Roads and Sidewalks

Rut Mitigation Techniques at Intersections

This document is the fifth in a series of best practices for the design, maintenance and management of municipal roads and sidewalks. For titles of other best practices in this and other series, please refer to *www.infraguide.ca.*

National Guide to Sustainable
Municipal Infrastructure

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Municipalities
Canadä

Rut Mitigation Techniques at Intersections

Issue No. 1.0

Publication Date: September 2003

INTRODUCTION

InfraGuide – Innovations and Best Practices

Why Canada Needs InfraGuide

Canadian municipalities spend $12 to $15 billion annually on infrastructure but it never seems to be enough. Existing infrastructure is ageing while demand grows for more and better roads, and improved water and sewer systems responding both to higher standards of safety, health and environmental protection as well as population growth. The solution is to change the way we plan, design and manage infrastructure. Only by doing so can municipalities meet new demands within a fiscally responsible and environmentally sustainable framework, while preserving our quality of life.

This is what the National Guide to Sustainable Municipal Infrastructure (InfraGuide) seeks to accomplish.

In 2001, the federal government, through its Infrastructure Canada Program (IC) and the National Research Council (NRC), joined forces with the Federation of Canadian Municipalities (FCM) to create the National Guide to Sustainable Municipal Infrastructure (InfraGuide). InfraGuide is both a new, national network of people and a growing collection of published best practice documents for use by decision makers and technical personnel in the public and private sectors. Based on Canadian experience and research, the reports set out the best practices to support sustainable municipal infrastructure decisions and actions in six key areas: 1) municipal roads and sidewalks 2) potable water 3) storm and wastewater 4) decision making and investment planning 5) environmental protocols and 6) transit. The best practices are available on-line and in hard copy.

A Knowledge Network of Excellence

InfraGuide´s creation is made possible through $12.5 million from Infrastructure Canada, in-kind contributions from various facets of the industry, technical resources, the collaborative effort of municipal practitioners, researchers and other experts, and a host of volunteers throughout the country. By gathering and synthesizing the best Canadian experience and knowledge, InfraGuide helps municipalities get the maximum return on every dollar they spend on infrastructure – while being mindful of the social and environmental implications of their decisions.

Volunteer technical committees and working groups — with the assistance of consultants and other stakeholders — are responsible for the research and publication of the best practices. This is a system of shared knowledge, shared responsibility and shared benefits. We urge you to become a part of the InfraGuide Network of Excellence. Whether you are a municipal plant operator, a planner or a municipal councillor, your input is critical to the quality of our work.

Please join us.

Contact InfraGuide toll-free at **1-866-330-3350** or visit our Web site for more information. We look forward to working with you.

The InfraGuide Best Practices Focus

Municipal Roads and Sidewalks

Sound decision making and preventive maintenance are essential to managing municipal pavement infrastructure cost effectively. Just as $1 of timely rehabilitation will save $5 of reconstruction, $1 of timely prevention will delay $5 of rehabilitation. Municipal roads and sidewalks best practices address two priorities: front-end planning and decision making to identify and manage pavement infrastructures as a component of the infrastructure system; and a preventive approach to slow the deterioration of existing roadways. The best practices set out will ensure for instance that the right treatment is selected for the right road at the right time and will provide guidance in implementing individual treatments successfully, e.g. crack-sealing, rut mitigation. Example topics include timely preventative maintenance of municipal roads; construction and rehabilitation of utility boxes; and progressive improvement of asphalt and concrete pavement repair practices.

Decision Making and Investment Planning

Elected officials and senior municipal administrators need a framework for articulating the value of infrastructure planning and maintenance, while balancing social, environmental and economic factors. Decision-making and investment planning best practices transform complex and technical material into non-technical principles and guidelines for decision making, and facilitate the realization of adequate funding over the life cycle of the infrastructure. Examples include protocols for determining costs and benefits associated with desired levels of service; and strategic benchmarks, indicators or reference points for investment policy and planning decisions.

Environmental Protocols

Environmental protocols focus on the interaction of natural systems and their effects on human quality of life in relation to municipal infrastructure delivery. Environmental elements and systems include land (including flora), water, air (including noise and light) and soil. Example practices include how to factor in environmental considerations in establishing the desired level of municipal infrastructure service; and definition of local environmental conditions, challenges and opportunities with respect to municipal infrastructure.

Potable Water

Potable water best practices address various approaches to enhance a municipality's or water utility's ability to manage drinking water delivery in a way that ensures public health and safety at best value and on a sustainable basis. Issues such as water accountability, water use and loss, deterioration and inspection of distribution systems, renewal planning and technologies for rehabilitation of potable water systems and water quality in the distribution systems are examined.

Transit

Urbanization places pressure on an eroding, ageing infrastructure, and raises concerns about declining air and water quality. Transit systems contribute to reducing traffic gridlock and improving road safety. Transit best practices address the need to improve supply, influence demand and make operational improvements with the least environmental impact, while meeting social and business needs.

Storm and Wastewater

Ageing buried infrastructure, diminishing financial resources, stricter legislation for effluents, increasing public awareness of environmental impacts due to wastewater and contaminated stormwater are challenges that municipalities have to deal with. Storm and wastewater best practices deal with buried linear infrastructure as well as end of pipe treatment and management issues. Examples include ways to control and reduce inflow and infiltration; how to secure relevant and consistent data sets; how to inspect and assess condition and performance of collections systems; treatment plant optimization; and management of biosolids.

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ACKNOWLEDGEMENTS

The dedication of individuals who volunteered their time and expertise in the interest of the *National Guide to Sustainable Municipal Infrastructure (InfraGuide)* is acknowledged and much appreciated.

This best practice was developed by stakeholders from Canadian municipalities and specialists from across Canada, based on information from a scan of municipal practices and an extensive literature review. The following members of the National Guide´s Municipal Roads and Sidewalks Technical Committee provided guidance and direction in the development of this best practice. They were assisted by the Guide Directorate staff and by John Emery, Geotechnical Engineering Limited (JEGEL), in association with Le Groupe Qualitas.

Mike Sheflin P.Eng., Chair
Former CAO Regional Municipality of
Ottawa-Carleton, Ontario

Brian Anderson
Ontario Good Roads Association, Chatham, Ontario

Vince Aurilio P.Eng.
Ontario Hot Mix Producers Association,
Mississauga, Ontario

Don Brynildsen P.Eng.
City of Vancouver, British Colombia

Al Cepas P.Eng.
City of Edmonton, Alberta

Brian E. Crist P.Eng.
City of Whitehorse, Yukon

Michel Dion M.Sc.
Axor Experts-Conseils, Montréal, Quebec

Bill Larkin, P.Eng.
City of Winnipeg, Manitoba

Cluny Matchim C.E.T.
Town of Gander, Newfoundland

Tim J. Smith P.Eng., M.Sc.Eng.
Cement Association of Canada, Ottawa, Ontario

Sylvain Boudreau M.Eng., P.Eng.
Technical Advisor, NRC

In addition, the Municipal Roads and Sidewalks Technical Committee would like to thank the following individuals for their participation in working groups and peer review:

Vince Aurilio, P.Eng.
Asphalt Institute and Ontario Hot Mix Producers
Association, Mississauga, Ontario

Don Brynildsen, P.Eng.
City of Vancouver, British Columbia

Nabil Kamel, P.Eng.
Petro-Canada, Oakville, Ontario

Bill Larkin, P.Eng.
City of Winnipeg, Manitoba

Michael Maher, P.Eng.
Golder Associates, Whitby, Ontario

Gord Malinowski, P.Eng.
City of Saskatoon, Saskatchewan

Tim J. Smith, P.Eng., M.Sc.Eng.
Cement Association of Canada, Ottawa, Ontario

Acknowledgements

This and other best practices could not have been developed without the leadership and guidance of the Project Steering Committee and the Technical Steering Committee of the *National Guide to Sustainable Municipal Infrastructure*, whose members are as follows:

Project Steering Committee:

Mike Badham, Chair
City Councillor, Regina, Saskatchewan

Stuart Briese
Portage la Prairie, Manitoba

Bill Crowther
City of Toronto, Ontario

Jim D´Orazio
Greater Toronto Sewer and Watermain
Contractors Association, Ontario

Derm Flynn
Mayor, Appleton, Newfoundland

David General
Cambridge Bay, Nunavut

Ralph Haas
University of Waterloo, Ontario

Barb Harris
Whitehorse, Yukon

Robert Hilton
Office of Infrastructure, Ottawa, Ontario

Joan Lougheed
City Councillor, Burlington, Ontario
Stakeholder Liaison Representative

René Morency
Régie des installations olympiques
Montréal, Quebec

Saeed Mirza
McGill University, Montréal, Quebec

Lee Nauss
City Councillor, Lunenburg, Nova Scotia

Ric Robertshaw
Region of Halton, Ontario

Dave Rudberg
City of Vancouver, British Columbia

Van Simonson
City of Saskatoon, Saskatchewan

Basile Stewart
Mayor, Summerside, Prince Edward Island

Serge Thériault
Department of Environment and Local
Government, New Brunswick

Alec Waters
Alberta Transportation

Wally Wells
Dillon Consulting Ltd., Ontario

Technical Steering Committee:

Don Brynildsen
City of Vancouver, British Columbia

Al Cepas
City of Edmonton, Alberta

Andrew Cowan
City of Winnipeg, Manitoba

Tim Dennis
City of Toronto, Ontario

Kulvinder Dhillon
Province of Nova Scotia, Halifax, Nova Scotia

Wayne Green
City of Toronto, Ontario

John Hodgson
City of Edmonton, Alberta

Bob Lorimer
Lorimer & Associates, Whitehorse, Yukon

Betty Matthews-Malone
Haldimand County, Ontario

Umendra Mital
City of Surrey, British Columbia

Anne-Marie Parent
Councillor, City of Montréal, Quebec

Piero Salvo
WSA Trenchless Consultants Inc., Ontario

Mike Sheflin
Former CAO, Regional Municipality of Ottawa-Carleton, Ontario

Konrad Siu
City of Edmonton, Alberta

Carl Yates
Halifax Regional Water Commission,
Nova Scotia

EXECUTIVE SUMMARY

This document outlines the best practice for the cost-effective, technically sound mitigation of intersection asphalt pavement rutting, and provides a municipal intersection pavement rut mitigation action plan to ensure good structural and functional performance of existing and new asphalt pavements. It is based on practical Canadian experience supplemented by a questionnaire and technical information scan.

There are three types of asphalt pavement rutting: wheel path wear and densification (consolidation) rutting, pavement structural rutting, and asphalt concrete instability rutting (permanent deformation). Wear rutting is not a significant problem with the control or banning of studded tire use. Densification rutting is generally avoided through proper compaction during construction. Pavement structural rutting is dealt with through appropriate pavement structural designs, materials selection, and quality construction. The focus of this best practice is the mitigation of asphalt concrete instability rutting.

The rutting of most concern to municipalities is asphalt concrete instability rutting at intersections, bus bays, and routes with considerable truck and bus traffic, particularly when it is slow moving and standing, and during hot weather. These truck and bus loadings result in higher stress/strain conditions that must be dealt with through appropriate hot-mix asphalt technology and proper construction techniques. Where there is a safety concern with asphalt concrete rutting (e.g., lowered frictional characteristics due to flushing), this should be dealt with as soon as practical.

The municipal intersection pavement rut mitigation action plan involves four key steps.

- Evaluate pavement performance problems and determine the cause of any rutting.
- Ensure the pavement is structurally adequate.
- Select and implement a cost-effective, technically sound pavement rut mitigation approach with appropriate materials selection and mix designs.
- Practise proper construction techniques with quality assurance.

This best practice covers pavement types and technology, the types of pavement rutting and their consequences, and rut mitigation methods. Pavement and rutting terminology is described and an annotated bibliography of key technical references enables the non-specialist to gain an appreciation of the asphalt pavement rutting problem.
The municipal intersection pavement rut mitigation strategy is introduced through a review of the three basic types of rutting and the technology for rut mitigation, with a focus on instability rutting (plastic deformation) of asphalt concrete. A detailed work description for the multi-stage action plan to mitigate asphalt concrete rutting at high stress/strain areas, such as intersections, is presented. The applications and limitations of a wide range of rut mitigation techniques are then discussed, including whitetopping and alternate pavement types, such as Portland cement concrete and concrete pavers. Finally, the evaluation of the rut mitigation action plan's effectiveness through pavement performance monitoring is recommended.

1. General

1.1 Introduction

The rutting of asphalt concrete at intersections (longitudinal depressions and shoving in wheel paths) is often a significant pavement performance problem requiring cost-effective, technically sound mitigation techniques. Rutting (permanent deformation) is a prime potential failure mode of hot-mix asphalt (HMA). Truck and bus heavy wheel loadings, particularly when slow moving or standing, and during hot weather, subject the asphalt pavement to stress/strain conditions, which may cause rutting. These high stress/strain conditions at intersections, bus bays, and sections of truck and bus routes with slow speeds (uphill, for instance), require these asphalt pavements to be designed, constructed, and maintained to withstand much more severe operating conditions than regular pavements.

1.2 Purpose And Scope

This best practice provides a municipal intersection pavement rut mitigation action plan to ensure good structural and functional performance of existing and new asphalt pavements. Alternative pavement types, such as Portland cement concrete (PCC), roller-compacted concrete (RCC), and interlocking concrete pavers (ICP) are also considered. With tight municipal transportation infrastructure maintenance and capital budgets, it is imperative that long-term pavement performance be optimized to provide safe, smooth roads. The focus of this best practice is the instability rutting (plastic deformation) of asphalt concrete.

The rutting of asphalt pavements is a costly rehabilitation problem best avoided at the new pavement design, specification, and construction stages. If rutting at intersections does occur, it is imperative to base the selected rut mitigation technique on appropriate material selection, mix design, construction method, and quality assurance, at the most favourable life cycle cost. An applied pavement management system is a powerful tool to assist in this decision making and to monitor the rut mitigation technique's effectiveness.

Using the guidelines presented in this best practice, hot-mix asphalt pavements can be designed, specified, constructed, and maintained to provide economic, long-life pavements for high stress/strain loading conditions, such as urban intersections and bus bays. While this best practice does provide background information on pavement structural design technology, the detailed information required to complete pavement designs is beyond its scope. Generally, professional technical input will be required to implement a pavement intersection strategy for rut mitigation, particularly for major intersections or severe rutting. Also, the effectiveness of any rut mitigation method, and its service life, is highly dependent on specific site conditions, materials, construction, and quality.

1.3 Glossary

Concrete pavers (pavers, interlocking concrete pavers, concrete paving blocks) — Paving blocks manufactured to close tolerances of dense, high-quality Portland cement concrete. They are used as the surface for a wide range of pavement (mainly flexible) applications from driveways to industrial roadways carrying very heavy loads.

Equivalent single axle loads (ESALs) — Summation of 80 kN single axle load applications used to combine mixed vehicle (trucks) and bus traffic to determine design traffic during the pavement design analysis period.

With tight municipal transportation infrastructure maintenance and capital budgets, it is imperative that long-term pavement performance be optimized to provide safe, smooth roads.

Manufactured sand — Fine aggregate produced by crushing and processing quarried rock or boulders (does not include screenings), cobbles and coarse gravel from which the natural fine aggregate has been removed.

Micro-milling — Removing the surface of an asphalt concrete pavement using a travelling machine equipped with a helical cutting head, typically to a texture depth of only about 1 mm, and having 5 mm groove-to-groove spacing.

Micro-surfacing — A thin surfacing of high-quality frictional aggregates and polymer modified emulsion, applied as a slurry over an existing old asphalt pavement using purpose-built equipment. This process has been used to fill shallow ruts and cracks in asphalt pavement, and restore the frictional properties of the pavement surface.

Milling (cold planing) — Removing the surface of an asphalt concrete pavement, using a travelling machine equipped with a transverse rotating cutter drum (milling head with carbide tips), typically 25 mm to 75 mm in depth. The resulting asphalt concrete millings are usually recycled.

Pavement condition index (PCI) — Numerical rating of the pavement condition that ranges from 0 to 100, with 0 being the worst possible condition (failed) and 100 being the best possible condition (excellent). It is determined through a systematic pavement condition survey (e.g., ASTM D6433) in terms of the type, severity, and extent of the pavement distresses.

Pavement distress — External indicators of pavement deterioration caused by loading, environmental factors, construction deficiencies, or a combination thereof. Typical distresses are cracks, rutting, and weathering of the pavement surface.

Pavement structure — All courses (components) of a pavement above the subgrade to the traffic surface, such as granular sub-base, granular base, treated (asphalt or cement) base, asphalt concrete, and concrete.

Performance graded asphalt cement (asphalt binder) (PG or PGAC) — An asphalt cement for which the physical properties can be directly related to field performance by engineering principles. Performance graded binders are defined by a term such as PG xx-yy. The first number, xx, is the high temperature grade and indicates the asphalt cement possesses adequate physical properties up to at least xx°C. The second number, -yy, is the low temperature grade and indicates the asphalt cement possesses adequate physical properties in pavements down to at least -yy°C.

Perpetual pavement — An asphalt pavement designed and constructed to last longer than 50 years without requiring rehabilitation, and needing only periodic surface renewal (termed "perpetual pavement" by the APA).

Polymer modified asphalt (PMA) — Asphalt cement that has had its physical and chemical properties modified/enhanced by the addition of a polymer. PMA provides enhanced durability, improved rutting resistance at high temperatures, and increased resistance to low temperature cracking.

Precision milling — Removing the surface of an asphalt concrete pavement, using a travelling machine, typically to less than 5 mm texture depth and having a groove-to-groove spacing of about 10 mm to 15 mm. This equipment can also be used to remove shallow faulting and restore texture in exposed Portland cement concrete pavement.

Roller-compacted concrete (RCC) — A stiff, zero-slump Portland cement concrete mixture that is mixed, placed and roller-compacted with the same commonly available equipment used for hot-mix asphalt pavement construction.

Rut (rutting) — A surface depression in the pavement along the wheel paths (generally asphalt concrete flexible pavements or the asphalt concrete surface of rigid pavements). Pavement uplift may occur along the sides of the rut but, in many instances, ruts are noticeable only after a rainfall when the wheel paths are filled with water. Rutting stems from permanent deformation in any of the pavement layers or subgrade, usually caused by densification and/or lateral movement of the materials due to traffic loading stresses/strains.

Whitetopping — A Portland cement concrete overlay placed on an existing hot-mix asphalt pavement. There are three types of whitetopping.

Conventional whitetopping — Placement of a 175 mm to 300 mm thickness Portland cement concrete overlay on an existing hot-mix asphalt pavement.

Thin composite whitetopping — Placement of a moderately thin (100 mm to 175 mm thickness) Portland cement concrete overlay on a milled hot-mix asphalt pavement.

Ultra-thin whitetopping — Placement of a thin (50 mm to 100 mm thickness) Portland cement concrete overlay on an existing hot-mix asphalt pavement.

1.4 Acronyms

1.4.1 Agencies and Associations

AASHTO — American Association of State Highway and Transportation Officials <*www.transportation.org*>.

ACI — American Concrete Institute <*www.concrete.org*>.

ACPA — American Concrete Pavement Association <*www.pavement.com*>.

AI — Asphalt Institute <*www.asphaltinstitute.org*>.

AI (OHMPA) — Ontario Hot Mix Producers Association <*www.ohmpa.org*>.

APA — Asphalt Pavement Alliance <*www.asphaltalliance.com*>.

ASTM — American Society for Testing and Materials <*www.astm.org*>.

CAC — Cement Association of Canada <*www.cement.ca*>.

CGSB — Canadian General Standards Board <*www.pwgsc.gc.ca/cgsb*>.

CSA — Canadian Standards Association <*www.csa.ca*>.

C-SHRP — Canadian Strategic Highway Research Program <*www.tac-atc.ca/programs/cshrp.htm*>.

CTAA — Canadian Technical Asphalt Association <*www.ctaa.ca*>.

FHWA — Federal Highway Administration <*www.fhwa.dot.gov*>.

FPP — Foundation for Pavement Preservation <*www.fp2.org*>.

ICPI — Interlocking Concrete Pavement Institute <*www.icpi.org*> [ICPI Canada].

MTO — Ontario Ministry of Transportation <*www.mto.gov.on.ca*>.

MTQ — Ministère des Transports du Québec <*www.mtq.gouv.gc.ca*>.

NAPA — National Asphalt Pavement Association <*www.hotmix.org*>.

NRC — National Research Council <*www.nrc.ca www.infraguide.ca*>.

PIARC — Permanent International Association of Road Congresses (PIARC/AIPCR) <*www.piarc.org*>.

SHRP — Strategic Highway Research Program <*www.infoguide.ca*>.

TAC — Transportation Association of Canada <*www.tac-atc.ca*>.

1.4.2 Technical Terms

AADT	annual average daily traffic
CBR	California bearing ratio
CRCP	continuously reinforced concrete pavement
CW	conventional whitetopping
ESALs	equivalent single axle loads
FWD	falling weight deflectometer
GB	granular base
GBE	granular base equivalency
GSB	granular sub-base
HDBC	heavy-duty binder course
HMA	hot-mix asphalt
ICP	interlocking concrete pavers
JPCP	jointed plain concrete pavement
JRCP	jointed reinforced concrete pavement
LCB	lean concrete base
LCCA	life cycle cost analysis
LSBC	large stone binder course
OGDL	open graded drainage layer
OGFC	open graded friction course
PCC	Portland cement concrete
PCCP	Portland cement concrete pavement
PCI	pavement condition index
PG	performance graded
PGAC	performance graded asphalt cement (binder)
PMA	polymer modified asphalt cement
RCC	roller-compacted concrete
SHRP	Strategic Highway Research Program
SMA	stone mastic asphalt
TGB	treated granular base (with cement, for instance)
TW	thin whitetopping
UTW	ultra-thin whitetopping

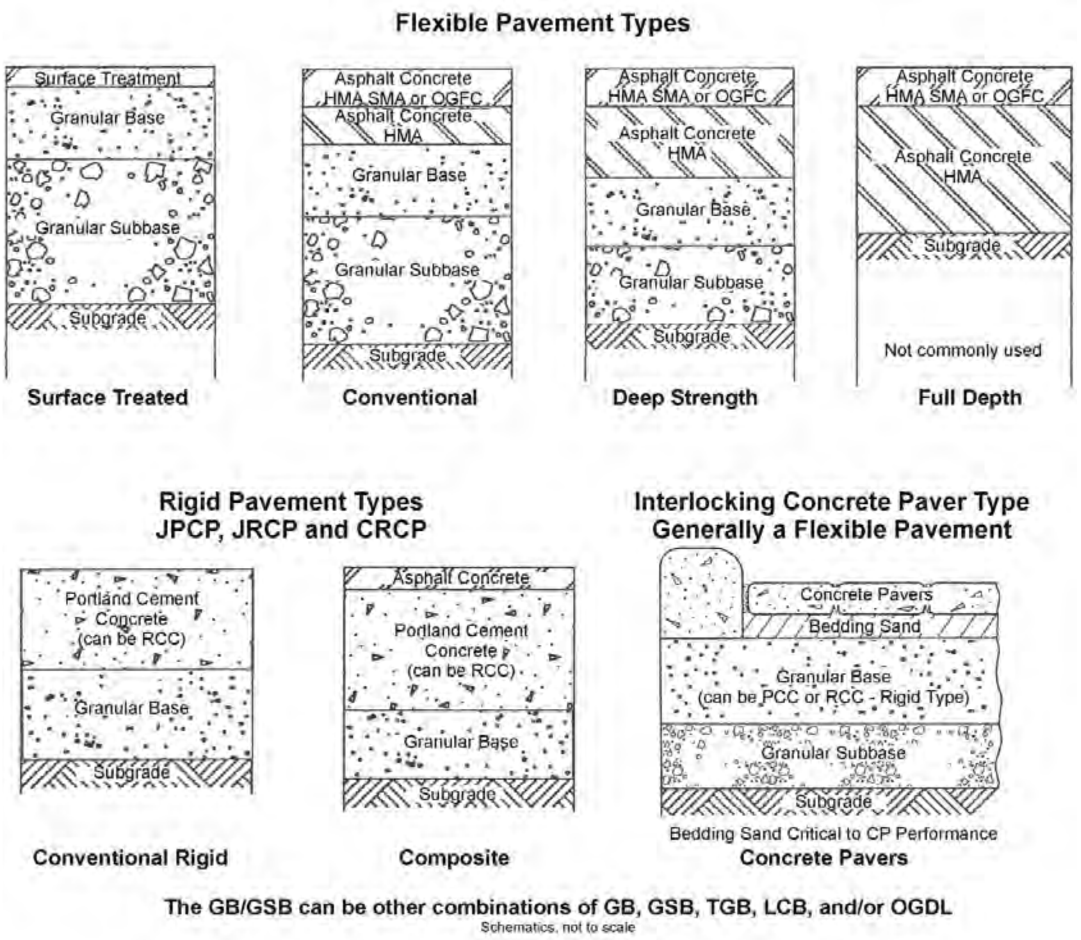
Figure 1-1
Pavement types

1.5 How to Use This Document

This best practice starts with a glossary covering pavement types and technology (see Figure 1-1), rutting, and rut mitigation. It is recommended that following a review of the terms, the non-specialist consider the annotated bibliography of key technical references in Appendix B along with photographs 2-1 through 2-4, to gain an appreciation of the asphalt pavement rutting problem and its consequences. The technical information presented is supplemented throughout with tables, figures, and photographs.

A rutting mitigation strategy is then introduced through a review of the three basic types of rutting and the technology of rut mitigation. Here, the focus is on instability rutting of asphalt concrete. The state-of-the-art technology was established through a scan questionnaire and technical literature review as described in Appendix A. A detailed work description for the multi-stage action plan to mitigate asphalt concrete rutting at high stress/strain areas, such as intersections, is then presented. The applications and limitations of a wide range of rut mitigation techniques are discussed, including whitetopping and alternate pavement types. Finally, the evaluation of the rut mitigation multi-stage action plan's effectiveness through pavement performance monitoring is recommended.

Figure 1-1: Pavement types



2. Rationale

2.1 Background

There have been considerable Canadian asphalt and pavement technology activities related to asphalt concrete rutting over the past 10 years (Aurilio, 2002; Burlie and Emery, 1997; TAC, 1991; Woodman et al., 1996). From the scan for this best practice (appendices A and B), it appears this Canadian experience parallels, draws upon and even contributes to American (APA, 2002; Buncher, 2002; Corun, 2001; Kandhal et al., 1993, 1998; NAPA, 1995; Walker and Buncher, 1999) and international (Cebon, 1999; Nicholls, 1998; PIARC, 1995, 2000) advances to asphalt concrete rut mitigation. There is general unanimity on asphalt pavement rutting basics and the need to adopt an action plan for mitigation at high stress application areas.

2.1.1 Concerns with Asphalt Pavement Rutting

The rutting of municipal asphalt pavements, particularly at intersections, causes several concerns to municipal agencies.

- **Safety** is the paramount concern. For vehicles, there is reduced frictional characteristics (e.g., wheel path flushing), changing lanes becomes hazardous, there is the risk of loss of control, water ponds in wheel paths, potentially forming ice, and snow and ice removal becomes more difficult. For pedestrians, vehicle stopping distances increase at crosswalks during inclement weather, and tripping on the ruts becomes a potential hazard. (It is recommended that any potential safety problems be mitigated as soon as practical.)
- The ruts become a **nuisance** to pedestrians, particularly in inclement weather due to splashing by passing vehicles.
- The **appearance** of the roadway results in poor public perceptions and political reactions.
- Rut mitigation incurs **costs**, including user costs due to traffic flow interruptions and increased vehicle maintenance and repair costs.

2.1.2 Types of Asphalt Pavement Rutting

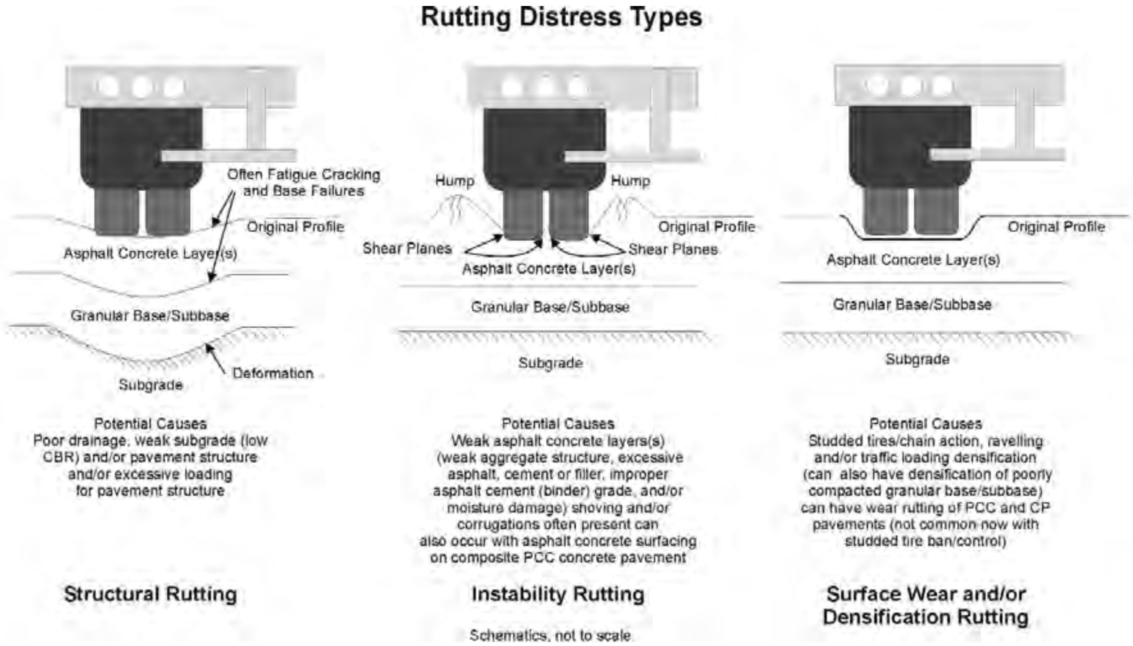
The three basic types of asphalt pavement rutting to consider are shown in Figure 2-1: surface wear and densification rutting, structural rutting, and instability rutting (permanent deformation of the asphalt concrete). Combinations of these three are possible.

While Portland cement concrete pavements can exhibit some wheel path rutting, this form of pavement rutting is no longer common with the banning or strict control of studded tires. Concrete pavements do not exhibit structural rutting. If a Portland cement concrete pavement is not structurally adequate, it fails through cracking. It should be noted that the asphalt concrete surfacing of a composite rigid pavement (asphalt concrete on a Portland cement concrete base) can undergo instability rutting (typically more severe than flexible pavement asphalt concrete) at high stress application areas (TAC, 1991; Burlie and Emery, 1997).

For pedestrians, vehicle stopping distances increase at crosswalks during inclement weather, and tripping on the ruts becomes a potential hazard.

Figure 2-1
Types of rutting

Figure 2-1: Types of rutting



Surface Wear and Densification Rutting

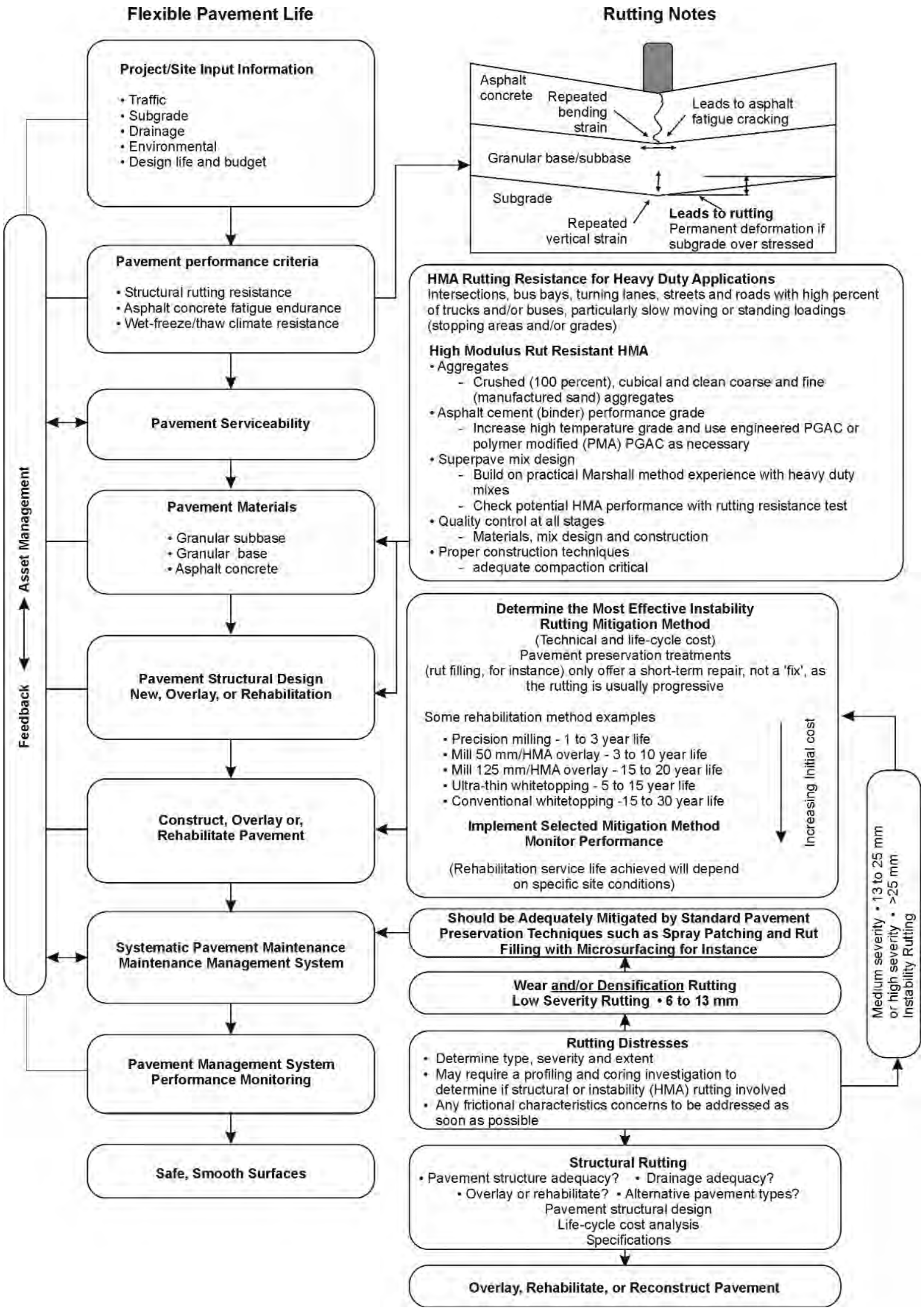
Surface wear and densification rutting do not appear to be a current concern. Wheel path surface wear rutting of asphalt pavements is no longer a significant problem as the use of studded tires is controlled or banned in most Canadian provinces. Ravelling of the asphalt concrete in wheel paths is minimized through a durable hot-mix asphalt surface course with sufficient asphalt cement content. The granular sub-base/base and hot-mix asphalt with insufficient density (compaction) may undergo further heavy traffic loading densification (consolidation). This densification of hot-mix asphalt can result in low air voids and susceptibility to instability rutting. Densification rutting is generally avoided through proper compaction during construction.

Structural Rutting

While the structural rutting of asphalt pavements (flexible pavements) is obviously of concern, this is a matter of an appropriate pavement design, materials specification, and construction quality. Detailed pavement design considerations are beyond the scope of this best practice. What is important is whether the asphalt pavement rutting distress involves structural rutting. Structural rutting requires a detailed pavement design evaluation and then addressing the causes (loadings, weak subgrade, poor drainage, frost action, etc.) through pavement reconstruction to a proper pavement structure design (AASHTO, 1993; MTO, 1990: TAC, 1997). The basic structural design of flexible pavements is outlined in Figure 2-2, which provides an overview of the flexible pavement life with detailed notes on asphalt concrete instability rutting mitigation covered by this best practice.

Figure 2-2: Flowchart of flexible pavement life

Figure 2-2
Flowchart of flexible pavement life



Project/Site Input Information
- Traffic
- Subgrade
- Drainage
- Environmental
- Design life and budget

Pavement performance criteria
- Structural rutting resistance
- Asphalt concrete fatigue endurance
- Wet-freeze/thaw climate resistance

Pavement Serviceability

Pavement Materials
- Granular subbase
- Granular base
- Asphalt concrete

Pavement Structural Design New, Overlay, or Rehabilitation

Construct, Overlay or, Rehabilitate Pavement

Systematic Pavement Maintenance Maintenance Management System

Pavement Management System Performance Monitoring

Safe, Smooth Surfaces

HMA Rutting Resistance for Heavy Duty Applications
Intersections, bus bays, turning lanes, streets and roads with high percent of trucks and/or buses, particularly slow moving or standing loadings (stopping areas and/or grades)

High Modulus Rut Resistant HMA
- Aggregates
  - Crushed (100 percent), cubical and clean coarse and fine (manufactured sand) aggregates
- Asphalt cement (binder) performance grade
  - Increase high temperature grade and use engineered PGAC or polymer modified (PMA) PGAC as necessary
- Superpave mix design
  - Build on practical Marshall method experience with heavy duty mixes
  - Check potential HMA performance with rutting resistance test
- Quality control at all stages
  - Materials, mix design and construction
- Proper construction techniques
  - adequate compaction critical

Determine the Most Effective Instability Rutting Mitigation Method
(Technical and life-cycle cost)
Pavement preservation treatments (rut filling, for instance) only offer a short-term repair, not a 'fix', as the rutting is usually progressive

Some rehabilitation method examples
- Precision milling - 1 to 3 year life
- Mill 50 mm/HMA overlay - 3 to 10 year life
- Mill 125 mm/HMA overlay - 15 to 20 year life
- Ultra-thin whitetopping - 5 to 15 year life
- Conventional whitetopping -15 to 30 year life

Implement Selected Mitigation Method Monitor Performance

(Rehabilitation service life achieved will depend on specific site conditions)

Should be Adequately Mitigated by Standard Pavement Preservation Techniques such as Spray Patching and Rut Filling with Microsurfacing for Instance

Wear and/or Densification Rutting
Low Severity Rutting • 6 to 13 mm

Rutting Distresses
- Determine type, severity and extent
- May require a profiling and coring investigation to determine if structural or instability (HMA) rutting involved
- Any frictional characteristics concerns to be addressed as soon as possible

Structural Rutting
- Pavement structure adequacy?
- Drainage adequacy?
- Overlay or rehabilitate?
- Alternative pavement types?

Pavement structural design
Life-cycle cost analysis
Specifications

Overlay, Rehabilitate, or Reconstruct Pavement

The key to achieving the desired performance of asphalt pavements at intersections is recognizing that intersection asphalt pavements may need to be specified, designed, and constructed differently than regular asphalt pavements.

2.2 Instability Rutting of Asphalt Concrete

The focus of this best practice now turns to the instability rutting (plastic deformation) of asphalt concrete (Figure 2-1) at high stress/strain areas such as intersections. As indicated, wear rutting is no longer a significant problem and structural rutting is essentially dealt with through an appropriate pavement design (Figure 2-2). Unfortunately, asphalt concrete instability rutting, particularly at intersections, continues to be a significant pavement performance problem for municipalities across Canada, as clearly indicated by the responses to the scan (Appendix A). The severity and impact of this instability rutting of asphalt concrete at intersections is shown in photographs 2-1 to 2-4.

2.2.1 Causes at Intersections

Some municipal road network locations, such as intersections, bus bays, and truck routes, are subjected to heavy, slow-moving, channelled traffic. These locations can also have areas, such as at intersection stop lines (bars), where severe braking, standing, accelerating, turning, and lateral stresses are applied. For intersections, there are additional harsher conditions, such as vehicle drippings, exhaust heat and cross-traffic load repetitions. For asphalt pavements, the darker, richer surface associated with any asphalt concrete surface flushing (and new hot-mix asphalt) can result in higher pavement temperatures.

The instability rutting at intersections, with their severe loading conditions, then takes place, because asphalt concrete exhibits lower stiffness (i.e., the asphalt cement is a viscoelastic material), with higher strains, under slow-moving or standing loads. This problem is aggravated at higher pavement temperatures, since the stiffness of asphalt concrete is further decreased at higher asphalt pavement temperatures. Often, even though there is significant asphalt concrete instability rutting at an intersection, there is no significant rutting in the same asphalt pavement away from the intersection.

Clearly, the key to achieving the desired performance of asphalt pavements at intersections, with their severe loading conditions, is recognizing that intersection asphalt pavements may need to be specified, designed, and constructed differently than regular asphalt pavements. It is quite logical that there is often the need to use a higher-performance, hot-mix asphalt at intersections.

2.2.2 Rutting Types

The instability rutting of asphalt concrete is sometimes triggered by heavy traffic wheel path densification (often with flushing), that results in low air voids, sustained higher surface temperature and reduced shear strength. This results in rutting through shear deformation (e.g., Photograph 2-4). There appear to be three cases of asphalt concrete instability rutting:

- immediate (problems with hot-mix asphalt materials, mix design, or construction quality);
- slow (marginal hot-mix asphalt resistance to rutting with progressive permanent deformation that may lead to instability); and
- triggered (some change that increases the wheel loading stresses, such as detour road use with trucks or buses, or a decrease in the hot-mix asphalt resistance to rutting, such as stripping).

Photo 2-1: Asphalt concrete rutting of a municipal connector road conventional flexible pavement

This road, with considerable heavy truck traffic, has medium to high severity instability rutting approaching the intersection, and flushing and high severity instability rutting at the intersection stop bars. Such flushing (traffic densification) is often associated with instability rutting. The instability rutting is so severe in places that the asphalt concrete has shoved laterally and buckled (inset).

Photo 2-2: Asphalt concrete rutting of a major municipal road composite pavement

This bus route, with considerable heavy truck traffic, has medium to high severity instability rutting (asphalt concrete surface of composite rigid pavement) approaching and at the intersection, and in the bus bay. Note the associated line (stop bar/pedestrian crossing) distortion (inset). The rutting is most severe for the curb (bus/truck) lanes near the stop bars and in the bus bays.

Photo 2-3: Flushing and low severity asphalt concrete rutting of a composite pavement

This major municipal road truck route, with considerable container traffic, has localized flushing and low severity instability rutting approaching and through the intersection. The wheel path flushing and rutting is probably due to traffic densification during hot weather. The rutting appears to have stabilized over a five-year period (inspection and coring, inset).

Photo 2-4: Evaluating the asphalt concrete rutting of a deep strength flexible pavement

This bus bay area, along a major municipal road bus route, with considerable heavy truck traffic, has localized high severity instability rutting where buses slow and stop (inset). The fieldwork to evaluate the extent, severity, and type of rutting involves transverse profiling and coring to check for pavement structure deformation.

2.3 Benefits

The responses to the scan questionnaire clearly support the need for this best practice. All the municipalities reported they have experienced problems with rutting at intersections, mainly with their major routes (arterial and collectors, generally with trucks and buses involved). While a few municipalities indicated some problems with wear and structural rutting, it is very clear municipalities need a standard approach for the identification, evaluation, and rehabilitation of high-stress-area rutted intersection pavements. Implementation of this best practice will result in longer-life asphalt pavements with significant overall construction and maintenance cost savings to municipalities.

2.4 Limitations

It is important to stress that this best practice provides an overview of the most common current techniques for mitigating rutting of municipal intersection asphalt pavements. The technical information provided for general use should always be checked for specific site conditions. This will generally involve the assistance of experienced pavement engineers who are familiar with local site conditions, materials, and construction techniques.

3. Action Plan Description

3.1 Multi-Stage Action Plan for Rut Mitigation

The recommended multi-stage action plan for municipal intersection pavement rut mitigation, with a focus on asphalt pavement instability rutting, involves four key steps (Aurilio, 2002; Buncher, 2002; Burlie and Emery, 1997; Kandhal et al., 1998; Walker and Buncher, 1999).

1. Evaluate pavement performance problems and determine the cause of any rutting.
2. Ensure the pavement is structurally adequate.
3. Select and implement a cost-effective, technically sound pavement rut mitigation approach with appropriate materials selection and mix designs.
4. Practise proper construction techniques with quality assurance.

Steps 1, 2 and 4, with emphasis on assessing the rutting problem, checking pavement structural adequacy, and construction requirements, are described below. Step 3, the selection and implementation of an appropriate rut mitigation approach, is then covered.

3.2 Performance Problems and Causes

3.2.1 Identification of Rutting Problems

The initial identification of rutting problems at intersections can be through user complaints, inspection by works staff/patrol supervisors, or surface condition monitoring as part of a pavement management system (visual and/or measured). Regardless of the method of identification, the type of rutting (Figure 2-1), its extent, and severity must be determined.

The ASTM D6433, *Standard Practice for Roads and Parking Lot Pavement Condition Index Surveys* (ASTM, 2002; Shahin, 1994), defines rutting severity as:

Low severity	6 mm to 13 mm depth
Medium severity	13 mm to 25 mm depth
High severity	25 mm depth

From the scan, these severity levels appear to agree with general Canadian practice (Appendix A). Some agencies add a very high severity level for >50 mm (MTO, 1990). It is important that the location (lane), extent (distance the rutting extends before and after the intersection), and severity of the rutting are established (ASTM, 2002). The rut depth (peak to valley) can be measured below a 1.2 m straight edge laid across the pavement surface (straight edge must span the full width of the rut — there are often dual wheel path ruts), or by full lane width transverse profile measurements (e.g., digital incremental profilometer/Dipstick or laser profilometer).

The rutting severity level at which some mitigation is required (intervention level) is a function of agency experience, road class, and traffic conditions (e.g., speed limit). No remedial action, beyond perhaps standard pavement preservation techniques to fill the wheel path ruts (e.g., spray patching or micro-surfacing), is generally necessary for low-severity asphalt concrete instability rutting (or wheel path densification). However, as instability rutting is often progressive (i.e., the asphalt concrete does not have adequate shear strength to resist the high stresses at intersections), it is important to monitor the pavement surface condition to establish the rate of deterioration.

As instability rutting is often progressive it is important to monitor the pavement surface condition to establish the rate of deterioration.

3.2.2 Evaluation Program

Where medium or high severity rutting is identified, an evaluation should be carried out to establish the cause(s) of the rutting. This requires a comprehensive program that considers site conditions (subgrade, environment, and drainage), pavement structural adequacy for the intersection traffic conditions (particularly trucks and buses), and the properties of the individual pavement structure components (e.g., asphalt concrete layers).

If the bottom of the lowest asphalt concrete course is not rutted then the rutting is clearly within the asphalt concrete course(s) as densification and/or instability rutting.

The evaluation of any roadway that may require rehabilitation (exhibiting medium to high severity rutting) should include (Photograph 2-4):

- visual inspection of surface condition (e.g., ravelling or bleeding in wheel paths) and transverse profile measurements;
- deflection testing to check for structural adequacy (FWD, Dynaflect, or Benkelman beam);
- coring and probe holes to obtain samples of the pavement materials and subgrade for laboratory examination;
- thickness measurements for all layers of the pavement structure, in both rutted and non-rutted areas (e.g., between wheel paths);
- determination of material properties of the subgrade (type, moisture condition, plasticity index, and strength), granular base/sub-base materials (type, thickness, moisture condition, gradation, crushed content, etc.), asphalt concrete (for each layer or mix type, in and out of rut — between wheel paths will not have traffic densification), thickness, air voids, gradation and asphalt cement content, crushed content, and flat or elongated particles content; and
- a review of the construction and maintenance information, with a focus on the overall quality of construction, particularly the incorporated hot-mix asphalt.

It is relatively straightforward, from the transverse profiles and cores (Photograph 2-4), to determine if pavement structural rutting is present. If the bottom of the lowest asphalt concrete course is not rutted (i.e., top of granular base is planar), then the rutting is clearly within the asphalt concrete course(s) as densification and/or instability rutting.

The asphalt concrete in-place air voids content, particularly for the top 25 mm at the surface, should also be considered when assessing the type of rutting involved. There is considerable practical experience that asphalt concrete is particularly susceptible to instability rutting at in-place air voids of less than one or two percent (TAC, 1991; Burlie and Emery, 1997).

The findings are then analyzed to determine the type (or types) of rutting that has occurred and its causes, to determine the most appropriate rut mitigation strategy (as indicated in Figure 2-2):

- pavement preservation (e.g., with low severity instability rutting);
- pavement overlay (e.g., with medium severity instability rutting);
- pavement rehabilitation (e.g., with high severity instability rutting); or
- pavement reconstruction (e.g., with pavement structural rutting).

Generally, a life cycle cost analysis (Hicks et al., 2000; NRC, 2002) is completed to select the most cost-effective mitigation method from the technically suitable alternatives. Selecting the appropriate approach (i.e., Step 3) is described in more detail in Section 4.

3.3 Pavement Structure Adequacy

It is imperative, when assessing intersection pavement performance problems (particularly structural rutting), to check for pavement structural adequacy (Figure 2-2). New pavements (flexible and rigid), and overlaid, rehabilitated, or reconstructed existing pavements must have structural adequacy for current and anticipated future traffic loads (ESALs). Again, the high stress/strain conditions at municipal intersections, bus bays, and truck/bus routes, must be considered when checking pavement structural adequacy.

While pavement design is beyond the scope of this best practice, an overview is given in Figure 2-2, with a focus on rutting resistance. There are excellent pavement guides available (e.g., AASHTO, 1993; AI, 2000; APA, 2002; Cebon, 1999; MTO, 1990; Smith et al., 2002; and TAC, 1997). For existing pavements, the structural capacity of the in-place materials must be checked, and any failed or weak areas removed or replaced (Buncher, 2002; Walker and Buncher, 1999).

3.4 Pavement Construction Techniques

The performance of any pavement is highly dependent on the pavement construction techniques followed, and the quality of construction achieved. No matter how much care is taken with the selection and specification of pavement type, materials, and mix designs, the rutting resistance still depends on proper construction techniques and quality control. For asphalt pavement instability rutting resistance and mitigation, proper construction techniques include the following (AI, 2000; Buncher, 2002; NAPA, 1995, 2002; Walker and Buncher, 1999).

- Prepare the substrate properly. Thoroughly clean old or milled surfaces, remove any old patches or thin asphalt concrete areas that may debond, and uniformly tack prepared surfaces at the appropriate application rate.
- Produce, place, and compact hot-mix asphalt at appropriate temperatures (i.e., avoid overheating).
- Do not use solvents (diesel) in truck beds. (A wide range of non-solvent release agents are available.)
- Avoid segregation with proper aggregate stockpiling, and hot-mix asphalt production, transportation, and placement techniques.
- Place a uniform and smooth mat.
- Construct transverse and longitudinal joints properly for durability and to prevent the ingress of water.
- Achieve the compaction (density) requirements.
- Follow an appropriate quality control plan to achieve the proper construction techniques and overall quality.

The importance of hot-mix asphalt compaction to asphalt concrete stability and instability rutting resistance should be particularly noted.

The performance of any pavement is highly dependent on the pavement construction techniques followed, and the quality of construction achieved.

4. Application of Rut Mitigation Techniques

4.1 New and Existing Pavements

The various rut mitigation techniques can be considered at the design stage for new construction or reconstruction, or at the intervention stage for existing rutted pavements requiring pavement preservation (maintenance), overlay, or rehabilitation. A number of these rut mitigation techniques are shown in photographs 4-1 to 4-6.

4.2 New Construction and Reconstruction

4.2.1 Flexible and Rigid Pavement Design

For new construction or reconstruction, the mitigation of potential rutting starts from the bottom of the pavement up as indicated in Figure 2-2 for flexible (asphalt) pavements. The key is to follow a pavement design procedure that has been "calibrated" for local conditions and experience. This can be an agency-specific standard design method or matrix (note that thicker pavement structures are generally used at intersections), or a common design method such as AASHTO 93, AI, PCAPAV and ICPI. The specific details of pavement structural design are beyond the scope of this best practice, but are available from the various asphalt, concrete, and paver associations (see the Acronyms). It is important that the full range of flexible and rigid pavement types (Figure 1-1) be considered, as appropriate to the specific intersection requirements, and in terms of life cycle cost effectiveness. For instance, the effective use of interlocking concrete block paving is shown in Photograph 4-6.

4.2.2 Mitigation of Instability Rutting

The methods to mitigate the instability rutting of asphalt concrete for high-stress/strain intersections are relatively straightforward for both new and existing pavements. These methods are applicable to hot-mix asphalt for flexible pavements and the surface course of composite pavements (Figure 1-1). The general performance requirements for hot-mix asphalt are summarized in Table 4-1, along with the specific recommended aggregate quality, asphalt cement grade selection, and mix design procedures for heavy-duty applications, such as intersections (Buncher, 2002; NAPA, 1995, 2002).

Rut-Resistant Hot-Mix Asphalt

There are four important considerations for any good hot-mix asphalt mix design that are particularly crucial for rut resistance (Buncher, 2002; Kandhal et al., 1998; NAPA, 1995, 2002; Nicholls, 1998; PIARC, 1995; TAC, 1991).

- Design the mix so the load is carried primarily by the stone skeleton (coarse aggregate). This is the main reason for using large maximum-size aggregate and a dense grading.
- Select coarse and fine aggregates with characteristics that develop good inter-particle interlock and shear strength. Use 100 percent, crushed, cubical, clean coarse aggregate and 100 percent, crushed (i.e., manufactured sand), cubical, clean fine aggregate. Practical experience indicates that about 10 percent natural fine aggregate (asphalt sand) in surface course hot-mix asphalt is beneficial to compactibility and stability (Burlie and Emery, 1997).
- Incorporate the proper asphalt binder (cement) grade and optimum content to hold the aggregate together and for durability (not too low), while providing an adequate air voids content (not too high, i.e., optimized). This could mean selecting an asphalt cement with low temperature susceptibility (resistant to thermal cracking at low pavement temperature and resistant to rutting at high pavement temperature), using an asphalt cement with higher stiffness at the high pavement temperature, or considering a modified asphalt binder (cement) such as PMA.

It is important that the full range of flexible and rigid pavement types be considered, as appropriate to the specific intersection requirements, and in terms of life cycle cost effectiveness.

- Use an appropriate mix design procedure to optimize the asphalt cement grade and content, and aggregate gradations to provide a stiff matrix. Adopt Superpave material requirements and mix design procedures, and evaluate the moisture susceptibility of the hot-mix asphalt.

An important additional consideration is the use of a laboratory test (e.g., loaded wheel tracking) to check the rutting resistance performance of the designed hot-mix asphalt. It should be noted that the stone skeleton is a more important contributor to rut resistance than stiffer asphalt binders (cements). Heavy-duty, hot-mix asphalts are summarized in Table 4-1.

Superpave Mix Design System

The Marshall method of hot-mix asphalt design, coupled with practical experience, has proven to be quite effective for the design of rut-resistant (heavy duty) hot-mix asphalt. However, the new Superpave overall method (asphalt cement performance grade selection, aggregate characteristic selection, and volumetric design based on gyratory compaction) certainly enhances the asphalt technology involved and is being adopted across Canada (AI, 1997, 2001; NAPA, 2002). Similarly, the move to performance-graded asphalt binder (cement) offers a rational basis to consider asphalt cement temperature susceptibility in hot-mix asphalt, compared to penetration grading, for instance (CGSB, 1990).

The Superpave mix design system recognizes the impacts of higher stress replications (ESALs) and heavy vehicle speed through the gyratory mix design method and aggregate quality requirements (Table 4-2), and “bumping” the PGAC grade (Table 4-3) (AI, 1997, 2001; C-SHRP 1999; Walker and Buncher, 1999). Some typical pavement reconstruction projects, with actual hot-mix asphalt technology (e.g., LSBC, HDBC, SMA, and PMA), are shown in photographs 4-2 to 4-4.

4.2.3 Perpetual Pavements

Perpetual pavements are long-lasting asphalt pavements (50 years or more) that require limited rehabilitation, typically consisting of resurfacing at about 20-year intervals (APA, 2002). Perpetual pavements consist of a rut- and wear-resistant surface course asphalt concrete (e.g., stone mastic asphalt), a rut-resistant intermediate asphalt concrete layer, and a lower layer of asphalt concrete of adequate thickness and flexibility to resist tensile strains caused by traffic and prevent deep fatigue cracking. Pavement distresses are confined to the uppermost layer of the asphalt concrete pavement structure.

When resurfacing is required, milling and replacement of the surface layer can be carried out quickly, which is important for busy urban intersections where traffic can only be diverted for short periods.

When resurfacing is required, milling and replacement of the surface layer can be carried out quickly, which is important for busy urban intersections where traffic can only be diverted for short periods. The perpetual pavement concept is not really that new as some Canadian municipalities regularly design for long service.

Photo 4-1: Precision Milling to Remove Asphalt Concrete Instability Rutting

The precision milled surface, with ruts removed, has quite a smooth texture with a maximum texture depth of about 5 mm (close milling teeth spacing, inset). The expected life of this treatment is 3 to 5 years depending on the progressive nature of instability rutting and milled surface durability. Precision milling and micro milling can also be used to enhance frictional characteristics.

Photo 4-2: Municipal Road Composite Pavement, with Water Cooling Before Traffic Use

The hot-mix asphalt frictional, rut-resistant surface course (inset) was designed in accordance with early Superpave aggregate requirements and incorporates polymer-modified performance graded asphalt cement. It has been found that early heavy traffic action on new, still warm asphalt concrete can result in traffic densification (low voids) that can then "trigger" localized instability rutting.

Photo 4-3: Reconstructed Municipal Road Intersection Deep Strength Flexible Pavement

The performance of this (1994) major truck and bus route, incorporating rut-resistant asphalt mixes, has been excellent. The LSBC and HDBC (inset), and surface course asphalt concrete, incorporate 100 percent crushed, cubical, clean coarse aggregate and manufactured sand fine aggregate (10 percent asphalt sand in surface course), and were designed as high stability mixes with rutting resistance tested.

Photo 4-4: Reconstructed Municipal Road Composite Pavement with SMA Surface Course

The performance of this major truck and bus route, an early (1994) trial of stone mastic asphalt (SMA) for rutting resistance, frictional characteristics and high durability, has been excellent. The SMA, which is a gap-graded, coarse mix, incorporates frictional, crushed coarse aggregate, manufactured sand fine aggregate, filler, fibre and polymer-modified asphalt cement.

Photo 4-5: Thin Composite Whitetopping of a Municipal Connector Highway Intersection

This rehabilitation project whitetopping (1999) involved the milling of 125 mm of severely rutted asphalt concrete and placement of 125 mm of 35 MPa air-entrained concrete containing 1.6 kg of 40 mm fibre per m3. The project was completed over two weekends. Some cracking has occurred in the northbound lane (rehabilitated first, new technique) however the southbound lanes are in excellent condition.

Photo 4-6: Interlocking Concrete Pavers Used to Reconstruct City Street

Interlocking concrete paver flexible pavements were used as part of downtown revitalization project (1983). The pavement, 80 mm thick wavy-edge pavers (45° herringbone placement pattern), 30 mm of bedding over 150 mm of granular base and 200 mm of granular subbase, is performing extremely well (only 6 to 8 mm of rutting, 3 mm of which is likely wear from extensive use of ice control sand).

Table 4-1
Dense Graded Hot-Mix Asphalt Checklists HMA Materials, Mix Design Requirements and Construction for Heavy-Duty Applications

Table 4-1: Dense Graded Hot-Mix Asphalt Checklists HMA Materials, Mix Design Requirements and Construction for Heavy-Duty Applications

A. General Functional and Structural Performance Requirements

- Workable during placement and compaction.
- Contributes to strength of pavement structure.
- Resists permanent deformation (rutting).
- Resists fatigue cracking.
- Resists thermal cracking.
- Resists the effects of air and water (durability).
- Impermeable to protect pavement structure from water.
- Easily and cost-effectively maintained, a plus for surface (wearing) course.
- Adequate frictional properties (skid resistance).
- Acceptable level of tire-pavement noise.
- Acceptable riding quality (smoothness).

B. Materials, Mix Design and Construction Requirements

- Aggregate physical characteristics and quality
  - heavy-duty performance (heavy traffic and/or slow speed (e.g., intersections), incorporate 100 percent crushed, cubical and clean coarse and fine (manufactured sand) aggregate. Practical experience shows that a limited amount of natural fine aggregate (asphalt sand), not exceeding 10 percent of total aggregate, assists in achieving surface course compaction and mat quality.
- Asphalt cement (binder) performance grade (PGAC)
  - heavy traffic and/or slow speed increase high temperature grade and use engineered PGAC, PMA, PGAC as necessary.
- Superpave mix design system
  - build on practical Marshall method mix design experience, particularly for heavy duty performance requirements;
  - consider any fines generation (minus 75 μm) during HMA production;
  - check potential HMA performance with rutting resistance test (loaded wheel tracking for instance).
- Quality control (testing/inspection) of HMA production/placement/compaction/agency quality assurance.
- Proper construction techniques
  - Prepare substrate properly (clean and tack), avoid segregation, place uniform and smooth mat, construct joints properly, and meet compaction (density) requirements.

Table 4-2: Superpave HMA Gyratory Compaction Density and Aggregate Consensus Property Requirements for Design ESALs and Depth from Pavement Surgace (Adapted from C-SHRP, 1999)

Design ESALs million	Gyratory Compaction Parameter Number of gyrations			Required DensityPercent of Maximum Density % of G_{mm}			Coarse Aggregate Angularity minimum %		Fine Aggregate Angularity Uncompacted Voids minimum %		Fine Aggregate Sand Equivalent minimum %	Coarse Aggregate Flat or Elongated maximum %
							Depth from Surface mm		Depth from Surface mm			
	$N_{initial}$	N_{design}	N_{max}	$N_{initial}$	N_{design}	N_{max}	< 100	>100	< 100	>100		
< 0.3	6	50	75	≤ 91.5	96.04% air voids	< 98.0	55/–	–/–	–	–	40	–
0.3 – < 3	7	75	115	≤ 90.5			75/–	50/–	40	440	45	10
3 – < 10	8	100	160	≤ 89.0			85/80	60/–	45	40	45	
10 – < 30							95/90	80/75	45	40	45	
≥ 30	9	125	205				100/100	100/100	45	45	50	

Table 4-2

Superpave HMA Gyratory Compaction Density and Aggregate Consensus Property Requirements for Design ESALs and Depth from Pavement Surgace (Adapted from C-SHRP, 1999)

Notes: Design ESALs are the anticipated project traffic level (commercial vehicle and bus axle loadings) expected on the design lane over a 20-year period. Typical roadway descriptions in terms of ESALs:

< 0.3	Roadways with very light traffic volumes such as local roads, country roads and city streets where truck/bus traffic is prohibited or is at a very minimal level.
0.3 to < 3	Roadways, such as medium traffic volume city streets and many access streets, collector roads and county roads.
3 to < 30	Roadways, such as medium to high traffic volume city streets, many access roads, many provincial highways and some rural freeways.
≥ 30	Roadways, such as urban and rural expressways and freeways, *special road, street and highway situations with considerable and/or slow heavy traffic (commercial vehicles and/or buses) would be considered at this level (truck climbing lanes on two lane roads and highways for instance).*

There are also Superpave mix design requirements for voids in the mineral aggregate (VMA), voids filled with asphalt (VFA) and dust-to-binder ration.

In terms of one fractured face/two or more fractured faces requirements. For instance, 85/80 indicates a minimum of 85 percent one fractured (crushed) face and 80 percent two or more fractured (crushed) faces is required at this *ESALs level and depth from the pavement surface* for the coarse aggregate.

Based on a five to one (5:1) maximum dimension to minimum dimension ration.

4. Application of Rut Mitigation Techniques

4.2 New Construction and Reconstruction

Table 4-3
Superpave Binder (PGAC) Selection Adjustments (Bumping) for Design ESALs and Depth and Loading Rate (Adapted from C-SHRP, 1999)

4.3 Pavement Preservation, Overlays, and Rehabilitation

Table 4-3: Superpave Binder (PGAC) Selection Adjustments (Bumping) for Design ESALs and Depth and Loading Rate (Adapted from C-SHRP, 1999)

Design ESALs million	High Temperature Grade Increase in 6°C Grade Equivalents		
	Heavy Traffic (Trucks and/or Buses) Loading Rate (Speed)		
	Standing < 20 km/hr	Slow 20 to 70 km/hr	Standard > 70 k,/hr
< 0.3	–	–	–
0.3 – < 3	2	1	–
3 – 10	2	1	–
10 – < 30	2	1	–
≥ 30	2	1	1

Notes: See Table 4-2 for typical roadway descriptions in terms of ESALs.

Consideration should be given to increasing the high temperature grade by one grade equivalent (6°C).

4.3 Pavement Preservation, Overlays, and Rehabilitation

4.3.1 Selection of Rehabilitation Method

It should be noted that any hot-mix asphalt used during pavement preservation (maintenance), resurfacing (overlays), and rehabilitation activities for existing intersection asphalt pavements with high stresses/strains should meet the recommendations of Table 4-1 for heavy-duty applications. With medium or high severity instability rutting, a wide range of rehabilitation methods are available ranging from precision milling (Photograph 4-1), a short-term mitigation method, to whitetopping (Figure 2-2), with an estimated service life of up to 25 years depending on design specifications. The selection of the most appropriate rehabilitation method for a specific intersection, and rutting problem, should be based on a life cycle cost comparison of technically suitable alternatives (NRC, 2002; Burnham and Rettner, 2003; Hicks et al., 2000). Typical rutting rehabilitation methods, with estimated service lives, are given in Figure 2-2. Where extensive rehabilitation of a major intersection requires removal of the asphalt concrete, consideration should be given to alternate rigid and interlocking paver pavement types (Figure 1-1) in addition to flexible asphalt pavements.

4.3.2 Mill and Overlay with Asphalt Concrete

Milling and overlaying with hot-mix asphalt (resurfacing) is the most common rehabilitation method for urban flexible and composite pavements. Depending on the structural adequacy of the pavement, it is possible to remove a portion of the rutted and/or rut-susceptible asphalt concrete by milling, and then replace or increase (if additional pavement structure is required) the thickness of the asphalt concrete pavement with rut-resistant hot-mix asphalt (Table 4-1). Evaluations of asphalt and composite pavement rutting in urban areas exposed to high-volume, heavy-vehicle traffic indicates the milling depth should extend to at least 125 mm (Burlie and Emery, 1997). This is particularly important for composite pavements, as the stress/strain levels induced in the asphalt concrete surface are higher than in a flexible pavement.

Where structural improvement is necessary to support the anticipated traffic, the structural overlay design should be carried out using an accepted pavement design procedure, such as AASHTO 93 (AASHTO, 1993) or AI (AI, 2000).

Care must be taken to ensure the interface between the milled surface and the hot-mix asphalt overlay is clean, any loose material is removed, and a good bond is provided by properly tack coating the milled surface before placing the overlay. Each lift of new hot-mix asphalt must be properly placed and permitted to cool before laying down successive lifts, or permitting heavy truck or bus traffic to travel over the new asphalt pavement. If there is an urgent need to restore traffic (often the case in busy intersections), water cooling can be used (Photograph 4-2).

Where medium severity instability rutting is present, grinding or precision milling can be used to restore the surface texture and profile of the rutted pavement.

4.3.3 Rut Filling Using Spray Patching, Thin Overlays, or Micro-Surfacing

Where wear rutting or low severity instability rutting is involved, the wheel path ruts can be filled by spray patching, or by micro-surfacing, and/or tacking, as necessary, before the hot-mix asphalt overlay/micro-surfacing application. Spray patching is appropriate for lower volume, rural or surface-treated pavements, with a thin overlay or micro-surfacing typically used in higher volume urban applications. Micro-surfacing, which incorporates a premium, frictional aggregate, should be considered where higher vehicle speeds, with stops and starts, may be involved.

While these pavement preservation methods provide satisfactory treatments to mitigate wear rutting problems, it should be recognized that rut filling should only be viewed as a relatively short-term mitigation measure for the treatment of instability rutting, as rutting will likely continue to occur.

4.3.4 Grinding and Precision Milling

Where medium severity instability rutting is present, grinding or precision milling can be used to restore the surface texture and profile of the rutted pavement (Photograph 4-1). Precision milling involves removing the rutted asphalt concrete (essentially the humps, Figure 2-1), resulting in a texture depth of about 5 mm per pass, and a groove spacing of between 10 mm and 15 mm. Precision milling offers a short-term solution to instability rutting with a service life of three to five years. Micro-milling has also developed with a texture depth of about 2 mm per pass and groove spacing of about 5 mm.

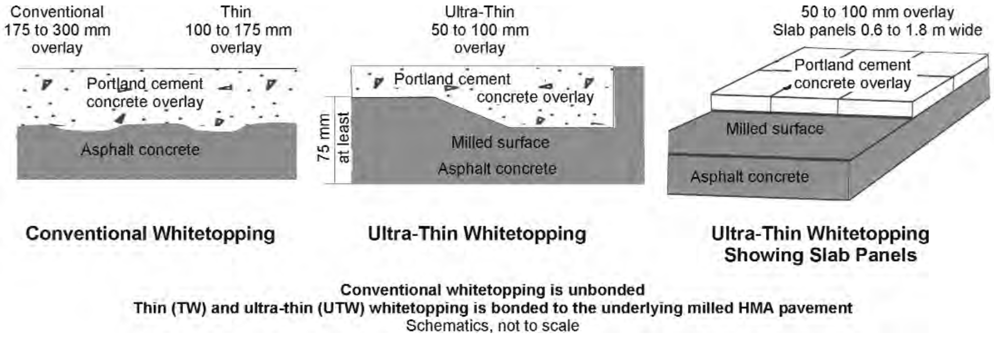
4.3.5 Whitetopping (Conventional and Concrete Inlay)

Conventional whitetopping is essentially the construction of a new Portland cement concrete pavement (PCCP), 175 mm or more, over a suitably prepared existing flexible pavement. A concrete inlay is a full depth concrete overlay placed in a trench milled out of a thick asphalt pavement. Sometimes it is also necessary to remove granular material under the asphalt to place the desired inlay thickness and meet pavement height restrictions. Whitetopping can be a technically and cost-advantageous rehabilitation alternative for badly deteriorated asphalt concrete at intersections, particularly for flexible pavements exhibiting instability, rutting, shoving, and alligator cracking (Smith et al, 2002).

The interface with the old asphalt concrete, as shown in Figure 4-1 and Photograph 4-5 may be a milled surface or a hot-mix asphalt-leveling course. There may also be no treatment at all (direct placement). However, repair of any badly distressed or failed pavement areas is required, and it is general practice to mill the old asphalt concrete surface to remove any instability rutting (humps) 50 mm or more in height (Figure 2-1), before placing the Portland cement concrete. Conventional whitetopping is generally suitable for the traffic loading associated with all classes of roads, including intersections and bus bays.

Figure 4-1: Types of whitetopping

Figure 4-1
Types of whitetopping



Conventional whitetopping is unbonded
Thin (TW) and ultra-thin (UTW) whitetopping is bonded to the underlying milled HMA pavement
Schematics, not to scale

Conventional whitetopping is designed assuming an unbonded condition with the old asphalt concrete substrate, although some bonding does occur. It is similar in thickness and structural behaviour to a new PCCP. It is essentially designed as a PCCP on a treated base course, in accordance with American Concrete Pavement Association design guidance (ACPA, 1998). This design guide also deals with whitetopping edge transition, joint spacing, and joint load transfer requirements (e.g., load transfer dowels).

The whitetopping may be constructed with fixed form or slipform Portland cement concrete paving equipment. A Portland cement concrete meeting CSA Class C-2 exposure requirements (minimum compressive strength of 32 MPa) is typically specified. If fast-track construction is required to open the intersection to traffic, a 24-hour compressive strength of at least 20 MPa (field cured specimens) is normally required.

4.3.6 Ultra-Thin Whitetopping

Ultra-thin whitetopping (UTW) is a pavement rehabilitation method in which a thin layer of Portland cement concrete (50 mm to 100 mm thick inlay) is placed over a prepared surface of distressed flexible pavement. The deteriorated asphalt concrete surface is cold milled (leaving an absolute minimum of sound asphalt concrete thickness of 75 mm) to enhance the bond between the Portland cement concrete and asphalt concrete to create a monolithic structure. Ultra-thin whitetopping is intended for parking areas, urban streets, bus bays, and intersection flexible pavements where instability rutting is a problem, but no other significant deterioration is present (ACPA, 1998; Smith et al., 2002). Any deteriorated areas that could detract from the load-carrying capacity of the ultra-thin whitetopping must be repaired. The UTW is generally intended for flexible pavements subject to lower volumes of heavy traffic (Smith et al., 2002).

Schematics of UTW showing the thickness, edge transition, milled surface, and short slab panels involved, are given in Figure 4-1. The short slab panels (typically square), between 0.6 mm and 1.8 m wide, help to reduce bending and thermal stresses. The UTW joints are not generally sealed unless a working joint develops. Most UTW installations have been jointed plain concrete pavement, incorporating fibre reinforcement (typically polypropylene or polymer blend monofilament) as secondary reinforcement to limit shrinkage and thermal cracking, and to increase toughness and post-cracking performance, designed and constructed in accordance with ACPA guidelines (ACPA, 1998, 1999a, b; Murison et al., 2002; Smith et al., 2002). As UTW is generally an inlay, it has the advantage of targeting the rutted areas while maintaining existing pavement elevations. Many UTW projects have incorporated fast-track concrete technology. A greater application of curing compound, and timely sawing of all joints (e.g., minimum 25 mm deep cuts and early-entry saws) are important to prevent random cracking.

Roller compacted concrete (RCC) with an asphalt overlay is another option for reconstruction of a deteriorated asphalt intersection.

4.3.7 Thin Composite Whitetopping

Thin composite whitetopping (TCW) is being considered as a new and emerging technology in the U.S. and is intended for high volume roadways carrying large number of heavy trucks. Unlike UTW, the overlay thickness is not an important part of the definition, but bonding to the underlying asphalt is. Therefore, TCW can be defined as: "A concrete overlay intentionally bonded to an existing asphalt pavement to create a composite pavement section. Joints are spaced at close intervals to reduce stresses in the concrete overlay" (Cole et al, 1998).

No computer program or design procedure currently exists for determining the required thickness of TCW pavement. Pavement thickness is based on engineering judgment and performance of previously placed TCW pavement installations. In general, TCW pavements are from 100 to 175 mm thick. Several installations have been constructed in the U.S. and one installation in Windsor, Ontario. The Ministry of Transportation of Ontario (MTO) constructed two trial sections, one each direction, of approximately 500 m in length at a Windsor intersection. The concrete pavement was 125 mm thick and had 1.25 m transverse and longitudinal joint spacing. The concrete strength was specified at 35 MPa with synthetic fibres. As identified in Photograph 4-5, the TCW has performed well to date.

4.3.8 Roller Compacted Concrete

Roller compacted concrete (RCC) with an asphalt overlay is another option for reconstruction of a deteriorated asphalt intersection. This option has been utilized at intersections and roadways in Calgary, Edmonton and Montréal.

Roller compacted concrete is a zero-slump mixture of aggregate, cement and water, (supplementary cementing materials [SCM] such as fly ash and blast furnace slag have also been used) that is compacted in place by vibratory rollers or plate compaction equipment like that utilized to compact asphalt pavement. Mixing of the materials is completed using continuous flow pugmills, twin-shaft mixers, conventional batch mixers, or tilting-drum truck mixers. Cement content is in the same range as conventional concrete, 300 to 350 kg/m^3, and compressive strength for intersection pavements is in the order of 30 to 40 MPa. The nominal maximum aggregate size is limited to 20 mm to provide a smooth, dense surface. Specifications usually require that the mix be transported, placed, and compacted within 60 minutes of the start of mixing; although ambient weather conditions and use of SCM may increase or decrease that time window.

RCC is typically placed in layers 125 to 250 mm in thickness using an asphalt-type paving machine. High-density paving equipment is preferred for layers thicker than 150 mm since the need for subsequent compaction by rollers is reduced. Following placement by a paver, RCC can be compacted with a combination of vibratory steel-wheeled rollers and rubber-tired equipment. Curing is vitally important in RCC pavement construction due to the very low water content at the initial mixing stage and the possibility that the RCC mix will dry out quickly once it is in place. Asphalt pavement is placed over the RCC to provide a smoother ride for the driving public. Another option to consider instead of an asphalt overlay is to diamond grind the RCC surface to ensure a smooth driving surface.

4.3.9 Interlocking Concrete Pavements

Interlocking concrete pavement (ICP), as shown in Figure 1-1, is another rut mitigation option for agencies to consider. This option has been utilized in various streets and intersections throughout Canada including: North Bay (20 year installation), Toronto, Hamilton, Edmonton, and Québec City.

Interlocking concrete pavement can be installed for partial depth repair or full depth repair of asphalt intersections. In both applications, 80 mm thick CSA A231.2 concrete pavers are placed in a herringbone pattern and vibrated into a 25 mm layer of screeded bedding sand conforming to the grading requirements of CSA A23.1. Dry joint sand, conforming to the grading requirements of CSA A179, is then swept into the joints and vibrated with a plate compactor until the joints are full.

A partial depth repair process can be used when rutted asphalt is thick enough to be milled to a consistent depth of 110 mm and can provide proper support for traffic. A geotextile fabric is placed over the milled asphalt prior to placement of the bedding sand and concrete pavers. In addition, drainage of the bedding layer should be provided either by edge drains or 50 mm diameter drains at the lowest point in the asphalt base. The drains should be filled with 10 mm open graded aggregate. A clean saw-cut face on the existing asphalt is required for edge restraint.

When the base support is inadequate for the ICP, the existing asphalt must be removed and the base replaced with either an acceptable aggregate base for flexible asphalt pavements or rigid pavement (full depth conventional concrete or RCC pavement). Aggregate bases, which are used for lower volume traffic applications, should be placed in 100 mm lifts and compacted to a minimum of 98% modified Proctor density. The sceeded bedding sand and concrete pavers are placed over the aggregate or concrete base. Edge restraint is provided by minimum 200 mm wide and 400 mm deep concrete curb.

5. Evaluation

5.1 Monitoring and Evaluation of Rut Mitigation Techniques

This best practice has provided the state-of-the-technology for the mitigation of asphalt pavement rutting at municipal intersections, with a focus on instability rutting. The technology described is also appropriate for other high stress/strain areas, such as bus bays and truck/bus routes with slow-moving or standing traffic. To assess the technical effectiveness and check the service life achieved, of any rutting mitigation method adopted, its long-term performance should be monitored on a site-specific basis. This can be done through a systematic monitoring and evaluation program, or as part of the municipality's general condition inspections or pavement management system (TAC, 1997; Shahin, 1994).

The evaluation and monitoring of a rut mitigation technique's effectiveness should include the following elements.

- **Site selection** — Select candidate sites, followed by a comprehensive investigation to determine site conditions and special features before construction.
- **Trial site and control site design** — Develop designs for the rut mitigation technique being considered for each trial and a control section with similar conditions, designed to agency-standard practices, for comparison purposes.
- **Construction quality and quality plan** — Develop and implement a plan for trial site and control site construction, including identification of any pre-trial testing that may be required (e.g., profile measurements) and coordination of all construction and monitoring activities.
- **Construction** — Monitor and document all aspects of the trial and control section construction, including materials production, transport, and placement, with materials samples taken for evaluation as necessary.
- **Post-construction monitoring and reporting** — Monitor the trial and control sites immediately after construction and then on an annual basis for a prescribed period, typically five years, with extensions to 10 or more years to verify in-service performance and any accelerated performance testing or modelling.

5.2 Rut Mitigation Action Plan Effectiveness

It is important that any feedback becomes part of the intersection action plan and is used to foster the use of cost-effective, technically sound rut mitigation methods.

The evaluation program's effectiveness closes the loop on the overall best practice multi-stage action plan for municipal intersection pavement rut mitigation.

1. Evaluate pavement performance problems and determine the cause of any rutting.
2. Ensure the pavement is structurally adequate.
3. Select and implement a cost-effective, technically sound pavement rut mitigation approach with appropriate materials selection and mix designs.
4. Practise proper construction techniques with quality assurance.

To assess the technical effectiveness and check the service life achieved, of any rutting mitigation method adopted, its long-term performance should be monitored on a site-specific basis.

Appendix A:
Questionnaire and Technical Literature Review

A.1 Background to Scan

Canada-wide concerns with the pavement performance, user, and cost impacts of asphalt concrete rutting at intersections, and other high wheel loading stress/strain areas, and its cost-effective mitigation, have not changed much since the early 1990s (TAC, 1991). However, there have been significant hot-mix asphalt and asphalt pavement technology advances in the last 10 years to enhance materials selection, mix design, and construction practices for rutting (permanent deformation), resistance, and mitigation. Also, there is a growing focus on pavement preservation techniques, new rehabilitation methods (e.g., ultra-thin whitetopping) and alternative pavement types (e.g., concrete pavers) for rut mitigation. These material, mix design, construction, rehabilitation, and pavement technology advances are occurring at the municipal road level (Aurilio, 2002) through to the international road associations (PIARC, 1995, 2000). It was considered important to complete a scan of municipal best practices for rut mitigation, both to benchmark the Canadian municipal progress with the intersection rutting problem, and to establish the state-of-the-technology evolving for the cost-effective, technically sound mitigation of intersection asphalt pavement rutting. This scan also provided an overview of a municipal intersection action plan, and its implementation, to ensure good structural and functional performance of existing and new asphalt pavements.

A.2 Components of Scan

The scan of municipal best practices for intersection pavement rut mitigation consisted of two components: a questionnaire/survey and a literature review.

- The questionnaire/survey was developed and sent to a selected list of municipal (24) and provincial (5) transportation agency, and technical association representatives (6). The overall response to the questionnaire was very positive: 21 municipalities, 5 provincial agencies, and 5 technical associations. Definitions of rutting and intersections were part of the questionnaire. Rutting is essentially a surface depression in the vehicle wheel paths, stemming from permanent deformation in any of the pavement layers or subgrade, usually caused by densification (consolidation) or lateral movement (shear) of the materials due to traffic loading. An intersection was considered to include not only the common area of pavement that two roads share, but also the roadway approaching and leaving the intersection for a distance of approximately 100 m in any direction.
- A comprehensive (asphalt technology, pavement design, pavement preservation and rehabilitation, and concrete pavements) review of the technical literature took place with a focus on asphalt pavement rutting and technical developments since 1995. An annotated bibliography of 16 of the most relevant technical articles is given in Appendix B.

There have been significant hot-mix asphalt and asphalt pavement technology advances in the last 10 years to enhance materials selection, mix design, and construction practices for rutting (permanent deformation), resistance, and mitigation.

A.3 Synthesis and Use of Scan

The responses to the questionnaire were synthesized to determine the most effective intersection pavement rutting mitigation measures being used across Canada, the United States, and internationally. Throughout, the focus was on the instability rutting (permanent deformation) of asphalt concrete at intersections and other heavy loading stress/strain areas, and cost-effective asphalt concrete rut mitigation techniques.

The extent and severity of rutting at intersections appears to increase with the size (population) of the municipality.

The responses of municipal agencies to the questionnaire clearly support the need for a best practice for rut mitigation techniques at intersections. All agencies reported they have experienced problems with rutting at intersections, mainly in their arterial and collector roadways. While some agencies indicated problems with wear rutting and structural (pavement structure adequacy) rutting, the overwhelming majority of agencies reported problems with instability rutting (plastic deformation) of asphalt concrete (flexible pavements and composite pavement surfaces). The extent and severity of rutting at intersections appears to increase with the size (population) of the municipality.

- Small municipalities (7) indicated rutting occurs between 3 m and 30 m before intersection stop bars.
- Medium-sized municipalities (4) observed that rutting is present 10 m to 30 m before stop bars.
- Larger municipalities (7 + 2 very large) reported rutting 20 m to 60 m before stop bars.

Traffic volume and composition were also key common factors, and while none of the agencies surveyed had specific data relating rutting at intersections to total traffic and composition, the majority of the responses indicated that rutting occurred where the average annual daily traffic (AADT) volume was between 15,000 and 45,000, and trucks and buses were involved.

While many municipal agencies have adopted similar approaches for dealing with intersection asphalt pavement rutting, there does not appear to be any standard approach for identifying, evaluating, and rehabilitating rutted intersection pavements. The specific municipal agency rut mitigation techniques identified, including performance and any problems, are incorporated as appropriate, with the comprehensive technology review and practical experience, in the best practice.

Appendix B:

Annotated Bibliography

Key references given by topic and date to show technology development over the last 10 years.

B.1 Asphalt Pavement Rutting and Technology

Transportation Association of Canada (TAC), 1991. *Asphalt Pavement Rutting Experience in Canada. (Also in 1990 Proceedings of the Canadian Technical Asphalt Association,* Emery, J.)

The problems, causes, "solutions," remedial measures, and action plans for the mitigation of asphalt concrete pavement rutting were summarized from nine seminars held across Canada. While wheel path wear rutting and structural rutting (pavement structure deformation) were considered, instability rutting (plastic deformation) of asphalt concrete, as a function of environment (hot weather), traffic (loadings, replications, tire types, tire pressures, axle configurations, buses, vehicle speed/stopping, early traffic action, etc.) and asphalt mix materials and design (aggregate characteristics, asphalt cement stiffness, voids, design methodology, etc.) was the major concern. It appeared the prime "solution" to instability rutting is through aggregate selection (dense grading, crushed, coarser, etc.), with engineered asphalt cements a secondary solution along with improved mix design/testing procedures. Alternate approaches, such as Portland cement concrete pavement and roller-compacted concrete, were also discussed. It was generally agreed that rut-resistant, hot-mix asphalt can be designed and placed, but contractors have to take care to avoid segregation and to achieve necessary compaction levels for the "harsh" mixes involved. There is a real asphalt concrete rutting problem across Canada, but it can be mitigated through material selection, appropriate mix designs and quality control. (Shortened from the Abstract.)

Permanent International Association of Road Congresses (PIARC), 1995. *Bituminous Materials With a High Resistance to Flow Rutting.*

This volume provides an international state-of-the-technology analysis, with significant Canadian input, on mechanisms of rutting, main parameters involved with instability rutting of asphalt concrete (bituminous materials), methods to characterize instability rutting (permanent deformation rutting) resistance, methods to model rutting (rut depth), practical mix design methods to achieve high resistance to rutting, and asphalt mix compositions (aggregates and asphalt cement requirements) to be used at sites with specific requirements for rutting resistance. Asphalt mixes should be designed for a high resistance to permanent deformation at sites where asphalt concrete is subjected to heavy, long loading times, truck and bus traffic (particularly during hot seasons), but without sacrificing fatigue strength and durability (resistance to aging and stripping effects).

Burlie, R. and J. Emery, 1997. *Evaluation of Urban Asphalt Concrete Rutting.* Canadian Technical Asphalt Association Proceedings.

Evaluation of 30 city pavement locations with asphalt concrete instability rutting indicated the areas of concern, with severe rutting, are associated with commercial vehicle use, particularly buses, in curb lanes, bus bays, and turn lanes. The use of high-stability, rut-resistant, hot-mix asphalt, meeting strict specification requirements, has been successful. A minimum milling depth of 125 mm is recommended before resurfacing areas with severe rutting. New rut-resistant asphalt mixes, such as a large stone binder course, heavy-duty binder course, and stone mastic asphalt, and the incorporation of polymer modified asphalt, have shown enhanced performance and favourable life-cycle costing.

Walker, D. and M. Buncher, 1999. "Developing Strategy for Better Performing Intersection Pavements – Parts 1, 2 and 3." *Asphalt, The Magazine of the Asphalt Institute* (AI).

Asphalt concrete pavements at intersections must be treated differently than regular open-road pavements due to the high-stress conditions (potential for instability rutting) related to heavy, low-speed, commercial vehicle loading and braking, accelerating and turning movements. Guidance is provided on the design, specification, materials, mix design, construction, quality control and life cycle costing of asphalt pavements for intersection high-stress conditions. Emphasis is placed on pavement structure adequacy, selecting and controlling materials, following proper construction practices, implementing a plan, life cycle costing, and the importance of short closures and easy maintenance.

Buncher, M., 2002. *Designing Asphalt Pavements at Intersections.* Asphaltopics (OHMPA).

The key to achieving satisfactory asphalt pavement performance at intersections is recognition that these pavements need to be designed differently than regular posted-speed asphalt pavements. The strategy described considers structural adequacy, materials and mixes, and proper construction practices.

Asphalt Pavement Alliance (APA), 2002. *Perpetual Pavements – A Synthesis – APA 101.*

This volume provides a state-of-the-technology analysis for flexible pavement designs, materials and mix designs, and construction of perpetual asphalt pavements. A perpetual pavement is defined as an asphalt pavement designed and constructed to last longer than 50 years without requiring rehabilitation, and only needing periodic surface renewal in response to distresses confined to the top of the pavement. The asphalt concrete pavement structure, designed for durability, combines a rut and wear-resistant top layer with a rut-resistant intermediate layer and a fatigue-resistant base layer. Hot-mix asphalt materials are addressed in terms of the properties needed in the various layers of the pavement.

Permanent International Association of Road Congresses (PIARC), 2000. *Choice of Materials and Design of Flexible Pavements for Severe Traffic and Climates.*

This supplement to the PIARC 1995 publication reports on asphalt concrete with a high resistance to instability rutting through a detailed survey of the choice of hot-mix asphalt materials and design for severe traffic and climates (significant Canadian input). The selection of materials and designs for various climatic conditions and high-volume roads is assessed through the potential performance of asphalt concrete in terms of load-carrying capacity, position in the pavement structure and rutting resistance, fatigue endurance, thermal cracking resistance, and durability (pavement deterioration).

B.2 Pavement Design and Maintenance

Ontario Ministry of Transportation (MTO), 1990. *Pavement Design and Rehabilitation Manual.*

This is a comprehensive manual on pavement design, rehabilitation and management practices that are widely used by planners and designers. Use of the manual practices assists in providing cost-effective pavement designs and overall detailed direction for pavement preservation.

American Association of State Highway and Transportation Officials (AASHTO), 1993 and 1998. *AASHTO Guide for Design of Pavement Structures (AASHTO 93) and Supplement to the AASHTO Guide for Design of Pavement Structures, 1998.*

These widely adopted pavement structural design guides provide comprehensive empirical design procedures for new flexible and rigid pavements, and for the rehabilitation of existing pavements. They are being replaced by the new mechanistic-empirical AASHTO 2002 pavement structural design guide.

Transportation Association of Canada (TAC), 1997. *Pavement Design and Management Guide.*

This comprehensive guide to Canadian pavement design and management practices covers the structural design of rigid and flexible pavements, pavement construction, maintenance, and rehabilitation practices, and the broad area of pavement management systems. The inherent focus of this guide is the promotion of good pavement design and management practices.

Hicks, R.G., S.B. Seeds and D.G. Peshkin, 2000. *Selecting a Preventative Maintenance Treatment for Flexible Pavements*. Foundation for Pavement Preservation (FPP).

State-of-the-technology information is provided on flexible pavement preventive maintenance to foster systematic, cost-effective pavement preservation. Practical implementation information is provided on types of pavement that are candidates for preventive maintenance, available treatments, where and when treatments should be used, treatment cost effectiveness, and the factors to be considered in selecting the appropriate treatment strategy. An overall methodology to determine the most effective treatment is given.

B.3 Whitetopping and Concrete Technology

American Concrete Pavement Association (ACPA) 1998. *Whitetopping – State of the Practice – EB210P.*

This volume provides a state-of-the-technology analysis for the design and construction of concrete overlays (whitetopping) on existing pavements.
The types of whitetopping include conventional whitetopping (overlay of thickness 100 mm or greater placed directly on asphalt pavement), concrete inlay (overlay placed in a trench milled out of a thick asphalt pavement), and ultra-thin whitetopping (overlay of thickness 50 to 100 mm placed on asphalt surface prepared to enhance the bond between the concrete and asphalt).

American Concrete Pavement Association (ACPA), 1999a. *Ultra-Thin Whitetopping – IS100.02P.*

This guide provides a state-of-the-technology guide to the design and construction of ultra-thin whitetopping (50 mm to 100 mm). It includes information on applications, history, materials, research, performance, load-carrying capacity, mechanistic analysis, joint design, construction, and repair.

American Concrete Pavement Association (ACPA), 1999b. *Construction Specification Guideline for Ultra-Thin Whitetopping* – IS120P.

This guideline gives specifications for ultra-thin whitetopping pavement projects. It includes references to material standards, test methods, and specifications of the ASTM, AASHTO, and CSA.

Murison, S., A. Shalaby and T. Smith, 2002. *Ultra-Thin Whitetopping in Canada: State-of-Practice.* Canadian Society for Civil Engineering Transportation Specialty Conference Proceedings.

This compendium outlines the state-of-practice in Canada for ultra-thin whitetopping pavement projects with respect to traffic, materials, design, construction, and repair. Determination of load-carrying capacity, performance measurement, and life-cycle cost analysis are discussed. Several Canadian case studies are presented.

Smith, K.D., H.T. Yu and D.G. Peshkin, 2002. *Portland Cement Concrete Overlays: State of the Technology Synthesis – FHWA-IF-02-045.* Federal Highway Administration (FHWA).

This volume presents the latest information on the technology, selection, design, construction, and performance of the four common types of concrete overlays: bonded and unbonded overlays, and conventional and ultra-thin whitetopping. Recommended applications, critical design elements, overlay design methods, recommended construction practices, design and construction aspects not adequately addressed, and research needs are given. Detailed information is provided on the use of concrete overlays as rehabilitation alternatives for existing concrete and asphalt pavements. There is a comprehensive annotated bibliography.

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