CANADIAN STRATEGIC HIGHWAY RESEARCH PROGRAM

Removal of Hazards Due to Ravelling of Granular Shoulder Material

John Emery Geotechnical Engineering Limited

In Association With

Hardy BBT Limited
CRCAC Inc.
B-A Consulting Group Ltd.
Clayton, Sparks & Associates Ltd.
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Language Notice: Un sommaire en français de ce rapport est inclus avant la table des matières

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Ravelling of Granular Shoulder Material

Ravelling of material from the inside edge of gravel shoulders causes a vertical drop and a trough to form at the pavement edge. The drop-off is a driving hazard and the trough traps run-off water which aggravates the ravelled condition. These conditions contribute to accidents, pavement edge damage and shoulder deterioration.

Shoulder design and accidents, and cost benefit analysis methods for design, construction and maintenance of shoulders are synthesised. The current Canadian state of practice and experience with respect to shoulder design, shoulder condition, accidents and maintenance treatments are reviewed.

Pavement edge drop-off, shoulder width and shoulder condition have an impact on roadway safety. The most tolerable edge drop-off for Canadian driving conditions is 40 mm, and the generally adopted "standard" shoulder width is 1.0 m. Maintenance practices are generally restricted to grade/reshape, regravelling and limited use of emulsified asphalt, calcium chloride and lignosulfate.

Keywords:
- ravelling
- granular shoulder
- pavement edge drop-off
- vertical drop
- shoulder width
- accidents
- scrubbing
- cost benefit
- shoulder maintenance
- shoulder treatment
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**Gestionnaire du projet**  
G.J. Williams

**Titre et sous-titre**  
L’effritement des accotements granulaires

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**Résumé**

L’effritement du matériel à la section intérieure des accotements granulaires cause une dénivellation verticale et une dépression au bord de la chaussée. La dénivellation est un danger pour les conducteurs tandis que la dépression retient l’eau de ruissellement, ce qui aggrave davantage l’effritement. Les accidents, les dommages aux chaussées et la détérioration des accotements sont les conséquences de ces deux conditions.

Les designs d’accotement versus les accidents, ainsi que les méthodes d’analyse coûts/bénéfices pour le design, la construction et l’entretien des accotements, sont synthétisés. L’état actuel de la pratique et de l’expérience canadienne en ce qui concerne le design des accotements, la condition des accotements, les accidents et l’entretien, sont étudiées.

La dénivellation à la bordure de la chaussée, la largeur de l’accotement, et la condition de l’accotement ont des répercussions considérables sur la sécurité routière. En ce qui concerne les conditions de conduite au Canada, une dénivellation tolérable est de 40 mm, et une largeur d’accotement "standard" est habituellement 1.0 m. Les méthodes d’entretien comprennent généralement un nivelage/taillage, un recouvrement de gravier et une utilisation restreinte d’émulsion, de chlorure de calcium et de lignosulfate.

**Mots-clés**  
effritement  
accotement granulaire  
dénivellation de la bordure du chemin  
largeur de l’accotement  
accidents  
coûts-bénéfices  
ettretien de l’accotement  
traitement pour l’accotement

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**Renseignements supplémentaires**
Executive Summary

This Interim Report presents the findings of Tasks 1 through 5 of the Removal of Hazards Due to Ravelling of Granular Shoulder Material project completed on behalf of the Canadian Strategic Highway Research Program (C-SHRP) by John Emery Geotechnical Engineering Limited in association with Hardy BBT Limited, CRCAC Inc., B-A Consulting Group Ltd. and Clayton, Sparks & Associates Ltd.

After preparation of a detailed work plan (Task 1), Task 2 of this project involved synthesis of the available literature to determine if relationships exist between shoulder design and accidents. Task 3 consisted of a synthesis of published cost-benefit analysis methods to determine if a meaningful cost-benefit framework could be developed for shoulder design, construction and maintenance in Canada. Task 4 comprised determination, through contact with Canadian provincial and territorial road agencies, of the current Canadian experience with respect to shoulder design, shoulder condition, accidents and maintenance treatments. Upon completing Tasks 1 through 4, Task 5 was to develop a detailed work plan for achieving the project goals (a final research report and state-of-the-art manual of shoulder maintenance practices) over the course of the remaining Tasks 7 through 11. This Interim Report has been prepared as Task 6 and is intended to provide C-SHRP with the information necessary to decide if the remaining tasks should be completed.

The work completed to the end of Task 5 of the Removal of Hazards Due to Ravelling of Granular Shoulder Material has indicated the following general conclusions:

1. There appears to be a relationship between shoulder design and accidents. The minimum ‘safe’ shoulder width for a roadway is 1.5 to 2.0 m regardless of classification, with higher volume, higher speed roads requiring safe shoulder widths that effectively approach the actual lane width.

2. Canadian road agencies have generally adopted a ‘standard’ minimum shoulder width of 1.0 m with some agencies reporting even narrower shoulder widths.

3. Shoulder condition and in particular the drop-off between the pavement and shoulder due to ravelling, has been found to be a major cause of head-on accidents due to the scrubbing phenomenon and associated loss of control.

4. The critical edge drop that may be tolerated by the average driver is between about 40 and 75 mm depending on the shape of the drop-off; 40 mm is considered to be the most appropriate tolerable drop-off for Canadian driving conditions.

5. The Canadian accident experience is quite limited with respect to shoulders but suggests that between 0.3 and 0.5 percent of all accidents involve shoulder deficiencies (inadequate width or poor condition). There is a concern that the accident reporting mechanism may not adequately recognize shoulder problems and especially the relationship between head-on accidents and pavement edge drop-off occurring on the opposite side of the road.
6. Meaningful cost-benefit analyses of shoulder designs and maintenance alternatives to reduce granular shoulder ravelling may not be possible if the only benefit to be considered is reduction of accidents (i.e., loss of life). This is due principally to the lack of consistently comparable and reliable accident data for various treatments and conditions. If the benefit of accident reduction is eliminated from the cost benefit framework, the analysis reduces essentially to a comparison of cost effectiveness (life cycle cost) of design, construction and maintenance alternatives.

7. Current granular shoulder maintenance practices are typically limited to conventional methods (grade/reshape, regravelling as necessary, some use of emulsified asphalt). Use of alternative shoulder treatments such as calcium chloride or lignosulphonates is largely undocumented with relatively little operational or maintenance performance data available. Maintenance standards and criteria (allowable pavement edge drop-off and rutting), specified shoulder materials and annual costs may vary considerably within region and province.

A work plan for the remaining Tasks 7 through 11 has been developed to achieve the overall project end products of a set of design guidelines for shoulder treatments under a variety of geometric conditions, traffic volumes and vehicle mixes and a manual of equipment, materials and procedures for applying shoulder treatments. These end products have important benefits to the transportation industry, to the driving public, and to the agencies responsible for providing a consistently safe road infrastructure. It is therefore recommended that this project be approved for completion as discussed.
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1.0 Introduction

1.1 Preamble

Ravelling is the removal of granular material from the inside edge of gravel shoulders adjacent to a paved lane. This ravelling is caused by the mechanical action of tires on vehicles which drift over the pavement edge onto the gravel surface, or erosion due to wind turbulence generated by large vehicles (trucks) moving at highway speeds. Ravelling can also be further aggravated by surface water movement across the pavement section.

Granular shoulder ravelling is considered to be a severe problem which impacts road safety and performance. The issue of safety is certainly of greatest concern and granular shoulder ravelling is a key routine maintenance activity that must be continuously addressed to ensure safe vehicle operation under all driving conditions and to enhance pavement performance.

A number of studies in Canada and abroad have documented isolated findings on shoulder treatment types and widths, and their relationship to accidents. It is perceived that a significant quantity of valuable knowledge and data exist in the field that is not documented. This Canadian Strategic Highway Research Program (C-SHRP) research study has been undertaken to evaluate the parameters that influence ravelling of granular shoulders in order to develop cost-effective corrective shoulder treatments.

1.2 Scope

The project objectives given by the C-SHRP Technical Steering Committee are:

i) To synthesize, from current practice and available literature, the state-of-the-art in shoulder design;

ii) To determine the relationship between shoulder design standards and accidents;

iii) To determine and quantify the parameters which influence ravelling under a variety of geometric conditions, traffic volumes and vehicle mixes; and

iv) To develop a cost-benefit framework for designing and constructing shoulder treatments.

In order to accomplish these objectives, key technical tasks were defined:

Task 1: Prepare a detailed work plan.

Task 2: Conduct a state-of-the-art review of the relationship between shoulder design and accidents.

Task 3: Prepare a synthesis of available shoulder design cost-benefit evaluations.
Task 4: Determine the adequacy of Canadian empirical knowledge and historical data.

Task 5: Define any supplemental field information required, identify required resources and methodology.

Task 6: Prepare an interim report on Tasks 1 through 5.

Task 7: Direct the collection of all supplemental field information defined in Task 4.

Task 8: Analyze the data and develop cost-effective corrective strategies.

Task 9: Prepare a final research report.

Task 10: Prepare a manual of material, equipment and design specifications.

Task 11: Present the research findings at a Canadian technical forum.

This interim report (Task 6) presents the project findings to the end of Task 5 in order that the C-SHRP Technical Steering Committee can elect to proceed with the supplemental data gathering and analysis tasks.
2.0 Shoulder Design Requirements

2.1 Basic Shoulder Characteristics

The Roads and Transportation Association of Canada (RTAC) defines the shoulder as "that part of the graded width of a roadway contiguous with the pavement and used to accommodate stopped vehicles" (1). The shoulder is therefore a necessary and vital portion of the total pavement structure. Clearly, the greater the traffic volume, the greater is the propensity for accidents to occur, and therefore more attention is warranted for shoulder design and maintenance to increase road safety and reduce accidents.

The basic shoulder characteristics that must be satisfied to provide a safe roadway are:

i) The shoulder must be strong enough to support vehicles under all weather conditions;

ii) The shoulder material must be able to withstand sudden braking and turning movements due to vehicles which swerve off the road at high speed and attempt to move back on the travelled way;

iii) The shoulder surface should always be level with the top of the pavement to permit safe deceleration to a stop i.e., no edge ravelling or rutting;

iv) The shoulder must be wide enough to keep vehicle from striking roadside hazards;

v) The shoulder geometry should be such that normal traffic and vehicle speeds are not reduced by a vehicle that is temporarily stopped on the shoulder; and

vi) A textural difference between the shoulder material and roadway is desirable to instantly warn drivers when their wheels leave the pavement.

The additional engineering benefits that are also attributable to improved shoulders include lateral support of the pavement edge, improved drainage and erosion control, easier snow clearance (with reduced winter costs), control of roadside vegetation and increased traffic movement in the travelled way.

While this project focuses on Item 3, these basic shoulder characteristics are inter-related, and each of the other items impacts the development of granular ravelling at the pavement edge. For example, the width of the pavement and edge delineation practices can influence the frequency that drivers cross over the edge of the pavement promoting increased accident rates and ravelling of the granular shoulder material. The elements that are considered to have the most profound impact on granular shoulder ravelling are pavement width and shoulder design, shoulder materials, and traffic (type, volume and operating speed).
2.1.1 Shoulder Types

As with roadways, three basic shoulder construction types are commonly encountered:

i) Granular shoulders;

ii) Paved or composite shoulders (asphalt concrete or other bituminous surfacing over granular base); and

iii) Concrete shoulders.

In addition, depending on the age and construction history of the road involved, shoulders constructed using the local soils (cohesive or otherwise) may also be regularly encountered, particularly on low volume rural roads in areas where suitable granular materials are not readily available.

For new construction, maintenance and rehabilitation, granular shoulder materials are generally specified to consist of relatively free draining, well graded, durable sand and gravel or crushed stone meeting either granular road base or subbase requirements. Ontario, for example, specifies that the granular materials used for shoulder construction satisfy Ontario Provincial Standard Specification Granular A requirements. However, depending on the construction history of a given roadway and recognizing that many rural roads have developed through continuous upgrading of former farm roads and trails, the materials in existing roads are frequently of substantially poorer quality that those currently specified.

In response to problems with safety and maintenance of granular surfaces, many jurisdictions have adopted ‘hard’ surfacings for their shoulders, especially for their relatively high volume, high speed highway and arterial roads. These surfacings include full or partial width asphalt concrete (or other bituminous surface such as chip seals or surface treatment) and/or concrete shoulders.

Paved or composite shoulders may be provided by extending the roadway pavement structure across the entire road width (Alberta has adopted this procedure as a standard in their new construction). More commonly however, a single lift of asphalt concrete is typically provided directly over the existing granular base for either the full or partial width. Nearly all Canadian provincial road agencies require at least partially paved shoulders on all arterial or higher classification roadways.

Concrete shoulders have seen only limited use in Canada and are more common in the U.S. where concrete pavements as a whole are used to a much greater extent. Concrete shoulders are typically constructed to a thickness of 150 mm and are positively connected by dowels or keyways to the adjacent roadway concrete base. Such shoulders usually extend across the full shoulder width.

As the topic of this study is directly concerned with the removal of hazards due to ravelling of granular shoulder material paved and concrete shoulders will only be examined as rehabilitation alternatives to mitigate ravelling problems, i.e., as ‘control’ measures.
2.2 Pavement Width and Shoulder Design

The design of shoulders must be considered within the overall context of geometric design of pavements, noting that the shoulders comprise a relatively narrow portion of the total roadway cross section. The selection of the appropriate pavement width is dependent on several factors including vertical alignment, horizontal alignment, line of sight, traffic volume, traffic type and operating speeds, climate, etc. Geometric design standards for roadways are well developed, with References 1 through 5 as well as numerous other unlisted references providing guidance for the geometric design of safe roadways. In virtually all cases, roadways are classified according to their service function (rural, urban, highway, freeway, arterial, collector, residential), traffic volume (Average Annual Daily Traffic, Average Daily Traffic, Design Hourly Volume, etc.), and operating speed (50 km/h to 120 km/h generally), and 'standard' cross sections have been developed for each classification.

Urban cross sections provide curb and gutter in lieu of shoulders and therefore, this project has focussed on the typical rural cross sections.

The RTAC manual "Geometric Design Standards For Canadian Roads and Streets" (1) represents the current state-of-the-art for roadway design in Canada. The RTAC rural pavement cross sections have been summarized on Figure 1 for comparison with the current standard cross sections for each province. These were compared with the current design standards in the United States (2, 3), Australia (4), the United Kingdom (5) and other international agencies (6) and were found to be quite representative of current practice. The minimum recommended lane width is 3.0 m for rural local two-lane roadways having operating speeds of 80 km/h or less, with a maximum lane width of 3.75 m recommended for rural roads of higher volume and traffic speed.

The geometric design requirements for road shoulders comprise several key elements: shoulder width, slope angle, shoulder support, edge delineation procedures and roadside development. Shoulder geometric design has been the subject of several comprehensive studies (7, 8, 12, 13) that report sometimes widely varying experience with different shoulder designs. Although it has been widely acknowledged that shoulder width is a critical factor in reducing accidents, several reports suggest that there is no conclusive relationship between shoulder width and accidents (9, 12 and 13, for example). The recent technical literature continues to support the 1954 finding that the optimal shoulder width for rural two lane roads is between 1.8 and 2.7 m (10) but also suggests that accidents may be more attributable to shoulder condition than its geometry. This is discussed in detail in Chapter 3.2 of this study. By comparison, RTAC has recommended shoulder widths ranging from 1.0 to 3.0 m, with some Canadian provincial road agencies adopting 'standard' shoulder widths as narrow as 0.5 m.
Figure 1 – Current Canadian Rural Design Standards

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King’s Highways

Secondary Highways

50km/hr standard not shown
Figure 1 – Current Canadian Rural Design Standards (cont’d)

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<th>AGENCY</th>
<th>DESIGN VOLUME</th>
<th>RAU</th>
<th>ROAD CLASSIFICATION</th>
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Legend:
- G – Granular
- P – Paved
- C – Partially paved (Composite)
- V – Variable
- S – Surface treated

Note: Volumes apply to 120 only
S – sealed basecourse

Lane width

Shoulder width

Shoulder type

Round width
3.0 Relationship Between Shoulder Design and Accidents

3.1 Types of Accidents

Two types of accidents are attributed at least partially to shoulders. 'Run off the road' accidents occur when the driver crosses the pavement edge onto the shoulder and loses control of the vehicle, running into the adjacent roadside. In addition to the driver factors (operator condition, response, etc.), this can be caused by inadequate shoulder width, poor slope angle, soft shoulder material, etc. 'Head-on' accidents involving the shoulder are, on the other hand, directly related to ravelling of the granular shoulder material along the pavement edge.

Ravelling of the granular shoulder material creates a drop-off between the paved surface and the shoulder. When a vehicle overrides the pavement edge, the driver's ability to recover and get back onto the travelled portion of the road is significantly impeded by the amount of drop off and its geometry.

A recent study (11) describes in detail the vehicle dynamics/pavement interaction in trying to recover the road. Four types of vehicle interaction are defined: nibbling, scrubbing, drag and roll. Only nibbling and scrubbing phenomena are of interest here. Drag and roll problems are normally only encountered in construction zones since they require pavement drop off greater than the clearance underneath an automobile.

Nibbling is associated with pavement longitudinal edges not more than 25 mm in height. In transversing a nibbled edge, a force is imparted to the tires which may cause the vehicle to shift laterally a small distance. Although mounting an edge of this height is usually not a problem for automobiles or stable truck configurations, it could cause some oscillation in double or triple combinations at critical speeds.

Scrubbing is identified as the predominant safety problem, and occurs where the edge drop is between 25 and 125 mm. For whatever reason (inattention, distraction, etc.), the right wheels of the vehicle drop off the edge of the pavement. As the driver tries to steer back onto the pavement, the right front wheel encounters the pavement edge at a very flat angle and is unable to remount the pavement. Consequently, the driver increases the steer angle. The vehicle continues to scrub the pavement edge and does not respond. The driver has not significantly reduced speed but continues to increase the steer input until the critical steering angle is achieved and the right front wheel finally mounts the paved surface. However, almost instantaneously (within one wheel revolution), the pavement edge force has disappeared and the cornering force of the right front wheel may have doubled (from increases in the available friction on the pavement and wheel loads due to cornering). The vehicle yaws drastically to the left about the right rear tire until that wheel manages to mount the pavement edge. The excessive left turn and yaw continue at such a rapid rate that the driver is unable to prevent moving into the opposite lane into the direction of oncoming traffic. A head-on collision or spin out may then occur. Scrubbing generally does not occur at drop-offs greater than 125 mm.
because automobiles are usually not able to mount edges this high. This could however still be a factor for large trucks having larger diameter tires.

The slope of the pavement edge has a significant effect on the ability of a vehicle to remount the pavement. If the pavement edge is bevelled or rounded, a vehicle can safely remount much greater drop-offs than if the pavement edge is vertical. This is shown in Figure 2.

![Diagram](image1)

Figure 2 – Relative Degrees of Safety for Various Edge Conditions (11)

3.2 Accident Experience and Shoulders

The technical literature reviewed falls into two general categories. The first category attempts to relate accident rates to shoulder width while the remaining literature addresses problems with vehicle control created while attempting to remount the pavement where a drop-off exists.
The effects of shoulder width on accident frequency have been examined primarily by statistical methods. Historically, the data have been contradictory with some other data which indicate accident reductions with increased shoulder width, while other data indicate no change or an increase in accident rates. To properly understand these studies, it is necessary to consider the source of the data and consequent potential weaknesses.

Zeeger and Perkins (12) in a state-of-the-art report describe two types of analyses. The first is a 'before and after' analysis compares the accident experience in a specific highway section before and after the addition or widening of shoulders, while the second is a 'comparative' analysis which relates the accident experience of different sections of highway over the same period of time. While both may be valid, there are potential limitations with each.

'Before and after' analyses usually require a long record (time) to allow sufficient accident events to occur in order to provide a statistically significant result. This usually creates inconsistencies due to changes over time in traffic volume and mix, average speed (for instance the 1974 speed limit change in the U.S. must be accounted for) and driver habits. It is also difficult to obtain sufficient highway sections where the only significant change over the study period was to the shoulder configuration. Finally, construction-related accidents should not be included in the analyses.

'Comparative' analyses have the advantage that a large data base can be assembled within only one or two years. This tends to minimize the impact of changes in traffic volume or driver behaviour. The disadvantage is that no two highway sections are ever exactly alike which makes data analysis problematic without the necessary control parameters.

Older studies may not be as compelling because of technical changes in highway design, striping, guardrails, etc. It is also important to exclude major intersections (which are accident generators more likely to be present on highways with wider shoulders), changes in geometry or setting (urban or rural).

Zeeger and Perkins further suggest that accident types are also relevant to the analyses. Rather than consider total accident rate as many past studies have done, they advocate considering specific types of accidents which logic that reductions in specific types of accidents would be reflected in the total rate, unless offsetting increases occurred in other types of accidents. In addition several older studies were reviewed which indicated negative safety features for shoulder widening projects, but conclude that these studies are only of limited value because they consider only tangent sections, total accident rates, and are out-dated. Other older studies include two in New York State which concluded that wider shoulders improved safety for only relatively narrow (6.1 m) two-lane highways.

Zeeger and Perkins also comment on a large comparative analysis which was controlled for geometric data, lane width, shoulder width, access points and traffic volume. Transitional sections and major intersections were excluded. It was found that shoulder widening from zero to between 2.1 and 2.7 m resulted in a 21 percent decrease in run-off-the-road and head-on accidents, with smaller reductions for less ambitious widening projects.

Rinde (13) conducted a before and after study of the effects of increasing the total pavement width from 7.3 m (24 ft) to 8.5 m (28 ft), 9.75 m (32 ft) and 12.2 m (40 ft). While he found that
there was some reduction in accidents for most widening projects, it appeared that widening to 8.5 m or 9.75 m in high volume situations had little positive impact or possibly increased the accident rate.

Barbaresco and Bair (9) undertook a comparative study on two-lane rural highways in a Michigan county. It appears that the shoulders of these roads were gravel. Their observations indicated that shoulder width had a significant effect only for fixed object accidents and that there were more accidents on highways with shoulder widths greater than 2.1 m (7 ft) than on those with narrower shoulders. It was claimed that this result could only be attributed to shoulder width, but it is unclear how the effect of traffic volume was taken into consideration. It is significant to note that this study was undertaken on behalf of a county road agency in response to law suits from drivers blaming their accidents on the narrow shoulders.

The only comprehensive reporting of the Canadian experience with regard to accidents involving shoulders appears to be by the Transport Canada Road Safety and Motor Vehicle Regulations Directorate.

Sanderson (14) re-analyzed data of Dean (1975) for rural two-lane New Brunswick highways and compared these with results reported by Silyanow (1973) for four different American studies, a Norwegian and a Russian study. The results show a major reduction (approximately 30 percent) in total accidents when the shoulder width is increased from 0.6 m to 2.0 m. Negligible safety benefits were attained from further widening. The results were consistent for all traffic volumes.

Armour (15) reported on the analysis of rural roadway accidents in New South Wales, Australia, and confirmed that unsealed shoulders have accident rates 3 to 4 times higher than sealed shoulders on rural roadways, depending on road classification, grades, alignment, etc., and that loss of control on the shoulder was responsible for over 50 percent of fatal accidents.

Hobal (4) reported on the recent Australian experience where existing shoulders on low volume rural highways were paved or sealed to a width of 1.2 m to 1.5 m. Accidents were reduced to approximately one third of their former levels. Other factors were not controlled and some of the effect may be due to improved geometrics and better road surfaces after recent rehabilitation. A review of accident report forms indicated that loss of control on gravel shoulder was a contributing cause in 17 percent of all accidents and 50 percent of the run-off-the-road type.

It is not established from the literature that wider shoulders lead to lower accidents. In some conditions, traffic volume, increased speed and driver attitudes may cause increases in accident rates. The data from the Australia (4, 15) and California (13) studies suggest that the shoulder condition may be more significant than its width and that safety problems may be influenced more by ravelling and/or soft gravel shoulders than geometry. This is supported by Davis (16) in his report concerning an Arizona Department of Transportation (1978) study of shoulder improvements. It was concluded that blading and reshaping of dirt and gravel shoulders to correct pavement drop-off and rutting resulted in an accident rate reduction of 28 percent and confirmed that smooth, traversable shoulders are very effective in reducing accident rates.
Ivey et al. (11) review the modes in which vehicle control problems can result from longitudinal elevation changes, either as a product of shoulder ravelling or of construction conditions. At smaller edge drop-offs, they identify two phenomena: ‘nibbling’ and ‘scrubbing’. For larger drop-offs, they identify undercarriage drag and vehicle roll as possible results of crossing the pavement edge. As the large drop-off is likely to occur only in construction situations, discussions will be limited to the ‘nibbling’ and ‘scrubbing’ phenomena, as previously defined.

Research by Zimmer and Ivey (17) using a professional driver at speeds of 56, 72 and 88 km/h on a test track indicates that ‘reasonably safe’ conditions exist at effective edge heights less than 75 mm.

Crossing into the next lane did not occur until the effective edge height was 100 mm. However Ivey and Sicking (18) developed an analytical model of the problem for use with the HVOSM model. The analysis indicates that a vehicle will cross its own lane at an effective edge height of 38 mm if the manoeuvre is attempted at 80 km/h. Zimmer and Ivey also report on a study where a naive driver encountered control problems at speeds greater than 48 km/h in tests of edge drops up to 100 mm. This information and the HVOSM analysis are considered to be more relevant to the skills of the ordinary driver and suggests that loss of control from scrubbing may be a concern, depending on speed, at edge heights as low as 38 mm.

The available literature does not directly address control problems created by driving off an edge drop. It may be that in the absence of problems created by penetration into the shoulder surface, control is not significantly affected at edge drops lower than the height where undercarriage drag becomes a significant risk. If this is the case then ravelling is not significant to this problem, since soft shoulders may exist even without ravelling.

### 3.3 Relationship Between Accidents and Shoulders

It appears from the literature review that a strong correlation exists between shoulder surface condition (ravelled shoulders or loose, soft shoulders) and accidents. This relationship may, in fact, be even more influential than that between shoulder width and accidents. Consequently, there are strong warrants for investigating materials and procedures to improve and maintain the shoulder condition. Given that pavement drop off due to ravelling of granular shoulder material appears to be the critical accident generator, subsequent research should consider the performance and cost-effectiveness of alternatives to granular shoulders (paved, partially paved or concrete shoulders), granular stabilization and alternative maintenance practices to prevent granular shoulder ravelling.
4.0 Synthesis of Available Shoulder Design Cost-benefit Evaluations

4.1 Introduction

A review of the literature has turned up little on the specific subject of cost-benefit analyses used for the purpose of evaluating alternative shoulder designs. The literature reviewed can generally be divided into two groups. First, there is appreciable literature on the more general subject of cost-benefit analysis, variants, and road design. This does not treat the specific subject of shoulder design in isolation from other components of the road. Second, there is some literature containing information required for a cost-benefit analysis. The best examples are the articles dealing with shoulder design and safety, some of which have been previously cited (11, for example). Except for incidental references, this material is not reviewed here.

It is important to differentiate between cost-benefit analyses, which may be subjective in their evaluation of benefits associated with reduced fatal accidents, and life cycle cost analyses which are concerned strictly with the maintenance and operational cost-effectiveness of various shoulder types.

4.2 Cost-Benefit Analyses Prior to 1985

Graham and Harwood (19) describe research on the effectiveness of clear recovery zones in reducing the number and severity of run-off-the-road accidents. In doing so, a cost-benefit analysis is used to compare various roadside design alternatives. Some observations on this work are:

i) Superficially (i.e., without having any actual figures on the budget and/or man-hours expended), it appears that most of the effort went into establishing the link between accident rates and roadside design alternatives. This may provide some insights into the relative effort required in a project such as the present one, where a cost-benefit analysis of alternative shoulder designs is the goal;

ii) The authors did not feel that it was advisable to develop a single cost-benefit analysis for all situations. Rather, they felt each section of a road had to be examined separately. In other words, a system-wide cost-benefit ratio cannot be developed that will suggest design policies for all situations. Each section of road has its own unique accident rates and construction conditions (costs). Presumably, this same condition would apply when considering shoulder drop-off issues (shoulder design/ravelling/accident rates);

iii) The basic construction of the cost-benefit analysis is simple: 'benefits' are measured as the present worth of 'accident cost savings', and 'costs' are the present worth of construction costs of alternative roadside designs. Benefits and costs are calculated over a 20-year period and a discount rate of 4 percent is used. The 4 percent represents the real cost of capital (i.e., inflation adjusted), and use of such a rate allows the analysis
to be conducted in current dollar terms. For example, an accident that doesn’t occur in ten years (an accident cost savings) can be measured in today’s dollars:

iv) The calculation of the benefit/cost ratio is quite sensitive to ADT estimates in that the number of accidents saved is a function of traffic volumes. It can be presumed that the importance of ADT would also be true in an examination of shoulder design policies;

v) Because of the importance of ADT, and for ease of interpretation, the actual method used in the analysis is to set $B/C = 1$ (for various road-type, roadside alternatives), and then calculate the ‘breakeven’ ADT. In effect, then, for traffic volumes greater than this breakdown ADT, the particular construction project is desirable (i.e., it has a B/C ratio greater than one); and

vi) The analysis is also sensitive to the estimates made of construction and maintenance costs (obviously from one site to another construction and maintenance costs vary), and to various estimates of accident costs. Since it is assumed that this latter estimate is more contentious than the first, it may be anticipated that estimates of accident costs are a more difficult part of the present project (i.e., who’s numbers should be used, and where can alternative numbers be found to test the sensitivity?).

4.3 Recent Cost-Benefit Analyses (Post 1985)

The most recent major study of aspects of road design, and in particular, aspects relevant to shoulder types, is “Designing Safer Roads – Practices for Resurfacing, Restoration, and Rehabilitation” (20). This 1987 Transportation Research Board Study looked at several areas of design. One of them, “Pavement Edge Drop and Shoulder Type” is summarized in the Executive Summary as follows:

“Research sponsored as part of this study indicated that pavement edge drop hazards are greater than previously believed. However, no basis exists for estimating how often pavement edge drops contribute to accidents or the cost and safety trade-offs involved in preventing or correcting them.” (pp 10, emphasis added).

Although this is an American study, the scale of the research appears to have been sufficiently broad to have reviewed and/or uncovered any research on the subject in other countries. Since it did not, a reasonable conclusion may be that there really is no previous work on cost-benefit analysis that can be ‘synthesized’ for this C-SHRP project.

The TRB study examines the following eight design features, and their relationship to safety:

i) lane and shoulder width and shoulder type;

ii) roadside features and sideslopes;

iii) bridge width;

iv) horizontal alignment;
v) sight distance;
vi) intersections;
vii) pavement surface conditions; and
viii) pavement edge drop

As the relationship between different designs and safety is a key feature of the present project, the following general statement is of some interest:

"The trade-offs between the cost of such improvement (geometric changes) and their safety is fundamental to the issue of minimum ... design standards. To make this trade-off requires quantitative knowledge of the relationships between safety and different roadway features. Despite numerous statistical studies of accident data, these relationships are not well known, and divergent relationships are suggested by different analyses. Isolating the effects of a specific geometric feature from other conditions of the roadway environment, vehicle characteristics, and driver characteristics has proved to be a formidable research task." (pp 30-31).

On the specific issue of shoulder type, the TRB study does provide some concrete statements about the relationship between safety and different designs. On the specific issue of pavement edge drop, the report suggests that "the data needed to make reliable estimates are not available." (pp 98).

Finally, the terms of procedure, the TRB study does not actually use a cost-benefit analysis to examine alternative designs. Instead, the method used is to calculate a "cost per accident eliminated", which, as the term suggests, is a relatively straightforward calculation of the annual cost of a particular design element divided by the annual number of accidents eliminated. Use of this method enables the decision maker to compare one design alternative with another (e.g., this design feature would cost $XX for every accident eliminated versus this one which would cost $YY for every accident eliminated).

This approach also avoids the potentially sensitive problem of having to estimate the accident cost which is inherent to a cost-benefit analysis. That is, in undertaking a cost-benefit analysis, accident costs become the 'benefit' part of the ratio. If this number is difficult to develop and/or somewhat subjective, then the resulting benefit-cost ratio can be called into question.
5.0 Extent and Adequacy of Existing Canadian Empirical Knowledge

5.1 Areas Investigated

Four main areas of existing Canadian empirical knowledge were investigated: current design standards, historical accident records, present maintenance procedures and alternative stabilization techniques used on granular shoulders. Data were obtained by written request through the designated C-SHRP representative from each province and territory, direct personal contact through telephone polls of regional, municipal and district agency representatives where specific contacts were identified, and publications from major Canadian technical forums such as RTAC, Canadian Technical Asphalt Association (CTAA), etc.

5.2 Current Design Standards

Figure 1 summarizes the rural road design standards used in each province and territory. For comparison, the RTAC recommended geometric design standards have also been included. The comparisons between Canadian highway agencies require some interpretation, as the functional classifications and design criteria are not standardized between agencies. For example, some agencies categorize their roadways in the same terms as RTAC (freeway, arterial, collector, local) while others subdivide their roadways strictly on the basis of traffic volume. In order to give Figure 1 some structure for comparisons to be made, the agency standard classifications have been shown in what is believed to be the appropriate location.

In most jurisdictions, the standard shoulder width on arterial roadways is between 2 and 3 m. In Alberta, the full pavement structure is carried across the entire road width, including the shoulder. In British Columbia and Prince Edward Island, the surface course asphalt concrete is carried across the shoulders directly over the granular shoulder material. Partially paved shoulders are employed for all arterial routes in New Brunswick, Nova Scotia, and Newfoundland. On major arterial roads in New Brunswick, only 0.75 m of the shoulder is paved, but the remaining shoulder is chip sealed. In Newfoundland, the partially paved portion of the shoulder is 1.5 m wide, which virtually constitutes a fully-paved shoulder. Saskatchewan uses a fully-paved shoulder section for its major arterials, with the full pavement section extending only 300 mm into the shoulder on its remaining arterial classifications (the remaining shoulder area is sealed with a single lift of asphalt concrete).

The 'standard' arterial road shoulder in Ontario, Manitoba and both Territories is unsurfaced. Where the traffic is especially high or in problem areas such as curve sections, partially paved shoulders have been used (although Ontario has recently deleted its Special Provision covering Partially Paved Shoulders). Partially paved shoulders have been restricted to AADT 2000 in Manitoba and AADT 4000.

In virtually all cases, the minimum shoulder widths specified for rural local and collector roadways are less than those advocated by RTAC and internationally. This is significant when
one considers that this group of roads constitutes the major portion of the rural road network and is responsible for carrying the bulk of the heavy agricultural traffic, particularly in the Western and East-Central provinces.

5.3 Historical Canadian Accident Experience

Records of accidents related to shoulders (either shoulder width or shoulder condition) are virtually non-existent in Canadian agencies. In our review of the literature and discussions with agencies, only two Canadian studies relating accidents and shoulders (width and operational effects) were identified (14 and 21 respectively). Of these, only the study by Sanderson (14) is directly relevant to the project at hand and supports the international technical opinion on minimum shoulder widths.

Only Manitoba, New Brunswick and Newfoundland were able to respond with any quantitative data concerning accidents involving shoulders. The data included the number of reportable accidents which, in the opinion of the investigating officer, could be attributed to defective shoulders as a major contributing cause. These data have been generally based on information obtained at the time of an accident by using a standard report form of the type given in Figure 3. A minimal amount of information pertaining to shoulders is indicated on the report form (only Field 39 "Shoulders Defective" is appropriate with no distinction as to the type of problem). Both Ontario and British Columbia have recently implemented similar systems for accident reporting but, as of the date of this report, no data were available from these agencies.

The 1987 Manitoba accident database included a short "Comments" field. No comments specifically mentioned pavement drop-off. Three accidents mentioned over-correction after the vehicle encroached onto the shoulder, consistent with the "scrubbing" phenomenon described in Section 3.1. Half of the accidents (10) indicated either soft shoulders or loose gravel as contributing factors, or generally referred to loss of control on the shoulder. Two accidents were blamed on loose gravel on the pavement and may also be related to ravelling of the granular shoulders. In contrast the Saskatchewan Department of Highways indicated no record of any accidents directly attributable to shoulder ravelling on their highways.

In Newfoundland, over the four years from 1984 to 1987, an average of 0.5 percent of all reportable accidents were attributable to problems with the shoulder. In New Brunswick over the same period, 0.3 percent of all accidents were attributable to a defective shoulder. In Manitoba, the available data covers only the years 1986 and 1987; in each year there were 20 accidents caused by defective shoulders, for an average rate of 0.3 percent.

This Canadian data does not indicate that improvement in shoulder condition is likely to result in significantly reduced accident rates in these provinces. This apparently contradicts available U.S. data found in the literature (previously discussed in detail in Chapter 3) which indicates that shoulder widenings with paved shoulders outperform widenings with gravel shoulders from a safety viewpoint. This also especially appears to contradict the apparent Australian experience (4, 15).
Figure 3 – Standardized Accident Report Form
The reasons for these apparent contradictions may include the following:

i) conditions are not comparable between Australia, the U.S. states the literature is based on, and the three Canadian provinces which provided accident data;

ii) the studies did not control some other characteristic of the highway that affects accident rates. This problem is recognized by Holban (4) for the Australian study;

iii) investigating officers in the Canadian provinces have not been recognizing accidents attributable to defective shoulders; and

iv) although no previous Canadian studies have been performed to determine the differences in accident rates between roads with paved or granular shoulders, it is possible that there are a significant number of accidents that would occur despite a well maintained gravel shoulder that would be prevented by a sealed or paved shoulder.

Although there certainly are differences in road conditions and driving habits between jurisdictions, it is not believed that the entire difference is attributable to Item 1. It is also likely that a policy officer’s view of what constitutes a defective shoulder would differ significantly from that of a highway engineer, particularly with regard to head-on accidents initiated by the scrubbing phenomenon.

Despite the relatively poor correlation of accident data with shoulder condition and its apparent contradiction with other data, Alberta and B.C. provincial agencies, neither of which include unpaved shoulders in their design standards, have identified loss of control on the gravel shoulder as a significant cause of accidents. Alberta has identified over-correction resulting in the vehicle entering the opposing lane as the most significant problem. Many over-correction accidents are probably related to an attempt to remount the pavement at a drop off.

5.4 Summary of Canadian Empirical Knowledge Pertaining to Design Standards and Accident Experience

Our review of the Canadian empirical knowledge concerning accidents in relation to shoulder design standards and condition has indicated the following:

i) to our knowledge there has not been any previously controlled Canadian study made of the difference in accident rates affected by gravel or sealed shoulders;

ii) documentation of existing accident data is not sufficient to assess the impact of poor shoulder condition and maintenance practices on accident type and frequency;

iii) a standard modified accident report form would be beneficial towards establishing a Canadian accident report database; and

iv) a controlled study supported by documented accident data would determine whether a significant number of shoulder related accidents would still occur with sealed shoulders.
6.0 CURRENT MAINTENANCE PRACTICES

6.1 Maintenance Information

In order to establish the current state of Canadian technology as it pertains to shoulder maintenance practices, each province and territory as well as various regional and district agencies were surveyed to provide information concerning their current policies and procedures for shoulder maintenance. The respective agencies were formally requested to provide information concerning maintenance standards and costs, as well as details on any special treatments that may have been tried including shoulder stabilization, improved materials, etc. The formal requests and agency responses were followed up by personal contact (usually by telephone) by members of the JEGEL project team (JEGEL, Hardy BBT and CRCAC) with agency representatives directly involved with routine shoulder maintenance.

Based on the information provided, it has been possible to determine general Canadian maintenance policies with respect to shoulder ravelling and edge drop-off for conventional and alternative shoulder treatments. However detailed documentation of specific maintenance requirements, costs and performance results of alternative shoulder treatments has not been possible, even where trial stabilizations have been completed. For instance, shoulder maintenance cost data collected by the various agencies typically do not differentiate between shoulder type, design or stabilization process, and are therefore not suitable for further reduction or comparison. In addition, many trial shoulder stabilizations have usually been completed on an irregular basis under the direction of either regional design and evaluation departments (occasionally documented but not to an adequate level of detail or duration of time to allow significant conclusions) or district maintenance departments (largely undocumented and maintenance completed to treat a specific problem).

6.2 Routine Maintenance Procedures

For most Canadian agencies, shoulder maintenance policies and practices are defined by Maintenance Performance Standards that specify the warrants for shoulder maintenance (grading for instance), procedures for completing this maintenance activity and a suggested frequency. General granular shoulder maintenance typically consists of regrading/shaping by dragging loose material off the edge of the shoulder, collecting the granular material into a window on the pavement edge, and then backblading the material onto the shoulder (with or without subsequent compaction). Depending on the severity of localized ravelling, additional granular (spot gravelling or regravelling) may be added to the shoulder. Additional surface treatments (sprayed emulsified asphalt, for instance) have been used by several agencies. Routine granular shoulder maintenance practices and reported costs for the various provincial agencies are summarized in Table 1.
<table>
<thead>
<tr>
<th>Agency</th>
<th>Operation</th>
<th>Frequency</th>
<th>Production</th>
<th>Equipment</th>
<th>Labour</th>
<th>Material</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ontario</td>
<td>Grading</td>
<td>Varies by region</td>
<td>(58%)</td>
<td>(42%)</td>
<td>Nil</td>
<td>$10.60/km</td>
<td>$10.90/tonne</td>
</tr>
<tr>
<td></td>
<td>Regravelling</td>
<td>Varies by region</td>
<td>(28%)</td>
<td>(19%)</td>
<td>(53%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>British Columbia</td>
<td>Grading</td>
<td>2 to 3 times</td>
<td>20-30 pass km/day</td>
<td>1 Grader</td>
<td>1 Operator</td>
<td>N.A.</td>
<td>$708,000/yr</td>
</tr>
<tr>
<td></td>
<td>Regravelling</td>
<td>annually</td>
<td>100-130 m³/day</td>
<td>1 Grader</td>
<td>4-6 plus</td>
<td>19 mm minus crushed or well graded pit run gravel</td>
<td>$2.7 million/yr</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.39 man-hrs/m³</td>
<td>Haul trucks</td>
<td>flagging</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Loader</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Compactors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sundry</td>
<td></td>
<td>As necessary</td>
<td>N.A.</td>
<td>Variable</td>
<td>Variable</td>
<td>N.A.</td>
<td>$400,000/yr</td>
</tr>
<tr>
<td>Saskatchewan</td>
<td>Reshape/Compact</td>
<td>As necessary</td>
<td>N.A.</td>
<td>1 Grader</td>
<td>3 Operators</td>
<td>Nil</td>
<td>Not available</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 Compactor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 Water truck</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rolling</td>
<td></td>
<td>Initially and</td>
<td>N.A.</td>
<td>1 Compactor</td>
<td>1 Operator</td>
<td>Nil</td>
<td>Not available</td>
</tr>
<tr>
<td></td>
<td></td>
<td>every 3 to 5 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC 30 Prime Coat</td>
<td></td>
<td>Annually</td>
<td>N.A.</td>
<td>Nil</td>
<td>1 Operator</td>
<td>1 to 2.1 l/m²</td>
<td>$0.25/m² or $37.5/km</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(20%) (80%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Seal Coat</td>
<td>Initially and</td>
<td>N.A.</td>
<td>1 Truck with Spray Bar</td>
<td>1 Operator</td>
<td>1.5 to 2.7 l/m²</td>
<td>$0.35/m² or $1050/km</td>
</tr>
<tr>
<td></td>
<td></td>
<td>every 3 to 5 years</td>
<td></td>
<td></td>
<td></td>
<td>(20%) (80%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aggregate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Seal Coat</td>
<td>Annually</td>
<td>N.A.</td>
<td>1 Truck with Spray Bar</td>
<td>4 Operators</td>
<td>1.5 l/m²</td>
<td>$0.60 to $0.80/m²</td>
</tr>
<tr>
<td></td>
<td>Maintenance, Rolling,</td>
<td>Spot Basis</td>
<td>N.A.</td>
<td></td>
<td></td>
<td>(80%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pothole Patching using</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cold Mix, Spot Sealing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 1  Summary of Provincial Routine Maintenance Standards (Cont’d)

<table>
<thead>
<tr>
<th>Agency</th>
<th>Operation</th>
<th>Frequency</th>
<th>Production</th>
<th>Equipment</th>
<th>Labour</th>
<th>Material</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manitoba</td>
<td>Grading</td>
<td>Dependent on Road Class.</td>
<td>0.29-0.34 hr/km</td>
<td>1 Grader (74%)</td>
<td>1 Operator (26%)</td>
<td>Nil</td>
<td>$15.75/km</td>
</tr>
<tr>
<td></td>
<td>Grading with Shoulder Machine</td>
<td>As Above</td>
<td>0.19-0.24 hr/km</td>
<td>1 Tractor 1 Shoulder Machine (64%)</td>
<td>1 Operator (36%)</td>
<td>Nil</td>
<td>$6.75/km</td>
</tr>
<tr>
<td></td>
<td>Sprayed Emulsified Asphalt</td>
<td>Initially and every 3 to 4 yrs.</td>
<td>N.A.</td>
<td>Truck with Spray Bar Grader Compactor (23%)</td>
<td>3 Operators (17%)</td>
<td>Emulsified Asphalt (60%)</td>
<td>$650/km</td>
</tr>
<tr>
<td>Newfoundland</td>
<td>Grade/Reshape</td>
<td>2 times annually, as necessary</td>
<td>16 km/day</td>
<td>1 Grader (63%)</td>
<td>1 Operator (37%)</td>
<td>Nil</td>
<td>$34/km</td>
</tr>
<tr>
<td></td>
<td>Rebuilding</td>
<td>As necessary</td>
<td>–</td>
<td></td>
<td>(48%)</td>
<td>76 or 19 mm minus crushed granular (52%)</td>
<td>$17.40/m³</td>
</tr>
<tr>
<td></td>
<td>Regravelling</td>
<td>Spot basis, as necessary</td>
<td>150 m³/day</td>
<td>1 Grader 1 Loader 2 Haul Trucks</td>
<td>4 Operators 2 Flagmen</td>
<td>19 mm minus gravel or 76 mm minus crushed granular</td>
<td></td>
</tr>
<tr>
<td>Nova Scotia</td>
<td>Grading</td>
<td>2 times annually, as necessary</td>
<td>–</td>
<td>1 Grader</td>
<td>1 Operator</td>
<td>Nil</td>
<td>$150/km</td>
</tr>
<tr>
<td>New Brunswick</td>
<td>Grade/Reshape</td>
<td>Annually and as necessary</td>
<td>12-20 km/day</td>
<td>2 Graders 1 Power Broom</td>
<td>3 Operators 1 Flagman</td>
<td>Nil</td>
<td>$58,000</td>
</tr>
<tr>
<td></td>
<td>Regravelling</td>
<td>As necessary</td>
<td>300-400 tonnes/day</td>
<td>3 Haul Trucks 1 Grader 1 Loader</td>
<td>5 Operators 1 Flagman</td>
<td>Graded Aggregate</td>
<td>$294,000</td>
</tr>
<tr>
<td></td>
<td>Spot Gravelling</td>
<td>As necessary</td>
<td>80-120 tonnes/day</td>
<td>1 Service Truck 1 Loader</td>
<td>1 Operator 2 Labourers</td>
<td>Pit Run Gravel</td>
<td>$215,000</td>
</tr>
</tbody>
</table>

**Total:** $567,000

($22/km)
<table>
<thead>
<tr>
<th>Agency</th>
<th>Operation</th>
<th>Frequency</th>
<th>Production</th>
<th>Equipment</th>
<th>Labour</th>
<th>Material</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yukon</td>
<td>Grade/Reshape</td>
<td>2 times annually, Spring/Fall</td>
<td>N.A.</td>
<td>1 Grader</td>
<td>1 Operator</td>
<td>Nil</td>
<td>$180/km</td>
</tr>
<tr>
<td>Northwest Territories</td>
<td>Grade/Reshape</td>
<td>Annually or as necessary, late April to September</td>
<td>12 km/day</td>
<td>1 Grader 1 Compactor</td>
<td>2 Operators</td>
<td>Nil</td>
<td></td>
</tr>
<tr>
<td>Prince Edward Island</td>
<td>Grade/Reshape</td>
<td>As necessary</td>
<td>N.A.</td>
<td>1 Grader</td>
<td>1 Operator</td>
<td>Nil</td>
<td></td>
</tr>
<tr>
<td>Quebec</td>
<td>Spot Gravelling</td>
<td>As necessary 50-150 tonnes/day</td>
<td>1 Grader 1 Loader Haul Trucks</td>
<td>3 to 4 Operators plus flagging</td>
<td>19 mm minus crushed stone or gravel</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Regravelling</td>
<td>As necessary 500-1000 tonnes/day</td>
<td>1 Grader 1 Loader 1 Compactor Haul Trucks</td>
<td>4 to 5 Operators plus flagging</td>
<td>19 mm minus crushed stone or gravel</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grade/Reshape</td>
<td>As necessary</td>
<td></td>
<td>1 Grader</td>
<td></td>
<td>Nil</td>
<td></td>
</tr>
</tbody>
</table>
Specific details obtained from each agency are discussed as follows:

Province of British Columbia, Ministry of Transportation and Highways

The majority of granular road shoulder maintenance practices incorporate standard grading techniques. Although provincial maintenance standards do not specify frequency of grading, follow-up discussions with regional maintenance personnel indicate that grading and reshaping are typically performed two to three times annually. Spot graveling is performed as necessary to eliminate pavement edge drop-off. Most recent budget figures indicate that the agency actually spent about $3.8 million maintaining granular shoulders, which comprise about 95 percent of the provincial road shoulder maintenance requirements.

Regional and district maintenance departments routinely perform shoulder sealing on problem shoulder areas using graded aggregate and sprayed emulsified asphalt; however, accurate costs and performance data for these shoulder treatments were not available. The availability (short supply) of quality granular borrow materials has a significant impact on shoulder treatments, particularly in the northern regions of the province and has contributed to the use of other stabilization processes. The existing maintenance standards also indicate that where shoulder rutting or ravelling is a continuous problem, shoulder paving should be considered. There is a current trend within the agency towards composite shoulders incorporating increased pavement width (0.5 m to 2 m depending upon design speed and traffic volume) and improved edge delineation. Current maintenance standards are being re-written in conjunction with privatization.

Saskatchewan Highways and Transportation

The Province of Saskatchewan routinely performs one of three granular shoulder maintenance alternatives dependent upon the severity of shoulder ravelling. Reshaping and compacting of untreated granular shoulders (rarely used immediately adjacent to driving lane) is performed annually on those sections which indicate 'some' shoulder ravelling. Untreated sections which have not deteriorated significantly are routinely recompacted once or twice a year, particularly after Spring thaw, using a self-propelled compactor. No specific cost or performance data is available for maintenance of untreated granular shoulders.

Where low severity ravelling is encountered, a heavy prime coat of MC 30 asphalt is usually applied in a 200 to 300 mm width adjacent to the pavement over a previously repaired (reshaped, graded and compacted) shoulder. The initial application rate is about 1.5 to 2.7 1/m² and cost about $0.25/m² (20 percent labour, 80 percent material). The portion of primed shoulder requiring annual maintenance has been estimated at less than 5 percent of the total shoulder area and as such, only costs about $35/shoulder km, including spot patching using cold mix.

Where severe ravelling of granular shoulders is a problem, a graded aggregate seal coat is used consisting of about 20 kg/m³ of 12.5 mm minus granular and about 1.5 1/m² of sprayed HF 250S or HF 150 emulsified asphalt. The initial application costs about $1800 to $2400/km depending upon application rates, treatment width, availability of material, shoulder width and has an estimated service life about 3 to 5 years. It is estimated that only about 2 to 4
percent of the sealed shoulder area requires annual maintenance. This is estimated to cost about $65/shoulder km on a spot repair basis including rolling, pothole patching using cold mix and spot sealing.

**Manitoba Highways and Transportation**

The specified frequency of shoulder maintenance in the Province of Manitoba varies with road classification, for instance: AADT > 2000, 5 times per season; 600 < AADT < 2000, 3 times; and AADT < 600, 2 times. Annual costs for shoulder maintenance using conventional motor grader and backblading (2 passes) and tractor pulled shoulder machine (single pass) are approximately $15.75/km (26 percent labour, 74 percent equipment) and $6.75/km (36 percent labour, 64 percent equipment), respectively.

Where these conventional methods are ineffective and edge ravelling is a continuous problem, shoulder stabilization adjacent to the pavement edge (300 to 450 mm width) is performed using sprayed emulsified asphalt. The initial application costs for 1989 are estimated to be about $650/km (16 percent labour, 24 percent equipment, 60 percent material) and has a life expectancy of about 4 to 6 years with only localized routine hand spraying maintenance required.

**Ontario Ministry of Transportation**

Existing maintenance quality standards are currently under review in the Province of Ontario. The most recent draft, dated December 1988, has been consulted to determine the current maintenance quality ‘policy’ standard and prescribed preventative maintenance practices (Section M-200-1) for granular shoulders. Routine general (patrol) and detailed inspections of granular shoulders are recommended annually during late Summer or early Fall to establish current road shoulder needs for maintenance planning. After completion of Winter operations, early Spring inspections are recommended to identify specific shoulder defects or hazardous conditions. Maintenance criteria pertaining directly to ravelling includes limiting pavement edge drop-off and shoulder rutting to less than 50 mm, which is consistent with regional and municipal maintenance practices in the province.

The MTO Maintenance Quality Standards Manual recognizes that where excessive pavement edge drop-off is a recurring maintenance problem, other alternative shoulder stabilization methods should be considered including application of dust palliatives (calcium chloride predominantly, with localized trial use of lignosulphonate and ‘pulvimixing’ of the existing granular with Recycled Asphalt Pavement (RRP)). Under regular roadside conditions, shoulder stabilization incorporating composite (partially paved) or paved shoulders are recommended where road gradients exceed 5 percent (for road gradients from about 3 to 5 percent, stabilization treatments may be considered based on local experience and established need), on inside shoulders of supereleveled curves and at isolated, problem areas where frequent erosion and ravelling have occurred and untreated granular shoulders have proven ineffectual.

In addition, utilization of partially paved shoulders is recommended for two-lane Kings Highway classifications with AADT > 4000 or AADT > 4000 projected within five years of construction; Kings
and Secondary highways with AADT > 2500 and narrow (<1 m) shoulders as an economical alternative to reconstruction; and all four-lane undivided and/or divided highways.

Fully paved shoulders are required on all freeways with three or more lanes in one direction, in urban areas where the sidewalk is located less than 3 m from the lane and reverse shoulders are utilized, in urban fringe areas where commercial buildings or density of entrances is greater than 10 per 300 m side, and as protection against erosion depending upon the road gradient.

In 1988 The Province of Ontario had combined road shoulder maintenance expenditures (grading and regraveling) totalling about $4.25 million. Approximately $1.85 million was spent ‘dragging’ about 175,000 km of granular shoulders at an approximate cost of $10.60/shoulder km (58 percent equipment, 42 percent labour). Approximately $2.4 million was spent placing about 219,000 tonnes of granular shoulder material at an approximate cost of $10.90/tonne (53 percent material, 28 percent equipment, 19 percent labour). The total unit maintenance cost including grading, spot graveling and regraveling was about $24/shoulder km.

Other routine shoulder stabilization treatments incorporating sprayed emulsified asphalts are typically performed on a district level with virtually no documented cost or performance data available.

The Province of New Brunswick, Department of Transportation

The Province of New Brunswick general specification for shouldering materials incorporates gradation limits in conjunction with loss of abrasion (less than 50 percent according to ASTM C131) and compaction (95 percent maximum dry density) requirements. Shoulder maintenance tasks indicating level of service, methods and procedure (equipment, frequency, production rates) are also specified. Pavement edge drop-off is to be limited to 30 mm.

In 1988, the province had shoulder maintenance expenditures totalling about $570,000 including grading/reshaping, regraveling and spot graveling of about 26,000 km of unpaved shoulders (about $22/km).

Prince Edward Island, Department of Transportation and Public Works

Approximately 90 percent of existing granular shoulders are sodded. Annual maintenance of sodded shoulders includes grass cutting from June to October (about 20 to 30 passes). The remaining 10 percent, as well as all new road construction, have either paved or untreated granular shoulders which require routine maintenance 2 to 3 times annually.

Nova Scotia, Department of Transportation and Communications

Granular shoulders are warranted on Local Type H and I roadways (AADT < 300). The only granular shoulder maintenance practices performed is standard grading and regraveling to maintain crossfall and pavement edge drop-off. In 1988, the province spent approximately $1.7 million maintaining about 11,300 km of granular shoulders (about $140/shoulder km.).

Bituminous shoulders are warranted on Arterial (RAU 110 450 and RAU 100 450) roadways and are optional on Collector Type D (RCU 80 400, 1000 < AADT < 3000) roadways.
Government of Newfoundland and Labrador, Department of Transportation

Two types (Class A and B) of granular shoulder material are used in developed and undeveloped regions, respectively. Class A material (100 percent passing 19 mm) has been found susceptible to ravelling and rutting by heavy truck traffic and erosion from water run-off. Class B material (100 percent crushed passing 76.1 mm, less than 6 percent passing 75 μm) retains crossfall and shape properties under more severe truck traffic and climate conditions, however is not suitable for use in developed regions. Shortage and cost of suitable granular borrow materials has resulted in use of typically more expensive crushed rock.

Untreated granular shoulders are warranted for use on RLU 60 and RLU 70 roadways. Available inventory data (1986-87) indicates the province has about 11,500 km of untreated granular shoulders. Composite (partially paved) shoulders are warranted for use on RLU 80 (0.5 m paved), RCU 80 (0.5 m paved), RAU 90 (1.5 m paved) and RAD 90 (1.5 m paved) roadways.

Most recent available cost data (1986-87) indicated that the province spent a total of approximately $2.25 million maintaining (grade/reshape and rebuilding) about 10,200 km of granular shoulders. Approximately $350,000 (37 percent labour/materials, 63 percent equipment) was spent grading/reshaping at an approximate cost of $34/shoulder km. Approximately $1.9 million (52 percent labour/materials, 48 percent equipment) was spent rebuilding about 109,000 m³ of granular shoulder material (unit cost about $17.40/m³).

Existing maintenance standards and manual are in the process of revision.

Northwest Territories, Public Works and Highways

Granular shoulders are used on all paved roadways regardless of design traffic levels. The width of granular shoulders (usable roadway width minimum pavement width) varies from 1 m (200 < AADT < 1000, 100 km/h design speed) to 0.25 m (100 < AADT < 200, 50 km/hr design speed). Shoulder widths are typically increased by 0.5 m where guardrails are necessary. The provisions for minimum shoulder widths are typically below specified R.T.A.C. standards primarily due to short supply and high cost of suitable granular (borrow or crushed) materials. Shoulder crossfall and pavement edge drop-off are maintained at 4 percent and less than 30 mm, respectively.

Yukon Community and Transportation Services

About 95 percent of existing shoulders are untreated granular material. The remaining 5 percent use bituminous surface treatment (chip sealed) using sprayed emulsified asphalt and graded aggregate. Total annual maintenance costs average about $180/shoulder km. No separate maintenance cost data is available for the bituminous surface treatment.

Alberta Transportation and Utilities

The Province of Alberta maintains fully paved shoulders on all provincial roadways, which requires the same maintenance effort (crack sealing and patching) as the adjacent travel lanes. No additional maintenance is required over the design life of the roadway pavement.
structure. Shoulder overlay treatments are typically coincident with resurfacing or reconstruction of the adjacent roadway. Approximately 10 percent of the pavement patching activity is attributed to maintenance of the shoulder portion. The estimated cost (prorated) of shoulder maintenance is currently about $100/km.

Previous research by Simlotte and Ghai (22), performed on behalf of Alberta Transportation Research and Development in 1986, included a literature search and review of road shoulder practices, operational and maintenance performance, and initial costs of construction.

The report indicated general cost savings (1985-86 $/km) of various shoulder types compared to full strength (two 50 mm thick asphalt concrete lifts), fully paved (3 m width) shoulders, as indicated in Table 2.

Based on operational and maintenance performance, as well as safety considerations, the following general conclusions were made at that time:

i) 3 m wide full strength fully paved shoulders should continue to be provided on high volume (6 and 8 lane RFD and RAD) highways;

ii) granular base double seal coated shoulders should be considered for use on low to medium traffic volume highways (RAU 211, RAU 213, RAD 412.5 and RFD 412.5); and

iii) full strength fully paved shoulders should be provided on very low traffic volume roads due to difficulty and impracticality of constructing and maintaining narrow (0.5 to 1 m width) shoulders.

Gouvernement du Québec Ministère des Transports

Granular shoulder maintenance standards and warrants specify maximum allowable shoulder depressions (rutting or drop off) and crossfall for various road classifications as indicated below.

<table>
<thead>
<tr>
<th>Road Classification</th>
<th>Spot Graveling (mm)</th>
<th>Regraveling (percent)</th>
<th>Grade/Reshape (mm)</th>
<th>Grade/Reshape (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principal</td>
<td>50</td>
<td>50</td>
<td>8</td>
<td>75</td>
</tr>
<tr>
<td>Regional</td>
<td>90</td>
<td>75</td>
<td>8</td>
<td>75</td>
</tr>
<tr>
<td>Municipal</td>
<td>75</td>
<td>100</td>
<td>10</td>
<td>100</td>
</tr>
</tbody>
</table>

Granular shoulder stabilization may also be performed using either sprayed emulsified asphalt, applied in two applications at about 1.4 l/m², or 35 percent calcium chloride solution applied at about 1.2 tonne/km (about 1.8 l/m²), typically in a 2 m width adjacent to the travel lanes.
<table>
<thead>
<tr>
<th>Shoulder Type</th>
<th>Cost Savings (1985-86 $/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesser Strength Fully Paved(^1) (0.6 m width full strength, 2.4 m width 50 mm asphalt concrete over granular base)</td>
<td>6,000</td>
</tr>
<tr>
<td>Granular Base Double Seal Coated(^1,2) (0.6 m width full strength, 2.4 m width double seal coated granular)</td>
<td>6,000</td>
</tr>
<tr>
<td>Partially Paved(^1) (0.6 m width full strength, 2.4 m width untreated granular)</td>
<td>25,000 to 80,000(^3)</td>
</tr>
<tr>
<td>Gravel</td>
<td>30,000 to 80,000(^3)</td>
</tr>
</tbody>
</table>

**Notes:**
1. Assumed costs of asphalt concrete $35/tonne, granular base $14/tonne, placed.
2. Assumed cost of double seal coat $2.50/m\(^2\).
3. Depending on road designation (shoulder width) and thickness of asphalt concrete pavement.

### 6.3 Alternative Shoulder Treatments

Canadian experience with trial stabilization of granular materials has been performed on a regional basis and is largely undocumented by provincial agencies. Information is more readily available from distributors and/or manufacturers of those various stabilizers. The following discussion is limited therefore to the direct experiences gained through the application of Calcium Chloride (manufactured by General Chemicals and distributed to licensed applicators) in the Province of Ontario, Calcium Lignosulphonates (manufactured by Temfibre Inc. and distributed by Kildair Service Limitée) in the Province of Quebec, and regional trial stabilization using B.C. (Base Course) Stabilizer developed by British Columbia Ministry of Transportation and Highways.

**Calcium Chloride**

The application of calcium chloride primarily as a dust palliative is common. Its ability to effectively stabilize fine grained material or the fine fraction of otherwise marginal (poorly graded) granular subsoil has led to its previous use as a basecourse stabilizer. However its high solubility limits its use on otherwise unsealed granular shoulders to that of a short term dust palliative requiring re-application.

Regional application rates on rural and regional roads in southwestern Ontario vary. Brant County for instance applies about 3 to 4 tonnes/km (6.5 m full width) or about 0.5 to 0.6 kg/m\(^2\).
Regions of Durham and Peel apply (sprayed) 35 percent liquid Calcium Chloride solution to shoulders only at a rate of about 1.8 l/m². The cost of liquid calcium chloride varies largely according to freight distances, however it is generally available within southwestern Ontario (shipped via rail from General Chemicals plant in Windsor) at a cost of about $275/tonne.

Previous full width rural road stabilization trials completed by John Emery Geotechnical Engineering Limited on behalf of General Chemical Limited in the Town of Pelham, Ontario involved increasing application rates from the 'standard' 3 tonnes/km used for dust control, to 12 tonnes/km with in-place mixing to develop a stabilized layer between about 100 to 150 mm thickness. Preliminary results indicated improved stability of the surface with decrease 'float' or stone loss and subsequent washboarding. The result was a significant reduction in short term maintenance requirements. The study indicated that the calcium chloride stabilized granular base had an equivalency factor of between about 1.2 to 1.3.

**Calcium Lignosulphonate**

Calcium Lignosulphonate (CALS) is a waste by-product of the pulp and paper industry. It is an organic polymer with polar hydrophilic groups attached to non-polar hydrophobic groups. Its unique chemical configuration lends itself to equally unique physical properties. The result is that CALS has strong dispersive, lubricating, cementitious and wetting characteristics. This combination of properties make CALS a useful dust palliative and potential stabilizer.

The use of calcium lignosulphonate (CALS) is not widespread and has typically been used on a regional basis to solve localized dust control, rather than stabilization, problems. Results of trial stabilizations by government agencies are poorly documented (no cost or performance data available).

CALS is manufactured and distributed in the Province of Quebec by Temfibre Inc. (Termiscamling) and Kildair Service Limitée (Montreal), respectively. More detailed information concerning site specific applications, cost and performance data is forthcoming from these companies.

The application of CALS as a long-term stabilizing material is typically limited by its high water solubility. Its suitability for use as a dust palliative is due to the limited time span which it must remain effective and relatively low application rates compared to what would be required if it were to be used as a stabilizer. It is apparent that if CALS is to be used as a soil stabilizer, that it must be in combination with other materials which compensate for its solubility.

**B.C. Stabilizer (Base Course Stabilizer)**

Trial applications performed by the Province of British Columbia, Ministry of Transportation and Highways from 1984 to 1986 are summarized in a paper by Mazuch et. al. (23). Five trial stabilization sections were performed on various marginal granular base materials. Three stabilization methods were investigated including in-place mixing, cold-mix recycling and cold central plant mixing.
Common to all these methods was the in line blending of the liquid stabilizer (1/3 SS-1 emulsified asphalt, 1/3 calcium lignosulphonate, 1/3 water). The resulting blend is composed of approximately 37 percent solids, has a relative density approximately equal to 1.09, and has 7.0 < pH < 8.0. About 4 percent by weight liquid stabilizer is mixed with the granular base material. The aggregate does not have to be absolutely dry since up to about 1.5 percent moisture content is acceptable. The optimum moisture content of the stabilized aggregate is typically about 4 percent (about 1.5 percent residual binder content). After initial curing the stabilized granular typically has unconfined compressive strength of about 2.1 MPa (300 psi) and Marshall stability of 24 kN (flow 8.5) at ambient temperature.

The liquid stabilizer incorporates valuable properties from each of its components into the resulting stabilized granular material. The investigations indicated that the following benefits are evident:

i) Increased compaction is obtained at lower optimum moisture content due to lubricating and wetting properties of calcium lignosulphonate. Fine grained aggregate is more readily separated as a result of the dispersive action and subsequently mixed into a denser compacted mass;

ii) Load bearing capacity is increased due to the cementitious nature of the calcium lignosulphonate and emulsified asphalt (2.1 to 2.4 MPa reported);

iii) Voids ratio is decreased with corresponding reduction in frost susceptibility of otherwise fine or very fine grained granular material;

iv) Encapsulation of calcium lignosulphonate and individual soil particles by emulsified asphalt results in a waterproofing (hydrophobic) coating and subsequent reduction in solubility;

v) Self healing of cracks is obtained in the presence of moisture by on-going curing due to cementitious nature of calcium lignosulphonate;

vi) Porosity is reduced due to wetting properties of calcium lignosulphonate and waterproofing characteristics of emulsified asphalt;

vii) Bleeding is controlled during cold mix recycling processes due to crystallization (curing process) of calcium lignosulphonate; and

viii) Deformations occur only when shear strength is exceeded resulting in reduced rutting.

Two of the successful stabilization trials indicated the following data:

i) Nakusp Hot Springs Road, Project S-0084-3411, completed August 1984.

Approximately 12 km of roadway 7.2 m wide was stabilized and compacted to 45 mm depth. The B.C. Stabilizer was applied at a rate of 4.2 l/m² prior to in-place mixing (using graders and compactors). An additional sand seal (0.35 l/m² SS-1 emulsified asphalt, 5 kg/m² sand) was applied over the stabilized base prior to final bituminous surface treatment (chip seal). The cost of granular base stabilization was approximately
$128,000 ($1480/km/m width of road). Site inspections performed in May 1985 and June 1986 indicated that the roadway had performed satisfactorily; and

ii) Okanagan Highway 97, Project C-2819, completed April 1986.

Approximately 3.4 km of medium grained sand base along a four-lane highway was stabilized to 90 mm depth using in-place methods. B.C. Stabilizer was applied at a rate of 4.7 l/m² at a cost of about $0.19/l (material cost $0.90/m² or $900/km/m width of road).

In addition to these alternative shoulder treatments, Ontario has experimented with a variety of shoulder stabilization techniques since the late 1950's. Several test sections were duplicated in the Huntsville and Sudbury districts involving calcium chloride/sodium chloride addition to stabilize the existing granular base; soil-cement; mixing of clay with granular base; and addition of high quality crushed stone to the existing granular base (24, 25). Both studies concluded that stabilization of the shoulder granular material by mixing it with some small amount of clay was the most economical stabilization approach. It should be noted that a very short monitoring period was involved, less than one year, and no long-term results could be located.

In 1987, Ontario experimented with mixing recycled asphalt pavement millings into the existing granular shoulder material in-place using Bomag MPH 100 Recycler or Bros Reclaimer II equipment. This treatment extends approximately 150 mm deep and results in a relatively stable surface resembling surface treatment. No performance data is available for this trial stabilization.

6.4 Summary of Current Maintenance Practices

The literature search and review of current maintenance practices indicated:

i) Granular shoulder maintenance typically consists of seasonal grading/reshaping and spot graveling as necessary to maintain edge drop-off and rutting;

ii) there is a lack of consistent maintenance warrants for treatment of granular shoulder raveling such as limiting pavement edge drop-off and rutting;

iii) reporting of annual maintenance costs ($/shoulder km) is inconsistent as indicated by the variation in reported costs for 'standard' grading/reshaping and regravelling, even on a regional basis within a given province;

iv) there is a variation in shoulder design and material standards due to regional, economic and geologic considerations (lack of quality granular borrow materials and/or high cost, for instance);

v) operational and maintenance shoulder performance data is poorly documented, particularly where alternative treatments such as emulsified asphalt or calcium chloride have been used as stabilizers;
vi) use of lignosulphonates in combination with emulsified asphalt (B.C. Stabilizer) appeared successful as a basecourse stabilizer and should be considered for use on granular shoulders;

vii) there is a growing trend toward composite (0.6 m partially paved) shoulders in combination with improved edge delineation; and

viii) no specific trial stabilizations have apparently been reported using cement kiln dust and/or fly ash, both of which are pozzolans and may be considered for use as an effective road shoulder stabilizer. However, their use in soil cement stabilized base applications is well documented (26).
7.0 Additional Data Requirements

7.1 Accidents

The findings reported in Tasks 1 through 4 indicate that the relationships between shoulder width, shoulder condition and accidents are neither well documented or in consistent agreement. While there appears to be a relationship between shoulder width and accidents for shoulders up to about 1.5 to 2 m wide, the impact of wider shoulders on accident reduction is not consistent internationally and there is a general lack of any corroborative Canadian accident data to support the international findings. Most low volume ‘local’ Canadian rural roads have been constructed to a standard 1.0 m shoulder width that is less than the 1.5 m ‘safe’ width suggested by other agencies and the literature, but the limited Canadian accident data does not suggest that this lower width has presented a significant safety hazard. There is however, a concern that the accident reporting and its overall lack of emphasis on shoulder features as a contributing cause of accidents, may be misleading. In this regard, the future work plan must address the need for more detailed Canadian accident information to reasonably address the issue of minimum ‘safe’ shoulder width and confirm the impact of shoulder condition as a safety hazard.

To date, only three provinces have responded with any quantitative accident data. It is perceived that other data may exist, but it will be necessary to more actively contact agencies directly involved with accidents including provinces, large municipalities, rural road agencies (country and township agencies), provincial police departments and insurance companies. It will not be possible within the scope of this study to revise and implement even locally, a shoulder specific accident reporting procedure, but it is hoped that more complete historical accident data can be obtained and analyzed to more definitively establish the Canadian accident experience.

7.2 Maintenance Information

The literature clearly indicates that shoulder condition and in particular, ravelling of the shoulder material along the pavement edge, is a contributing cause of accidents. While there is some technical disagreement over the critical edge drop that can be safely handled by the average driver (between 40 and 100 mm), it can be assumed that any edge drop greater than 40 mm should be considered as hazardous and should not be tolerated. The most commonly used corrective action is maintenance regrading, either annually or biannually, with very few agencies requiring any additional work or treatment rather than on a spot repair/patrol activity basis, i.e. locally regrade as necessary. Due to the spot repair nature of this treatment, the associated costs for this activity are quite variable. In addition, there are a number of alternative shoulder treatments to reduce ravelling of granular shoulder material and frequency of maintenance regrading that should also be considered in terms of their effectiveness and cost. These options include use of improved shoulder materials and specifications, full or partial shoulder stabilization using cementitious materials such as portland cement or waste kiln dust, asphalt materials such as emulsions or recycled asphalt pavement, and chemical treatments such as calcium chloride or lignosulphonate.
7.3 Alternative Maintenance Treatments

The technical literature and review of the Canadian experience has indicated that there are a number of alternative maintenance treatments that can be considered to control ravelling of granular shoulder material other than paving of the shoulder. However, there does not appear to be sufficient documentation of a comparative nature to allow a direct assessment of the cost effectiveness of these alternatives to be confirmed. Noting the problems with ‘before and after’ analyses previously discussed in Section 3, it is recommended that comparative analysis of a number of trial sections be completed. The selection and construction of these trial sections will require the assistance and direct participation of the C-SHARP member agencies.

The literature has suggested the following alternatives to conventional granular and fully paved shouldering:

1. Improved granular materials, i.e. ‘premium’ materials such as 100 percent crushed aggregates or other high particle index material

2. Stabilization of existing granular shoulder material by:
   i) emulsified asphalt addition;
   ii) portland cement addition;
   iii) RAP addition;
   iv) byproducts utilization - waste kiln dust - lignosulphonate;
   v) calcium chloride addition; and
   vi) other (?) methods.

Each of these alternatives should be comparatively analyzed for their initial cost, service life, maintenance demand and overall pavement quality improvement to establish the most practical shoulder improvement approach. Regional factors must also be taken into account including materials availability, special equipment requirements/modifications and staff training. For example, ‘premium’ high quality granular materials and industrial byproduct materials such as lignosulphonate (associated with pulp and paper manufacture) and waste kiln dust (cement manufacturing byproduct) may only be practical in a limited geographic area. However, calcium chloride, emulsified asphalt and portland cement are commonly used construction products readily available in most areas of the country.
8.0 CONCLUSIONS

The work completed to date has indicated the following general conclusions:

i) There appears to be a relationship between shoulder design and accidents. In summary, the minimum 'safe' shoulder width for a roadway is 1.5 to 2.0 m regardless of classification, with higher volume, higher speed roads requiring safe shoulder widths that effectively approach the actual lane width.

ii) Canadian road agencies have generally adopted a 'standard' minimum shoulder width of 1.0 m with some agencies reporting even narrower shoulder widths.

iii) Shoulder condition and in particular the drop-off between the pavement and shoulder due to ravelling, has been found to be a major cause of head-on accidents due to the scrubbing phenomenon and its associated loss of control.

iv) The critical edge drop that may be tolerated by the average driver is between about 40 and 75 mm depending on the shape of the drop-off; 40 mm is considered to be the most appropriate tolerable drop-off for Canadian driving conditions.

v) The Canadian accident experience is quite limited with respect to shoulders but suggests that between 0.3 and 0.5 percent of all accidents involve shoulder deficiencies (inadequate width or poor condition). There is a concern that the accident reporting mechanism may not adequately recognize shoulder problems and especially the relationship between head-on accidents and pavement edge drop-off occurring on the opposite side of the road.

vi) Meaningful cost-benefit analyses of shoulder designs and maintenance alternatives to reduce granular shoulder ravelling may not be possible if the only benefit to be considered is reduction of accidents (i.e. loss of life). This is due principally to the lack of consistently comparable and reliable accident data for various treatments and conditions. If the benefit of accident reduction is eliminated from the cost-benefit framework, the analysis reduces essentially to a comparison of cost effectiveness (life cycle cost) of design, construction and maintenance alternatives.

vii) It is clear that the key to successful completion of the project Terms of Reference is to obtain granular shoulder performance data which does not currently exist. In order to
generate this data it will be necessary to perform field monitoring and data collection of in-service pavements to determine the significance of ravelling and its relationship to:

a) Safety (accident rates, etc.);

b) Geometry (slope angle or gradient, crossfall, alignment, width, edge delineation, clear zone, etc.);

c) Material Properties (gradation, plasticity, angularity, density compaction), bulk density, moisture content;

d) Traffic (volume, capacity, speed, vehicle type and mix); and

e) Environment (temperature, precipitation, etc.).

This phase of the research has identified data requirements which are well in excess of the resources available to the project. Major advances in the collection of accident details are required, for a prolonged period of time, before direct correlations of roadway geometry and engineering features to accidents can be made confidently.
References


SUPPLEMENTARY REFERENCES

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Shoulder Design


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Cost-Benefit


Cost-Benefit


