# Economic Feasibility and Related Issues of Highway Shoulder Rumble Strips

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Highway shoulder rumble strips are intended to alert drivers of errant vehicles by providing audible and tactile warning. Although recent literature has advanced the state of knowledge in this subject, a number of information gaps remain. This paper reports research in the economic feasibility of shoulder rumble strips and related issues of technology, design, and maintenance. Specifically, facets of this subject covered include rationale for the use of rumble strips, existing practice, technology of installation, design, noise characteristics, maintenance issues, effect of indented rumble bars on the service life of paved shoulders, effectiveness in reducing run-off road accidents, and cost-benefit of rumble strips. The installation of rumble bars requires partially or fully paved shoulders as a prerequisite, so the cost-benefit of paving shoulders with rumble strips is reported for two-lane highways, multilane highways, and freeways. Results are highly favorable in terms of economic feasibility of installing rumble bars on existing paved shoulders. The installation of rumble bars enhances the economic feasibility of paving shoulders. Design innovations are noted that can address a number of highway operation and maintenance problems.

A variety of shoulder delineators for enhancing safety has been in use over the years. These include edgeline marking, contrasting pavement color, textured pavement (rumble areas), and rumble bars. Rumble strips installed on paved shoulders of highways are intended to alert errant drivers to reduce "run-off-road" (ROR) accidents. These have been used mostly on access controlled highways (i.e., freeways). For highways with at-grade intersections or for highways with narrow bridge approaches, rumble strips could alert drivers who encroach on shoulders to become more attentive upstream of potentially hazardous sites.

A recently published synthesis of highway practice by the NCHRP covered the use of rumble strips to enhance safety (*1*). A number of future research needs were identified, including safety effectiveness on the left and right sides of the traveled way and cyclist issues. There are other information gaps in the use of rumble strips that were not noted in the NCHRP study. These include the use of rumble bars on partially paved shoulders, noise characteristics of rumble bar designs, the effect of indentations on the service life of shoulder pavement, maintenance issues, and recent cost-effectiveness information. This paper reports research results that supplement the findings of the NCHRP study and addresses information gaps.

## RATIONALE FOR THE USE OF RUMBLE STRIPS

Over the years, studies sponsored by transportation agencies (e.g., the FHWA, the NCHRP, and others) recommended that textured shoulders should be considered for delineating pavement edges to alert errant drivers at high ROR accident locations. Commercial vehicle safety studies focusing on trucks colliding with parked or stopped vehicles on highway shoulders recommended the use of a contrast in texture for alerting dozing drivers (*2*).

Rumble areas, whether bars or textured pavement, provide a vibration as well as varying noise tones. The purpose is to alert the driver into taking the appropriate actions.

Shoulder rumble strips are primarily intended to be installed on long, straight stretches of rural highways that are known to cause drivers to become inattentive or fall asleep while driving. For freeways shoulder rumble strips have been installed on the long, straight stretches and at approaches to bridges. For highways with at-grade intersections, these have been used to alert drivers who encroach on the shoulder to be more attentive to major intersections downstream.

The pattern of ROR accidents suggest that drivers of errant vehicles could take appropriate action to avoid a crash if alerted to the fact that they are heading away from their travel lane. Such drivers frequently do not notice edgeline stripes or color contrasts between main-lane and shoulder pavements, if present. For night driving conditions or when the pavement is covered with snow or slush, such methods of shoulder delineation may not be effective at all. When visibility is good, in relative terms, edgeline stripping is believed to be just as effective and cheaper than color contrasts between main-line and shoulder pavements. A high percentage of highway accidents are the ROR type, so there is a logical role for shoulder rumble strips.

On highways with medians, errant vehicles could exit a travel lane toward the outside shoulder or median shoulder. Figure 1 shows that a high percentage of median cross-over accidents at selected locations could be prevented through the use of rumble areas on shoulders (e.g., about 20 percent of accidents were classified as "apparently asleep" and "inattentive").

## EXISTING PRACTICE

In the early 1980s, the state of California installed shoulder rumble strips on selected Interstate highways. This practice has continued over the years. A questionnaire survey carried out indicated that in Canada and in the United States, there is a growing trend toward the use of shoulder rumble strips, although a blanket policy and formal warrants for the use of shoulder rumble strips are not available. Even in the state of California, which pioneered the development and successful application of shoulder rumble strips, a blanket policy of grooving shoulders is not followed. In the United States, district/regional transportation engineers specify sites and projects for the installation of rumble areas based on their judgment.

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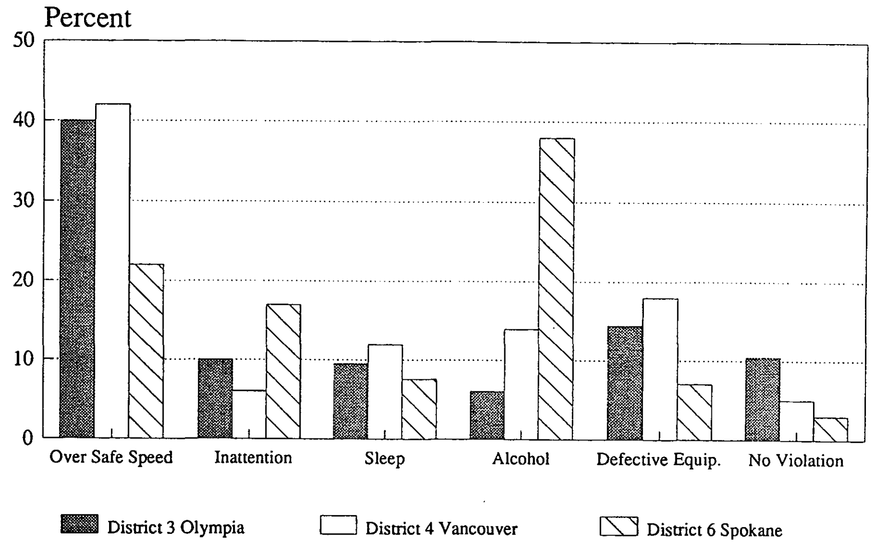



**FIGURE 1 Median crossover accidents at selected locations in Washington state, January 1985 to December 1989.**

A number of U.S. State Departments of Transportation have tested and now use shoulder rumble strips. According to one study, more than 60 percent of U.S. states use rumble bars as low cost countermeasures for ameliorating ROR crashes (*3*). In Canada, the province of Ontario has installed a short test section on Highway 401, west of Toronto. The province of Alberta has recently adopted the practice of including the placement of rumble strips on paved shoulders of freeways and multilane highways as part of paving contracts. In all cases, the rumble strips are placed on the outside as well as on the median side of paved shoulders.

The U.S. FHWA Technical Advisory T5040.29 recommends that consideration should be given to the installation of rumble strips on the shoulder portion of widened lanes (*4*). According to this advisory, in cases in which a full width paved shoulder cannot be cost-effective, a standard widening of 0.61 m (or 0.5 m) to 0.91 m outside of the travelled way should be considered. Considering the safety requirements, the placement of rumble strips could be considered for partially paved shoulders of 0.5 m to 0.9 m paved width.

## TECHNOLOGY AND DESIGN

Many types and designs of shoulder rumble strips have been developed. These can be characterized according to technology and design features. The technology factors are (*a*) indented versus raised surface features, and (*b*) rolling indentations in new or reconstructed shoulder pavement versus grinding grooves by tungsten or diamond tip machine. The design factors are (*a*) continuous versus clusters of rumbles, (*b*) spacing of bars, (*c*) spacing between clusters, and (*d*) shape, dimensions, and angle of indentations (bars).

### Technology Factors

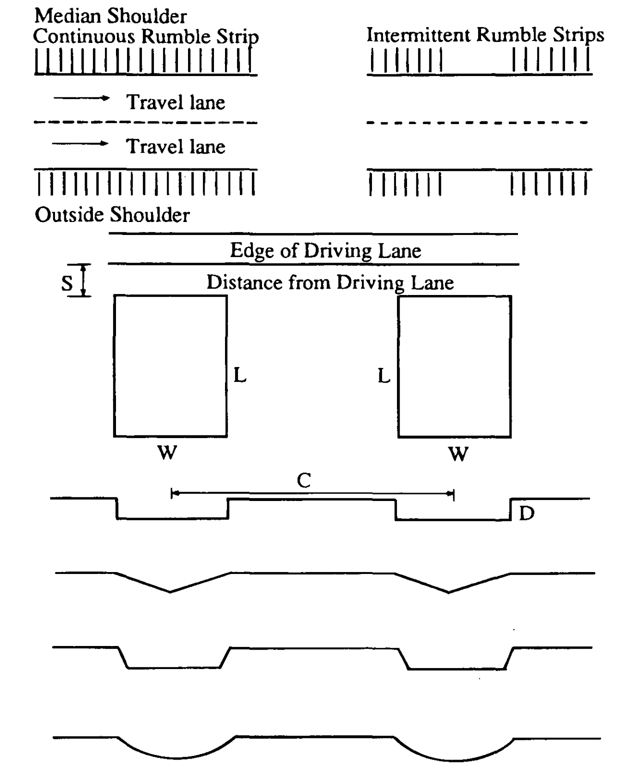
The rumble strips of prime interest in this study are those that are indented on the shoulder part of the highway cross section just outside the edge line (Figure 2). For regions in the snow belt, raised surfaces interfere with snow plough operation. In such areas, it is logical to find that the application of indented rumble bars is the common practice. For asphalt pavements, indented rumble strips can be formed by rolling asphalt concrete with a modified roller, or they can be milled-in. In the case of portland cement concrete, rumble areas are generally formed by combing the new surface. Although asphalt shoulder grooves can be applied at the time of new construction or while resurfacing highways, in the case of concrete, shoulder textured treatments can be added to new construction.

The State of California initiated the trend of rolling rumble bars (of 0.91 m length) on Interstate routes just outside the edgeline to form a continuous strip. The indentations were achieved by compacting the pavement with raised bars on vibratory rollers. Other states, namely Utah, Arizona, and Nevada, have also used this technique. More recently, among other jurisdictions, the province of Alberta has also used this approach. A prerequisite for the rolling-in technique is that new asphalt shoulders must be under construction or shoulder pavements must be being overlaid.

According to recent practice, existing or new shoulder pavements can be equipped with grooves by the milling-in process. For example, the Ontario test section was milled-in. A number of districts in the state of Washington prefer to grind rumble bars as opposed to rolling them. The reasons stated were that the resulting indentations keep their intended shape during construction and produce a better sound effect than those that are rolled-in. However, no comparative decibel data have been reported in support of this observation. It was also suggested that the rolling-in technique of obtaining grooves according to specifications requires good quality control during construction. A limitation of this technique is that it does not deliver satisfactory shoulder compaction because of the presence of the rumble bars.

According to the experience of the Pennsylvania Turnpike Commission, milling-in rumble bars was preferred by contractors than the roll-in method. Even in the case of repaving of the highway, which provided the opportunity to roll-in indentations, the milling-in process was chosen and was carried out after repaving and line painting (*5*).

The shapes used by various agencies have varied, although the semi-circular shape has been widely used for rumble bars formed




Range of Values of Design Variables

| W | C | L | S |
|---|---|---|---|
| 1.27 - 17.8cms | 19.1 -91.4 cms | 50-152.4cms | 0-76.2cms |

**FIGURE 2 Shoulder rumble strip design factors.**

by the rolling process. This shape results in very little tearing of the mat during placement and provides a good finished appearance. Although the temperature of the mat required for construction of semicircular grooves is a critical factor, it has been found to be workable. For rolling operation, this shape is the easiest to weld to the drum of the roller, and it is relatively easy to keep wet during placement.

The triangular (V) shape is easier than other shapes to roll-in because the temperature of asphalt concrete could be cooler than required for other shapes. On the other hand, during placement, this shape tends to tear the mat. It produces a good depression, and its sound effect was rated good (*6*).

The rectangular shape is suitable for milling-in operations, but it tends to tear the mat during construction by the rolling method. The shape with side slopes combines the attributes of the triangular and rectangular cross section. It lends itself to both the rolling and milling-in methods of construction without adverse effects.

### Design Factors

A number of design factors of rumble bars are shown in Figure 2. Also, the range of values of design variables is noted. In the case of asphalt concrete, rumble bars are installed at a right angle to the travel direction, although angles other than 90 degrees have been used. These could be continuous or intermittent type. There is no basis for installing spaced rumble bars through the use of a roller. For the sake of economy, rumble bars can be clustered but would require appropriate milling-in equipment.

As for safety, studies of accidents did not show significant differences between intermittent versus continuous shoulder textured treatments (*7*). This result is not surprising. For the speed and entry angle of vehicles, the distance between clusters of rumble bars can be traversed in less than a second. Consequently, spaced rumble bars can potentially perform the same function as the continuous variety.

The choice of distance from driving lane is influenced by functional, operational, and maintenance factors. Although safety considerations may call for the placement of the strip close to the edge, in order not to interfere with the smooth snow ploughing operations, a buffer distance is allowed. In the case of forming rumble bars by the rolling method, because of the difficulty of maintaining the precise line of the roller and the need to avoid placing the rumble bars on the traveled way, a certain amount of separation is allowed.

A variety of shapes and dimensions of rumble bars has been used (Figure 2). The design of the rumble areas is intended to provide the required audible and vibrational effect regardless of where a vehicle exits. For drainage reasons, in all cases, the rumble bar is beveled.

The decision to form various shapes is guided by the method of indenting bars, known noise characteristics, and maintenance considerations. There is no consensus on the best shape or dimensions. As discussed in the following section, from a noise perspective, for a given center-to-center distance (C), the higher the width (W) and depth (D), the better the noise performance. These observations of course apply within the range of values of variables tested. According to studies, accident reduction experience does not show any significant difference between wide versus narrow shoulder textured treatment (*7*).

In all cases, the groove depth is less than the depth of the asphalt concrete lift. The depth is also affected by the temperature of the asphalt concrete (*6*).

As for the length of the rumble bar, recent experience suggests the desirability of short bars for economy and highway operation and maintenance reasons. A design with sloped sides and continuous pattern adopted for installation throughout the Pennsylvania Turnpike calls for short rumble bars close to the edgeline in order not to encroach on the wheel paths of maintenance vehicles that use shoulders for debris collection (*5*). Other reasons for using short bars and placing these close to the edgeline are (a) highway shoulders can accommodate a bicycle lane on the outside shoulder, and (b) shoulders could be used for traffic on a temporary basis.

## NOISE CHARACTERISTICS

Tire-rumble bar contact shown in Figure 3 explains how a tire deforms and produces noise when it touches the side of the rumble bar. Because of higher degree of tire surface contact with bars in the case of wide bars, a higher noise level is emitted. In order not to create uncomfortable vibrations and not to damage the suspension system of the vehicle, the width of rumble bars should not be increased beyond the limit noted in Figure 2.

The sound performance of all shapes is generally recognized to be satisfactory. According to research reported by the state of California, the sound effects of groove spacing tended to favor

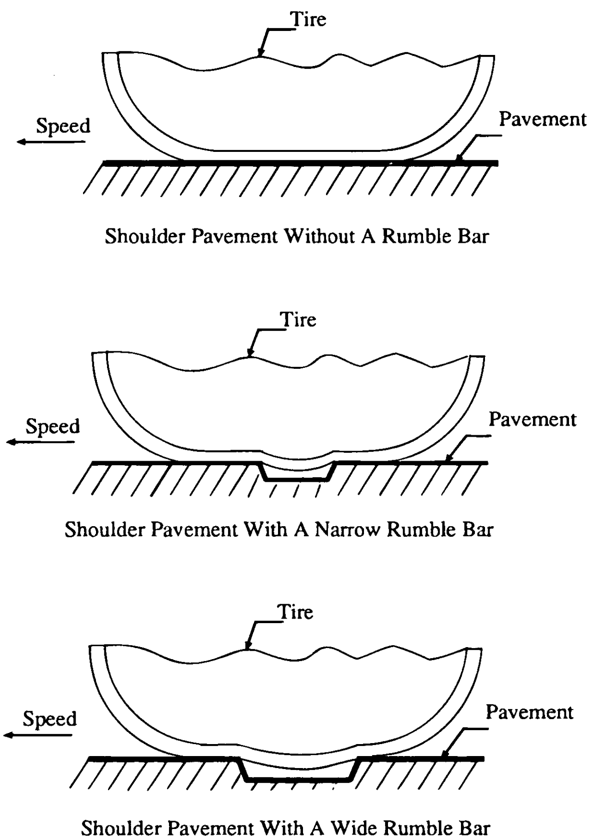



**FIGURE 3 Tire–rumble bar contact.**

20 cm (*6*). Other studies show that rumble bars within a cluster could be placed closer for a higher noise effect than is the case with the continuous design.

According to noise tests carried out for the Pennsylvania Turnpike Commission, rumble strips of 10.2 cm width, 1.3 cm depth, and 0.305 m center-to-center distance produced satisfactory noise level for alerting drivers of errant vehicles. For example, at 96.5 km/h, a sedan produced 80 decibels. This design resulted in 82 decibels in a truck cab at 96.5 km/h. The sound level in a truck cab was 79 decibels without a rumble bar, so a rumble strip had to produce a higher noise level to be effective for truck traffic (*5*). Another design tested had a 17.8 cm width, 1.3 cm depth, and 0.305 m center-to-center distance. This design yielded, on the average, 3 decibels higher than the design described above (*5*).

Past research indicates that a 4-db(A) increase above the ambient noise level produced by rumble areas tested was judged to be sufficient to be noticed as a warning device (*8,9*). It is believed that shoulder rumble strips produce a noise level higher than this magnitude inside automobiles. In the case of trucks, a noise level of 79 decibels in truck cab would require 83 decibels to be effective. According to the Pennsylvania Turnpike study, a rumble bar design with W = 10.2 cm and D = 1.27cm produces 82 decibels at 96.5 km/h and 86 decibels at 104.6 km/h. A design based on W = 17.8 cm and D = 1.27 cm produced 3 decibels more than that of W = 10.2 cm.

On the basis of noise data produced for the Pennsylvania Turnpike Commission, regression equations (Figure 4) were developed for the estimation of noise inside a sedan. The designs tested kept the center-to-center distance between bars (C) constant at 25.4 cm and varied W, D, and speed (V). Although both linear and nonlinear forms of the equation are satisfactory, in relative terms, the nonlinear equation shows better calibration results. The equations suggest that decibels of noise increase with increasing W, D, and V. The limits of values for the variables are noted in Figure 4.

## MAINTENANCE ISSUES

Literature citations and survey returns have not uncovered significant maintenance problems with indented rumble strips. No maintenance issues have been reported for the Ontario rumble strips. In the case of Alberta, there is a lack of information on structural and maintenance problems with shoulder rumble strips because of only 1 year of experience.

According to literature, a partial accumulation of foreign matter in the rumble recess was observed only in isolated instances in the United States (*7*). Studies carried out by the Pennsylvania Turnpike Commission over an 18-month period revealed no problems with debris, water, ice, or snow accumulation in the rumble bars (*5*).

In general, grooved rumble strips do not appear to retain debris and winter abrasives (e.g., sand). In most situations, the sand debris is blown out by traffic. Even in wet conditions, because of the drainage design of rumble bars, the potential for accumulation of sand is rather limited. Because of salt application, there is no freezing of water. However, in extreme conditions encountered in areas such as Yukon, where less salt or no salt is applied, the water may freeze in rumble bars and over time may result in loss of aggregates.

Normally, shoulder textured treatments do not require maintenance. According to Caltrans Highway Maintenance Department, the rumble strips installed in the early 1980s are still in use, and their maintenance is not an issue. At the time of repaving the main travel lanes, the rumble receives a fogseal treatment only (*6*).

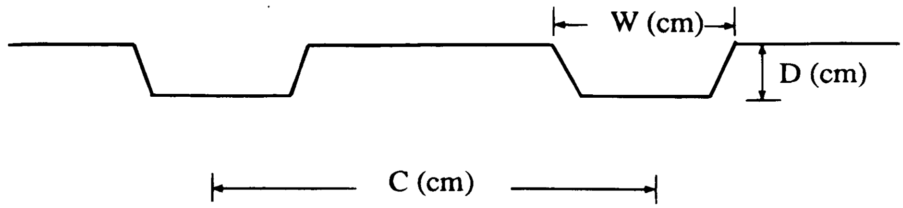
From the perspective of maintenance efficiency, compared with other shapes, the semi-circular shape and the cross section with sloped edges are more desirable because these are easier to clean (if necessary). Furthermore, because of a small number of sharp edges, these would resist the loss of aggregates.

## EFFECT OF RUMBLE BARS ON PAVED SHOULDER SERVICE LIFE

Field reports do not indicate pavement damage due to grooves. On high speed highways, grooving shoulder pavements of two lifts does not become the cause of a weakness in structural terms (*7*). The shoulder pavement is subjected to a very small volume of traffic compared with travel lanes. Consequently, traffic-induced damage to shoulders at grooves is largely absent (*6,7*).

Field studies in Alberta revealed minor cracks at the top edges of triangular grooves. The age of the grooves is about 1 year or less, so these cracks are attributable to the method of construction.

Analytical studies were carried out to supplement field observations. The following steps were followed: (*a*) Shoulder pavement structures "with" and "without groves" were defined; (*b*) by applying the Ministry of Transportation (MTO) pavement design method [Ontario Pavement Analysis of Costs (OPAC)], the number of




Note: V is speed in km/h

Linear Form:

$$db_A = 53.636 + 0.585\ W + 3.284\ D + 0.161\ V$$

(7.0) (2.6) (6.3)

$R^2 = 0.87$ F-Ratio = 39.5

Non-Linear Form:

$$db_A = e^{3.412}\ W^{0.074}\ D^{0.048}\ V^{0.172}$$

(7.8) (3.5) (7.2)

$R^2 = 0.90$ F-Ratio = 49.9

Values in parentheses are "t" values.

Range of Values:
W 5.1 - 17.8 cms
D 0.64 - 1.27 cms
V 64.4 - 96.5 km/h

For Constant C = 25.4 cms

**FIGURE 4 Regression equation for shoulder rumble strip noise estimation for asphalt pavement.**

equivalent standard axle loads (ESAL) were determined for the two shoulder pavement thicknesses (*10*). As a check on results obtained from the MTO method, the AASHTO and California design methods were used. These checks suggest that the MTO method gave logical answers; (*c*) from analysis results, the reduction in the ability of the shoulder pavement option "with indented rumble bars" to serve traffic without structural damage was found.

The calculations based on the OPAC are presented here for pavement thickness of 90 mm without rumble bars of 20 mm depth and 90 mm to 20 mm = 70 mm for pavement with rumble bars:

*With Rumble Bar*

**Granular Thickness**

$$H_e = 2h_1 + h_2 + (2/3)\,h_3 = 2 \times 70 + 1 \times 150 + 0.67 \times 450 = 592 \text{ mm}$$

where

$h_1$ = surface thickness (mm),
$h_2$ = base thickness (mm), and
$h_3$ = Subgrade thickness (mm).

**Subgrade Deflection**

$$w = (9000/\{2M_s Z\,[1 + (6.4/Z)^2]^{1/2}\})\text{ (in.)} \times 25.4 = w \text{ in mm}$$

$$Z = [0.9H_e\,(M_2/M_s)^{1/3}\text{ (in.)} \times 25.4 = Z \text{ in mm}$$

where

$M_s$ = Subgrade Layer Coefficient, Assumed 5,000,
$M_2$ = Granular Layer Coefficient, Assumed 50,000, and
$w$ = 0.503 mm.

$P_T$ Loss in Riding Comfort Index due to traffic(n); Assumed $P_T = 0.2$

$$P_T = 2.4455\Psi + 8.805\Psi^3 \rightarrow \Psi^3 + 0.2777\Psi - 0.0227 = 0$$

where

$\Psi = 1000w^6N$ ($w$ in in.),
$\therefore \Psi = 0.08$, and
$\therefore N = 1.3 \times 10^6$ (ESAL)

*Without Rumble Bar*

$$H_e = 2h_1 + h_2 + (2/3)\,h_3 = 90 \times 2 + 150 \times 1 + 450 \times 0.67 = 630 \text{ mm}$$

**Subgrade Deflection**

$$w = 9000/\{2M_s Z\,[1 + (6.4/Z)^2]^{1/2}\} = 0.0186\text{ (in.)} \times 25.4 = 0.47\ \text{ mm}$$

$$P_T = 2.44455\Psi + 8.805\Psi^3$$

where:

$\Psi = 1000w^{6N}$
$\therefore N = 1.9 \times 10^6$ (ESAL).

Therefore, a 20 mm of reduction in the thickness of the shoulder pavement will produce $(1.9 \times 10^6 - 1.3 \times 10^6) = 0.6 \times 10^6$ ESAL difference or a 31.6 percent reduction in ESAL or a 31.6 percent loss in carrying ESAL.

It should be noted that if rumble bars are applied on shoulder pavements of one lift of asphalt concrete of normally 40 mm thickness (or 50 mm max), the absence of one-half of the asphalt concrete might become a cause for concern. However, shoulder pavements that are designated for placement of grooves should receive two lifts. Under these conditions, shoulder pavements with indented rumble bars, even with their reduced ESAL capability, can serve their function for a long period of time because of only occasional traffic encroachments.

## ECONOMIC FEASIBILITY

### Cost of Rumble Strips

Because of the nature of the rolling method, the state of California achieved texturing in an economical fashion. The rumble strips were constructed as a part of resurfacing of the highway at a cost of US$0.16/m (1982$) (*11*). The milling-in method is costlier than the rolling method. The Pennsylvania Turnpike experience shows US$1,243/km (1992$) as the cost of milling-in rumble strips (*5*). A more expensive estimate suggested by the Washington State experience amounts to US$1,429.50/km by the grinding method (1993$). The NCHRP Report on Synthesis of Highway Practice indicates that 0.61- to 1.52-m rumble bars rolled-in during resurfacing would cost US$93.20 to 360.50/km (per one shoulder). In this research, the following costs are used: Canadian $1,906/km for two shoulders and Canadian $3,812 for four shoulders. These cost estimates are based on US$1,429.50/km for two shoulders or US$2,859.00/km for four shoulders.

### Cost-Benefit and Sensitivity Analysis

Decision making regarding the installation of rumble bars on highway shoulders may take place in conjunction with the assessment of the economic feasibility of paving shoulders. On the other hand, for shoulders that are already paved, the investigation of incremental cost and benefit of adding rumble bars would be required. In this section of the paper, following a description of the effectiveness of rumble strips, results of both types of analyses are illustrated.

Studies in California, Washington, and elsewhere have revealed that shoulder rumble strips of the indented type, when used at high ROR sites, have been successful in reducing such accidents. The state of California study showed that, at high ROR accident sites on Interstate routes, a 16 percent reduction in overall accidents and a 52 percent reduction in ROR accidents were achieved (*12–14*).

The Pennsylvania Turnpike experience with rumble strips was even more impressive in terms of reducing drift-off-road accidents. As a result of the first five rumble strip installation projects, a 70 percent reduction in ROR accidents was reported (*5*).

In the state of Washington, rumble areas were placed on highway shoulders in response to a large number of ROR accidents. A high proportion of these involved trucks. These rumble areas have been successful in reducing ROR type of accidents. According to Washington State Department of Transportation officials, before and after studies have shown a 37 to 50 percent reduction in ROR accidents. The overall accident rates dropped by 33 to 42 percent. Their success clearly suggests that the high engine noise levels of trucks do not significantly decrease their effectiveness.

In addition to the primary function of shoulder textured treatments, namely reducing ROR accidents, another advantage of using rumble strips on highway shoulders relates to bicyclist safety. Should bicyclists be allowed to use paved shoulders, the rumble strips can serve as a buffer, separating bicyclists from motorized traffic.

As for disadvantages of grooving shoulders, the rumble areas may interfere with smooth snow ploughing operation if placed next to the edgeline. Also, long rumble bars become a problem at the time of using the shoulders as travel lanes while the main lanes undergo repair. However, short bars placed on full width shoulders overcome this disadvantage.

In this research, the quantification of the economic value of reducing ROR-type accidents started with the accident rates for various types of highways. For Ontario, these are "Other King's Highways" (i.e., two-lane and multilane): 1.08 accidents/million vehicle-km; and freeways: 0.74 accidents/million vehicle-km. Available information indicates that depending on the site, 2 percent to 20 percent of highway accidents are of the single vehicle ROR type and that shoulder rumble strips could potentially reduce at least 20 percent of such accidents. Here, it was assumed that the lower estimate (i.e., 2 percent) was used.

The economic value of reducing a highway shoulder-related accident was recently estimated for Ontario conditions to be $76,638.84 (1994 Canadian $). This cost to society of saving an accident compares well with an estimate of saving/accident developed by using the FHWA approach, which amounts to $75,982.90 (1994 Canadian $).

The benefit-cost analysis results for paving shoulders on all types of highways "with" and "without rumble strips" are presented in Table 1 and Figure 5. In this research, sensitivity analysis of economic feasibility with respect to traffic volume was used to find threshold traffic levels for the feasibility of paving shoulders without rumble strips. Both partially paved and fully paved shoulder options were covered. The benefits are the sum of savings of travel lane and shoulder maintenance expenditures plus the economic value of reducing accidents.

In Table 1, threshold annual average daily traffic (AADT) values for the economic feasibility of paving shoulders are presented. Additionally, the cost of shoulder pavement and the benefit/cost ratio are noted. Given that the option of installing rumble bars has to be analyzed, the design of pavement is based on two lifts of asphalt concrete. The life of rumble bars is assumed to be the same as for shoulder pavement. All analyses were performed in the 1994 constant (Canadian) dollars, and an interest rate of 6 percent (real) was used. The identification of threshold AADT to the nearest thousand has resulted in benefit/cost ratios (B/C) of more than 1.0 in a number of cases.

Here, the example of two-lane highway and 1.5-m shoulder pavement is presented to describe the process of estimation of costs and benefits. For an AADT of 8,000 (both directions), roadway surface

TABLE 1 Benefit-Cost Analysis of Paving Shoulders Without and With Rumble Strips (1992 Canadian Dollars)

| | Two Lane | Four Lane Undivided | Multilane With Median | Freeway |
|---|---|---|---|---|
| Shoulder Pavement | | | | |
| 1.5m on Both Sides | | | NA | NA |
| Without Rumble Bars | | | | |
| AADT Threshold | 8000 | 8000 | | |
| Cost | $54,144 | $54,144 | | |
| Benefit/Cost Ratio | Appr.1.0 | Appr.1.0 | | |
| With Rumble Bars | | | | |
| @AADT = 8000 | | | | |
| Cost | $56,050 | $56,050 | | |
| Benefit/Cost Ratio | 1.09 | 1.09 | | |
| 1.5m Outside, | | | | |
| 0.5m Median | NA | NA | | |
| Without Rumble Bars | | | | |
| AADT Threshold | | | 16000 | 20000 |
| Cost/Km | | | $72,192 | $79,112 |
| Benefit/Cost Ratio | | | Appr.1.0 | 1.01 |
| With Rumble Bars | | | | |
| @AADT = 16000 | | | $76,004 | |
| Cost/Km | | | 1.15 | |
| Benefit/Cost Ratio | | | | |
| With Rumble Bars | | | | |
| @AADT = 20000 | | | | |
| Cost/Km | | | | $82,924 |
| Benefit/Cost Ratio | | | | 1.16 |
| 3.0m Both Sides | | | NA | NA |
| Without Rumble Bars | | | | |
| AADT Threshold | 9000 | 9000 | | |
| Cost/Km | $108,288 | $108,288 | | |
| Benefit/Cost Ratio | 1.07 | 1.06 | | |
| With Rumble Bars | | | | |
| @AADT = 9000 | | | | |
| Cost/Km | $110,196 | $110,196 | | |
| Benefit/Cost Ratio | 1.13 | 1.12 | | |
| 3.0m Outside, | | | | |
| 1.0m Median | NA | NA | | |
| Without Rumble Bars | | | | |
| AADT Threshold | | | 18000 | 20000 |
| Cost/Km | | | $144,384 | $147,317 |
| Benefit/Cost Ratio | | | 1.05 | 1.05 |
| With Rumble Bars | | | | |
| @AADT = 18000 | | | | |
| Cost/Km | | | 148,196 | |
| Benefit/Cost Ratio | | | 1.15 | |
| With Rumble Bars | | | | |
| @AADT = 20000 | | | | |
| Cost/Km | | | | $151,129 |
| Benefit/Cost Ratio | | | | 1.13 |

Notes: (1) Shoulder pavements for two lane, 4 lane undivided and multilane highways are 80mm depth (two lifts) and life is 12 years. Freeway shoulder pavement is full strength (more than 80mm depth) and life is 15 years. (2) Interest rate is 6% (real). (3) NA Not applicable.

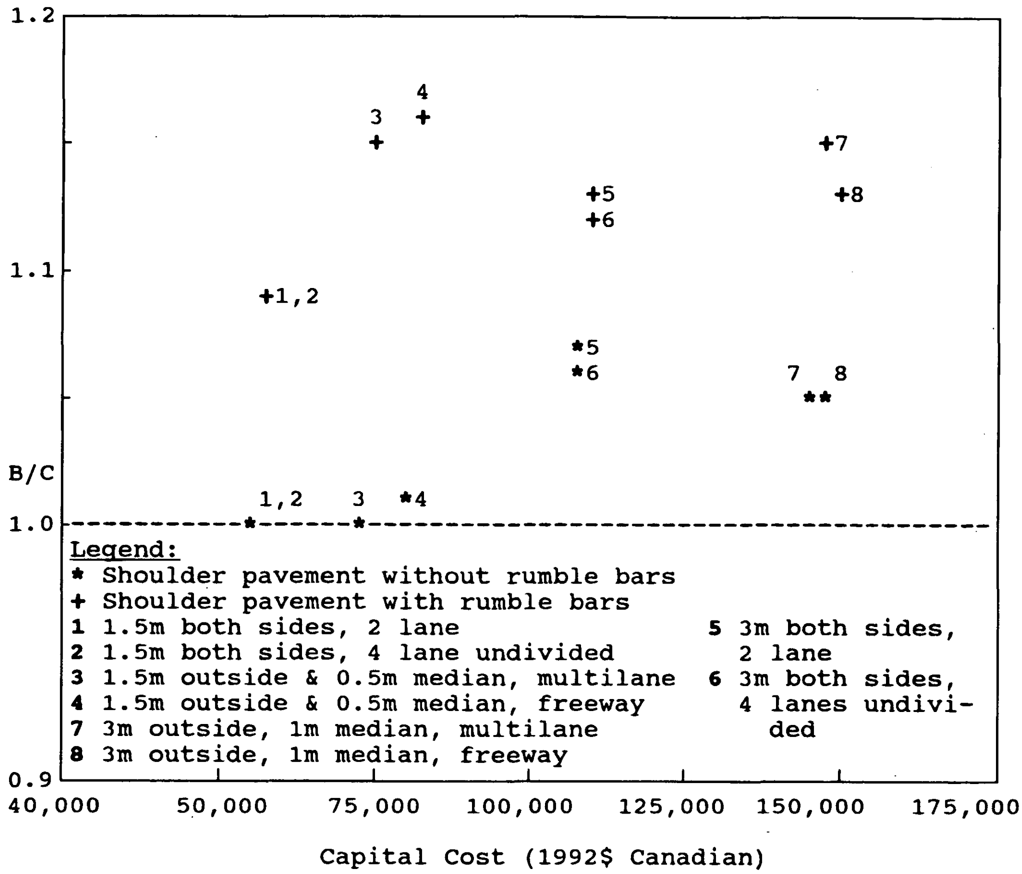



**FIGURE 5 Cost-effectiveness of partially/fully paved shoulders with and without rumble strips.**

patching and shoulder maintenance cost per year are found in constant dollars for the cases of without paved shoulders and with paved shoulders. Regression equations developed in this research were used for cost estimation. The difference between these costs is maintenance cost reduction attributable to 1.5-m paved shoulders. The present worth of maintenance cost saving/km is found to be equal to $1,530 for pavement life of 12 years and an interest rate of 6 percent (real).

Next, safety benefits were found by estimation of accident reduction due to paved shoulders and converting accident reduction into dollar benefits/year (in constant dollars). These savings amount to $51,709 in terms of their present worth. A safety model reported by Zegeer is used for the estimation of accident reduction due to 1.5-m paved shoulders (*15*). The addition of maintenance cost reduction and safety benefits amounts to $53,239/km of total benefits. The cost/km of 1.5-m paved shoulder for two sides is $54,144. At an AADT of 8,000, the B/C = 0.98 (approximately 1.0) (Table 1). It should be noted that at an AADT of 9,000, the B/C = 1.11.

At an AADT of 8,000, the benefits of rumble bars in present worth is $8,100/km, and the costs of rumble bars/km is $1,906. This gives a B/C of 4.25 (Table 2). The net present worth is $6,914/km. The benefits of 1.5-m paved shoulders with rumble bars is $61,339, and costs is $56,0507. This gives a B/C of 1.09 (Table 1). Further details of the costs and benefits of paving shoulders are reported in Khan and Holtz (*16*).

As illustrated in Tables 1 and 2, because of high incremental savings attributable to rumble bars for every dollar invested, the B/C ratios for shoulder pavements with rumble bars improve considerably. Figure 5 presents the cost versus B/C ratio information for partially/fully paved shoulders with and without rumble strips. The B/C ratio is being used as an indicator of effectiveness. The information presented in Figure 5 clearly shows that the addition of rumble bars improves the economic feasibility of shoulder pavements. A related observation would be that shoulder pavements with rumble bars become feasible at lower AADT threshold levels than those for pavements without rumble strips.

On the assumption that rumble bars are to be applied on existing shoulder pavements or that the decision to install rumble bars is separated from that of shoulder pavement feasibility, it is useful to study the economic desirability of investment in this safety measure. The benefit-cost analysis results shown in Table 2 suggest that despite extremely conservative estimates of accident reduction and the use of high cost estimates for milling-in rumble bars, the B/C ratio exceeds 4 in all cases.

## CONCLUSIONS

1. Rumble strips of indented type installed on highway shoulders are effective in reducing ROR accidents and show highly favorable economic feasibility results. The B/C ratio exceeds 4 for a

TABLE 2 Benefit-Cost Analysis of Shoulder Rumble Strips (1992 Canadian Dollars)

| Shoulder Pavement | Two Lane | Four Lane Undivided | Multilane With Median | Freeway |
|---|---|---|---|---|
| 1.5m on Both Sides | | | | |
| AADT Threshold for Shoulder Pavement Feasibility | 8000 | 8000 | NA | NA |
| Cost of Rumble Bars per Km (2 shoulders) | $1,906 | $1,906 | | |
| Benefit/Cost Ratio | 4.25 | 4.25 | | |
| 1.5m Outside, 0.5m Median | NA | NA | | |
| AADT Threshold for Shoulder Pavement Feasibility | | | 16000 | 20000 |
| Cost of Rumble Bars per Km (4 shoulders) | | | $3,812 | $3,812 |
| Benefit/Cost Ratio | | | 4.25 | 4.22 |
| 3.0m Both Sides | | | NA | NA |
| AADT Threshold for Shoulder Pavement | 9000 | 9000 | | |
| Cost of Rumble Bars per Km (2 Shoulders) | $1,906 | $1,906 | | |
| Benefit/Cost Ratio | 4.78 | 4.78 | | |
| 3.0m Outside, 1.0m Median | NA | NA | | |
| AADT Threshold for Shoulder Pavement Feasibility | | | 18000 | 20000 |
| Cost of Rumble Bars per Km (4 shoulders) | | | $3,812 | $3,812 |
| Benefit/Cost Ratio | | | 4.78 | 4.22 |

Notes: (1) Shoulder pavements for two lane, 4 lane undivided and multilane highways are 80mm depth (two lifts) and life is 12 years. Freeway shoulder pavement is full strength (more than 80mm depth) and life is 15 years. (2) Interest rate is 6% (real). (3) NA Not applicable.

number of cases tested. The addition of rumble bars on highway shoulders improves the economic viability of partially or fully paved shoulders.

2. Rumble bars can be designed to produce satisfactory noise levels for passenger and freight vehicles. These can be applied on partially and fully paved shoulders of all rural highways. In the case of freeways and multilane highways rumble bars should be placed on both outside and median shoulders. These pavements should receive two lifts of asphalt concrete. Rumble bars can serve as a buffer between bicyclists and vehicular traffic.

3. Short rumble bars are effective, and they enable the use of full width shoulder pavement for maintenance vehicles or serve as temporary lanes.

4. The technologies for installing bars on asphalt shoulder pavement with a roller or by the milling-in method are well developed.

5. There are no appreciable maintenance problems associated with indented rumble strips even in areas within the snow belt.

6. A 20-mm reduction in thickness of the shoulder pavement results in a loss of 31.6 percent in carrying EASL. However, for two-lift shoulder pavements, there would be no appreciable service life reduction because of only occasional traffic encroachments.

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