Date Submitted: January 30, 2013	**Submitted By:** SHSP Challenge Area 14

Challenge Area: 14. Enhance Work Zone Safety

Action Description: Evaluate the effectiveness of using temporary transverse rumble strips when flaggers are present within work zones to reduce speeds and improve safety upstream and through the work area on two-lane high speed roadways. If found effective, develop guidelines and specifications for the use of temporary transverse rumble strips.

Issue(s): Driver inattention and driving too fast are the key causes of collisions on two-lane high speed roadways ahead and within the work zone's activity area. Motorists on high speed two-lane highways are provided with numerous visual cues ahead of work area (e.g., PCMS, flashing beacons, signs) to encourage them to slow down. However, the resulting speed reductions are often times minimal and the exposure of workers and flaggers to speeding traffic remains high.

Solution & Benefits: Test portable transverse rumble strips in two two-lane high speed roadway work zones involving flagging operations where traffic speeds need to be reduced far ahead of flagging stations. Since it is important to observe motorists reaction over a period of time select work zone locations where work will span over a few hours and repeat for a few days.

The test would provide immediate and effective evaluation on driver's reaction to the rumble strips. The driver's reaction to the visual cues (PCMS and flashing beacons) placed ahead of the rumble strips would be compared with their reaction after crossing over the rumble strips.

Use of the temporary transverse rumble strips will help in the overall reduction of crashes with distracted drivers. The above test data will provide the necessary tools to generate guidelines for the most efficient and adequate use of temporary transverse rumble strips. Specifications would be generated afterwards.

Target Completion Date: The estimated completion date is June 2014

Detailed Description: The evaluation consists of the following tasks as follows:

1. Conduct discussions to address concerns of all stakeholders, such as SHSP Challenge Area 12.
2. Select work zones that fit the criteria mentioned above.
3. Identify liaison staff at Caltrans Districts to test the rumble strips
4. Data Collection
5. Data Analysis
6. Documentation and presentation of research results to SHSP Challenge Areas 12 and 14
7. Make recommendations for when and where to install portable transverse temporary rumble strips on 2-lane high speed roadway work zones.
8. Implement in Maintenance and develop specs to use on Construction projects (NSSP)
9. Evaluate affects on motorcycle through data collection and interviews.

Milestones:

1) Early Progress: Two work zones were identified in District 3 and District staff were identified to test the temporary transverse rumble strips. Data was collected during August 2011 (completed).
2) Underway: Evaluate additional sites, obtain more data, analyze it and gain support for the rumble strips. March 2013
3) Substantial Progress: If effective results in terms of reductions in speeds, number of crashes and severity of crashes are obtained then a presentation and a report of results will be provided to Challenge 12 and 14 Committee. Completion date : May 2013
4) Completed: June 2014 - When the following three tasks are finished:
   (a) Develop guidelines for when and where to install portable transverse temporary rumble strips on 2-lane high speed roadway work zones
   (b) Develop SSP's
   (c) Include in Chapter 8 Maintenance Manual

Performance Measures:

- A speed reduction of 7 – 8 mph resulting from the use of temporary transverse rumble strips (after situation) when compared with the speed reductions resulting from the use of only visual cues (before situation). The attached survey conducted by Division of Maintenance showed an additional 46.5% speed reduction when rumble strips are used compared to just visual cues.
- A 10 %reduction in crashes compared to projects where flaggers are used without advance warning temporary transverse rumble strips.

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Costs to Implement & Other Resources: Low < $250,000. The rumble strips cost $1,500 for an 11 ft long set (3 sections, 44 inch-long each). Each project needs a minimum of 2 sets (6 sections). Therefore, for 80 projects on two-lane highways the cost will be 2 x $1500 x 80 = $240,000. Study costs will run approximately $10,000 in employee and printing costs.

Risks/Barriers to Success & Mitigation Strategies: SHSP Challenge Area 12 raised concerns over the safety of motorcycles crossing over the rumble strips. To address the above concern, we conducted testing at the CHP Academy on August 27th, 2012, during which officers on motorcycles crossed over the rumble strips at various speeds in dry and wet conditions. Officers commented after the tests that they never lost control during any of the runs they made.

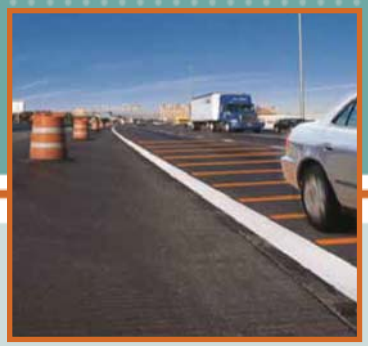
During later communications, members of the above committee raised the concern that motorcycles tires momentarily lost contact with the ground immediately after crossing the rumble strips. This could have been caused by the fact that the strips used during the above testing were beveled only on the approach side. However the strips that would be required for use per specifications would be beveled on both sides.

The positive results measured during the testing on two California construction projects in terms of speed reduction as motorists approached the work zone area outweigh the concern over momentarily tire contact loss with the ground. These concerns will be alleviated in future specifications requiring the use of beveled strips on both sides and limiting the use of the strips to tangent sections of the roadway. Signing will also be provided to warn approaching drivers of the existence of bumps in the roadway.

Attachments:
1. Power Point slides on use of temporary transverse rumble strips.
2. Survey conducted by Caltrans Maintenance.

Steering Committee Recommendation Date: 2/11/2013	**Executive Committee Approval Date:** 3/13/2013

SHSP Reference Number: 14.16



Guidance for the Use of **Temporary Rumble Strips in Work Zones**

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INTRODUCTION

In 2011, there were 1114 total injuries reported in work zones, 587 of which were fatal. Crash occurrence in work zones may be impacted by a variety of work zone parameters such a layout, speed limit, reduced lane width, visual obstructions, and the use of a temporary traffic lane (El-Rayes, Liu, and Elghamrawy 2013). A survey conducted by the Illinois Department of Transportation (IDOT) showed that approximately 69 percent of work zone crashes were caused by improper driving, and 40 percent of fatal and injury-related work zone crashes occurred in work zones that had no traffic signals or rigorous restrictions at the scene of the crash.

This indicates that temporary traffic control (TTC) countermeasures should be used to increase drivers' alertness and to provide advance warning of changing conditions within the work zone (El-Rayes, Liu, and Elghamrawy 2013). Even though other warning devices such as warning signs, portable changeable message signs, arrow panels, temporary pavement markings, etc. may be sufficient to guide drivers through work zones, a stronger and timelier response can be achieved by combining audible and tactile stimuli to improve driver compliance; this would be a useful addition to other TTC devices when drivers may be inattentive or misperceive the upcoming conditions (Sun, Edara, and Ervin 2011).

Rumble strips are a countermeasure that provides both an audible warning and physical vibration to alert motorists as the vehicle tires traverse the rumble strips. Because there is no specific message associated with rumble strips, they can be used to alert motorists to a variety of conditions. The *Manual on Uniform Traffic Control Devices* (MUTCD) indicates that transverse rumble strips, which extend across the travel lanes, are intended to notify road users of upcoming hazards or changes in roadway features, such as unexpected changes in alignment, and conditions requiring a reduction in speed and/or a stop (FHWA 2009). This could encompass a variety of situations such as lane closures, speed reductions, changes in alignment, new merge patterns, visual obstructions, nighttime work zones, and more. The circumstances and restrictions of work zones can vary greatly, and transverse rumble strips can alert drivers to the changing conditions and information being provided by TTC devices.

Due to the temporary nature of work zones, a need exists for rumble strips that can be installed and removed quickly and efficiently while providing the same auditory and tactile warnings to drivers as permanent rumble strips. This guidance document provides practitioners with information on the use of temporary rumble strips to increase the safety of work zones.

Objectives of this Document

The objectives of this document are as follows:

- To provide information on the use of temporary rumble strip types and configurations for work zones and their benefits and limitations;
- To discuss when and how to implement temporary rumble strips in work zones;
- To present other key aspects to consider before and during implementation; and
- To provide a list of reference materials.

TEMPORARY RUMBLE STRIPS IN WORK ZONES

ADVANTAGES

Permanent rumble strips are recessed below the pavement by milling or rolling, while temporary rumble strips consist of a raised surface that is placed on, or temporarily adhered to, the pavement. As a result, temporary rumble strips are much easier to install and remove compared to permanent rumble strips, and some forms are even reusable; this makes them particularly useful for deployment in work zones. Ease of installation, removal, and reusability vary based on the type of temporary rumble strip (please see Table 1 for a description of different types of rumble strips). Figure 1 shows temporary portable reusable rumble strips applied on the approach to a work zone (Plastic Safety Systems 2013).

Advantages of Temporary Rumble Strips

- Ease of installation and removal compared to permanent rumble strips
- Potential for reuse of rumble strips
- Increased driver awareness of upcoming conditions and compliance to other traffic control devices
- Increased braking and reduced speeds

The primary benefit of temporary rumble strips is their effectiveness in alerting drivers to other traffic control devices and upcoming circumstances such as lane changes, detours, or other hazardous conditions (Morgan 2003). The audible and vibratory stimuli produced by rumble strips can increase awareness among drivers as they travel through work zones, which can be particularly helpful for inattentive, fatigued, or sleepy drivers (Maryland SHA 2011). An increase in driver awareness can lead to positive behavior modification in terms of speed reduction, braking, and increased compliance withwarning signs and devices, all of which are behaviors that can reduce crashes in work zones. It has also been found that the application of rumble strips can improve traffic flow in cases where additional warning signs and changeable message signs (CMS) do not reduce late merges and when there is excessive congestion (Pigman and Agent 1988).

Figure 1. Temporary rumble strips applied on the approach to a work zone.
(Source: Plastic Safety Systems 2013)

Permanent rumble strips have proven to be effective in producing levels of auditory and tactile stimuli required to alert motorists; therefore, the effectiveness of temporary rumble strips in alerting motorists is often evaluated by comparing sound levels to those of permanent rumble strips. El-Rayes, Liu, and Elghamrawy (2013) measured the effectiveness of an adhesive rumble strip, a manually adhesive rumble strip, and a portable reusable rumble strip in generating adequate sound levels to alert inattentive drivers and found that all three types of temporary rumble strips generated

adequate sound levels compared to those produced by permanent rumble strips. A sample of the sound measurements collected can be found in Appendix B.

Braking is one indication of driver awareness of unusual or changing road conditions, and thus can be used to investigate the effectiveness of temporary rumble strips in work zones. Studies have shown that temporary rumble strips in work zones can result in braking by 10 to 80 percent of vehicles (Sun, Edara, and Ervin 2011; Wang et al. 2011a).

Vehicle speed reductions are the most common measurement for determining the effectiveness of temporary rumble strips in work zones. For example, The California Department of Transportation (2012) tested rumble strips in areas leading up to work zones and found that 46 percent of traffic slowed down, with nearly half of all vehicles slowing down by an average speed of 8 mph (Richards, 2012). Several research studies have examined temporary rumble strips at work zones and have found positive effects in terms of vehicle speed reduction (Fontaine and Carlson 2001; Fontaine, Carlson and Hawkins 2000; McAvoy n.d.; Meyer 2000; Sun, Edara, and Ervin 2011a; Sun, Edara, and Ervin 2011b; Wang et al. 2011a; Wang et al. 2011b), though the strength of the speed reduction results are mixed. Some of the studies show significant speed reductions of 4.6 – 11.4 mph for cars (Wang et al. 2011a) and 3.5 – 11.7 mph for trucks (Fontaine and Carlson 2001; Fontaine, Carlson, and Hawkins 2000; Wang et al. 2011a), while other studies report smaller speed reductions of 1.1 – 2.2 mph for cars (Fontaine and Carlson 2001; Fontaine, Carlson, and Hawkins 2000; Horowitz and Notbohm 2002; Meyer 2000) and 0.9 – 2.3 mph for trucks (Meyer 2000). Additionally, the effectiveness of rumble strips is influenced by a variety of factors, such as rumble strip size, configuration, and type of rumble strip, which may account for variability in the results.

Though some of the smaller speed reductions may not be practically significant, temporary rumble stripscan still alert inattentive drivers to visual information that they otherwise may not have noticed and thus have the potential for reducing accidents or intrusions in the work areas.

Disadvantages

Although there are many benefits to the application of temporary rumble strips at work zones, there are potential negative effects which should also be considered.

Disadvantages of Temporary Rumble Strips

- Potential for erratic or avoidance maneuvers by drivers
- Potential rough ride or hazard for motorcycles or bicyclists
- Potential for movement of rumble strips due to inadequate installation
- Noise complaints by nearby residents

Inattentive drivers may be surprised when they inadvertently cross rumble strips, which could lead to erratic maneuvers such as hard braking or swerving. Several documents have indicated that transverse rumble strips do not appear to induce erratic maneuvers (Miles, Pratt, and Carlson 2006) and can have positive effects on the brake patterns of sleep-deprived drivers at stop-controlled intersections (Harder and Bloomfield 2005), although little research has documented or reported erratic maneuvers in work zones specifically.

CONCLUSIONS

- Temporary rumble strips are much easier to install and remove compared to permanent rumble strips, and some forms are even reusable; this makes them particularly useful for deployment in work zones.

- The audible and vibratory stimuli produced by rumble strips can increase driver awareness while traveling through work zones, which can be particularly useful for inattentive, fatigued, or sleepy drivers.

- Practitioners should use caution when installing temporary rumble strips on high-volume roads as there is potential for erratic or avoidance maneuvers by drivers.

- Failing to properly clean the roadway prior to installation of rumble strips can cause the strips to shift or become dislodged from the pavement; installation instructions provided by manufacturers should be followed strictly.

- Outreach to local residents may be required to notify them of the work, duration of the work, and potential for noise caused by the rumble strips.

- The different types of temporary rumble strips that are available allow for the use of rumble strips in stationary, slow-moving, and long- and short-duration work zones.

- Many factors influence the stimuli created by the rumble strips, such as pattern, spacing, size, and type of rumble strips, as well as vehicle-related factors such as speed and type of vehicle.

- Temporary rumble strips should be selectively located with respect to the potential hazard so as to maximize their effectiveness; placement within the work zone may ultimately be dictated by the signing plan.

- Multiple arrays (sets) of rumble strips spaced several hundred feet apart can be used to provide repeated warnings.

- The pattern (number of rumble strips) should be adequate enough to alert drivers, without being so dramatic that they make motorists uncomfortable or promote unsafe maneuvers to avoid the rumble strips; rumble strips are often deployed in sets of 3, 4, 6, or 10 strips.

- The spacing of temporary rumble strips is dependent on the speed within the work zone; lower speeds require less spacing between strips, whereas higher speeds require more spacing.

- The spacing of rumble strips may be reduced as the distance to the approaching condition decreases in order to convey that an action is imminent and/or give the impression that the driving speed is too fast.

- Acceptable heights of temporary rumble strips range from around 0.25 - 0.81 inches.

- Practitioners should follow State DOT specifications, traffic control plans, and manufacturer recommendations, when available.

- If the color of transverse rumble strips used is not the same color as the pavement they should be black, white, or orange.

- Transverse temporary rumble strips may be placed continuously across the entire lane or in the wheel paths only.

- Additional warning signs may be placed in advance of the rumble strips in order to warn drivers and motorcyclists of the onset of rumble strips.

- Temporary rumble strips can also be utilized at the edge of work zones or along centerlines where traffic is flowing in opposite directions in order to alert drivers if they encroach in the work area, although this is not commonly practiced.

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