RUMBLE STRIP GAP STUDY

Final Report

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EXECUTIVE SUMMARY

Rumble strips can offer significant reductions in run-off-road crashes on rural highways. Newer ground-in rumble strip designs can be installed on a much wider variety of shoulders, but these new designs have a much greater negative effect on bicycle traffic than previous designs.

This study investigated the feasibility of placing gaps in a rumble strip pattern to permit bicycle traffic to cross the rumble strip area without striking the rumble strip pattern itself. This study also determined a recommended minimum length for these gaps to accommodate bicyclists of varying abilities at speeds representative of downhill conditions.

Based on the experimental information collected, this study recommends that rumble strips on all non-controlled access highways include periodic gaps of 12 ft (3.7 m) in length, and that these gaps be placed at periodic intervals at a recommended spacing of 40 ft (12.2 m) or 60 ft (18.3 m).

INTRODUCTION

PURPOSE

This study was initiated to determine the optimum length for gaps in continuous shoulder rumble strips to allow bicyclists traveling on the roadway or shoulder to cross the rumble strip without having to enter the rumble strip pattern.

SHOULDER RUMBLE STRIP HISTORY

Many states have installed longitudinal rumble strips on the shoulders of rural highways. These rumble strips have been shown to have a significant effect on drowsy or inattentive drivers, and have effected reductions of up to 80% in the run-off-road crash rate on some rural highways(1).

In the past, many of these rumble strips were created by placing a special roller on the shoulder during the asphalt concrete paving process, creating a pattern of small indentations approximately 1 to 2.5 in (25-63 mm) long by 1 in (25 mm) deep by 2-3 ft (600-900 mm) wide on 8-12 in (200-300 mm) centers(**1**). This is what is described by many as a "tractor-tread" type rumble strip.

These rumble strips were effective in reducing run-off-road crashes, but were limited in application due to the inability to place them except during the initial placement of the shoulder surface. Another problem associated with this type of rumble strip occurred when the roller did not track straight along the roadway edge line. This caused the rumble strip pattern to displace laterally across the shoulder, sometimes completely to the far edge of the shoulder.

While these rumble strips were not considered enjoyable to operate a bicycle on, they did not cause any significant vertical motion or instability of the bicycle. This is because bicycle wheels rode over the tops of the indentations without dropping completely into the grooves.

NEW RUMBLE STRIP DESIGN AND ITS EFFECT ON BICYCLES

Due to the limitations inherent in the rolled rumble strip design, many states, including Arizona, have begun evaluating the use of a new type of longitudinal shoulder rumble strip. This rumble strip consists of grinding 1/2 in (13 mm) deep by 7 in (180 mm) long cylindrical grooves in the pavement on approximately 1 ft (300 mm) centers(**2**). These rumble strips can be installed at any time, on any width shoulder, and on any type of pavement surface.

Because of this ease of installation, economical cost, and significant potential to reduce run-off-road crashes, ADOT began to install this new type of rumble strip on state highways on an interim basis.

Soon after the installation of these rumble strips in certain areas, bicyclists complained to ADOT that these strips had a much more severe effect on bicycle handing and comfort than the previous design.

The reason these new rumble strips have a much greater negative effect on bicyclists is due to the fact that the wheels of a bicycle riding upon the rumble strip drop completely into every groove of the rumble strip. This induces 1/2 in (13 mm) of vertical motion for every 12 in (300 mm) of forward motion of the bicycle.

The vast majority of bicycles operated on streets and highways do not have any sort of suspension or shock absorption, except that provided by the tires, saddle, handle grips, and the rider themselves. Because of this, vertical displacements on the roadway have a much more severe effect on bicycles than on cars, trucks, or motorcycles.

Due to these concerns, means of mitigating this negative effect of the rumble strip on bicycle traffic were considered.

At first, it was thought that changing the spacing of the individual grooves might have some beneficial effect, as the bicycle's wheelbase could be interacting with the groove spacing to magnify the vertical motion of the bicycle. A further analysis of this concept showed that the primary problem was the vertical motion of the bicycle itself, and not necessarily with the location or period of the motion.

Another suggestion was to reduce the depth of the rumble strip grooving to 3/8 in (10 mm) to reduce the vertical motion associated with the grooving. However, field evaluations of ground-in rumble strip installations of this type by others(**3**) have indicated that this reduction in depth has little effect on bicyclist comfort and handling.

Therefore, a better solution would be to create a rumble strip design containing periodic gaps in the rumble strip grooving pattern. This would satisfy the need for bicyclists to cross the rumble strip pattern without entering the grooved area.

These gaps would need to be sufficiently long so as to permit a typical bicyclist to cross the gap without entering the grooved area, but not so long as to permit a vehicle tire at a typical run-off-road angle of departure to cross the gap without entering the grooved area.

It should be noted that placing gaps in rumble strips will serve only to improve opportunities for bicyclists to comfortably cross the rumble strip. If the rumble strip itself is placed in a location where it is near the expected wheel path of bicyclists, such as on a narrow shoulder, then placing gaps in the rumble strip will provide little benefit to bicycle travel. If the bicyclist rides on shoulders where the rumble strip is concurrent with their typical wheel path, then it is likely that the bicyclist will enter the rumble strip pattern during normal operation. In these cases, it is important that the roadway and/or shoulder provide adequate travel space for bicyclists without encroachment by the rumble strip pattern.

DO BICYCLISTS NEED TO CROSS RUMBLE STRIPS?

A question was raised as to whether bicyclists needed to cross a rumble strip in the first place. There is a perception among many that bicyclists do not need to leave the shoulder, or are invariably safer upon the shoulder. This is incorrect for a number of reasons.

First, bicyclists on all roadways in Arizona other than controlled-access freeways have the legal right to operate within the rightmost lane, regardless of the presence of a shoulder. Second, shoulders frequently contain obstacles and obstructions, such as parked vehicles, sand and gravel, broken glass, and other debris. Finally, at right turn lanes, it significantly reduces the potential for collisions when the bicyclist rides to the left of the right turn lane, and not on a shoulder to the right of a turn lane.

SELECTION OF TEST SPEED

ADOT intends to install this new style of shoulder rumble strip on most rural state highways that have sufficient shoulder width. Many of these highways have downgrades of 5 to 6 percent or more.

When designing specifically for bicycle traffic, AASHTO generally recommends the use of a 20 mph (32 km/h) design speed. However, bicyclists can easily reach speeds at or above 25 mph (40 km/h) on these downgrades. So, any gap in a rumble strip on downgrades should be designed to accommodate a bicyclist traveling at such a speed. Since such a gap length will also accommodate bicyclists at lower speeds, this length should be serviceable for all locations, and for the sake of uniformity, the adopted rumble strip pattern should use this gap in all locations open to bicycle travel.

TESTING METHODOLOGY

DESCRIPTION OF TEST

The testing was performed on March 27-28, 1999. The weather conditions were sunny and warm, with no adverse conditions.

The test site was set up on a residential street in Phoenix, Arizona. The pavement condition was excellent, with no visible cracks, rutting or other deformities. The roadway had been recently swept and cleaned.

The rumble strip test was placed at the end of a moderate downgrade so bicyclists entering the test area would typically be traveling at speeds between 23-28 mph (37-45 km/h) or above. The area immediately preceding the test area, as well as the test area, had no geometric or sight restrictions that could affect the test results.

Raised pavement markers placed in a 12 in (300 mm) wide pattern were used to simulate a rumble strip and gap installation. These markers could be moved easily to vary the length of the gap for testing.

This simulated rumble strip was placed at a distance of 4 ft (1.2 m) from the right side gutter pan edge.

Spot speeds were measured with a calibrated radar gun as the subjects entered the rumble strip test area.

Two video cameras were used to record and verify the results of the tests, and to provide a visual record of the evaluation.

TEST SUBJECTS

A total of 28 test subjects of varying skill levels participated in this study.

The subjects were recruited from local bicycle rides that traveled through the area during the days of the testing, with some prior coordination with the ride leaders.

5 (18%) of the subjects could be classified as "basic" type bicyclists(4), while 17 (61%) could be classified as "skilled" bicyclists. 6 (21%) of the subjects could be classified as "skilled and experienced" bicyclists.

While this cross section of bicyclists may not be fully representative of the entire cycling population, it could be considered to be representative of the population of bicyclists that typically ride on rural state highways, where rumble strips of this type are often installed.

TESTING

The test subjects were instructed to ride toward the test area at as high a speed as possible from a location approximately 1000 ft (300 m) uphill from the test site. The subjects were instructed to maintain a 15-20 second separation between each other (with the exception of one run) in order to minimize interference with one another.

The first test sequence evaluated a wide range of gap spacings in order to focus on a smaller set of spacings for further study.

A group of four bicyclists of moderate to high skill levels (Group 1) tested a variety of gap spacings. Each bicyclist made two runs at a 20 ft (6.1 m) gap spacing, then each bicyclist made one run each at 18 ft (5.5 m), 16 ft (4.9 m), 14 ft (4.3 m), 12 ft (3.7 m), and 10 ft (3.0 m) spacings. The bicycles in this group consisted of one cruiser-type bike and three road bicycles. The speeds for this first group of tests ranged from 20-28 mph (32-45 km/h), with an average speed for the entire test of 24.9 mph (40.1 km/h).

Run	Gap	Avg. Speed - mph (km/h)
1-1	20 ft	22.3 (35.9)
1-2	20 ft	25.5 (41.0)
1-3	18 ft	25.8 (41.4)
1-4	16 ft	25.8 (41.4)
1-5	14 ft	25.0 (40.2)
1-6	12 ft	25.0 (40.2)
1-7	10 ft	24.5 (39.4)

100% of the subjects cleared all tested distances without striking the rumble strip. The test subjects expressed no difficulty with clearing the gap lengths at all distances down to 12 ft (3.7 m), but some of the subjects did state that the 10 ft gap seemed "rather tight" for the test speeds.

Since 100% of the test subjects consistently cleared all the measured gaps at speeds in the vicinity of 25 mph (40 km/h) down to a distance of 10 ft (3.0 m), the spacings ranging from 20 to 14 ft were rejected. The 10 and 12 ft (3.0 and 3.7 m) gap spacings were selected for further study.

The second test sequence utilized a larger number of test subjects to evaluate the 10 and 12 ft (3.0 and 3.7 m) gap spacings in order to determine which of these would be the optimum spacing for general use.

Four different groups of bicyclists tested these spacings.

A group of 8 bicyclists of moderate to high skill levels (Group 2a) tested the 12 ft (3.7 m) and 10 ft (3.0 m) gaps, making one run each at each spacing. The bicycles in this group consisted of all road and racing bicycles. The speeds for this group of tests ranged from 24-31 mph (km/h), with an average speed for the entire test of 27.7

mph (44.6 km/h).

Run	Gap	Avg. Speed - mph (km/h)
2a-1	12 ft	27.4 (44.1)
2a-2	10 ft	28.0 (45.1)

100% of the subjects cleared both distances without striking the rumble strip. This group of test subjects expressed no difficulty with the 12 ft (3.7 m) gap length, but some of the subjects stated that they perceived the 10 ft gap to be "too tight" for "real-world" conditions.

A group of 7 bicyclists of basic to moderate skill levels (Group 2b) then tested a 10 ft (3.0 m) gap, making one run each. The bicycles in this group consisted of one mountain bike and six road bicycles.

Run	Gap	Avg. Speed - mph (km/h)
2b-1	10 ft	24.5 (39.4)

86% of the subjects cleared this distance without striking the rumble strip, with one subject failing to move to cross the strip.

The two groups listed above were then instructed to ride through the test area in small groups of 2 to 4 bicyclists. This was to evaluate whether cycling in a group had a significant effect on the ability to cross the rumble strip. Based on the concerns expressed by some of the group during the 10 ft (3.0 m) test, the gap spacing was set at 12 ft (3.7 m).

Run	Gap	Avg. Speed - mph (km/h)
2ab-1	12 ft	26.3 (42.3)

After this run, the subjects noted that bicyclists in the back of a group could not clearly see the location of the gap in the rumble strip, but could obtain visual cues to the location of the gap from the motions of the other subjects in the group. This was verified in a review of the videotape. The net effect of this was that 100% the bicyclists in all these groups were able to cross the gap without striking the rumble strip.

A group of 6 bicyclists of basic to moderate skill levels (Group 3) tested the 12 ft (3.7 m) gap, making two runs each.

Run	Gap	Avg. Speed - mph (km/h)
3-1	12 ft	20.2 (32.4)
3-2	12 ft	19.0 (30.6)

100% of the subjects cleared both distances without striking the rumble strip. After testing the 12 ft (3.7 m) gap twice, this group of test subjects refused to test a 10 ft (3.0 m) gap spacing, stating that they felt uncomfortable in testing any gap smaller than the one recently tested.

A group of 2 bicyclists of moderate skill level (Group 4) tested the 12 ft (3.7 m) gap, making two runs each.

Run	Gap	Avg. Speed - mph (km/h)
4-1	12 ft	20.5 (33.0)
4-2	12 ft	19.5 (31.4)

100% of the subjects cleared the gap distance without striking the rumble strip.

A group of 2 bicyclists of high skill level on one tandem bicycle (Group 5) tested the 12 ft (3.7 m) gap, making two runs.

Run	Gap	Avg. Speed - mph (km/h)
5-1	12 ft	23.0 (37.0)
5-2	12 ft	24.0 (38.6)

In the first of these tests, the subjects did slightly enter the far side rumble strip area, but successfully navigated the gap on the second run.

DISCUSSION OF RESULTS

EFFECT OF BICYCLE TYPE ON RESULTS

A number of bicycle types were used in the testing, including road, racing, touring, hybrid, mountain, cruiser, short and long wheelbase recumbent, and tandem type bicycles.

None of these bicycle types exhibited any significant problems in executing these tests.

SIMULATION OF THE RUMBLE STRIP VS. ACTUAL RUMBLE STRIP

This test was conducted with a simulated rumble strip consisting of raised markers, and not in a location with actual rumble strips.

The reason for this arrangement was so the length of the gap could be quickly and readily changed, without having to "fill in" grooves on an existing rumble strip, or install grooves on short notice.

There could be a concern regarding the greater visibility of the raised markers used in the test versus the ground-in grooves that will actually be installed on highways. However, field surveys have indicated that the ground-in shoulder grooves are easily visible under conditions typical for bicycle travel on state highways. Also, a repetitive pattern of gaps in a shoulder rumble strip pattern will make it much easier for bicyclists to locate gaps when traveling in these areas.

PATH OF BICYCLISTS THROUGH THE TEST AREA

When crossing the rumble strip gap, bicyclists typically moved approximately 2 ft (0.6 m) to the right of the rumble pattern, then turned smoothly to cross the gap diagonally, then countersteered slightly to resume their movement parallel to the rumble strip on the opposite side.

The total lateral movement for most bicyclists was in the range of 4 ft (1.2 m) while traveling across the gap. From video analysis, there seemed to be little correlation between lateral movement and bicycle type, or bicyclist skill level.

RUMBLE STRIP WIDTH VS. GAP LENGTH

As mentioned above, the total lateral movement was about 4 ft (1.2 m). This is significantly larger than the width of the rumble strip tested.

From video analysis of the motion of the bicycles through the gap, it would appear that the movement across the rumble strip was governed more by the length of the gap than by the width of the gap. Changing the rumble strip width to 8 or 5 in (200 or 125 mm) would probably not significantly affect the lateral movement of the bicyclist, or the necessary length needed for crossing.

Therefore, the same length of gap should be used for all widths of rumble strips up to 12 in (300 mm).

If the rumble strip width is significantly greater than 12 in (300 mm), then a longer gap length may be advisable. Since the maximum rumble strip width proposed in Arizona is 12 in (300 mm), this was not evaluated in this study.

FREQUENCY OF GAPS

A regular pattern of these gaps should be established, so bicyclists will have frequent opportunities to cross the rumble strip pattern. Also, a regular pattern of gaps will make it easier for bicyclists to find gaps when necessary.

The question then becomes one of selecting the proper cycle length for ease of construction.

A 12 ft (3.7 m) gap in a 60 ft (18.3 m) cycle will result in 80% coverage of the shoulder with rumble strips. Also, a 60 ft (18.3 m) cycle is exactly one and one half times the MUTCD recommended cycle length for lane line striping.

A 40 ft (12.2 m) cycle, consisting of a 28 ft (8.5 m) long rumble strip with a 12 ft (3.7 m) gap, could also be considered for use. This matches the MUTCD recommended cycle for rural lane line marking. This pattern provides 70% coverage of the total shoulder length with rumble strip.

At a speed of 15 mph (24 km/h), and a spacing of 60 ft (18.3 m), a bicyclist will encounter a gap in the rumble strip every 2.7 seconds. At this same speed and a gap spacing of 40 ft (12.2 m), a bicyclist will encounter a gap every 1.8 seconds. Both these patterns should provide gaps at sufficient frequency to permit bicyclists to cross the rumble strips in advance of hazards or intersections, though the 40 ft (12.2 m) spacing will provide gaps more frequently for a given speed. At higher speeds, gaps will be encountered more frequently, regardless of spacing.

OTHER ISSUES

EFFECT OF THE GAP ON MOTOR TRAFFIC

Placing a gap in a rumble strip pattern introduces the possibility that a vehicle could pass over the gap in the rumble strip as it departs the roadway, negating the benefit of the rumble strip.

According to other studies(**5**), the typical departure angle for run-off-road crashes is 3 degrees. At an angle of 3 degrees, the center of the critical tire (typically the right front tire) will travel 7.5 in (190 mm) laterally for every 12 ft (3.7 m) longitudinally.

This means that for a typical run-off-road crash at a 3 degree angle, it will be impossible for the tire to completely miss an 8 in (200 mm) or 12 in (300 mm) rumble strip, if a 12 ft (3.7 m) gap is used.

When the width of the tire, typically 8 in (200 mm) for a passenger motor vehicle is factored in, it becomes impossible for the tire to completely miss a 12 ft gap in a rumble strip as narrow as 5 in (125 mm) or less.

Finally, the intermittent nature of the rumble strip could have a stronger effect on alerting the driver than a continuous rumble strip. However, this effect could not be verified in this study.

EFFECT OF THE GAP ON COST AND CONSTRUCTIBILITY

Inclusion of these periodic gaps should have the beneficial effect of reducing the total cost of rumble strip installation. For example, if a 12 ft (3.7 m) gap is placed every 60 ft (18.3 m), this should reduce the cost of the rumble strip installation by 20%. Placing more frequent gaps, such as in a 40 ft (12.2 m) cycle, could further reduce installation costs.

Inclusion of these gaps should create no significant constructibility problem. When laying out the rumble strip line on the pavement, the layout crew could simply place boundary marks on the pavement. Also, the rumble strip cutter could possibly be programmed to provide this gap, but this has not been confirmed with the manufacturer of the equipment.

OTHER TYPES OF RUMBLE STRIPS

Ground-in rumble strips are not the only solution for reducing run-off-road crashes. Other roadway edge treatment options do exist that create fewer problems for bicyclists.

Profile thermoplastic edge line marking may be used in lieu of ground-in rumble strips. This marking consists of a thermoplastic line with small raised ribs in the surface. This provides both an edge line marking and an effective rumble strip that has far less negative effect on bicycle operation.

Drawbacks to the use of profile thermoplastic include high initial cost and the marking's inability to withstand snowplow operations.

Use of these alternative treatments on narrow shoulders in non-snow areas may greatly reduce negative impacts on bicyclists, without compromising the safety of other road users.

RUMBLE STRIPS ON CONTROLLED-ACCESS HIGHWAYS

It is recognized that bicyclists are permitted to use the shoulders of fully controlled-access highways in most rural areas in Arizona, and that there may be situations where the bicyclist may need to cross the rumble strip.

However, these controlled access highways also have the highest potential for high speed run-off-road crashes. Also, bicyclists in Arizona are not legally empowered to use the travel lanes of these controlled-access highways, unlike other roadways.

Therefore, continuous rumble strips may still be warranted on fully controlled-access highways where sufficient clear shoulder width exists for bicycle travel after rumble strip installation.

CONCLUSIONS AND RECOMMENDATIONS

The results of the testing indicate that a 12 ft (3.7 m) gap will perform acceptably to permit bicyclists to cross a ground-in rumble strip pattern.

Either a 40 ft (12.2 m) or 60 ft (18.3 m) cycle for the rumble strip and gap will serve well for ease of construction and convenience of bicyclists. The 60 ft (18.3 m) cycle will provide greater rumble strip coverage, while the 40 ft (12.2 m) cycle will provide more frequent gaps with a small difference in coverage.

All rumble strips installed on non-controlled access roadways should include these gaps, as bicyclists will be using these roadways, and will need to cross the rumble strips.

The same gap length and cycle should be used for all widths of rumble strips.

FUTURE RESEARCH NEEDS

While this study did determine an acceptable gap length in rumble strips to accommodate bicyclists, there are still quite a number of future research opportunities regarding bicycles and rumble strips.

First, there still exists a need to evaluate other new and improved rumble strip designs that will have fewer negative effects on bicyclists, while still providing adequate warning to errant motor vehicle operators.

Other potential research needs:

- Verification of this study's findings on actual grooved rumble strip and gap sections
- Verification of acceptable gap lengths for different cycling populations and different grades
- Analysis of lateral movement across rumble strips and gaps vs. shoulder width, rumble strip width, etc.
- Analysis of the interaction and effect of rumble strip grooving on bicycle handling, stability, and safety
- Analysis of the relative effect of continuous vs. intermittent rumble strip designs on motorist warning and guidance

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REFERENCES

1. NCHRP Synthesis of Highway Practice 191: Use of Rumble Strips to Enhance Safety, TRB, National Research Council, 1993.

2. Draft Longitudinal Shoulder Grooving Details, Arizona Department of Transportation, 1997.

3. H. M. Elliott, written correspondence to author, 1999.

4. Selecting Roadway Design Treatments to Accommodate Bicyclists, Federal Highway Administration, 1994.

5. Portland Cement Concrete Shoulders, Research and Development Report #27, Illinois Division of Highways, 1970.