Rumble Strips and Paint Stripes at a Rural Intersection

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ABSTRACT

A common cause of traffic accidents at low-volume rural intersections is failure by drivers on the minor approaches to stop or slow down sufficiently, as warranted. The current experimental field study compared the effectiveness of transverse paint stripes, such as those developed by the U.K. Transport and Road Research Laboratory, and similarly placed rumble strips in inducing drivers to reduce speed and stop at intersections. The experiment was conducted on the two minor approaches to the same four-way rural low-volume intersection. A geometrically converging pattern of 38 paint stripes, each 60 cm (2 ft) wide, were laid out over a distance of 270 m (886 ft) of one leg, and a similar pattern of rumble strips, 12 to 15 mm (1/2 to 5/8 in.) high, was laid on the opposite leg. A before-and-after and a crossover (after a year) experimental design were used. Speeds were monitored at eight points on each leg along 420 m leading to the intersection for a total of over 2,500 lead vehicles. The main results and conclusions are as follows: (a) paint stripes have only minor influence on driver behavior; (b) rumble strips lowered speeds by an average of 40 percent; (c) both treatments had a small positive effect on compliance rate; (d) with no pavement treatment, deceleration began at 150 m (492 ft) and peaked within the last 60 m (197 ft); (e) with rumble strips, most of the deceleration took place before the vehicle passed the first strip, followed by an additional deceleration within the last 60 m (197 ft); deceleration become uniform and moderate; (f) rumble-strip effects remained stable after a year; and (g) a 150-m (492-ft) treatment of 12-mm strips is long enough to produce the positive effects of rumble strips.

A common cause of traffic accidents at low-volume rural intersections is, apparently, driver failure to stop or yield on the minor approach legs of the intersections. It is generally believed that insufficient speed reduction during the approach phase plays a direct causal role in the generation of such accidents and in increasing their severity. Therefore, some of the measures for preventing accidents at such intersections, as well as at other critical locations such as sharp curves and highway work zones, are specifically designed to bring about vehicle speed reduction during the approach phase.

Slowing down increases the likelihood of compliance with right-of-way rules (1); it improves the margin of safety in critical situations by allowing for more time and longer distances in case of an emergency stop, and it mitigates accident severity by reducing the energy levels in the case of a collision.

During the last 25 years, several studies have reported the use of rumble strips and paint stripes to induce drivers to slow down or to exhibit otherwise appropriate behavior at intersections and other critical locations. Rumble strips or rumble areas were used as early as 1954 (2). They gained in popularity during the 1970s when hundreds of installations were implemented (3). Rumble strips come in so many forms and dimensions that it is doubtful whether they should all be grouped under the same heading. Nevertheless, most rumble-strip treatments share four basic features:

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1. They involve certain degrading of the roadway pavement surface smoothness.
2. The basic treatment element is either a groove in the pavement [about 12 mm (1/2 in.) deep x 100 mm (4 in.) wide] or a tacked-on strip of rough pavement material [10 to 20 mm (3/8 to 3/4 in.) high and 10 cm (4 in.) to many meters wide].
3. The basic elements are repeatedly placed as transverse strips across the roadway in a certain geometric pattern, starting some distance upstream and stopping some distance before the critical location.
4. The rumble treatment is assumed to provide drivers with visual, auditory, and tactile-vibratory stimulation, thus compelling them to be attentive to the demands of the situation.

If the physical properties of the strips are harsh enough, the noise, vibration, and bumpy ride associated with high speed may become too unpleasant to ignore, thus forcing drivers to slow down in order to reduce the stimulation.

Paint stripes for controlling driver speed at approaches to intersections or curves were also tried more than 20 years ago (4). Renewed interest in the idea can be attributed to studies by the U.K. Transport and Road Research Laboratory (TRRL) on the use of paint stripes at approaches to roundabouts (5-7). Paint stripes are usually narrow, 10 to 60 cm (4 in. to 2 ft), and are placed in a pattern of decreasing distance between stripes toward the critical location. Paint stripes, like rumble strips, have an obvious visual impact that may be informative to the driver and attract his attention. As paint stripes are considerably cheaper than rumble strips, it would be useful to know which device is more effective and under what conditions.

A review and analysis of U.S., European, and other experience with rumble strips and paint stripes (8) revealed large variations in physical and geometrical attributes of the treatments and in the criteria and methods of their application and evaluation. It was not possible to conclude that paint stripes, which appear to be a success in Britain, can effectively substitute for the more expensive and pavement-destructive rumble strips used elsewhere. Furthermore, other than the unsupported allusion to a "visual speed illusion" associated with a converging pattern of stripes, there is no evidence that any given pattern of stripes (or strips) is preferable over other, equally reasonable, patterns. Similarly, there is a lack of strong rationale or empirical justification for the distance of surface treatment, and intersection applications range anywhere from 90 to 450 m (295 to 1,476 ft).

It is clear that in order to derive engineering design criteria for paint stripes and rumble strips, a better understanding is required of their operating mechanism. This experimental field study evaluated paint stripes and similarly placed rumble strips under comparable conditions. Vehicle behavior was monitored and analyzed in order to determine vehicle speed, deceleration, and stopping behavior and, finally, to develop application criteria and design guidelines.

METHOD

Overall Experimental Design

The experiment was conducted on the two minor legs, controlled by a stop sign, to the same four-way low-volume rural intersection. A before-and-after and a crossover experimental design were used. The behavioral measures included stopping behavior, speed, and deceleration functions of each vehicle. In the "after" period, one approach was treated with paint stripes whereas the other was furnished with an identical geometric pattern of rumble strips. Data were collected 1 month and 1 year after treatment. Subsequently, the approach previously treated with paint stripes was treated with a shorter pattern of rumble strips and monitored again. A total of 2,500 vehicles were monitored by eight speed traps placed on each approach leg along 420 m (1,378 ft) leading to the intersection. Figure 1 shows the layout of the intersection, positions of the measuring traps, and the geometric pattern of the stripes and strips.

Site Description

The experimental site has the following features:

1. It is an intersection of a primary rural road with a secondary rural road controlled by stop signs.
2. The primary and secondary roads have similar roadway geometry standards, traffic volumes, and speeds: 7.0 m (23 ft) wide, 2.0-m (7-ft) soft shoulders, 2,100 to 2,000 annual average daily traffic (AADT), and an average speed of 75 km/hr (47 mph).
3. The two minor approaches appear similar from the driver's point of view.
4. Sight distance is limited on both approaches. Although warning signs and other cues to the approaching intersection are present at a distance of 400 to 500 m (1,312 to 1,640 ft), the crossing road is not in view until much closer to the intersection. Drivers could be misled into assuming that they are on the major road.
5. The intersection has had a consistent history of accidents attributable to nonyielding vehicles on the minor road. The characteristics of the site present the kind of problems that paint stripes and rumble strips are believed to help overcome. The similarity of the two approaches is essential, of

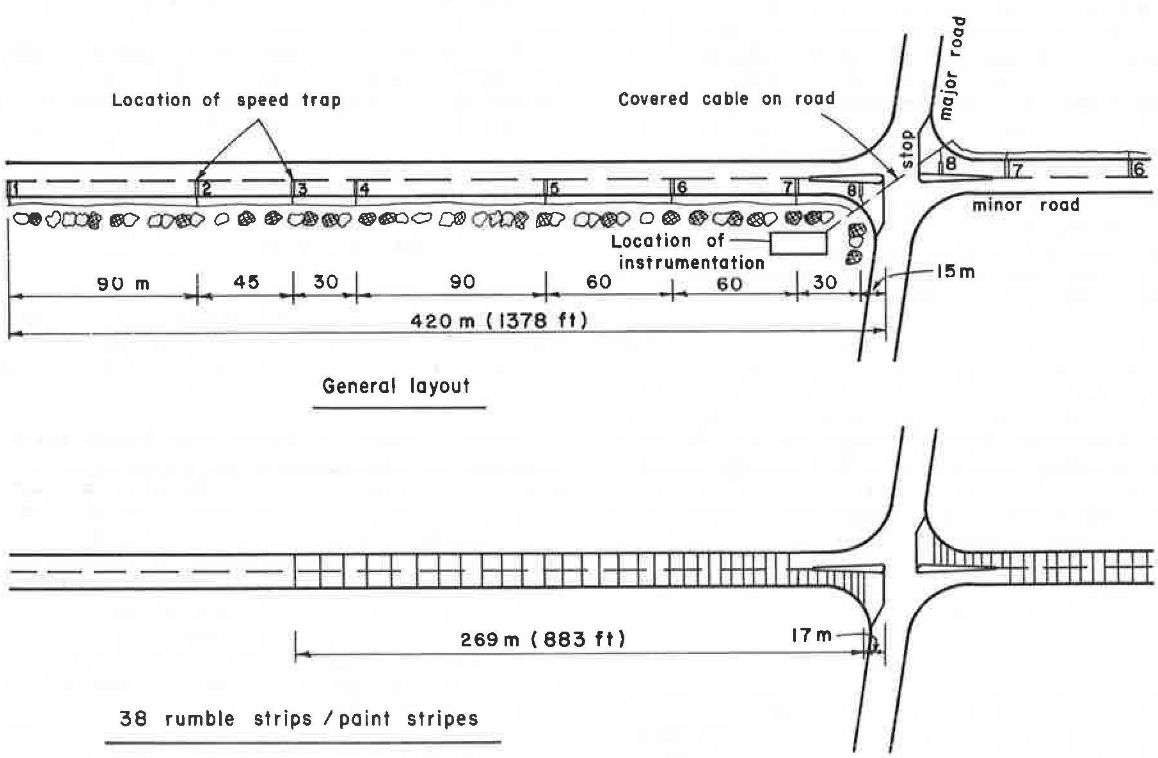

FIGURE 1 General view of intersection, layout of equipment, and arrangement of rumble strips or paint stripes.

course, for a valid comparison between the stripes and strips.

Description of Paint Stripes and Rumble Strips

A reasonable criterion for determining the distance of treatment application is to take the calculated stopping distance at a comfortable deceleration from a free approach speed to a full stop at the intersection. Preliminary speed measurements established that the 85th-percentile free-flowing speed at the site was about 80 km/hr (50 mph). Using the standard deceleration formula with a low deceleration value of 0.9 m/sec^2 (3 ft/sec^2), a treatment distance of ≈ 270 m (885 ft) was obtained ($s = v^2/2a$).

In order to facilitate comparisons with previous studies, a geometrically converging pattern of stripes was chosen, although there is no evidence of its hypothetical superiority. The converging pattern was designed so that a vehicle entering the treated zone at a speed of 80 km/hr and decelerating at a constant rate of 0.9 m/sec^2 would cross two stripes per second. In the case of rumble strips, this results in a 2-Hz rate of vibration. A total of 38 stripes (or strips) were installed, the first at 269 m (883 ft) upstream from the intersection, and the last one 17.4 m (55 ft) from the stop line. The last 17 m was left clear. In the third phase of the experiment, a modified, shorter pattern of strips was applied: 28 strips over 150 m (492 ft) up to 10 m (32.8 ft) from the stop line.

All stripes and strips were 60 cm (2 ft) wide. They were installed across the full width of the two-lane road except close to the intersection where the lanes are separated by a painted traffic island. The rumble strips were made of a premixed bituminous aggregate, size 3/8 to 1/2 in., hand rolled to a height of 12 mm (1/2 in.) and tapered at the edges. Both rumble strips and paint stripes were sprayed yellow with regular roadway marking paint mixed with reflective glass beads. Special advance warning signs were added to the normal sequence of signs on each approach.

Measurement System

Figure 1 shows the location of eight pairs of tapeswitches used to sense the passage of vehicles and calculate the speeds at these locations. Figure 2 shows the last measuring point and the other major components of the data collection system. Theoretical calculations of the different sources of errors and comparison with speed data obtained by radar showed that the accuracy of the measurement system is high. The maximal total error in measuring a 50-km/hr spot speed is less than 5 percent and decreases for lower speeds. The probability of a maximal error is less than 2 percent.

Data Collection Procedure

At all phases of the experiment, data were collected during four consecutive days, Monday through Thursday, from 8:30 a.m. to 6:00 p.m. Except for one day, weather was clear and dry. Traffic volumes were measured on the first day of each data collection period and were found stable: 2,000 ADT on the minor road and 2,100 on the major one. Right-turning vehicles made up about 10 percent of the volume. Data collection was carried out on both legs at the same time, with little intervention by the crew. The system's logic monitored a random sample of about equal numbers of free-flowing vehicles on each leg. Care was taken to conceal the measuring system and crew and to minimize the conspicuity of cables. The following variables were obtained for each observed vehicle:

1. Spot speeds at each of eight distances,
2. Decelerations between the speed traps,
3. Vehicle type,
4. Stopping behavior (not stopping, rolling, complete stop),
5. Direction through intersection, and
6. Presence of oncoming vehicles on major road.

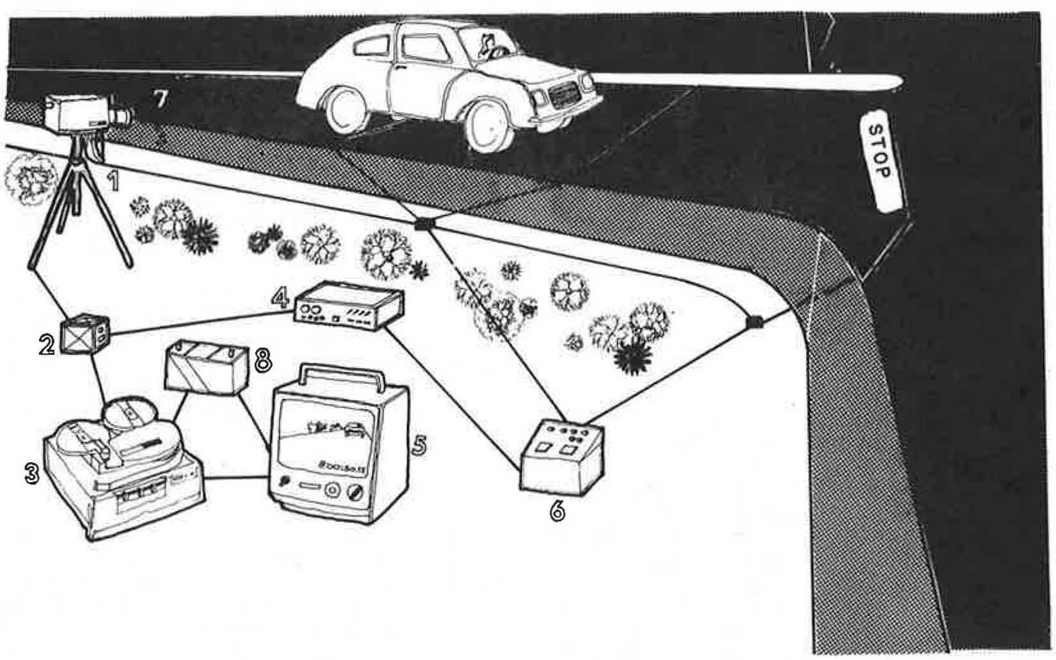

FIGURE 2 Arrangement of data collection system and its major components: 1, video camera; 2, synchronization box; 3, video tape recorder; 4, digital clock; 5, TV monitor; 6, control box; 7, tapeswitches; 8, power source.

TABLE 1 Average Speeds Before and After Painting Stripes and After a Modified Rumble-Strip Treatment

	Distance (m)							
Period	420	330	285	255	165	105	45	15
Paint stripes								
Before	77.8	76.4	74.5	73.0	66.2	57.0	43.7	25.9
After								
Speed	77.9	75.3	71.4	69.3	62.5	53.4	42.3	23.7
Percent change	1.0	1.5	5.0	5.0	5.6	6.3	3.2	8.4
Modified rumble strips								
Speed	77.7	71.4	68.3	66.2	53.9	38.7	27.4	17.0
Percent change	0	6.5	8.3	9.3	18.6	32.1	37.3	34.4

Note: 1 m = 3.3 ft; 1 km/hr = 0.6 mph. Speeds are given in kilometers per hour.

The interjudge reliability for the items that had to be detected visually from video was 97 percent and the errors appeared to be random.

RESULTS

Influence of Paint Stripes on Speed, Deceleration, and Stopping Behavior

The average speeds (of all vehicles) at the eight measuring points before and after painting stripes are given in Table 1. Figure 3 shows the 85th-percentile speeds.

It is evident that the free approach speeds just before the stripes are encountered, at 420 m and 330

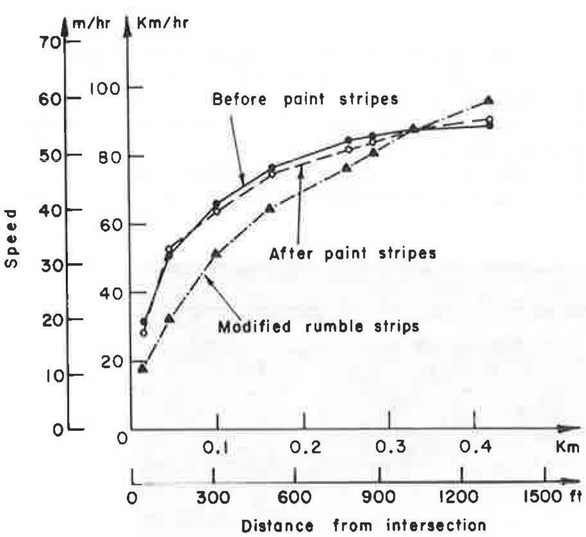

FIGURE 3 The effect of paint stripes and modified rumble strips on the 85th-percentile speeds.

m, have not changed. Afterwards the stripes produce a small, yet significant average speed reduction of about 3 km/hr and a smaller reduction close to the intersection. There were no significant changes in either average or maximum deceleration patterns. During both periods, average deceleration ranged from 0.20 m/sec^2 farthest from the intersection up to 1.6 m/sec^2 at the nearest distance measured [45 to 11 m (148 to 36 ft)]. Individual vehicles, however, differed considerably in their deceleration rates, and maximum deceleration values reached 5.8 m/sec^2 (19 ft/sec^2). About 7 percent of the drivers decelerated at rates that at some point exceeded 3.3 m/sec^2 (1/3 *g*). Compliance with the stopping requirement was quite high in both periods. Before treatment, 79 percent stopped, 11 percent made a rolling stop, and 10 percent did not stop. After treatment, 85 percent stopped completely, 7 percent rolled through, and 8 percent did not stop.

Influence of Rumble Strips on Speeds, Deceleration, and Stopping Behavior

Table 2 shows the average speeds before and after rumble-strip treatment, and Figure 4 presents the 85th-percentile speeds. Before treatment, speeds were only 2 to 4 km/hr lower than on the opposite approach leg, thus allowing a direct comparison between the two treatments. Rumble strips have had a definite restraining effect on the approach speeds. The effect is apparent even at a distance of 420 m, where the strips could not yet be seen. At a distance of 285 m (934 ft), just before actual physical contact with the strips, the average speed is already 17 km/hr lower than it was in the "before" period. Speeds over the treated area are further reduced by an average of 40 percent. There is, however, some increase in the variance of vehicle speeds at each point. An examination of Figure 4 suggests that under no-treatment conditions, most of the deceleration occurred along 150 m up to the intersection. Rumble strips change that pattern so that much of the speed reduction takes place over the first 100 m from the point at which the strips are fully seen. A second, more moderate slowing down takes place during the final approach to the stop line. The foregoing pattern is also reflected in the values of average and maximum decelerations. These reached lower peaks, and only 1 percent of the vehicles decelerated at rates higher than 1/3 *g*.

Initial compliance rate at the stop sign was quite high, 82 percent, and rumble strips did not bring about any significant changes in stopping behavior.

The stability of treatment effects was evaluated after 1 year. There were no significant changes on the approach with paint stripes. The rumble strips maintained their speed-reducing effect, which became even more pronounced at the 85th-percentile speeds. Compliance rate also increased to a 90 percent level.

Crossover Manipulation

At this phase of the experiment, the approach previously treated with paint stripes was equipped with rumble strips. However, it was not deemed necessary to prove the ineffectiveness of paint stripes again on the alternate approach leg. Based on the speed and deceleration patterns previously observed, a modified rumble treatment was designed. Strips were laid along 150 to 10 m (492 to 33 ft) from the stop line.

Of the 28 strips, 25 were placed on the same

TABLE 2 Average Speeds and Standard Deviations Before and After Applying Rumble Strips

	Distance (m)							
Period	420	330	285	255	165	105	45	15
Before rumble strips								
Mean	73.2	72.1	70.8	70.1	64.6	57.5	41.6	24.7
SD	11.7	11.7	11.6	11.6	10.9	9.6	8.0	5.1
After rumble strips								
Mean	69.5	63.1	54.0	43.5	32.9	31.6	24.5	14.7
SD	11.5	12.8	15.4	18.5	14.0	11.6	8.3	6.2
Percent reduction in mean speeds	5	12.4	23.8	38.0	49.0	45.0	41.1	40.3

Note: 1 m = 3.3 ft; 1 km/hr = 0.6 mph. Speeds are given in kilometers per hour.

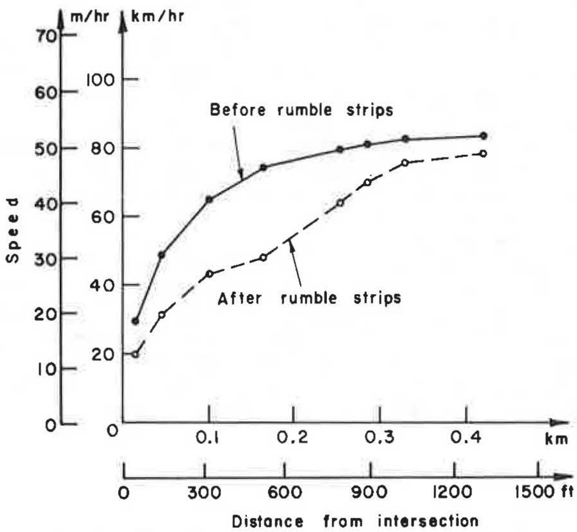

FIGURE 4 The effect of rumble strips on the 85th-percentile speeds.

spaces previously occupied by paint stripes. Table 1 presents the average speeds for the modified rumble treatment in comparison with the previous speeds measured on the same leg. Figure 3 presents the 85th-percentile speeds.

The modified rumble treatment caused a significant speed reduction, starting about 60 to 100 m before the first strip and continuing at a fairly uniform rate to the stop line. Compliance improved by another 4 percent--from 9 percent who did not stop with paint stripes to 5 percent with the modified rumble strips.

Additional Findings

Vehicle Type

Speed and deceleration functions for four vehicle classes--trucks, vans, private cars, and taxis--were essentially similar. So was stopping behavior.

Rain

No difference was detected between the data collected during the one rainy day and the rest of the data.

Traffic on Major Road

Presence of approaching vehicles on the major road had no effect on the deceleration pattern of vehicles on the minor approaches. However, all observed vehicles stopped (complete or rolling) when there was a vehicle on the major road at a range of 100 m (330 ft) from the intersection.

Accidents

The intersection was the scene of two to three right-angle collisions a year during the 3 years preceding the experiment. A total of 7 injury accidents occurred with 45 casualties (17 slightly injured, 15 seriously injured, and 3 fatalities). Small passenger-carrying pickup trucks were often involved. Although these are hardly the kind of accident data that can be considered experimental evidence, it was assuring to record that during the 4 years since the installation of rumble strips at the site, there have been only four accidents with seven casualties (five slightly injured and two seriously injured). Traffic volumes increased during this period.

Drivers' Opinion

Drivers understood the purpose of the rumble strips, rated them as quite tolerable, and endorsed their use. During an earlier test, they strongly objected to rumble strips 15 to 19 m (5/8 to 3/4 in.) high.

DISCUSSION OF RESULTS

Speed and Deceleration Effects

The small effect of paint stripes on vehicle speeds is in line with the relatively small, 3- to 10-km/hr speed reductions reported elsewhere (5,9,10,11). It should be noted that in Britain, the stripes (called "yellow bars") are made of thermoplastic paint stripes, and are not sprayed on with paint. Therefore, they have some thickness and a certain rumble effect. The rumble-strip effects in the current study are large in comparison with those in previous studies at similar locations (4,12-14). This is probably due to the particular design and placement employed. Many of the rumble-strip or rumble-area designs based on grooves or aggregates bonded to the road surface appear too gentle in their vibratory effect to achieve significant speed reduction. In addition, in many applications (3), the last 100 m or so close to the intersection was left untreated, thus leaving space for unchecked speed or even acceleration. Speed patterns in this study and others (11,13) show that at 80 km/hr, drivers do most of their deceleration during the last 150 m, and particularly the last 60 m. Therefore, this is the section of the vehicles' course that should be treated.

Influencing Mechanism of the Strips

Much of the speed reduction occurred before the strips were passed. Paint stripes had a similar, although much smaller, influence. This phenomenon, also observed by others (5,11,12,15), suggests that the visual pattern provides early information or warning about the approach to an intersection. This form of information may attract more attention than the regular warning signs by virtue of its conspicuity and rarity. Because of the latter, the strip pattern may be more convincing to the driver concerning its implied message: "slow down and prepare to stop." The preparation or planning is, perhaps, the factor mediating the influence of the stripes. The visual pattern, if appropriately laid out, may assist in planning a uniform and comfortable deceleration. The auditory and vibratory stimulation added by rumble strips delivers, however, a more compelling message that drivers cannot ignore. The expectation of vibration by itself induces drivers to plan their deceleration in advance. This is evident in the initial slowing before the strips are passed, which is not abrupt and is often accomplished by coasting without brake application.

Design Implications

It is recommended that treatment distance correspond to the declaration distance of the 85th speed percentile, empirically observed before treatment. About 10 to 15 m of pavement before the stop line should be left clear. The number and spacing of strips were not manipulated in this experiment. In view of the deceleration patterns observed, it should be possible to reduce the number of strips substantially. Also, the geometry of spacing is probably not that important. It is expected that at the study site, pairs or trios of strips placed 6 m (20 ft) apart and at about 50-m (165-ft) intervals over the 150 m (490 ft) would be sufficient to achieve similar effects. For a width of 50 to 60 cm (20 to 24 in.), the strip height should not exceed 12 to 15 mm (1/2 to 5/8 in.). Should more drastic decelerations be necessary at a given site, this can be achieved by spacing more strips, thus producing a harsher ride.

Where wide shoulders exist, treatment should extend onto the shoulder to deter evasive maneuvers. On asphalt roads, some sagging can be expected after 3 to 4 years. Repainting is also necessary. Snow and snow ploughing might eliminate the use of rumble strips.

Stopping Behavior

Previous experimental studies reported large, 30 percent improvements in stopping rates (4,16). A smaller improvement, 5 to 10 percent, was noted in a later survey (3). This study shows a small increase in compliance, perhaps because of a ceiling effect. At low-volume installations, it is not always clear to what extent stopping rate is correlated with safety. Often, at locations with sufficient visibility, stop signs could be safely changed to yield signs.

The failure to observe throughout the entire data collection effort even a single case of a "dangerous nonstopping" incident is rather typical of the conditions at low-volume intersections and of accident analysis in general. Counting those who do not stop at an intersection, therefore, may be a poor indicator of risk, as well as of countermeasure effectiveness. It is suggested that slowing down enough to be able to stop if necessary might be a more useful criterion for evaluating the effectiveness of rumble strips or similar treatments. Indeed, paint stripes in advance of roundabouts are credited with a substantial decrease in accidents, even though the reductions in speed are fairly small (7).

Criteria for Application

It may well be that the utility of stripes and other special measures depends in part on their being used sparingly. Their special attention-attracting characteristic can certainly be diminished if they are associated with the critical sites as often as the regular warning signs are. However, well-designed rumble strips may be unique in their resistance to familiarity. The vibration at high speeds is uncomfortable no matter how many times the driver encounters the strips. Their appearance would therefore arouse the expectation of vibration and, concurrently, induce a planned deceleration response. Nevertheless, there appears to be no need or justification for widespread use of rumble strips (in addition to cost and maintenance considerations). In the case of low-volume rural intersections, they should be considered only in instances in which an intersection is afflicted with poor sight distances, misleading cues about exact location, and ambiguity about which are the minor and which are the major approach legs, and where excessive speeds are diagnosed as causal factors in accidents. They should be installed only if these factors cannot be easily or cost-effectively improved or removed.

Summary

1. Paint stripes had a minor influence on driver behavior, whereas rumble strips lowered speeds by an average of 40 percent.
2. Both treatments had a small, though positive, effect on compliance with the stopping requirement.
3. The effects on driver behavior did not diminish after a period of 1 year.
4. Rumble strips changed the pattern of decelerations to a more moderate rate, with few vehicles exceeding the 1/3-*g* level.
5. A modified, shorter rumble-strip treatment was found to be just as effective as the previous, longer installation.

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A Further Note on Undulation as a Speed Control Device

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ABSTRACT

Conventional speed bumps have sometimes been used as a passive means of controlling speed, but there are problems associated with them, such as damaging the suspension and front-end alignment of crossing vehicles and causing loss of control for drivers of two-wheeled vehicles under certain circumstances. The U.K. Transport and Road Research Laboratory (TRRL) developed a new speed control device known as an undulation (or speed hump) that eliminates many of the deficiencies associated with conventional speed bumps. This new design has been gaining acceptance in the United States; it has been installed in a number of cities and the results so far have been favorable. The results of a research study to evaluate the effectiveness of the undulation as a speed control device are reported. The study consisted of three parts: a speed study, an instrumented-vehicle study, and a questionnaire survey. The study results indicated that that the undulation design is an effective speed control device and is more desirable and acceptable than the conventional speed bump. The study results also suggested that the level of speed control can be varied by adjusting the height of the undulation for use with various speed limits.

Speed control on residential streets has long been a concern among traffic engineers. Some drivers tend to ignore the speed limit, thereby creating a hazardous condition to pedestrians and other motorists. It may be possible to alleviate the speeding problem by increased law enforcement or a safety campaign, but the effects are mostly short lived. It is sometimes necessary to resort to some form of passive speed control device.

One commonly used passive speed control device is the conventional speed bump. Typical dimensions of a speed bump are a height of up to 6 in. and a length (in the direction of vehicle travel) of up to 3 ft.

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