

***Best Practices for the  
Implementation of Shoulder and  
Centreline Rumble Strips***

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ISBN 1-55187-145-9

# TAC REPORT DOCUMENTATION FORM

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| Project No.<br>9132                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Report No.          | Report Date<br>2001-08                                                                                                           | IRRD No.                                                                  |
| Project Manager                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                     |                                                                                                                                  |                                                                           |
| Title and Subtitle<br><br>Synthesis of Best Practices for the Implementation of Shoulder and Centerline Rumble Strips                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                     |                                                                                                                                  |                                                                           |
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| Abstract<br><br>In Canada, a number of provinces have developed guidelines and policies for the implementation of shoulder rumble strips. As well, as of 2000, Alberta is the only province that has implemented centreline rumble strips. Other provinces wanting to apply shoulder and centreline rumble strips lack experience and require guidance based on other jurisdictions' results of such applications.<br><br>The purpose of this document is to provide highway agencies with a summary of current practices to assist these agencies in the development of local guidelines and policies. The Executive Summary provides an overview of the best practices and can be used as a quick reference to the key recommendations that are provided throughout the body of this document. |                     |                                                                                                                                  | Keywords (IRRD)<br><br>rumble strip<br>hard shoulder<br>centre<br>highway |
| No. of Pages<br>44 + appendices                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | No. of Figures<br>3 | Language<br>English                                                                                                              | Price                                                                     |
| Supplementary Information                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                     |                                                                                                                                  |                                                                           |

## FICHE DE RAPPORT DE L'ATC

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| Projet n°<br>9132                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Rapport n°             | Date du rapport<br>2001-08                                                                                                        | DIRR n°                                                                     |
| Gestionnaire du projet                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                        |                                                                                                                                   |                                                                             |
| Titre et sous-titre<br><br>Synthesis of Best Practices for the Implementation of Shoulder and Centerline Rumble Strips                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                        |                                                                                                                                   |                                                                             |
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| Résumé<br><p>Un certain nombre de provinces du Canada ont élaboré des lignes directrices et des politiques concernant la mise en place de bandes striées sur les accotements de chaussées. De plus, depuis 2000, l'Alberta est la seule province à utiliser des bandes striées dans les zones médianes des chaussées. Les autres provinces qui souhaitent avoir recours à ces deux applications des bandes striées manquent cependant d'expérience en la matière et ne peuvent donc que profiter des conseils des autres administrations.</p> <p>L'objet du présent document est de fournir aux administrations routières un résumé des pratiques actuelles concernant les bandes striées, de manière à aider ces dernières à élaborer leurs propres politiques et lignes directrices sur le sujet. Ce résumé propose un aperçu des meilleures pratiques appliquées dans ce domaine. De consultation facile, les intéressés pourront donc rapidement prendre connaissance des principales recommandations énoncées au fil de ce document.</p> |                        |                                                                                                                                   | Mots-clés<br><br>bande bruisante<br>accotement stabilisé<br>centre<br>route |
| Nombre de pages<br>44 p. + app.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Nombre de figures<br>3 | Langue<br>Anglais                                                                                                                 | Prix                                                                        |
| Renseignements supplémentaires                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                        |                                                                                                                                   |                                                                             |

## **ACKNOWLEDGEMENTS**

This report was prepared by the authors as commissioned research under the auspices of the Transportation Association of Canada. Funding for the study was provided by Alberta Transportation, the Insurance Corporation of British Columbia, Transport Canada and the Region of Ottawa-Carleton. Additional funds were provided by the Chief Engineers' Council of TAC.

The project was completed under the guidance of a project steering committee of volunteer members. TAC and the authors of this document would like to express their appreciation and gratitude to the committee members for their time and effort throughout the project.

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## **EXECUTIVE SUMMARY**

Road and traffic professionals have used rumble strips on roads, as a warning device, for many years. More recently, highway authorities have adopted a more systematic application of rumble strips along shoulders. Shoulder rumble strips are warning devices intended to alert drivers that they are leaving, or have left, the travelled way and that a steering correction is needed to return to the travelled way.

Even more recent in the use of rumble strips is the implementation of rumble strips along the centreline of undivided roads. Centreline rumble strips serve a similar function to shoulder rumble strips and are intended to alert drivers that they have crossed the centre of the road and are travelling in the opposing traffic lanes.

In Canada, a number of provinces have developed guidelines and policies for the implementation of shoulder rumble strips. As well, as of 2000, Alberta is the only province that has implemented centreline rumble strips. Other provinces wanting to apply shoulder and centreline rumble strips lack experience and require guidance based on other jurisdictions' results of such applications.

The purpose of this document is to provide highway agencies with a summary of current practices to assist these agencies in the development of local guidelines and policies. The Executive Summary provides an overview of the best practices and can be used as a quick reference to the key recommendations that are provided throughout the body of this document.

## **SHOULDER RUMBLE STRIPS**

### **Types**

There are three basic types of shoulder rumble strips in use in North America: rolled, milled, and raised. The application methodology and use in different climates varies among the three types of shoulder rumble strips. Key findings are summarized below:

- Rolled-in or milled-in rumble strips may be installed on new, reconstructed, or rehabilitated pavement during the construction of the pavement.
- The milled-in method has been found to be more accurate and is becoming less expensive to install than the rolled-in method.
- The milled-in method of rumble strip application is recommended for all types of implementation strategies on new or existing pavement.
- Raised rumble strips are suitable in Canada on a temporary basis in work zones where their use is restricted to seasons where there is no snow.
- Discontinuities in the rumble strip pattern (intermittent rumble strips) may be used, where required, to facilitate the movement of bicycles to and from the shoulder, and at intersections with residential or commercial driveways and side roads.

- The highway agency may undertake a benefit / cost analysis to confirm the cost effectiveness of implementing shoulder rumble strips, in particular, for low AADT volume roads.

## Design Dimensions

Currently provinces and cities in Canada apply varied dimensions for shoulder rumble strips. This synthesis identifies a range of design dimensions for their use, as summarized below:

|     |                                |                                       |
|-----|--------------------------------|---------------------------------------|
| 'A' | Distance from Travelled Way    | 0 – 200 mm                            |
| 'B' | Length of Intermittent Pattern | Approximately 4 m                     |
| 'C' | Width of Intermittent Pattern  | 300 mm typical<br>500 mm heavy trucks |
| 'D' | Number of Strips per Pattern   | 12 strips                             |
| 'E' | Spacing Between Patterns       | 4 m                                   |
| 'F' | Strip Shape                    | Rounded                               |
| 'G' | Strip Width                    | 300 mm typical<br>500 mm heavy trucks |
| 'H' | Spacing Between Strips         | 150 ± 40 mm                           |
| 'I' | Strip Depth                    | 8 ± 2 mm                              |
| 'J' | Strip Length                   | 150 ± 25 mm                           |

In addition:

- On roads marked as cycling routes or used by cyclists, 1.5 m of clear pavement between the right edge of the rumble strip and the outside edge of the paved shoulder provides the necessary path for cyclists.
- On roads with partially paved shoulders that are not used by cyclists, 200 mm of pavement between the outside edge of the rumble strip and the outside edge of the paved shoulder protects the pavement structure integrity.
- On multi-lane divided highways with a barrier along the median shoulder, 200 mm of pavement between the outside edge of the rumble strip and the barrier provides the space required for maintenance of the strips.

## Noise

There is a concern regarding the acceptable increase in noise from rumble strips to the surrounding environment. Therefore, a balance is required between installing effective rumble strips and minimizing noise impacts. Studies show that rumble strips terminated 200 m away from residential or urban areas produce tolerable noise impacts on residences. At an offset of 500 m the noise from rumble strips is negligible.

There is also a concern regarding the appropriate dimensions for rumble strips to effectively alert drivers inside their vehicles, particularly truck drivers. Studies show that a rumble strip depth of 8 mm is required to create any noticeable effect in the cabins of tractor-trailers. Depths of 6 mm or less produce no increase in sound level and vibration inside tractor-trailers.

Studies also show that a rumble strip width of 500 mm is more effective in the following circumstances:

- When a large proportion of the highway traffic is heavy vehicles,
- In known locations where large trucks typically encroach on the roadside,
- Where there is a history of run-off-the-road collisions involving trucks,
- When a benefit / cost analysis shows that the additional cost for a wider shoulder rumble strip is cost effective.

### **Application**

Shoulder rumble strips are cost effective measures to reduce run-off-the-road collisions and can be considered for installation on all two-lane and multi-lane highways. Shoulder rumble strips are applied in the following locations:

- On two-lane and multi-lane highways with partially or fully paved shoulders where 200 mm of paved shoulder can be maintained between the outside edge of the rumble strip and the edge of pavement,
- On multi-lane highways on the median shoulder where 200 mm of paved shoulder can be maintained between the outside edge of the rumble strip and the edge of pavement or physical constraint such as a barrier,
- In interchange areas on a selective basis, based on collision-prone locations,
- In the above noted locations, even when scheduled for rehabilitation, if a benefit / cost analysis shows that the installation is cost effective.

Shoulder rumble strips are not used in the following locations:

- Where the recommended dimensions do not exist,
- Through urban areas,
- Where pavement deterioration or cracking is evident,
- On bridge decks and overpass structures,
- Within 1.0 m of sawn and sealed traverse joints, sealed traffic counting loop detector lead wires, and expansion joint dams.

Once locations have been identified for the implementation of shoulder rumble strips, there are specific circumstances that require consideration. In the special circumstances noted below, further application guidelines to consider include the following:

- On two-lane and multi-lane highways with cyclist use, shoulder rumble strips can be applied where 1.5 m of clear paved shoulder can be maintained between the outside edge of the rumble strip and the edge of pavement.
- Shoulder rumble strips are interrupted at intersections with side roads, commercial driveways, and residential driveways, or wherever it is needed to allow cyclists to merge to the left of the shoulder rumble strip.
- Development of appropriate machinery and continued practice results in effective implementation of shoulder rumble strips, as evidenced by Alberta Infrastructure.

## **Maintenance**

Once shoulder rumble strips are installed, standard annual road maintenance is sufficient. The installation of shoulder rumble strips in new or well maintained pavement does not alter the rate of deterioration of the pavement. Concerns regarding debris collecting in the rumble strip or water and ice collecting in the rumble strip during the freeze / thaw weather periods are for the most part unfounded. Rumble strips are self-cleaning as the vibration of vehicles travelling over the rumble strips breaks down and knocks out water, ice, or debris that may collect in the groove.

## **Benefit / Cost**

The benefit of installing shoulder rumble strips is the reduction in run-off-the-road collisions. Many American states have completed before / after collision analyses to determine the reduction in this type of collision due to the installation of shoulder rumble strips. Reported reductions in run-off-the-road collisions from the use of shoulder rumble strips range from 18% to 65%. A 30% reduction in run-off-the-road collisions, resulting in a collision modification factor (CMF) of 0.70, is adopted in this document.

The results of the benefit / cost analysis example completed in the body of this report show that the benefits of installing shoulder rumble strips in terms of the collision cost savings far outweigh the cost of installation, even at low AADT volumes, on a 2-lane rural highway. The results further show that small road sections with rumble strips are cost effective.

## **CENTRELINE RUMBLE STRIPS**

### **Types**

Typically, two types of centreline rumble strips are installed: milled or raised. Key findings on these two types of rumble strips are summarized below:

- The milled-in method of centreline rumble strip application has been successfully applied on new and existing pavement.
- Raised centreline rumble strips are not appropriate for application in Canada due to winter weather conditions.
- Centreline rumble strips are mostly applied in no-passing zones on undivided highways.

- The effects of implementing centreline rumble strips in passing zones should be reviewed once additional studies on this topic have been completed.
- Continuous centreline rumble strips are applied on undivided highways as mitigation measures, if the local agency identifies a history of head-on or side-swipe collisions and a benefit / cost analysis shows that the implementation of centreline rumble strips is cost effective.
- The highway agency may undertake a benefit / cost analysis to confirm the cost effectiveness of implementing centreline rumble strips for low AADT volume roads.

### Design Dimensions

Design dimensions for centreline rumble strips, based on a review of current North American practices, are summarized below:

- The following dimensions for continuous milled-in centreline rumble strips are typically used:

|     |                        |                             |
|-----|------------------------|-----------------------------|
| 'F' | Strip Shape            | Rounded                     |
| 'G' | Strip Width            | 300 mm within painted lines |
| 'H' | Spacing Between Strips | 300 mm                      |
| 'I' | Strip Depth            | 8 ± 2 mm                    |
| 'J' | Strip Length           | 175 ± 25 mm                 |

- Centreline rumble strips should be placed in the centre of the road within the centreline pavement markings.

### Noise

Similar to shoulder rumble strips, the noise increase to the surrounding environment from rumble strips requires attention. However, a balance is required between installing effective rumble strips and minimizing noise impacts. Studies show that rumble strips terminated approximately 200 m away from residential or urban areas produce tolerable noise impacts on residences. At an offset of 500 m, the noise from rumble strips is negligible.

Studies on the appropriate dimensions for rumble strips to effectively alert drivers, particularly truck drivers, show that a rumble strip depth of 8 mm is required to create any noticeable effect in the cabin of a tractor-trailer. Depths of 6 mm or less produce no increase in sound level and vibration in tractor-trailers.

### Application

Unlike the use of shoulder rumble strips, centreline rumble strip application is best limited to the following areas until further research is completed.

Centreline rumble strips are appropriate for use in the following locations:

- On two-lane and four-lane undivided roads in no-passing zones,

- On horizontal curves with high collision history or low radius curves,
- On climbing or passing lanes with no-passing zones.

Centreline rumble strips are not appropriate for use in the following locations:

- Within 200 m of a residential or urban area,
- On bridge decks,
- In passing zones on two-lane roads,
- Across the intersections of a road or commercial entrance. A 45 m gap should be provided to allow for the turning movement of vehicles.

To date, centreline rumble strips have been installed on highways with lane widths as narrow as 3.4 m.

### **Maintenance**

Maintenance issues specific to centreline rumble strips currently are not identified. Standard annual highway maintenance practices outlined for shoulder rumble strips may be followed for centreline rumble strips.

### **Benefit / Cost**

Limited cost information is currently available regarding the installation of centreline rumble strips. In 2000, Alberta is the only province in Canada to install centreline rumble strips on a highway.

Currently, limited data is available on the effectiveness of centreline rumble strips in reducing head-on and side-swipe collisions.

Once information is available on the cost and effectiveness of centreline rumble strips, benefit / cost analyses could be completed.

### **Additional Research Needs**

The following issues are identified for future studies:

- Rumble strips effectiveness at urban applications where lower travel speeds prevail. Currently, tests have been carried out at sites where travel speeds range from 80 km/h to 120 km/h,
- Safety and cost effectiveness of centerline rumble strips on different road classes,
- Safety performance of motorcycles at curves with centerline rumble strips,

- Positioning of shoulder rumble strips at very narrow shoulders,
- Safety and cost effectiveness of rumble strips at work zones.

## 1.0 INTRODUCTION

Road and traffic professionals have used rumble strips on roads, as a warning device, for many years. More recently, highway authorities have adopted a more systematic application of rumble strips along shoulders. Shoulder rumble strips are warning devices intended to alert drivers that they are leaving, or have left, the travelled way and that a steering correction is needed to return to the travelled way.

Even more recent in the use of rumble strips is the implementation of rumble strips along the centreline of undivided roads. Centreline rumble strips serve a similar function to shoulder rumble strips and are intended to alert drivers that they have crossed the centre of the road and are travelling in the opposing traffic lanes.

In Canada, a number of provinces have developed guidelines and policies for the implementation of shoulder rumble strips. Only the province of Alberta has implemented centreline rumble strips. Other provinces wanting to apply shoulder and centreline rumble strips lack experience and require guidance based on other jurisdictions' results of such applications.

In April, 2000 a document was produced for the Transportation Association of Canada (TAC) Road Safety Sub-Committee titled '*Shoulder Rumble Strips State-of-the-Art and Current Canadian Experience*' by iTRANS Consulting Inc. Since the release of that document, TAC decided to pursue the development of National Best Practices for the implementation of shoulder and centreline rumble strips. This document '*Synthesis of Best Practices for the Implementation of Shoulder and Centreline Rumble Strips*' is the result of that pursuit. The purpose of this document is to provide highway agencies with a summary of current practices to assist these agencies in the development of local guidelines and policies.

Documentation exists on the use of temporary and raised rumble strips across travel lanes in workzones. However, information on the specific use of shoulder and centreline rumble strips in workzones was not available during the preparation of this document; therefore, guidelines on the use of these warning devices in workzone areas are not presented in this document.

Chapter 1 provides an introduction to the synthesis of best practices document.

Chapter 2 describes the background of the current applications of rumble strips in North America.

Chapter 3 defines shoulder rumble strips and provides a synthesis of design parameters applied in Canada, supported by guidelines for their application and maintenance.

Similarly, Chapter 4 describes centreline rumble strips and synthesizes the state-of-the-art design parameters and guidelines for application and maintenance.

The acronyms referred to in this document, as well as their definitions, are found following Chapter 4. Subsequent to the Definitions section is a listing of references used in this document and a bibliography of resources consulted during the development of this document.

## 2.0 BACKGROUND

In North America, the use of shoulder rumble strips has been in practice since the 1970s. In the past 10 years, more focus and attention has been placed on developing standard practices and implementation policies for the use of shoulder rumble strips to reduce single vehicle run-off-the-road collisions. Highway authorities have adopted a more systematic application of rumble strips along shoulders. More recent is the use of rumble strips along the centreline of undivided roads to reduce the incidence of head-on collisions that occur when drivers cross into traffic travelling in the opposite direction.

### Shoulder Rumble Strips

Shoulder rumble strips are intended to alert drivers that they are leaving, or have left, the travelled way. Shoulder rumble strips may consist of continuous rumble strip grooves in the surface of an asphalt shoulder, rumble strip patterns at regular intervals on asphalt or concrete shoulders, or rumble strip patterns at critical locations such as exit ramps, entrance ramps, or at narrow bridge approaches.

In the United States, single vehicle run-off-the-road fatalities account for one third of all traffic fatalities. In rural areas, two thirds of run-off-the-road collisions result in fatalities (1). In Canada, 27% of all collisions are defined as single-vehicle collisions (20-24).

A before / after study of collisions by the New Jersey Turnpike Authority of right-shoulder rumble strips showed that run-off-the-road collisions dropped by 34.3% after the installation of shoulder rumble strips during a time when total mainline collisions increased by 11.4% (1).

A benefit / cost (B/C) ratio compares the financial benefits of a measure such as the implementation of shoulder rumble strips in terms of dollars saved by reducing the future number of collisions to the costs of installing and maintaining the measure. The New York State Thruway calculated B/C ratios for the installation of shoulder rumble strips of 66:1 up to 182:1. The Nevada Department of Transportation calculated B/C ratios of 30:1 to 60:1 for rumble strips and noted that the B/C ratio for rumble strips was better than any other feature implemented. A survey completed by the Maine Department of Transportation of 50 State Departments of Transportation resulted in B/C ratios of 50:1 for milled shoulder rumble strips on rural sections of the Interstate Highway System nationwide (1).

A B/C ratio greater than 1:1 indicates that the financial savings outweigh the cost of implementation. As shown by the above estimates, shoulder rumble strips are cost-effective measures to reduce single vehicle run-off-the-road collisions. A summary of findings in terms of the reduction in collisions attributable to the installation of shoulder rumble strips in many American locations is included in **Table 1**.

**Table 1**  
**Reduction in Collisions Attributable to the Installation of Shoulder Rumble Strips**

| Location                          | Type of Collisions Targeted                                                                        | Reduction from Application of Shoulder Rumble Strips (standard deviation) |
|-----------------------------------|----------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|
| Illinois (7)                      | Single vehicle run-off-the-road collisions                                                         | 18.3% ( $\pm$ 6.8%)                                                       |
| Illinois (7)                      | Single vehicle run-off-the-road injury collisions                                                  | 13% ( $\pm$ 11.7%)                                                        |
| Illinois (7)                      | Rural freeway single vehicle run-off-the-road collisions                                           | 21.7% ( $\pm$ 10.2%)                                                      |
| Illinois (7)                      | Rural freeway single vehicle run-off-the-road injury collisions                                    | 7.3% ( $\pm$ 11.7%)                                                       |
| New Jersey Turnpike Authority (1) | Single vehicle run-off-the-road collisions                                                         | 34.3%                                                                     |
| Pennsylvania (8)                  | Mechanically sound single vehicles that drove rather than slid off the right side of the road      | 60%                                                                       |
| California (4)                    | Run-off-the-road collisions                                                                        | 33%                                                                       |
| New York State Thruway (4)        | Collisions attributed to driver fatigue or drowsiness, inattention, distraction, or medication use | 65%-70%                                                                   |
| Utah (4)                          | Run-off-the-road collisions                                                                        | 27%                                                                       |
| Massachusetts Turnpike (4)        | Run-off-the-road collisions                                                                        | 42%                                                                       |
| Kansas Turnpike (4)               | Run-off-the-road collisions                                                                        | 34%                                                                       |
| Washington (4)                    | Run-off-the-road collisions                                                                        | 18%                                                                       |

In the past decade, six Canadian provinces (Alberta, Ontario, British Columbia, Saskatchewan, and New Brunswick) have started to implement rumble strips on rural freeways and highways in an attempt to reduce single vehicle run-off-the-road collisions.

Alberta has applied shoulder rumble strips on their two-lane and four-lane divided highways since 1992. Alberta, in the past two years, has also introduced centreline rumble strips on their two-lane undivided highways for testing purposes.

Ontario has been applying shoulder rumble strips over the past 3 years and has recently issued a Ministry Directive (dated October 23, 2000) regarding the application and installation of highway shoulder rumble strips.

British Columbia has developed a set of guidelines (dated April 25, 2000) for the use of shoulder rumble strips on rural highways. They are currently investigating variations to the design of shoulder rumble strips to allow implementation on narrower shoulder widths and in particular when cyclists are present.

Saskatchewan developed guidelines on the use of shoulder rumble strips in 1997 and they currently install shoulder rumble strips on selected highway shoulders.

New Brunswick recently (Fall 2000) implemented its first two test locations of shoulder rumble strips on arterial highways.

Although Quebec has not implemented shoulder rumble strips, the province is currently in the process of adding a new chapter to their design guideline to address the application of shoulder rumble strips on rural highways.

### **Centreline Rumble Strips**

Centreline rumble strips serve a similar function to shoulder rumble strips. They are intended to alert drivers that they have crossed the centre of the road and are travelling in the opposing direction traffic lanes. All applications tested so far involve the use of continuous or intermittent rumble strips along the centreline of the road, with gaps in the rumble strip pattern at intersections and driveways. To date, there are few guidelines for the implementation of centreline rumble strips. Their effectiveness in reducing head-on collisions is currently being assessed.

In the US, limited evaluation data is available at this time as most states have only implemented centreline rumble strips in the past 1-3 years (2).

California uses an elaborate centreline rumble strip system consisting of milled-in centreline rumble strips with raised inverted profile thermoplastic traffic stripes and raised plastic reflectors. The centreline rumble strips are only applied in no-passing zones. A review of 36 months of before / after collision data resulted in an 11.1 % reduction in collisions and a 76.9% reduction in fatalities (2).

Two states, Arizona and Colorado, apply centreline rumble strips in no-passing and passing zones. Although before / after studies have not been completed to date, the installation of centreline rumble strips is believed to have cut down “ill-advised” passing and dangerous “peeking out” behaviour (2).

The state of Minnesota undertook two separate applications of centreline rumble strips, one in 1995 and one in 1996. Each location consisted of a 2-lane rural road with a posted speed limit of 55 mph (89 km/h). A review of 3-year before and after collision data along these sections of road revealed that the number of head-on collisions was not reduced after the installation of centreline rumble strips (3).

Pennsylvania and Delaware have implemented centreline rumble strips along with other countermeasures in no-passing zone areas and they have realized a reduction in collisions; however, a number of factors may have contributed to this reduction (4).

In Alberta, in April 1999, a briefing note from the provincial government noted that ‘the Ministry has expressed a desire to implement additional centreline rumble strips’. As such, the province developed installation criteria for centreline rumble strips to be installed on highway segments with the following characteristics:

- Selected horizontal curves on undivided highways that have a history of collisions that could be reduced through the use of additional guidance to assist drivers in keeping within the designated lanes,
- All horizontal curves of undivided highways where there are double barrier lines (no passing in both directions),

- All double-barrier lines at no-passing zones of climbing lanes or passing lanes,
- All double-barrier lines at no-passing zones at tangent sections where the length is greater than 300 m,
- Short sections of double-barrier centrelines in advance of intersections do not require rumble strips if they are on tangent (straight alignment) (5).

As Alberta's experience is relatively new, they are unable to report on the safety effectiveness of centreline rumble strips in reducing head-on collisions at this time (6).

All centreline rumble strips tested have been milled-in. This method allows for greater accuracy in placement and dimension. The highway agencies noted above all agreed that the milling-in process did not affect the structural integrity of either asphalt or concrete roads (2). The most serious concerns noted to date seem to be noise related disturbances of residents along the subject highway (2).

## 3.0 SHOULDER RUMBLE STRIPS

### 3.1 Definition

Quoting the Ontario Ministry of Transportation Directive PLNG-B-004, 2000: “A shoulder rumble strip is a grooved formation installed within the paved shoulder or partially paved shoulder on a highway. The intention of shoulder rumble strips is to provide the motorist with both an audible and tactile warning that the vehicle has partially or completely departed the travelled way of a highway. An audible warning to the motorist is produced by noise generated by the vehicle tires passing over the shoulder rumble strip. A tactile warning to the motorist is provided by the vibration induced in the vehicle by the shoulder rumble strip. An encounter with shoulder rumble strips is expected to alert an inattentive motorist to steer the vehicle back onto the travelled way of the highway.”

Several types of shoulder rumble strips are used on roadways today. They are:

- **Rolled shoulder rumble strips** were developed in the 1970's by pressing depressions in hot asphalt shoulders during construction and reconstruction projects. Similarly, formed rumble strips are used on new concrete-paved shoulders.
- **Milled shoulder rumble strips** are deeper and wider than rolled rumble strips, and they can be installed on new or existing pavements and on both asphalt and concrete shoulders, even in snow-prone areas. Field tests demonstrate that milled rumble strips produce more noise and vibration than the rolled type, which makes them particularly effective in alerting drivers of large trucks that they are leaving the road (7).
- **Raised shoulder rumble strips** are markers that adhere to new or existing pavement. The markers are often reflective to define traffic lanes at night and in poor weather. Raised rumble strips are usually restricted to warmer climates that do not require snow removal because they extend above the pavement.

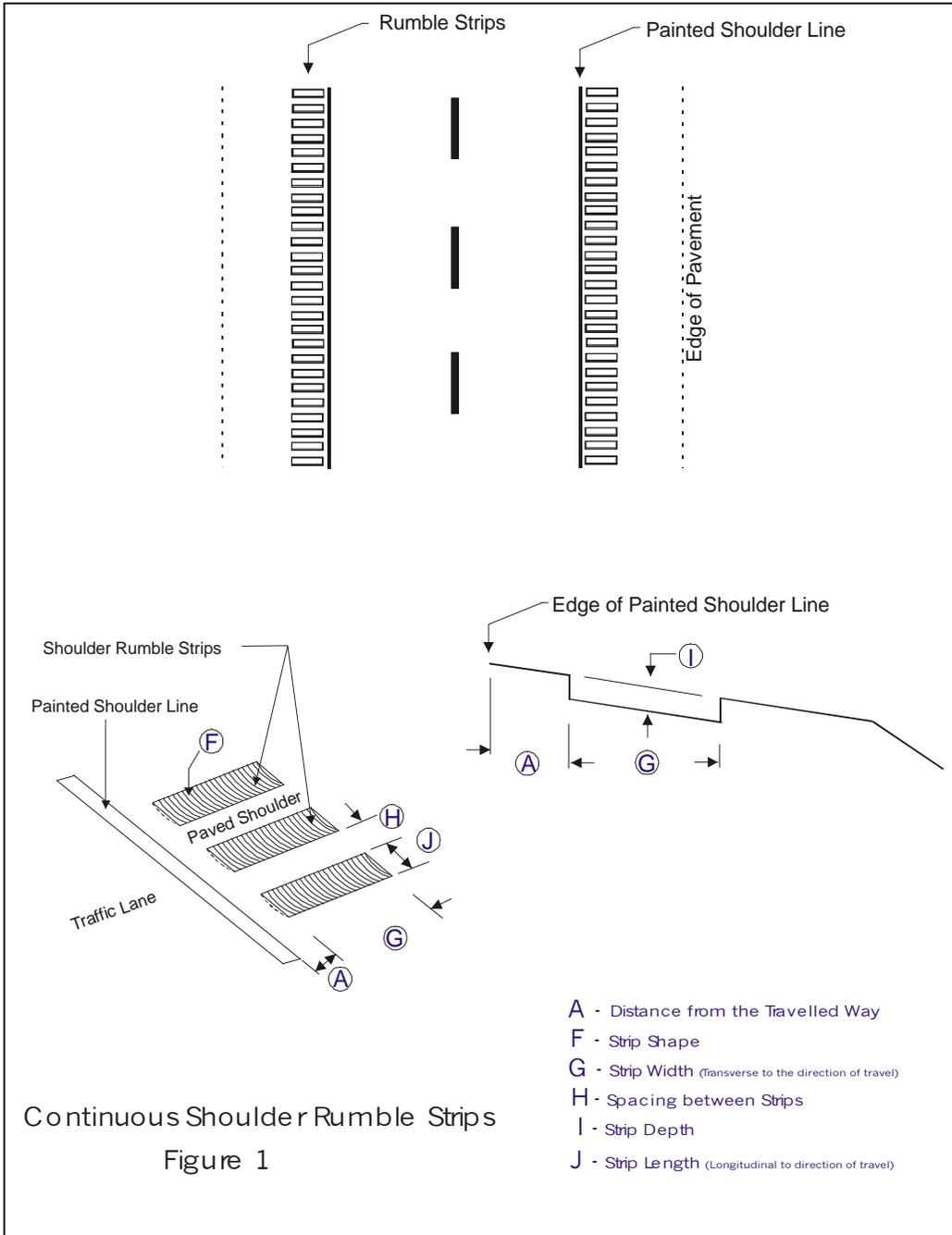


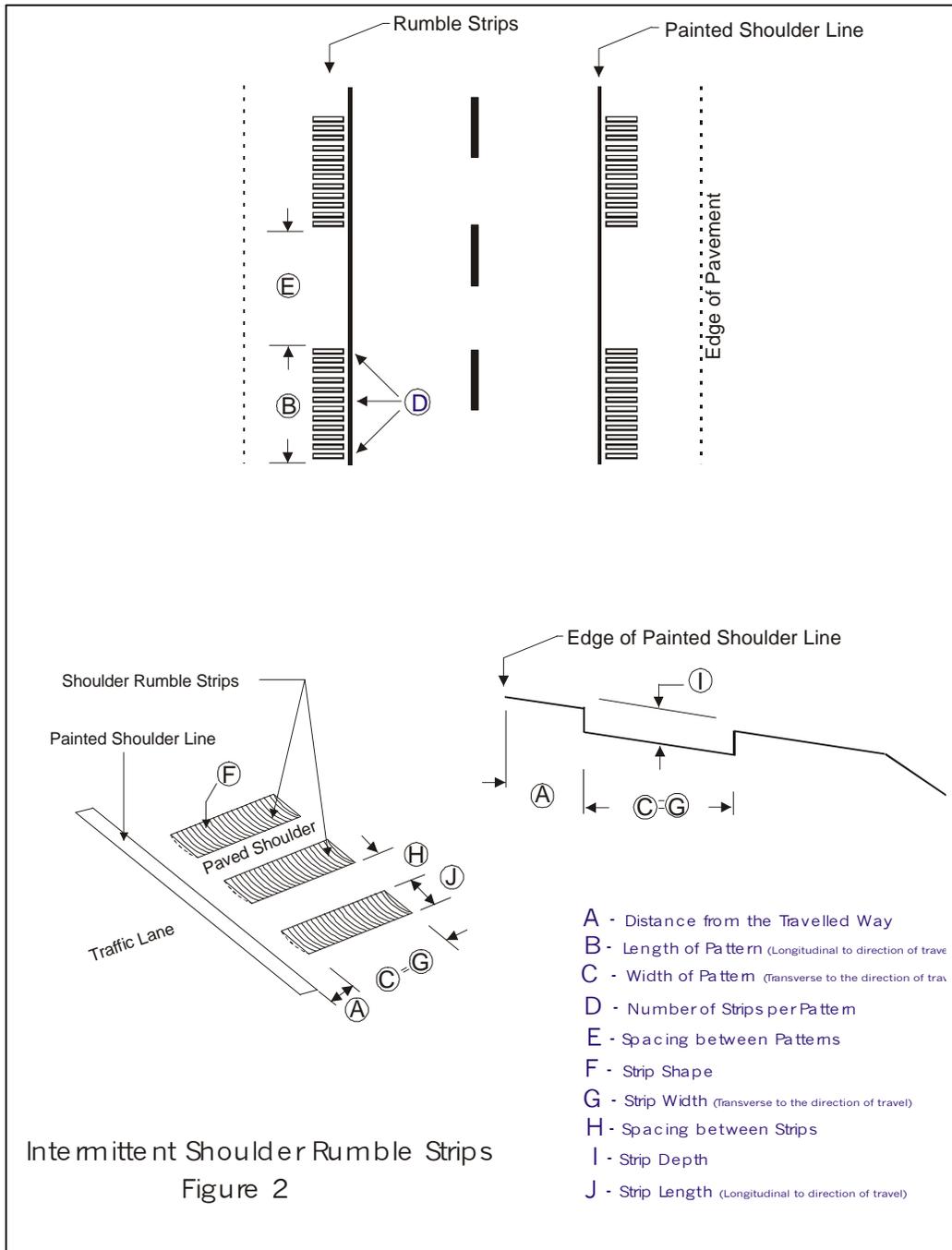
An example of a milled-in shoulder rumble strip

## 3.2 Design Parameters

### 3.2.1 Terminology

Currently, there are some inconsistencies in the terminology used by Canadian highway agencies in describing the dimensions and design parameters for shoulder rumble strips. **Figures 1 and 2** provide a diagrammatic definition of the dimensions required for the application of shoulder rumble strips. **Figure 1** illustrates continuous shoulder rumble strips and **Figure 2** illustrates intermittent shoulder rumble strips.





### 3.2.2 Types of Shoulder Rumble Strips

There are three basic types of shoulder rumble strips in use in North America: rolled, milled, and raised, as initially described in Section 3.1. The differences in the three types are their method and flexibility in application and their use in different climates.

Milled rumble strips are the most popular type in use currently. Field tests have found that milled rumble strips are 12.6 times tougher and 3.4 times louder than rolled-in rumble strips (9). This makes them particularly effective in alerting large trucks that leave the road. In the past, milled rumble strips were up to four times more expensive to install than rolled-in rumble strips; however, milled rumble strips are superior for asphalt shoulders in terms of audibility and tactility effectiveness, quality control, and ease of construction (10). Rolled-in strips sometimes wander laterally across the shoulder due to difficulties in having the roller track straight along the roadway edge line (11).

In Alberta, it has been found that the cost of installation of milled rumble strips has been reduced substantially over the past few years and is competitive with the cost of rolled rumble strips, particularly when applied through a separate contract (6). The cost of milled rumble strips is gradually decreasing with increasing practice by contractors (6).

The synthesis of practices resulted in the following guidelines for the use of the three different types of shoulder rumble strips:

- Raised rumble strips are not suitable on a permanent basis given the problems created by snow removal in winter months.
- Raised shoulder rumble strips may be used in work zones during construction on a temporary basis during the spring, summer, and fall seasons.
- Milled rumble strips may be applied on existing pavement.
- Milled rumble strips may be applied where outside shoulder widths are narrow and greater accuracy in depth is required, as well as at locations where the shoulder is used by cyclists.
- Rolled or milled rumble strips may be installed on new, reconstructed, or rehabilitated pavement during the construction of the pavement. However, there is evidence from practice in Canada that milled-in is more accurate and is becoming less expensive to install by the increased practice and availability of machinery by contractors (6).
- When the rolled-in method of application is used on new pavement, only continuous rumble strip patterns can be implemented. However, using the milled-in method of application allows the flexibility to implement continuous or intermittent rumble strip patterns.
- Intermittent shoulder rumble strip patterns may be used in areas where there are cyclists using the roadway. The intermittent pattern will allow cyclists to cross the rumble strip pattern without encroaching on the rumble strip. Tests have shown that milled-in rumble strips impact cyclists due to the vertical deflection of the bicycle as it travels across the rumble strip. The milled rumble strips are wide enough to permit a bicycle tire to drop into the groove of the rumble strip (11).

- Continuous shoulder rumble strip patterns may be used in all other areas where cyclists do not normally travel on the roadway.
- Studies of collisions did not show significant differences between intermittent versus continuous shoulder textured treatments. For speed and entry angle of vehicles, the distance between clusters of rumble strips can be traversed in less than a second. Consequently, spaced rumble strips can potentially perform the same function as the continuous variety (12).

**Summary:**

- Rolled-in or milled-in rumble strips may be installed on new, reconstructed, or rehabilitated pavement during the construction of the pavement.
- The milled-in method of rumble strip application is suitable for all types of implementation strategies on new or existing pavement, and provides greater accuracy in depth and location than the rolled-in method.
- Raised rumble strips are not appropriate for use in Canada, except on a temporary basis in work zones where their use is restricted to seasons where there is no snow.
- Discontinuities in the rumble strip pattern (intermittent rumble strips) may be used, where required, to facilitate the movement of bicycles to and from the shoulder, and at intersections with residential or commercial driveways and side roads.

### 3.2.3 Design Dimensions

A summary of the current dimensions in use in the various provinces and cities in Canada is provided in **Appendix A**. From this summary, guidelines on recommended dimensions to use when constructing shoulder rumble strips have been developed.

The domain of design dimensions for shoulder rumble strips are summarized in **Table 2** for milled-in shoulder rumble strips. The overall paved or partially paved shoulder width requirements for implementation of shoulder rumble strips will vary depending on the width of rumble strip used and the offset from the travelled way. However, the required paved area will be governed by the following guidelines:

- On roads marked as cycling routes or used by cyclists, 1.5 m of clear pavement provides a path between the right edge of the rumble strip and the outside edge of pavement. A 1.5 m paved area is the typical width for a bicycle lane; however, this width can range between 1.2 m and 1.5 m where space is limited (13). Since the far right side of a highway shoulder typically contains gravel and debris, 1.5 m for cyclists would allow for a reasonable clear paved path for the cyclist, even if some of the gravel and debris encroaches on the paved area.
- On roads with partially paved shoulders that are not used by cyclists, 200 mm of pavement between the outside edge of the rumble strip and the outside edge of the paved shoulder provides for the integrity of the pavement, concrete, or barrier / guide rail of median and outside shoulders.

**Table 2**  
**Design Dimensions – Milled-In Shoulder Rumble Strips**

| <b>Dimension</b>                                            | <b>Guideline</b>       | <b>Comments</b>                                                                                                                                                                                                                                                                                                                                       |
|-------------------------------------------------------------|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| A<br>(distance from travelled way)                          | 0-200 mm               | This guideline is similar to that in place in BC.<br><br>The offset is provided as a range to provide flexibility in implementing rumble strips on shoulders used by cyclists and to ensure that the pavement integrity is maintained.                                                                                                                |
| B<br>(length of pattern for intermittent design)            | Approximately 4 metres | This is consistent with current practices in Canada.                                                                                                                                                                                                                                                                                                  |
| C<br>(width of pattern for intermittent design)             | 300 mm<br><br>500 mm   | For use on typical highways. The 300 mm width is preferred to maximize the remaining clear shoulder width.<br><br>An increased strip width may be used in locations where large trucks typically encounter problems (i.e. ramps, tight horizontal curves, acceleration lanes) as a 500 mm width has been shown to be more effective for large trucks. |
| D<br>(number of strips per pattern for intermittent design) | 12 strips              | With 300 mm width.                                                                                                                                                                                                                                                                                                                                    |
| E<br>(spacing between patterns for intermittent design)     | 4 metres               | This is consistent with current practices in Canada.                                                                                                                                                                                                                                                                                                  |
| F<br>(strip shape)                                          | Rounded                | This is consistent with current practices in Canada and most available milling equipment.<br><br>The semi-circular shape is preferred because it is easier to clean, if necessary, and it resists the loss of aggregates due to the small number of sharp edges (12).                                                                                 |
| G<br>(strip width)                                          | 300 mm<br><br>500 mm   | For use on typical highways. The 300 mm width is preferred to maximize the remaining clear shoulder width.<br><br>An increased strip width may be used in locations where large trucks typically encounter problems (i.e. ramps, tight horizontal curves, acceleration lanes) as a 500 mm width has been shown to be more effective for large trucks. |

|                               |             |                                                                                                                                                                                         |
|-------------------------------|-------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| H<br>(spacing between strips) | 150 ± 40 mm | This is consistent with current practices in Canada.                                                                                                                                    |
| I<br>(strip depth)            | 8 ± 2 mm    | This is consistent with current practices in Canada. A depth of 8 mm provides sufficient noise and vibration to alert drivers without creating excessive noise in the surrounding area. |
| J<br>(strip length)           | 150 ± 25 mm | This is consistent with current practices in Canada.                                                                                                                                    |

**Summary:**

- On roads marked as cycling routes or used by cyclists, 1.5 m width provides a clear path between the right edge of the rumble strip and the outside edge of the paved shoulder.
- On roads with partially paved shoulders that are not used by cyclists, 200 mm of pavement between the outside edge of the rumble strip and the outside edge of the paved shoulder provides for the integrity of the pavement, concrete, or barrier / guide rail of median and outside shoulders.
- The following design dimensions for milled-in rumble strips are recommended:

|                                      |                                       |
|--------------------------------------|---------------------------------------|
| ‘A’ – Distance from Travelled Way    | 0 – 200 mm                            |
| ‘B’ – Length of Intermittent Pattern | Approximately 4 m                     |
| ‘C’ – Width of Intermittent Pattern  | 300 mm typical<br>500 mm heavy trucks |
| ‘D’ – Number of Strips per Pattern   | 12 strips                             |
| ‘E’ – Spacing Between Patterns       | 4 m                                   |
| ‘F’ – Strip Shape                    | Rounded                               |
| ‘G’ – Strip Width                    | 300 mm typical<br>500 mm heavy trucks |
| ‘H’ – Spacing Between Strips         | 150 ± 40 mm                           |
| ‘I’ – Strip Depth                    | 8 ± 2 mm                              |
| ‘J’ – Strip Length                   | 150 ± 25 mm                           |

### 3.2.4 Noise Concerns

The purpose of rumble strips is to create noise and vibration that can be heard and felt by the driver inside a vehicle when the vehicle drives on the rumble strip, alerting drivers that they have left, or are leaving, the travelled lane of the road.

There is a concern regarding the acceptable increase in noise to the surrounding environment from rumble strips. Therefore, a balance is required between installing rumble strips and minimizing noise impacts on the surrounding area, particularly in a more developed area.

Complaints about noise from rumble strip contact (both shoulder and centreline) prompted the province of Alberta to commission a noise study on rumble strips to identify the optimum

dimensions for rumble strips in terms of alerting drivers, as well as the noise impacts of rumble strips on the surrounding area (14). The testing involved continuous and intermittent milled rumble strips of varying depths (2 mm to 8 mm) and varying widths (300 mm and 500 mm). The tests were carried out using three different vehicles (tractor trailer, passenger vehicle, and motorcycle). The terrain topography was flat or rolling at the test locations.

The key findings of this study regarding noise impacts to the surrounding area are outlined below:

- The majority of the rumble strip sound had dissipated at a lateral distance of around 100 m.
- The sound from the tractor-trailer was predictably louder at greater distances, but further analysis showed that the majority of this noise was not coming from rumble strip contact, but rather noise from the vehicle itself. For passenger vehicles, as distance from the roadway increased, rumble strip noise became the dominant contributor to elevated sound levels. Elevated sound levels from motorcycles did not really pose any problems as the sound level of the bike dropped to less than 45 dBA at a lateral distance of 200 m from the roadway regardless of the rumble strip depth.
- For all test vehicle / rumble strip combinations, it was concluded that increased sound level from the rumble strip is negligible beyond a distance of 500 m.
- Generally, more noise was produced from a vehicle driving on rumble strips as opposed to operating in the normal driving lane (10-14 dBA more for the tractor-trailers, 14-17 dBA for the passenger vehicle, and 5-7 dBA for the motorcycle, as measured at the road edge).
- An increase in speed from 80 km/h to 120 km/h does little to increase the sound level when the vehicle is in the normal driving lane; however, sound level was greatly affected by increased vehicle speed with the vehicle driving on the rumble strips. Only the passenger vehicle was used for this test.

The key findings regarding appropriate rumble strip dimensions to alert drivers are outlined below:

- At depths of 6 mm and less, changes in sound level and vibration are subtle in both the passenger vehicle and the tractor trailer.
- At a depth of 8 mm, increased noise and vibration was noticed within the passenger vehicle and tractor-trailer; the driver of the motorcycle began to feel vibration through the handle bars.
- Although similar sound levels were produced from intermittent and continuous rumble strips of similar depths, the test drivers found that the best performance came from the intermittent rumble strip. It is likely that the variable nature of an intermittent sound makes it more noticeable and less likely to blend into background noise.
- There is no in-cab sound contribution in tractor-trailers from rumble strips until the strips reached a depth of 8 mm. With the radio on, noise was only picked up on strips of 8 mm depth and 500 mm wide. Strips of 300 mm width were not found to be as effective for tractor-trailers because they closely matched the tire width of approximately 230 mm. For the passenger vehicle there was a noticeable increase in sound level for all depths.

- In general, sound level increased with rumble strip depth.

The tests also measured the amount of traffic contact with the rumble strips (both shoulder and centreline) on horizontal curves. The test results showed that approximately 17 % of passenger vehicles and 47 % of all trucks contacted the rumble strips (centreline and shoulder inclusive) (14).

**Summary:**

**In-Vehicle Noise**

- A depth of 8 mm is required to create any noticeable effect on the tractor-trailers. Depths of 6 mm or less produce no changes in sound level and vibration.
- A rumble strip width of 500 mm is more effective where a large proportion of the highway traffic is heavy vehicles, in known locations where large trucks typically encroach to the roadside, there is a history of run-off-the-road collisions involving trucks, and a B/C analysis shows that the additional cost for a wider shoulder rumble strip is cost effective.

**Environment Noise**

- Studies show that rumble strips terminated 200 m prior to residential or urban areas produce tolerable noise impacts on residences. At an offset of 500 m, the noise from rumble strips is negligible.

### 3.3 Application Guidelines

The provinces of Alberta, British Columbia, Ontario, Saskatchewan, as well as the City of Edmonton have guidelines on the application of shoulder rumble strips. The guidelines specify the type of road (urban and rural highways, two-lane and multi-lane), the location on the road (median and outside shoulder), and the minimum required shoulder width for installation. A compilation and review of these guidelines has led to the selection of appropriate locations for the application of shoulder rumble strips.

Given the known safety benefits and cost effectiveness of shoulder rumble strips, their use should be considered on all two-lane and multi-lane highways as warning measures for drivers. Section 3.3.1 outlines general guidelines related to the application of shoulder rumble strips on highways. Once locations have been identified for the implementation of shoulder rumble strips, there are specific circumstances that require consideration. Section 3.3.2 outlines additional guidelines to consider under special circumstances such as highways with substantial bicycle use or highways that are designated as bicycle routes.

#### 3.3.1 General Guidelines

Experience shows that shoulder rumble strips **are effective and appropriate** in the following locations:

- On all two-lane and multi-lane highways,
- On two-lane and multi-lane highways with partially or fully paved shoulders, where 200 mm of paved shoulder can be maintained between the outside edge of the rumble strip and the edge of pavement,
- On multi-lane highways on the median shoulder where 200 mm of paved shoulder can be maintained between the outside edge of the rumble strip and the edge of pavement or physical constraint such as a barrier,
- In an interchange area, milled-in shoulder rumble strips may be used selectively on the left and right shoulders of all ramps to address on-going collision patterns or to reduce the incidence of run-off-the-road collisions in the vicinity of major hazards such as concrete structures,
- In the above noted locations, even when scheduled for rehabilitation, if a benefit / cost analysis shows that the installation is cost effective.

**Additional roadway characteristics** that should be reviewed and considered by the highway agency when implementing shoulder rumble strips are summarized below:

- Shoulder rumble strips should be interrupted at intersections with side roads, commercial driveways, and residential driveways and wherever it is needed and required to allow cyclists to merge to the left of the rumble strip:
  - They are normally terminated 60 m prior to an intersection, measured from the beginning of the intersection treatment.
  - They are reinstated 30 m past an intersection, measured from the end of the intersection treatment.

- Shoulder rumble strips should terminate 30 m prior to the start of a right turn lane or taper.
- Shoulder rumble strips should be considered at critical locations such as approaches to narrow bridges or parapet walls, narrow clear zones, gore or bull-nose areas, in advance of impact attenuators and at-grade railway crossings, and at other critical locations.
- Shoulder rumble strips may be installed in conjunction with a construction project or as a separate contract on a new or existing road.
- Shoulder rumble strips should be installed at right angles to the direction of travel.
- Shoulder rumble strips should be considered for installation on vertical or horizontal curves at collision-prone areas.
- The installation of shoulder rumble strips should be deferred if planned construction will require traffic diversion onto the shoulder for a substantial period.
- The jurisdiction should ensure that the installation does not invalidate any existing pavement warranty.
- When shoulder rumble strips are applied on a highway, the far right lane on the side of the highway where the installation is taking place should be closed to traffic and traffic management measures applied (i.e. signing, traffic control) in accordance with the applicable standards in place. This should include appropriate protection measures for workers and traffic travelling through the area.
- Where shoulder rumble strips are proposed, the locations and patterns should be illustrated on construction plans and reviewed and accepted by the project sponsor.
- Shoulder rumble strips can be used during construction staging contracts. Alberta has used shoulder rumble strips as a temporary measure in construction staging for paving contracts. Alberta Infrastructure uses either milled or rolled-in rumble strips for these applications where the shoulder rumble strip will be in place for a limited time period of 2-3 years (6).
- For long-term rehabilitation projects requiring traffic to use the shoulder, the rumble strips should be filled and after construction is complete, the shoulder should be resurfaced and a new milled shoulder rumble strip created.

Experience has shown that shoulder rumble strips **are not appropriate** in the following locations and in the following circumstances:

- Where the recommended dimensions cannot be attained,
- Through urban areas,
- On highways with partially paved shoulders (0.5 m width) that are designated as bicycle routes or have substantial bicycle traffic,
- Where pavement deterioration or cracking is evident to avoid problems such as excessive break-up of the pavement,

- Within 1.0 m of sawn and sealed traverse joints,
- Within 1.0 m of sealed traffic counting and traffic signal loop detector lead wires,
- On bridge decks and overpass structures and within 1.0 m of expansion joint dams.

**Summary:**

- Shoulder rumble strips may be applied in the following locations:
  - On all two-lane and multi-lane highways,
  - On two-lane and multi-lane highways with partially or fully paved shoulders and no cyclist use, where 200 mm of paved shoulder can be maintained between the outside edge of the rumble strip and the edge of pavement,
  - On multi-lane highways on the median shoulder where 200 mm of paved shoulder can be maintained between the outside edge of the rumble strip and the edge of pavement or physical constraint such as a barrier,
  - In interchange areas on a selective basis, based on collision-prone locations,
  - In the above noted locations, even when scheduled for rehabilitation, if a benefit / cost analysis shows that the installation is cost effective.
- Shoulder rumble strips should not be used in the following locations:
  - Where the recommended dimensions do not exist,
  - Through urban areas,
  - Where pavement deterioration or cracking is evident,
  - On bridge decks and overpass structures,
  - Within 1.0 m of sawn and sealed traverse joints, sealed traffic counting and traffic signal loop detector lead wires, and expansion joint dams.
- Shoulder rumble strips should be interrupted at intersections with side roads, commercial driveways, and residential driveways, or wherever it is needed to allow cyclists to merge to the left of the shoulder rumble strip.
- Development of appropriate machinery and continued practice results in effective implementation of shoulder rumble strips, as evidenced by Alberta Infrastructure.

### 3.3.2 Guidelines for Shared-Use Shoulders (Bicycle Routes)

Shoulder rumble strips are effective measures to warn drivers that they are leaving the travelled way. However, the application of shoulder rumble strips on roads used by bicyclists has been of concern in the past. This section provides information on studies undertaken to determine the impact on bicycles from the use of shoulder rumble strips as well as guidelines to consider when rumble strips are applied on highways with bicycle use.

A survey of cyclists in Utah (15) concluded that 17% did not want rumble strips at all, 46% preferred the placement of the rumble strips against the travel lane to create a buffer zone against traffic, and 35% preferred the rumble strips placed as far to the right as possible, allowing cyclists to ride with the least amount of gravel and debris. The use of the rumble strip as a buffer between

cyclists and traffic is generally acceptable as long as there is sufficient pavement width to the right of the rumble strip that is free of gravel and debris.

A study undertaken in Arizona (11) recommends that rumble strips on all uncontrolled highways include periodic gaps of 12ft (3.7 m) in length to permit bicycle traffic to cross the rumble strip area without striking the pattern itself. These gaps should be placed at intervals of 40ft (12.2 m) or 60ft (18.3 m). These distances were tested on sites by a sample of cyclists with varying abilities, at speeds representative of downhill conditions.

A 3.7 m gap in a 18.3 m cycle will result in 80 % coverage of the shoulder with rumble strips. A 12.2 m cycle (8.5 m long rumble strip with 3.7 m gap) should also be considered for use as it provides 70% coverage (11).

Typical departure angle for run-off-the-road crashes is approximately 3 degrees (11). At this angle, the centre of the critical tire (right front tire) will travel 190 mm laterally for every 3.7 m longitudinally. Therefore it will be impossible for the tire to completely miss a 200 mm or 300 mm width rumble strip if a 3.7 m gap is used (11).

In 2000 and 2001, British Columbia is pioneering testing the application of shoulder rumble strips on narrow shoulder widths by placing the rumble strip on or straddling the painted edge line.

The following guidelines are applied when installing shoulder rumble strips on highways that are designated as **bicycle routes** or that **have substantial volumes of bicycle traffic**:

- Shoulder rumble strips can be installed on fully paved shoulders where a clear paved width of 1.5 m can be maintained between the outside edge of the rumble strip and the edge of pavement. A 1.5 m paved area is the typical width for a bicycle lane; however, this width can range between 1.2 m and 1.5 m where space is limited (13). If the rumble strip is placed with no offset from the painted line, has a width of 300 mm, and 1.5 m of clear pavement is maintained, a paved shoulder width of 1.8 m is required to accommodate cyclists.
- Shoulder rumble strips should not be installed on highways with partially paved shoulders (0.5 m pavement width).
- Shoulder rumble strips should be interrupted wherever it is needed and required to allow cyclists to merge to the left of the shoulder rumble strip (such as to avoid riding over a drainage grate).
- Openings in the shoulder rumble strip pattern should be carefully selected to ensure that the locations provide good visibility for cyclists and drivers and are on straight alignments, not curves.

**Summary:**

- Cyclists and rumble strips can coexist on the shoulder of a highway.
- A width of 1.5 m of clear paved shoulder between the outside of the rumble strip and the edge of pavement is adequate to provide cyclists with a clear travel path. Where space is limited, the clear paved width for cyclists can range between 1.2 m and 1.5 m.

- Shoulder rumble strips should be interrupted where necessary to allow cyclists to merge to the left of the shoulder rumble strip.

### 3.3.3 Machinery Requirements

In Ontario, there is a specification in the Ministry's Directive that states "An inspection of the proposed site of the Shoulder Rumble Strips will be required to confirm the distance from the travelled way to any obstructions as the current machinery used to mill-in Rumble Strips requires a minimum lateral clearance of 0.85 m between the outside edge of the depression and any obstruction such as guide rail, concrete barrier, concrete curb, etc." (17).

In Alberta, the province specifies the final product requirements and tolerances and it is up to the contractor to decide on the appropriate machinery to use for the specific contract. An example of contract specifications used in Alberta is provided in **Appendix B**. These specifications include details on the equipment to be used in accordance with the standard drawings for shoulder rumble strips, highway operations, measurement, and payment.

Milling machines should be equipped with an integral sweeping device mounted directly behind the cutter; otherwise, a separate sweeping operation should be conducted as construction of the rumble strips progresses within the signed construction zone.

### 3.4 Maintenance Guidelines

Once shoulder rumble strips are installed, there are very few maintenance issues to be addressed. It has been shown in the United States and in Canada that the installation of shoulder rumble strips in new or well maintained pavement does not alter the rate of deterioration of the pavement. It has also been shown that concerns regarding debris collecting in the rumble strip or water and ice collecting in the rumble strip during the freeze / thaw weather periods are for the most part unfounded. Rumble strips are self-cleaning as the vibration of vehicles travelling over the rumble strips breaks down and knocks out water, ice, or debris that may collect in the groove.

The following guidelines are recommended to ensure the proper maintenance of shoulder rumble strips:

- When grading the gravel shoulders adjacent to partially paved shoulders, care should be taken to eliminate getting debris in the shoulder rumble strips.
- After milling, the shoulder rumble strip must be swept and the debris disposed of in an appropriate manner.
- During the winter months, plowing and deicing materials should be applied as part of the normal road maintenance procedures. If ice or snow accumulates in the grooves, additional applications of de-icing material should be applied.
- During summer months, inspection for cracking, potholing, water ponding and snow plow blade damage should be conducted. If required, corrections should be undertaken, such as crack sealing, pot hole patching, measures to ensure positive drainage, rehabilitation of pavement grinding, paving and re-grooving.

## 3.5 Benefit / Cost Analysis

A benefit / cost analysis example is described below. This analysis aims to estimate the cost-effectiveness of installing shoulder rumble strips on highways. Current cost information from Alberta, who have extensive experience with shoulder rumble strips, and from New Brunswick, who are new to the application of shoulder rumble strips have been incorporated into this example.

The benefit of installing shoulder rumble strips is the reduction in run-off-the-road collisions. Many states have completed before / after collision analyses to determine the reduction in these types of collisions due to the installation of shoulder rumble strips. This data was summarized in **Table 1**.

### 3.5.1 Costs

Alberta and New Brunswick supplied year 2000 costs for the installation of milled shoulder rumble strips.

The province of Alberta has had significant experience with the installation of shoulder rumble strips. The cost to install milled-in shoulder rumble strips has decreased in the past few years, mainly due to the ability of the province to tender a separate contract just for the installation of shoulder rumble strips.

In Alberta, two shoulder rumble strip installations were completed in 2000, each under separate contract. The costs to install milled continuous shoulder rumble strips ranged from \$400 / km for a 155 km stretch of highway to \$425 / km for a 129 km stretch of highway (6).

In New Brunswick, the first shoulder rumble strip installations were completed in 2000 at a cost of \$1,080 / km for two 5 km sections of highway (18).

As shown, as the project length for implementation increases, the unit price to install the shoulder rumble strip is reduced.

### 3.5.2 Benefit / Cost Calculation Example

An example benefit / cost analysis was completed for the installation of shoulder rumble strips on a two-lane rural highway. The detailed calculations and the resulting B/C ratios are summarized in **Table 3**.

An estimate of the number of collisions per kilometre-year was developed for a two-lane highway without rumble strips using the safety performance function (SPF) for a Kings Arterial road ( $\leq 4$  lanes, rural) in Ontario (19). The SPF provides an estimate of collisions based on the AADT of the roadway. For this example, a range of AADTs from 2,000 to 10,000 vehicles / day was used to show the impact of different AADT volumes on the overall benefit / cost ratio.

The Ontario Road Safety Annual Reports were reviewed and it was determined that approximately 27% of all collisions in Ontario are single vehicle collisions for the years between 1992 to 1996 (20-24). Single vehicle collisions are normally caused by vehicles leaving the travelled lane and either hitting a roadside object or overturning (25). It was assumed that 27% of the estimated number of collisions on the two-lane highway were those that could be prevented

by the use of shoulder rumble strips. This 27% represents the target collisions for the shoulder rumble strip countermeasure.

Various sources from the United States were reviewed to determine the reduction in single vehicle run-off-the-road collisions due to the installation of shoulder rumble strips. These sources are shown in **Table 1**. A 30% reduction in single vehicle run-off-the-road collisions, representing a collision modification factor (CMF) of 0.70 was adopted for this example analysis. This reduction is in total number of collisions and does not provide specific information on reduction in injury or property-damage-only collisions.

The total cost savings by a reduction of one collision per kilometre-year was derived from a study completed in a 1995 economic evaluation of rumble strips. In this study it was stated that the economic value of reducing a highway shoulder-related collision was estimated for Ontario conditions to be \$76,638 (in 1994 CDN\$) (12). Using a 2% inflation rate, this cost was factored up to \$86,110 to reflect year 2000 costs.

To determine the total cost savings per kilometre-year from the installation of shoulder rumble strips, the total number of collisions that can be reduced (total number of collisions multiplied by the target collision percentage of 27% multiplied by the percent reduction in collisions of 30%) was multiplied by the cost savings of reducing one collision.

The costs to install the shoulder rumble strips were taken from the current year 2000 costs provided by Alberta and New Brunswick. The information from both provinces was used (including unit cost and length of contract) to illustrate the difference between implementing a small test strip, which has a high unit cost, with implementation in a large area, which has a lower unit cost. A mobilization cost was also included to account for the additional costs required to mobilize the equipment to complete the work.

The service life of rumble strips is expected to be the same as the pavement itself (2-8 years for asphalt pavement and 25 years for concrete pavement) (25). Individual agencies will determine the life span of the pavement identified for the rumble strip application. Maintenance and operational issues related to weather or to pavement degrading by milling the shoulder have proved to be of no concern (9). Therefore, it was assumed for this analysis that there are no additional maintenance requirements for shoulder rumble strips beyond normal pavement and shoulder maintenance.

To complete the benefit / cost analysis, the annual collision cost savings were brought to a net present value, assuming asphalt shoulders with a life span of 5 years and a discount rate of 6%. Since the cost of shoulder rumble strips includes installation only, these costs are already at present value.

The results of the benefit / cost analysis show that the benefits of installing shoulder rumble strips in terms of the collision cost savings far outweigh the cost of installation, even at low AADT volumes, on a 2-lane rural highway. For AADT volumes from 2,000 to 10,000, the B/C ratios range from 21.0 to 77.7 using the Alberta cost and installation information and from 5.2 to 19.1 using the New Brunswick cost and installation information. The large range in B/C ratios between Alberta and New Brunswick is due to the large difference in installation costs and the difference in the length of section for application of the shoulder rumble strips. The results also show that short sections with rumble strips are cost effective.

**Table 3**  
**Benefit / Cost Example Calculation**

Assume a highway with a  
2-lane cross section

Use **Safety Performance Function (SPF)** for  
Non-Intersection Collisions on Road Sections  
**Target Collisions** (single vehicle) = 27% of total collisions  
(20-24)  
**Collision Modification Factor (CMF)** = 0.70 (30% of  
projected reduction of target collisions)  
**Average Cost** of a Target Collision (2000 \$) = \$86,110 (12)

$SPF = a(AADT)^b$   
= Expected Collisions per km- year

**Expected Collisions**

| SPF    | a         | b      |
|--------|-----------|--------|
| Fatal  | 0.0000261 | 0.8116 |
| Injury | 0.0003976 | 0.8116 |
| PDO    | 0.0009228 | 0.8116 |

| AADT                                          | 2000    | 4000    | 6000     | 8000     | 10000    |
|-----------------------------------------------|---------|---------|----------|----------|----------|
| Total Collisions / km-year                    | 0.64    | 1.13    | 1.57     | 1.98     | 2.37     |
| Target Collisions / km-year                   | 0.17    | 0.30    | 0.42     | 0.53     | 0.64     |
| # collisions reduced / km-year                | 0.05    | 0.09    | 0.13     | 0.16     | 0.19     |
| Collision cost savings / km-year<br>(Benefit) | \$4,486 | \$7,874 | \$10,942 | \$13,820 | \$16,563 |

**Collision Cost Savings per Year**

|                      |           |             |             |             |             |
|----------------------|-----------|-------------|-------------|-------------|-------------|
| Alberta (155 km)     | \$695,336 | \$1,220,424 | \$1,696,003 | \$2,142,036 | \$2,567,314 |
| New Brunswick (5 km) | \$22,430  | \$39,369    | \$54,710    | \$69,098    | \$82,817    |

**Net Present Value of Collision Savings** (Asphalt shoulder life span - 5 years  
(Discount Rate – 6%)

|               |             |             |             |             |              |
|---------------|-------------|-------------|-------------|-------------|--------------|
| Alberta       | \$2,929,010 | \$5,140,871 | \$7,144,180 | \$9,023,036 | \$10,814,460 |
| New Brunswick | \$94,484    | \$165,835   | \$230,457   | \$291,066   | \$348,854    |

**Installation Costs (both sides)**

|                             |           |           |           |           |           |
|-----------------------------|-----------|-----------|-----------|-----------|-----------|
| Alberta (\$425 / km)        | \$131,750 | \$131,750 | \$131,750 | \$131,750 | \$131,750 |
| New Brunswick (\$1080 / km) | \$10,800  | \$10,800  | \$10,800  | \$10,800  | \$10,800  |

**Mobilization Costs**

|                                            |         |         |         |         |         |
|--------------------------------------------|---------|---------|---------|---------|---------|
| Alberta                                    | \$7,500 | \$7,500 | \$7,500 | \$7,500 | \$7,500 |
| New Brunswick (assumed same as<br>Alberta) | \$7,500 | \$7,500 | \$7,500 | \$7,500 | \$7,500 |

**TOTAL COSTS**

|               |           |           |           |           |           |
|---------------|-----------|-----------|-----------|-----------|-----------|
| Alberta       | \$139,250 | \$139,250 | \$139,250 | \$139,250 | \$139,250 |
| New Brunswick | \$18,300  | \$18,300  | \$18,300  | \$18,300  | \$18,300  |

**Benefit / Cost Ratio**

|               |      |      |      |      |      |
|---------------|------|------|------|------|------|
| Alberta       | 21.0 | 36.9 | 51.3 | 64.8 | 77.7 |
| New Brunswick | 5.2  | 9.1  | 12.6 | 15.9 | 19.1 |

## 4.0 CENTRELINE RUMBLE STRIPS

### 4.1 Definition

Modelled after shoulder rumble strips, which alert drivers that they are leaving the travelled roadway, centreline rumble strips are placed between opposing lanes of traffic on an undivided roadway to alert drivers that they have crossed over into the path of oncoming traffic (14). This warning is in the form of increased noise heard inside the vehicle and a vibration of the vehicle, similar to that from shoulder rumble strips.

Two different types of centreline rumble strips are currently in use, milled-in and raised. Rolled-in centreline rumble strips, similar to those discussed in Section 3.1 for shoulder rumble strips, are not used in centreline rumble strip applications.

- **Milled centreline rumble strips** are installed using the same milling technique discussed in Section 3.1 for milled-in shoulder rumble strips.
- **Raised centreline rumble strips** typically consist of inverted, thermoplastic markers or striping and raised plastic reflectors that adhere to new or existing pavement.



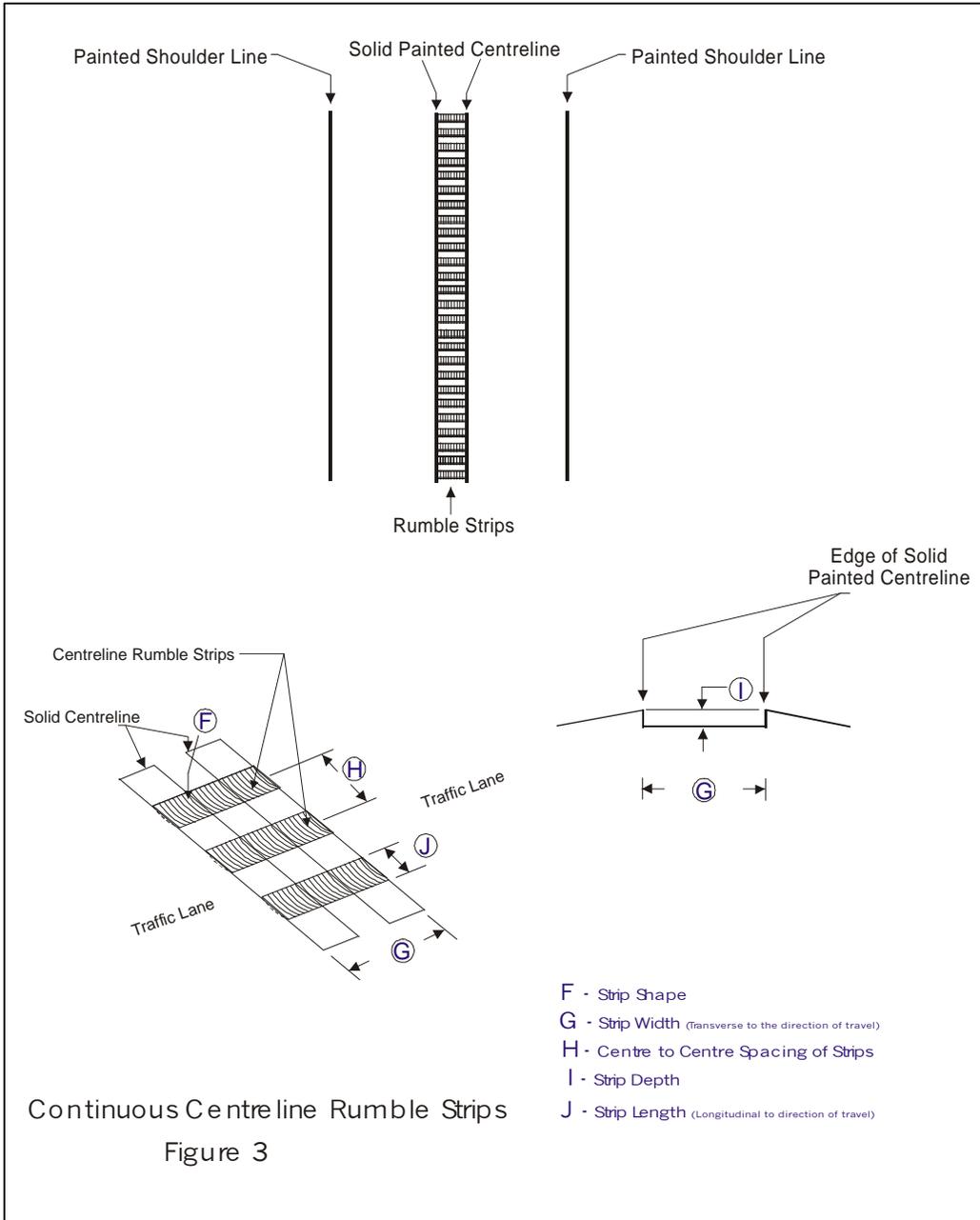
**An example of milled centreline rumble strips undertaken by Alberta Infrastructure**

**Photo thanks to: Dr. John Morrall, University of Calgary  
Equipment Courtesy: All West Bobcat Services**

## 4.2 Design Parameters

### 4.2.1 Terminology

To ensure consistency in terminology used by Canadian highway agencies in describing the dimensions and design parameters for centreline rumble strips, **Figure 3** provides a diagrammatic definition of the dimensions required for the application of centreline rumble strips.



## 4.2.2 Types of Centreline Rumble Strips

Typically, two types of centreline rumble strips are installed: milled or raised.

The technique used for milling centreline rumble strips provides the flexibility to install rumble strips along the centreline of new and existing pavement and on both asphalt and concrete pavement. The milled-in process is also used to ensure accuracy in placement and dimension of the centreline rumble strips, an important consideration in the installation process. To date it has been found that the milling-in process does not affect the structural integrity of either asphalt or concrete roads (2).

Raised centreline rumble strips are reflective to define the centreline of the road at night and in poor weather. Because they extend above the pavement, raised centreline rumble strips are usually restricted to warm climates that do not require snow removal.

### Summary:

- The milled-in method of centreline rumble strip application is appropriate for use on new or existing pavement.
- Raised centreline rumble strips are not appropriate in Canada due to winter weather conditions.

## 4.2.3 Design Dimensions

Currently few North American jurisdictions have implemented centreline rumble strips.

In Kansas, various widths of rumble strips as well as continuous 12 inch (300 mm) and 24 inch (400 mm) spacing and alternating 12 inch / 24 inch (300 mm / 600 mm) spacing are undergoing testing for noise levels. Noise levels inside and outside the vehicle were tested using 6 different types of vehicles and two different speeds. Preliminary findings suggest that the continuous 12 inch spacing created the highest decibel readings. Differences in noise with the different width of strips are not so obvious (26).

Testing in Alberta (14) has found that many motorists encroach on the centreline of the road and this has resulted in complaints from nearby residents of the excessive noise. Testing of various depths of milled-in rumble strips, retaining the same length and spacing of strips, using three different vehicle types (tractor trailer, pick-up truck, and motorcycle) was completed. For centreline rumble strips, the testing led to the recommendation that rumble strips be at least 8 mm deep and 300 mm wide. Motorcycles encountered no adverse handling conditions when riding on or over the rumble strips except for braking, which was not an issue since it was unlikely that deceleration would occur entirely within the rumble strip zone. Where significant heavy vehicle use was encountered, a 500 mm wide rumble strip created more significant noise and vibration in the cab of a tractor-trailer.

A summary of the current dimensions in use in North America is provided in **Appendix C**. From this summary, guidelines on recommended dimensions to use when constructing centreline rumble strips have been developed. The recommended design dimensions for centreline rumble strips are summarized in **Table 4**.

**Table 4**  
**Design Dimensions – Milled-In Centreline Rumble Strips**

| Dimension                                 | Guideline       | Comments                                                                                                                                                                                                                                                                     |
|-------------------------------------------|-----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| F<br>(strip shape)                        | Rounded         | This is consistent with current practices in North America and with most milling equipment.<br><br>The semi-circular shape is preferred because these are easier to clean, if necessary, and they resist the loss of aggregates due to the small number of sharp edges (12). |
| G<br>(strip width)                        | 300 mm          | For use on typical highways in no-passing zones. Rumble strips span the width of the two solid pavement markings plus the space in between the pavement markings. The rumble strip remains entirely within the painted lines.                                                |
| H<br>(centre to centre spacing of strips) | 300 mm          | This is consistent with most current practices in North America.                                                                                                                                                                                                             |
| I<br>(strip depth)                        | $8 \pm 2$ mm    | A depth of 8 mm provides sufficient noise and vibration to alert drivers without creating excessive noise in the surrounding area.                                                                                                                                           |
| J<br>(strip length)                       | $175 \pm 25$ mm | This is consistent with most current practices in North America.                                                                                                                                                                                                             |

**Summary:**

- The following design dimensions for continuous milled-in centreline rumble strips are appropriate:

|                              |                              |
|------------------------------|------------------------------|
| ‘F’ – Strip Shape            | Rounded                      |
| ‘G’ – Strip Width            | 300 mm, within painted lines |
| ‘H’ – Spacing Between Strips | 300 mm                       |
| ‘I’ – Strip Depth            | $8 \pm 2$ mm                 |
| ‘J’ – Strip Length           | $175 \pm 25$ mm              |

- Centreline rumble strips should be placed in the centre of the road within the centreline pavement markings.

#### 4.2.4 Noise Concerns

Complaints about noise from rumble strip contact (both shoulder and centreline) prompted the province of Alberta to commission a noise study on rumble strips to identify the optimum dimensions for rumble strips in terms of alerting drivers, as well as the noise impacts of rumble strips on the surrounding area.

Various depths of milled-in rumble strips were tested, retaining the same length and spacing of strips, using three different vehicle types (tractor trailer, pick-up truck, and motorcycle). The topography of the test locations is flat or rolling terrain.

Preliminary findings in Kansas using 12-inch continuous, 24-inch continuous, and 12-inch / 24-inch alternating spacing suggest that the continuous 12-inch spacing created the highest decibel readings; however, differences in noise with the different width of strips (5-inch, 8-inch, 12-inch, and 16-inch) was not so obvious (26).

The results of the Alberta and Kansas testing are summarized in Section 3.2.4 in the shoulder rumble strips chapter and led to the recommendation to prohibit the installation of rumble strips (shoulder or centreline) 200 m prior to a residential area due to noise concerns. Beyond 200 m the sound from the rumble strips is 'comfortable' and beyond 500 m the sound is negligible (14).

**Summary:**

**In-Vehicle Noise**

- A depth of 8 mm is required to create any noticeable effect on the tractor-trailers. Depths of 6 mm or less produce no changes in sound level and vibration.

**Environment Noise**

- Studies show that rumble strips terminated approximately 200 m prior to residential or urban areas produce tolerable noise impacts on residences. At an offset of 500 m, the noise from rumble strips is negligible.

## 4.3 Application Guidelines

### 4.3.1 General Guidelines

Most states in the United States and the province of Alberta restrict the use of centreline rumble strips to areas where there is a double solid painted centreline – a no-passing zone. Although some states use centreline rumble strips in passing zones, many jurisdictions have two main concerns on the use of centreline rumble strips in passing zones:

- The impact on the handling of vehicles crossing the centreline to pass, particularly motorcycles.
- The concern of sending a mixed message to drivers regarding the use of rumble strips. The purpose of rumble strips is to indicate to drivers that when you hear and feel the rumble strips you should move back into your lane, however, drivers will hear and feel the centreline rumble strips in areas where they are legally permitted to cross the rumble strips to pass (6).

Two American states (Colorado and Arizona) apply centreline rumble strips in passing zones, with the viewpoint that drivers are more likely to go to sleep on long, straight stretches (passing zones) thus centreline rumble strips may be most effective at these locations (26). Anecdotal comments from staff in Colorado indicate that they feel that centreline rumble strips in passing zones have cut the ill-advised passing and dangerous “peeking out” behaviour considerably (2).

Testing in Alberta (14) with motorcycle drivers found that no adverse handling conditions were experienced when driving on the 8 mm deep rumble strips, except for some braking issues. However, the reduction in deceleration performance was determined to be of no major concern since it was unlikely that deceleration would occur entirely within the rumble strip zone.

The placement of centreline rumble strips also varies between states. Most states, as well as the province of Alberta, place the milled centreline rumble strip on the double painted centrelines (no-passing lines) so that the rumble strips are within the centreline pavement markings (2). California places the pavement markings on the outside of the rumble strips and the reflective pavement markings, creating a centre median effect since the centreline markings are approximately 28 inches (710 mm) apart (2). In states where rumble strips are placed in passing zones, they may be placed on either side of the dashed pavement marking (4).

A study conducted by Kansas State University in 1999 – 2000, included a survey of jurisdictions currently using centreline rumble strips. Some of the comments received in this survey are included below for information (2).

- No jurisdiction indicated concern with drivers jerking the wheel the wrong way when they drove over centreline rumble strips.
- No jurisdiction was aware of negative effects of vehicles crossing centreline rumble strips.
- Few responses were received from the motorcycle communities in states with centreline rumble strips.
- There were no negative comments about the safety of centreline rumble strips.

- The most serious concern seems to be noise disturbing residents along the highway.

Current experience indicates that centreline rumble strips **are appropriate** in the following locations:

- On two-lane or four-lane undivided rural roads where double solid painted barrier lines currently exist, demarcating a 'No-Passing' zone, including horizontal and low radius curves, climbing or passing lanes, and tangent section no-passing zones where the length is greater than 300 m,
- On two-lane or four-lane undivided rural roads where there has been a high occurrence of cross-over or head-on collisions,
- On horizontal curves on all undivided highways with a high collision history.

**Additional guidelines** for installation follow:

- When centreline rumble strips are applied on a highway, appropriate lane closures and / or traffic management measures (i.e. signing, traffic control) in accordance with the applicable standards are generally required. This should include appropriate protection measures for workers and traffic travelling through the area.
- Centreline rumble strips in residential or urban areas are not used due to the noise impact.
- If it is desired to retrofit centreline rumble strips on existing pavement, the pavement should be in sufficiently good condition to effectively accept the milling process without ravelling or deteriorating. Otherwise the pavement should be upgraded prior to milling the centreline rumble strips.
- The application of centreline rumble strips can be completed at a rate of about 1 km per hour. It may take slightly longer to apply centreline rumble strips than shoulder rumble strips since the centreline application is more intermittent due to passing zones (6).
- Centreline rumble strips may be installed by separate contracts and do not have to be part of a construction or restoration project.
- The milling of centreline rumble strips is coordinated with traffic line painting operations to avoid milling newly applied traffic lines and to ensure that new yellow centrelines are installed within a short period of time after completion of the milling of the centreline rumble strip.
- Reinstallation of the centreline pavement markings is completed in both directions to ensure adequate paint coverage in the rumble strip groove.

**Travel lane widths** for the application of centreline rumble strips:

- In the United States, jurisdictions consistently applied centreline rumble strips on roads with travel lane widths of 11 feet (3.4 m). Many jurisdictions recommend that centreline rumble strips be applied on roads where the travel lane width ranges between 11 feet (3.4 m) and 12 feet (3.6 m) (2).

- Some jurisdictions require that a paved shoulder width of 1.2 m be available on roads where the travel lanes are 3.4 m wide and centreline rumble strips are to be installed (2).

Current experience indicates that centreline rumble strips **are not appropriate** in the following locations:

- 200 m prior to a residential or urban area,
- Across the intersection of a commercial entrance or of a side road. A 45-m gap in the centreline rumble strips for turning traffic is current practice,
- On bridge decks.

**Summary:**

- Centreline rumble strips are appropriate in the following locations:
  - On two-lane and four-lane undivided roads in no-passing zones,
  - On horizontal curves with high collision history or low radius curves,
  - On climbing or passing lanes with no-passing zones.
- Centreline rumble strips are not appropriate in the following locations:
  - Within 200 m of a residential or urban area,
  - On bridge decks,
  - In passing zones on two-lane roads,
  - Across the intersections of a road or commercial entrance.
- The effects of implementing centreline rumble strips in passing zones should be reviewed once additional studies on this topic have been completed.
- Continuous centreline rumble strips may be applied on undivided highways if the local agency identifies a history of head-on or side swipe collisions and a B/C analysis shows that the implementation of centreline rumble strips is cost effective.
- The highway agency should undertake a benefit / cost analysis to verify the cost effectiveness of implementing centreline rumble strips for low AADT volume roads.
- To date, centreline rumble strips have been installed on highways with lane widths as narrow as 3.4 m.

### 4.3.2 Machinery Requirements

The installation of centreline rumble strips does not require different machinery than the installation of milled-in shoulder rumble strips.

As with shoulder rumble strip installation, the province of Alberta specifies the final product requirements and tolerances for the installation of centreline rumble strips and the contractor is responsible to decide on the appropriate machinery to use for the specific contract. An example of contract specifications used in Alberta is provided in **Appendix B**. These specifications include

details on the equipment to be used in accordance with the standard drawings for shoulder rumble strips, highway operations, measurement, and payment.

Milling machines should be equipped with an integral sweeping device mounted directly behind the cutter otherwise; a separate sweeping operation should be conducted as construction of the rumble strips progresses within the signed construction zone.

After milling, the contractor should pick up and dispose of all debris created from the milling operation.

### **4.3.3 Temporary Traffic Control**

The installation of centreline rumble strips is a mobile operation and, typically, the highway must be kept open for traffic during the installation.

Appropriate temporary traffic control measures, consistent with local policies and guidelines for temporary traffic control in mobile workzones, are suitable to protect the workers and road users during the centreline rumble strip installation procedures.

## 4.4 Maintenance Guidelines

Generally all states surveyed in the Kansas State University study agreed that milling-in centreline rumble strips did not affect the structural integrity of either asphalt or concrete roads (2).

Most American jurisdictions that currently use centreline rumble strips have noted no problems with the rumble strip visually affecting the night time retroreflectivity of the yellow painted lines (2).

In Alberta, the highway agency repaints the centreline markings after the installation of centreline rumble strips. This painting is done to increase the visibility of the centreline, although the centreline is still quite visible after the milling process. The repainting has to be done in both directions to ensure that the rumble strip is completely painted (6).

Alberta has experienced no difficulties or adverse wear of pavement markings after the installation of centreline rumble strips. Alberta Infrastructure's staff have observed that the pavement marking in the groove of the rumble strip may actually experience less wear and tear from plows and vehicles as the paint is protected from the surface (6).

Maintenance issues specific to centreline rumble strips were not identified by the highway agencies. Regular highway maintenance practices are, at present, followed by all.

## 4.5 Benefit / Cost Analysis

Limited cost information is currently available regarding the installation of centreline rumble strips. In 2000, Alberta is the only province in Canada to install centreline rumble strips on a highway.

Even more limited information is currently known on the effectiveness of centreline rumble strips in reducing head-on and side-swipe collisions.

The state of Minnesota undertook two separate applications of centreline rumble strips, one in 1995 and one in 1996. Each location consisted of a 2-lane rural road with a posted speed limit of 55 mph (89 km/h). A review of 3-year before and after collision data along these sections of road revealed that the number of head-on collisions was not reduced after the installation of centreline rumble strips (3).

Pennsylvania and Delaware have implemented centreline rumble strips along with other countermeasures in no-passing zone areas and they have realized a reduction in collisions; however, a number of other factors may have contributed to this reduction (4).

California uses an elaborate centreline rumble strip system consisting of milled-in centreline rumble strips with raised inverted profile thermoplastic traffic stripes and raised plastic reflectors. The centreline rumble strips are only applied in no-passing zones. A review of 36 months of before / after collision data resulted in an 11.1 % reduction in collisions and a 76.9% reduction in fatalities (2).

Additional before / after studies are required to determine the effectiveness of centreline rumble strips.

### 4.5.1 Costs

In 2000, two separate rumble strip contracts were completed for the province of Alberta. Each contract involved the installation of shoulder and centreline rumble strips as well as rumble strip sets at STOP controlled locations.

The unit cost per kilometre to install the centreline rumble strips was slightly more than for the shoulder rumble strips even though the same milling equipment and process was followed for each. The added cost was due to the more extensive traffic management requirements for the centreline installation as both traffic lanes were kept open during the installation (6).

The cost to mill-in centreline rumble strips was \$600 / km for the first contract (23 km) and \$1,000 / km for the second contract (8 km) (6).

Alberta Infrastructure requested the contractor reinstall the centreline lane markings on the highway where the centreline rumble strips were installed, at a cost of \$800 / km for the 23 km section and \$900 / km for the 8 km section (6). It has not yet been confirmed that the centreline pavement markings require reinstallation after milling. Although the centreline pavement markings were still visible between the centreline rumble strips, the province decided to repaint the pavement markings to ensure that the pavement markings were as visible as possible. It should be noted that reinstallation of the centreline painting requires the contractor to paint the line in both directions to ensure adequate paint coverage in the rumble strip. Alberta

Infrastructure specified in these contracts that the reinstallation of pavement markings be undertaken within two weeks of the completion of the milling. This specification resulted in very high costs. In future projects, this specification may be modified to decrease painting costs.

Therefore, the overall cost in 2000 to install the centreline rumble strips and reinstate the centreline pavement markings ranged from \$1,400 / km to \$1,900 / km in Alberta.

#### 4.5.2 Benefit / Cost Calculation

An example benefit / cost calculation was not completed for the centreline rumble strips as adequate information on the costs, cost savings, and reduction in target collisions is currently not available, given the recent installation of centreline rumble strips in Canada and the United States.

The following information is required to complete the benefit / cost analysis for centreline rumble strips:

- An estimate of the number of collisions per kilometre-year. This can be calculated using the SPFs as done in the shoulder rumble strip analysis.
- The percentage of all collisions that are target collisions. Statistics are required on the proportion of collisions that are head-on or side-swipe collisions that would be impacted by the installation of centreline rumble strips.
- The reduction in the head-on and side-swipe collisions (the target collisions) attained through the installation of centreline rumble strips. Further studies on the before and after collisions at sites where centreline rumble strips have been installed are required to determine what proportion of the target collisions are reduced from their installation.
- The total cost savings by a reduction of one head-on or side swipe collision per kilometre-year.
- Installation costs for centreline rumble strips. Currently only Alberta has installed centreline rumble strips in Canada. As additional installations are undertaken, a better estimate of the cost of installation will be available.
- Maintenance costs for centreline rumble strips. To date research and practice have shown that there are few to no additional maintenance requirements after the installation of centreline rumble strips.

Once sufficient statistics and data become available, the benefit / cost analysis can be completed following the same procedure outlined in Section 3.5.2 for the shoulder rumble strips.

## **DEFINITIONS**

### **AADT**

Annual Average Daily Traffic (vehicles / day).

### **B/C**

Benefit / Cost ratio.

### **CMF**

Collision Modification Factor - Used to estimate the safety impacts of countermeasures, it indicates the reduction (or increase) in the frequency and severity of collisions after the implementation of the countermeasure.

### **dB**

Noise level (decibels) measured on a logarithmic scale.

### **dBA**

Noise level (effective decibels) measured using the A-scale on a standard sound level meter. The A-scale most closely correlates to human reaction to sound.

### **SPF**

Safety Performance Function – A mathematical relationship between the amount of traffic (AADT) on a highway and the safety of the highway, which is defined as the collision frequency expected on the highway per unit of time (or per unit of time and highway length).

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**APPENDIX A**  
**SHOULDER RUMBLE STRIPS**  
**CURRENT CANADIAN PRACTICES**

**SHOULDER RUMBLE STRIPS**  
Current Canadian Practices

| Agency           | Rumble Strip Frequency      | Distance from the Traveled Way<br>"A"                                      | Length of Pattern (longitudinal to direction of travel)<br>"B" | Width of Pattern (transverse to the direction of travel)<br>"C" | Number of Strips per Pattern<br>"D" | Spacing between Patterns<br>"E" | Strip Shape<br>"F"             | Strip Width (transverse to direction of travel)<br>"G" | Spacing between Strips<br>"H"                  | Strip Depth<br>"I"                                                       | Strip Length (longitudinal to direction of travel)<br>"J"                                    | Cost                                   |
|------------------|-----------------------------|----------------------------------------------------------------------------|----------------------------------------------------------------|-----------------------------------------------------------------|-------------------------------------|---------------------------------|--------------------------------|--------------------------------------------------------|------------------------------------------------|--------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|----------------------------------------|
| <b>Rolled-In</b> |                             |                                                                            |                                                                |                                                                 |                                     |                                 |                                |                                                        |                                                |                                                                          |                                                                                              |                                        |
| Saskatchewan     | Continuous                  | 75 mm min to 150 mm max                                                    | N/A                                                            | N/A                                                             | N/A                                 | N/A                             | N/A                            | 600 mm                                                 | 150-160 mm                                     | 13 mm                                                                    | 40-50 mm                                                                                     | N/A                                    |
| Alberta          | Continuous                  | 75 mm min to 150 mm max                                                    | N/A                                                            | N/A                                                             | N/A                                 | N/A                             | Rounded                        | 600 mm                                                 | 150-160 mm                                     | 13-16 mm                                                                 | 40-50 mm                                                                                     | N/A                                    |
| <b>Milled-In</b> |                             |                                                                            |                                                                |                                                                 |                                     |                                 |                                |                                                        |                                                |                                                                          |                                                                                              |                                        |
| Saskatchewan     | Intermittent                | 75 mm min to 150 mm max                                                    | 4 meters                                                       | 600 mm                                                          | 20 strips                           | 4 meters                        | N/A                            | 600 mm                                                 | 150-160 mm                                     | 13 mm                                                                    | 40 - 50 mm                                                                                   | N/A                                    |
| Alberta          | Continuous and Intermittent | 150-200 mm                                                                 | 4 meters                                                       | 300 mm                                                          | 12 strips                           | 4 meters                        | Rounded                        | 300 mm                                                 | 150 ± 40 mm                                    | 8 mm 6 2 mm                                                              | 125-175 mm                                                                                   | \$400 - \$425 / km (2000)              |
| City of Edmonton | Continuous and Intermittent | 75-100 mm                                                                  | 4 meters                                                       | 300 mm                                                          | 10-12 strips                        | 4 meters                        | Rounded                        | 300 mm                                                 | 200 mm                                         | 8 mm 6 2 mm                                                              | 125-175 mm                                                                                   | N/A                                    |
| Quebec           | Continuous                  | 300 mm                                                                     | N/A                                                            | N/A                                                             | N/A                                 | N/A                             | Rounded                        | 400 mm                                                 | 120 mm                                         | 13 mm                                                                    | 180 mm                                                                                       | N/A                                    |
| Ontario          | Continuous                  | 100 mm (not to be varied)                                                  | N/A                                                            | N/A                                                             | N/A                                 | N/A                             | Circular concave cross-section | 300 mm                                                 | 150 mm (300 mm centre to centre at inner edge) | 5 mm inner edge max - 10 mm ± 2 mm (lateral slope of shoulder = 2 to 6%) | Outer = 150 mm ± 20 mm<br><br>Inner = 75 mm min and 170 mm max (never more than outer width) | N/A                                    |
| British Columbia | Continuous                  | 100mm ± 10mm for shoulders > 1.5 m wide<br>0 mm for shoulders ≤ 1.5 m wide | N/A                                                            | N/A                                                             | N/A                                 | N/A                             | Rounded                        | 300 mm                                                 | 160 mm                                         | 8 ± 2 mm                                                                 | 140 ± 20 mm                                                                                  | \$750/lane-km - \$1,300/lane-km (1999) |
| New Brunswick    | Continuous                  | 200 mm                                                                     | N/A                                                            | N/A                                                             | N/A                                 | N/A                             | Rounded                        | 300 mm                                                 | 150 mm                                         | 10 mm 6 2 mm                                                             | 150 mm                                                                                       | \$1.08 / m (2000)                      |

**APPENDIX B**  
**EXAMPLE OF CONTRACT DOCUMENT**

**3.52 MILLED RUMBLE STRIPS****3.52.1 GENERAL**

This specification covers the construction of milled rumble strips on the shoulders of roadways to alert drivers when they leave the travel lanes and across the travel lanes to alert drivers of an upcoming stop condition.

**3.52.2 EQUIPMENT****3.52.2.1 General**

The Contractor shall provide all equipment necessary for completion of the Work.

**3.52.2.2 Milling Machine**

The milling machine shall be equipped to meet or exceed the following requirements:

- (i) For milling of shoulder strips, the cutting head shall be capable of producing grooves meeting the requirements as shown on Dwg. No. CB6-3.52M1 or CB6-3.52M2 as applicable.

For milling of rumble strips for stop conditions, the cutting head shall be capable of producing grooves meeting the requirements as shown on Dwg. No. CB6-3.52M3.

- (ii) The machine shall either be equipped with an integral sweeping device mounted directly behind the cutter or,

a separate sweeping operation shall be conducted as construction of the rumble strips progresses within the signed construction zone.

**3.52.3 HIGHWAY OPERATIONS****3.52.3.1 General**

All work shall be performed during daylight hours only. No Work shall be performed if the visibility is less than 700 metres. The maximum work area shall be 4 kilometres in length.

The Contractor shall supply a sequential arrowboard in accordance with Specification 1.2, General.

**3.52.3.2 Construction of Milled Rumble Strips**

For milling of shoulder strips, the Contractor has the option of choosing either the intermittent typical layout or the continuous typical layout for milled rumble strips. The Contractor shall construct milled rumble strips as shown on either Drawing CB6-3.52M1 - Typical Layout for Continuous Milled Rumble Strips for Shoulders or CB6-3.52M2 - Typical Layout for Intermittent Milled Rumble Strips for Shoulders.

When required, the Contractor shall construct milled rumble strips for stop conditions as shown on Drawing

CB6-3.52M3 - Typical Layout for Milled Rumble Strips for Stop Conditions. Due to space constraints, it may not be possible to construct all of the strips at some intersections. In these cases, the Contractor shall construct the number of strips as shown in the special provisions or as directed by the Consultant.

No grooving will be done across intersections, tapers or accesses nor at any other locations specified by the Consultant.

After milling the grooves, the Contractor shall pickup and dispose of all detritus created from the milling operation.

**3.52.3.3 Workmanship and Final Acceptance**

The completed milled rumble strips shall be constructed in accordance with the plans, shall show careful finished workmanship and when measured shall not show any of the following defects:

- (i) Groove length variation of more than 10 mm;
- (ii) Groove spacing variation more than 40 mm.

Patterns of milled rumble strips constructed outside the tolerances as shown on the plans or exhibiting any of the above defects will be rejected, and the Contractor shall be responsible for repairing the unacceptable work.

**3.52.4 MEASUREMENT AND PAYMENT****3.52.4.1 Milled Rumble Strips**

Measurement of milled rumble strips will be made parallel to the road centreline, to the nearest 0.001 km of through highway chainage for each side of the road where accepted milled rumble strips have been constructed.

Payment will be made at the unit price bid per kilometre per side for "Milled Rumble Strips." Payment will be the same for either the continuous or intermittent layout pattern. This payment will be full compensation for constructing the milled rumble strips, removing and disposing of all debris and traffic accommodation.

**3.52.4.2 Milled Rumble Strips for Stop Conditions**

Milled Rumble strips for stop conditions will be measured by the set as the total of all completed strips at each stop location.

Payment will be made at the unit price bid per set for "Milled Rumble Strips for Stop Conditions". This payment will be full compensation for constructing the milled rumble strips, removing and disposing of all debris and traffic accommodation.

**APPENDIX C**  
**CENTRELINE RUMBLE STRIPS**  
**CURRENT NORTH AMERICAN PRACTICES**

**CENTRELINE RUMBLE STRIPS**  
Current North American Practices

| Agency          | Rumble Strip Type and Frequency | Strip Shape<br>"F" | Strip Width (transverse to direction of travel)<br>"G" | Centre to Centre Spacing of Strips<br>"H"                          | Strip Depth<br>"I" | Strip Length (longitudinal to direction of travel)<br>"J" | Rumble Strips in Relation to Centreline Markings | Cost                                                       |
|-----------------|---------------------------------|--------------------|--------------------------------------------------------|--------------------------------------------------------------------|--------------------|-----------------------------------------------------------|--------------------------------------------------|------------------------------------------------------------|
| <b>Canadian</b> |                                 |                    |                                                        |                                                                    |                    |                                                           |                                                  |                                                            |
| Alberta         | Milled-in continuous            | Rounded            | 300 mm                                                 | 300 mm                                                             | 8 mm min           | 150-200 mm                                                | Markings within rumble strips                    | \$600 - \$1000 / km<br>line painting at \$800 - \$900 / km |
| <b>American</b> |                                 |                    |                                                        |                                                                    |                    |                                                           |                                                  |                                                            |
| Minnesota       | Milled-in continuous            | Rounded            | 400 mm and 300 mm                                      | 300 mm                                                             | 12-16 mm           | 175 mm                                                    | Markings within rumble strips                    | N/A                                                        |
| Minnesota       | Milled-in continuous            | Rounded            | 130 mm                                                 | 300 mm                                                             | 10-13 mm           | 180 mm ± 13 mm                                            | Markings in middle of two rows of rumble strips  | N/A                                                        |
| Kansas          | Milled-in continuous            | Rounded            | 200, 300, and 400 mm                                   | 300 mm continuous<br>600 mm continuous<br>300 / 600 mm alternating | 12 mm              | 165 mm ± 12 mm                                            | N/A                                              | N/A                                                        |
| Connecticut     | Milled-in continuous            | Rounded            | 400 mm                                                 | 300 mm                                                             | 12 mm              | 175 mm                                                    | Markings within rumble strips                    | N/A                                                        |
| Washington      | Milled-in continuous            | Rounded            | 400 mm                                                 | 300 mm<br>600 mm                                                   | 12 mm              | 175 mm                                                    | Markings within rumble strips                    | N/A                                                        |
| Oregon          | Milled-in continuous            | Rounded            | 400 mm                                                 | 300 mm                                                             | 15 mm              | 175 mm                                                    | Strips between 2 sets of double yellow lines     | N/A                                                        |
| Massachusetts   | Milled-in continuous            | Rounded            | 450 mm                                                 | 300 mm                                                             | 12 mm              | 175 mm                                                    | Markings within rumble strips                    | N/A                                                        |
| Pennsylvania    | Milled-in continuous            | Rounded            | 350 mm                                                 | 600 mm<br>1200 mm                                                  | 12-15 mm           | 175 mm                                                    | Markings within rumble strips                    | N/A                                                        |
| Colorado        | Milled-in continuous            | N/A                | 300 mm                                                 | 310 mm                                                             | N/A                | 180 mm                                                    | N/A                                              | N/A                                                        |
| Arizona         | Milled-in                       | N/A                | 125 mm<br>200 mm<br>in passing zones                   | N/A                                                                | N/A                | N/A                                                       | N/A                                              | N/A                                                        |
| California      | Milled-in continuous            | N/A                | 400 mm                                                 | N/A                                                                | 12 mm              | N/A                                                       | Strips between 2 sets of pavement markings       | N/A                                                        |