MIDWEST SMART WORK ZONE DEPLOYMENT INITIATIVE

MwSWZDI

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Report Title

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# Testing Temporary Work Zone Rumble Strips

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Supplemental Notes

Abstract

The purpose of this project was to help identify the optimal design of temporary rumble strips that would be used in a work zone. The project involved a focus group and a psychological scaling experiment, where each subject was asked to evaluate a temporary rumble strip relative to a cut-in-pavement rumble strip. In addition, sound and vibration measurements were made from within a vehicle passing over the strips. The ATM rumble strips (0.25 inches thick) were deployed within an actual work zone in Washington County (WI), while the RTI strips (0.75 inches thick) were tested in a large parking lot. An ATM strip when traversed at 55 mph was about as effective a warning device as a cut-in-pavement rumble strip. This same strip configuration when traversed at 40 mph was ineffective. The RTI product is an effective warning device for vehicle speeds between 10 and 40 mph.

For more information on the MwSWZDI Pooled fund Study, go to http://www.matc.unl.edu/research/MwSWZDI/

# Testing Temporary Work Zone Rumble Strips

**Alan J. Horowitz and Thomas Notbohm**

**March 4, 2005**

## INTRODUCTION

### Purpose

The purpose of this project was to help identify the optimal design of temporary rumble strips that would be used in a work zone. The project involved a focus group and a psychological scaling experiment, where a subject was asked to evaluate a temporary rumble strip relative to a cut-in-pavement rumble strip. In addition, sound and vibration measurements were made from within a vehicle passing over the strips. The two rumble strips were:

- Recycled Technology, Inc. (RTI): A molded rectangular bump composed primarily of recycled tires, ¾" x 6" x 72", placed on the pavement surface, either with or without adhesive;
- Advance Traffic Markings (ATM): A molded plastic rectangular bump of indefinite length, 4" wide and 250-mil thick, placed on the pavement with an adhesive pad.

The RTI product was not available at the time of full-scale testing and there were concerns that the product is not suitable for a high speed traffic situation, so it was subjected to a more limited test. Instead, the ATM product was tested at two different speeds on separate sections of the same active work zone.

### Review of Previous Rumble Strip Tests by the Midwest Smart Work Zone Deployment Initiative (MwSWZDI)

The Midwest Smart Work Zone Deployment Initiative (MwSMZDI) has previously conducted several tests of temporary rumble strips. These previous tests influenced the experimental design of the current project.

In 2002 MwSWZDI published a report from a Wisconsin test of the Rumbler, a similar product to those tested here. The Rumbler was designed to be more permanent and was somewhat more difficult to install. Two conclusions about the Rumbler's effectiveness as a warning device were made. "The Rumbler is much quieter than a conventional [cut-in-pavement] rumble strip. The Rumbler also produced considerably less vibrations in the test automobile. The quality of sound from the Rumbler is also distinctly different from a conventional rumble strip. However the Rumbler's sound is qualitatively different and louder than road noise. The Rumbler did not elicit a large behavioral response from drivers. This lack a response is not by itself a criticism of the Rumbler, because other traffic calming devices were not tested at the same location."

Kansas also tested the Rumbler for the MwSWZDI in 2002. This comparison was against a series of bumps composed of asphalt mounded to ¾ inches high. The researchers stated: "In general, the Rumbler rumble strips performed comparably to the asphalt rumble strips with respect to sound and vibration generated and speeds observed. Slightly higher sound levels were observed at the roadside. The roadside noise is not likely to be problematic unless the strips are used on a longer-term application that is located in a residential area on a segment with substantial nighttime traffic."

Tests by Missouri of the Rumbler in 2002 concentrated exclusively on speed reductions by drivers. The report concluded "reductions in mean speed and standard deviation of speed were not consistently present."

A review by Iowa of a thinner ATM product reached this conclusion: "strip's thickness of one-eighth of an inch does not provide an adequate rumbling sensation. However, the double layered strips were effective in providing adequate sound and rumbling sensation to passenger cars and pickup trucks. Having no effects on the Iowa DOT maintenance truck, it can be suggested the double-layered strips provide no rumbling sensation to commercial trucks." The testing methodology was confined to subjective evaluations by the evaluation team.

A Kansas study of this same ATM product, but layered to double in thickness, found it to be an effective warning device when compared to a strip composed of raised asphalt bumps.

Finally, a review by Missouri of the 1/8 inch ATM product looked at lane distribution downstream from the strip and determined that the strip encouraged drivers to abandon the closed lane ahead of the taper.

These tests indicate that there may be positive benefits from temporary rumble strips, but a behavioral response from drivers is not necessarily observable through objective observations of vehicular speeds. All of these reports may be found on the MwSMZDI web page.

## Location and Deployment

The ATM rumble strips were deployed within an actual work zone in Washington County, Wisconsin along STH 33. This essentially rural work zone was 3 miles long with its western end located east of West Bend, WI and its eastern end located within Newburg, WI. STH 33 is a two-lane highway. The rumble strips were first deployed to locations just ahead of flaggers on a Thursday, then left as they were for the subject evaluation by drivers on Friday and objective measurements on Sunday. Figure 1 shows the installation of the eastbound (EB) rumble strip on new pavement, and Figure 2 shows the installation of the westbound (WB) rumble strip on pre-existing pavement. Each rumble strip consisted of 5 bumps spaced 7 feet apart. The spacing was chosen by WisDOT such that a motorcycle would be unlikely to have both wheels over bumps at the same time.

**FIGURE 1 Eastbound Test Strip, Viewed Looking West (Upstream)**

**FIGURE 2 Westbound Rumble Strip, Viewed Looking West (Downstream)**

The original intent of choosing a Friday for the subjective evaluation was to expose drivers to construction activity. For unexplained reasons, the contractor decided not to do any work on that Friday.

The RTI bumps were installed in a very large parking lot so that sound levels could be measured at varying speeds from 10 to 40 miles per hour. The pavement within the parking lot was almost new condition. The RTI product was not affixed to the pavement with adhesive. Figure 3 shows the location of the strips within the parking lot.

Each RTI bump was 6 feet long, so they were aligned in pairs to create a bump that was 12 feet long. Six pairs were arrayed for each test. Thus, the amount of time a vehicle spent over each strip was affected by the spacing. The total longitudinal distance across all bumps ranged from 10.5 feet for the 2-foot spacing to 35.5 feet for the 7-foot spacing.

Once the bumps were placed on the pavement, chalk marks were made along each bump so that any displacement could be ascertained.

**Figure 3  Deployment of RTI Bumps in Parking Lot at Seven Foot Spacing**

## RESULTS

### Objective Measurement of Sound Levels and Sound Character

*ATM*

Sound levels were measured with a Quest Electronics 2800 impulse integrating sound level meter. This instrument was equipped with a digital read-out of sound levels. The meter was set for fast response and A-weighting. In addition the actual sounds were passed through the meter to a laptop computer through its microphone jack for later processing. Sounds were saved as a WAV file, digitized at 44,100 Hz, 16-bit mono. To prevent clipping of the sound by the laptop, a headphone volume control was inserted between the meter and the laptop. The calibrator provided with the meter produced a 110 dB tone at 1000 Hz, which would have caused clipping with the volume control setting best suited for recording the actual sounds, so it was not used. Instead, the meter readings were voice-recorded for all important events throughout the data collection. The meter readings were used primarily to establish the average sound level for the cut-in-pavement strips (our standard stimulus). All other sound levels could be established by computer analysis of the WAV file, relative to the standard. Since WAV files are rescaled so that the maximum sound amplitude is always set to $2^{15}$; it was necessary to record all sounds in the same file so as to retain the correct relative amplitudes of the sounds. The digital meter readings of road noise and the test strips were used as checks against the WAV file analysis.

The test vehicle was a 2004 Nissan Altima, 4-door sedan. This vehicle has a wheelbase of 110 inches. The meter was hand-held at ear height on the passenger side of the front seat of the test vehicle. Windows were closed and air conditioning was off. Weather conditions were clear and the pavement was dry.

The test automobile was driven across each of the two standard (cut-in-pavement) rumble strips four times at 40 mph, the same speed as the subjects drove them. In order to ascertain the speed sensitivity of sound levels, these same strips were twice traversed at 55 mph. The EB test strip in the work zone was driven at 55 mph four times and the WB strip was driven at 40 mph four times. All sound levels for a strip at a given speed were logarithmically averaged ($L_{eq}$). The average sound level (across 8 readings) for both the standard CIP strips at 40 mph was found to be 75.2 dBA. This sound level should be used with caution as it is vehicle dependent.

Table 1 reports the differences in sound level between the standard strips at 40 mph and all other strips. Differences between road noise and the standard strips are also shown. These differences were, in all cases, calculated by computer analysis of the WAV file. No frequency weighting was used. For all rumble strips, the average sound level ($L_{eq}$) was calculated across the central 0.30 seconds of the duration of the elevated sound above road noise. This duration was selected in order to assure that both wheels of the test vehicle were over the strips, producing the largest amount of sound. For the road noise, the average sound level was calculated from the 2.00 seconds immediately prior to the strip. Table 1 also reports the average time that sound was elevated over the road noise.

**TABLE 1 Sound Levels Relative to a Standard, Cut-In-Pavement Strip and Durations of Sound Levels above Road Noise**

| Test Section | Sound Level Relative to Standard, $L_{eq}$, dB | Duration, seconds |
|---|---|---|
| Standard, CIP Strip, 40 mph | +0.00 | 0.63 |
| CIP Strip, 55 mph | +0.63 | 0.49 |
| Work Zone EB Strip, 55 mph | +1.60 | 0.56 |
| Work Zone WB Strip, 40 mph | -4.27 | 0.63 |
| Road Noise Standard, 40 mph | -16.20 | ---- |
| Road Noise, CIP, 55 mph | -12.95 | ---- |
| Road Noise, EB Strip, 55 mph | -12.90 | ---- |
| Road Noise, WB Strip, 40 mph | -12.95 | ---- |

Peak sound levels within the 0.3 second time interval were also obtained for all strips. Peak sound levels for the standard CIP strips at 40 mph were 6.5 dB above its average, 7.5 dB above its average for the CIP strips at 55mph, 7.9 dB above its average for the EB test strip, and 9.0 above its average for the WB test strip. The large difference between the peak and average sound levels for the WB test strip was due primarily to the larger amount of time in which the tires were in between the individual bumps that formed the strip.

It is well known that road noise increases with the speed of the vehicle. It is interesting to note that there was very little change in average sound level over the CIP strip between 40 and 55 mph. It would be difficult to draw a conclusion as to which speed the strip provides the greatest warning to drivers because the higher sound levels, both average and peak, at 55 mph are compensated by a shorter duration.

Conversely, the sound levels from the test strips in the work zone showed strong speed dependence. The EB strip was measured as being 5.9 dB louder than the WB strip. Since the road noise and layout of both strips were nearly identical, the only explanation of the large sound difference is the speed.

Although the road noise immediately ahead of the WB strip was no greater than the EB strip, the pavement further upstream had numerous bumps, which are not reflected in the data in Table 1.

The WAV file was also analyzed for frequency characteristics using fast Fourier transform (FFT) analysis. All of the sounds were dominated by frequencies below 200 Hz. The CIP strip at 40 mph had a marked peak at about 100 Hz. The EB test strip had a flat peak between 70 and 80 Hz, and the WB test strip peaked at about 85 Hz. There was no evidence from the FFT analysis that there were any significant differences between the audible frequency characteristics of the sounds.

Visual representation of the WAV file is shown in Figure 4. The horizontal axis spans exactly a 1-second duration and the vertical axis is arbitrary, but the same for all sounds so they can be directly compared.

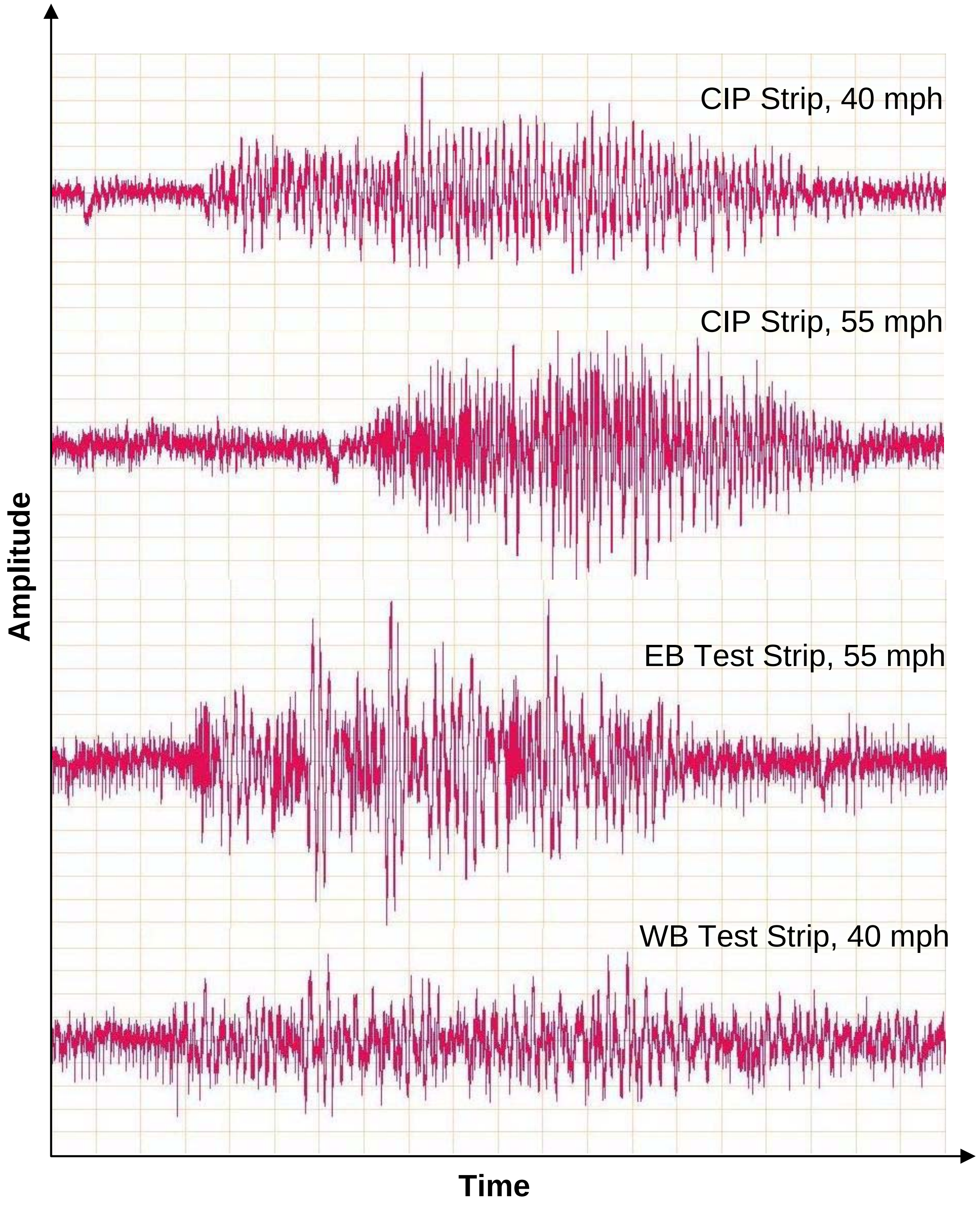

**FIGURE 4 Sound Amplitudes over One Second of Time (Vertical Scale is Arbitrary)**

The amplitudes of the sounds in Figure 4 indicate that the character of the sounds differ considerably across types of strips. For example, the EB strip exhibits strong peaks interspersed with quieter intervals, while the CIP strip shows a more constant sound. The WB test strip, as expected has the smallest amplitudes, barely discernable in this figure above the road noise. The EB test strip has the strongest peaks.

*RTI*

The same sound level equipment was used for the RTI bumps, but the vehicle was a 1993 Ford Taurus wagon. This vehicle was older, but of comparable size to the Altima used for the ATM bumps. Sound level data were taken in a two-way factorial experimental design by varying speed and spacing between bumps. Speeds were 10, 20, 30, and 40 mph. Bump spacings were 2, 3, 5, and 7 feet. One additional reading was made at the fastest speed that could be safely attained by this vehicle within the parking lot at 47 mph and at 2 foot spacing.

The sound levels obtained from the recorded wave form are shown in Table 2. An instrument failure prevented recording the sound level for 30 mph at 7 foot spacing. These sound levels pertain to the peak 0.3 second of each event. The absolute sound levels were obtained from relative sound levels in the wave form by matching the average of peak sound levels ($L_{eq}$) recorded directly from the meter for all 16 events.

**Table 2 Peak Sound Level Readings (dBA) from RTI Tests**

| | Spacing (ft) | | | | |
|---|---|---|---|---|---|
| Speed (mph) | 7 | 5 | 3 | 2 | Average ($L_{eq}$) |
| 10 | 74.9 | 71.4 | 76.2 | 76.1 | 75.0 |
| 20 | 82.4 | 85.3 | 87.0 | 85.1 | 85.2 |
| 30 | | 85.3 | 88.7 | 86.2 | 87.6 |
| 40 | 85.7 | 86.8 | 89.8 | 85.5 | 87.3 |
| 47 | | | | 88.7 | |

An inspection of the data shows an unambiguous increase in sound levels with increasing speed; however the effect of spacing is less clear. Although only slightly louder, the 3-foot spacing produced the highest sound levels for all speeds. Working around the missing data point, there are two separate two-way analyses of variance that can be performed: speed (10, 20, 30, 40) against spacing (2, 3, 5) or speed (10, 20, 40) against spacing (2, 3, 5, 7). Both analyses revealed that speed was a highly significant factor (F values of 58.4 and 62.3, respectively) while spacing was at best marginally significant (F values of 5.7 and 2.5, respectively).

An inspection of the sound amplitudes revealed that the amount of sound is governed largely by the shock associated with a single axle (two tires) hitting a single bump. Thus, sounds would be louder when the spacing allowed both the front axle and the rear axle to hit strips at approximately the same time. It might very well be the case that the 3-foot spacing is optimal for the test vehicle, and the louder sounds observed at this spacing might not carry over to other vehicles. The wheelbase of the test vehicle is 8.83 feet, almost equivalent to the distance spanning 4 strips, spaced 3 feet apart.

The increases in sound levels seem to be fairly consistent with a hypothesis that the sound energy is proportional to the square of the speed. Under this hypothesis, the difference in sounds between 10 and 20 mph should be 6 dB (using the common rule of thumb that there is a 3 dB increase for each doubling of energy). Between 20 and 30 mph, the hypothesized increase would be 3.5 dB; between 30 and 40 mph just 2.5 dB. The largest deviation from this hypothesis is from 10 to 20 mph, where the measured sound level difference was 10.2 dBA

## Objective Measurement of Vibration (ATM)

Vibration was measured by a single piezoelectric accelerometer that was mounted vertically on the dashboard of the test vehicle, just over the steering column. The signal from the accelerometer was passed through an amplifier and through a headphone volume control to a laptop computer. The accelerations were stored in a WAV file. The test vehicle was the same Nissan Altima as used for sound levels. The accelerometer was not calibrated. Rather the accelerations at the test trips are compared with the accelerations at the standard strips. To assure that this comparison could be made accurately, all strips were recorded into one file.

All strips were traversed four times each. Thus, the average vibration level of the standard strips was established by 8 measurements. Speeds were consistent with the psychological scaling experiment. The standard strips and the WB test strip were traversed at 40 mph, while the EB test strip was traversed at 55 mph. All results are reported in decibels. Averages were taken logarithmically ($L_{eq}$) to be consistent with the previous sound analysis. As with the sound level analysis, data for the strips were drawn from the central peak 0.3 second and the data for the road noise was taken from the 2.0 seconds immediately prior to reaching the strip. All measurements were unweighted by frequency. Table 3 shows the relative vibrations levels.

**TABLE 3 Vibration Levels Relative to a Standard, Cut-In-Pavement Strip**

| Test Section | Acceleration Amplitude Relative to Standard, $L_{eq}$, dB |
|---|---|
| Standard, CIP Strip, 40 mph | +0.00 |
| Work Zone EB Strip, 55 mph | +2.59 |
| Work Zone WB Strip, 40 mph | -2.13 |
| Road Noise Standard, 40 mph | -19.37 |
| Road Noise, EB Strip, 55 mph | -14.23 |
| Road Noise, WB Strip, 40 mph | -11.56 |

Peak vibration levels within the 0.3 second time interval were also obtained for all strips. Peak acceleration amplitudes for the standard CIP strips at 40 mph were 5.9 dB above its average, 6.0 dB above its average for the EB test strip, and 7.7 above its average for the WB test strip.

FFT analysis of the vibrations was limited by the software to frequencies above 43 Hz, probably a higher frequency than can be readily felt by drivers. The CIP standard strips had a flat peak between 43 and 220 Hz. The EB test strip showed a peak at about 90 Hz, and the WB test strip's vibrations peaked at 43 Hz (the lowest end of the scale). A better understanding of the very low frequency vibrations can be achieved by looking directly at the WAV file. By simply counting the number of strong, regular peaks in an interval of time, the CIP standard was found to have a pronounced frequency at about 55 Hz and a less pronounced frequency at about 110 Hz; lower frequencies that might be felt as a buzz were not seen.

Accelerations for the EB and WB test strips are illustrated in Figure 5. The data spans an interval of exactly 1 second. As with the sound amplitudes, the vertical scale is arbitrary, but consistent between strips. The EB test strip WAV file showed several strong shocks spaced roughly 0.08 seconds apart, with lesser amounts of vibration at higher frequencies. The WB test strip showed distinct shocks at about 0.13 seconds apart. These intervals of time are consistent with the front tires hitting each of the components of the strip.

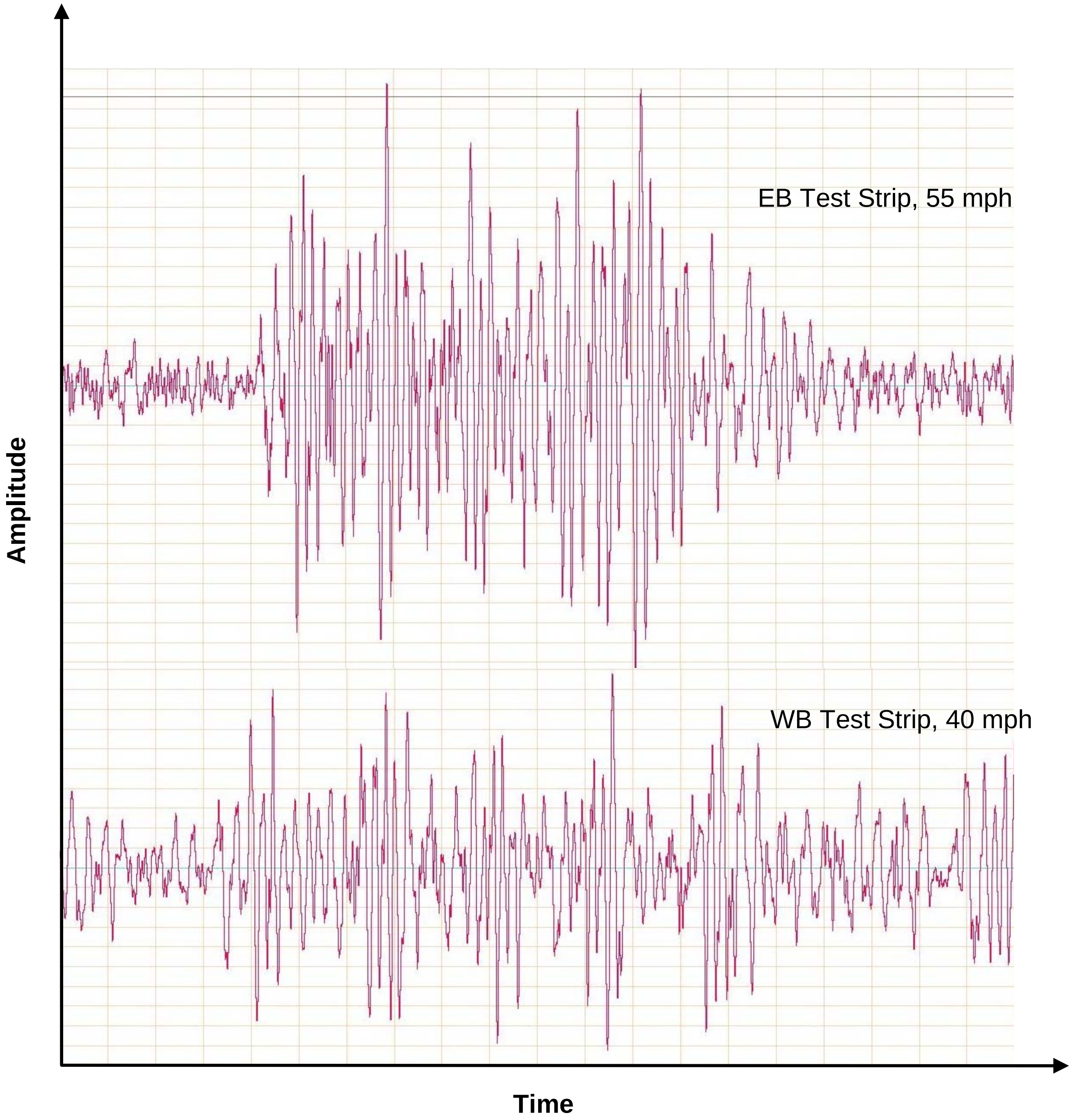

**FIGURE 5 Accelerometer Amplitudes Indicating Degree of Vibration over One Second of Time (Vertical Scale is Arbitrary)**

### Subjective Measurement of Sound, Vibration and Visibility (ATM)

Each of the test strips were evaluated subjectively by a panel of eleven Wisconsin drivers, recruited from the surrounding community. These subjects drove their own vehicles across the two standard CIP strips and across both the EB and WB test strips. Immediately upon traversing the test strips, the subjects were asked a series of questions about their experiences. Later, the subjects were assembled into one of two focus groups in order to share their experiences and to reach a consensus as to the usefulness of the product. Subjects were paid for their participation. Ages ranged from 21 to 75; all subjects reported having good vision.

The primary method of obtaining responses from subjects was a technique known as magnitude estimation. Magnitude estimation is a well-known technique of psychophysics that ascertains a rating of one stimulus relative to another. Results of a magnitude estimation experiment produce a ratio scale. Subjects are first exposed to a standard stimulus, which is given a predetermined scale value (referred to as a modulus). Then subjects are exposed to a comparative stimulus and are asked to rate it relative to the standard stimulus, using the modulus as a reference.

For this experiment, the standard CIP strips were given a value of 10. Thus, a value of 20 for noise would suggest that a test strip was perceived as twice as loud as the standard, while a value of 5 would suggest that the test strip is perceived as half as loud. Variations between the subjects' ratings were expected due to the subjects' vehicles, ages, and other personal factors. The questions asked of each subject after each test strip are as follows.

On a scale of 0 to 100, where 10 is a cut-in-pavement rumble strip and 0 is smooth pavement, rate the audible (sound) warning provided by the work zone rumble strip?

_______

On a scale of 0 to 100, where 10 is a cut-in-pavement rumble strip and 0 is smooth pavement, rate the tactile (feel) warning provided by the work zone rumble strip?

_______

On a scale of 0 to 100, where 10 is a cut-in-pavement rumble strip and 0 is smooth pavement, rate the visual warning provided by the work zone rumble strip?

_______

How would you rate the overall intensity of the warning provided by the work zone rumble strip?

____Too little
____About right
____Too much

How would you rate the distance between the work zone rumble strip and the work zone?

____Too close to the work zone
____About right
____Too far from the work zone

Subjects were earlier told to report a rating of 100 for any stimulus that was more than 10 times the standard. Since all of the ratings were well less than 100, the cap on the ratings implied by the questionnaire should not have introduced any distortions to the results.

The course driven by the subjects is shown in Figure 6. The approximate amount of time to complete the experiment for a single subject was 35 minutes. The course started at the WisDOT field office, progressed through the cut-in-pavement strips (WB on 33, then SB on CTH G), then returned to STH 33, where the EB test strip and the WB test strip were traversed.

Although the experiment was planned to occur during construction, there was no activity the day of the experiment. Many work-zone signs were in place and the pavement was obviously still unfinished. All lanes were open and unobstructed. Traffic was light. None of the subjects reported having problems maintaining the speed limits across the work zone test strips.

The visibilities of the strips were expected to be influenced by the sun angle at different times of the day. A more important influence, it was found, was the soiling of the WB strip, which became worse as the day progressed. The soiling was caused by loose oil that had been spilled about 100 ft upstream of the strip. Figure 7 is a picture of the WB strip, taken about ½ hour after the last subject completed the course. The view is from the east. Late in the day the strip was barely visible to an approaching driver and would probably have been unseen by any driver not specifically looking for it.

Average ratings across all 11 subjects are shown in Table 4. Average ratings for the cut-in-pavement rumble strips are set at exactly 10, consistent with the instructions to the subjects.

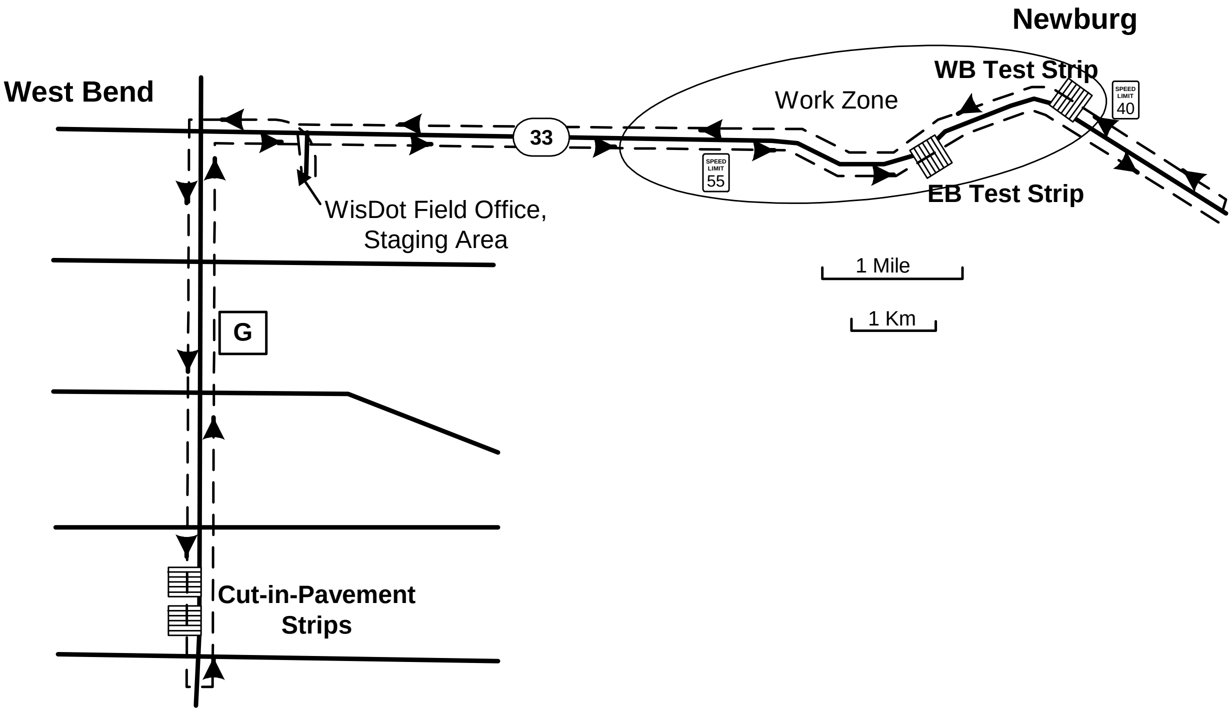

FIGURE 6 Locations of the Work Zone, Rumble Strips and Course of Travel for Subjects

**TABLE 4 Average Ratings from the Magnitude Estimation Questions**

| Rumble Strip | Audible Warning | Tactile Warning | Visual Warning |
|---|---|---|---|
| Standard, CIP Strip, 40 mph | 10.0 | 10.0 | 10.0 |
| Work Zone EB Strip, 55 mph | 11.2 | 10.5 | 19.4 |
| Work Zone WB Strip, 40 mph | 8.0 | 8.5 | 13.1 |

**FIGURE 7 WB Test Strip at End of the Day of Psychological Scaling, Viewed Looking Downstream**

It is seen that the ratings of the EB test strip are higher than the standard. For the WB test strip, only the visual warning was rated higher than the standard.

The question about the overall intensity of the strips is intended to have the subjects evaluate the whole experience. For the EB test strip, 10 of 11 subject rated it "about right", with the remaining subject rating it as "too little". For the WB test strip, only 4 subjects rated it "about right", with the remaining 7 subjects rating it as "too little". Nobody rated either strip as "too much".

The results from the question about the distance between the strips and the work zone were muddled, because both test trips were deployed within the work zone and there was no construction activity. No agreement between subjects could be seen for the EB test strip, although 8 subjects felt that the WB test strip was "too close". The reason for this rating was made apparent during the focus groups (see next section).

### Focus Groups (ATM)

Because of the varied locations of the residences of the subjects, two focus groups sessions were held. The first session had 8 subjects and the second session had just 3 subjects. A list of 12 questions was prepared ahead, and all questions were asked. However, responses from the subjects did not necessarily relate directly to the questions, as spontaneity was encouraged. Questions dealt with the rumble strips and with work zone design, in general. The major findings of the focus groups are listed below.

- Subjects disagreed as to whether the EB test strip was better than the standard. Some subjects believed that the quality of sound from the CIP strips was superior. Those subjects believed that the continuous sound from a CIP strip was more effective.
- All subjects agreed that the WB test strip was inferior to EB test strip. Only two subjects felt that the WB test strip was superior to the CIP strip.
- The WB test strip was positioned too close to the work zone. It was located amongst warning signs. A better idea would be to place the strip ahead of the signs so a driver could be alerted to the presence of signs.

- All subjects agreed that the smooth pavement ahead of and within the EB test strip accentuated the warning. The rough pavement ahead of the WB test strip diminished its effectiveness.
- All subjects agreed that the visibility of the EB test strip was good. An orange strip might have better connoted a work zone, even though the MUTCD specifies white.
- All subjects agreed that the feel of the EB test strip was a more effective warning than the CIP strips. Some subjects expressed a desire to have even more bumps in a strip to increase the number of shocks. More than one strip should be deployed at a single location to increase the effectiveness of the warning.
- Although the MUTCD says reduced speed zoning should be avoided as much as practical, subjects were surprised that speed limits had not been reduced from normal during work zone activity. They felt that 55 mph was probably too fast for a work zone on this two-lane road.
- Rough pavement ahead of the WB test strip diminished its effectiveness for some subjects.
- Two suggestions on the operation of work zones in general were made by the group. Changeable message signs should be used wherever possible to alert drivers to hazards, delays and hours of construction activity. Work zone warning signs should be hidden from drivers when there is not any construction activity, so as to avoid desensitizing drivers to warning devices when they are unnecessary.

A number of other suggestions about work zone operations were made, but a consensus was not achieved on those suggestions.

*Subjective Evaluations for the RTI Bumps*

The RTI bumps were evaluated subjectively only by the evaluation team of three people. The consensus was that the shocks of the vehicle hitting a bump were strong and very noticeable, even at 10 mph. At 40 mph the shocks were unpleasant. The front and rear bevels of each bump were black in color, making the bumps difficult to see at a distance, even though the top of a bump was white in color.

**Ease of Deployment, Damage and Deterioration**

*ATM*

Not only were the strips deployed within the Highway 33 work zones, but Washington County also used the strips ahead of a new stop sign for a period of 1 week. Interviews with persons who deployed the test strips indicated that they readily adhered to the pavement and remained in place for the desired duration (5 days, 3 days, and 7 days). It took about 15-20 minutes for a single worker to place the strips and about 10 minutes for two workers to place the strips. About the same amount of time was later needed to remove them. With this installation and removal time, construction project staff believed it would be feasible to install and remove the strips on a daily basis to accommodate daytime-only flagging operations or projects where the work site changes location from one day to the next. The bumps could be removed easily with a shovel to loosen one end; then the bumps could be pulled off the pavement by hand. The adhesive stayed with the bumps. The adhesive that needed to be applied to an already used bump seemed weaker than the adhesive that originally came on the bumps. The manufacturer indicated the bumps could be re-applied a maximum of four times after the initial installation.

Figure 8 shows the installation process for the EB strip. Although this photograph shows two people applying a bump, it was later ascertained that one person could do the job in about the same amount of time. The tamping cart and extra bump material can be seen on the left hand side of the figure, just in front of the worker holding the broom handle. Washington County used a small asphalt roller that they owned for pothole repair to press the strips to the pavement.

The bumps remained fixed to the pavement through out the tests and showed no sign of loosening or deterioration.

*RTI*

Given that no adhesive was used, the RTI product was very easy to deploy and remove. A strip consisting of 6 bumps (12 pieces) could be deployed in less than 10 minutes by a single worker. A strip could be removed in less than 5 minutes.

The bumps were undamaged by the tests. The bumps did not displace at speeds of 10 and 20 mph and only minor displacements were noticed from a car traveling at higher speeds up to 47 mph.

**FIGURE 8 Installation of the Work Zone Test Rumble Strip**

## CONCLUSIONS

### *ATM*

The objective measurements of sound and vibration are largely consistent with the subjective ratings. The one substantial difference is that subjects believe that a more continuous sound constitutes a better warning. Subjects also indicated that the road condition ahead of the rumble strip influenced their ratings.

Speed was an important determinant of the amount of sound coming from a work zone rumble strip.

A work zone rumble strip, designed and deployed as described here and traversed at 55 mph was about as effective a warning device as a cut-in-pavement rumble strip. This same strip traversed at 40 mph was ineffective.

### *RTI*

Speed was found to be the most important determinant of sound produced by the RTI product. Spacing between bumps was relatively unimportant. The RTI product is an effective warning device for vehicle speeds between 10 and 40 mph. It is uncertain how well the RTI product would stay in place with heavy truck traffic.

## RECOMMENDATIONS

Rumble strips of a design similar to the ATM product with a 250 mil thickness are appropriate warning devices where traffic speeds exceed 50 mph. They are ineffective at lower speeds, as compared to a conventional cut-in-pavement rumble strip, unless the bumps are spaced much closer together than the 7 feet used in our tests. Because of the strong relationship between vehicle speed and sound levels, this design could be very useful at alerting drivers traveling at speeds above 50 mph.

Previous studies have shown that it is difficult to measure direct behavioral responses from warning devices such as rumble strips. Such devices are designed principally to alert inattentive drivers. The psychological scaling and focus groups from this study indicated that a greater amount of information about potential behavioral responses can be systematically obtained. It is recommended that future studies of warning devices employ such human factors evaluation techniques.

Rumble strips of a design similar to the RTI product with a ¾ inch thickness are appropriate warning devices where desired traffic speeds are less than 25 mph. This design could be very useful at alerting drivers traveling at speeds of up to 40 mph.

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