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Temporary Rumble strips

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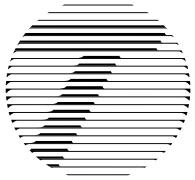

SPECIAL REPORT 140
TRANSPORTATION RESEARCH AND DEVELOPMENT BUREAU
NEW YORK STATE DEPARTMENT OF TRANSPORTATION
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TEMPORARY RUMBLE STRIPS

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ABSTRACT

The New York State Department of Transportation recently adopted seven work zone intrusion countermeasures to increase safety of the workers and driving public. Among these countermeasures adopted was the use of temporary rumble strips at work zones to alert drivers of an approaching work zone or a change in the driving pattern or highway condition. A literature search was performed, of past and ongoing research and use of temporary rumble strips in work zones, to verify that current specifications used by the Department are sufficient. In addition, several installations at contracted and maintenance work zones were examined to determine if our current specifications are appropriate or need refinement. Results of this study showed that the use of rumble strips at work zones is effective and should be continued. The Department's specifications are within the accepted practices of other states that use rumble strips for this purpose. These specifications should be modified to allow for variable spacing of the strips within a set and for the use of other types of rumble strips besides the types currently allowed. Sound engineering judgement should be used before placing them to ensure they are necessary and effective. Even though the rumble strips that were used at the maintenance work zones do not meet Department standards, they are effective for the usual short duration of a maintenance operation. Minor modifications of these would improve their effectiveness without significantly increasing cost or installation time.

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I. INTRODUCTION

The New York State Department of Transportation (NYSDOT) is committed to improving the overall level of safety in work zones for both the driving public and workers. As part of these continuing efforts, an Engineering Directive (ED) was issued in 1999 in an attempt to reduce the incidents of traffic intrusions into highway work zones. ED 99-002 "Work Zone Intrusion Countermeasures"[1] called for the implementation of seven specific measures including temporary rumble strips for advance warning to alert drivers visually, audibly, and tactilely of approaching work zones with exposed workers. This ED was extended for the 2000, 2001, and 2002 construction seasons respectively by EB 00-020, EB 01-031, and EB 02-042 , all titled "Work Zone Intrusions Countermeasures- Extension of ED 99-002".[2,3,4]

After the 1999 construction season, each Region was asked to provide comments and observations on the effectiveness of the seven counter measures. Their comments regarding temporary rumble strips included concerns about proper thickness and spacing of the strips, color of the strips, problems with the strips adhering to the pavement, drivers leaving the travel lane to avoid the strips, noise created by traffic over the strips disturbing nearby residents, and drivers not understanding the purpose of the strips.

The Offices of Engineering and Operations requested the Transportation Research & Development Bureau (TR&DB) to investigate the use of rumble strips at both contracted and maintenance work zones to determine if the Department's current specifications are appropriate or need refinement. The current specifications for spacing, thickness, and location are found in Engineering Instruction EI 96-001 "Temporary Rumble Strips for Construction Work Zones".[5] Presently, temporary rumble strips are recommended for use in advance of long-term warning signs that alert drivers to changed highway condition. Although, there is no conclusive proof demonstrating their effectiveness in slowing traffic, they do provide audible and tactile warning of roadway changes to inattentive drivers. By alerting drivers, rumble strips have the potential of reducing accidents or intrusions into work zones.

Initially, TR&DB performed a literature search of past and ongoing research and the current practices on the use of rumble strips in work zones. All available literature was reviewed and summarized. The Department's current specifications require that temporary rumble strips be made using removable black preformed pavement marking tape, raised asphalt strips, or saw-cut or milled-in grooves in the pavement surface. Literature search indicated that our current specifications and requirements fall within the accepted practices of other states that use rumble strips in this manner.

Based on the literature search and some preliminary examinations of work zone rumble strips in consultation with the Department's Construction Division, it was decided to further investigate the spacing and thickness of the strips. As part of this investigation, two proprietary products used by contractors and three temporary rumble strips already in use by various DOT maintenance residencies were also examined.

II. SUMMARY OF LITERATURE SEARCH

At the time of the literature search, there were nine states using rumble strips in work zones: Michigan, California, Delaware, Illinois, Pennsylvania, Ohio, Maryland, Indiana, and Kentucky. New Mexico and South Dakota have tested rumble strips in work zones. A portable rumble strip was developed through the Strategic Highway Research Program (SHRP) to be used at low speed work zones. Five of the nine states currently using temporary rumble strips in work zones have either plans or specifications for work zone rumble strips that were available in the reviewed literature. A summary of the specifications for the rumble strips from these 5 states is given below.

California uses either raised (no greater than 0.75" high) or indented strips (no deeper than 1.0") that extend across the full width of the lane. The pattern they use nor the width of the strips were not given but their standard pattern in non-work zones are intermittent distances between 50' to 100' spacing between sets that are 25' long with 3" wide strips. California only allows their use when it is determined that they are a reasonable solution to an identified problem.[10,12]

Illinois uses raised high-strength polycarbonate strips that are 0.5" high and 3.5" wide with a tapered edge towards the approaching traffic. They use 6 strips evenly spaced over 25', placed 200' before each construction sign extending the entire width of the travel lane. The strips have 2 channels running the length of the strip's bottom to act as a reservoir for the adhesive that holds them in place.[10,12]

Pennsylvania uses raised 4" wide asphalt strips that are formed by nailing 0.5" x 4" plywood strips to the pavement and filling with asphalt overlay material. The plywood is then removed and the strips are rolled. These are in sets of 15 or 20 strips spaced 12" apart extending onto the shoulder. The sets are spaced at intermittent distances from 200' between sets 1 and 2, 100' between sets 2, 3, and 4 and 50' between sets 4 and 5 with 6th set (also at 50') used in advance of a detour. A "RUMBLE STRIPS AHEAD" sign is also required.[10,12]

Kentucky uses raised 8" wide asphalt strips. They are placed in sets of 10 that are spaced at varied distances dependent on the speed limit. The strips' height and spacing within the sets is also dependent on the speed. For speeds of 45 mph or less, the strips are 0.25" to 0.38" high at 12" spacing and for speeds greater than 45 mph they are 0.38" to 0.5" high at 24" spacing. They do not require the strips to extend onto the shoulders. Sets were placed at 1.5 mi., 1.0 mi., 0.6 mi., 0.3 mi., and 0.1 mi. before the lane change. Kentucky also recommends, on high speed multi-lane highways such as interstates, the use of "WORK ZONE AHEAD" signs at every mile beginning 5 mi. before the zone when there is a lane closure or detour. Kentucky has also tested hard plastic vinyl strips that are 0.5" high and 4" wide in sets of 8 spaced 24" apart.[10,11,12]

Ohio uses either raised or grooved strips both at a maximum of 0.5" high or deep. The number of strips in a set and the spacing of the groups are both dependent on the speed limit. They use 10 sets with 8 to 16 strips per set. They are placed in groups of 3 sets, 4 sets, and then 3 more sets with the distance between groups of sets varying from 100' to 250' and the distance between sets varying from 35' to 100' dependent on the speed.[10,12]

Indiana uses buzz strips (thermal plastic rumble strips) prior to traffic changes and in high accident areas. They are considered to be successful in getting drivers attention.[14]

New Mexico[12] and South Dakota[12,13] tested AKT temporary rumble strips made by the AKT Corp. of Wisconsin. AKT rumble strips are made of high-strength foamed polycarbonate material that are 3.5" wide and 0.5" high similar to those used in Illinois. These have an additional feature of the tapered approach edge not being smooth but stepped (10 steps) to increase the noise. They were placed in sets of 6 at 10" spacing, 200' before each work zone sign.

A portable rumble strip weighing about 36.4 kg was developed through SHRP. These were tested by several state transportation agencies and found to be most effective when one or two strips were placed in advance of a flagman on lower speed roads. Under high speed high volume traffic the strips tend to creep along with traffic but these were designed to augment the flagman's warning to slow down or stop, under low speed traffic conditions[15].

Most of the studies indicate that rumble strips are most effective when used in conjunction with other traffic control devices and that they do not cause a significant reduction in the traveling speeds but their effectiveness is in alerting drivers of the other devices, lane changes, detours, or other hazardous conditions. Overall, the intermittent spacing of sets and strips were generally determined to be more effective than either regular or logarithmic spacing.

III. CONTRACTOR WORK ZONE RUMBLE STRIPS

Nineteen work zones, with rumble strips installed, were examined. Rumble strips were installed at ten sites in accordance with NYSDOT specifications using multiple layers of temporary pavement marking tape. The Rumbler®[6] was installed at five sites and a rumble strip made from strips of recycled tire treads[7] was installed at one site (See Appendix A for details of these sixteen sites). Three of the sites were maintenance work zones using temporary rumble strips they had developed or were evaluating (See Chapter IV and Appendix B for details). One of these maintenance sites also had tape rumble strips installed. At the five Rumbler® sites, the contractors received permission to use this product. The recycled tire tread rumble strips were used at the request of TR&DB, for evaluation. All the rumble strips were black due to concerns that strips of different colors might confuse motorists or cause them to swerve into the adjacent lane while trying to avoid them or stopping abruptly, thus creating a dangerous situation.

At all sites, the rumble strips were driven over by the author in a 1988 Chevy Suburban, a minimum of three times at the posted speed limit. The windows of the vehicles were kept rolled up during driveovers. Several sites including the two sites where the spacing was varied, one Rumbler® site, and the recycled tire tread strips, were driven over by the author in a 1991 GMC Sonoma small-size pick-up truck, a minimum of three times at the posted speed limits with windows up.

The goal of this investigation was to examine effectiveness of the Departments current standards for rumble strip thickness and spacing and to recommend changes if required. The effectiveness of the strips in terms of noise generated and tactile sensation are the subjective opinions of the author. The other rumble strips were included because these devices were in use and it was convenient to examine them at this time. The examination of the strips for adhesion effectiveness was investigated to address some concerns as to tape adhesion problems but also to provide a comparison of tape strips to the other types of temporary rumble strips.

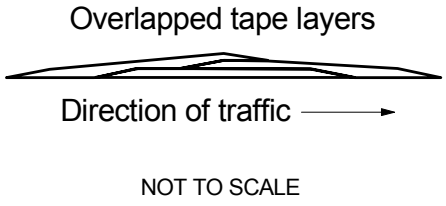
A. Thickness

Thickness was measured by laying a straight edge across the strip. The distance between the bottom of the straight edge and the pavement surface was measured with a 150 mm steel ruler, perpendicular to the pavement surface. The measurements were taken at a minimum of four strips in each set, on both the approach and leave sides of the strips. The measurements were taken at a distance of 150 mm to 200 mm in from the edge of pavement and 37 mm to 50 mm from each edge of the rumble strip, and were then averaged to obtain the thickness for the rumble strip sets.

NYSDOT current specifications require a final compacted thickness of 10 mm ± 3 mm. Eight of the ten sites with tape did not meet current NYSDOT specifications. Three had an average thickness of 4 to 5 mm and the other five had an average thickness of 5 to 6 mm. Only two sites met specifications with the average thickness of 8 to 10 mm.

All sites used a minimum of three layers of black tape placed directly over each other with the following exceptions. The two sites that met specifications used a fourth tape layer. Two of the sites where the average thickness was 4 to 5 mm, the contractor placed two layers of white temporary pavement marking tape with a required black tape top layer. According to the contractor, the reason for this was not having enough black rumble strip tape to place all three layers during installation. This method could create monetary savings as the white strips are less expensive than the black strips as long as the top black layer is maintained and the required thickness can be attained.

At two of the five sites with 5 to 6 mm thickness, the three layers of tape were not placed directly on top of each other (see sketch below). The second layer was placed so approximately ⅓ of the tape overlapped onto the pavement on the leave side of the rumble strip, and ⅓ of top layer overlapped onto the pavement on the approach side of the strip. This increased the overall width of the rumble strip by approximately 100 mm.



The most effective tape rumble strips were the strips between 8 to 10 mm thick. These were noticed both audibly and tactilely. The other sets gave the sensation of riding over pavement joints and were not as loud as the 8 to 10 mm thick rumble strips. The 4 to 5 mm thick strips were not noticeably different from the strips that were 5 to 6 mm thick. The strips that were placed so the layers overlapped seemed slightly more audible than the other strips at 6 mm or less but the tactile sensation was not as pronounced. This can be attributed to the strip tapering up to its high area and than tapering back down.

The Rumbler® is 6.35 mm thick but is as loud as the tape rumble strips at 8 mm to 10 mm thick and has almost the same tactile sensation as tape strips[6].

The recycled tire tread strips are at NYSDOT specified thickness. These are very effective, as least as loud if not louder than either the tape or Rumbler® and with the same tactile sensation as the tape at 8 to 10 mm thick. This site was in an area of high daily commuter traffic and these strips were annoying enough that motorists were slowing and driving on the shoulders to avoid them.

B. Spacing

NYSDOT specifications require six strips evenly spaced 3.0 m apart, across the entire width of the lane(s). Seven tape sites, one Rumbler® site, and the recycled tire tread strip site used the spacing as required by NYSDOT specifications. At four tape sites and four Rumbler® sites, the strips were not spaced as recommended. At two of these tape sites, the strips were placed at varied spacing as per TR&DB's request.

At the first tape site with the requested spacing variations, on US Rte. 20, Nassau, Rensselaer Co., NYSDOT Region 1, rumble strips were only placed at the east end of the work zone. There was an apartment complex at the west end and rumble strips were not installed to avoid disturbing the residents. Three sets of six rumble strips were placed at the east end. The first set was spaced at 3.0 m, the second set spaced at 2.4 m and the third set spaced at 1.8 m, in the direction of traffic. These rumble strips were driven over several times with the two previously mentioned vehicles at the work zone construction speed limit (40 mph). The rumble strips spaced at 1.8 m definitely were more pronounced than either of the other two sets. The sets spaced at 2.4 m and 3.0 m, gave the feel and sound of driving over closely spaced pavement joints while the set spaced at 1.8 m gave a rumbling affect. Another Department employee accompanied the author during the examination of the strips with Chevy Suburban and was in agreement that the strips at 1.8 m were the more pronounced set.

The second tape site at which rumble strips were placed at varied spacing was I-88, Schenectady Co., Region 1. At this location, rumble strips were placed at both ends of the work zone. In the westbound lanes, two sets of six strips and one set of five strips were placed at 2.4 m spacing. On the eastbound side, three sets of six strips were placed at 1.8 m spacing. Both sets were driven over several times with the two previously mentioned vehicles at the posted speed limit of 65 mph. Several Department employees who regularly drive this highway were also questioned about the rumble strips. The consensus was that the strips spaced at 1.8 m (eastbound) were more noticeable than the rumble strips at 2.4 m spacing.

The third tape site at which the tape rumble strips were placed at other than the 3 m spacing was on US Rte. 9, Schroon Lake., Essex Co., Region 1, where the strips were spaced at 1.4 m. There were three sets of six strips in both directions. These were driven over at 45 mph with the two vehicles. At this spacing the set was driven over too quickly and the full effect (both audible and tactile) of the rumble strips was not realized.

The fourth tape site with different spacing was on I-81, Oswego Co., Region 3, where three sets of six rumble strips were placed in both directions. The spacing of the strips varied within each set from 2.4 to 2.7 m. These were driven over at 45 mph. This uneven spacing of the rumble strips took away the feel and sound of driving over regularly spaced pavement joints. This site was also one of the sites that had strips with an average thickness of 8 to 10 mm, which enhanced the effect of the strips.

At four of the five Rumbler® sites, the strips were spaced other than 3.0 m. At one site the spacing was 1.2 m, at two sites the spacing was 0.6 m, and at the fourth site the spacing was 0.45 m. Although the Rumbler® was as loud as the tape, these spacings are too close and they are driven over too quickly to be effective. The close spacing used at four of the five sites diminished the

effectiveness of the Rumbler® strips. The site at which Rumbler® strips were spaced at 1.2 m had an additional problem. The rumble strips were placed on Portland cement concrete exit ramps from a highway that crossed over the work zone. These ramps were in extremely poor condition (cracked, patched, potholes, and faulted joints). It was difficult to distinguish between the rough pavement conditions and the rumble strips.

C. Adhesion

At ten of the eleven tape sites, including a maintenance work zone site where tape was used, the rumble strips were generally in good condition. There was some minor tearing, slight shoving, and short sections missing in a few strips (usually less than a third of a meter in length), all on the upper layer.

One tape site had significant adhesion problems. The majority of strips were either completely or partially missing. More than 50% of the strips were missing when first inspected, and less than 20% remained approx. 7 weeks after first inspection. The Engineer-in-Charge's office was contacted to obtain information about installation and probable causes of the failure of these strips. The information obtained indicated that the strips were installed as per manufacturer's specifications concerning temperature, moisture, and cleaning of the pavement surface. Loss of adhesion and the subsequent removal of the strips by traffic was attributed to the following factors: 1) asphalt cement pavement was quite old and dried out, 2) pavement surface was pitted and rough. 3) high AADT, >25,000 with heavy truck traffic, and 4) strips were placed on a downgrade approaching a lower speed limit zone with a traffic light at the bottom of the downgrade, causing drivers to apply their brakes on the strips.

Of the five sites with the Rumbler®, two sites had initial adhesion problems. At one site, the strips were installed on a cool damp day, when temperatures were below the manufacturer's recommended specifications and moisture was present on the pavement surface. These strips were finally fastened to the pavement with screws to keep them in place. At the time of inspection, after installation of the screws, the strips had lost several 1.3 m sections (the Rumbler® is manufactured in 1.3 m lengths). The remaining strips had numerous rips across strips, gouges in both the approach and leave sides of the sections, and pieces missing from the sections. In several sections, screws had pulled free from the pavement and the sections were flapping with traffic. This site was driven over with both test vehicles.

At the other Rumbler® site with adhesion problems, the strips were installed according to manufacturer's specifications concerning temperature, cleanliness and dryness of pavement surface, etc but an improper adhesive was used. Strips were reinstalled using another epoxy adhesive. At this site after second installation and at the other three sites at which there were no initial adhesion problems, the strips adhered quite well. There were some minor tears and gouges on some strips and an occassional 1.3 m sections were missing. There were no significant problems affecting their overall performance.

The recycled tire tread strips had significant adhesion problems but, being in the developmental stage, the manufacturer was experimenting with different types of tire treads, lengths and widths of strips, adhesives, and the use of primers. Strips were coming loose regularly but the manufacturer was replacing them as requested.

See Appendix A for more detailed information on the field inspection of various sites.

D. Noise

The audible sensation that rumble strips create for motorists can also be an annoyance to nearby residents and businesses. At one site, a set of rumble strips (Rumbler®) was removed in response to numerous complaints. At another site where rumble strips (Rumbler®) were installed directly in front of a home, the resident stated that the strips were quite annoying, especially at night and that he had to keep the windows closed on that side of the house. Tape strips were not installed at the end of one work zone in consideration of the residents of an apartment complex.

IV. MAINTENANCE WORK ZONE RUMBLE STRIPS

Independent of the spacing and thickness examinations of rumble strips, three types of rumble strips used by NYSDOT maintenance forces were examined to determine if they produced enough of an affect to be effective in alerting the driving public of short term maintenance work zones. These were raised asphalt rumble strips, traffic count tubes, and reinforced rubber belting that was screwed to pavement. See Appendix B for details of these rumble strips.

Raised asphalt rumble strips were used on State Rt. 149, Washington Co., Region 1. These strips were made using a plywood form with five slots cut into it. After the slots were filled with hot mix asphalt, the form was removed and the strips were compacted with a hand roller. These rumble strips were quite effective, although not as loud as the tape at proper thickness but provided a good tactile sensation. Their overall effectiveness could be improved with minor modifications. The strips were too close together (212 mm). This could be resolved by cutting only two slots in the plywood and placing the form down three times for a set of six rumble strips. A second set in each direction would have increased their effectiveness, but time, money, and manpower restraints at residencies may not always permit this. These strips could also be made to extend across the entire width of the lane with minor adaptations. But, as long as they span both wheelpaths they should alert drivers of the approaching work zone.

Traffic count tubes were used as rumble strips at a maintenance job on State Rte. 74, Essex Co., Region 1. These rumble strips were quite audible but did not have much feel to them. The effectiveness of these rumble strips could be improved by either increasing the spacing or placing more tubes per set. Either of these changes would provide drivers with a longer audible sensation thus increasing their effectiveness in alerting drivers of the approaching work zone. A second set would also improve the rumble strip effectiveness. As these strips provide a continuing use for traffic count tubes that are due for disposal, these have a monetary savings and are environmentally friendly, as disposal of these old tubes, considered hazardous waste, is delayed.

A Highway Maintenance Supervisor II (HMS-II) at the Columbia Co. maintenance residency in Hudson, Region 8 developed a rumble strip using reinforced rubber belting screwed to the pavement. One set of six strips were installed at a work zone on State Rte. 9H. There were also two sets of six tape rumble strips at the work zone. Initially 1-ply unreinforced rubber belting was used. This created too much flexibility in the rumble strips causing them to pull free of the pavement. They were installed a second time using 2-ply reinforced belting. Originally the reinforced strips were fastened with four to five screws along both the approach and leave edges of the rumble strip. One rumble strip pulled free from the pavement shortly after the second installation. This strip was reinstalled using nine screws along the approach edge of the rumble strip. The approach edges on

the remaining strips were reinforced with an additional four to five screws to insure that they would remain in place. The rumble strips made from the belting were more audible and tactile than the 5 mm thick tape strips. There was a minor problem with some of the screws pulling loose from the pavement. They remained in the holes and did not come free from the reinforced belting. The majority of the screws that came loose were in the wheelpaths. These rumble strips are reusable, less expensive, and quicker to install than tape rumble strips employing a smaller crew but, they probably are not suitable for PCC pavements.

V. OTHER RUMBLE STRIPS

After the initial literature search and during the course of the field investigation, information was obtained on several other types of rumble strips but could not be examined during this study. The following is provided for informational purposes only.

1. ATM (Advanced Traffic Markings) of North Carolina makes ATM Removable Rumble Strips.[8] They are 3 mm thick and 100 mm wide raised plastic strip with polymeric tapes treated with pre-applied adhesive. They can be placed in multiple layers similar to tape and come in three colors (orange, black, and white). The orange strips have been tested in Iowa, Kansas, Missouri, and Nebraska with satisfactory results.

2. Svedala of Hamburg, Germany, produces "Speedblocker"[9], a 2.2 m wide by 2.6 m long, fabric and metal reinforced rubber mat which can be fastened to the pavement by screws. They weigh enough (190 kg) to stay in place for short periods of time without fasteners on low speed/low volume roadways. It has four transverse areas of raised ridges that are 325 mm wide. This has been used mainly in Europe but there is a company in New York State that supplies them (Advanced Technology Concepts of Berne, NY). The Town of Guilderland Highway Dept. placed this product on a local road to test it but had to remove it the next day as drivers were crossing into the opposing lane to avoid them.

3. An HMS-II at the Friendship residency in Allegany Co., Region 6 developed an idea for a mat for use as a rumble strip. This mat is 2 m wide by 1.3 m long with four 100 mm wide ridges across the mat and was initially designed to be heavy enough to remain in place without fasteners. EnvironForm of Geneva, NY was proposing to produce a prototype and for a test in Region 3 if a site could be located. A prototype of the mat was placed at the residency entrance as a preliminary test. It stayed in place quite well at the low speeds of the traffic entering and exiting the residency.

VI. CONCLUSIONS

Use of rumble strips at work zones is effective and should be continued. The 8 to 10 mm thick tape, recycled tire tread strips, and the Rumbler® performed similar. The current requirements for 10 mm ± 3 mm of final compacted tape thickness is adequate as long as they are placed according to specifications. The Rumbler®, although thinner than required by Department specifications, creates significant sensory input to produce the desired effect. When tape is used, the layers should be placed directly over each other to provide the proper thickness over the widest area and to eliminate the tapering at approach and leave edges which reduces performance. Comparison of similarly spaced sets of rumble strips show that the Rumbler® is a viable alternative to tape rumble strips if used at the proper spacing, under proper conditions. The recycled tire tread strips is also an effective alternative, if the adhesion problem can be resolved. Both strips also have the advantage of potentially being reuseable. The recycled tire tread strips have the added benefit of providing a use for old tires.

Rumble strips in use by the various residencies are sufficient to provide the results required for the usual short duration on most maintenance jobs. The minor modifications mentioned in their discussion would enhance the capabilities of the rumble strips to alert motorists to the approaching work zone and thus provide an added degree of safety to both motorists and workers.

VII. RECOMMENDATIONS

Sound engineering judgement should be used before placing rumble strips to ensure that they are necessary, will be effective, and are properly installed. Care should also be taken in choosing their location to minimize the disturbance to residents and businesses near the work zone area.

Based on the literature search and field examination of rumble strips the following are recommended:

1. Rumble strips of 10 mm thickness ± 3 mm should be in sets of six strips spaced at no more than 2.7 m apart and preferably at irregular intervals with the spacing determined by the speed limit. A spacing of 1.8 m to 2.4 m between strips should be used when the speed limit is below 50 mph and 2.1 m to 2.7 m spacing when the speed limit is 50 mph or greater. The irregular spacing of individual strips will eliminate the regular beat and feel of pavement joints. The wider spacing will provide drivers of vehicles at the higher speed limits sufficient time to realize an upcoming change in driving conditions.

2. The installation of rumble strips shall closely follow the specifications (either the Department's or the manufacturer's) for both air and pavement temperatures, presence of moisture, cleaning of pavement, and method of adhesion to survive the anticipated duration in service.

3. Rumble strips should only be used where audible and tactile warnings are necessary for the safety of exposed workers or drivers. Some examples include a detour, lane splits, exit only lanes, one lane traffic with a stop light ahead, major reduction in the speed limit, and varying traffic patterns.

4. EI 96-001 should be rewritten to include a provision to permit the use of rumbles strip types other than the 4 types currently specified.

5. A study should be initiated to quantitatively document the durability, ease of installation and removal, effects on the pavement surface after removal, and installation and maintenance costs of rumble strips for both long term and short tem applications.

ACKNOWLEDGMENTS

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APPENDIX A: FIELD NOTES AND COMMENTS ON RUMBLE STRIPS USED BY CONTRACTORS

FIELD TRIPS TO EXAMINE TEMPORARY RUMBLE STRIPS
AT CONTRACTOR WORK ZONES

Conventional (Tape):

Rt. 20, Rensselaer Co., Reg. 1

EB only(AC)(Posted limits - 55 reduced to 40 mph by 3rd set)(sets numbered in direction of traffic)

1st set - 6 strips @ 3.0 m spacing, ave. thickness 5 - 6 mm
2nd set - 6 strips @ 2.4 m spacing, ave. thickness 5 - 6 mm
3rd set - 6 strips @ 1.8 m spacing, ave. thickness 5 - 6 mm

Comments: Drove over all 3 sets several times with a Chevy Suburban and a GMC Sonoma pick-up. Not much difference between the 2.4 m and 3.0 m spaced strips. Felt and sounded like driving over pavement joints. Definite difference with the 1.8 m spaced strips. Felt and sounded more like rumble strips. They were all more pronounced in the suburban than in the S-10 pick-up. No noticeable problems with adhesion or rips. Only in place for approx. 1 week when 1st examined.

I88, Schenectady Co., Reg. 1 (PCC)(Posted limits - 65 reduced to 45 mph by 3rd set)

EB - 3 sets of 6 strips @ 1.8 m spacing, average thickness 5 - 6 mm
WB - 2 sets of 6 strips @ 2.4 m spacing, average thickness 5 - 6 mm
1 set of 5 strips @ 2.4 m spacing, average thickness 5 - 6 mm

Comments: Drove over each set with both the Chevy Suburban and the GMC Sonoma pick-up. The strips @ 1.8 m spacing were definitely more noticeable both audibly and tactilely driving over them with either vehicle and audibly sitting next to them. No noticeable problems with rips or shoving but these had only been in place for approx. 1 week when first examined.

Rt. 85, Albany Co., Reg. 1

SB (PCC)(Posted limits - 55 reduced to 45 mph by 3rd set) - 3 sets of 6 strips @ 3.0 m spacing, 1st set ave. thickness 10 mm, other 2 sets ave. thickness 8 mm.
NB (AC, 55 to 45 mph) - 1 set of 6 strips @ 3.0 m spacing, ave. thickness 8 mm.

Comments. 4 layers of tape instead of 3 layers. These are definitely rumble strips, felt and heard these. These felt and sounded great. Generally in good condition, couple of minor rips and some shoving of top layer of tape.

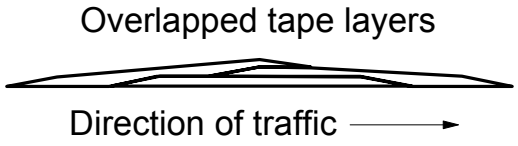
I87, Warren Co., Reg.1 (near marker 1240)

NB (AC)(Posted limits - 65 reduced to 45 mph) - 3 sets of 6 strips @ 3.0 m spacing, 1st and 3rd sets ave. thickness 5 mm, 2nd set ave. thickness 6 mm.

SB (AC)(Posted limits - 65 reduced to 45 mph) - 3 sets of 6 strips @ 3.0 m spacing, ave. thickness 5 - 6 mm.

Comments: The 3 layers of tape were not placed directly on top of each other (see diagram below). The 2nd layer was offset approx. 1/3 of its width in the direction of traffic, and the 3rd layer was offset approx. 1/3 its width against traffic. This caused only about 1/3 of the 3 strips to completely overlap but also all 3 strips had some part in contact with the pavement surface. This increased the overall width of the rumble strip by approx. 100 mm. Gave the strips a tapered approach and leave. Overall these were holding up quite well. Only one small piece missing in one strip about 0.3 m long and one rip in another strip. Both in the 3rd set NB.

Diagram of tape placement



NOT TO SCALE

I87, Warren Co., Reg. 1 (near marker 1340)

NB (AC)(Posted limits - 65 reduced to 45 mph) - 3 sets of 6 strips @ 3.0 m spacing, ave. thickness 5 - 6 mm.

SB (AC)(Posted limits - 65 reduced to 45 mph) - 3 sets of 6 strips @ 3.0 m spacing, ave. thickness 5 - 6 mm.

Comments: These strips are placed in the same manner as the previous job, each layer offset. All these strips are in excellent condition. This type of placement of the layers seems to make the strips slightly more audible than strips of the same thickness where the layers are placed directly over each other but still not as audible as the 8 to10 mm thick strips. This placement doesn't seem to improve the feel of them, if anything it lessens the feel slightly. All strips are in good condition, no rips, shoving, or missing pieces.

I87, Clinton Co., Reg. 7 (near marker 1069)

NB only (AC)(Posted limits - 65 reduced to 55 mph) - 3 sets of 6 strips @ 3.0 m spacing, ave. thickness 1st & 3rd sets was 4 mm, 2nd set was 5 mm.

Comments. 3 layers placed directly on top of each other, hardly felt or heard any of these at either speed. In good condition, one small rip in one strip

I87, Essex Co., Reg. 1, (near marker 1200)

SB (AC)(Posted limits - 65 reduced to 55 mph) - 3 sets of 6 strips @ 3.0 m spacing, ave. thickness 4 - 5 mm.

NB (AC)(Posted limits - 65 reduced to 55 mph) - 3 sets of 6 strips @ 3.0 m spacing, ave. thickness 4 - 5 mm.

Comments: 3 layers directly on top of each other, hardly felt or heard these either. Contractor didn't use 3 layers of the black tape. For the bottom 2 layers he used temporary white construction tape. Talked to someone from the contractor's office about this. He stated that originally it was done because they didn't have enough of the black tape and he was able to get the required thickness using the white tape. I asked if he had saved money doing it this way and he said yes. These were holding up just as well as any of the other ones, some small rips, nothing larger than 152.4 mm

Rt. 9, Essex & Warren Co., Reg. 1, (south of Schroon LK.)

SB (PCC)(Posted limit - 45 mph) - 3 sets of 6 strips @ 1.4 m spacing, ave. thickness 4 mm

NB (PCC)(Posted limits - 55 reduced to 45 mph) - 3 sets of 6 strips @ 1.4 m spacing, ave. thickness 5 mm

Comments: Same as the previous I87 job in Essex Co., 2 layers of white tape topped with 1 layer of black tape. Felt these some but still hardly heard them. Too close together. In good condition.

I81, Oswego Co., Reg. 3

NB (AC)(Posted limit - 45 mph) - 2 sets of 5 strips and 1 set of 6 strips @ 2.4 m to 2.7 m spacing (irregular, some 2.4 m, some 2.7 m, some in between 2.4 m & 2.7 m). The 2 sets of 5 may have originally been sets of 6. It appeared that there used to be a 6th strip and the lay-out marks called for a 6th strip. Strips are in DL only, to warn the driving public that this lane is exit only, thru traffic keep to the left 2 lanes.

SB (AC)(Posted limit - 45 mph) - 3 sets of 6 strips @ 2.4 m to 2.7 m spacing (same irregular spacing as NB). Across DL and CL, the passing lane is closed off. Used to warn the drivers that the 2 lanes split ahead and cars exiting should keep right.

All strips were 4 layers of tape directly on top of each other with an average thickness of 10 mm.

Comments: These are, in my opinion, the perfect use of temporary rumble strips in a work zone. They are the right thickness - 10 mm - you feel and hear them great. The slightly irregular spacing adds to their effect in that it gives them a slightly irregular beat so you don't think you have driven over pavement joints. They are there for the right purpose, to warn the driving public that there is something out of the ordinary in this work zone not just a lane closure or a work zone but something unusual, (right lane exit only NB and the 2 lanes splitting SB).

Rt. 17, Chemung Co., Reg. 6, (East of Elmira)

Comments: Drove over these on trip between sites for another project in Corning and Binghamton and noticed that numerous strips (seemed like near 50%) were missing. E-mail was received from the Reg. 6 Traffic Engineer relating that they had problems with the tape adhering. The EIC's office was contacted and either someone from there or the contractor's office returned the call. He said that they were placed under the proper conditions, on a warm dry day in May. He thought it was a combination of factors that caused their failure (only about 20% remain at this time). These factors are as follows: 1. The pavement surface is quite rough. 2. The AC pavement is old and dried out. 3. High AADT, >25,000 with heavy truck traffic. 4. Placed on a downhill slope with a stop light and change of speed limit at the bottom, so there is a lot of braking. These are the only conventional temporary rumble strips that I drove over this summer where I noticed any major problems.

<u>Rumbler®</u>

The Rumbler® is a proprietary product made of reinforced rubber that is glued to the pavement, supposedly reusable. It is 152 mm wide, and 6.35 mm thick with tapered edges and two 38 mm wide grooves running its length that are 3.8 mm deep. They come in 1.2 m long sections so it takes 3 sections to cross a lane. This is definitely louder than 5 mm of tape. 5 work zones on which this product was being used as rumble strips were examined.

Rt.5, Herkimer Co., Reg. 2.

WB (AC)(Posted limit - 55 mph) - 3 sets of 6 strips @ 3.0 m spacing. There were problems with these. All sets had to screwed down (3 or 4 screws per section) and pieces were missing.

Set 1: Strip 1: Missing ≈0.45 m in outer wheelpath (OWP) - Driving Lane (DL) with 1 screw pulled up. Also a diagonal rip @ centerline (℄) edge of inner wheelpath (IWP) - DL
Strip 2: diagonal rip @ ℄ edge of IWP - DL
Strip 5 Missing ≈0.45 m in IWP - DL with 1 screw pulled up

Set 2: Strip 1: Diagonal rips each side OWP - DL and missing from ℄ of IWP to Center of lane - Passing lane (PL) ≈0.75 m
Strip 2: Diagonal rips each side OWP - DL
Strip 3: Diagonal rips each side OWP - DL
Strip 4: Missing entire DL strip.
Strip 5: Diagonal rip ≈0.3 m from ℄ road - DL

Strip 6: Leave edge of sections @ Edge of pavement (EP) and center of lane starting to split - DL, and leave edge of section @ center of road starting to split - PL

Set 3: Strip 1: Diagonal rip ℄ edge OWP -DL

Strip 2: Leave edge of section @ EP starting to split, center section ≈ ½ leave edge missing, section @ ℄ of road entire leave edge missing with screw missing - staring to flap w/ traffic - DL

Strip 3: All DL missing & center section missing - PL

Strip 4: Leave edge of section @ EP starting to split, diagonal rip @ ℄ of center section, section @ ℄ road ½ leave edge missing - DL

Strip 5: Diagonal rip @ ℄ of center section, section @ ℄ road ≈ ½ leave edge missing with screw missing - starting to flap with traffic - DL

Strip 6: Center section ≈ ½ leave edge missing - DL and center section missing ≈0.45 m @ OWP edge - PL

Comments: Both the EIC and a construction supervisor were interviewed. The EIC said they were placed near the end of April on a cool damp day (4 - 7°C). Lost some the 1st day. These are placed in 55 mph zone on a downhill curve just west of a 35 mph zone with traffic lights. So drivers are speeding up after the low speed zone. May have held better if installed on a better day in a different location but had no choice of either. He thought they are quite effective when the work was being performed at that end of the project. The farther the work area was from the rumble strips, the less the effect, the drivers seem to have forgotten about them. The construction supervisor generally agreed with the EIC. Screws were put in shortly after installation because they were not adhering. Tried some of his own epoxy before the screws, they still didn't hold.

Rt. 265, Niagara Co., Reg. 5

NB Rt. 265, (AC)(Posted limit - 55 mph) 2 sets of 6 strips @ 0.6 m spacing, all holding well.

SB Rt. 265, (AC)(Posted limit - 55 mph) 1 set of 6 strips @ 0.6 m spacing, all holding well.

WB upper Mountain Rd., (AC)(Posted limit - 40 mph) 1 set of 6 strips @ 0.6 m spacing, all holding well.

EB Ramp from I90, (PCC)(Posted limits - 55 reduced to 35 mph) 2 sets of 6 strips @ 0.6 m spacing,

1st set: missing center section of 1st strip in DL

2nd set: all holding well.

Rt. 265 is reasonably new AC pavement, in good condition

Upper Mountain Rd. is an older AC pavement with potholes, cracks and aggregate missing.

I90 ramp is a PCC pavement with some cracks.

Comments: Talked to EIC and a homeowner near 2nd set NB Rt. 265. EIC said they went down well and have had no trouble with them. Placed in June on a warm dry day. Contractor didn't want the expense of the tape. Homeowner whose house was directly across from one set said they were quite annoying at first but they got used to them. Keeps windows closed on that side of the house at night.

There is a work zone south of here on Rt. 265 that has tape rumble strips @ 3.0 m spacing. The Rumbler® strips are definitely more noticeable, both audibly and tactilely, but you drive over them so quickly because of the 0.6 m spacing and the limited sets in each direction, they don't seem to register as well as the tape rumble strips.

Rt. 219, Hamburg/Boston/Rt. 391 Exit, Erie Co., Reg. 5

NB (PCC)(Posted limits - 55 reduced to 45 mph): 3 sets of 6 strips @ 0.3 m - 0.45 m spacing, 2nd time placed

1st set: 1st 2 strips have approx. a 51 mm x 102.5 mm gouge @ IWP end of center section, DL

2nd set: missing center section of 1st strip, DL

3rd set: 4th strip has approx. a 51 mm x 102.5 mm gouge @ IWP end of center section, DL

SB (ACC)(Posted limits - 55 reduced to 45 mph): 3 sets of 6 strips @ 0.3 m - 0.45 m spacing

1st set: missing center section 1st strip, DL

Missing OWP section 4th strip, PL

Missing IWP section 5th strip, PL

Missing entire 6th strip, PL

2nd set: Generally in good condition - couple of minor rips

3rd set: Missing IWP section of 1st & 6th strips, DL

Comments: Talked to EIC. Originally placed in April, above manufacturer's specifications for temperature and dampness. They had to be replaced because they didn't use the proper adhesive originally. He thinks they are too close together, drivers go over them so quickly, they don't really register.

Rt. 79, Hamburg, Erie Co., Reg. 5, On 2 ramps from Rt. 5.

EB exit ramp (PCC)(Posted limit - 30 mph): 2 sets of 3 strips @ 1.2 m spacing, holding well.

WB exit ramp (PCC)(Posted limit - 30 mph): 2 sets of 3 strips @ 1.2 m spacing, missing IWP section of 1st strip, 1st set, DL otherwise holding well.

Comments: Placed in late June on a warm dry day. Useless because the ramps are so rough. Hardly could differentiate between them and all the cracking and patching that was on the ramps. Could hear them quite well when standing on the shoulder to examine them.

Rt. 17, Binghamton, Broome Co., Reg. 9

EB (AC)(Posted limit - 55 mph): 3 sets of 6 strips @ 0.6 m spacing, all holding well.

WB (Posted limit - 55 mph):

1st set of 5 strips @ 0.6 m spacing on AC across center and passing lanes only. Missing OWP section of strips 3 & 4 CL, there is deep rutting in this area. Rest are holding well.

2nd set of 6 strips @ 0.6 m spacing on PCC across CL & PL only. All holding well.

3rd set of 6 strips @ 0.6 m spacing on PCC across all 3 lanes. All holding well.

Comments: Talked with EIC a few weeks later over the telephone. They removed the 1st set EB because of numerous complaints about the noise. Placed in June on a warm sunny day. No problems with installation or performance.

IRC's Rumble Strip

These strips are made from strips of used tire treads. The rumble strips come in lengths of 1.0, 1.3, 1.65, and 2.0 m, widths of 100 or 150 mm, and are 10 to 12 mm high. The adhesive is a pressure sensitive, double sided foam tape, 3 mm thick made by 3M. The strips can be placed with or without primer applied prior to placement.

These strips were originally placed at the State Office Bldg. Campus in Albany to demonstrate ease of installation and removal. 6 strips (3 - 1.33 m long and 3 - 2.0 m long) were placed in 2 rows across an entrance to a delivery dock and state vehicle parking area. 3 of the strips were placed using the primer and 3 without. 1 row of strips was placed over pavement with no cracking and the other over pavement that was cracked rather badly. These were left in place for 60 days. All strips were still in place at this time, although one strip had approx. 50% not adhering to the pavement and 2 other strips had minor areas (< 150 mm wide not adhering). All the strips that had adhesion problems were the strips on which primer was used. Also these are the strips that left epoxy on the pavement when removed. All strips pulled up easily with no visible damage to the pavement surface.

The next experimental installation was on Rt. 366, Ithaca in July 2002, at both ends of a bridge reconstruction job. The west end of the job 2 set of strips were within Ithaca city limits and the 3rd set was on state highway. The 3 sets on the east end were on the state highway near the entrance of Cornell Univ. IRC (Interstate Recycling Corp.) was trying a variety of adhesives and lengths of strips at this site. A crew of 6 installed over 125 m in ≈ 90 min. IRC personnel returned several times to replace strips that had come loose over the duration of the construction season. Inspected these in September for 1st time. East end of job on all the strips were adhering except one section of strip in the 3rd set. On the west end, on the city street several sections of strips were loose and one section was missing. The strips were being pushed into the pavement in some areas almost to the thickness of the strip. The set on the state highway had small sections of strips loose but none missing.

Returned in November to observe their removal. Several section and strips were missing. All remaining strips came up easily, leaving minor amounts of epoxy residue and causing no visible damage to the pavement surface other than the depressions caused by them being pushed into the surface especially on the city street, although there was some minor depressions at the sets on the state highway but nothing that seem to be an apparent hazard to the driving public.

Comments: Drove over both sets with a full-size pick-up and a small-size pick-up. Felt and heard these quite well. If the manufacturer solves the adhesion problem than these are an excellent use of recycled tires especially if they can be re-used more than once.

Talked with the EIC and a contractor representative, they were quite pleased with the performance of the strips. Noticeable both audibly and tactilely. Stated that there was a good deal of commuter traffic on the job and the drivers would go onto the shoulder at the east end to avoid them. The EIC drove a motorcycle and stated that he thought these were better to drive across with the bike than tape strips. It was their opinion that the strips on the west end on the city street were being depressed into the pavement due to the apparent low large aggregate content of the mix.

APPENDIX B: FIELD NOTES AND COMMENTS ON RUMBLE STRIPS USED BY NYSDOT MAINTENANCE FORCES

FIELD TRIPS TO EXAMINE MAINTENANCE USED RUMBLE STRIPS

Three different types of temporary rumble strips being used by different maintenance residencies were examined.

Used traffic count tubes

Rt 74, Essex Co., Reg.1. Talked with Jack McGuire, Essex Co. Resident Engineer. He first tested them in the residency's yard and they seem to work. Placed them on 2 different maintenance jobs. At first job they were spaced @ 0.3 m, these were too close together the driving public didn't notice them. At 2nd job, they were placed @ 0.9 m apart much more effective. Both jobs lasted approximately 2 weeks and experienced no problems with pull-outs, besides they were there working every weekday so if any did come loose they could repair them.

Examined a 3rd job where 2 sets of 6 tubes @ 0.6 m spacing were placed, one set @ each end of the work zone. These were quite noticeable audibly but they didn't have much of a feel to them. They are not spaced far enough apart but increasing the spacing probably won't improve the feel of them. A second set in each direction would be helpful and more tubes per set would expand the duration of the noise. These are an effective type for short term work on lower volume roads.

Raised asphalt strips

Rt. 149, Washington Co. Three sets were placed, two westbound (one at start of job and second near middle of job before a curve and one eastbound. Placed using a 16 mm thick sheet of plywood with 2.5 m long by 88 mm wide slots cut into it. 5 strips @ 212 mm spacing. The form is placed on the lane and the slots are filled with either hot or cold patch asphalt cement. The form is removed and the strip hand rolled. Rt. 149 only has 3.0 m lanes so the 2.5 m long strips cover both wheelpaths and the majority of the lanes. They are quite noticeable but they would be more effective if they could be spaced farther apart and a 2nd set was used in each direction. These could also be made to extend across the entire width of the lane with minor adaptions.

Screwed down reinforced two-ply rubber belting

Rt. 9H, Columbia Co. 1 set of 6 strips @ 3.0 m spacing, 9.5 mm thick. Screwed down with 9 screws on the approach side and 4 to 5 screws on the leave side of each strip. Originally placed using one-ply rubber belting and with 4 or 5 screws per edge. The one-ply belting wasn't stiff enough and pulled free from the pavement easily. The 4 to 5 screws on the approach edge were not enough even with the 2-ply belting. It left too mech area free to create movement in the belt which created pressure on the screws causing them to pull free. After fastening them with 9 screws on the approach edge there were minor problems with screws pulling free from the pavement but they did

not come loose from the strips and remained in the pavement holes. There were also 2 sets of 6 tape strips @ 3.0 m spacing with an average thickness of 5 - 6 mm. The rubber belting was definitely louder and you felt them more than the tape strips. Quicker to install than the tape, 0.5 hrs. compared to 1.5 hrs. for the tape with a crew of less workers.