

# Roads and Sidewalks



## Reuse and Recycling of Road Construction and Maintenance Materials

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This document is the eleventh 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](http://www.infraguide.ca)>.

National Guide to  
Sustainable Municipal  
Infrastructure



**NTR · CNRC** **FCM** Canada  
Federation of Canadian Municipalities  
Fédération canadienne des municipalités

## **Reuse and Recycling of Road Construction and Maintenance Materials**

Version 1.0

Publication Date: October, 2005

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ISBN 1-897094-86-8

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## INTRODUCTION

# InfraGuide® — Innovations and Best Practices

## 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: decision making and investment planning, potable water, storm and wastewater, municipal roads and sidewalks, environmental protocols, and transit. The best practices are available online 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 at [www.infraguide.ca](http://www.infraguide.ca) for more information. We look forward to working with you.

# The InfraGuide® Best Practices Focus

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## 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 Municipal Roads Technical Committee provided guidance and direction in the development of this best practice, assisted by InfraGuide Directorate staff. The best practice was developed by John Emery Geotechnical Engineering Limited, Consulting Engineers.

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In addition, the Municipal Roads and Sidewalks Technical Committee would like to express its sincere appreciation to the following individuals for their participation in working groups:

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and The Asphalt Institute  
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The Committee would also like to thank the following individuals for their participation in peer review:

Steve Goodman  
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Bart Kanters  
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## Acknowledgements

## Acknowledgements

This and other best practices could not have been developed without the leadership and guidance of the InfraGuide Governing Council, the Relationship Infrastructure Committee and the Municipal Infrastructure Committee, whose members are as follows:

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## EXECUTIVE SUMMARY

This Best Practice describes the current practices being used by municipal agencies to reuse and recycle asphalt pavements and concrete recovered during road construction and maintenance work carried out within the public right-of-way. The Best Practice also discusses the current practices for recycling of winter sand (also called street sand) spread to enhance road surface friction during winter maintenance activities and collected by road sweepers during spring maintenance. Reuse options for asphalt pavement, concrete pavement, granular materials, earth, rock and like materials encountered during excavation work for the installation of underground services and utility cut restorations are also described.

Reuse and recycling asphalt materials can be recovered from grindings, millings, asphalt pavements, rejected materials or asphalt plant waste. Techniques described in this Best Practice for asphalt materials include:

- Central plant recycling (recycled hot mix);
- Hot in-place recycling;
- Cold in-place recycling:
  - Emulsion and rejuvenator emulsion
  - Lime or cement stabilization;
- Cold central plant recycling; and
- Full depth rehabilitation (FDR), with or without stabilization:
  - Pulverization (in-place reprocessing)
  - FDR with lime stabilization
  - FDR with Portland cement stabilization
  - FDR with foamed asphalt stabilization.

Reuse and recycling concrete materials can be recovered from pavements, sidewalk, curbs, curbs and gutters, building construction, renovation and demolition waste. However, within this Best Practice, the concrete materials will be recovered from with-in the right of way, including pavements, sidewalks, curbs and curb and gutters.

Techniques for concrete described in this Best Practice include:

- Material used in as granular base coarse/subbase;
- Concrete aggregate; and
- Rubblization (in-place recycling of concrete pavement).

The City of Edmonton Pilot Study on winter sand recycling is currently in progress. The engineering properties of winter sand and environmental challenges to successful winter sand recycling and reuse are described in this Best Practice.

Reuse of materials excavated during installation of underground services and utility cut restorations requires consideration of the engineering properties of the materials, and the potential presence, if any, of contamination. The Best Practice provides a framework for the evaluation of trenching materials.

A pavement evaluation methodology has also been given describing the main considerations in selecting reuse and recycling options, with a list of research and development needs.

The Best Practice confirms that there is a broad range of technically proven, cost effective reuse and recycling options available to municipalities, engineers and road managers that conserve natural resources and extend landfill life. These technologies are demonstrated by a separate set of supplementary Case Study sheets describing specific, successful projects where these techniques were employed. These Case Studies include; City of Edmonton Pilot Study on Winter Sand Recycling; Hot in-Place recycling on Highway 401 between Woodstock and London and Rubblization with cold Central Plant and Cold in-place Recycling in Oxford County. In addition, users of this Best Practice are directed to references and resources for more detailed technical information on asphalt and concrete reuse and recycling.

## Executive Summary

*There is a broad range of technically proven, cost-effective reuse and recycling options available to municipalities, engineers and road managers that conserve natural resources and extend landfill life.*



# 1. General

---

## 1.1 Introduction

This is one of a number of best practices being developed under the auspices of the National Guide to Sustainable Municipal Infrastructure (InfraGuide).

The reuse and recycling of materials from road construction and maintenance activities, and from the construction and repair of utility cuts within the public right-of-way, has and continues to make a modest, but significant, contribution to aggregate conservation and reduced landfill disposal requirements in Canadian municipalities. Where landfills are still accepting construction materials from road and utility construction and maintenance activities, the cost of tipping fees has risen substantially, and there is increasing pressure to keep all potentially reusable and recyclable materials from taking up limited landfill space and to conserve aggregate resources.

While the need to reuse and recycle is perhaps most acute in the major urban centres such as Toronto, Montréal, Ottawa, Halifax, Winnipeg, Calgary, Edmonton and Vancouver, municipal, provincial and federal agencies across Canada and internationally have adopted or are evaluating a broad range of applications for reuse and recycling of materials from road construction, maintenance, and utilities excavations. There is also significant energy and/or cementitious materials conservation associated with asphalt and/or concrete pavement recycling. In addition to engineering and physical properties considerations that are important for the end-use, there are also some environmental considerations involved for relatively innocuous or low-level contaminated materials from within the public right-of-way. For instance, the presence of asbestos mineral filler or coal tar in asphalt, petroleum products such as gasoline and diesel fuel in road base and subgrade materials, or heavy metals, chlorides and cyanides in street sweepings and catch basin clean-out materials, may limit

or preclude some reuse or recycling applications without some intermediate processing to address contaminants concerns.

## 1.2 Purpose and Scope

The purpose of an InfraGuide Best Practice is to provide state-of-the-art methodologies for municipal infrastructure planning, design, construction, management, assessment, maintenance and rehabilitation that consider local economic, environmental and social dimensions to achieve sustainable communities. The goals and objectives of this best practice on *Reuse and Recycling of Road Construction and Maintenance Materials* are:

- To present techniques and examples from across Canada on the recycling and reuse of road construction and maintenance materials from within the public right-of-way, with emphasis on four main categories of materials: asphalt concrete, Portland cement concrete (road, base, sidewalks and curbs), winter sand and trench materials;
- To identify technically sound techniques and technologies for reusing and recycling materials for all sizes of municipalities;
- To determine the economic benefits of various techniques;
- To determine the sustainable benefits;
- To determine the social and environmental impact; and
- To provide environmentally acceptable methods of disposal for excess materials that are not suitable for reuse or recycling.

## 1.3 How to Use This Document

This Best Practice describes the current practices being used by municipal agencies to reuse and recycle asphalt and concrete recovered during road construction and maintenance work carried out within the public right-of-way. The Best Practice discusses the current practices for recycling

## 1. General

- 1.1 Introduction
- 1.2 Purpose and Scope
- 1.3 How to Use This Document

*There is increasing pressure to keep all potentially reusable and recyclable materials from taking up limited landfill space and to conserve aggregate resources.*

## 1. General

1.3 How to Use  
this Document

1.4 Glossary

of winter sand spread to enhance road surface friction during winter maintenance activities and collected by road sweepers during spring maintenance, and potential reuse of pavement and earth or similar materials encountered during service trench/utility cut installations/restorations. The Best Practice provides municipalities, engineers and road managers with information on current reuse and recycling techniques, and guidance on the selection of appropriate reuse/recycling options for agency consideration and implementation. Users of this Best Practice are also referred to key sources where additional, more detailed technical information can be obtained. For ease of use, the key references cited have been listed separately for asphalt reuse and recycling, concrete reuse and recycling, winter sand recycling and trenching materials reuse. In addition, three stand-alone Case Study summaries have also been developed in conjunction with this Best Practice: a two-page Case Study describing the City of Edmonton Pilot Winter sand Recycling Project; a four-page Case Study providing examples of Canadian projects involving successful reuse and recycling of asphalt and concrete; and a two page Case Study providing a performance comparison of different road recycling/rehabilitation techniques including new hot in-place recycling (HIR) technology.

### 1.4 Glossary

**Absorption** — Fluid entering permeable pores of a solid material, given as percent increase in mass.

**Aggregate** — Granular material of mineral composition, such as sand, gravel, crushed stone, slags, and crushed concrete used in building and road construction.

**Asphalt** — Dark brown to black cementitious material in which the predominating constituents are bitumens that occur in nature or are obtained during crude petroleum refining.

**Asphalt cement (AC)** — Asphalt that is refined to meet specifications for paving, industrial and special purposes.

**Asphalt recycling agent** — Petroleum product additive, such as flux oil, used to restore aged asphalt cement to desired specification.

**Asphalt pavement** — Pavement consisting of surface and binder (or base) course asphalt concrete on supporting courses such as concrete base (composite pavement), asphalt treated base, cement treated base, granular base and/or granular subbase placed over the subgrade.

**Asphalt pavement surface recycling** — See hot in-place recycling or cold recycling.

**Base course** — Layer of material immediately beneath the asphalt concrete or Portland cement concrete surface of a pavement. (See asphalt pavement for instance.)

**Binder course** — The lower asphalt concrete course(s) of a flexible pavement.

**Catch basin clean-out material** — Earth and/or rock material removed from catch basins, including any accumulated debris such as leaves and litter that may have washed into the catch basin.

**Cement** — Portland cement or blended cement (CSA Standard A3000-03 Cementitious Materials Compendium).

**Coarse aggregate** — Aggregate that is predominantly retained on the 4.75 mm (or 5.00 mm) sieve size.

**Cold recycling (cold asphalt pavement recycling)** — Full or partial depth reuse of old asphalt concrete pavement (can be used for surface treatment, and can include treated and untreated base) that is either processed in-place (by cold in-place recycling train or full-depth in-place asphalt pavement reprocessing method) or at a central plant, typically with the addition of emulsified asphalt (or other additive such as cutback asphalt, lime or cement) and occasionally new aggregate to achieve desired cold mix quality, followed by placement and compaction.

Crushed stone — Aggregate, from crushing of quarried rock, with all faces fractured (crushed).

Ditch clean-out material — Earth and/or rock material removed during ditch excavation and maintenance, including ditch vegetation, and any accumulated debris such as leaves and litter. See catch basin clean-out material.

Earth — All soils except those defined as rock, excluding stone masonry, concrete and other manufactured materials.

Emulsified asphalt — Anionic or cationic emulsion of asphalt cement and water that contains a small amount of an emulsifying agent, which sets by water separation/evaporation and/or chemical reaction, leaving the asphalt cement to perform its cementing function.

Excess material — Rock, earth, aggregate, old asphalt concrete, old concrete, wood, etc., resulting from construction, that cannot be used at the site.

Fill — Material placed to level or raise the height of a site.

Fine aggregate — Aggregate that predominantly passes the 4.75 mm (or 5.00 mm) sieve size.

Foamed asphalt — A mixture of undried, cold RAP and/or virgin aggregate that is bound together by mixing it with an expanded asphalt cement binder formed by injecting a metered amount of cold water into a stream of hot asphalt cement in a mixing unit (causing it to foam, enabling it to coat the finer particles).

Full depth reclamation (FDR) — Full thickness of existing asphalt concrete is processed and recycled, usually with mixing/blending with underlying granular base/subbase or subgrade. Full depth reclamation may also include stabilization using foamed asphalt, cement or lime.

Granular — Aggregate used in granular base, granular subbase or select subgrade.

Gravel — Granular material consisting of rounded, water-worn rock fragments 2 mm to 75 mm in size usually intermixed with sand.

HL, hot mix, mixture, mix — Hot-mixed, hot-laid asphalt concrete.

Hot-mix asphalt (HMA) — Designed aggregate and asphalt cement mix produced in a hot-mix plant (batch, drum or drum/batch) where the aggregates are dried, heated and then mixed with heated asphalt cement, then transported, placed and compacted while still at an elevated temperature (about 125 to 135°C) to give a durable, deformation resistant, fatigue resistant pavement course.

Hot in-place recycling (HIR) — Hot reworking of the surface of an aged asphalt pavement (typically 50–75 mm) using preheaters and a heat reforming machine, typically with the addition of a rejuvenator, aggregate or new hot mix (HMA) to restore the condition of the scarified old asphalt pavement, and sometimes with an integral surface course overlay, all suitably placed and compacted in a single or multi-pass process.

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

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

Portland cement — Calcium silicate hydraulic cement produced by pulverizing Portland-cement clinker, and usually containing calcium sulphate and other compounds.

Portland cement concrete (PCC) — Composite material consisting essentially of a mixture of cement and water (binding paste) which are mixed with particles of fine and coarse aggregates.

Portland cement concrete recycling — Reuse of old concrete (PCC) such as foundation elements and pavements by processing into

## 1. General

### 1.4 Glossary

## 1. General

### 1.4 Glossary

aggregates for use in place or, or mixed with, conventional aggregates in application such as trench bedding, granular base, treated base, asphalt concrete (HMA) and concrete (PCC).

Reclaimed asphalt pavement (RAP) — Removed and/or processed pavement materials containing asphalt cement and aggregates.

Reclaimed concrete material (RCM) — Removed and/or processed old Portland cement concrete (PCC).

Recycling — When material is reclaimed from the waste stream and put to some use after varying degrees of processing.

Recycled hot mix (RHM) — Removal (surface milling or full depth) of old asphalt concrete (reclaimed asphalt pavement, RAP), processing, heating and mixing in a hot-mix plant (batch, drum or drum/batch) with new aggregates and new asphalt cement (softer grade or with recycling agent), relaying and compacting to meet specifications for conventional hot mix asphalt concrete (HMA).

Reuse — When material is reclaimed from the waste stream and put to some use with little or no processing.

Reworking — Processing existing unbound pavement materials in place, such as granular base, mechanically and/or by stabilization to improve performance.

Road sweepings — Material swept from roadways in the spring following winter sanding operations, containing recovered winter sand, road salt, and litter, sometimes contaminated with heavy metals, oil and grease. See Winter Sand.

Rubblization — In-place processing of old concrete pavement whereby the existing concrete pavement is broken into small pieces using specialty equipment.

Sand — Fine aggregate resulting from natural disintegration and abrasion of rock or processing of completely friable sandstone.

Stone — Any natural rock deposit or formation if igneous, sedimentary and/or metamorphic origin, usually used as dimension stone or crushed stone in building or road construction.

Street sand — See Winter Sand and/or Road Sweepings.

Subbase course — Layer of material in a pavement immediately above the subgrade. (See asphalt pavement for instance.)

Subgrade — Soil prepared through cut, fill and/or fine dressing to support a pavement. (See asphalt pavement for instance.)

Surface course — Top hot-mix asphalt course (HMA) of a pavement, sometimes called asphalt wearing course. (See asphalt pavement for instance.)

Trenching materials — Earth, rock and existing pavement materials (granular base and subbase, concrete base and/or asphalt surfacing) removed during excavation for service trenches and utility cuts.

Unshrinkable fill — A low-strength (0.4 MPa 28-day maximum) mixture of concrete aggregates, water, Portland cement and admixtures, having a minimum slump of 150 mm that may be used as backfill for utility cuts.

Winter sand — Sand placed on roads and streets during winter for traction control and to maintain surface friction. Winter sand may be collected by vacuum sweepers during spring road maintenance work. Materials collected during summer sweeping operations are not considered recyclable. Sometimes known as street sand. See Road Sweepings.

## 1.5 List of Acronyms/Abbreviations

### 1.5.1 Agencies and Associations

AASHTO — American Association of State Highway and Transportation Officials

<[www.transportation.org](http://www.transportation.org)>

ACI — American Concrete Institute

<[www.concrete.org](http://www.concrete.org)>

ACPA — American Concrete Pavement Association

<[www.pavement.com](http://www.pavement.com)>

AI — Asphalt Institute

<[www.asphaltinstitute.org](http://www.asphaltinstitute.org)>

APA — Asphalt Pavement Alliance

<[www.asphaltalliance.com](http://www.asphaltalliance.com)>

ARRA — Asphalt Reclamation and Recycling Association

<[www.arra.org](http://www.arra.org)>

ASTM — ASTM International

<[www.astm.org](http://www.astm.org)>

CAC — Cement Association of Canada

<[www.cement.ca](http://www.cement.ca)>

CAEAL — Canadian Association of Environmental and Analytical Laboratories

<[www.caeal.ca](http://www.caeal.ca)>

CSA — Canadian Standards Association

<[www.csa.ca](http://www.csa.ca)>

C-SHRP — Canadian Strategic Highway Research Program

<[www.cshrp.org](http://www.cshrp.org)>

CTAA — Canadian Technical Asphalt Association

<[www.ctaa.ca](http://www.ctaa.ca)>

ECCO — Environmental Council of Concrete Organizations

EPA — Environmental Protection Agency

<[www.epa.gov](http://www.epa.gov)>

FCM — Federation of Canadian Municipalities

<[www.fcm.ca](http://www.fcm.ca)>

FHWA — Federal Highway Administration

<[www.fhwa.dot.gov](http://www.fhwa.dot.gov)>

MNR — Ontario Ministry of Natural Resources

<[www.mnr.gov.on.ca](http://www.mnr.gov.on.ca)>

MTO — Ontario Ministry of Transportation

<[www.mto.gov.on.ca](http://www.mto.gov.on.ca)>

NAPA — National Asphalt Pavement Institute

<[www.hotmix.org](http://www.hotmix.org)>

NCHRP — National Cooperative Highway Research Program

NGSMI — National Guide to Sustainable Municipal Infrastructure

<[www.infraguide.ca](http://www.infraguide.ca)>

NRC — National Research Council

<[www.nrc.ca](http://www.nrc.ca)>

OECD — Organisation for Economic Cooperation and Development

<[www.oecd.org](http://www.oecd.org)>

OHMPA — Ontario Hot Mix Producers Association

<[www.ohmpa.org](http://www.ohmpa.org)>

PCA — Portland Cement Association

PIARC — Permanent International Association of Road Congresses (PIARC/AIPCR)

<[www.piarc.org](http://www.piarc.org)>

SHRP — Strategic Highway Research Program

<[www.infoguide.ca](http://www.infoguide.ca)>

TAC — Transportation Association of Canada

<[www.tac-atc.ca](http://www.tac-atc.ca)>

TRB — Transportation Research Board

<[www.trb.org](http://www.trb.org)>

### 1.5.2 Technical Terms

AADT — Average Annual Daily Traffic

CBR — California Bearing Ratio

CCPR — Cold Central Plant Recycling

C&D — Construction and Demolition

CIR — Cold In-Place Recycling

CRCP — Continuous Reinforced Concrete Pavement

EC — Electrical Conductivity

ESAL — Equivalent Single Axle Loads

FDR — Full Depth Reclamation

FWD — Falling Weight Deflectometer

GBE — Granular Base Equivalency

HIR — Hot In-place Recycling

HMA — Hot mix Asphalt

## 1. General

### 1.5 List of Acronyms/Abbreviations

## 1. General

### 1.5 List of Acronyms/ Abbreviations

JPCP — Jointed Plain Concrete Pavement

LCC — Life-cycle cost

MHB — Multiple head breakers

OPSS — Ontario Provincial Standard  
Specifications

PCC — Portland Cement Concrete

PG — Performance Graded

PGAB — Performance Graded Asphalt Binder

PGAC — Performance Graded Asphalt Cement

PMA — Polymer Modified Asphalt

QC — Quality Control

QA — Quality Assurance

RAP — Reclaimed Asphalt Pavement

RCM — Reclaimed Concrete Material

RHM — Recycled Hot Mix

SAR — Sodium Adsorption Ratio

SMA — Stone Mastic Asphalt



## 2. Rationale

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### 2.1 Background

The need for quality construction aggregates for buildings, roads, utilities, and transportation infrastructure construction and associated maintenance continues to grow across Canada, placing ever-increasing demands on our non-renewable aggregate resources (pits and quarries), fuels and binders (asphalt cements and Portland cements, for instance). At the same time, there is also increasing waste management environmental pressure to keep all potentially reusable and recyclable materials from taking up valuable space in ever-scarce landfills and pressure to reduce energy consumption and green house gas emissions.

It has long been recognized that reuse and recycling of construction materials such as asphalt concrete and Portland cement concrete recovered during road construction and maintenance activities can make an important contribution to aggregates resource conservation and the sustainable development of both our pits and quarries and our municipal landfills. Asphalt pavement and Portland cement concrete are 100 percent recyclable. Municipalities, engineers and road managers, and the construction industry have been very progressive in adopting and applying reuse and recycling technologies in the Canadian municipal sector. Buoyed by these successes, some municipal landfills have stopped accepting any potentially recyclable road construction and maintenance materials altogether.

The successful reuse and recycling of asphalt and concrete has led to consideration of other potentially surplus materials from road construction and maintenance. Winter sand that is routinely spread on roadways for traction enhancement during winter, then recovered by street sweepers in the spring, and excavated materials removed during

installation of underground services and the restoration of utility cuts within the public right-of-way are two other potentially reusable materials encountered/produced in significant volumes during municipal road construction and maintenance activities.

### 2.2 Benefits

The social and economic benefits of reuse and recycling of potential waste materials such as old asphalt and old concrete are well known. Recycled aggregates tend to be less costly than natural aggregates, particularly when the cost of processing is offset against the substantially greater cost of disposal. When properly processed and incorporated into appropriate road construction materials applications, the performance of the recycled product can be equivalent to that for conventional natural aggregate products. Reuse and recycling of these excess or waste materials also results in a substantial reduction in the quantity of new aggregates required for road construction/rehabilitation work, extending the life of our non-renewable aggregate resources. Reuse and recycling also reduces the volume of reusable material that is placed in municipal landfills, where it takes up ever-dwindling space that is better reserved for domestic waste, thereby extending the life of the landfill and decreasing the need for new landfills. There are also significant transportation cost savings (time and fuel costs) that can be realized by reusing or recycling excess or surplus materials close to their point of origin, and not hauling them to disposal sites. This Best Practice will assist municipalities in determining technically viable and cost effective reuse and recycling options and management practices for old asphalt, old concrete, winter sand and trenching materials.

## 2. Rationale

### 2.1 Background

### 2.2 Benefits

*Reuse and recycling of these excess or waste materials also results in a substantial reduction in the quantity of new aggregates required for road construction/rehabilitation work, extending the life of our non-renewable aggregate resources.*

### 3. Work Description

#### 2.3 Risks

*With proper project evaluation and characterization of the physical and chemical properties of the recycled material, the risks associated with reuse and recycling of old asphalt and old concrete are minimal.*

### 2.3 Risks

Reuse and recycling of asphalt and concrete are well-established, demonstrated technologies for which there exists a broad base of experience across Canada and internationally. With proper project evaluation and characterization of the physical and chemical properties of the recycled material, the risks associated with reuse and recycling of old asphalt and old concrete are minimal. However, it cannot be over-emphasized that the evaluation of individual projects and the selection of the most appropriate rehabilitation techniques should be determined in consultation with an experienced, qualified materials and pavement engineer.

Recycling of winter sand and reuse of materials excavated during service installation and utility cut restoration require consideration of environmental properties in addition to engineering properties, and consequently, the use of only accredited environmental laboratories is recommended for all environmental analyses, with interpretation of the results carried out by a qualified professional engineer or geologist/geoscientist.

## 3. Work Description

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### 3.1 Asphalt Concrete Reuse and Recycling Techniques

Reuse and recycling of asphalt is not a 'new' concept, with both hot and cold recycling of asphalt materials recovered from roadways having been completed since at least the early 1900's (ARRA, 2001). However, little advancement in asphalt recycling technology and equipment was made until the 1970's, when, spurred by the Energy Crisis, asphalt recycling efforts increased in response to social and environmental pressure to reduce the demand for products made using non-renewable fossil fuels/petroleum hydrocarbons.

The use of reclaimed asphalt pavement (RAP) to produce recycled hot-mix in a central asphalt plant (batch drum or combined batch-drum plants) is well-established and continues to grow across Canada, with recycled hot mix (RHM) included in most Canadian agency (provincial and many municipal) specifications for binder course mixes in particular, and some use in surface course mixes (Emery, 1991). However, continuing advancements in recycling technologies, including hot in-place recycling (HIR), cold in-place recycling (CIR), cold central plant recycling (CCPR), and full-depth reclamation (FDR), and their successful implementation and growing positive performance record, are providing pavement managers with a wider variety of technically acceptable, cost effective reuse and recycling options for roadway maintenance and rehabilitation work. In recent years, CIR and FDR have become the preferred cold recycling processes for structural improvement/strengthening and maintenance of municipal asphalt pavements, while evolving Canadian third generation forced hot-air preheater technology is resulting in enhanced quality for HIR asphalt rehabilitation. These pavement rehabilitation methods have been proven to provide cost effective, enhanced life-cycle performance.

Asphalt recycling has become a key component of the Canadian paving industry, and it is critical that the appropriate technology is adopted to ensure that the desired pavement quality is achieved and that the properties of the recycling materials are evaluated to ensure that the problem you are correcting does not re-occur. While RAP grindings, millings and/or pieces can be blended with conventional aggregate (sand and gravel or crushed rock) or RCM (reclaimed concrete materials) for use as granular subbase or shouldering material, it is suggested to aim for the highest-best use of the recycled materials. It is encouraged to use the RAP in processes that take full advantage of the engineering properties of both the aggregate and the asphalt cement. Reuse in paving mixtures is therefore preferred from both materials management and sustainable development viewpoints.

Current methods for reuse and recycling of asphalt are described in the following sections. The *ARRA Basic Asphalt Recycling Manual* (ARRA, 2001) and the OHMPA (Ontario Hot Mix Producers Association) *ABCs of Asphalt Pavement Recycling* (OHMPA, 2003) are recommended references for additional information.

#### 3.1.1 Central Plant Recycling (Recycled Hot Mix)

The use of processed RAP in batch, drum, and combined drum-batch asphalt plants to produce RHM is the most common type of asphalt recycling, and is considered standard asphalt technology in Canada and internationally (TAC, 1994; MTO, 1995; OECD, 1997; FHWA, 2002, OHMPA, 2003, for instance). The two most common types of HMA plants capable of incorporating RHM are shown in **Photo 3-1** and **Photo 3-2**.

### 3. Work Description

- 3.1 Asphalt Concrete Reuse and Recycling Techniques

*Asphalt recycling has become a key component of the Canadian paving industry, and it is critical that the appropriate technology is adopted to ensure that the desired pavement quality is achieved and that the properties of the recycling materials are evaluated to ensure that the problem you are correcting does not re-occur.*

### 3. Work Description

#### 3.1 Asphalt Concrete Reuse and Recycling Techniques

##### Photo 3-1

Typical parallel flow HMA  
drum asphalt plant

##### Photo 3-2

Typical counterflow drum-  
batch asphalt plant



**Photo 3-1:** Typical parallel flow HMA  
drum-asphalt plant

The conveyor on the right transfers processed RAP to the top-centre where it is fed into the continuous drum mixer.

On major road and highway rehabilitation projects, a substantial amount of RAP may be generated on-site by partial-depth milling of the existing surface or complete removal of asphalt concrete layers, then processed (crushed and screened) and re-incorporated directly into RHM for reuse on the project. However, in larger urban centres, RAP recovered from a number of small roadway and commercial paving projects may be collected and centrally stockpiled, usually at a hot-mix producer's plant, for reuse in RHM mixtures.

It is important that the RAP be properly processed to ensure that the engineering properties of the RAP are equivalent to virgin materials. Proper blending and crushing is required to produce a consistent gradation and asphalt cement content. This RAP management minimizes variations in the properties of the RAP from different sources, resulting in a relatively homogeneous material in stockpiles. The RAP is processed (crushed and screened) using a portable plant or integrated processing operation that can handle both RAP and new hot-mix asphalt. It is recommended that the processed RAP be stored in an open-sided shed or building to minimize the moisture content and variation within the stockpile; covering RAP stockpiles with tarpaulins is not recommended as this practice can trap moisture within the stockpile.



**Photo 3-2:** Typical counterflow drum-batch  
asphalt plant

The RAP cold feed bin and conveyor is shown in the right corner.

For batch mix plants, the amount of RAP incorporated is typically limited to less than 30 percent to ensure adequate drying and heat transfer in the pugmill from superheated aggregate, and to limit 'blue smoke' emissions. Depending on the amount of RAP to be incorporated in the RHM, it may be necessary for the new asphalt cement to have a higher (softer) penetration grade (lower viscosity) in order to offset the harder 'aged' asphalt cement in the RAP; this is generally not necessary with RAP addition rates less than about 25 percent. The need to soften the aged asphalt cement and to control potential emissions (blue smoke) limits the amount of RAP that can be incorporated in drum asphalt plants to between 40 and 60 percent (JEGEL, 1992; Earl and Emery, 1987).

The maximum amount of RAP permitted in HMA varies somewhat from province to province. All provinces except Nova Scotia and Prince Edward Island permit RAP to be used in HMA, provided that testing is completed to ensure the quality (penetration/viscosity, or performance grading for Superpave mixture or the asphalt cement) and uniformity of the RAP source and that the RHM meets all specification requirements for asphalt concrete. Ontario (OPSS 1150) limits the amount of RAP in surface course HMA to 15 percent maximum with 30 percent in conventional binder course mixes and up to 50 percent in certain situations subject to

*All provinces except Nova Scotia and Prince Edward Island permit RAP to be used in HMA, provided that testing is completed to ensure the quality and uniformity of the RAP source and that the RHM meets all specification requirements for asphalt concrete.*

confirmatory testing. Newfoundland allows 10 percent RAP in leveling course only, whereas Québec accepts up to 15 percent RAP in RHM. Alberta and New Brunswick permit higher RAP addition levels (30 percent and 40 percent ( $\pm 5$  percent), respectively). British Columbia, Saskatchewan and Manitoba do not limit the amount of RAP that can be added to HMA. The steps involved in designing a recycled hot mix are:

- Obtain representative samples of the RAP and determine its properties (gradation, asphalt cement content, penetration and viscosity of the recovered asphalt cement binder) in the laboratory;
- Complete Marshall mix design in accordance with AI MS-2 procedures; alternatively, for Superpave volumetric mix designs, the mix design should be completed in accordance with the most current (2003) AASHTO MP-2 and AASHTO PP-28 procedures (NCHRP 452, *Recommended Use of Reclaimed Asphalt Pavement in the Superpave Mix Design Method—Technician’s Manual*, also provides specific technical guidance for mix designers);
- Conduct quality control and quality assurance (acceptance) testing during RHM production and placement to confirm that it meets specification requirements.

Central plant recycled hot-mix asphalt production is considered to be standard asphalt technology, with the only impediment to more widespread use being the current lack of hot-mix asphalt plants suitably equipped for introduction of the RAP and control of potential air emissions (mainly ‘blue smoke’, especially at higher RAP proportions) in some areas in Canada.

### 3.1.2 Hot In-Place Recycling

In Hot In-Place Recycling (HIR), the asphalt pavement surface is heated, softened and scarified to depths of 20 to 60 mm, the scarified material is then remixed, placed, and compacted as a part of a continuous in-place process. New aggregates, new asphalt

cement, recycling/softening agents, and/or new HMA (commonly referred to as ‘admix’) can also be added to improve the engineering properties of the existing pavement and for increased structural capacity (for a total treatment thickness up to 75 mm). Pavement distresses which can be treated by HIR include: flushing/bleeding; raveling; rutting; shoving; poor surface friction (macrotexture and microtexture); and longitudinal and transverse cracking, and reflection cracking (Emery et al, 1989; MacKay and Emery, 1989; Kazmierowski et al, 1994; Dunn et al, 1997).

There are three types of HIR treatment (MacKay and Emery, 1989):

- **Surface Recycling:** To improve the profile of an asphalt surface course deformed by rutting or wearing, but in comparatively unaged condition with only minor cracking (no rejuvenation required). Surface Recycling consists of heating, scarifying, leveling, reprofiling and compaction of the mixture.
- **Remixing:** To improve the quality of old, cracked, aged surface course through the addition of a recycling agent/rejuvenator, aggregate or new hot-mix asphalt. Remixing involves heating, scarifying (with rejuvenator, mixing aggregates and/or new hot-mix asphalt added), mixing, leveling, reprofiling and compaction.
- **Repaving:** To improve the profile of an asphalt surface course severely deformed by rutting or wearing, improve frictional characteristics, and/or provide some strengthening. Repaving involves heating, scarification (with rejuvenator, aggregate and or new hot-mix added, if necessary), mixing, leveling and laying of new hot-mix asphalt, reprofiling and compaction, all in one pass.

It is recommended that a proper pavement evaluation be carried out to fully determine the cause(s) of the pavement distress and the most appropriate HIR process then selected to address the pavement conditions. Materials characterization and mix design by a qualified,

## 3. Work Description

- 3.1 Asphalt Concrete Reuse and Recycling Techniques

*It is recommended that a proper pavement evaluation be carried out to fully determine the cause(s) of the pavement distress and the most appropriate HIR process then selected to address the pavement conditions.*

### 3. Work Description

#### 3.1 Asphalt Concrete Reuse and Recycling Techniques

##### Photo 3-3

Current HIR Remixing train  
rehabilitating a municipal  
roadway in a single pass,  
2002



**Photo 3-3:** Current HIR Remixing train rehabilitating a municipal roadway in a single pass, 2002

Three combination forced hot-air/radiant low-level heat preheaters lead the HIR train (left side of photo), followed by the preheater/milling unit; new HMA admix is loaded into a hopper at the front of the remixing unit where it is fed and mixed with the existing pavement material and distributed by the asphalt paver. Conventional HMA compaction equipment is used to simultaneously compact the HIR mix.

*New third generation combined forced hot-air/radiant low-level heat preheaters have overcome previous issues with heater-scarification quality and depth.*

experienced laboratory, in conjunction with quality control (QC) and with quality assurance (QA) verification testing during the rehabilitation work, are critical components of a successful HIR project. The most current HIR equipment is shown in **Photo 3-3** (Martec, 2002).

HIR technology has been steadily evolving, with continuing improvements in the overall quality and performance of HIR pavements. New third generation combined forced hot-air/radiant low-level heat preheaters have overcome previous issues with heater-scarification quality and depth, allowing increased treatment depth without degradation (aging) of the existing asphalt cement binder, including polymer-modified asphalt cements. This equipment has also reduced 'blue smoke' (emissions factor) to below that of conventional hot-mix asphalt plants (EPA/FHWA/Martec, 2003).

When determining the application for HIR, its use is more appropriate for long stretches of pavement with limited turns as the train is quite long. As well, the designer should consider the overhead clearance and the number of utility boxes along the stretch of pavement.

#### 3.1.3 Cold In-Place Recycling

Cold in-place recycling (CIR) is an on-site process for the rehabilitation of asphalt-surfaces (on both flexible and composite pavements) to depths up to 150 mm. The old asphalt is milled to a specified depth, mixed with emulsified asphalt, and repaved to the required grade and profile. A surface treatment or hot-mix asphalt wearing surface is applied after the CIR mix has properly cured. Curing of cold-in-place recycled mix is greatly dependent upon the types of emulsion used and the weather conditions. Curing is generally 2–6 weeks and is greatly affected by colder temperatures.

This process is being widely implemented by cities, rural agencies, provinces and states, and there are a number of qualified specialists, Canadian contractors, having state-of-the-art equipment and demonstrated direct municipal projects experience. Pavements exhibiting the following distresses can be considered for cold in-place recycling: longitudinal and transverse cracking; bleeding; corrugations; potential bonding problems; raveling; rutting; shoulder drop off; and shoving. The CIR mix is relatively stiff with high air voids

and hence is effective in mitigating reflective cracking. Initially used mainly for rehabilitation of low volume roads, CIR is now considered to be a proven technology for higher AADT (average annual daily traffic) or higher ESAL (equivalent single axle loads) roadways.

The CIR process involves: milling or grinding of the existing asphalt surface to depth typically 75 to 125 mm; processing/mixing of the pulverized RAP (with addition of beneficiating aggregate, if any, water and emulsion (plus cement [one to three percent] or lime [one to two percent] addition to increase mix stability and reduce stripping potential, if necessary); compaction with water as an aid to densification, and densification as the water content comes into equilibrium with ambient conditions and surroundings. The CIR mixture continues to increase in strength and stiffness with time. Once fully cured, the CIR mix must be overlaid with a wearing surface (conventional hot-mix asphalt or other surfacing depending on AADT).

A standard 'Cold Marshall' mix design method has been widely adopted for the design of CIR mixtures. It is important that the CIR mix design be completed by a qualified laboratory with CIR experience, using representative samples of the existing asphalt from each section (millings or cores [preferred]). A new approach to CIR mix design based on the SHRP Gyratory Compactor is currently under development (Emery, 2003).

It is recommended that a pavement evaluation be carried out to assess overall suitability for CIR treatment, and the specific CIR process requirements. Materials characterization and mix design by a qualified, experienced laboratory, in conjunction with quality control (QC) and quality assurance (QA) verification testing during the rehabilitation work, are critical components of a successful CIR project. Cold mix layers are typically thicker than similar hot mix applications for comparable performance.

CIR modifications developed for improved economics and/or special conditions include addition of supplementary beneficiating aggregate, special emulsions and cement or lime slurry addition. Typical CIR equipment in use on Canadian (Ontario) municipal projects is shown in the **Photos 3-4** and **3-5** below:

CIR of the existing pavement overlaid with a surface course hot-mix asphalt layer designed to meet Superpave mix requirements has been used for enhanced durability and to minimize reflective and/or thermal cracking. CIR of the existing pavement, in conjunction with the placement of open graded cold mix wearing surface, is being developed for a 'total cold' system. A total cold system might be of interest for remote areas where there is not a hot mix plant in close proximity to the project.

### 3. Work Description

- 3.1 Asphalt Concrete Reuse and Recycling Techniques

**Photo 3-4**

Ontario CIR Project, 2000

**Photo 3-5**

Ontario CIR Project with cement slurry addition, 1999

*CIR modifications developed for improved economics and/or special conditions include addition of supplementary beneficiating aggregate, special emulsions and cement or lime slurry addition.*



**Photo 3-4:** Ontario CIR Project, 2000

This four piece recycling train consists of an emulsion tanker, milling machine, RAP crushing and screening unit and computerized pugmill/paver.



**Photo 3-5:** Ontario CIR Project with cement slurry addition, 1999

Added to this CIR recycling train is a cement slurry tanker which gives the pugmill/paver the ability to add cement slurry to the mix.

### 3. Work Description

- 3.1 Asphalt Concrete Reuse and Recycling Techniques

#### Photo 3-6

Conventional full-depth foamed asphalt stabilization unit

#### Photo 3-7

Paver-Laid surface recycling foamed asphalt train.

*The use of cold mix as a base asphalt instead of hot mix asphalt on low volume roads has met with good success.*

### 3.1.4 Cold Central Plant Recycling

Cold central plant recycling (CCPR) produces the same end product as cold in-place recycling. The RAP obtained from the roadway, or from centrally-located homogeneous stockpiles, is processed (crushed and/or screened), then fed into a central mixing plant where the emulsified asphalt and any additives are added and blended. The CCPR mixture is then transported to the paving site and placed in the same manner, using conventional hot mix asphalt or RHM paving equipment. The cold central plant recycling option should be considered where large stockpiles of high quality RAP are readily available and where recycling the existing pavement in place due to variability in the existing pavement may be impractical, or where in-place recycling equipment is unavailable. The use of cold mix as a base asphalt instead of hot mix asphalt on low volume roads has met with good success. Cold mix layers are typically thicker than similar hot mix applications for comparable performance. Cold mix can also be used to upgrade gravel roads at a much lower cost than hot mix.

The same mix design procedures and QC/QA inspection and testing methods are required for CCPR as for CIR.

### 3.1.5 Full Depth Reclamation

There are a number of different types of full depth reclamation (FDR) techniques available to Canadian municipalities, including pulverization-mixing ('pulvi-mixing')/in-place reprocessing (without stabilization); FDR with bituminous stabilization (using asphalt emulsion (normal, high-float, polymer modified) or foamed asphalt); FDR with chemical stabilization (using cementitious systems such as Portland cement, fly ash, lime (hydrated or quicklime), cement kiln dust or lime kiln dust, or additives such as calcium chloride or magnesium chloride); and/or FDR with mechanical stabilization (by addition of corrective aggregate).

Full depth reclamation involves pulverization and in-place mixing of the full thickness of the asphalt pavement and a predetermined portion of the underlying materials (base, subbase

and/or subgrade) to provide a homogeneous base material (ARRA, 2001). Full depth pulverization ensures mitigation of reflective cracking by eliminating pre-existing cracks. The pulvi-mixed base material may be structurally enhanced by stabilization.

The most common form of FDR includes bituminous stabilization with foamed asphalt. Until recently, this technology was not widely used in Canada (Dawley et al, 1993; TAC, 1994), but is rapidly growing (Brown et al, 2000; Donovan and Stefaniw, 2003; Emery and Uzarowski, 2003; Johnston et al, 2003; Lane and Kazmierowski, 2002). Two foamed asphalt stabilization processes in current use are shown in **Photos 3-6** and **3-7**. The primary advantage of foamed asphalt stabilization is



**Photo 3-6:** Conventional full-depth foamed asphalt stabilization unit

Foamed asphalt is added to and mixed with pre-pulverized base in the milling chamber, then discharged. The stabilized mix is distributed across the lane to the required grade using a motor grader. Compaction is completed with heavy vibratory compaction equipment.

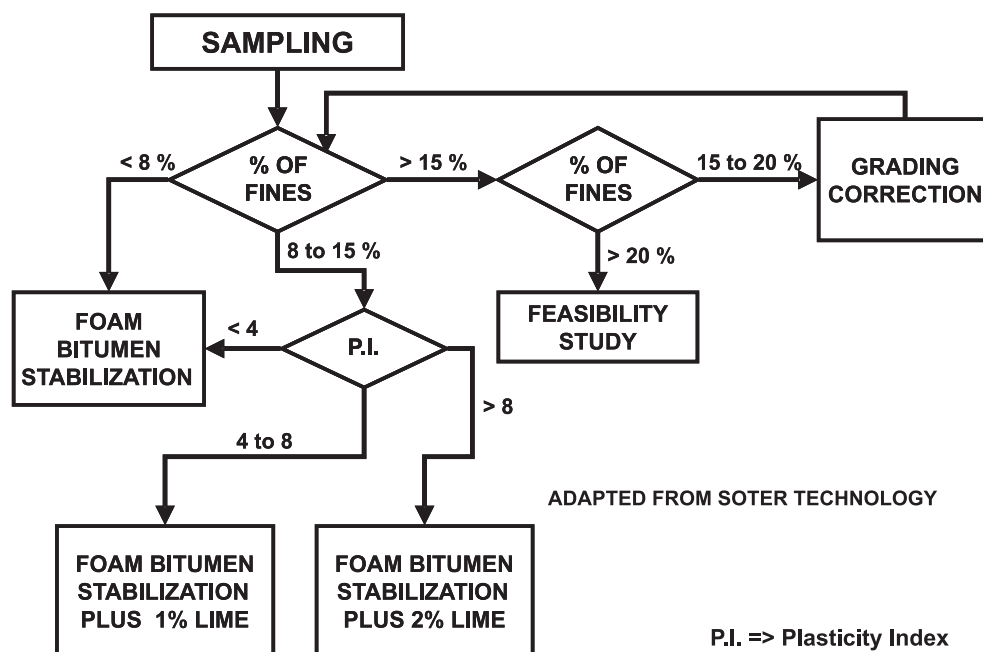


**Photo 3-7:** Paver-Laid surface recycling foamed asphalt train (Adapted from SOTER Technology)

The Paver-Laid foamed asphalt train consists of a milling machine, aggregate screening and weighing unit, pugmill mixer and asphalt spreader to process as existing asphalt pavement in a single pass. Considered a surface recycling process, typically not full depth.



**Figure 3–1:** Decision tree for the determination of lime addition to foamed asphalt stabilization (JEGEL, 2002)



that the resulting (compacted) base may be overlaid in as little as 48 hours when compared to 2–6 weeks required for cold-in-place recycling. This is of great benefit to municipalities where the project must be completed quickly and the base layer cannot be left unpaved for longer periods of time.

FDR with foamed asphalt stabilization consists of full depth pulverization of the existing roadway followed by addition and mixing of foamed asphalt with the pulverized material (typically at addition rates between 2 and 3.5 percent) to create a stabilized base. Depending on the properties of the material being stabilized, the FDR with foamed asphalt stabilization process may be enhanced by addition of lime or Portland cement (JEGEL, 2002). One to two percent lime may be added, if necessary, subject to the plasticity of the granular base/subbase or subgrade material to be stabilized, to increase mix stability or provide enhanced resistance to moisture damage/stripping (Figure 3–1). If the base material does not contain adequate fines for lime stabilization and/or increased stability is required, typically 1 to 3 percent Portland cement may be added to the FDR with foamed asphalt process. Treatment depths vary depending on the thickness of the existing pavement structure, but

generally range between 100 and 300 mm (4 to 12 inches). Additional corrective granular or RAP material (mechanical stabilization) may be added, if necessary, to increase the pavement structural capacity.

The main advantages of foamed asphalt stabilization include: ease of application in a variety of municipal and highway settings; provision of a flexible layer with good rut resistance and fatigue properties; the ability to correct the pavement profile; and reflective cracking mitigation.

The design of a foamed asphalt mixture should be carried out by an experienced and qualified asphalt laboratory. The foamed asphalt cement expansion properties (expansion ratio and half-life with percent injection water) are determined in the laboratory, and a foamed asphalt mix design is developed for the optimum tensile strength ratio (TSR, resistance to moisture). There are several similar mix design methods available which are essentially based on the Wirtgen procedure (Wirtgen Cold Recycling Manual, 1998).

Proper quality control (QC) and quality assurance (acceptance) (QA) testing of both the foamed asphalt cement and the foamed asphalt mix during a foamed asphalt project are critical to

### 3. Work Description

- 3.1 Asphalt Concrete Reuse and Recycling Techniques

**Figure 3–1**  
Decision tree for the determination of lime addition to foamed asphalt stabilization (JEGEL, 2002)

*The primary advantage of foamed asphalt stabilization is that the resulting (compacted) base may be overlaid in as little as 48 hours when compared to 2–6 weeks required for cold-in-place recycling.*

### 3. Work Description

3.1 Asphalt Concrete Reuse and Recycling Techniques

3.2 Concrete Reuse and Recycling Techniques

#### Photo 3-8

Full depth reclamation with lime stabilization

#### Photo 3-9

Full depth reclamation with cement stabilization

*Proper quality control (QC) and quality assurance (acceptance) (QA) testing of both the foamed asphalt cement and the foamed asphalt mix during a foamed asphalt project are critical to its successful performance.*

its successful performance. During construction, the asphalt cement temperature, injection water percentage, expansion ratio and half-life are monitored for process control.

The technology and equipment for full depth reclamation with stabilization using chemical/cementitious systems is also widely available in Canada. Two full depth reclamation projects demonstrating the use of hydrated lime and Portland cement to stabilize the full-depth pulverized granular base/subbase and subgrade are shown in **Photo 3-8** and **Photo 3-9**.

In a recent Canadian research project carried out by Laval University, a pavement section in the City of Québec was rehabilitated by pulverizing and mixing the existing asphalt pavement and underlying granular base/subbase to a depth of 500 mm (Tighe et al, 2001). A Portland cement slurry was then added to the pulverized mixture in-place (at relatively high cement contents of 9%, 12% and 15% by dry mass), then compacted using conventional pavement compaction procedures. This trial FDR with cement slurry project effectively resulted in a roller compacted concrete base. Similarly, cement stabilization was successfully used to rehabilitate a major arterial road in Verdun, Québec (Bernard, 1997), and this type of process has been adopted for other Québec municipal roadways.

As with bituminous stabilization, chemical stabilization may also be combined with one or more bituminous or mechanical stabilization processes to achieve the optimal final product



**Photo 3-8:** Full depth reclamation with lime stabilization

The Hato Mayor-Sabana de la Mar roadway in the Dominican Republic required lime stabilization of the lateritic soils before resurfacing.

meeting project requirements. Chemical stabilization also begins with full depth pulverization of the existing roadway followed by chemical stabilization (typically 3 to 5 percent lime or Portland cement depending on the required strength; the addition of fly ash as a supplementary cementitious material or pozzolan can also be considered). Treatment depths are dependent on the ability to compact the stabilized material and may be up to 500 mm (20 inches).

Pavements exhibiting block cracking, edge cracking, longitudinal and transverse cracking, and slippage cracking; bleeding; inadequate structural capacity; stripping; and permanent deformations (corrugation, rutting, shoving) can be considered as candidates for full depth reclamation.

It is recommended that a pavement evaluation (as described in more detail in Section 5 of the Best Practice) be carried out to assess overall suitability for FDR treatment, and the specific FDR process requirements. Materials characterization and mix design by a qualified, experienced laboratory, in conjunction with quality control (QC) and quality assurance (QA) verification testing during the rehabilitation work, are critical components of a successful FDR project.

### 3.2 Concrete Reuse and Recycling Techniques

The reuse and recycling of concrete recovered from pavements, sidewalks, curbs



**Photo 3-9:** Full depth reclamation with cement stabilization

The Natchez Trace Parkway in Mississippi employed cement stabilization to address variable, wet and soft base and subgrade conditions.

and curb and gutters is well established. This concrete is 100 percent recyclable in roadway construction applications such as pavement base coarse and subbase, as concrete aggregate in Portland cement concrete mixtures, or processed in-place using rubblization techniques. The need to rubblize the concrete pavement will depend on its condition and the environmental conditions in which the pavement is exposed. The document does not discuss the in-place rehabilitation of concrete pavement by applying CPR3 (restoration, resurfacing and reconstruction) techniques. Details on this restoration and resurfacing process for concrete pavement can be found in *Reference Manual of Pavement Preservation Techniques* (InfraGuide, 2005) and should be considered before the other reuse and recycling options identified below.

### 3.2.1 Reclaimed Concrete Material as Granular Base/Subbase

Portland cement concrete is normally produced using high quality coarse and fine aggregates that are well-suited for recycling. The use of reclaimed concrete material as construction aggregate and fill material is well-established and is largely considered standard practice (TAC, 1994; OECD, 1997; FHWA, 1997; FHWA, 2004; Melton, 2004); for example, RCM has been an approved source of aggregate in Ontario Provincial Standard Specifications (OPSS) 1001 Aggregates—General, and OPSS 1010 Aggregates—Granular A, B, M and Select Subgrade Material, since the late 80s. Crushing and screening of RCM results in a well-graded, 100 percent crushed, angular material that has high strength when used in pavement base course applications (equivalent to 100 percent crushed natural aggregates) with good drainage properties.

Reclaimed concrete material (RCM) is generated through the demolition of concrete pavements, sidewalks, curb and gutter, runways and transportation structures, mostly in urban areas. Portland cement concrete from building foundations, walls and floor slabs recovered during the demolition of building

structures can also be considered, but without careful source separation, these materials can potentially contain construction and demolition (C&D) wastes such as brick, wood, wallboard, glass, plastic, coatings (moisture and fire-proofing for instance), and other materials that are generally not suitable in construction aggregates. Consequently, it is recommended that a proper evaluation of all C&D wastes considered for use as construction aggregate be performed to ensure they meet appropriate standards before use.

After processing (crushing and screening, and removal of metal), the processed RCM can be reused as granular base and subbase material. The RCM may also include some old asphalt from composite (asphalt over concrete) pavements; for strength considerations, the amount of old asphalt that can be included in RCM subbase is typically limited to about 30 to 50 percent by mass. For example, based on Ontario Ministry of Transportation (MTO) research (Senior, 1992) indicating that the California Bearing Ratio (CBR) strength of the natural and recycled concrete aggregate decreases with increasing RAP content, OPSS 1010 limits the total amount of asphalt-coated particles in Granular A base and Granular B Type 1 subbase to 30 percent by mass. RCM has also been used as aggregate in lean-concrete, cement-stabilized base and in soil-cement mixtures (CAC, 2002).

A typical RCM processing operation consists of breaking large concrete pieces/slabs using crane and ball-drop, hydraulic or pneumatic breakers (hoe-ram equipment for instance), diesel hammers, etc.; removal of reinforcing steel; primary crushing and sizing (using jaw crushers most typically); and secondary crushing (cone, roll or impact crushers) and final screening. The crushing and screening circuit may also include a magnetic separator for additional metals removal/recovery (as scrap, potentially providing an additional source of revenue that may partially offset processing costs), and spray bars for dust control. Both portable and permanent crushing circuits are used, depending on the amount of RCM available.

## 3. Work Description

### 3.2 Concrete Reuse and Recycling Techniques

*Reclaimed concrete material (RCM) is generated through the demolition of concrete pavements, sidewalks, curb and gutter, runways and transportation structures, mostly in urban areas.*

### 3. Work Description

#### 3.2 Concrete Reuse and Recycling Techniques

##### Photo 3-10

A resonant breaker in operation in Oxford County, Ontario

*The use of processed RCM has been mainly in granular subbase in urban areas where supply and transportation costs favour such use (JEGEL, 1992)*

#### 3.2.2 Recycled Concrete Aggregate

RCM has also been used as an aggregate in hot-mix asphalt (TAC, 1994) and in Portland cement concrete (FHWA, 1997; FHWA, 2004; Kasai, 2004). The term *recycled concrete aggregate* is generally used to refer to processed RCM used as aggregate in recycled concrete mixtures ('new' Portland cement concrete produced using recycled concrete aggregates). Recycled concrete aggregate has a higher absorption than conventional natural aggregates and generally yields concrete of lower strength at equivalent water/cement ratios and lower slump than conventional aggregates (JEGEL, 1992). If fine recycled concrete aggregate is used, the workability of the fresh concrete also decreases. In addition, potentially deleterious substances, such as sulphates (from old plaster for instance), chlorides and alkali reactive aggregates, must be strictly controlled.

With careful attention at the mix design stage, quality concrete can be produced using recycled concrete aggregates. The higher absorption of recycled concrete aggregates may require adjustment to water and Portland cement content to achieve the appropriate water-cement ratio for concrete strength and durability (ECCO, 1999; CAC, 2002; Kasai, 2004). Due to their high absorption, prewetting of

recycled concrete aggregates is recommended (FHWA, 1997; Kasai, 2004).

Reuse of recycled concrete aggregate in Portland cement concrete may be particularly appropriate in locations where there is a lack of natural aggregates satisfactory for use in quality concrete. However, in Canada, the use of processed RCM has been mainly in granular subbase in urban areas where supply and transportation costs favour such use (JEGEL, 1992).

#### 3.2.3 Rubblization

Rubblization is an in-place rehabilitation technique that involves breaking the concrete pavement into pieces having a nominal maximum size of about 75 mm or less above and 200 mm or less below any reinforcement (AI, 2000). This process results in a structurally sound, rut resistant base layer which prevents reflective cracking (by obliterating the existing concrete pavement distresses and joints) that can then be overlaid with asphalt or Portland cement concrete. Proper drainage is critical to the success of a rubblization project. In areas of weak subgrade or high water table, the drainage system should be functioning as far in advance of the rubblizing as possible to allow the subgrade to be as stable as possible (Wolters, 2003).



**Photo 3-10:** A resonant breaker in operation in Oxford County, Ontario

There were three resonant breakers employed on this project traveling in echelon rubblizing 450 mm of concrete pavement per pass.

The two most common types of rubblization equipment are resonant breakers and multiple head breakers. Resonant breakers, shown in **Photo 3–10**, produce low amplitude, high frequency blows by vibrating a large steel beam connected to a foot that can vary in width from 150 to 300 mm. The foot is moved along the concrete pavement surface in multiple passes to rubblize the full width of the pavement.

Multiple head breakers employ a number of large drop hammers (550 to 675 kg) in two rows with half of the hammers in a forward row and the remainder diagonally offset in the rear row. Each pair of hammers is attached to a hydraulic lift typically capable of cycling between 30 to 35 impacts per minute and generating between 2,000 and 12,000 foot pounds of energy depending on the drop height selected. Multiple head breakers can rubblize up to 3.95 m wide at 1.6 lane km per shift.

During the rubblization process, the concrete pavement is fractured into small pieces (generally 50 to 150 mm). The effectiveness of the rubblizing equipment in producing the desired particle sizes is also a function of the condition of the underlying base/subgrade, with smaller sizes more readily achieved over a firm stable base/subgrade (Wolters, 2003).

Prior to placement of the asphalt or concrete overlay, the rubblized concrete must be rolled with at least three passes of a high-frequency vibratory roller fitted with Z-pattern bars on the roller face (AI, 2000; Wolters, 2003). This further pulverizes the surface of the rubblized layer.

The thickness of the asphalt or concrete overlay over the rubblized base material must be properly designed to meet pavement structural requirements.

Rubblization is a cost effective, technically proven method for 100 percent recycling/reuse of an existing concrete pavement.

### 3.3 Winter Sand Recycling

Winter sand is the material swept from roadways in the spring following winter maintenance sanding (typically salt-sand blends) and de-icing operations and routine

maintenance operations to control dust and to minimize sediment loading to natural watercourses. On rural roads and pavements with granular shoulders, the material is typically swept to the shoulder. However, in urban sections and highways/freeways with medians and paved shoulders, winter sand is collected (power swept and vacuumed) and removed. Some winter sand and other debris is also washed from the pavement surface and accumulates in catchbasins and outlet pipes and in roadside ditches, in both the urban and rural settings. Periodic cleaning of catchbasins and ditches results in additional materials (catchbasin clean-out material and ditch clean-out material) that may also be potentially considered for reuse or recycling (MTO, 1995).

New winter sand applied to the road surface for traction control during road surface winter maintenance tends to be relatively high quality, durable aggregates (sand or crushed bedrock), with physical properties covered by specifications such as OPSS 1004 in Ontario. The physical requirements (resistance to abrasion and attrition) for new winter sand are similar to those specified for hot-mix fine aggregate and concrete sand, and are in short supply and hence costly in many areas of Canada. The maximum particle size is limited to about 9.5 mm (to prevent windshield damage due to cast off) and the fines content is also limited to prevent caking and for ease of distribution, as well as to reduce the amount of dust and mud during the spring.

The winter sand sweepings generally consist of relatively dry sand and grit, litter and organic matter, along with other waste materials such as glass, metal and plastic. Testing of collected street sweepings generally indicates that the recovered winter sand, after removal of debris and larger particles, satisfies the physical requirements for new winter sand. When collected in the spring by street sweepers, this winter sand has degraded somewhat, containing more fines than new winter sand. Winter sand may also contain contaminants such as excessive heavy metals (lead and cadmium), petroleum hydrocarbons (oil and grease), and chlorides

## 3. Work Description

3.2 Concrete Reuse and Recycling Techniques

3.3 Winter Sand Recycling

*The physical requirements (resistance to abrasion and attrition) for new winter sand are similar to those specified for hot-mix fine aggregate and concrete sand, and are in short supply and hence costly in many areas of Canada.*

### 3. Work Description

#### 3.3 Winter Sand Recycling

#### 3.4 Trenching Materials Reuse

*The municipalities that responded to the Best Practice survey indicated that, for the most part, winter sand, along with catchbasin and ditch clean-out materials, was sent for disposal at municipal landfills where it was used as landfill cover material.*

(from deicing salts), requiring disposal in accordance with environmental regulations (MTO, 1995; Land Technologies, 1997).

The municipalities that responded to the Best Practice survey indicated that, for the most part, winter sand, along with catchbasin and ditch clean-out materials, was sent for disposal at municipal landfills where it was used as landfill cover material. Some agencies have tried mixing the winter sand, after screening off the collected debris, with new winter sand to reduce the amount of new sand required. However, due to the higher fines content and moisture content of the recovered winter sand, some caking and dust/mud problems were reported.

Recognizing the large quantity of winter sand applied to Canadian roads each year, and the amount of winter sand subsequently recovered each spring, winter sand clearly represents a significant resource utilization and waste disposal problem. It is therefore desirable to develop a method to economically process these materials to remove litter/debris, organic materials and contaminants, and separate the mineral constituents into size fractions that permit reuse as winter sand or recycling in other end-products.

The City of Edmonton has undertaken an ambitious pilot program to process and recycle its winter sand. The City has collected approximately 70,000 tonnes of winter sand and has developed a processing system to remove litter and contaminants, and classify the recovered materials for reuse as winter sand during Winter 2004/05, and for other markets (fine sand as bedding sand for concrete pavers for instance). Early results indicate that the City of Edmonton will be able to reduce its requirements for new winter sand by about 60 percent at substantial cost-savings. Specific details on this two-year pilot study, which commenced in 2004, are provided in a separate Case Study.

### 3.4 Trenching Materials Reuse

#### 3.4.1 Trenching Materials

A variety of earth, rock and similar materials are routinely encountered when excavating for service trenches. These materials may include components of the roadway pavement structure (asphalt concrete, concrete, granular base and/or subbase) in which the service trench is being cut, the underlying soils (either natural undisturbed materials or possibly old fill materials), pipe bedding and cover materials (in trenches excavated for repair or replacement of existing services), and possibly the buried utility material (pipe, cable, plant, etc.) itself.

In older cities across Canada, there are large areas of the city constructed on reclaimed lands that may include old wastes/byproducts that do not meet current environmental legislation/protocols.

Depending on the location within the roadway and the site history, these excavated materials may contain some low-level chemical or biological contamination from spills (fuel near accident scenes), deicing salts (chloride contamination), or leakage of product (sewage for instance) from the utility itself.

When assessing the suitability of these excavated materials for potential reuse/recycling, it is necessary to consider both the physical properties of the materials and their environmental condition. Materials excavated during service trench construction may be considered for reuse as trench backfill provided that they have suitable physical and environmental properties and are properly managed during construction.

The most significant factor in assessing the suitability of trenching materials for reuse is the ability for the material to be placed as engineered backfill, with the trench materials evaluation and service trench construction work properly undertaken to ensure that there are no long-term impacts on the roadway due to settlements, swelling or frost action. The need for proper construction practices and continuous construction supervision and

quality control/quality assurance (QC/QA) inspection and testing throughout trench backfill placement and compaction cannot be over-emphasized.

### 3.4.2 Physical Properties

Any asphalt surfacing or concrete pavement removed from service trenches or cuts in existing roads should be collected and transported to a central location for processing and recycling in the most appropriate highest-best use, as previously described (asphalt used in recycled hot mix, concrete processed (crushed and screened) as recycled aggregate).

To be practically considered for reuse as trench backfill, the material excavated from service trenches and utility cuts within the public right-of-way, including any pavement granular base and subbase materials and underlying earth (sand, silt and/or clay soils) must be free of any obviously objectionable or deleterious materials such as topsoil or organics (peat, wood, etc.), large pieces of rock or boulders, etc. The excavated material must also be compactible, having its moisture content within  $\pm 2$  percent of its optimum Proctor moisture content as determined in a Standard Proctor Maximum Dry Density Test. If the excavated material is to be stockpiled for any significant period of time (particularly during periods of inclement weather), care must be taken to protect the stockpiled material—it cannot be permitted to become excessively wet due to precipitation (or conversely, too dry due to exposure to sun and wind), and must not be used as backfill if frozen. If excessively wet at the time of excavation, the material must spread and permitted to dry to within  $\pm 2$  percent of optimum.

The trench material must be capable of being placed and compacted to a uniform consistently dense state so that the service trench and adjacent pavement does not settle. This typically requires that the backfill material be placed in uniform lifts not exceeding 200 mm loose thickness, and compacted using appropriate compaction equipment (for example, smooth drum vibratory or plate

compactors for granular materials; vibratory pad or sheepsfoot compactors for cohesive soils). QC/QA to ensure specifications compliance during backfilling should consist of compaction checks using a nuclear density gauge or other accepted method. Local climate (seasonal) and geotechnical conditions and the properties of the soil (swelling potential, frost susceptibility, etc.) should also be considered. Where frost action is a factor due to a combination of freezing conditions, presence of moisture and frost susceptible soils, frost susceptible materials such as sandy silts and silts should not be used without special considerations such as limiting the use of the material to below the depth of frost penetration, or other measures such as provision of frost tapers (MacKay, 1992).

Where it is not practical to properly place and compact the excavated materials in small emergency repairs/reinstatements, or where potential damage to the adjacent pavement may occur due to undermining or lack of temporary excavation support, consideration should be given to using unshrinkable fill in lieu of the excavated material. For additional information on the proper methods for construction and reinstatement of utility boxes in pavements, please refer to *InfraGuide Best Practice: Construction of Utility Boxes in Pavements and Restoration* (InfraGuide, 2003b) and *Repair of Utility Boxes in Pavements* (InfraGuide, 2003b).

### 3.4.3 Environmental Properties

Materials excavated from service trenches and utility cuts within the public right-of-way may contain levels of contamination exceeding applicable provincial or federal environmental regulations, codes or guidelines, or local agency environmental requirements that preclude such reuse. This may include the presence of petroleum hydrocarbons (gasoline or diesel fuel spills from accidents or leaks), chlorides/sodium absorption ratio (SAR) exceedances due to deicing salt use, or leakage/spills from existing utilities (oil pipelines or sewer systems).

## 3. Work Description

### 3.4 Trenching Materials Reuse

*The need for proper construction practices and continuous construction supervision and quality control/quality assurance (QC/QA) inspection and testing throughout trench backfill placement and compaction cannot be over-emphasized.*

### 3. Work Description

#### 3.4 Trenching Materials Reuse

Potential contamination may be indicated by the appearance (discoloration or staining) of the sub-excavated granular base/subbase materials and soils, olfactory evidence (such as strong or noxious odours), the presence of waste or byproduct materials (for example, in reclaimed land areas where dredgings, cinders, ash, slags, etc. may have been used as fill) and from historical records (spills reporting or leakage records from previous excavations/cuts in the area). Where such potential contamination is suspected, sampling and environmental analyses should be carried

out and the material handled in conformance with the applicable federal or provincial/territorial regulations. Where contamination is confirmed by such testing, it may be necessary for the municipality or its representative(s) to report such contamination in accordance with the applicable environmental regulations. For reference purposes, a listing of the provincial environmental regulations is provided in the Appendix, with links for on-line access to the regulations/agencies, where available.



## 4. Applications and Limitations

### 4.1 Reuse and Recycling in Road Construction and Maintenance Activities

Successful reuse and recycling of road construction and maintenance materials involves consideration of several interacting elements: the recovered materials must have suitable engineering properties for the intended reuse/recycling; there must be sufficient quantities of material(s) available to economically justify their reuse and recycling; and the recovered materials must not have any potentially harmful environmental impacts with the reuse or recycling activity.

It is also important to appreciate and adopt the concept of 'highest-best use' in selecting the technically most appropriate, and environmentally most sustainable, reuse and recycling options for road construction and maintenance materials. This concept is based on the premise that the best use of a material is in that which the material has the highest value. For instance, the best use for reclaimed asphalt pavement (RAP) is in applications where the full value of both the asphalt binder and the aggregates is realized. Recycling of RAP in asphalt mixtures can result in significant reductions in both the amounts of new asphalt binder and new aggregate required for pavement construction, and reduced energy consumption. However, while the use of RAP as granular base or subbase does reduce the amount of new granular material required, the value of the RAP asphalt cement as a binder and the energy invested to produce it is lost. Similarly, recovered concrete aggregates should, wherever possible, be reused as construction aggregates, thereby decreasing the demand for new aggregates, rather than used as bulk fill.

### 4.2 Engineering Materials Considerations

In order to be practically considered for reuse or recycling, the recovered materials must

have, or be properly processed to have, suitable engineering properties for the intended application. Generally, recovered materials with the highest potential for general use as construction aggregates will have adequate (equivalent to natural aggregates) soundness, hardness, gradation and particle shape, resistance to chemical and physical deterioration, and require a minimum of processing such as crushing, blending and screening. It is also important to identify any potentially deleterious components in the recovered material so that their impact can be properly assessed and addressed for the reuse/recycling application being considered. For instance, the presence of volumetrically unstable steel slag aggregates in old asphalt pavement should be evaluated before using such RAP in recycled hot mix.

Most provincial agencies have standard specifications that define the specific engineering, physical and chemical (if any) requirements for any recycled materials or the products in which they are used. For instance, the materials specifications for hot-mix asphalt generally include provisions for recycled hot mix. Standard test methods (CSA, ASTM and AASHTO, for instance, as well as agency specific test methods such as MTO Laboratory Series (LS) for example) are used in conjunction with the material and construction specifications to assess the physical properties and overall quality of construction aggregates.

### 4.3 Environmental Considerations

The environmental properties of the recovered materials must be evaluated through proper sampling and testing in accordance with applicable environmental legislation, codes/regulations and/or protocols/guidelines, to ensure that there are no potentially harmful constituents present (no leaching of toxic constituents, dust/particulate or air emissions concerns, etc.) during use in construction or

## 4. Applications and Limitations

- 4.1 Reuse and Recycling in Road Construction and Maintenance Activities
- 4.2 Engineering Materials Considerations
- 4.3 Environmental Considerations

*It is also important to appreciate and adopt the concept of 'highest-best use' in selecting the technically most appropriate, and environmentally most sustainable, reuse and recycling options for road construction and maintenance materials.*

#### 4. Applications and Limitations

- 4.3 Environmental Considerations
- 4.4 Economic Considerations
- 4.5 Limiting Factors for Increased Reuse and Recycling

*It should also be recognized that the environmental regulations and health and safety practices vary somewhat across Canada, and it is important that the local requirements be applied.*

following incorporation of the material in the construction application. It is not uncommon for materials from within the public right-of-way to be contaminated due to accidental spills (mainly gasoline or diesel fuel near accident locations), leakage of buried utilities or from adjacent sites, or vehicle exhaust emissions (particularly in areas where leaded fuels may have been used).

It should also be recognized that the environmental regulations and health and safety practices vary somewhat across Canada, and it is important that the local requirements be applied. For instance, the City of Toronto limits the amount of asbestos fibre (crysotile) in an existing asphalt mixture to less than 2 percent by mass of asphalt cement for the asphalt concrete to be considered for recycling.

#### 4.4 Economic Considerations

The overall economic feasibility of reusing or recycling of materials recovered during road construction and maintenance is a function of the location, quantity and market for the recycled product, the technical requirements for the particular application(s), the resource replacement value of the components of the material in bulk and/or cementitious applications, and ecological and social considerations such as resource conservation and sustainable development. For instance, while it is certainly desirable from a resource conservation and sustainable development (highest-best use) viewpoint to recycle all old asphalt back into recycled asphalt mixtures for roadway pavements, and there are a wide range of options and few technical impediments to preclude such recycling, it may not be economically practical where the amount of RAP available is low or suitable asphalt plant and equipment does not exist. In such cases, the most viable option may be to reuse the RAP as aggregate in granular base or subbase, or disposal at a municipal landfill. However, when comparing the overall 'cost' of recycling, it is also important to consider not only the total life cycle costs but also the initial

cost savings, if any, attributed to the use of recycled product in lieu of new material, but also the cost of disposal (tipping fee for instance) if the recovered material cannot be practically reused or recycled.

#### 4.5 Limiting Factors for Increased Reuse and Recycling

While reuse and recycling of old asphalt and old concrete is well-established, equipment and process improvements and the introduction of improved supplementary materials (recycling/softening agents, polymer-modified asphalts, etc.) have and continue to result in a steady evolution of the recycling techniques and their application. Further, with the continuing consumption of non-renewable aggregate resources and higher materials and production costs (asphalt cement for instance), there will be increased interest/pressure to reuse and recycle. The major impediments to enhanced reuse and recycling continue to be the same as were identified in 1992 (JEGEL, 1992 and Melton, 2004):

- agency resistance to adopting new materials and construction technology (conservatism);
- obsolete specifications;
- inadequate research and development budgets;
- liability/performance concerns over innovative technologies;
- environmental constraints on recyclable materials that are not applied to conventional materials;
- industry processing and pricing that are based on new materials;
- widely scattered distribution or small quantities of potentially recyclable materials;
- collection, storage and processing costs; and
- lack of technical guidance.

# 5. Evaluation

## 5.1 Evaluation Methodologies

Selection of appropriate reuse and recycling options for materials encountered within the public right-of-way during road construction and maintenance work requires careful consideration of the engineering, environmental and economic parameters discussed in Section 4, **Applications and Limitations**. The importance of proper pavement and materials evaluations in establishing the most technically-appropriate, cost effective reuse and recycling options cannot be over-emphasized. An evaluation methodology to assess reuse and recycling options for existing asphalt and concrete pavements is described. In addition, a simple flowchart to evaluate trenching materials for potential reuse as backfill material in service trenches and utility cuts is also presented.

## 5.2 Pavement and Materials Evaluations

The overall selection and design of the most appropriate reuse and recycling approach to be applied during pavement rehabilitation should be based on a systematic evaluation of the pavement section to be rehabilitated and the potential excess materials within the section. The design approach consists of the following steps:

1. Evaluate the pavement section for suitability for the candidate processes, including pavement distress types and conditions; appurtenances such as utility access boxes, catchbasins; overhead and in-pavement services (wires, signal loops); structure load limits; special features; etc.
2. Check the overall pavement surface and sub-surface drainage function, and improve or install as necessary
3. Conduct a structural evaluation to confirm structural adequacy and need, if any, and amount of pavement strengthening required

- Geotechnical investigation, including boreholes/probeholes to confirm pavement structure and subgrade conditions
- Coring, to obtain representative samples of the asphalt and/or concrete materials for laboratory testing and mix designs
- Structural capacity testing—falling weight deflectometer (recommended), dynamic cone penetrometer, Dynaflect, Benkleman beam, etc., to determine if any strengthening is required

### 4. Determine the properties of the RAP, RCM, existing asphalt pavement or existing Portland cement concrete pavement

For RHM and HIR:

- Asphalt cement content
- Gradation
- Recovered penetration and/or viscosity

For CIR and FDR:

- Pavement thickness
- Asphalt cement content
- Gradation
- Moisture content

For Rubblization:

- Pavement thickness
- Types of reinforcement

Review the pavement conditions and recycling options to select the most cost-effective approach for the site conditions and structural requirements (use of AASHTO 93 pavement design method (AASHTO, 1993) or the new (draft) Mechanistic-Empirical Pavement Design Guide (available on-line at [www.trb.org/mepdg](http://www.trb.org/mepdg)) recommended for asphalt concrete pavement and Portland cement concrete pavement structural design, and PCA pavement design method for concrete pavement structural design).

## 5. Evaluation

- 5.1 Evaluation Methodologies
- 5.2 Pavement and Materials Evaluations

*The importance of proper pavement and materials evaluations in establishing the most technically-appropriate, cost effective reuse and recycling options cannot be over-emphasized.*

## 5. Evaluation

### 5.3 Trenching Materials Evaluation

**Figure 5-1**  
Methodology for Evaluating  
Trenching Materials

## 5.3 Trenching Materials Evaluation

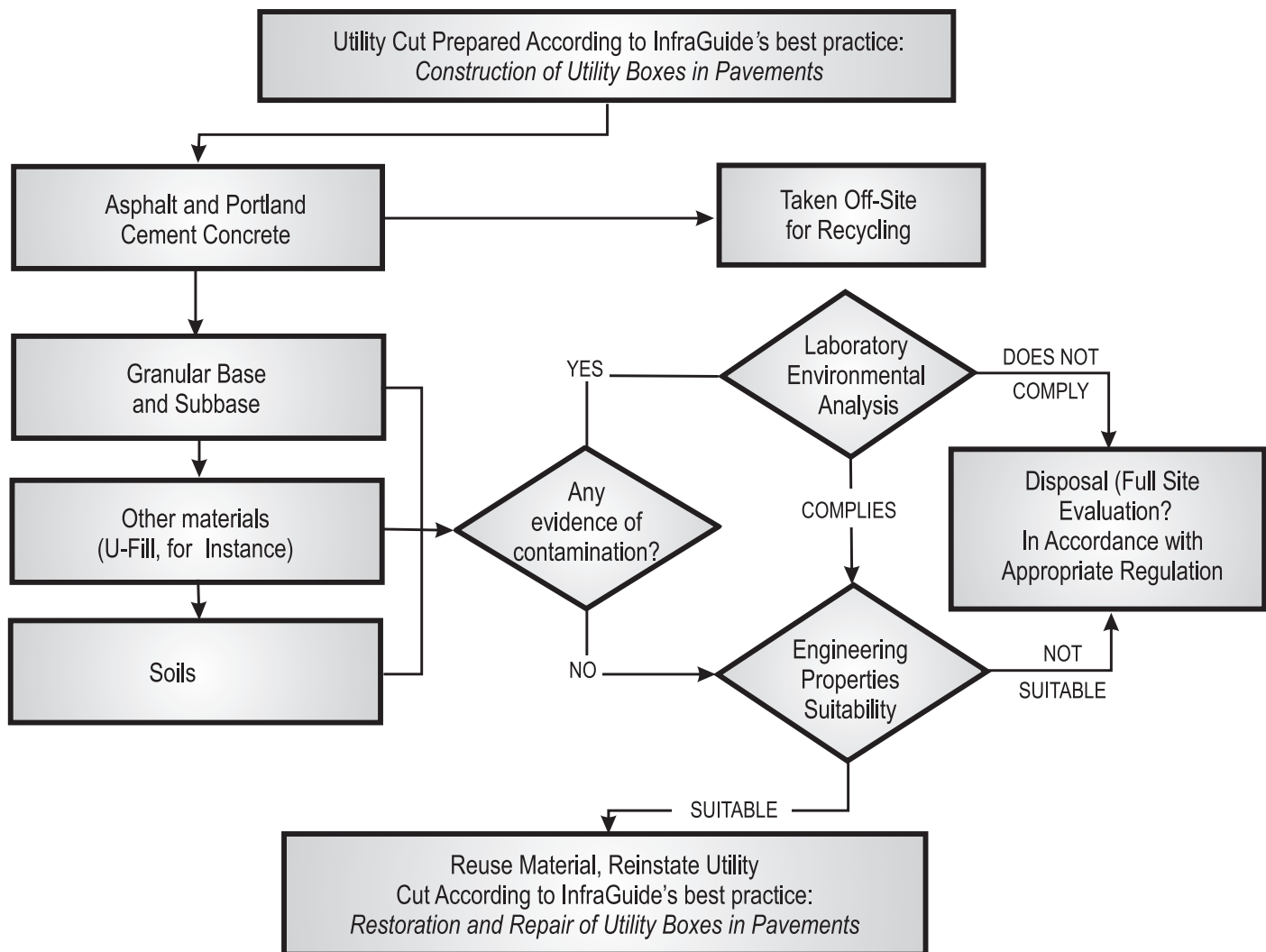
**Figure 5-1** gives a step-by-step methodology for evaluating trenching materials from the public right-of-way for potential reuse and recycling.

Where the excavated material has satisfactory physical properties and is environmentally acceptable (complies with provincial or federal environmental legislation, guidelines and/or protocols), such material could be considered for reuse as trench backfill providing that it can be properly placed and compacted without having any adverse effects

on the roadway pavement adjacent to the trench/cut. However, factors such as the moisture content of the material, or presence of obviously objectionable and deleterious materials such as organics may preclude reuse/recycling of the material as trench backfill, requiring backfilling to be carried out using imported material or unshrinkable fill.

If environmental analysis results indicate exceedances of applicable environmental regulations, the material must be handled in accordance with the local environmental requirements.

**Figure 5-1:** Methodology for Evaluating Trenching Materials



## 6. Areas for Future Research

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Although reuse and recycling of excess materials such as old asphalt and old concrete is well established in many respects, the enhanced reuse and recycling of road construction and maintenance materials within the public right-of-way requires a coordinated, continuing research and development effort, both in Canada and internationally. Significant potential research and development areas include:

- Development of guide end-result (end-product) specifications for various recycling techniques that can be used by municipal agencies across Canada;
- Development of laboratory testing data for various recycled materials/processes, including resilient modulus, rutting resistance, fatigue resistance, smoothness, etc., that can be used in both empirical and mechanistic pavement designs (such as the current draft AASHTO 2002 Mechanistic-Empirical Design Guide) and pavement life cycle costing;
- Collection and synthesis of pavement performance information for roads rehabilitated using HIR, CIR, and FDR techniques, that can be used for long-term performance prediction and life-cycle costing of alternative pavement rehabilitation treatments;

- Impacts, if any, on recycling of new pavements designed using Superpave mix design methods and incorporating performance graded asphalt cement, including polymer-modified and engineered asphalts;
- Re-“recycling” factors, if any, affecting recycling of pavements that were previously recycled using the same process (for instance, use of HIR on a road that has been previously rehabilitated using HIR) or another recycling technique; and
- Impacts of new environmental standards (such as more restrictive air emissions criteria) on reuse and recycling initiatives.

The trial FDR with cement slurry research project being conducted at Laval University should continue to be monitored for performance and costs. Once the benefits of this process are confirmed by the demonstration project through additional trials, this process could then be considered as a reuse option for flexible pavements.

There are undoubtedly other areas of research and development that will become apparent as reuse and recycling increases across Canada, and with the continuing innovation and evolution in construction materials, equipment and processes.

### 6. Areas for Future Research

*The enhanced reuse and recycling of road construction and maintenance materials within the public right-of-way requires a coordinated, continuing research and development effort, both in Canada and internationally.*



# Appendix A: Case Studies

## A.1 Case Study—Rubblization with Cold Central Plant and Cold In-Place Recycling

In 1999, Oxford County in Ontario initiated a \$1.5 million rehabilitation of a 9 km long section of County Road 2 near Woodstock. This section of County Road 2 was initially constructed in the late 1950s and consisted of 6.1 m wide, 225 mm thick, mesh-reinforced Portland cement concrete pavement placed directly on the subgrade. A 75 mm HMA overlay was applied in the late 1970s. Subsequently, other than routine maintenance, County Road 2 did not receive any other major rehabilitation and was in very poor condition, with significant reflective cracking and indications of slab movement (some slabs could be seen moving under regular traffic action with the naked eye with some joints having stepped/faulted at a number of locations).

A number of reconstruction solutions were considered including: surface overlay; full depth rehabilitation using CIR of the HMA surface course; selective joint repair; and pulverization. Due to past history with reflective cracking and the instability of the PCC slabs rubblization along with cold in-place recycling (actually a hybrid of cold in-place recycling and cold central plant recycling) was chosen as the ultimate solution.

After milling the HMA surface and stockpiling the RAP at a nearby sand and gravel pit, the rubblization was carried out as shown in the sequence of photos in **photo A-1**, below.

Following rubblization, 120 mm of cold recycled asphalt was placed in two lifts. The first 70 mm lift of cold recycled asphalt was produced using cold central plant recycling techniques. The cold recycled asphalt consisted of 80 percent RAP, which had been



a) Pulverization of PCC using three IRB resonant breakers working in echelon.



b) Surface appearance of the rubblized PCC before compaction.



c) Low amplitude compaction of the rubblized PCC using a steel drum roller.



d) Appearance of rubblized and compacted Oxford County Road 2.

**Photo A-1:** Examples of rubblization: before compaction, a) and b) and after compaction c) and d)

## A. Case Studies

- A.1 Case Study—  
Rubblization with  
Cold Central Plant  
and Cold In-  
Place Recycling

### Photo A-1

Examples of rubblization, before compaction and after.

## A. Case Studies

A.1 Case Study—  
Rubblization with  
Cold Central Plant  
and Cold In-  
Place Recycling

**Photo A-2**  
Cold recycled asphalt  
application

**Photo A-3**  
View of Completed Oxford  
County Road 2 Project



a) Loading of stockpiled cold recycled asphalt into dump truck for paving



b) Paving of first 70 mm lift of cold recycled asphalt

### **Photo A-2:** Cold recycled asphalt application

stockpiled crushed and classified at a nearby sand and gravel pit, 20 percent Granular A, with 3 percent of total mass of aggregates water and 2.5 percent of CMS 2S emulsion (this special emulsion allowed the cold recycled asphalt to be stockpiled for at least 24 hours, ensuring a constant supply for the project). During cold recycled asphalt production, the crushed RAP and virgin aggregate were fed into the two calibrated bins of a Midland pug mill where the emulsion, water, aggregate and RAP was mixed in the twin shaft 9x4 pug mill at an average rate of 350 tonnes/h (Reference: Aggregates and Roadbuilding, 2001). The stockpiled cold recycled asphalt was then loaded into dump trucks for delivery to site and laid using a Midland paver as seen in the photograph set seen in **Photo A-2**.

The second 50 mm lift of cold recycled asphalt was produced using conventional cold in-place recycling equipment. The stockpiled RAP was distributed on top of the first lift then recycled in-place. The cold in-place recycled asphalt consisted of 80 percent RAP, 20 percent Granular A, 3 percent of total mass of aggregates water and 2.0 percent of CSS 1 emulsion and was laid using a Midland paver.

The recycled asphalt was compacted and allowed to cure to its target moisture and compaction levels for approximately two weeks before a scratch coat of HL 8 hot-mix asphalt binder course was placed on top of the recycled asphalt to correct cold mix wheelpath densification. A 50 mm lift of HL 4 hot-mix asphalt wearing course was applied to complete the rehabilitation.



**Photo A-3:** View of Completed Oxford County Road 2 Project



## A.2 Case Study—Full Depth Reclamation (FDR) with Foamed Asphalt Stabilization

The Wellington County County Road 50 full depth reclamation with foamed asphalt stabilization project was initiated in 1997 to rehabilitate this low traffic volume road that was no longer in a serviceable condition. This 6.3 km long section was heavily patched, delaminated, and exhibited severe block cracking, longitudinal cracking, transverse cracking and edge cracking. A pavement evaluation indicated that the pavement was somewhat deficient from a structural viewpoint, requiring some strengthening.

Representative samples of the asphalt pavement and underlying granular based material were taken from the site and a mix design was completed. The roadway and pavement conditions were considered to be

suitable for FDR with foamed asphalt stabilization, consisting of pre-pulverizing the asphalt surfacing, addition and mixing with new granular, and stabilization using foamed asphalt. After FDR/foamed asphalt stabilization, a double layer surface treatment was applied as the wearing surface. The FDR mix design consisted of:

### County Road 50 Mix Design

Foamed asphalt .....	3.2 %
Total asphalt cement content .....	4.98 %
Existing asphalt concrete (RAP) .....	64.9 %
Granular material added .....	31.9 %
Air voids .....	10.7 %
Stability .....	28130 N
TSR.....	Pass

After initially pulverizing the road surface, the FDR stabilization was carried out as shown in the following photos.



a) Placing additional granular material on top of pre-pulverized old pavement.



b) 150 mm of foamed asphalt stabilization asphalt cement at 150°C plus 2% water.



c) Shaping the stabilized material and adding water to optimum moisture condition for compaction.



d) Initial compaction with heavy rubber tired roller followed by vibratory steel roller.

**Photo A-4:** FDR stabilization and compaction. (Photo source, JEGEL)

## A. Case Studies

A.2 Case Study—  
Full Depth  
Reclamation (FDR)  
with Foamed  
Asphalt Stabilization

### Photo A-4

FDR stabilization and compaction.

### Photo A-5

A core of the finished product and the foamed asphalt process.

## A. Case Studies

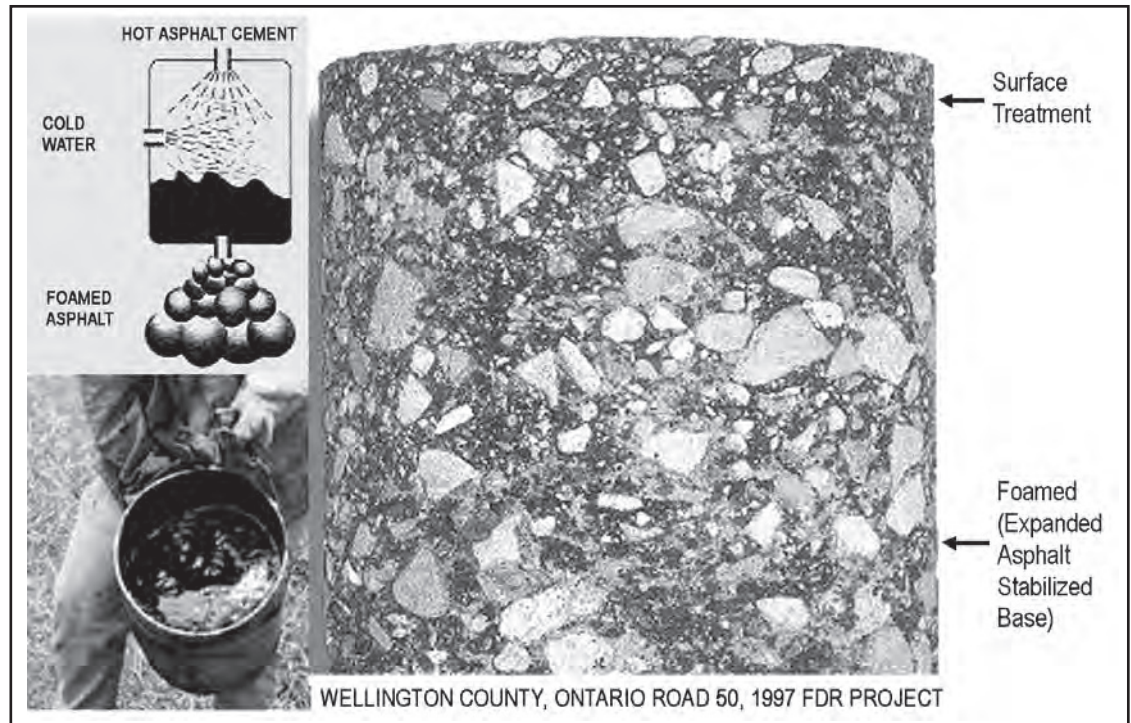
A.2 Full Dept  
Reclamation (FDR)  
with Foamed  
Asphalt Stabilization

### Photo A-5

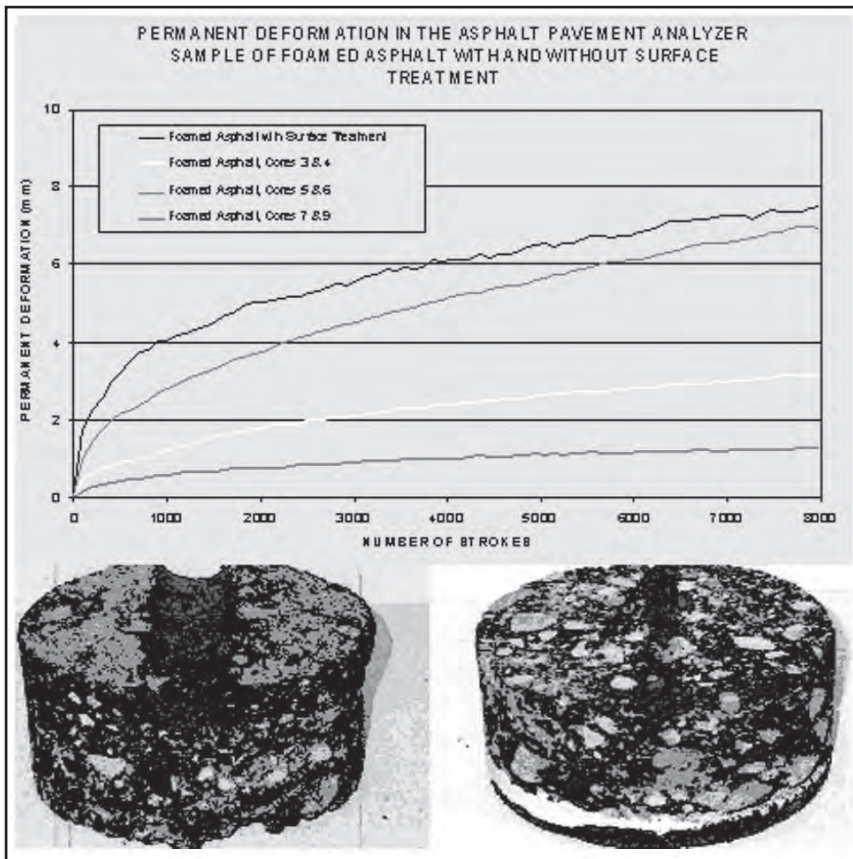
A core of the finished product and the foamed asphalt process

### Photo A-6

Asphalt Pavement Analyzer  
Testing chart and samples



**Photo A-5:** A core of the finished product and the foamed asphalt process.



**Photo A-6:** Asphalt Pavement Analyzer Testing chart and samples

Quality control testing for this project consisted of continuous monitoring of the expansion characteristics of the asphalt cement (expansion ratio and half-life) and the quality of the foamed asphalt mix (asphalt cement distribution, density and mat thickness) during the project. **Photo A-5** shows a core of the finished product.

The performance of the Wellington County Road 50 FDR/foamed asphalt project has been excellent. The Pavement Condition Index (PCI), load deflection (FWD), profile, and frictional characteristics were monitored until 2001. The pavement condition was very good to excellent; some localized low severity flushing of the surface treatment and intermittent medium severity cracking was observed in low, wet areas. Asphalt Pavement Analyzer testing of the combined lift of foamed asphalt and surface treatment (left), see **photo A-6** with figure below, exhibited medium severity rutting, but testing of the foamed asphalt stabilized material, without the surface treatment, showed little to no rutting, indicating that the rutting was largely occurring in the surface treatment, not in the FDR/foamed asphalt material.



**Photo A-7:** Sand recycling site and equipment

**A.3 Case Study—City of Edmonton Winter Sand Recycling Pilot Project**

Over the past 25 years, the City of Edmonton has operated a major aggregate recycling program (the collection, crushing, screening and re-use of concrete and asphalt material). In 2003, the City of Edmonton, in partnership with the Edmonton Waste Management Centre of Excellence, used its significant knowledge in processing recycled materials (materials handling, transportation, dust suppression, processing methods, equipment), in development of a two-year pilot project to determine the feasibility of winter sand recycling.

The City of Edmonton places approximately 140,000 to 180,000 tonnes of winter sand annually during winter maintenance operations. Of this, approximately two-thirds or 90,000 to 120,000 tonnes of winter sand can be recovered by street sweepers during spring maintenance. A review of the gradation data collected on the City of Edmonton street sweepings over the past 20 years indicated that 80 percent of the sweepings collected annually, based on physical characteristics, was potentially recyclable.

Historically, only about 25 percent of the recovered winter sand had been reused, generally by blending the recycled winter sand with new material. Some of the remaining 75 percent of recovered winter sand was used as leveling or landfill cover but the majority was disposed of at a Class III Landfill.

New stricter Alberta Environment guidelines have resulted in City of Edmonton street sweepings being classified as exceeding electrical conductivity (EC) and sodium absorption ratio (SAR) of the Salt Contamination Assessment and Remediation Guidelines (AENV 2001). The sweepings, therefore, are no longer suitable for land application. Also, the street sweepings are not acceptable for disposal in Class III landfill due to the high salinity and presence of hydrocarbons and disposal in Class II landfill is discouraged due to limited landfill space and high tipping fees that are more than seven times those of Class III landfill disposal sites.

Increasing cost of disposal and concerns regarding the limited reserves and escalating



**Photo A-8:** Stockpile of preprocessed City of Edmonton street sweepings

**A. Case Studies**

A.3 Case Study—City of Edmonton Winter Sand Recycling Pilot Project

**Photo A-7**

Sand recycling site and equipment

**Photo A-8**

Stockpile of preprocessed City of Edmonton street sweepings

*In 2003, the City of Edmonton, in partnership with the Edmonton Waste Management Centre of Excellence, used its significant knowledge in processing recycled materials (materials handling, transportation, dust suppression, processing methods, equipment), in development of a two-year pilot project to determine the feasibility of winter sand recycling.*

## A. Case Studies

### A.3 Case Study—City of Edmonton Winter Sand Recycling Pilot Project

**Figure A-1**

Flowchart showing the preliminary system for the sand recycling pilot project for the City of Edmonton.

costs of quality natural winter sand have required the City of Edmonton to re-evaluate their winter sand recycling and disposal process. Disposal of street sweepings in a Class II landfill would cost an estimated \$2.0 million dollars a year. The City estimates that, once properly established, the re-use of winter sand could save the City nearly \$1.5 million dollars a year along with significantly extending the life of natural winter sand reserves, reducing greenhouse gas emissions and damage to their roadway infrastructure by reducing trucking distances (currently 180 km round trip). There has been roughly \$1 million dollars of capital investment in the recycling project.

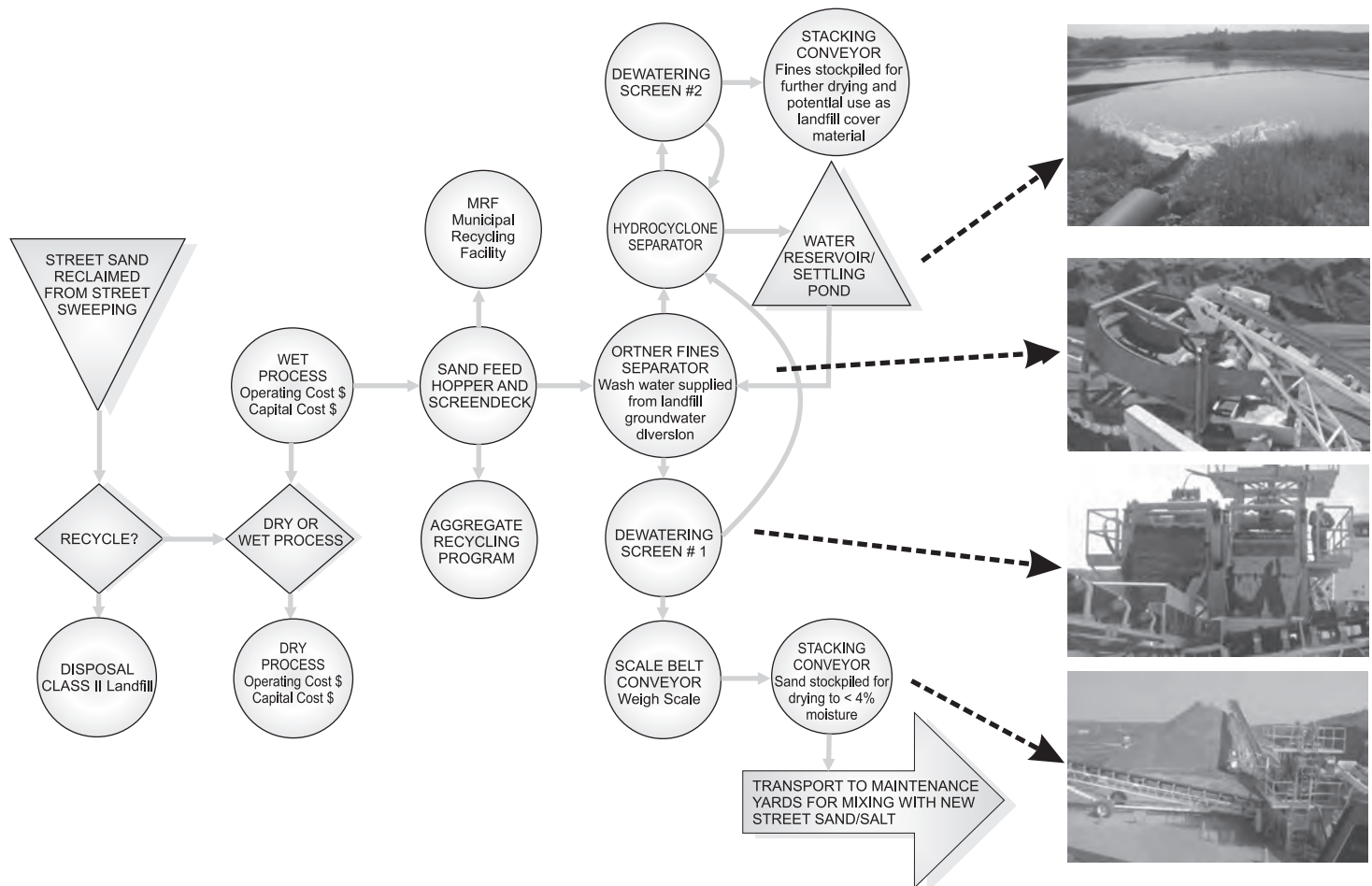
The City of Edmonton preliminary Sand Pilot Project recycling system is described in **Figure A-1**, below.

The results of the first year of processing in the pilot study have been very promising.

Average sand recovery from the street sweepings has been 80 percent, clean fine sand 10 percent, contaminated fine sludge 4.5 percent, litter 4 percent and oversize gravel 1.5 percent. Chemical analysis of the fine sludge from the settling pond indicates that most of the contaminants (salt, hydrocarbons, heavy metals etc.) are ending up in the fine sludge suitable for disposal in Class 2 landfill. Physical test results of the recovered sand do not indicate any difference between the recycled and virgin winter sand. The pilot study has also been experimenting with the reuse of the clean fine sand for mudjacking and in fillcrete which could potentially, if successful, provide another stream of revenue to help offset recycling costs.

For more detailed information on the City of Edmonton winter sand recycling project please contact John Mundy at [John.Mundy@edmonton.ca](mailto:John.Mundy@edmonton.ca).

**Figure A-1:** Flowchart showing the preliminary system for the sand recycling pilot project for the City of Edmonton.





**Photo A-9:** Hot in-place recycling and equipment used, past and present

#### A.4 Case Study—Hot In-Place Recycling

In June 2002, a three year review of an Ontario Ministry of Transportation demonstration project evaluating and comparing the performance of different surface recycling/rehabilitation techniques was completed. The surface recycling/ rehabilitation techniques evaluated in the demonstration project included: Second Generation HIR; Mill and Overlay with new Dense Friction Course (DFC); Third Generation HIR; Mill and Overlay with DFC incorporating Recycled Hot Mix (RHM DFC); and Microsurfacing. One of the main objectives of the MTO study was to determine the effectiveness of new third generation (Martec AR2000) combined forced hot-air/radiant low-level heat HIR equipment. The test section for the Martec Hot In-Place Recycling process (**Photo A-10**) was 2.8 km of the driving and centre lanes of Highway 401 between Woodstock and London. The third generation HIR section had been recycled in the fall of 1999. All construction work was completed at night to minimize traffic disruption. The HIR recycling train recycled the full lane width (3.75 m) to 45 mm depth, at an average production rate of about 4 m/min throughout the project.



**Photo A-10:** The test section for the Martec Hot In-Place Recycling process between Woodstock and London

HIR is a well-established process, having its origins in the early 1900's (ARRA, 2001), and photo (left, above). Previously, the main limitations to this technology had been achieving adequate treatment depths (heating depth) so that the heated asphalt mix could be scarified and processed without damaging the aggregate and oxidizing (burning) the binder, and mitigation of potential 'blue smoke' emissions. New third generation HIR equipment has advanced to a point where asphalt concrete can be evenly heated to depths approaching 75 mm and then remixed with new state-of-the-technology rejuvenators with 'blue smoke' emissions lower than those of conventional central HMA plants (See **Table A-1**).

**Table A-1:** Comparison of emission factors of second and third generation HIR trains and 400 conventional asphalt plants in the United States (EPA/FHWA/Martec)

Pollutant	Martec AR2000 Hot Air Recycler	Typical Infra-Red Recycler	Asphalt Plant Stack Emissions (1990)
	kg/tonne	kg/tonne	kg/tonne
CO	0.0085	0.290	0.019
NOx	0.0014	0.015	0.018
Sox	0.0017	—	0.146
Particulates	0.0009	0.002	—
Total Hydrocarbons	0.0007	0.013	0.014

**Table A-2 to Table A-4** show the performance of the different pavement recycling/rehabilitation methods based on MTO Ride Comfort Rating (RCR), International Roughness Index (IRI), average rutting and surface frictional properties measurements.

#### A. Case Studies

A.4 Case Study—  
Hot In-Place Recycling

##### Photo A-9

Hot in-place recycling and equipment used, past and present

##### Photo A-10

The test section for the Martec Hot In-Place Recycling process between Woodstock and London

##### Table A-1

Comparison of emission factors of second and third generation HIR trains and 400 conventional asphalt plants in the United States (EPA/FHWA/Martec)

## A. Case Studies

A.4 Case Study—  
Hot In-Place Recycling

**Table A-2**  
Roughness of different  
recycling methods

**Table A-3**  
Average rut depth for  
different recycling methods

**Table A-4**  
Frictional characteristics of  
different recycling methods

**Table A-2:** Roughness of different recycling methods

Demonstration Section	RCR (Note 1)			IRI (Note 2)	
	Before 1999	After 1999	One Year 2000	Two Years 2001	Three Years 2002
Second Generation HIR	8.1	8.5	8.8	1.33	1.29
New DFC	8.6	8.2	8.2	1.13	1.12
Martec HIR	8.3	8.5	8.7	1.02	0.98
RHM DFC	8.5	8	8	0.98	0.98
Microsurfacing—2000	8.4	8.6 (Before)	8.2	0.92	0.90
Microsurfacing—1999	8.7	8.0	8.4	0.78	0.78

Note 1: RCR is ride comfort rating, scale 0 to 10 with 10 being the smoothest ride using MTO PURD equipment.

Note 2: IRI is international roughness index, roughness scale of 0 to 16 with 0 being absolute perfection using ARAN equipment.

**Table A-3:** Average rut depth for different recycling methods

Demonstration Section	Average Rutting (mm)		
	One Year 2000 (Note 1)	Two Years 2001 (Note 2)	Three Years 2002 (Note 2)
Second Generation HIR	3.1	5.2	4.2
New DFC	2.8	4.3	2.9
Martec HIR	2.8	4.3	2.3
RHM DFC	2.9	4.4	2.6
Microsurfacing—2000	—	6.0	4.2
Microsurfacing—1999	4.0	5.2	4.6

NOTE 1: Average for lanes 2 and 3 unless specified      NOTE 2: Average value for lane 3 unless specified

**Table A-4:** Frictional characteristics of different recycling methods

Demonstration Section	Average Rutting (mm)			
	Before 1999	After 1999	One Year 2000	Three Years 2002
Second Generation HIR	41	43	39	44
New DFC	41	41	41	44
Martec HIR	41	41	43	47
RHM DFC	42	40	40	46
Microsurfacing—2000	49	Not Placed	44	44
Microsurfacing—1999	45	42	37	41

The key finding in the three year evaluation of the MTO Demonstration Project was that “the third generation HIR section is in excellent

condition, performing the best of all the sections constructed on the contract.”

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