002

# Removable Orange Rumble Strips

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Supplemental Notes

Abstract

A previous evaluation of this product found that the ease of application and removal represented a significant advantage over traditional asphalt rumble strips, but that a single thickness was insufficient to be reliably perceptible by drivers. The orange color of the strips was found to cause a reduction in mean speed, even though little or no sound or vibration was generated. This evaluation was conducted as a followup to explore four issues: 1) the effectiveness of the strips installed in a double thickness, 2) the persistence of the speed reduction due to the orange color (i.e., is this a novelty effect), 3) the quantified sound and vibration generated inside the vehicle compared to asphalt strips, and 4) the durability of the strips as installed per manufacturer's specifications. A rural two-lane highway was identified where bridge repairs were to require a lane closure and installation of a temporary signal. KDOT standards require two sets of rumble strips on each approach whenever a temporary signal is used. Traditional asphalt strips were used on one approach to the site, while on the other approach the removable strips were used for the most upstream set of strips. Vehicle speeds were monitored on both approaches for several weeks, installation and removal time was measured, and sound and vibration inside the vehicle were measured for both the orange rumble strips and the asphalt rumble strips. The double thickness of this strip was found to be effective, generating similar sound and vibration to the asphalt strips. They are more expensive than asphalt strips, and reuse is not recommended by the manufacturer. The shorter installation times to imply safety benefits, although these were not quantified. The orange color of the strips was responsible for a reduction in mean speeds, but the reduction dissipated over time.

# Comparison of ORS and Asphalt Rumble Strips

by

Eric Meyer

The University of Kansas

And

Scott Walton

The University of Kansas

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# Nomenclature

*A-weighting filter* ⇨ weighting curve applied to measurements recorded with a microphone to transform them into sound levels that a human would perceive. Figure 8 on page 14 shows a plot of the correction factors applied to recorded measurements.

*dB* ⇨ decibel = 10 log (value)
herein: value = (Measured pressure/Reference pressure)^2
therefore: decibel = 20 log (Measured pressure/Reference pressure)

*dBA* ⇨ decibel measured with A-weighting filter, used for sound measurements

$L_{eq}$ ⇨ equivalent sound level (dB)

$L_{10}$ ⇨ sound level exceeded 10 percent of the time (dB)

*Reference pressure* ⇨ 20 micropascals (μPa) for sound

# Technology

In Kansas, the Department of Transportation (KDOT) uses rumble strips primarily in advance of work zones where two or more lanes of traffic traveling in opposite directions are forced to share a single lane, as is common for two lane bridge repairs. In these situations, temporary traffic signals are used to control traffic movement through the work zone. Rumble strips are used to alert drivers that an unusual situation (i.e., the traffic signal) is ahead. In this evaluation, the Removable Rumble Strip from Advanced Traffic Markings was compared with the KDOT standard asphalt rumble strips (Asphalt). The Removable Rumble Strips are manufactured by

Advanced Traffic Markings, Inc.
P.O. Box H
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(252) 536-2574 (voice)
(252) 536-4940 (fax)
www.trafficmarking.com

The strips are available in orange, black, and white. Available in 90-ft rolls, the strips cost $8/ft, or $720/roll. Adhesive is pre-applied. Orange strips were used in this evaluation, and are referred to as "orange rumble strips" or "ORS."

## Layout

Rumble strip patterns range from a single continuous section of textured roadway to single strips placed at varying spacings. The most common rumble strip layout patterns consist of a few sets with each set containing a few small groups of closely spaced strips. In Kansas, the current practice for work zones consists of two sets spaced 152.4–304.8 m (500–1000 ft) apart, with each set containing three groups of strips spaced 30.5 m (100 ft) apart. Each of the six groups consists of six strips with 0.6 m (2 ft) center-to-center spacing. [1] Rumble strips at an approach to an intersection consist of a single group containing 25, 10 cm (4 in) grooves with 0.3 m (1 ft) center-to-center spacing. [2]

The orange rumble strips are non-reflective, self-adhesive, and come in rolls of 27.4 m (90 ft). The orange rumble strips are available in orange, white, black, or customized colors. All are non-reflective. Previous studies using the orange rumble strips with a single thickness have determined that they were effective, but that their effectiveness was mostly due to their high visibility. [1, 4] It was suggested that the strips might be more effective if the thickness of the strips were doubled. In this study, a double thickness was used.

The asphalt rumble strips consist of a raised strip formed from cold-mix asphalt. The asphalt strips typically have a cross-section that is best described as dome shaped. This type of strip is currently the most commonly used type of raised rumble strip [2].

## Installation

The orange rumble strips were first cut to the appropriate length, 1.2 m (4 ft), using tin snips. The pavement temperature was 45˚ C (113˚ F), and the pavement was completely dry. The pavement surface was swept clear of debris using a push broom. The placement of the rumble strips was determined using a tape measure and marked using masking tape. The adhesive, which is pre-applied to the strip by the manufacturer, was exposed by the removal of the protective backing. The strip was then positioned on the pavement and rolled with a 22 kg (48 lb) tamper cart carrying an additional 90 kg (198 lb). The plastic backing tore on approximately one out of every five pieces, significantly increasing the effort required for installation. This was reported to the manufacturer who was able to identify the cause of the problem within the manufacturing process and affirmed the problem would be addressed. The orange rumble strips are 3.8 mm (0.150 in) thick. Based on previous research concluding that a single thickness was insufficient to produce sufficiently noticeable noise and vibration [1, 4], two pieces were laid down, one on top of another, in order to double the thickness, effectively doubling the installation time as well.

Asphalt rumble strips are usually installed using one of two methods. Sometimes asphalt strips are installed by using wooden forms that consist of seven pieces of 3 cm x 31 cm x 3.7 m (1 in x 12 in x 12 ft) lumber. These boards are placed on the pavement at 0.6 m (2 ft) center-to-center spacing, and the spaces between the boards are filled with asphalt and compacted using a shovel. Asphalt strips are sometimes placed without using the forms. Instead, the pavement is marked with chalk or paint, and the asphalt is put in place and formed using shovels. The asphalt is then compacted by driving over it with a truck. The asphalt strips used in these tests were installed using the later method.

## Cross-Sections

The cross-section of the rumble strip directly affects the amount of sound and vibration that each type of strip will produce. The removable rumble strips are less wide and less thick than the asphalt rumble strips. Figure 1 contains detailed drawings and dimensions of the cross-sections of both types of rumble strips. The dimensions for the asphalt strip are approximations of a typical strip, as the cross-section can vary.

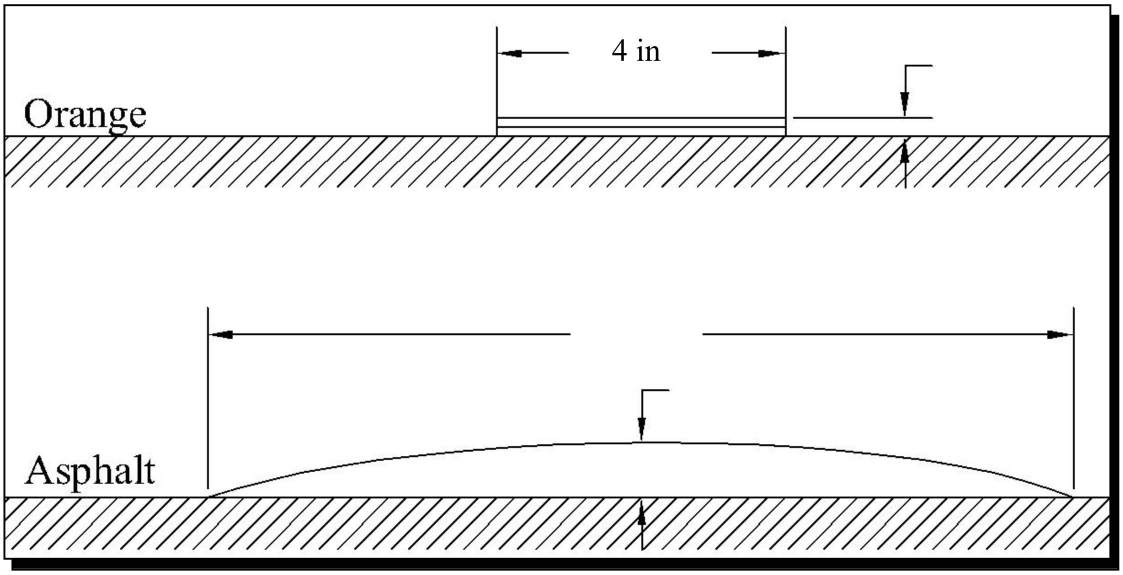



**Figure 1 - Rumble Strip Cross-Sections**

# Study Sites

Data were collected at two work zones. The Orange Rumble Strips (ORS) were used for the most upstream set on one approach at one location. Another removable product (*not* ORS) was used at the most upstream set on one approach at the other location. The remaining sets were asphalt rumble strips. Sound and vibration measurements were taken for both smooth pavement and asphalt rumble strips at both locations.

## Lake Perry Test Site

One test site was the eastbound approach to a bridge maintenance project on Kansas State Route 93 at Perry Lake, just south of Ozawkie, Kansas. This location had an ADT of 900 on the westbound approach, and 1200 on the eastbound approach during the study period. This location had two 3.7 m (12 ft) lanes and a posted speed of 105 kph (65 mph). The temporary rumble strips tested at this site (and shown in Figure 3) were not the ATM product. Speeds collected on the opposite approach (with asphalt rumble strips) are discussed later in this report.

## Horton Test Site

The orange rumble strips were installed on the westbound approach to a bridge maintenance project on Kansas State Route 20, west of Horton, Kansas. This location had an ADT of 1350 on the westbound approach during the study period. This location had two 3.4 m (11 ft) lanes, and a posted speed of 89 kph (55 mph).

## Layout

Sound and vibration levels were taken on asphalt strips at both sites. Speed data were collected on the asphalt strips at the Lake Perry test site, opposite the test strips approach .

Figure 2 through Figure 5 are work zone diagrams of the test sites. The boxes that contain only a three-digit number represent automatic traffic recorders, which were used to measure speeds, volumes, and classifications. Figure 2 shows where the speeds were collected on the asphalt strips, and Figure 4 shows where the speeds were collected on the orange rumble strips.

In Kansas, rumble strips are most commonly applied using cold mix asphalt in a configuration comprised of two sets of strips. The sets are spaced 152 – 228 m (500 ft - 750 ft) apart, with the downstream set being 305 m (1000 ft) upstream of the stop bar. Each set contains three groups with 31 m (100 ft) between groups. Each group contains six rumble strips, spaced 0.6 m (2 ft) center to center. These strips often stretch across the entire width of the lane, although sometimes a 0.6 to 1.22 m (2 to 4 ft) channel is left in the center of the strips for motorcycles. In order to compare the two types of temporary rumble strips to the asphalt rumble strips, the temporary rumble strips were deployed using the same pattern, although, a gap was included in the center of the lane and 15 cm (6 in) between the edge of the strips and the edgeline and centerline. A gap of 0.6 m (2 ft) was used for the orange rumble strip test location, which had 3.4 m (11 ft) lanes. Figure 6 shows diagrams of a typical rumble strip deployment for a single approach, a set of rumble strips, and a single group of temporary rumble strips.

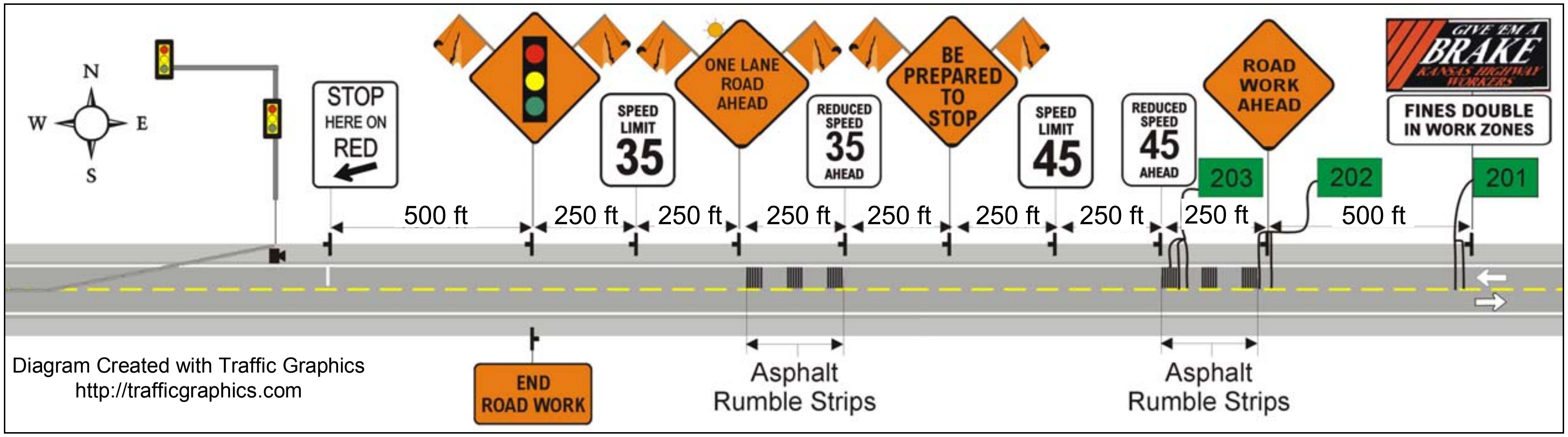



**Figure 2 - Westbound Approach at Perry Lake Test Site**

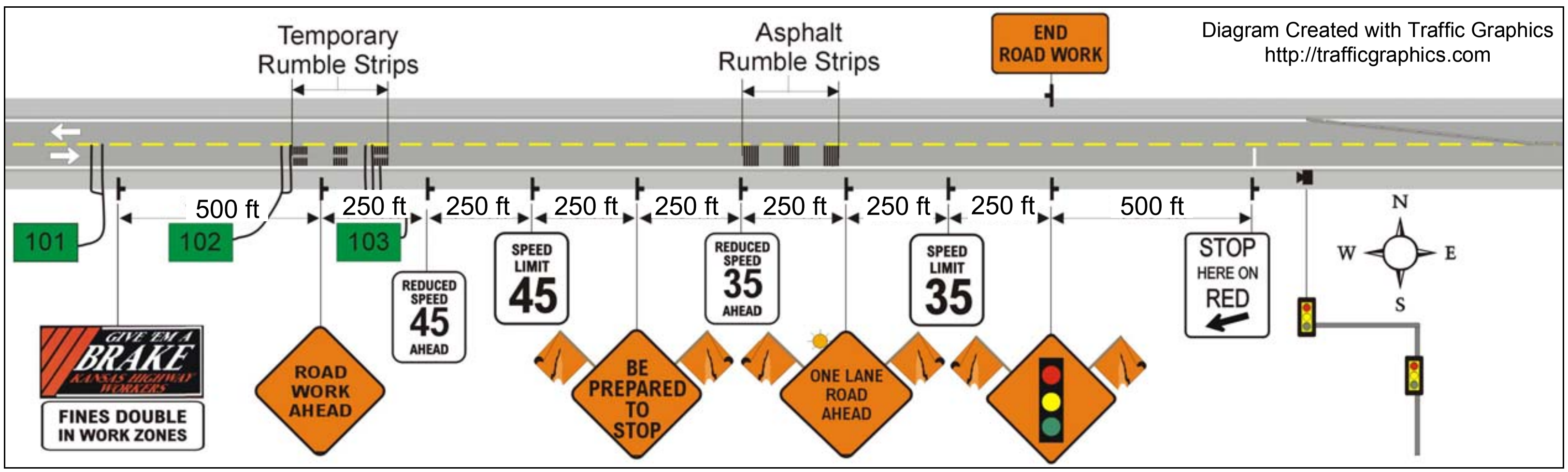



**Figure 3 - Eastbound Approach at Perry Lake Test Site**

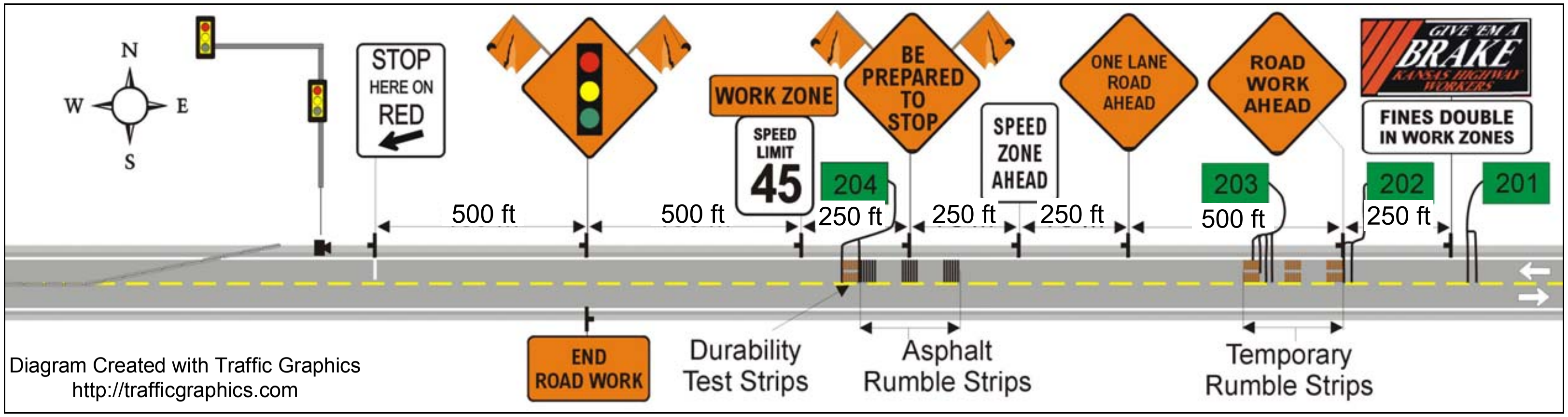



**Figure 4 - Westbound Approach at Horton Test Site**

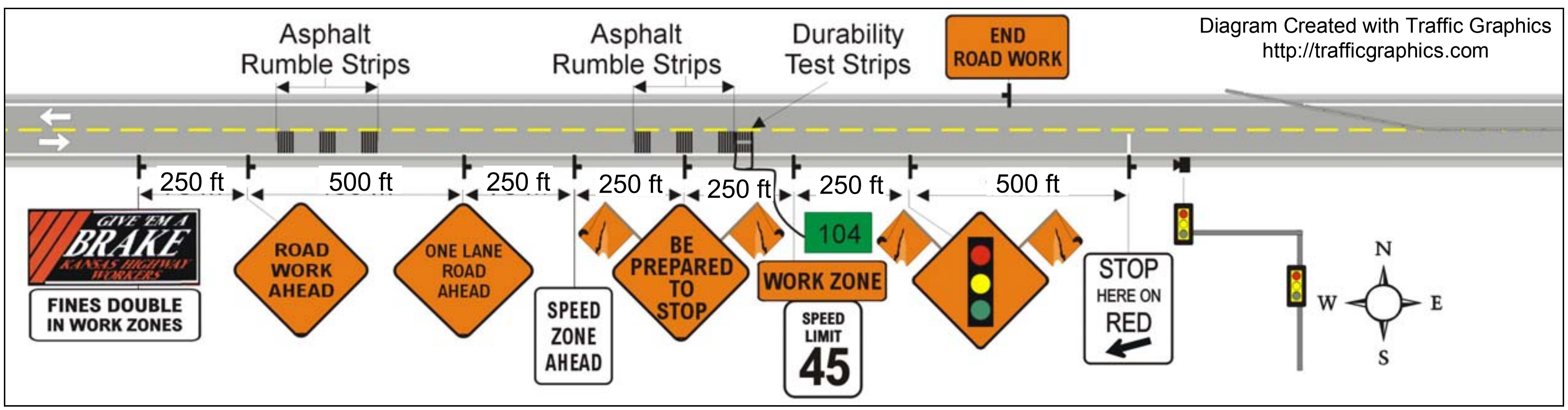



**Figure 5 - Eastbound Approach at Horton Test Site**

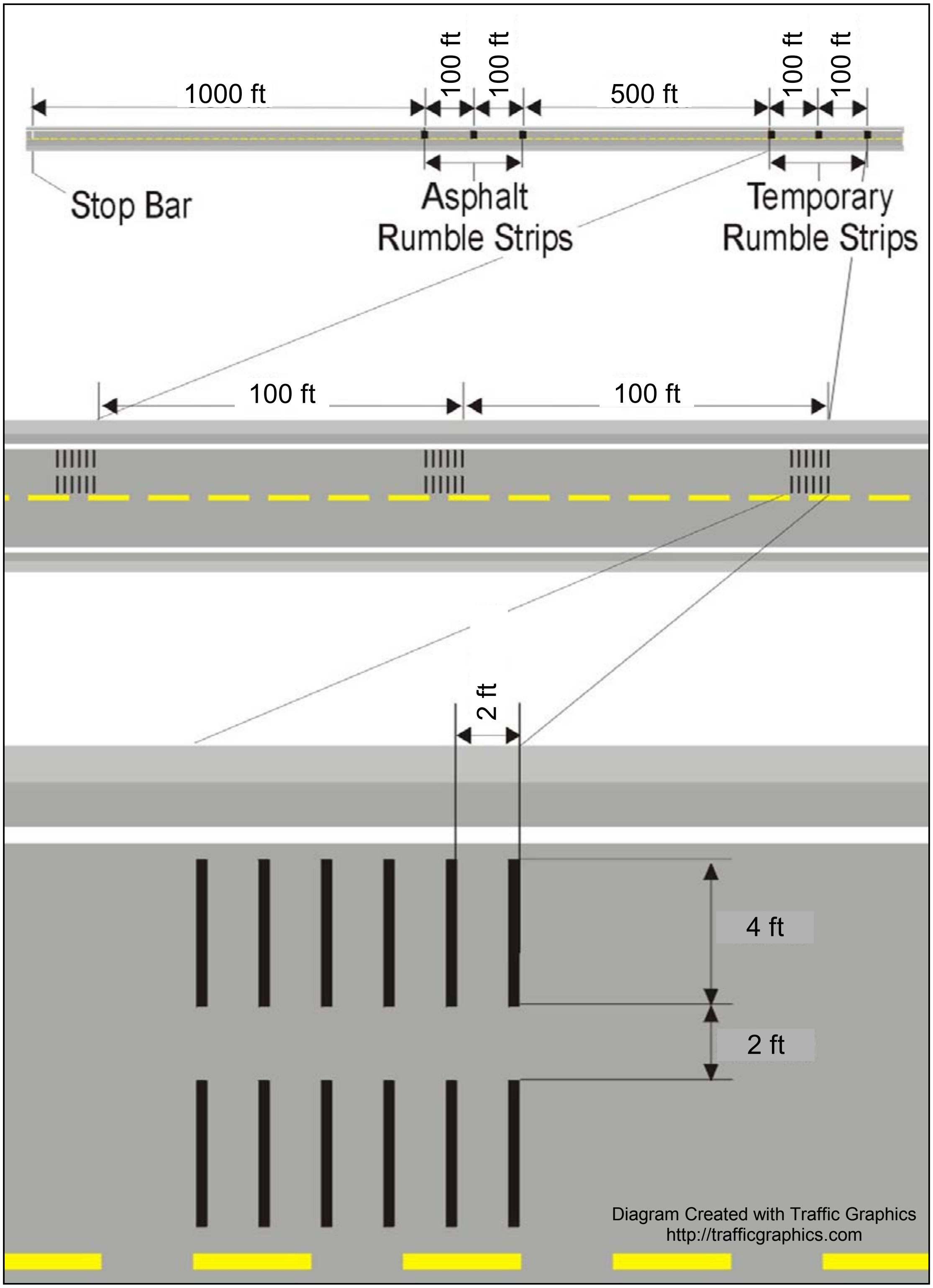



**Figure 6 - Typical Experimental Rumble Strip Deployment**

# Data Collection—Sound and Vibration

Rumble strips work by producing sound and vibration, which alerts the driver. While there are undoubtedly many other factors involved, the ability of rumble strips to get the driver's attention is directly related to the levels of sound and vibration they produce. With that in mind, the sound and vibration levels generated by the strips are very important points of comparison between different types of strips. In addition to measuring the sound in the vehicle and the vibration of the vehicle body, roadside noise levels were also measured for the KDOT standard configuration.

In order to collect the sound, vibration, and roadside noise levels, it was necessary to deploy a set of each of the types of the strips that were to be tested. These strips were then traversed repeatedly with three test vehicles at three different speeds until all of the data necessary for the comparisons had been collected. Vehicle speed data was collected in order to compare the rumble strips effect on vehicle speeds and speed reductions. Through the process of installing these model deployments, the times and costs of the installation were observed and quantified. The strips were then left in place for the duration of the respective construction projects in order to allow for the collection of speed data and to test the durability of the strips for use in long-term deployments. When the strips were removed, the removal times and costs were recorded. The amount of damage suffered by the strips was observed in order to get a better understanding of the durability of the different types of strips.

For measuring sound and vibration, three vehicles were used: a typical compact car (1998 Ford Escort SE), a typical midsize passenger car (1992 Honda Accord LX), and a dump truck (Kansas Department of Transportation Maintenance Truck). The measurements were taken for each vehicle at each of three different speeds: 64, 80, and 97 kph (40, 50, and 60 mph). These speeds were chosen in order to obtain measurement ranges that would be typical for approaches to highway work zones. Table 1 shows the different characteristics of the test vehicles.

Sound and vibration levels were measured as Equivalent Sound Level ($L_{eq}$) in decibels (dB). Table 2 shows sound levels in dB for common sounds. The measurements were recorded using a Norsonic Nor-110 Sound/Vibration Analyzer, shown in Figure 7. $L_{eq}$ values were recorded using a 3 ms measurement interval. The vibration levels were measured with no frequency weighting (sometimes referred to as flat or linear), and the sound levels were measured using the A-Weighting filter. This filter is used to transform the levels collected by a microphone (sound energy scale) into levels that would be perceived by a human (perceptual loudness scale). Humans have difficulty hearing very low or very high frequency sounds. The A-Weighting filter simply accounts for this, and makes adjustments to the $L_{eq}$ based on the frequency of the sound, so that the recorded data are more representative of what an average human would perceive. [2] Figure 8 shows a graph of the function comprising the A-Weighting filter.

**Table 1 - Test Vehicle Parameters**

| Parameter | Test Vehicle<br>Compact | <br>Midsize | <br>Truck |
|---|---|---|---|
| Manufacturer | Ford | Honda | Sterling |
| Model | Escort SE | Accord LX | LT-7501 |
| Year | 1998 | 1992 | N/A |
| Length (in) | 174.7 | 185.2 | N/A |
| Width (in) | 67 | 67.1 | 96 |
| Height (in) | 53.3 | 54.7 | 116 |
| Weight (lb) | 2468 | 2857 | 47000 |
| Wheel base (in) | 98.4 | 107.1 | 204 |
| Number of Axles | 2 | 2 | 3 |
| Ground Clearance (in) | N/A | 6.3 | N/A |
| Tires | 185/65-14 | 185/70-14 | 275/80-22 |
| Inner Diameter (in) | 14 | 14 | 22 |
| Outer Diameter (in) | 23.5 | 24.2 | 39.3 |
| Width (in) | 7.3 | 7.3 | 10.8 |
| Pressure (psi) | 35 | 34 | 95-105 |
| Number of Tires | 4 | 4 | 10 |

**Table 2 - Typical Sound Levels for Common Sounds in Decibels (dB) [2]**

| | |
|---|---|
| Soft whisper | 30 dB |
| Refrigerator | 40 dB |
| Normal conversation | 50 dB |
| Television | 60 dB |
| Noisy restaurant | 70 dB |
| Dishwasher | 75 dB |
| Blow dryer | 80 dB |
| Electric razor | 85 dB |
| Lawn mower | 90 dB |
| Roar of crowd | 95 dB |
| Power tools | 100 dB |
| Stereo headset | 110 dB |
| Subway train screech | 115 dB |
| Rock concert | 120 dB |
| .22 caliber rifle | 130 dB |
| Jet take-off | 140 dB |


**Figure 7 - Sound and Vibration Analysis Equipment**

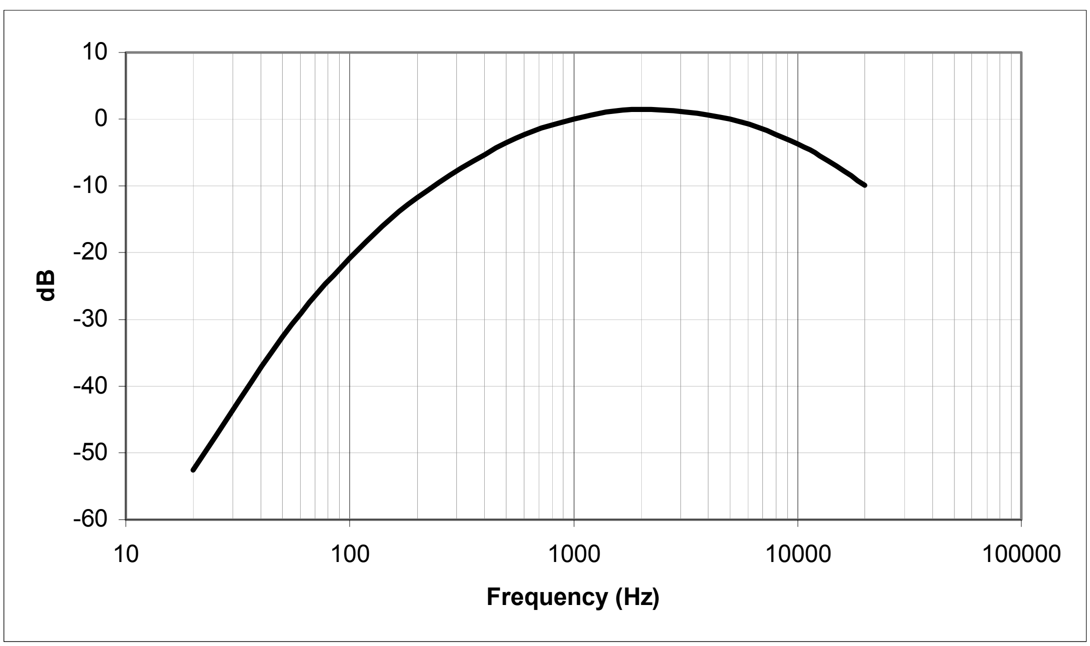
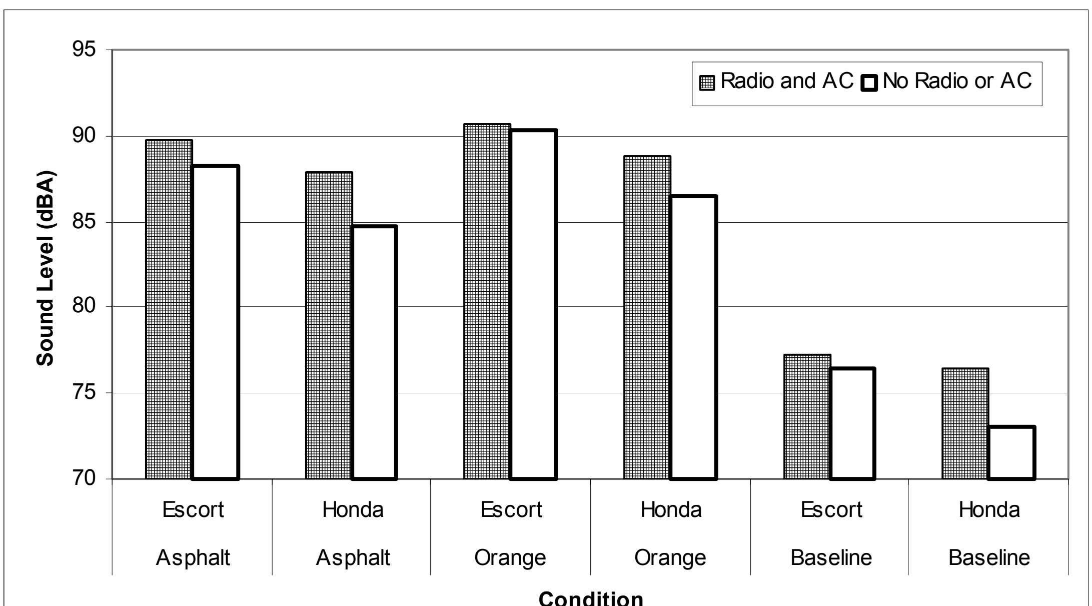



**Figure 8 - A-Weighting Filter**

## Instrument Placement

<u>In-Vehicle Sound</u>

The in-vehicle sound data were recorded by placing the microphone on a tripod with the microphone oriented horizontally forward, centered between the driver and passenger seats, 19 cm (7.5 in) below the ceiling, and even with the joint between the seat back and seat bottom of the driver's seat. The location was intended to approximate the position of the ear of a typical driver. All measurements used in the analysis were taken with the windows rolled up and the air-conditioner and stereo turned off. Measurements were also taken to compare the sound generated by the rumble strips with the sound generated by the radio (at a moderate volume setting) and the air-conditioner (on the highest fan setting). Figure 9 shows a comparison of the measurements collected with and without the radio and air conditioner. The chart shows that the increase in the sound levels caused by the added noise affected the sound levels on both the baseline data point and on the strips by approximately the same amount. This indicates that while the stereo and air conditioner do affect the sound levels, they do not affect the difference between the baseline levels and the levels produced by the strips. Since the differences in sound levels observed without the radio and the air conditioner are quite similar to the differences in the sound levels that would be experienced with the radio and air conditioner, it is reasonable to assume that the differences determined under these ideal conditions are representative of the differences that would be experienced in more realistic situations.




Note: measurements with radio and AC were not taken in the dump truck.

**Figure 9 - Sound Levels with and without the Radio and Air Conditioner**

Vehicle-Body Vibration

There are several ways in which the vibration caused by the interaction of the tires and the road surface can propagate through the vehicle to the driver's body. The driver can feel vibration through the steering wheel, the seat, and the floor of the vehicle. The amount of vibration that would be transferred through each of these means varies tremendously from vehicle to vehicle, depending on vehicle characteristics such as the suspension system, the type of and quality of the seat, and any damping mechanism between the steering wheel and the tires. To accurately measure the precise vibratory sensations caused by a set of rumble strips would require measuring the vibratory energy transmitted to the driver through each of these mechanisms. Additionally, the method and extent of the transmission of vibratory energy would also be a function of the driver's body. The weight of the driver, the length of the driver's arms and legs, and the thickness and fat content of the skin will all effect what levels of vibration will be perceived through each of the possible mechanisms.

Because this study is a comparison between a new device and a typical device, it is only necessary that a measurement be taken whose relative magnitude varies similarly to driver-perceived vibration. Toward this end, *vehicle body vibration* was use as the comparative measure. The implied assumption is that as vehicle body vibration increases, the vibratory energy propagating through the vehicle to the driver would be increased for every propagation mechanism. The vehicle body vibration was measured using an accelerometer that was magnetically mounted to the roof of the vehicle, directly above the mounting location of the microphone. Figure 10 shows the accelerometer mounted to the roof of a test vehicle (left) and the microphone on a tripod inside of a test vehicle (right).

Roadside Noise

The Federal Highway Administration's standards were followed for the roadside noise measurements. The microphone was mounted on a tripod and placed at the roadside 15.2 m (50 ft) from the center of the lane in which the test vehicle would be driven and 1.5 m (5 ft) above the road surface. [5] The microphone was oriented perpendicular to the road and was covered with a foam windscreen in order to reduce the effect of wind noise on the data.

**Figure 10 - Accelerometer (Left) and Microphone (Right)**

## Data Analysis—Sound and Vibration

Comparisons of both sound and vibration were based on the maximum of the Leq values measured over 3 ms intervals while crossing the rumble strips. When multiple observations of the same condition were made, the average was used. The measure used to compare data from different sites was the difference between the maximum $L_{eq}$ values observed while traversing the rumble strips and the maximum $L_{eq}$ observed while traversing smooth pavement under the same conditions. By using the difference in maximum $L_{eq}$ relative to smooth pavement, differences between locations such as wind speed, temperature, and atmospheric pressure can be removed from the data, assuming these factors remained constant during the data collection. The relative values measured for the different types of rumble strips can be directly compared.

The relative maximum $L_{eq}$ values were subjected to Analysis of Variance (ANOVA) tests. In this case the ANOVA tests were used to simply determine whether or not the difference between the means of the two data sets was statistically significant. A confidence interval of 95% was used in all of the comparisons.

To help simplify and expedite the data analysis process, a computer program was developed. The program was used to find the maximum $L_{eq}$ values using certain default parameters and limited user interaction. The maximum $L_{eq}$ values were then exported to a file with additional data indicating the condition for which the maximum was obtained. Figure 11 shows a plot of the data recorded for a typical sound level measurement, and Figure 12 shows a screenshot of the data analysis program.

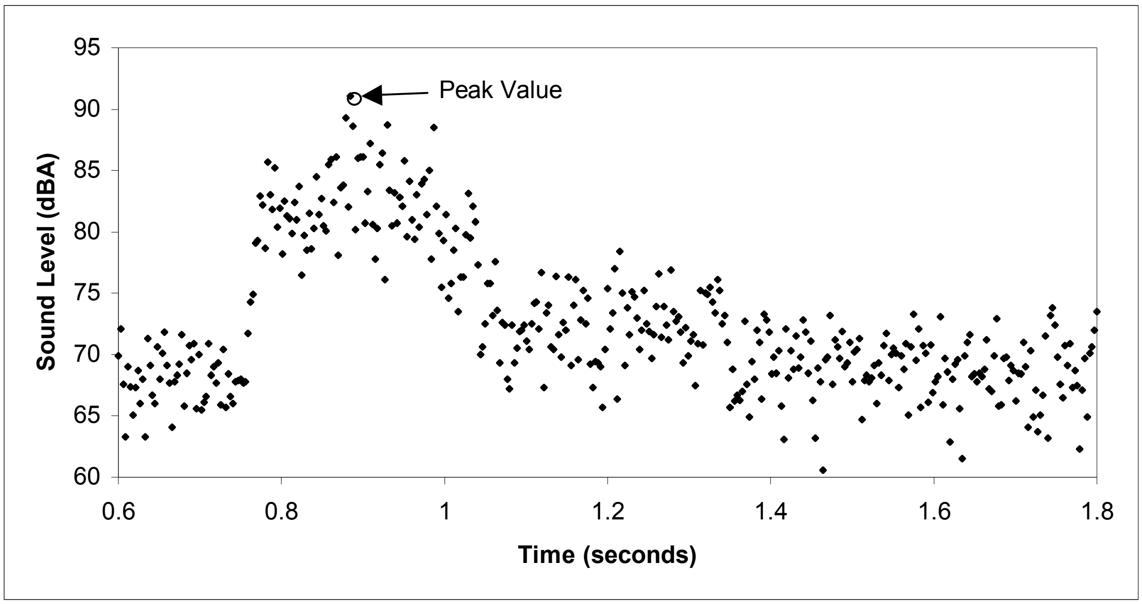



**Figure 11 - Typical Sound Level Measurements**

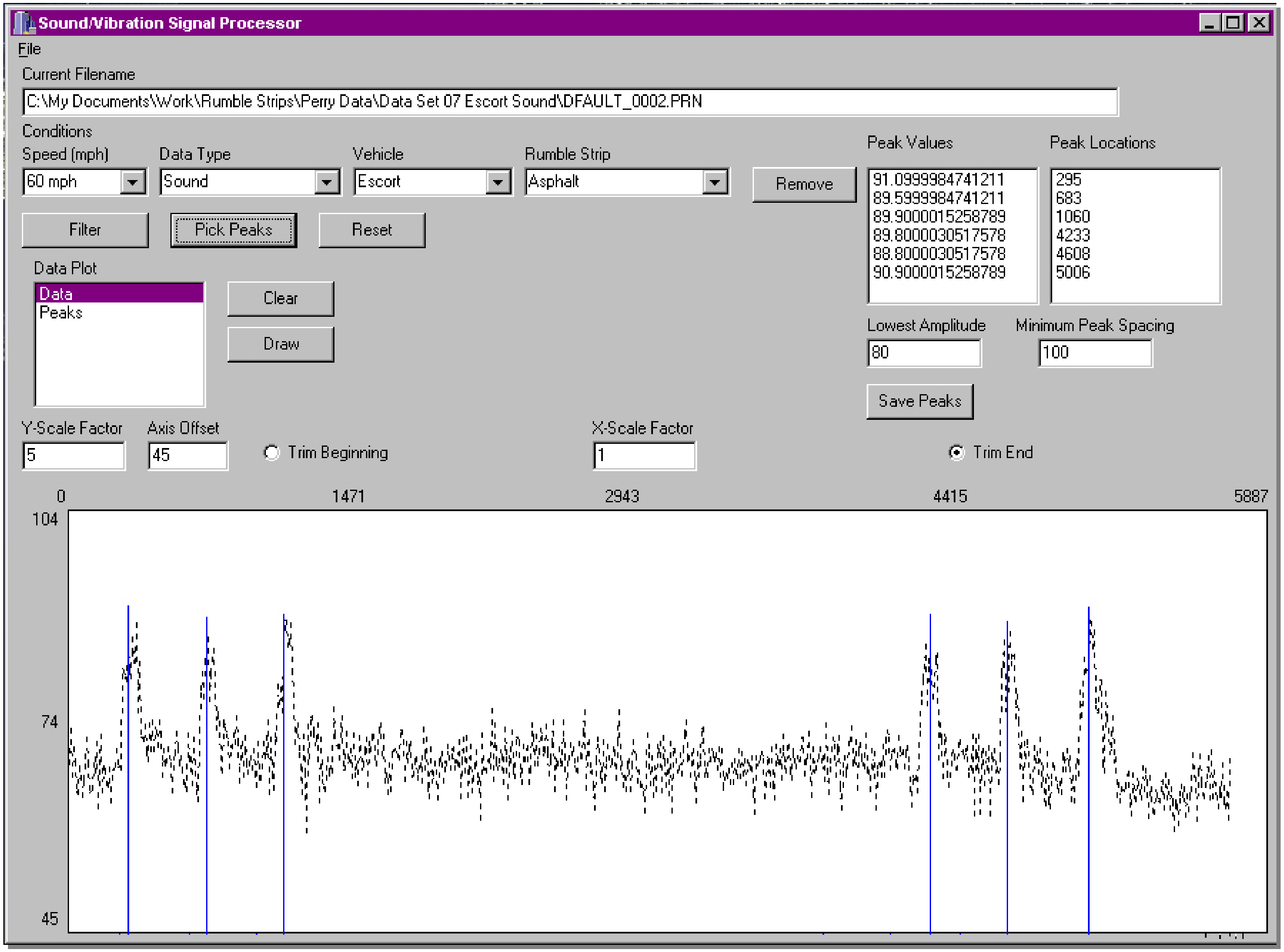



**Figure 12 - Screenshot of Sound and Vibration Data Analysis Program**

## Hearing Limitations

How the sound and vibration produced by the rumble strips are perceived by the driver is not only a function of the sound and vibration levels but is also a function of human perception. Therefore, the perceptibility of the differences in sound and vibration must be considered in addition to the statistical significance. Humans cannot detect very small changes in sound levels. The smallest detectable change in sound level is 1 dB, and a change of 3 dB is a slightly noticeable difference for most people. [6] Therefore, if one set of strips were only 1 dB louder than the other, to say that it produced more sound would be misleading, because a human would perceive them to be equally loud. A 1 dB difference is only detectable under ideal conditions. 3 dB is a more appropriate threshold for considering a difference to be practically significant in field tests such as those in this study. Therefore, if the sound levels produced by two groups of rumble strips differ by less than 3 dB, then they are considered to perform equally well with respect to the sound produced inside the vehicle or at the roadside.

## Vibration Perception

The threshold at which differences in vibration become detectable by humans is not well defined. Most studies involving the perception of vibration are done in order to find the limits at which vibration becomes discomforting or hazardous, but little attention has been given to the human ability to differentiate one vibration from another nearly equal vibration [7]. These studies typically rely on simple harmonic vibrations caused by machines, which are quite different than the vibrations consisting of a wide range of frequencies and amplitudes experienced while driving over rumble strips. Additionally, the measures used are generally subjective, and therefore an objective threshold is difficult to specify [8, 9]. In light of these complicating issues, 3 dB is taken as the threshold of perceptibility of vibration in order to provide symmetry with the sound measurements. The subjective assessment based on the experience of those who collected the vibration data was that using 3 dB as the threshold of perceptibility was reasonable.

# Results—Sound and Vibration

## In-Vehicle Sound

In most cases the temporary rumble strips did not differ by an amount that was statistically significant and noticeable. Table 3 shows comparisons of in-vehicle sound levels relative to levels experienced on smooth pavement. There were no in-vehicle sound comparisons that yielded differences that were statistically significant but not noticeable, nor were there any comparisons that had noticeable but not statistically significant differences. Comparisons that yielded both statistically significant and noticeable differences are highlighted in Table 3. The rumble strip comparisons that show the greatest difference are those involving the orange rumble strips being traversed by the dump truck. When the orange rumble strips were compared to the asphalt rumble strips at the same location, the dump truck experienced a noticeable and statistically significant decrease in the sound $L_{eq}$. This is perhaps because the orange rumble strips are the least thick of the three strips, and the dump truck has very large tires. However, regardless of the reason or the noticeable amount of difference between the two strips, the orange rumble strips still create in-vehicle sound levels that are noticeably greater than the levels on produced by the smooth pavement, and would therefore be noticeable to the driver of the dump truck. It can also be seen that the asphalt strips at one location produce significantly different sound levels in the Honda Accord than the asphalt rumble strips at the other location. While this is not much of a concern for these sets of strips, since both produce easily noticeable sound levels, it does show that the variation inherent to the cross-sections of asphalt strips can have a significant effect on the levels of sound these strips produce.

**Table 3 - In-Vehicle Sound Comparisons**

| Vehicle | Compact Car | | | Midsize Car | | | Dump Truck | | |
|---|---|---|---|---|---|---|---|---|---|
| Speed, kph (mph) | 64 (40) | 80 (50) | 97 (60) | 64 (40) | 80 (50) | 97 (60) | 64 (40) | 80 (50) | 97 (60) |
| Asphalt (Perry) | +15 | +14 | +13 | +15 | +16 | +16 | +10 | +9 | +7 |
| Asphalt (Horton) | +14 | +12 | +12 | +12 | +12 | +13 | +12 | +10 | +8 |
| | | | | | | | | | |
| Orange (Horton) | +14 | +14 | +14 | +14 | +13 | +15 | +6 | +6 | +5 |
| Asphalt (Horton) | +14 | +12 | +12 | +12 | +12 | +13 | +12 | +10 | +8 |

- Values are in dB relative baseline, which are the measurements collected on smooth pavement.
- Highlighted values show statistically significant and noticeable differences.
- Underlined values show statistically significant but not noticeable differences.

## Vehicle Body Vibration

The data collected for the vehicle body vibration are quite similar to the data collected for in-vehicle sound. Table 4 shows the comparisons of vehicle body vibration for the two types of rumble strips. Comparisons that yielded statistically significant and noticeable differences are highlighted in gray, and comparisons that yielded differences that were statistically significant but not noticeable are underlined. Overall, differences in vibration $L_{eq}$ values were greater than those observed for the sound measurements. The relative vibration experienced by the dump truck is typically less than that of the passenger cars. For some cases, as the speed decreased the vibration caused by the rumble strips increased. This is an undesirable affect. The rumble strips are mostly used in areas where drivers need to decrease their speed. If the vibratory sensation increases as the speed decreases, then drivers might be encouraged to maintain higher speeds in order to limit the somewhat unpleasant vibratory sensation. However, as mentioned earlier, this is only the case for a few conditions. This happens with the asphalt rumble strips deployed in Perry for the dump truck and the midsize car, and with the asphalt rumble strips deployed in Horton for the midsize car.

**Table 4 - Vehicle Body Vibration Comparisons**

| Vehicle | Compact Car | | | | Midsize Car | | | | Dump Truck | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Speed, kph (mph) | 64 (40) | 80 (50) | 97 (60) | | 64 (40) | 80 (50) | 97 (60) | | 64 (40) | 80 (50) | 97 (60) |
| Asphalt (Perry) | +16 | +14 | +14 | | +21 | +13 | +12 | | +13 | +10 | +4 |
| Asphalt (Horton) | +14 | +13 | +15 | | +15 | +14 | +11 | | +11 | +15 | +11 |
| | | | | | | | | | | | |
| Orange (Horton) | +13 | +11 | +16 | | +14 | +16 | +12 | | +8 | +15 | +9 |
| Asphalt (Horton) | +14 | +13 | +15 | | +15 | +14 | +11 | | +11 | +15 | +11 |

- Values are in dB relative to baseline, which are the measurements collected on smooth pavement.
- Highlighted values show statistically significant and noticeable differences
- Underlined values show statistically significant, but not noticeable difference.

## Roadside Noise

Some rumble strip deployments have been met with complaints about excessive noise levels from neighboring areas. The complaints often result in expensive studies being performed and sometimes even more expensive noise abatement measures being installed [10, 10]. While these types of complaints normally result from permanent rumble strip deployments, noise could potentially be an issue for temporary rumble strips deployments that are in place for an extended period of time (e.g., more than a few weeks). The amount of roadside noise that is acceptable depends on several factors. The noise level and pitch, the frequency of occurrence, the duration of the noise, proximity of dwellings to the roadside, terrain, the propagation of the noise through walls (affects noise levels that would be experienced inside someone's home), and the time of day that the noise occurs are all common factors that are used to determine if a noise level is excessive. Most of these factors are lumped into a single factor, the $L_{10}$, which is the noise level exceeded 10 percent of the time. The $L_{10}$ accounts for the noise level and pitch, the frequency of occurrence, and the duration of the noise. Different $L_{10}$ maximums are set for day, night, and type of area [5, 12]. Another factor that complicates the problem is that there are different criteria for noise levels in work zones, which is where temporary rumble strips would be used most frequently, at least in Kansas. Noise in work zones is considered by the public and officials to be necessary and only temporary. The $L_{10}$ is as much a function of traffic patterns as it is of strip type, and is consequently very site specific. Thus $L_{10}$ is not an appropriate measure for this study and only roadside noise $L_{eq}$s were considered. The roadside noise $L_{eq}$s alone cannot determine whether a type of rumble strip is either acceptable or unacceptable for use, but will provide a means of comparing between strip types. Table 5 shows the maximum roadside noise levels generated by the rumble strips.

**Table 5 - Maximum Roadside Noise $L_{eq}$s**

| Vehicle | Compact Car | | | Midsize Car | | | Dump Truck | | |
|---|---|---|---|---|---|---|---|---|---|
| Speed, kph (mph) | 64 (40) | 80 (50) | 97 (60) | 64 (40) | 80 (50) | 97 (60) | 64 (40) | 80 (50) | 97 (60) |
| Baseline (Perry) | 76 | 77 | 80 | 72 | 76 | 80 | - | - | - |
| Asphalt (Perry) | +3 | +5 | +4 | +5 | +5 | +2 | - | - | - |
| | | | | | | | | | |
| Baseline (Horton) | 78 | 85 | 83 | 80 | 84 | 87 | 82 | 82 | 85 |
| Asphalt (Horton) | - | - | - | - | - | - | - | - | - |
| Orange (Horton) | +4 | +2 | +4 | +2 | +2 | 0 | +3 | +2 | +3 |

- Baseline values are in dB and others are in dB relative to baseline
- '-' indicates that no measurement is available.
- Most values represent a single measurement, therefore ANOVA tests cannot be used to determine the statistical significance of any differences.

Table 5 shows that the roadside noise caused by the orange rumble strips was comparable to that caused by the asphalt strips. The levels above the baseline were smaller, but the baseline at Horton was somewhat higher. As with any rumble strips, consideration should be given to the context of the installation, particularly if it is in proximity to a residential area. However, the orange rumble strips will cause less roadside noise than asphalt strips, so no special consideration is necessary in this regard.

# Data Collection—Vehicle Speeds

Vehicle speeds were monitored to compare driver response to the temporary rumble strips with driver response to the asphalt rumble strips in terms of speed reduction. Only the speeds of vehicles that were considered to be freeflowing (as defined by the Highway Capacity Manual, vehicles having headway greater than or equal to 5 seconds [13]) were considered. A computer utility was used to identify specific vehicles at each data point on an approach in order to generate vehicle specific speed profiles. Vehicles that could not be identified at one or more data points were excluded from the analysis. At all sites, at least 85% of the vehicles were identified at all data points.

The vehicle speed data were collected using pneumatic hoses and automatic traffic recorders. The hoses were placed in sets of two or more in order to determine vehicle speeds at three points on each approach. Hoses were deployed on two approaches, one with asphalt strips and one with the orange rumble strips. Hoses were not deployed to measure vehicle speeds on the approach using the asphalt strips at the Horton test site because the approach was located on a downgrade that was severe enough to have a significant effect on the data. Figure 13 shows a topographic map of the construction site. The construction site is indicated by the shaded rectangle, and the black circle indicates the steep downgrade. Since the vehicle speeds for the asphalt rumble strips at the orange rumble strip test site were not collected, the speeds observed on the orange rumble strips had to be compared to the speeds observed on the asphalt rumble strips at a separate test site.

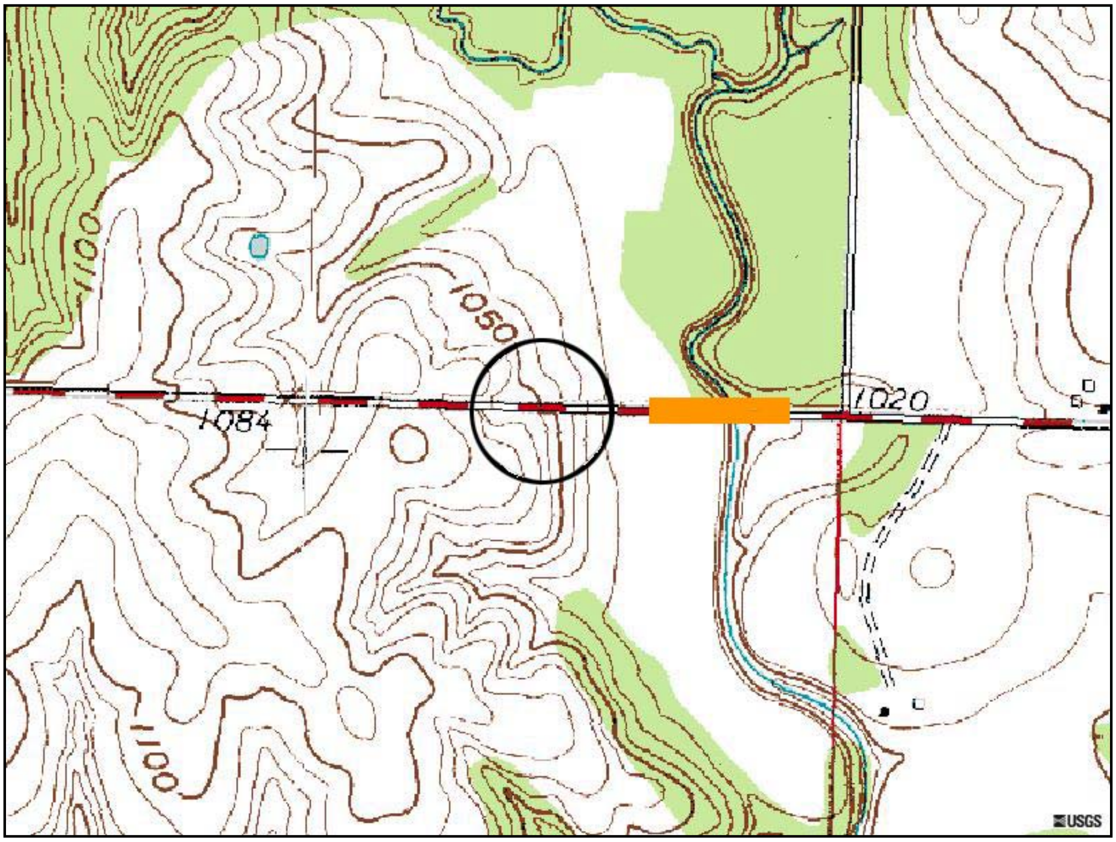



**Figure 13 - Topographic Map of Horton Construction Site [14]**

The hoses were deployed the day after the temporary rumble strips were installed so that sound and vibration measurements could be completed first. The hoses were put in place at the Perry Lake location on March 26, 2001, and removed on April 14, 2001. This allowed data to be collected for 19 days. The hoses near Horton, Kansas, were put in place on June 12, 2001, and removed on July 17, 2001. However, some of the data were not usable due to hose failures. Approximately 21 days worth of usable data were collected. Daytime and nighttime data were analyzed separately. For the data collected at the Perry Lake site, daytime was defined as the hours between 8:30 AM and 7:30 PM. For the data collected at the Horton test site, daytime was defined as the hours between 7:30 AM and 7:30 PM. Nighttime was taken as the hours between 10:30 PM and 5:30 AM for both sites. The differences are due to the time of the year the strips were deployed.

## Data Analysis—Vehicle Speeds

The speed data collected on each set of rumble strips were analyzed as a whole, by vehicle type (passenger cars and trucks), by time of day (daytime and nighttime), and by time relative to rumble strip installation (first and second half of collected data, chronologically).

Table 6 shows all of the data subgroups for a single set of rumble strips. Where differences of practical significance were found between subgroups, both groups are presented and the difference is discussed. When all data sets produced relatively similar results, either the overall results or a single representative subgroup are presented.

Speeds were examined relative to the baseline speed measured 150 m (500 ft) upstream of the strips. Variation among vehicles is represented by the standard deviation of speeds at each location, the 85$^{th}$ percentile speeds, and by the percentage of vehicles within the 16-kph (10-mph) pace.

**Table 6 - Speed Data Analysis Subgroups**

| Vehicle Type | Time of Day | Collected Data Set | Rumble Strip |
|---|---|---|---|
| Cars | Day | 1st | Asphalt |
| Trucks | Day | 1st | Asphalt |
| All | Day | 1st | Asphalt |
| Cars | Night | 1st | Asphalt |
| Trucks | Night | 1st | Asphalt |
| All | Night | 1st | Asphalt |
| Cars | 24 Hour | 1st | Asphalt |
| Trucks | 24 Hour | 1st | Asphalt |
| All | 24 Hour | 1st | Asphalt |
| Cars | Day | 2nd | Asphalt |
| Trucks | Day | 2nd | Asphalt |
| All | Day | 2nd | Asphalt |
| Cars | Night | 2nd | Asphalt |
| Trucks | Night | 2nd | Asphalt |
| All | Night | 2nd | Asphalt |
| Cars | 24 Hour | 2nd | Asphalt |
| Trucks | 24 Hour | 2nd | Asphalt |
| All | 24 Hour | 2nd | Asphalt |
| Cars | Day | All | Asphalt |
| Trucks | Day | All | Asphalt |
| All | Day | All | Asphalt |
| Cars | Night | All | Asphalt |
| Trucks | Night | All | Asphalt |
| All | Night | All | Asphalt |
| Cars | 24 Hour | All | Asphalt |
| Trucks | 24 Hour | All | Asphalt |
| All | 24 Hour | All | Asphalt |

# Results—Vehicle Speeds

All speed-related variables showed predictable patterns, and the patterns were very similar between the test sites.

## Speed Reduction

Figure 14 and Figure 15 show plots of the mean and 85$^{th}$ percentile speeds, respectively. Figure 16 shows a plot of the speed reductions observed on the different strips. Statistical descriptions of the collected speed data for the rumble strips are located in Table 7 and Table 8. The speeds observed on the orange rumble strips are generally lower because the posted speed was 89 kph (55 mph) upstream of the orange rumble strip test location. Both types of rumble strips show speed reductions that are statistically significant at the 99% level. However, it is not possible to determine what portion of the reduction is attributable to which traffic control measures since all measures were in place for the duration of the construction. Similar levels of speed reduction were observed on both types of rumble strips.

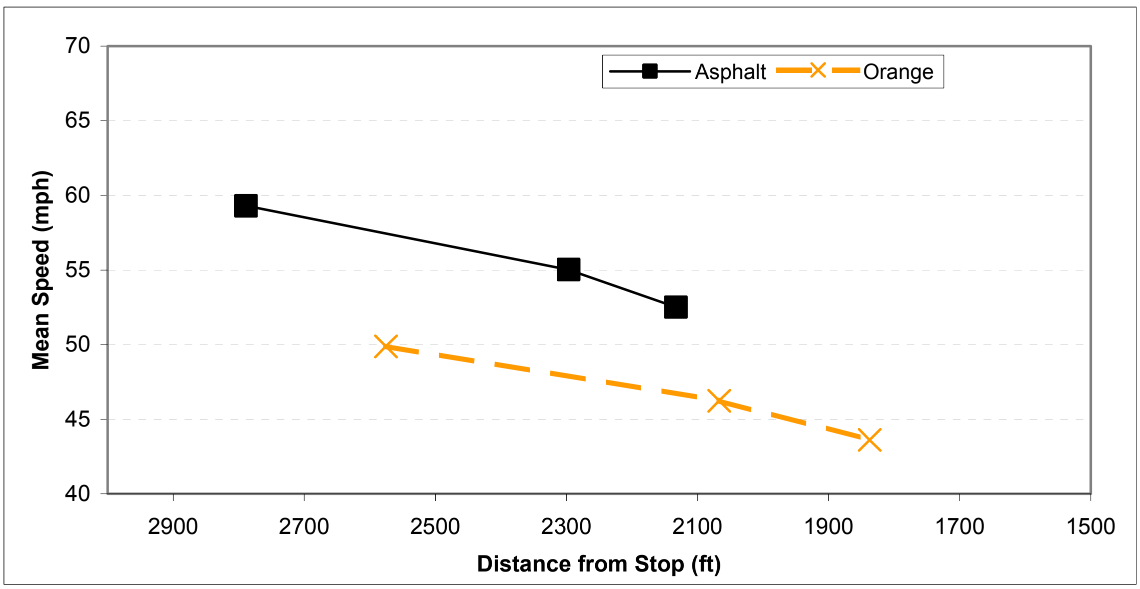



**Figure 14 - Mean Speeds Comparison (Passenger Cars, 24 Hours)**

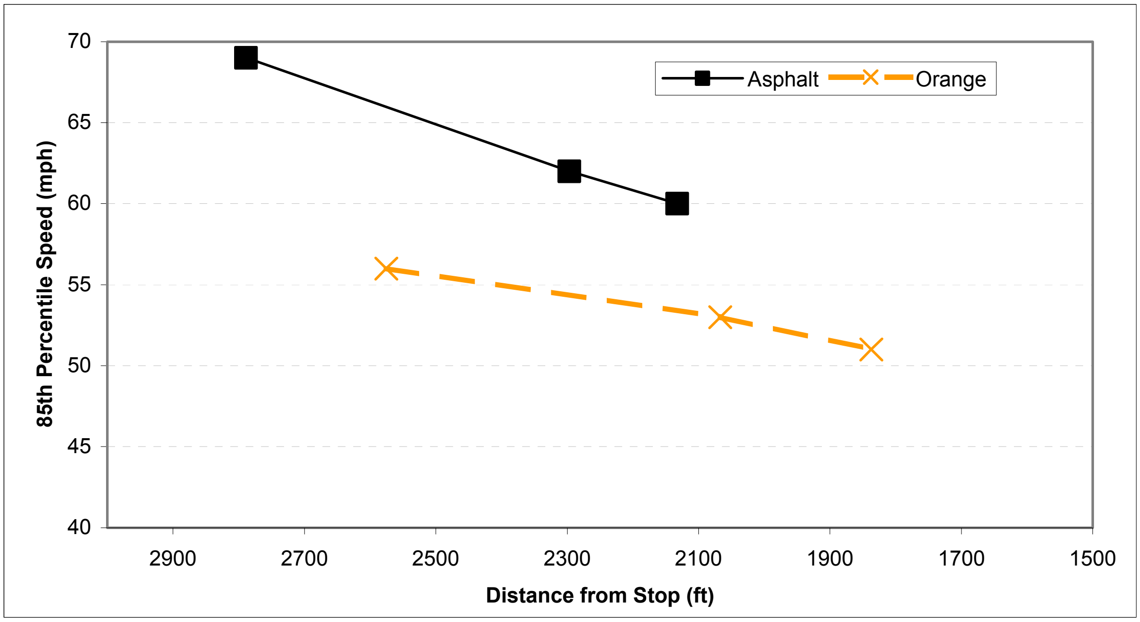



**Figure 15 - 85th Percentile Speed Comparison (Passenger Cars, 24 Hours)**

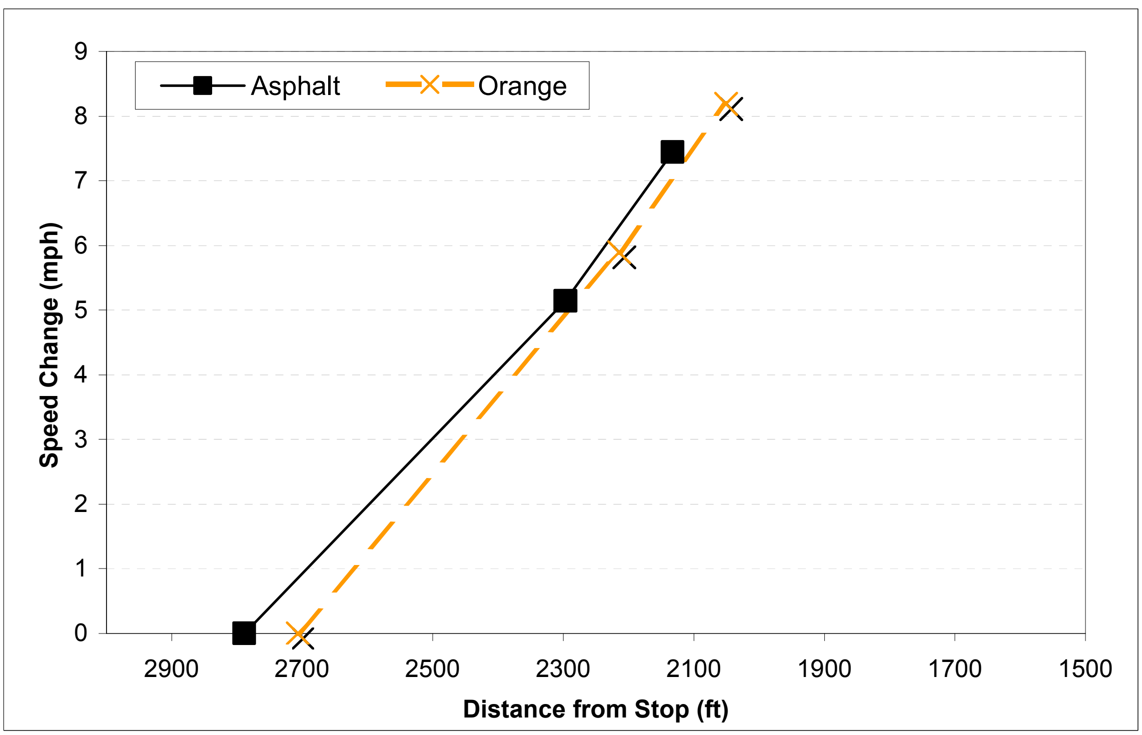



**Figure 16 - Speed Reductions (All Vehicles, 24 Hours)**

### Table 7 – Overall Speed Summary for Asphalt Rumble Strips

| | Asphalt | | |
|---|---|---|---|
| Data Point* | 201 | 202 | 203 |
| Distance from Stop (ft) | 2788.714 | 2296.588 | 2132.546 |
| | **Passenger Cars** | | |
| Count | 11531 | 11435 | 11346 |
| Mean (mph) | 59.3 | 55.0 | 52.5 |
| 85th Percentile (mph) | 69 | 62 | 60 |
| Pace (mph) | 65 | 58 | 51 |
| Std Deviation (mph) | 11.5 | 8.5 | 8.4 |
| % of Vehicles in Pace | 43% | 45% | 46% |
| ∆ Speed (mph) | 0.0 | -5.1 | -7.4 |
| | **Trucks** | | |
| Count | 927 | 986 | 968 |
| Mean (mph) | 58.5 | 54.1 | 51.0 |
| 85th Percentile (mph) | 68 | 61 | 58 |
| Pace (mph) | 65 | 53 | 50 |
| Std Deviation (mph) | 11.6 | 8.8 | 8.8 |
| % of Vehicles in Pace | 43% | 45% | 47% |
| ∆ Speed (mph) | 0.0 | -5.3 | -7.5 |

** See Figure 2 and Figure 3 on page 9 for the location of the data points.*

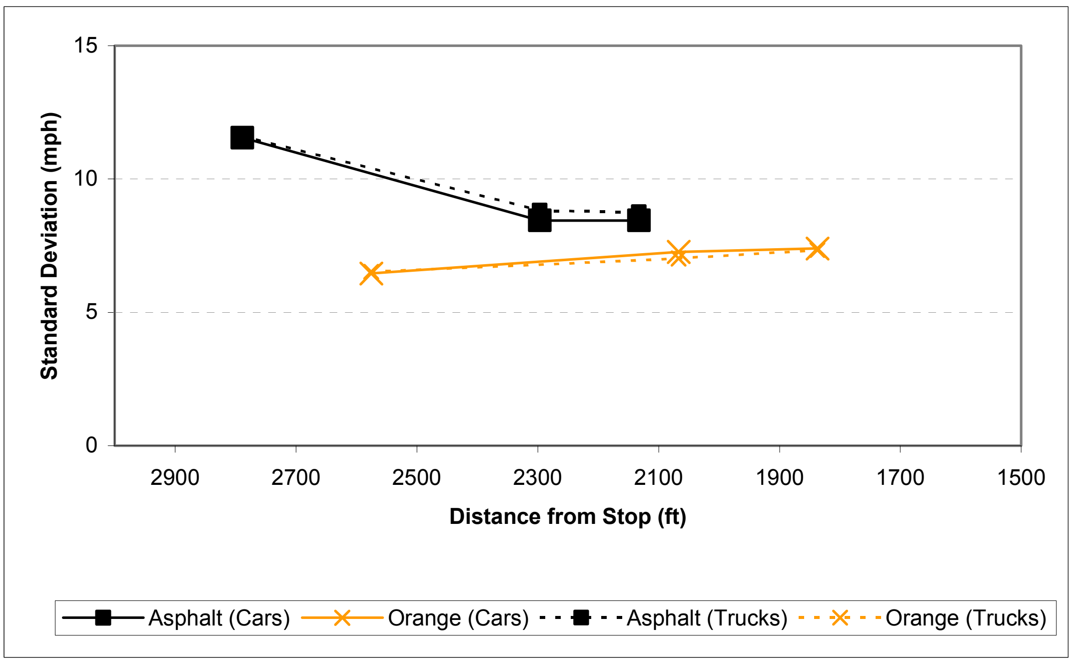
### Table 8 – Overall Speed Summary for Orange Rumble Strips

| | Orange Rumble Strips | | |
|---|---|---|---|
| Data Point* | 201 | 202 | 203 |
| Distance from Stop (m) | 2575.459 | 2066.929 | 1837.27 |
| | **Passenger Cars** | | |
| Count | 17276 | 17055 | 17158 |
| Mean (mph) | 49.9 | 46.2 | 43.6 |
| 85th Percentile (mph) | 56 | 53 | 51 |
| Pace (mph) | 50 | 47 | 43 |
| Std Deviation (mph) | 6.5 | 7.3 | 7.4 |
| % of Vehicles in Pace | 58% | 52% | 50% |
| ∆ Speed (mph) | 0.0 | -5.9 | -8.2 |
| | **Trucks** | | |
| Count | 962 | 1133 | 1019 |
| Mean (mph) | 49.5 | 46.0 | 43.4 |
| 85th Percentile (mph) | 56 | 53 | 50 |
| Pace (mph) | 51 | 47 | 44 |
| Std Deviation (mph) | 6.5 | 7.0 | 7.3 |
| % of Vehicles in Pace | 58% | 52% | 53% |
| ∆ Speed (mph) | 0.0 | -6.2 | -8.7 |

** See Figure 4 and Figure 5 on page 10 for the location of the data points.*

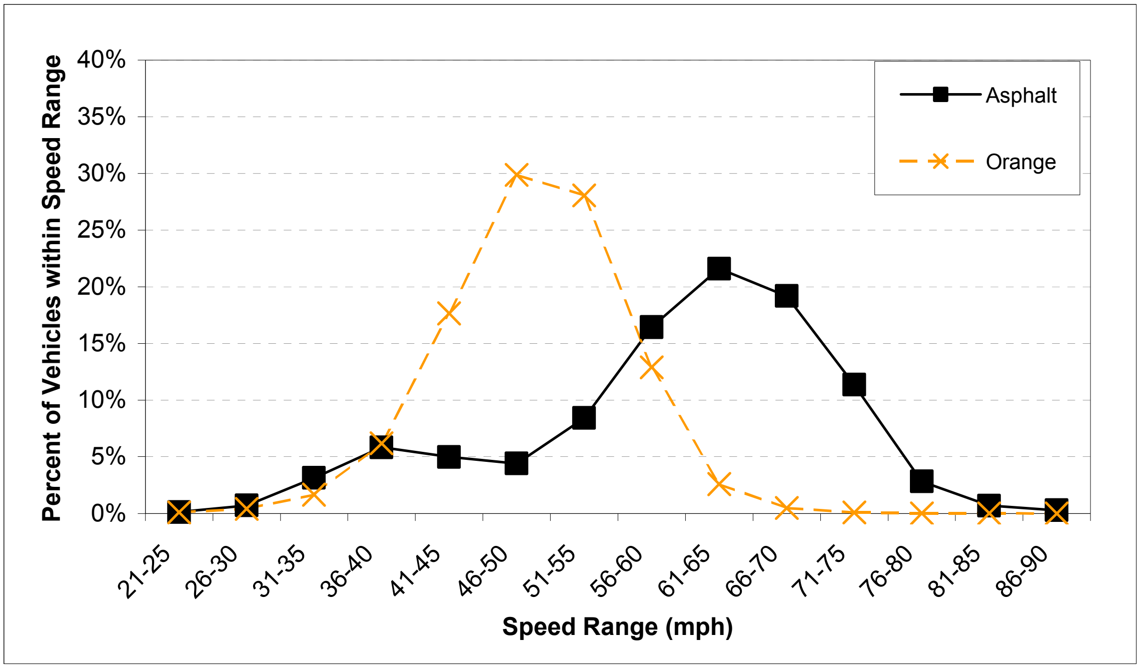
## Speed Variation

When a large variation in the speeds of vehicles traveling the same path exists, an increase in the frequency of accidents can be expected [15]. The standard deviation of speeds found in Table 7 and Table 8 is an indication of speed uniformity. The standard deviation did not vary much from the baseline point to the most downstream point for the orange rumble strips. Figure 17 shows the standard deviation of speeds observed on the two types of strips. While the asphalt strips seemed to have a decreasing affect on the speed variance, the standard deviation of the observed speeds was always greater on the asphalt strips. Figure 18, Figure 19, and Figure 20 show the speed distributions observed on the rumble strips for the most upstream data point, the first point on the rumble strips, and the most downstream data point, respectively. The higher standard deviations on the asphalt strips may be attributable to the downgrade upstream of the asphalt rumble strip approach. At each successive data point, the speed distributions become increasingly similar.



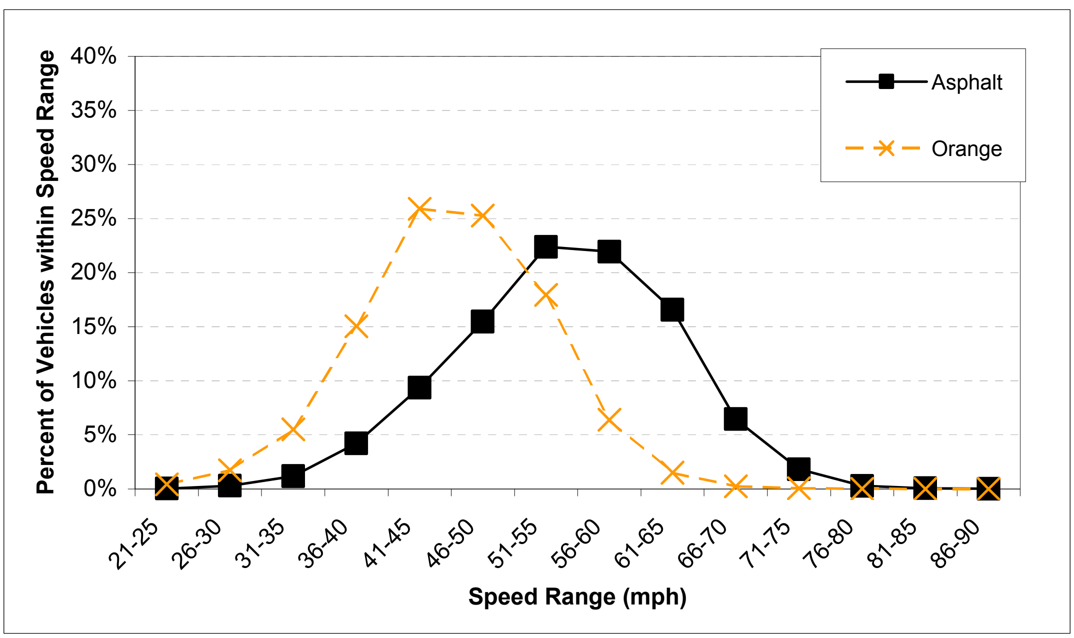

**Standard Deviations for day and night, and first and second data sets.*

**Figure 17 - Standard Deviation of Speeds**




**Distribution for passenger cars, day and night, first and second data sets.*

**Figure 18 - Speed Distribution Comparison for First Data Point (Cars)**




**Distribution for passenger cars, day and night, first and second data sets.*

**Figure 19 - Speed Distribution Comparison for Second Data Point (Cars)**

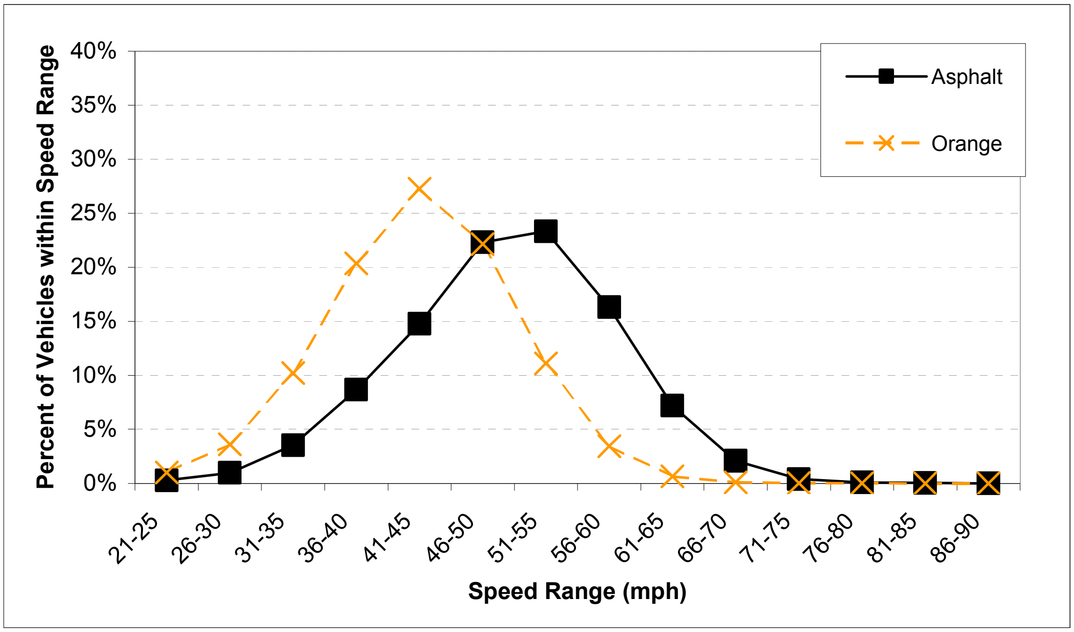
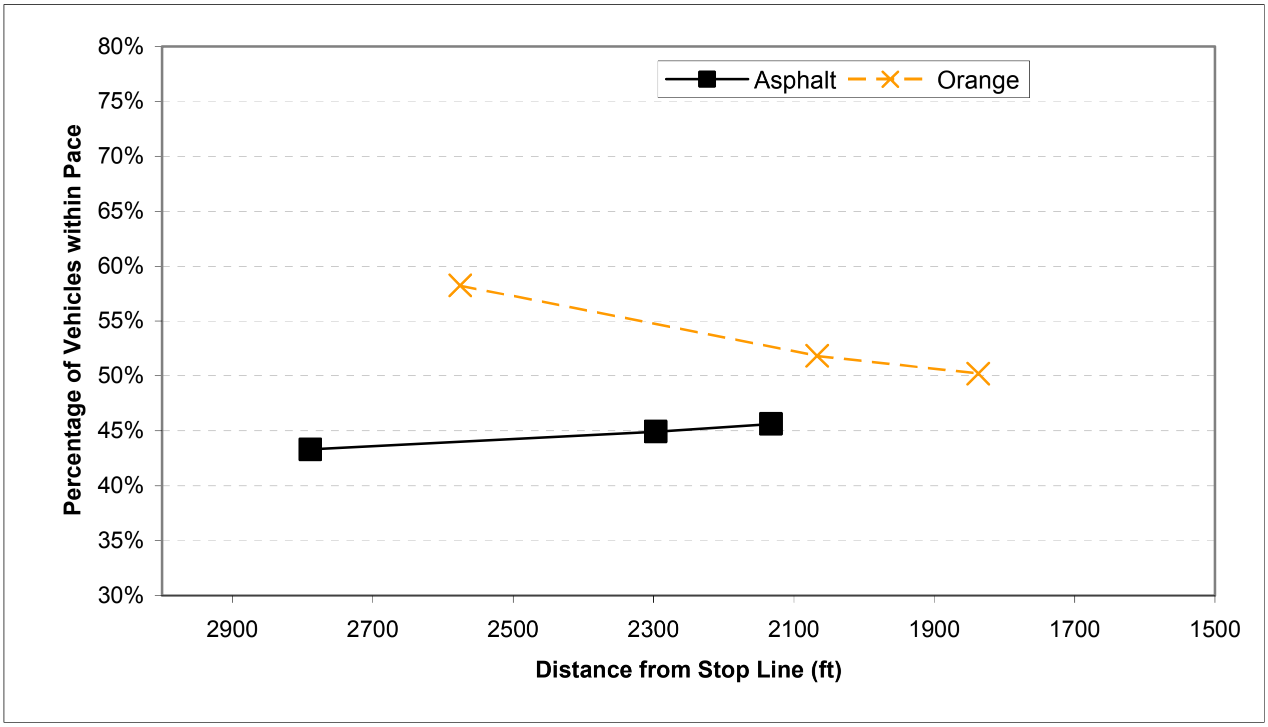



**Figure 20 - Speed Distribution Comparison for Third Data Point (Cars)**

**Distribution for passenger cars, day and night, first and second data sets.*

The 16-kph (10-mph) pace at each data point is shown in Table 7 and Table 8. In all cases, the percentage of vehicles within the 16 kph (10 mph) pace is greater for the temporary rumble strips than it is for the asphalt rumble strips. However, the percentage was decreasing on the temporary rumble strips and increasing on the asphalt strips. Figure 21 shows the percent of passenger cars within the 16 kph (10 mph) pace. A similar pattern was observed for trucks.




**Plotted data includes passenger cars data for day and night, and first and second data sets.*

**Figure 21 - Percent of Passenger Cars within the 16 kph (10 mph) Pace**

## Temporal Effects

One objective of this study was to assess the temporal change in the effectiveness of the strips, that is, to determine the extent to which the effectiveness may be due to a *novelty effect*. If a novelty effect is present, speeds immediately after installation of the strips will be lower than those observed several weeks later, after drivers have come to expect the strips. This did not seem to be the case with these deployments. The segment used for the test simply links small neighboring communities, and is not major through route. Consequently, most of the traffic is repeat traffic, local travelers who traverse the segment frequently.

The speed data were collected over a period of 3-4 weeks and split into two data sets. The first data set contained data observed for 8 - 10 days immediately after the deployment. The second data set was collected over a period of 10 – 12 days, at least 2 weeks after the initial deployment. The second half of the speed data gives results almost identical to the first half for the Rumbler rumble strip. The two sets of data for the asphalt strips are also quite similar except that greater baseline speeds were observed upstream of the strips in the latter time period. This indicates that no novelty affect was evident for either of these types of strips. Table 9 shows the mean and 85$^{th}$ percentile speeds from the first data set and the second data set for the asphalt rumble strip.

**Table 9 - Change in Speed Reduction Over Time on Asphalt Strips**

| | | | 85th Percentiles | | | Means | | |
|---|---|---|---|---|---|---|---|---|
| Rumble Strip | Class. | Data Set | 201 | 202 | 203 | 201 | 202 | 203 |
| Asphalt | Cars | 1st | 69 | -6 | -8 | 59 | -4 | -7 |
| Asphalt | Cars | 2nd | 70 | -7 | -9 | 59 | -4 | -7 |
| Asphalt | Trucks | 1st | 70 | -8 | -11 | 59 | -5 | -8 |
| Asphalt | Trucks | 2nd | 68 | -6 | -9 | 58 | -4 | -7 |

**Speed values for Data Point 201 are in mph, all others are in mph relative to Data Point 201.*

The pattern of vehicle speeds observed on the orange rumble strips did change from the first data set to the second. The first half of the data, which is essentially the speeds measured during the first week after the deployment, indicates that the largest changes in speed occurred between the baseline data point (upstream of the first set of strips) and the second data point (on the first set of orange rumble strips). A few weeks later, when the second half of the data was collected, this pattern was no longer observed. The speed decreases were more gradual, and occurred over the entire length of the rumble strip deployment. This suggests that there was a novelty effect for the orange rumble strips, most likely due to their high visibility. However, speed decreases observed in the second data set on the orange strips more closely resembled the patterns observed on the other types of strips. Most likely, the orange color of the strips is responsible for the novelty effect, providing additional speed reduction during the first few days following deployment.

Since the orange rumble strips are not reflective, there is some concern about how visible they are at night. The speed patterns observed during nighttime hours exhibited this same pattern, although to a lesser extent. This indicates that while the strips are visible at night, they are less visible than they are during daylight hours. Table 10 shows the $85^{th}$ percentile and means speeds observed on the orange rumble strips for the first and second data set separately, for day, night, and overall. Figure 22 shows the mean speeds of passenger cars for both types of strips. The patterns observed for all subgroups were almost identical to the patterns seen in Figure 22 and are therefore not shown.

**Table 10 - Change in Speed Reduction Over Time on Orange Rumble Strips**

| | | | 85th Percentile | | | Mean | | |
|---|---|---|---|---|---|---|---|---|
| Time | Class. | Data Set | 201 | 202 | 203 | 201 | 202 | 203 |
| 24 Hour | Cars | 1st | 56 | -5 | -7 | 49 | -5 | -8 |
| 24 Hour | Cars | 2nd | 56 | -2 | -4 | 50 | -3 | -6 |
| 24 Hour | Trucks | 1st | 55 | -6 | -8 | 49 | -5 | -8 |
| 24 Hour | Trucks | 2nd | 56 | -2 | -4 | 50 | -3 | -5 |
| Day | Cars | 1st | 56 | -4 | -6 | 51 | -6 | -8 |
| Day | Cars | 2nd | 57 | -2 | -5 | 51 | -3 | -6 |
| Day | Trucks | 1st | 56 | -6 | -8 | 50 | -6 | -8 |
| Day | Trucks | 2nd | 56 | -1 | -4 | 50 | -3 | -5 |
| Night | Cars | 1st | 51 | -2 | -5 | 45 | -2 | -6 |
| Night | Cars | 2nd | 54 | -2 | -4 | 48 | -2 | -5 |
| Night | Trucks | 1st | 51 | -2 | -8 | 45 | -2 | -9 |
| Night | Trucks | 2nd | 53 | -1 | -3 | 47 | -2 | -4 |

**Speed values for Data Point 201 are in mph, all other values are mph relative to Data Point 201*

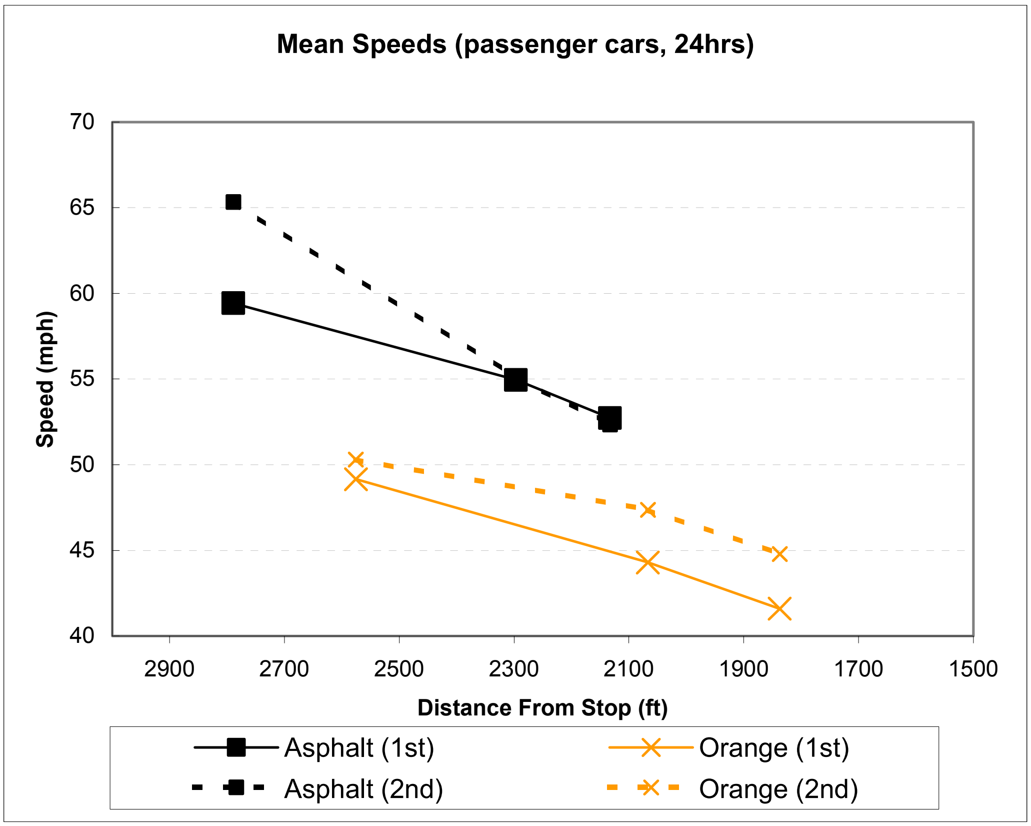



**Figure 22 - Change in Speed Reduction Patterns Over Time**

## Data Collection—Cost and Durability

The cost of the rumble strips is directly related to their durability. If the strips need to be replaced every few weeks, then they will have higher life-cycle cost. If they never need to be replaced, and they can be reused indefinitely, then their life-cycle cost will be much less. Durability is also important for reasons other than its effect on cost. Strips that are likely to fail require more attention and frequent fixing. If individual strips become damaged, torn, or detached from the pavement, the effectiveness of the overall deployment of strips may decrease. In order to provide a detailed and thorough comparison between the temporary rumble strips and the asphalt rumble strips, a comparison of the cost/benefit ratio associated with each of the strips is essential. Comparisons of the installation and removal times, the durability, the reusability, and the amount of damage done to the pavement were also examined.

## Data Analysis—Cost and Durability

The costs associated with rumble strips fall into two basic categories; installation and removal costs, and material costs. To analyze the costs it was necessary to observe and record data detailing the processes and methods used for the installation and removal of the strips.

### Installation

The installation process was similar for both types of temporary rumble strips. The locations where the strips were to be placed, was determined using a tape measure and marked with masking tape. The dry pavement was swept with a push broom.

The orange rumble strips came in 27.4 m (90 ft) rolls and had to be cut to length prior to installation. This was done offsite before the deployment and took two workers about 15 minutes per group (6 strips, 24 1.2 m (4 ft) pieces) to complete the task. The need for a double thickness strip effectively doubled the installation time, as compared to an installation using a single thickness. The process required three workers plus appropriate traffic control, and took approximately 15 minutes per group of strips. Figure 23 on page 46 in the Appendix shows pictures of the installation.

The asphalt rumble strips required slightly more time and effort to install than did the temporary rumble strips. The installation required three workers plus appropriate traffic control and took approximately 40 minutes per group to complete.

### Removal

To remove the temporary rumble strip, a corner was pried free with a crow bar or other similar tool, and the strips were pulled by hand until they were entirely removed. The process proceeded quickly with one or two individuals plus appropriate traffic control. Since the removal of each strip took less than a minute, when vehicles were seen approaching, workers could step onto the shoulder, allow the vehicles to pass, and then resume removing the strips. This allowed the strips to be removed with little or no disruption of traffic. All strips came up in one piece.

The process required two workers approximately 4 minutes to remove a group of orange rumble strips.

The removal of the asphalt rumble strips required more than 5 times the labor required to remove the temporary rumble strips, and it required heavy equipment. The asphalt rumble strips were removed using a Skid Steer Loader or a Loader/Backhoe to scrape the raised asphalt strips off of the pavement. Two additional workers, equipped with shovels and brooms, removed the loose pieces of asphalt and gravel from the roadway. The loaders had to back into the other lane of traffic in order to be able to scrape off the strips starting at the center of the lane, requiring that traffic in both directions be temporarily stopped. Removal required approximately 15 minutes per group of strips with 5 workers.

## Cost Estimation

The installation and removal times, and the material costs for the temporary rumble strips were all measured directly. However, to determine the total costs for all three types of strips, a few estimations were necessary. The labor rates for those installing the strips and providing traffic control were estimated, as well as the cost of the loaders used to remove the asphalt rumble strips. The cost for the material used to make the asphalt rumble strips was estimated based on the compacted volume. All estimates were derived using R.S. Means Facility Construction Cost Data 2001 [16].

## Durability

The durability of the rumble strips was compared by simply observing the amount of damage the strips had incurred over the length of their deployment. The orange rumble strips were in place for 6 months (225,000 vehicles). The durability of the asphalt strips is generally not a problem, although it is not uncommon for small pieces of the asphalt strip to become detached. The thickness of the asphalt rumble strips decreases over time as well, which could decrease the levels of sound and vibration they produce. An important point to consider is that failures of temporary rumble strips are easier to repair than failures of asphalt strips. If a single temporary rumble strip is removed or damaged, it can be easily replaced. Asphalt strips are more difficult to repair.

## Benefit/Cost Analysis

The primary benefit of rumble strips is their positive effect on safety and the subsequent reduction in accidents and fatalities. It was not possible to quantify the safety benefits because the length of deployment was minimal. Several years of before and after accident data would be needed to provide a reasonable quantitative benefit/cost analysis. Consequently, the safety benefits can only be examined indirectly using sound and vibration levels and installation and removal times.

# Results—Cost and Durability

The temporary rumble strips may have some advantages over the asphalt rumble strips with respect to installation and removal times, they are also more expensive than asphalt strips. The largest portion of the temporary rumble strip's expense is in the material, or the cost of the actual rumble strips. While the costs associated with the labor hours and the equipment required to install and remove the rumble strips are less for the temporary rumble strips, this decrease alone is not sufficient to offset the greater material costs.

## Benefits

Because the asphalt strips and the removable strips were similar with respect to the sound and vibration generated, any resulting safety benefits would also be similar. The temporary rumble strips might, however, have increased benefits in terms of safety because of the decreased installation and removal times and their high visibility. Additionally, the differences in the amount of damage done to the pavement by the removal of the strips is notable, but assigning an actual monetary value to this benefit is also quite difficult since there are so many other factors involved such as the type and age of the pavement, the quality installation, the duration of the deployment, and the method used to remove the strips.

## Total Deployment Costs

Table 11 shows the cost estimates for labor costs, material costs, equipment costs, and the total cost. The largest portion of the costs associated with the use of temporary rumble strips was the material costs. While the cost of asphalt is almost negligible, the cost of the temporary rumble strips is not.

Costs associated with the asphalt strips were compared with previous studies [2] and found to be reasonable. No comparison was available for the temporary strips, but all costs were observed costs, and as such are considered to be reliable.

**Table 11 - Deployment Costs**

**Labor Costs**

| Type of Strip | Installation Time min/Group | Number of Installation Workers | Removal Time min/Group | Number of Removal Workers | Estimated Labor Cost/hr | Total Labor Cost/Group |
|---|---|---|---|---|---|---|
| Orange | 20 | 5 | 4 | 3 | $16.28 | $30.39 |
| Asphalt | 40 | 5 | 15 | 5 | $16.28 | $74.62 |

**Material Costs**

| Type of Strip | Material Cost per meter | (per foot) | Total Length meters | (feet)/Group | Total Material Cost/Group |
|---|---|---|---|---|---|
| Orange | $13.12 | ($4.00) | 29.3 | (96) | $384.00 |
| Asphalt | $0.66 | ($0.20) | 21.9 | (72) | $14.40 |

**Equipment Costs**

| Type of Strip | Equipment Cost/hr | Equipment Cost/Group |
|---|---|---|
| Orange | $0.00 | $0.00 |
| Asphalt | $33.75 | $8.44 |

**Total Cost**

| Type of Strip | **Total Cost/ Group** | **Total Cost/ Approach** |
|---|---|---|
| Orange | **$414.39** | **$2,486.34** |
| Asphalt | **$97.45** | **$584.73** |

## Installation

As mentioned previously the installation of the temporary rumble strips was quite simple and expeditious. The time estimates for the installation of the temporary rumble strips may be conservative, assuming that a more experienced crew would be more efficient. The installation time decreased from over an hour for the first group to less than 30 minutes on the last group. The time taken to install the final group for each type of strip was used as the estimate for installation time.

## Removal

The time required to remove all types of rumble strips was much less than the time required to install them. The temporary rumble strips required no special equipment and fewer workers to remove them than their asphalt counterparts. No time estimates were available for the time required to remove asphalt strips without heavy machinery, although it is probable that significantly more time would be required.

## Reusability

Since the orange rumble strips are self-adhesive, the damage done to the adhesive backing makes the strips no longer usable with the same adhesive. The orange rumble strips could be reused if they were nailed to pavement or cleaned and then attached using another adhesive. However, there are drawbacks with both of these installation methods, and neither method is recommended by the manufacturer. While it may be possible to reuse the orange rumble strips, it was not attempted in this study and therefore cannot be recommended.

## Durability

Although the durability of the rumble strips depends on many factors, such as the number and type of vehicles that will traverse them, the duration of deployment, and the quality of the initial installation, the temporary rumble strips were found to be quite durable.

The orange rumble strips had little to no durability problems throughout the duration of their deployment. A few strips were slightly chipped, but none of the strips had large pieces missing nor were there any strips detached from the pavement.

The asphalt rumble strips were damaged. None of the strips were entirely removed from the pavement, but many had pieces of significant size removed from the strips, totaling as much as about 10% of the entire strip. Pictures of the damaged strips can be found in the Appendix on page 48.

Tests of the same types of temporary rumble strips have found similar results. Several tests have been conducted using the orange rumble strips. Some tests indicated no durability problems, and others indicated that strips had torn. Tests performed as part of the Midwest Smart Work Zone Deployment Initiative (MWSWZDI) all found that the orange rumble strips, if installed correctly, would stay attached to the pavement and not suffer excessive damage due to traffic. However, improper installation can lead to total failure of the adhesive and the deployment. A deployment that was made on wet pavement and rolled using a truck instead of a tamping cart had most of the strips become detached from the pavement in a single day. Another test that was also part of the MWSWZDI had several strips become detached. The pavement was not swept prior to installation, and the strips that were detached had a large amount of debris and gravel stuck to the adhesive. The un-swept pavement was believed to be the cause of the failures. All other strips remained attached for the duration of the project. [4]

## Pavement Condition

Part of the motivation to use temporary rumble strips is that they cause less damage to the pavement than asphalt rumble strips upon removal. Although small bits of gravel remained on the back of the rumble strips, and some of the adhesive remained on the pavement, the pavement was not significantly damaged by removing the temporary rumble strips. The remaining adhesive only slightly discolored the pavement, and it quickly wore away under normal traffic and weather conditions. The removal of the asphalt strips damaged the pavement more than the temporary rumble strips. Pictures of the pavement after removal of the strips can be seen in the Appendix on page 49. Both locations had asphalt pavement. Results on concrete pavement may differ.

# Conclusions

In general, the ATM Removable Rumble Strips performed comparably to the asphalt rumble strips with respect tot sound and vibration generated and speeds observed. The orange color appeared to increase the speed reductions, but that reduction was short lived. For very short applications, the color may be an added benefit, but for longer applications it does not appear to be so (or at least the magnitude of the benefit decreases over time). It should be noted that while the added effect of the color may dissipate over time, it does not become a detriment. The effectiveness of the strips does not decrease over time, but only the additional effect of the orange color.

The strips were very easy to install, and even easier to remove. Very little damage was done to the pavement. The only complaint about the installation process was that the backing tore frequently, increasing the effort necessary to lay down each strip. The vendor attributed this to the manufacturing process (specifically, the blades that cut the strips at the time our samples were produced must have become dull and needed to be replaced) The factory was contacted to ensure that it had since been corrected.

The data confirmed the earlier findings that a single thickness of the ORS was insufficient. A double thickness, however, performed similarly to the asphalt strips, even though it was considerably thinner.

The cost of the strips is substantially greater than that of asphalt strips. They do not appear to be easily reusable. They proved to be quite durable. No strips became detached during the 6-month evaluation. Very little scarring was apparent upon removal.

Table 12 shows a qualitative comparison of the removable rumble strips relative to the asphalt rumble strips. Table 13 lists the advantages and disadvantages of the strips.

**Table 12 - Rumble Strip Qualitative Comparison Table**

| | Orange (Single Thickness) | Orange (Double Thickness) |
|---|---|---|
| **In-vehicle Sound** | — — | = |
| **Vibration** | — — | = |
| **Roadside Noise** | NA | = |
| **Speed Control** | — | = |
| **Durability** | = | = |
| **Cost** | — | — — |
| **Installation Time** | + + | + |
| **Removal Time** | + | + |

- All strips are being compared to the KDOT standard asphalt strips
- Much Better (+ +), Much Poorer (- -): difference of substantial practical significance
- Slightly Better (+), Slightly Poorer (-): definite difference, but practical significance is small
- Similar (=): the same or nearly the same, including real differences that are unlikely to be of any practical significance
- Not Available (NA): data needed for judgment was not collected or was inconclusive

**Table 13 - Rumble Strip Type Summary**

| | Asphalt Rumble Strips | Orange Rumble Strips |
|---|---|---|
| **Advantages** | ▪ The cheapest option<br>▪ More familiar to workers and drivers<br>▪ No need to order and pay shipping for expensive materials<br>▪ Can be formed to any size or shape desired | ▪ Quick and easy and installation and removal<br>▪ Easy repair of broken or removed strips<br>▪ Bright orange color increases effectiveness<br>▪ Consistent size and shape<br>▪ Does little damage to pavement |
| **Disadvantages** | ▪ Removal typically damages the pavement<br>▪ Time consuming installation and removal<br>▪ Inconsistent size and shape<br>▪ Thickness of strips decrease over time<br>▪ Not reusable | ▪ Leaves adhesive on pavement<br>▪ Most expensive of the three strips<br>▪ Double thickness requires double installation time and double cost<br>▪ Unfamiliar to workers and drivers<br>▪ Strips require cutting to size prior to installation<br>▪ Not reusable |

# Recommendations

Rumble strips have been demonstrated to be an effective means of alerting drivers and enhancing safety. New materials and manufacturing techniques have opened the door to temporary rumble strips, which are intended to replace asphalt rumble strips for temporary deployments. While these strips are not a wholesale replacement for asphalt strips, they do offer advantages in some circumstances—such as work zone approaches—that make them an attractive alternative. Given due consideration and used with discretion, removable rumble strips may have the potential to improve the safety of both drivers and construction workers.

Based on the results of this study, it is recommended that the ATM Orange Rumble Strip be allowed as a substitute for asphalt rumble strips on work zone approaches. Both orange and black are in conformance with the MUTCD. Orange may have some additional benefit, especially for short-term applications.

Reuse of the rumble strips should be investigated. If life-cycle costs could be reduced by allowing the strips to be reused, they would be a much more attractive device for a much broader range of applications. Similarly, if a thicker strip were available, the use of a double thickness could be averted, saving both installation time and capital cost. As it stands, cost is the most significant drawback to using this device.

In this evaluation, the Removable Rumble Strip from Advance Traffic Markings demonstrated itself to be durable, effective, and easy to use. It is highly recommended as an alternative to asphalt rumble strips for work zone applications.

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# APPENDIX

**Table 14 - Maximum Leq Values in Decibels (dB)**

| Sound | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Vehicle | Compact Car | | | Midsize Car | | | Dump Truck | | |
| Speed, kph (mph) | 64 (40) | 80 (50) | 97 (60) | 64 (40) | 80 (50) | 97 (60) | 64 (40) | 80 (50) | 97 (60) |
| Baseline (Horton) | 73 | 76 | 78 | 72 | 73 | 75 | 80 | 82 | 84 |
| Asphalt (Horton) | 87 | 88 | 90 | 84 | 85 | 88 | 93 | 92 | 92 |
| Orange (Horton) | 88 | 91 | 93 | 86 | 87 | 90 | 87 | 88 | 89 |

| Vibration | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Vehicle | Compact Car | | | Midsize Car | | | Dump Truck | | |
| Speed, kph (mph) | 64 (40) | 80 (50) | 97 (60) | 64 (40) | 80 (50) | 97 (60) | 64 (40) | 80 (50) | 97 (60) |
| Baseline (Horton) | 76 | 77 | 77 | 79 | 82 | 85 | 96 | 88 | 89 |
| Asphalt (Horton) | 90 | 90 | 92 | 94 | 96 | 96 | 107 | 103 | 101 |
| Orange (Horton) | 89 | 89 | 93 | 93 | 98 | 97 | 105 | 104 | 98 |

| Roadside Noise | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Vehicle | Compact Car | | | Midsize Car | | | Dump Truck | | |
| Speed, kph (mph) | 64 (40) | 80 (50) | 97 (60) | 64 (40) | 80 (50) | 97 (60) | 64 (40) | 80 (50) | 97 (60) |
| Baseline (Horton) | 78 | 85 | 83 | 80 | 84 | 87 | 82 | 82 | 85 |
| Asphalt (Horton) | X | X | X | X | X | X | X | X | X |
| Orange (Horton) | 82 | 87 | 86 | 83 | 87 | 87 | 85 | 84 | 88 |

**Figure 23 - Installation of the Orange Rumble Strips**

Peeling the plastic backing from the strip

Rolling the strips with a tamper cart

**Figure 24 - Removal of the Asphalt Strips**

Removal of asphalt strips with Loader/Backhoe

Bucket scraping up the asphalt strips

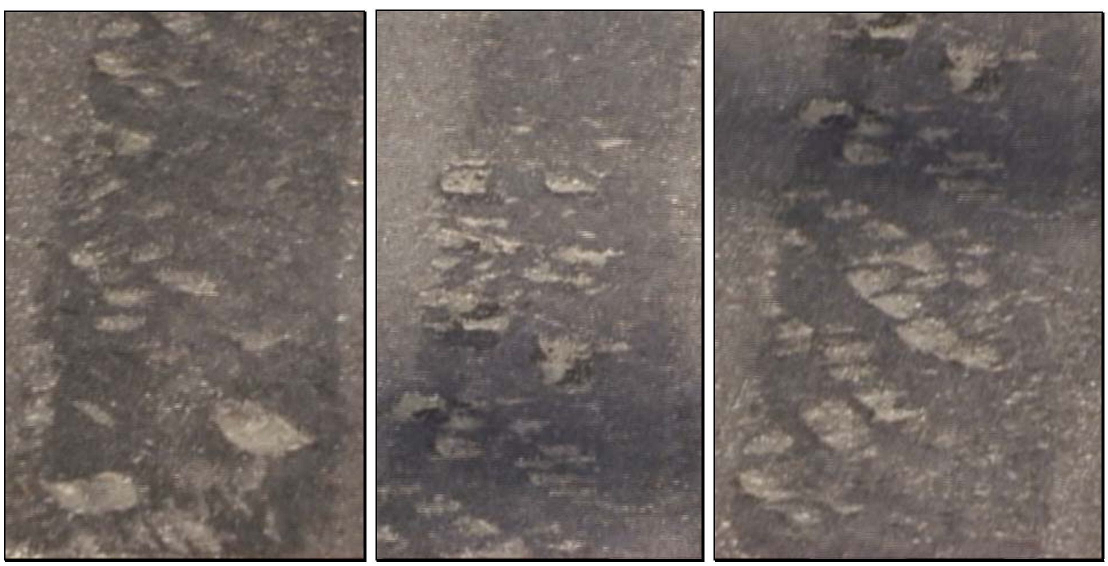
**Figure 25 - Damaged Asphalt Rumble Strips**

Damaged asphalt strips

Close-up of damage

**Figure 26 - Pavement Damage from Asphalt Strips**

Overview



Close-ups

**Figure 27 - Temporary Strips After Removal**

Underside of orange test strips