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METHODOLOGY FOR THE DEVELOPMENT OF EQUIVALENT PAVEMENT STRUCTURAL DESIGN MATRIX FOR MUNICIPAL ROADWAYS

INCLUDING MAINTENANCE & REHABILITATION SCHEDULES AND LIFE CYCLE COST ANALYSIS

January 18, 2011

ARA Project Number 000830

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FINAL REPORT

Prepared for:

Ready Mixed Concrete Association of Ontario
&
Cement Association of Canada

ARA Project 000830

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LIST OF ABBREVIATIONS

AADT	Average Annual Daily Traffic
AADTT	Average Annual Daily Truck Traffic
ESAL	Equivalent Single Axle Load
HMA	Hot-Mix Asphalt
JPCP	Jointed Plain Concrete Pavement
LCCA	Life-Cycle Cost Analysis
MEPDG	Mechanistic-Empirical Pavement Design Guide
MTO	Ministry of Transportation, Ontario
M&R	Maintenance and Rehabilitation
OPSS	Ontario Provincial Standard Specification
PCC	Portland Cement Concrete
PW	Present Worth

1.0 INTRODUCTION

Both rigid and flexible pavements are commonly used in Ontario for both provincial highways and municipal streets. Each pavement type is designed and constructed based on local traffic and site conditions.

Rigid pavements in Ontario typically consist of a Jointed Plain Concrete Pavement (JPCP) over a granular base which provides uniform support for the concrete slabs. The structural strength of a concrete pavement is largely within the concrete itself due to its rigid nature. Concrete's rigidness spreads the load over a large area and keeps the pressure on the subgrade low, which is why less base material is required. Portland Cement Concrete (PCC) pavements have been used in many areas of the Province ranging from low volume residential roadways to our major 400 series highways.

Flexible pavements typically consist of Hot-Mix Asphalt (HMA) pavement over a granular base and subbase to distribute the traffic loads over the underlying layers. The asphalt concrete materials used in Ontario municipalities typically consist of Superpave asphalt mix designs.

Government agencies can benefit from a two-pavement system, where an agency is able to pave more roadways with the same amount of funding when compared to a single pavement system. Although concrete and asphalt have been used for municipal roads for decades, the use of alternate bids with life cycle cost as part of the tender process for pavement choice evaluation is fairly new. This process has been evolving in Canada since the first MTO contract tendered in 2001. The decision to use LCCA as part of the alternate bid process provides government agencies with better knowledge of the true cost of a roadway rather than just considering the initial cost of the pavement. The Ministry of Transportation of Ontario (MTO) uses an alternative bid process for major highways to ensure that the pavement selected is the most appropriate for the particular location and site conditions. This process uses an established Life-Cycle Cost Analysis (LCCA) procedure (ARA 2006) to help evaluate the ongoing maintenance and rehabilitation (M&R) costs against any differences in initial construction costs. While the MTO procedure focuses on the high volume highways across the province, a similar procedure can be used for pavement type selection of municipal roadways. The purpose of this report is to describe the pavement type selection process between concrete and asphalt pavements and to provide typical pavement cross-section information and accompanying M&R plans that are appropriate for use by Ontario municipalities.

These designs are established to be structurally equivalent and have the same design life such that a fair comparison may be made. The M&R plans have been developed for both pavement types to ensure that the minimum level of service will be maintained through preventative maintenance and rehabilitation activities commonly used by Ontario municipalities. It should be noted that the maintenance and rehabilitation plans for provincial highways tend to be more frequent than for municipal roadways due to differences in posted speed and the higher focus on pavement smoothness for the faster moving highways. The recommended municipal maintenance and rehabilitation plans have been established to provide a reasonable level of service throughout the asset life.

Creating equivalent pavement designs has historically been difficult due to differences in the pavement design procedures used for rigid and flexible pavements. However, the most recent release of the AASHTO pavement design guide, the Mechanistic-Empirical Pavement Design Guide (MEPDG) (AASHTO 2008), provides a more robust design procedure that uses substantially more design information and a larger source of data to calibrate the performance predictions than previous editions. Equivalent designs used in this document are based on the MEPDG.

This study includes pavement designs and maintenance plans for collector, minor arterial and major arterial roadways in Southern and Eastern Ontario.

2.0 MECHANISTIC-EMPIRICAL PAVEMENT DESIGN GUIDE

The MEPDG is the pavement design guide developed for AASHTO under the U.S. National Cooperative Highway Research Program (NCHRP) Project 1-37A. The MEPDG uses mechanistic-empirical principles to predict the deterioration of pavements and their expected service lives. The design procedure is very comprehensive. It includes procedures for the analysis and design of new and rehabilitated rigid and flexible pavements, procedures for evaluating existing pavements, procedures for subdrainage design, recommendations on rehabilitation treatments and foundation improvements, and procedures for life cycle cost analysis.

The MEPDG uses state-of-the-practice mechanistic models to predict the accumulation of pavement distresses based on the traffic loads and the material properties. This process is repeated hundreds of thousands of times to account for all of the possible traffic load combinations and the changes in materials due to age and climatic conditions.

To ensure that the models closely represent the distress conditions of in-service pavements, the process was calibrated to match known performance information from the Long Term Pavement Performance study and other test tracks across North America. These comprehensive data sources have been used to perform an empirical calibration to the field conditions documented from over 20 years of detailed performance observations. The design procedures used in the Guide are based on mechanistic-empirical concepts, which are a quantum leap from the old AASHO Road Test empirical designs that are used by many Canadian transportation agencies.

Mechanistic-empirical design focuses on pavement performance and accounts for many factors that have not been well addressed previously. All of these new design inputs that directly affect pavement performance such as materials, climate, traffic loads and construction procedures are used to estimate the distress condition of the pavement over time (Figure 2.1).

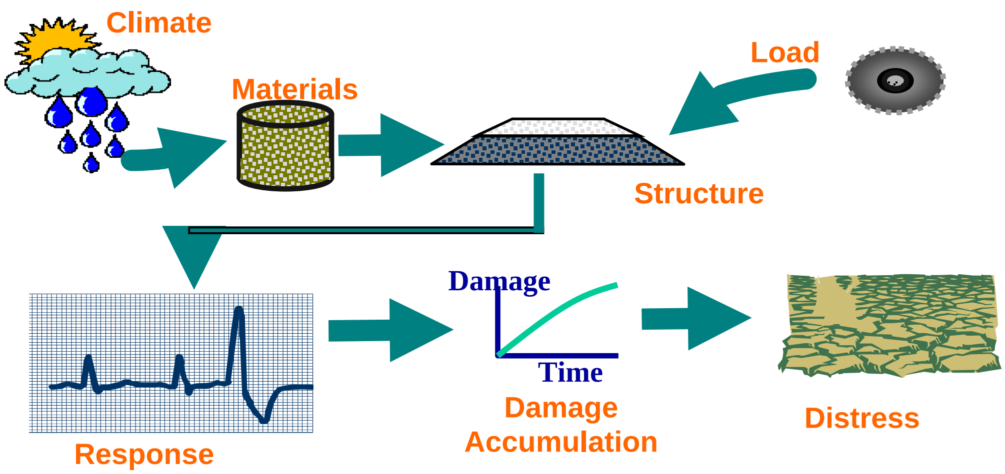


Figure 2.1: General Pavement Design Procedure and Analysis

One of the other major advancements of the MEPDG and the accompanying software is the ability to establish local calibration of the models. Since there are many differences in both the climate and materials used by different agencies, there are many factors that are expected to contribute to the variability in the analysis. As a part of the implementation of the MEPDG by Canadian transportation agencies, local calibration efforts are being completed to both develop the appropriate inputs as well as to monitor the performance of their pavements. The list of design inputs and applicable values developed for Ontario are discussed in this report.

The design inputs have been subdivided into categories for ease of implementation. The following inputs are used by the MEPDG to model the pavement performance:

- General Inputs
- General Information
- Site/Project Identification
- Analysis Parameters
- Traffic
- Traffic Volume Adjustment Factors
- Axle Load Distribution Factors
- General Traffic Inputs
- Climate
- Structure
- Drainage and Surface Properties
- Pavement Structural Layers
- Asphalt Concrete Layers
- Rigid Concrete Layers
- Granular Layers
- Foundation/Subgrade
- Thermal Cracking
- Distress Potential

2.1 Traffic Information

The volume and composition of traffic has always been a major focus of pavement design due to the impact it has on determining the thickness of the pavement. Traffic has been traditionally described as the number of vehicles using the road in terms of the Average Annual Daily Traffic (AADT). In the 1993 AASHTO Design Guide (AASHTO 1993), the traffic was described in terms of Equivalent Single Axle Loads (ESALs), which described the total damage caused by different vehicles in terms of the damage caused by 80 kN (18,000 lbf) single axles.

The MEPDG takes a different approach to more accurately evaluate the damage caused by each axle load on a specific cross-section over the range of conditions it is expected to endure, commonly known as axle load spectra. To accomplish this, the MEPDG uses a large range of traffic parameters. This level of traffic detail is not commonly available for municipal roadways and some assumptions or regional defaults are necessary.

2.1.1 Traffic Volume

The most common traffic input is the number of vehicles expected to pass over a roadway during its design life. As the load applied by passenger vehicles is very low, the MEPDG does not consider them in the analysis. The number of load applications from trucks and buses is summarized using the Average Annual Daily Truck Traffic (AADTT). For the purpose of providing equivalent designs a range of AADTT values are used ranging from 250 to 10,000 trucks per day. These traffic levels represent collector, minor arterial, and major arterial roadways.

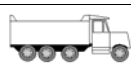
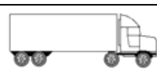
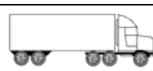
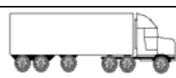
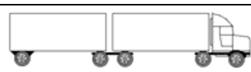
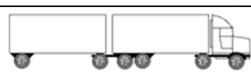
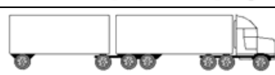
For the purposes of this analysis, it is assumed that half of the traffic travels are in each direction. Collector and minor arterial roadways are assumed to have only one lane in each direction, while major arterial roadways are assumed to have 2 lanes in each direction, with 80 percent of the commercial vehicle traffic in the design lane. A compound growth rate of 2 percent was used to account for increases in vehicle volume over time.

2.1.2 Truck Type Distribution

The MEPDG uses a rigorous process to estimate the traffic loads on a roadway. To complete this part of the process, the traffic volume for each month, is divided into the 13 vehicle classes as established by the US Federal Highway Administration (FHWA). Light vehicles, class 1 through 3 (motorcycles and light passenger vehicles), are ignored with the remaining vehicle classes being the focus of the pavement structural design.

The types of vehicles that travel a roadway are typically dependent on the functional classification, the location, and the proximity to industry and natural resources. While conditions may vary locally, typical distributions for the three functional classifications being modelled are shown in Table 2.1.

Table 2.1. Expected Commercial Vehicle Distribution for Municipal Roadways

FHWA Class	Commercial Vehicle		Distribution of Commercial Vehicles		
			Collector	Minor Arterial	Major Arterial
4		Two or Three Axle Buses	2.9 %	3.3 %	1.8 %
5		Two-Axle, Six-Tire, Single Unit Trucks	56.9 %	34.0 %	24.6 %
6		Three-Axle Single Unit Trucks	10.4 %	11.7 %	7.6 %
7		Four or More Axle Single Unit Trucks	3.7 %	1.6 %	0.5 %
8		Four or Less Axle Single Trailer Trucks	9.2 %	9.9 %	5 %
9		Five-Axle Single Trailer Trucks	15.3 %	36.2 %	31.3 %
10		Six or More Axle Single Trailer Trucks	0.6 %	1.0 %	9.8 %
11		Five or Less Axle Multi-Trailer Trucks	0.3 %	1.8 %	0.8 %
12		Six-Axle Multi-Trailer Trucks	0.4 %	0.2 %	3.3 %
13		Seven or More Axle Multi-Trailer Trucks	0.3 %	0.3 %	15.3 %

The commercial vehicle distributions are used in conjunction with axle type and load distributions for Southern and Eastern Ontario. The default values for the following list of parameters were used to represent Ontario municipal conditions:

- Hourly vehicle distribution
- Monthly vehicle distribution
- Vehicle length and axle spacing

2.2 Climate Conditions

A significant factor influencing the performance of pavements is climate. While the climate conditions do not differ substantially across Ontario, Mount Forest was selected as having a typical climate representing Southern and Eastern Ontario. Extreme temperatures located in other locations are often accounted for by adjusting materials such as the asphalt binder type. Table 2.2 is a summary pavement surface temperatures expected based on the Mount Forest climate data.

Table 2.2. Average Monthly Quintile Surface Temperature – Mount Forest

Month	1st Quintile (ºC)	2nd Quintile (ºC)	3rd Quintile (ºC)	4th Quintile (ºC)	5th Quintile (ºC)	Mean Temp. (ºC)	Std. Dev. (ºC)
January	-13.0	-8.4	-5.5	-2.9	0.3	-5.9	4.8
February	-13.2	-8.7	-5.5	-2.7	1.4	-5.7	5.2
March	-7.9	-3.4	-0.6	2.3	7.3	-0.4	5.4
April	-1.1	3.3	6.7	10.7	17.4	7.4	6.7
May	5.2	10.4	14.1	18.4	26.0	14.8	7.4
June	11.9	16.9	20.7	25.2	32.4	21.4	7.3
July	14.6	19.6	23.4	27.8	34.4	23.9	7.1
August	13.3	17.9	21.3	25.6	32.1	22.1	6.7
September	8.3	13.1	16.6	20.3	26.7	17.0	6.6
October	2.8	6.8	9.9	13.3	19.2	10.4	5.9
November	-2.2	1.1	3.1	5.3	9.1	3.2	4.1
December	-9.3	-5.4	-3.1	-0.7	2.8	-3.1	4.3

2.3 Pavement Materials

The other major advancement in using mechanistic pavement models is the ability to better describe the pavement materials and any changes in their behaviour throughout the year, and over their expected service life. With the climate data available, the effects of temperature on pavement materials can be accounted for, as well as the effects of drainage and freezing.

2.3.1 Portland Cement Concrete

PCC used across Ontario is primarily based on OPSS 350 (MTO 1998), with the following exceptions. All non-structurally reinforced concrete exposed to chlorides and freezing & thawing is 32MPa, Class C-2, with Air Category 1 (varying depending on aggregate size used) with a maximum water to cementing materials ratio (W/CM) of 0.45 (as per CSA A23.1-09). Based on the minimum specifications, the concrete properties in Table 2.3 were used in the analysis.

Table 2.3. Portland Cement Concrete Properties

Property	Value
Concrete Strength	32 MPa - 28-day Compressive Strength 5.6 MPa - 28-day Modulus of Rupture 29.6 GPa - 28-day Elastic Modulus
Unit Weight	2,324 kg/m^3
CSA Exposure Class	C-2
Water to cementing materials Ratio	0.45

Concrete pavements 200 mm or thicker are dowelled in this analysis with 32M dowel bars placed at 300 mm intervals across the transverse joints. The slabs for collector roads are 4.0 m in length, and the slabs for minor and major arterial roads are 4.5 m in length. Collector, minor arterial and major arterial (2,500 and 5,000 AADTT) roads have a tied concrete shoulder/curb on the outside of the pavement, whereas major arterial roads (7,500 and 10,000 AADTT) have a widened slab on the outside lane. For urban sections, a tied concrete curb or a monolithic slab and curb can be used as a tied should or widened slab respectively. All roads are constructed with concrete using Type GU Portland cement, and cured with a white pigmented curing compound.

2.3.2 Hot Mix Asphalt (HMA)

The HMA used for municipal roadways in Ontario is primarily based on the MTO's specification OPSS 1151 (MTO 2005). This specification provides guidance on the mix design and placement of the different types of mixes commonly used for municipal roadways. The mixes most commonly used as a surface course for collector and arterial roadways are Superpave 12.5, Superpave 12.5 FC1, and Superpave 12.5 FC2. For the base course asphalt, Superpave 19 is assumed. The properties of the HMA materials used in the analysis are shown in Table 2.4.

Table 2.4. Hot Mix Asphalt Properties

Property	Superpave 12.5 (Surface Course)	Superpave 12.5 FC1 (Surface Course)	Superpave 12.5 FC2 (Surface Course)	Superpave 19 (Base Course)
Asphalt Cement Type	PG 58-28	PG 64-28	PG 64-28	PG 58-28
Asphalt Cement	5.0 to 5.5 %	5.0 to 5.5 %	5.0 to 5.5 %	4.0 to 5.5 %
Voids in the Mineral Aggregate (VMA)	14.0 % minimum	14.0 % minimum	14.0 % minimum	13.0 % minimum
Air Voids	4.0 %	4.0 %	4.0 %	4.0 %
Gradation Retained 19 mm	0 %	0 %	0 %	0 to 10 %
Gradation Retained 9.5 mm	10 to 72%	10 to 55%	10 to 55%	20 to 77 %
Gradation Retained 4.75 mm	40 to 55%	40 to 55%	45 to 55%	35 to 77 %
Gradation Passing 75 µm	2 to 10 %	2 to 10 %	2 to 10 %	2 to 8 %

The surface HMA is selected based on the expected traffic volume (MTO 2009). Superpave 12.5 is commonly used for lower traffic volume roadways and replaced the traditional HL 3, HL 3 Fine and HL 4 mixes. Superpave 12.5 FC1 replaced the traditional HL 1 mix and is typically recommended for most collector and minor arterial roadways. The MTO also uses Superpave 12.5 FC2 for very high traffic volume roadways to replace traditional DFC, and is utilized for the high volume, major arterial roadway classification.

2.3.3 Granular Base and Subbase

The most commonly available aggregates used in pavement construction in Ontario consist of Granular A base and Granular B subbase. These materials, described in OPSS 1010 (MTO 2004), can both used beneath the flexible and rigid pavement structures (Table 2.5).

Table 2.5. Granular Base and Subbase Properties

Property		Granular A		Granular B	
Aggregate Gradation (min. and max. percent passing)	106 mm	N/A	N/A	100	100
	26.5 mm	100	100	50	100
	19.0 mm	85	100	N/A	N/A
	13.2 mm	65	90	N/A	N/A
	9.5 mm	50	73	N/A	N/A
	4.75 mm	35	55	20	55
	1.18 mm	15	40	10	40
	300 µm	5	22	5	22
	75 µm	2	8	0	10
Plasticity Index		0		0	
Modulus		250 MPa		200 MPa	
Poisson's Ratio		0.35		0.35	
Coefficient of Lateral Pressure (k_0)		0.5		0.5	

These materials are commonly available and widely used across Ontario. For municipal roadways, the use of an open graded drainage layer is not common and has not been included in any of the pavements in this study. It is however assumed that adequate drainage is provided for both flexible and rigid pavement sections.

2.4 Subgrade Materials

The selection of appropriate properties for the subgrade is an important component of any pavement design. For all detailed pavement designs, geotechnical investigations are required to determine specific conditions for the purposes of providing support to the roadway as well as information on the constructability of the pavement. This is an important step for all pavement design projects.

For this project, a more generic pavement design process was used to develop the pavement designs based on typical subgrade materials for Ontario. To characterize the sensitivity of this parameter and to describe the range of potential conditions across the province, the subgrade parameters shown in Table 2.6 were used in the analysis.

Table 2.6. Subgrade Properties

Soil Properties	Low Plasticity Clay	Inorganic Silt	Silty Sand
Subgrade Strength Category	Low	Medium	High
Representative Resilient Modulus (annual average)	30 MPa	40 MPa	50 MPa
Equivalent CBR	3	4	5
Soil Classification	CL	ML	SM
Liquid Limit	30	20	8
Plasticity Index	20	5	2

2.5 Recommended Terminal Service Level

When designing a pavement, the performance criteria of terminal serviceability represents the lowest acceptable condition that will be tolerated before rehabilitation is required. The limits selected represent those typical for a municipality for an arterial roadway and are shown in Table 2.7. Traditionally, the performance parameters are set based on the importance of the roadway and other factors such as the design speed. The level of reliability is higher for higher trafficked roadways to reflect the importance of preventing premature failures.

Table 2.7. Design Performance Parameters

General Pavement Limits	
Initial Design Life	25 years
Design Reliability	Collector - 75% Minor Arterial - 80 % Major Arterial - 90% (2,500 to 5,000 AADTT) Major Arterial - 95% (7,500 to 10,000 AADTT)
Flexible Pavement Terminal Serviceability Limits	
Fatigue (Alligator) Cracking	10 %
Thermal (Transverse) Cracking	200 m/km
Rutting	10 mm
International Roughness Index (IRI)	3.0 mm/m
Rigid Pavement Terminal Serviceability Limits	
Cracked Slabs	10 %
Faulting	6 mm
International Roughness Index (IRI)	3.0 mm/m

3.0 DEVELOPMENT OF RECOMMENDED PAVEMENT DESIGNS

In order to develop pavement designs for both the concrete and asphalt pavements, a defined process was used to assess the structural capacity of various trial cross-sections. Since the pavement designs were established for municipal pavements in Ontario, the materials chosen as well as many of the design features were established based on current Ontario design standards and common practice.

The thickness of the granular and bound surface layers was the primary factor used to satisfy the design requirements. An initial design was selected based on typical municipal cross-sections and then evaluated within the MPEDG. For each trial section, the MEPDG analysis was completed and results were examined to determine when and how the pavement was expected to fail. The results were then used to modify the trial design to either address premature failure due to one or more of the distresses, or to prevent the over-design of a pavement. The cycle was repeated as necessary to obtain appropriate pavement cross-sections for all traffic and subgrade combinations.

The design process was completed for each combination of subgrade, traffic volume, and pavement type. The primary mode of failure for the pavements was not always the same. For low traffic flexible pavements, the most common cause of failure was a reduction in smoothness. For higher traffic flexible pavements however, fatigue cracking was the limiting factor, with some surface defects expected before the end of the 25 year design life.

For rigid pavements, the modes of failure were primarily based on the pavement design features such as slab length and steel properties. The low traffic designs without dowels typically failed due to a reduced joint load-transfer and subsequent faulting of the joints. However with the addition of dowel bars and a widened slab for higher volume designs, the load transfer was substantially improved and smoothness became the critical distress.

In order to ensure that the results were fair and reasonable, all of the design cross-sections were then reviewed by a panel of design experts. The proposed designs were compared to municipal standards and other design procedures such as StreetPave (ACPA 2005) and the 1993 AASHTO Guide for the Design of Pavement Structures (AASHTO 1993). The review was completed to ensure that the cross-sections matched conditions and municipal performance expectations in Ontario.

The resulting pavement designs are shown in Table 3.1. These designs are considered to be typical for municipal pavements across Ontario. It is however important to note that conditions do vary across the province and some adjustments may be necessary to ensure that they are appropriate for local conditions. A detailed pavement design report should be prepared for each project by a qualified engineer.

Table 3.1 – Representative Pavement Designs for Ontario Municipalities

		Average Annual Daily Truck Traffic (AADTT) - 25 Year Pavement Design							
		Collector		**Minor Arterial**		**Major Arterial**			
		250	**500**	**1,000**	**1,500**	**2,500**	**5,000**	**7,500**	**10,000**
Subgrade Strength: 30 MPa (CBR=3)	**PCC**	180 mm PCC 200 mm Granular A	190 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	210 mm PCC 200 mm Granular A	230 mm PCC 200 mm Granular A
	HMA	40 mm SP 12.5 80 mm SP 19 150 mm Granular A 350 mm Granular B	40 mm SP 12.5 80 mm SP 19 150 mm Granular A 400 mm Granular B	40 mm SP 12.5 FC1 90 mm SP 19 150 mm Granular A 450 mm Granular B	40 mm SP 12.5 FC1 100 mm SP 19 150 mm Granular A 450 mm Granular B	40 mm SP 12.5 FC1 110 mm SP 19 150 mm Granular A 450 mm Granular B	40 mm SP 12.5 FC1 120 mm SP 19 150 mm Granular A 600 mm Granular B	40 mm SP 12.5 FC1 130 mm SP 19 150 mm Granular A 600 mm Granular B	40 mm SP 12.5 FC2 140 mm SP 19 150 mm Granular A 600 mm Granular B
Subgrade Strength: 40 MPa (CBR=4)	**PCC**	180 mm PCC 200 mm Granular A	190 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	210 mm PCC 200 mm Granular A
	HMA	40 mm SP 12.5 80 mm SP 19 150 mm Granular A 300 mm Granular B	40 mm SP 12.5 80 mm SP 19 150 mm Granular A 350 mm Granular B	40 mm SP 12.5 FC1 80 mm SP 19 150 mm Granular A 350 mm Granular B	40 mm SP 12.5 FC1 100 mm SP 19 150 mm Granular A 350 mm Granular B	40 mm SP 12.5 FC1 100 mm SP 19 150 mm Granular A 400 mm Granular B	40 mm SP 12.5 FC1 120 mm SP 19 150 mm Granular A 450 mm Granular B	40 mm SP 12.5 FC1 130 mm SP 19 150 mm Granular A 500 mm Granular B	40 mm SP 12.5 FC2 140 mm SP 19 150 mm Granular A 550 mm Granular B
Subgrade Strength: 50 MPa (CBR=5)	**PCC**	180 mm PCC 200 mm Granular A	190 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A
	HMA	40 mm SP 12.5 80 mm SP 19 150 mm Granular A 300 mm Granular B	40 mm SP 12.5 80 mm SP 19 150 mm Granular A 300 mm Granular B	40 mm SP 12.5 FC1 80 mm SP 19 150 mm Granular A 300 mm Granular B	40 mm SP 12.5 FC1 100 mm SP 19 150 mm Granular A 300 mm Granular B	40 mm SP 12.5 FC1 100 mm SP 19 150 mm Granular A 350 mm Granular B	40 mm SP 12.5 FC1 110 mm SP 19 150 mm Granular A 400 mm Granular B	40 mm SP 12.5 FC1 130 mm SP 19 150 mm Granular A 450 mm Granular B	40 mm SP 12.5 FC2 140 mm SP 19 150 mm Granular A 500 mm Granular B
Concrete Slab and Joint Properties		No dowels Slab length = 4 m Tied shoulder/curb *		32M Dowel bars, 300 mm spacing Slab length = 4.5 m Tied shoulder/curb *		32M Dowel bars, 300 mm spacing Slab length = 4.5 m Tied shoulder/curb *		32M Dowel bars, 300 mm spacing Slab length = 4.5 m 0.5 m Widened outside slab or integral curb *	

Notes:

- All materials are based on current OPS Specifications
- Subgrade levels are based on three common subgrade materials in Ontario
  - Low Category (30 MPa) - Low Plasticity Clay Subgrade
  - Medium Category (40 MPa) - Low Plasticity Silt Subgrade
  - High Category (50 MPa) - Sandy Silt Subgrade

* For urban sections, a tied concrete curb or a monolithic slab and curb can be used as a tied shoulder or widened slab respectively.

Reliability Levels

- AADTT 250 to 500 - 75%
- AADTT 1,000 to 1,500 - 80%
- AADTT 2,500 to 5,000 - 90%
- AADTT 7,500 to 10,000 - 95%

4.0 LIFE CYCLE PAVEMENT COSTS

When selecting a pavement alternative, it is important to understand the expected pavement performance and costs for the entire life-cycle of the pavement. The overall costs and value need to be determined over many years to effectively consider the different options in terms of pavement type, design life, and future rehabilitation. Life-cycle cost analysis (LCCA) has been used for many years in the Province of Ontario to help make decisions regarding pavement type as well as selecting pavement preservation options.

In a typical LCCA, two or more alternate choices are available for an initial pavement design or cross-section. Based on the initial pavement designs, the expected maintenance and rehabilitation over the design life are then determined and incorporated into a single, inflation adjusted, cost in order to evaluate and compare the different options in a fair and consistent manner.

The pavements designed for this project have an initial design life of 25 years. At the end of the initial service life, some form of rehabilitation, such as a mill and overlay for a flexible pavement, or slab repairs for a rigid pavement, is usually required. An analysis period of 50 years was used for this project to include the initial service life as well as at least one major rehabilitation activity.

The maintenance and rehabilitation plans provided were developed for municipal roadways with speeds between 50 km/h and 80 km/h. The maintenance and rehabilitation plans for provincial highways tend to be more frequent than for municipal roadways due to differences in posted speed and the higher focus on pavement smoothness for the faster moving highways. The recommended municipal maintenance and rehabilitation plans have been established to provide a reasonable level of service throughout the asset life.

4.1 Concrete Pavement Maintenance and Rehabilitation Plans

Concrete pavements are often constructed for their long service life and the reduced level of maintenance expected due to their slower rate of deterioration. Four maintenance and rehabilitation plans for each pavement type have been developed to coincide with the different functional classifications of the roadways. The initial pavement designs were developed based on the three subgrade types shown in Table 2.6.

For the maintenance and rehabilitation of concrete pavements, the most common activities include improving joint performance through resealing, partial depth repairs, and slab replacements with full depth repairs. On higher volume roadways, the smoothness of the roadway has more significance and some surface texturization is recommended to ensure an acceptable performance.

The recommended maintenance and rehabilitation plans are outlined in Table 4.1 through Table 4.4. These plans were developed to provide a consistent level of service in a cost effective manner. The maintenance and rehabilitation quantities provided are for a 1km length of roadway and will need to be adjusted for different section lengths.

Table 4.1 Rigid Collector Pavement Preservation Plan (AADTT 250-500)

Expected Year	Activity Description	Quantity (per 1 km of road)
12	Reseal joints	10 %
25	Partial depth PCC repair	2 %
25	Full depth PCC repair	5 %
25	Reseal joints	20 %
40	Partial depth PCC repair	5 %
40	Full depth PCC repair	10 %
40	Reseal joints	20 %

Table 4.2 Rigid Minor Arterial Pavement Preservation Plan (AADTT 1,000-1,500)

Expected Year	Activity Description	Quantity (per 1 km of road)
12	Reseal joints	20 %
25	Partial depth PCC repair	5 %
25	Full depth PCC repair	10 %
25	Reseal joints	25 %
40	Partial depth PCC repair	5 %
40	Full depth PCC repair	15 %
40	Reseal joints	25 %

Table 4.3 Rigid Major Arterial Pavement Preservation Plan (AADTT 2,500-5,000)

Expected Year	Activity Description	Quantity (per 1 km of road)
12	Reseal joints	25 %
12	Partial depth PCC repair	2 %
25	Partial depth PCC repair	5 %
25	Full depth PCC repair	10 %
25	Reseal joints	25 %
40	Partial depth PCC repair	5 %
40	Full depth PCC repair	15 %
40	Reseal joints	25 %

Table 4.4 Rigid Major Arterial Pavement Preservation Plan (AADTT 7,500-10,000)

Expected Year	Activity Description	Quantity (per 1 km of road)
12	Reseal joints	25 %
12	Partial depth PCC repair	2 %
25	Partial depth PCC repair	5 %
25	Full depth PCC repair	10 %
25	Reseal joints	50 %
25	Texturize	25 %
40	Partial depth PCC repair	5 %
40	Full depth PCC repair	15 %
40	Reseal joints	50 %
40	Texturize	50 %

4.2 Hot Mix Asphalt Pavement Maintenance and Rehabilitation Plans

Hot mix asphalt pavements have been commonly used by Ontario municipalities due to their history of use and experience with maintenance and rehabilitation. HMA pavements typically deteriorate faster than PCC pavements and require a more extensive maintenance schedule to maintain an acceptable level of service.

The recommend maintenance and rehabilitation schedules for HMA pavements are outlined in Table 4.5 through Table 4.8. These plans use a combination of preventative maintenance and rehabilitation to ensure a cost effective preservation plan. The maintenance and rehabilitation quantities provided are for a 1km length of roadway and will need to be adjusted for different section lengths.

Table 4.5 Flexible Collector Pavement Preservation Plan (AADTT 250-500)

Expected Year	Activity Description	Quantity (per 1 km of road)
10	Rout and seal	250 m
10	Spot repairs, mill 40 mm/patch 40 mm	2 %
20	Mill HMA	40 mm
20	Resurface with Superpave 12.5	40 mm
25	Rout and seal	500 m
30	Spot repairs, mill 40 mm/patch 40 mm	5 %
35	Mill HMA	40 mm
35	Full depth asphalt base repair	5 %
35	Resurface with Superpave 12.5	40 mm
40	Rout and seal	500 m
43	Spot repairs, mill 40 mm/patch 40 mm	5 %
48	Mill HMA	40 mm
48	Resurface with Superpave 12.5	40 mm

Table 4.6 Flexible Minor Arterial Pavement Preservation Plan (AADTT 1,000-1,500)

Expected Year	Activity Description	Quantity (per 1 km of road)
10	Rout and seal	250 m
10	Spot repairs, mill 40 mm/patch 40 mm	2 %
15	Spot repairs, mill 40 mm/patch 40 mm	10 %
20	Mill HMA	40 mm
20	Resurface with Superpave 12.5FC1	40 mm
25	Rout and seal	500 m
30	Spot repairs, mill 40 mm/patch 40 mm	5 %
35	Mill HMA	40 mm
35	Full depth asphalt base repair	10 %
35	Resurface with Superpave 12.5FC1	40 mm
40	Rout and seal	500 m
43	Spot repairs, mill 40 mm/patch 40 mm	5 %
48	Mill HMA	90 mm
48	Resurface with Superpave 19	50 mm
48	Resurface with Superpave 12.5FC1	40 mm

Table 4.7 Flexible Major Arterial Pavement Preservation Plan (AADTT 2,500-5,000)

Expected Year	Activity Description	Quantity (per 1 km of road)
5	Rout and seal	200 m
10	Rout and seal	500 m
10	Spot repairs, mill 40 mm/patch 40 mm	5 %
20	Mill HMA	40 mm
20	Resurface with Superpave 12.5FC1	40 mm
25	Rout and seal	1000 m
30	Spot repairs, mill 40 mm/patch 40 mm	10 %
35	Mill HMA	90 mm
35	Resurface with Superpave 19	50 mm
35	Resurface with Superpave 12.5FC1	40 mm
40	Rout and seal	1500 m
45	Spot repairs, mill 40 mm/patch 40 mm	10 %
48	Mill HMA	40 mm
48	Full depth asphalt base repair	5 %
48	Resurface with Superpave 12.5FC1	40 mm

Table 4.8 Flexible Major Arterial Pavement Preservation Plan (AADTT 7,500-10,000)

Expected Year	Activity Description	Quantity (per 1 km of road)
8	Rout and seal	200 m
8	Spot repairs, mill 40 mm/patch 40 mm	5 %
13	Rout and seal	1000 m
13	Spot repairs, mill 40 mm/patch 40 mm	15 %
18	Mill HMA	50 mm
18	Full depth asphalt base repair	10 %
18	Resurface with Superpave 12.5FC2	50 mm
23	Rout and seal	500 m
28	Rout and seal	1500 m
28	Spot repairs, mill 40 mm/patch 40 mm	10 %
32	Mill HMA	90 mm
32	Resurface with Superpave 19	50 mm
32	Resurface with Superpave 12.5FC2	40 mm
37	Rout and seal	1500 m
40	Spot repairs, mill 40 mm/patch 40 mm	10 %
45	Mill HMA	50 mm
45	Full depth asphalt base repair	10 %
45	Resurface with Superpave 12.5FC2	50 mm
48	Rout and seal	1500 m

4.3 Pavement Construction Unit Costs

To estimate the cost of various items over the life of a pavement, unit costs of various construction tasks are required. These unit costs are then multiplied by the expected quantities required at different times throughout the service life.

In order for the LCCA to be realistic, it is important to have accurate unit costs for the initial construction and the expected maintenance and rehabilitation plans. These unit costs are typically provided in a format that is consistent with the way construction estimates and bids are generated.

Actual unit costs can vary significantly from project to project depending on conditions, specific project requirements, equipment availability, and location of the project. The unit costs used for the LCCA are considered typical for municipal roadways in Southern and Eastern Ontario.

The unit prices used for the LCCA are shown in Table 4.9 and Table 4.10. While these values are considered reasonable at the time of this report, it is important to note that prices will fluctuate with time and can vary dramatically depending on the location and size of the project. Review and updating of these unit costs is a critical component of any evaluation.

Table 4.9 Unit Costs for Initial Pavement Construction

Pavement Layer	Description of Pavement Layer	Unit Cost
HMA	Superpave 12.5FC2 (t)	$120.00
	Superpave 12.5FC1 (t)	$115.00
	Superpave 12.5 (t)	$105.00
	Superpave 19 (t)	$96.00
PCC	180 mm PCC pavement, no dowels (m^2)	$41.20
	190 mm PCC pavement, no dowels (m^2)	$42.60
	200 mm PCC pavement, 32M dowels (m^2)	$49.50
	210 mm PCC pavement, 32M dowels (m^2)	$50.90
	230 mm PCC pavement, 32M dowels (m^2)	$53.70
Base	Granular A (t)	$18.00
Subbase	Granular B (t)	$15.00
Excavation	Earth excavation (m^3)	$18.00
	Rock excavation (m^3)	$150.00
	Hot mix asphalt pavement excavation (m^3)	$65.00
	Concrete pavement excavation(m^3)	$82.00
	Contaminated material excavation(m^3)	$80.00

Table 4.10 Unit Costs for Maintenance and Rehabilitation Activities

Description of Maintenance and Rehabilitation Treatments	Unit Costs
Rout and seal (m)	$5.00
Spot repairs, mill and patch (m^2)	$35.00
Asphalt base repair (m^2)	$45.00
Mill HMA (t)	$15.00
Resurface with Superpave 12.5FC2 (t)	$120.00
Resurface with Superpave 12.5FC1 (t)	$115.00
Resurface with Superpave 12.5 (t)	$105.00
Resurface with Superpave 19 (t)	$96.00
Reseal joints (m)	$10.00
Partial depth PCC repair (m^2)	$125.00
Full depth PCC repair (m^2)	$100.00
Texturize (m^2)	$10.00

4.4 Excavation Costs

The costs of excavation are not always necessary to include in an LCCA. They are not applicable to many sites were the pavement geometry is adjusted and the final road grade can be adjusted. Depending on the longitudinal profile and the existing grade of new construction projects, the extent of excavation required may be reduced during the geometric design process.

Due to the difference in the material strength, the total thickness required for PCC pavements is less than that of HMA pavements. When a pavement is being placed to match an existing grade, excavation of existing materials is required. For thicker pavement structures this can add cost for more earth movement and for any haulage and disposal of material that cannot be used on site. The excavation costs, where appropriate, can be a substantial project cost. The typical pavement sections provided have been designed to include excavation costs when necessary. The thinner pavement structure required by concrete pavements can make this a definitive cost advantage.

In the case of pavement reconstruction, the grade of the pavement surface is typically maintained and materials must be excavated to a depth where the new cross-section can be placed. Since the vast majority of pavement works completed by municipalities are for existing roadways and not green field construction, it has been assumed that excavation needs to be accounted for and has been included in the examples provided.

4.5 Estimating Life-Cycle Costs

To ensure a fair comparison of different options, life cycle costs are typically evaluated in terms of their Net Present Worth (NPW). The present worth represents the cost of a future activity in terms of today's dollars. The initial costs and on-going costs are then combined to evaluate the total project present worth.

The future costs are discounted to adjust for inflation and interest rates. The discount rate used to adjust the future costs is typically set at an agency level. The current discount rate used by the Province of Ontario is 5.0%.

When evaluating the life-cycle cost, it is typically understood that there is a margin of error due to possible differences in quantities, unit costs, and pavement performance over the service life. Comparisons with marginal differences in cost may require further investigation into other factors to determine the optimal pavement type.

An example LCCA for a major arterial roadway (AADTT = 2,500) on the low strength subgrade is shown in Table 4.11 and Table 4.12. This example shows the reduced cost of activities due to discounting, as well as the relatively low cost of the maintenance and rehabilitation compared to the initial construction. The comparison of the costs shown in Figure 4.1 illustrates the relative difference between the two pavement types. For this example, the concrete pavement option has an 11 % lower cost over the pavement life-cycle.

The LCCA process has also been followed and cost comparisons have been generated for other conditions. Full costs comparisons have been developed for all combinations of pavement type, traffic level, and subgrade material. Summaries of the LCCA results can be found in Table 4.13 through Table 4.15 along with all results in Appendix B.

Table 4.11 Example LCCA for a Major Arterial Concrete Pavement (AADTT = 2,500)

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	200 mm PCC pavement, 32M dowels (m²)	200	7500	$ 49.50	$ 742,500
Base	Granular A, mm (t)	200	3600	$ 18.00	$ 129,600
Excavation	Earth Excavation, mm (m^3)	400	3000	$ 18.00	$ 108,000
	Total Initial Cost				**$ 980,100**

Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost	Net present worth
12	Partial depth PCC repair, % area (m²)	2	300	$ 125.00	$ 37,500	$ 20,881
12	Reseal joints, % Length (m)	25	833	$ 10.00	$ 8,333	$ 4,640
25	Partial depth PCC repair, % area (m²)	5	750	$ 125.00	$ 93,750	$ 27,685
25	Full depth PCC repair, % area (m²)	10	1500	$ 100.00	$ 150,000	$ 44,295
25	Reseal joints, % Length (m)	25	833	$ 10.00	$ 8,333	$ 2,461
40	Partial depth PCC repair, % area (m²)	5	750	$ 125.00	$ 93,750	$ 13,317
40	Full depth PCC repair, % area (m²)	15	2250	$ 100.00	$ 225,000	$ 31,960
40	Reseal joints, % Length (m)	25	833	$ 10.00	$ 8,333	$ 1,184
50	Residual Value				$ 109,028	$ 9,508
	Total M&R Cost				**$ 515,972**	**$ 136,916**

Table 4.12 Example LCCA for a Major Arterial Asphalt Pavement (AADTT = 2,500)

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	Superpave 12.5FC1, mm (t)	40	1,512	$ 115.00	$ 173,880
Binder	Superpave 19, mm (t)	110	4,059	$ 96.00	$ 389,664
Base	Granular A, mm (t)	150	5,400	$ 18.00	$ 97,200
Subbase	Granular B, mm (t)	450	13,500	$ 15.00	$ 202,500
Excavation	Earth excavation (m^3)	750	11,250	$ 18.00	$ 202,500
Total Initial Cost					**$ 1,065,744**

Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost	Net present worth
5	Rout and seal, m (m)	200	200	$ 5.00	$ 1,000	$ 784
10	Rout and seal, m (m)	500	500	$ 5.00	$ 2,500	$ 1,535
10	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	750	$ 35.00	$ 26,250	$ 16,115
20	Mill HMA, mm (t)	40	1500	$ 15.00	$ 22,500	$ 8,480
20	Resurface with Superpave 12.5FC1, mm (t)	40	1512	$ 115.00	$ 173,880	$ 65,534
25	Rout and seal, m (m)	1000	1000	$ 5.00	$ 5,000	$ 1,477
30	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	10	1500	$ 35.00	$ 52,500	$ 12,147
35	Mill HMA, mm (t)	90	3375	$ 15.00	$ 50,625	$ 9,178
35	Resurface with Superpave 19, mm (t)	50	1845	$ 96.00	$ 177,120	$ 32,110
35	Resurface with Superpave 12.5FC1, mm (t)	40	1512	$ 115.00	$ 173,880	$ 31,523
40	Rout and seal, m (m)	1500	1500	$ 5.00	$ 7,500	$ 1,065
45	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	10	1500	$ 35.00	$ 52,500	$ 5,843
48	Mill HMA, mm (t)	40	1500	$ 15.00	$ 22,500	$ 2,163
48	Full depth asphalt base repair, % area (m^2)	5	750	$ 45.00	$ 33,750	$ 3,245
48	Resurface with Superpave 12.5FC1, mm (t)	40	1512	$ 115.00	$ 173,880	$ 16,717
50	Residual value				$ 191,775	$ 16,723
Total M&R Cost					**$ 553,480**	**$ 191,192**

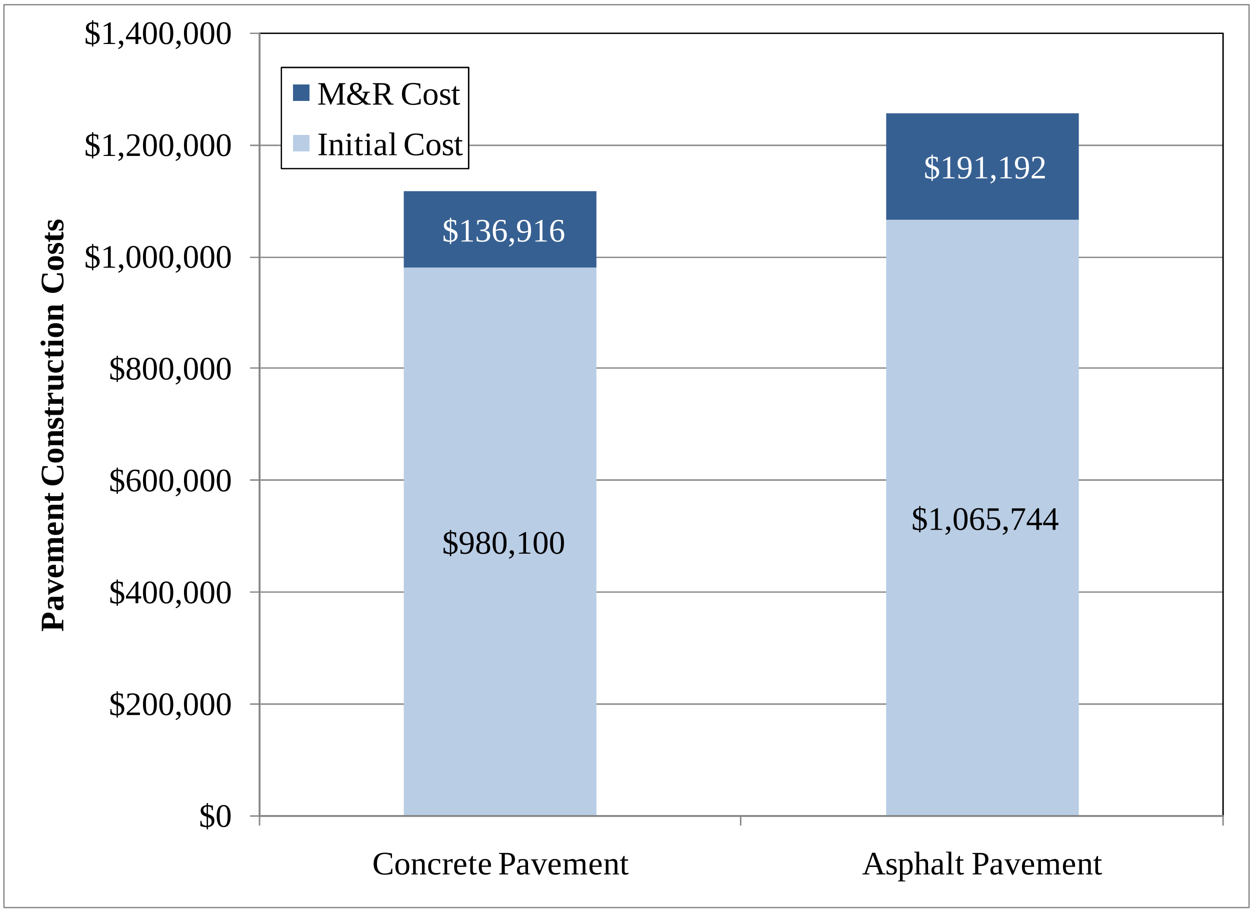


Figure 4.1. Example LCCA Comparison of Costs for a Major Arterial Pavement (AADTT = 2,500)

Table 4.13 Summary of LCCA Results for Low Subgrade Strength

Typical Ontario Municipal Pavements

LIFE CYCLE COST ANALYSIS SUMMARY

Listed by 25 Year AADTT and Pavement Type for Low Strength Subgrade

Item	Collector			
	250 PCC	**250 HMA**	**500 PCC**	**500 HMA**
Initial Cost	$ 425,100	$ 430,236	$ 436,950	$ 448,236
M&R Cost (Discounted)	$ 32,955	$ 64,406	$ 32,955	$ 64,406
Total Cost	$ 458,055	$ 494,642	$ 469,905	$ 512,642
LCC Difference	**7%**		**8%**	

Item	Minor Arterial			
	1,000 PCC	**1,000 HMA**	**1,500 PCC**	**1,500 HMA**
Initial Cost	$ 490,050	$ 494,748	$ 490,050	$ 513,810
M&R Cost (Discounted)	$ 57,553	$ 87,998	$ 57,553	$ 86,278
Total Cost	$ 547,603	$ 582,746	$ 547,603	$ 600,088
LCC Difference	**6%**		**9%**	

Item	Major Arterial			
	2,500 PCC	**2,500 HMA**	**5,000 PCC**	**5,000 HMA**
Initial Cost	$ 980,100	$ 1,065,744	$ 980,100	$ 1,211,868
M&R Cost (Discounted)	$ 136,916	$ 191,192	$ 136,916	$ 191,192
Total Cost	$ 1,117,016	$ 1,256,936	$ 1,117,016	$ 1,403,060
LCC Difference	**11%**		**20%**	

Item	Major Arterial			
	7,500 PCC	**7,500 HMA**	**10,000 PCC**	**10,000 HMA**
Initial Cost	$ 1,070,720	$ 1,333,325	$ 1,121,280	$ 1,382,054
M&R Cost (Discounted)	$ 170,523	$ 342,478	$ 170,523	$ 349,035
Total Cost	$ 1,241,243	$ 1,675,803	$ 1,291,803	$ 1,731,090
LCC Difference	**26%**		**25%**	

Table 4.14 Summary of LCCA Results for Medium Subgrade Strength

Typical Ontario Municipal Pavements

LIFE CYCLE COST ANALYSIS SUMMARY

Listed by 25 Year AADTT and Pavement Type for Medium Strength Subgrade

Item	Collector			
	250 PCC	**250 HMA**	**500 PCC**	**500 HMA**
Initial Cost	$ 425,100	$ 412,236	$ 436,950	$ 430,236
M&R Cost (Discounted)	$ 32,955	$ 64,406	$ 32,955	$ 64,406
Total Cost	$ 458,055	$ 476,642	$ 469,905	$ 494,642
LCC Difference	**4%**		**5%**	

Item	Minor Arterial			
	1,000 PCC	**1,000 HMA**	**1,500 PCC**	**1,500 HMA**
Initial Cost	$ 490,050	$ 439,686	$ 490,050	$ 477,810
M&R Cost (Discounted)	$ 57,553	$ 87,998	$ 57,553	$ 86,278
Total Cost	$ 547,603	$ 527,684	$ 547,603	$ 564,088
LCC Difference	**4%**		**3%**	

Item	Major Arterial			
	2,500 PCC	**2,500 HMA**	**5,000 PCC**	**5,000 HMA**
Initial Cost	$ 980,100	$ 991,620	$ 980,100	$ 1,103,868
M&R Cost (Discounted)	$ 136,916	$ 200,051	$ 136,916	$ 191,192
Total Cost	$ 1,117,016	$ 1,191,671	$ 1,117,016	$ 1,295,060
LCC Difference	**6%**		**14%**	

Item	Major Arterial			
	7,500 PCC	**7,500 HMA**	**10,000 PCC**	**10,000 HMA**
Initial Cost	$ 1,045,440	$ 1,256,525	$ 1,070,720	$ 1,343,654
M&R Cost (Discounted)	$ 170,523	$ 342,478	$ 170,523	$ 349,035
Total Cost	$ 1,215,963	$ 1,599,003	$ 1,241,243	$ 1,692,690
LCC Difference	**24%**		**27%**	

Table 4.15 Summary of LCCA Results for High Subgrade Strength

Typical Ontario Municipal Pavements

LIFE CYCLE COST ANALYSIS SUMMARY

Listed by 25 Year AADTT and Pavement Type for High Strength Subgrade

Item	Collector			
	250 PCC	**250 HMA**	**500 PCC**	**500 HMA**
Initial Cost	$ 425,100	$ 412,236	$ 436,950	$ 412,236
M&R Cost (Discounted)	$ 32,955	$ 64,406	$ 32,955	$ 64,406
Total Cost	$ 458,055	$ 476,642	$ 469,905	$ 476,642
LCC Difference	**4%**		**1%**	

Item	Minor Arterial			
	1,000 PCC	**1,000 HMA**	**1,500 PCC**	**1,500 HMA**
Initial Cost	$ 490,050	$ 421,686	$ 490,050	$ 459,810
M&R Cost (Discounted)	$ 57,553	$ 87,998	$ 57,553	$ 86,278
Total Cost	$ 547,603	$ 509,684	$ 547,603	$ 546,088
LCC Difference	**7%**		**0%**	

Item	Major Arterial			
	2,500 PCC	**2,500 HMA**	**5,000 PCC**	**5,000 HMA**
Initial Cost	$ 980,100	$ 955,620	$ 980,100	$ 1,029,744
M&R Cost (Discounted)	$ 136,916	$ 191,192	$ 136,916	$ 191,192
Total Cost	$ 1,117,016	$ 1,146,812	$ 1,117,016	$ 1,220,936
LCC Difference	**3%**		**9%**	

Item	Major Arterial			
	7,500 PCC	**7,500 HMA**	**10,000 PCC**	**10,000 HMA**
Initial Cost	$ 1,045,440	$ 1,218,125	$ 1,045,440	$ 1,305,254
M&R Cost (Discounted)	$ 170,523	$ 342,478	$ 170,523	$ 349,035
Total Cost	$ 1,215,963	$ 1,560,603	$ 1,215,963	$ 1,654,290
LCC Difference	**22%**		**26%**	

5.0 CONCLUSIONS

Municipalities are always looking for opportunities to improve the performance of their roadways and more efficiently spend their available budgets. While there are many pavement types available to municipalities, the most common alternatives have historically been asphalt and concrete pavements. Both of these pavement types have been used throughout Ontario.

The MEPDG process has many advantages over historic pavement design procedures. More robust design inputs have led to improvements in the design of both asphalt and concrete pavements based on long term pavement performance. The designs developed will meet the needs of municipalities. These designs have been evaluated to ensure that they are consistent with municipal practices across Ontario.

Pavement type selection is one of the more challenging engineering decisions facing roadway administrators. The process includes a variety of engineering factors such as materials and structural performance which must be weighed against the initial and life-cycle costs, as well as, sustainable benefits. The technical part of the evaluation includes an analysis of pavement life-cycle strategies including initial and future costs for construction and maintenance, supplemental costs for engineering and contract administration and traffic control/protection and societal costs such as user delay and environmental impact. Non-economic factors such as roadway geometry, availability of local materials, qualified contractors and construction experience, conservation of materials/energy, stimulation of competition, impact on winter maintenance, light reflectance, safety and comfort can also be factored into the decision process. The evaluation helps to select an alternative that is consistent with the agency's financial goals, policy decisions, and experience.

The pavement design and life-cycle cost analysis presented in this report is considered to be typical for Southern and Eastern Ontario municipal pavements. While every attempt has been made to ensure that both PCC and asphalt pavements were treated equally, it should be recognized that specific local factors such as project timing and local experience will often influence the choice of a particular pavement type.

The decision to use life-cycle cost analysis and evaluate sustainable benefits including non-economic factors as part of the pavement type selection process provides government agencies with better knowledge of the true cost of a roadway rather than just considering the initial cost of the pavement. As this report shows, concrete pavements can offer both attractive initial construction costs and favourable life cycle costs when compared to asphalt.

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APPENDIX A

SOUTHERN AND EASTERN ONTARIO MUNICIPAL ROADWAY DESIGN MATRIX

		Average Annual Daily Truck Traffic (AADTT) - 25 Year Pavement Design							
		Collector		Minor Arterial		Major Arterial			
Subgrade Strength		250	500	1,000	1,500	2,500	5,000	7,500	10,000
30 MPa (CBR=3)	PCC	180 mm PCC 200 mm Granular A	190 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	210 mm PCC 200 mm Granular A	230 mm PCC 200 mm Granular A
30 MPa (CBR=3)	HMA	40 mm SP 12.5 80 mm SP 19 150 mm Granular A 350 mm Granular B	40 mm SP 12.5 80 mm SP 19 150 mm Granular A 400 mm Granular B	40 mm SP 12.5 FC1 90 mm SP 19 150 mm Granular A 450 mm Granular B	40 mm SP 12.5 FC1 100 mm SP 19 150 mm Granular A 450 mm Granular B	40 mm SP 12.5 FC1 110 mm SP 19 150 mm Granular A 450 mm Granular B	40 mm SP 12.5 FC1 120 mm SP 19 150 mm Granular A 600 mm Granular B	40 mm SP 12.5 FC1 130 mm SP 19 150 mm Granular A 600 mm Granular B	40 mm SP 12.5 FC2 140 mm SP 19 150 mm Granular A 600 mm Granular B
40 MPa (CBR=4)	PCC	180 mm PCC 200 mm Granular A	190 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	210 mm PCC 200 mm Granular A
40 MPa (CBR=4)	HMA	40 mm SP 12.5 80 mm SP 19 150 mm Granular A 300 mm Granular B	40 mm SP 12.5 80 mm SP 19 150 mm Granular A 350 mm Granular B	40 mm SP 12.5 FC1 80 mm SP 19 150 mm Granular A 350 mm Granular B	40 mm SP 12.5 FC1 100 mm SP 19 150 mm Granular A 350 mm Granular B	40 mm SP 12.5 FC1 100 mm SP 19 150 mm Granular A 400 mm Granular B	40 mm SP 12.5 FC1 120 mm SP 19 150 mm Granular A 450 mm Granular B	40 mm SP 12.5 FC1 130 mm SP 19 150 mm Granular A 500 mm Granular B	40 mm SP 12.5 FC2 140 mm SP 19 150 mm Granular A 550 mm Granular B
50 MPa (CBR=5)	PCC	180 mm PCC 200 mm Granular A	190 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A	200 mm PCC 200 mm Granular A
50 MPa (CBR=5)	HMA	40 mm SP 12.5 80 mm SP 19 150 mm Granular A 300 mm Granular B	40 mm SP 12.5 80 mm SP 19 150 mm Granular A 300 mm Granular B	40 mm SP 12.5 FC1 80 mm SP 19 150 mm Granular A 300 mm Granular B	40 mm SP 12.5 FC1 100 mm SP 19 150 mm Granular A 300 mm Granular B	40 mm SP 12.5 FC1 100 mm SP 19 150 mm Granular A 350 mm Granular B	40 mm SP 12.5 FC1 110 mm SP 19 150 mm Granular A 400 mm Granular B	40 mm SP 12.5 FC1 130 mm SP 19 150 mm Granular A 450 mm Granular B	40 mm SP 12.5 FC2 140 mm SP 19 150 mm Granular A 500 mm Granular B
Concrete Slab and Joint Properties		No dowels Slab length = 4 m Tied shoulder/curb *		32M Dowel bars, 300 mm spacing Slab length = 4.5 m Tied shoulder/curb *		32M Dowel bars, 300 mm spacing Slab length = 4.5 m Tied shoulder/curb *		32M Dowel bars, 300 mm spacing Slab length = 4.5 m 0.5 m Widened outside slab or integral curb *	

Notes:

- All materials are based on current OPS Specifications
- Subgrade levels are based on three common subgrade materials in Ontario
  - Low Category (30 MPa) - Low Plasticity Clay Subgrade
  - Medium Category (40 MPa) - Low Plasticity Silt Subgrade
  - High Category (50 MPa) - Sandy Silt Subgrade

* For urban sections, a tied concrete curb or a monolithic slab and curb can be used as a tied shoulder or widened slab respectively.

Reliability Levels

- AADTT 250 to 500 - 75%
- AADTT 1,000 to 1,500 - 80%
- AADTT 2,500 to 5,000 - 90%
- AADTT 7,500 to 10,000 - 95%

APPENDIX B

LIFE-CYCLE COST ANALYSIS RESULTS

Typical Ontario Municipal Pavements

LIFE CYCLE COST ANALYSIS SUMMARY

Listed by 25 Year AADTT and Pavement Type for Low Strength Subgrade

Item	Collector			
	250 PCC	**250 HMA**	**500 PCC**	**500 HMA**
Initial Cost	$ 425,100	$ 430,236	$ 436,950	$ 448,236
M&R Cost (Discounted)	$ 32,955	$ 64,406	$ 32,955	$ 64,406
Total Cost	$ 458,055	$ 494,642	$ 469,905	$ 512,642
LCC Difference	**7%**		**8%**	

Item	Minor Arterial			
	1,000 PCC	**1,000 HMA**	**1,500 PCC**	**1,500 HMA**
Initial Cost	$ 490,050	$ 494,748	$ 490,050	$ 513,810
M&R Cost (Discounted)	$ 57,553	$ 87,998	$ 57,553	$ 86,278
Total Cost	$ 547,603	$ 582,746	$ 547,603	$ 600,088
LCC Difference	**6%**		**9%**	

Item	Major Arterial			
	2,500 PCC	**2,500 HMA**	**5,000 PCC**	**5,000 HMA**
Initial Cost	$ 980,100	$ 1,065,744	$ 980,100	$ 1,211,868
M&R Cost (Discounted)	$ 136,916	$ 191,192	$ 136,916	$ 191,192
Total Cost	$ 1,117,016	$ 1,256,936	$ 1,117,016	$ 1,403,060
LCC Difference	**11%**		**20%**	

Item	Major Arterial			
	7,500 PCC	**7,500 HMA**	**10,000 PCC**	**10,000 HMA**
Initial Cost	$ 1,070,720	$ 1,333,325	$ 1,121,280	$ 1,382,054
M&R Cost (Discounted)	$ 170,523	$ 342,478	$ 170,523	$ 349,035
Total Cost	$ 1,241,243	$ 1,675,803	$ 1,291,803	$ 1,731,090
LCC Difference	**26%**		**25%**	

Road Class **Municipal Collector PCC**
AADTT **250**
Subgrade **30 MPa (CBR=3)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design	
180	mm PCC
200	mm Granular A
No	Dowels
4	m Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	180 mm PCC pavement, no dowels (m^2)	180	7500	$ 41.20	$ 309,000
Base	Granular A, mm (t)	200	3600	$ 18.00	$ 64,800
Excavation	Earth excavation (m^3)	380	2850	$ 18.00	$ 51,300
	Total Initial Cost				**$ 425,100**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Reseal joints, % Length (m)	10	188	$ 10.00	$ 1,875	$ 1,044
25	Partial depth PCC repair, % area (m^2)	2	150	$ 125.00	$ 18,750	$ 5,537
25	Full depth PCC repair, % area (m^2)	5	375	$ 100.00	$ 37,500	$ 11,074
25	Reseal joints, % Length (m)	20	375	$ 10.00	$ 3,750	$ 1,107
40	Partial depth PCC repair, % area (m^2)	5	375	$ 125.00	$ 46,875	$ 6,658
40	Full depth PCC repair, % area (m^2)	10	750	$ 100.00	$ 75,000	$ 10,653
40	Reseal joints, % Length (m)	20	375	$ 10.00	$ 3,750	$ 533
50	Residual Value				$ 41,875	$ 3,652
	Total M&R Cost				**$ 145,625**	**$ 32,955**

Road Class **Municipal Collector HMA**
AADTT **250**
Subgrade **30 MPa (CBR=3)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design	
40	mm SP 12.5
80	mm SP 19
150	mm Granular A
350	mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490
Binder	Superpave 19, mm (t)	80	1,476	$ 96.00	$ 141,696
Base	Granular A, mm (t)	150	2,700	$ 18.00	$ 48,600
Subbase	Granular B, mm (t)	350	5,250	$ 15.00	$ 78,750
Excavation	Earth excavation (m^3)	620	4,650	$ 18.00	$ 83,700
	Total Initial Cost				**$ 430,236**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
10	Rout and seal, m/km (m)	250	250	$ 5.00	$ 1,250	$ 767
10	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	2	150	$ 35.00	$ 5,250	$ 3,223
20	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 4,240
20	Resurface with Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490	$ 29,205
25	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 738
30	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	375	$ 35.00	$ 13,125	$ 3,037
35	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 2,040
35	Full depth asphalt base repair, % area (m^2)	5	375	$ 45.00	$ 16,875	$ 3,059
35	Resurface with Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490	$ 14,048
40	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 355
43	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	375	$ 35.00	$ 13,125	$ 1,610
48	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 1,082
48	Resurface with Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490	$ 7,450
50	Residual value				$ 73,950	$ 6,449
	Total M&R Cost				**$ 158,155**	**$ 64,406**

Road Class **Municipal Collector PCC**
AADTT **500**
Subgrade **30 MPa (CBR=3)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design	
190	mm PCC
200	mm Granular A
No	Dowels
4	m Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section, m	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	190 mm PCC pavement, no dowels (m²)	190	7500	$ 42.60	$ 319,500
Base	Granular A, mm (t)	200	3600	$ 18.00	$ 64,800
Excavation	Earth excavation (m³)	390	2925	$ 18.00	$ 52,650
	Total Initial Cost				**$ 436,950**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Reseal joints, % Length (m)	10	188	$ 10.00	$ 1,875	$ 1,044
25	Partial depth PCC repair, % area (m²)	2	150	$ 125.00	$ 18,750	$ 5,537
25	Full depth PCC repair, % area (m²)	5	375	$ 100.00	$ 37,500	$ 11,074
25	Reseal joints, % Length (m)	20	375	$ 10.00	$ 3,750	$ 1,107
40	Partial depth PCC repair, % area (m²)	5	375	$ 125.00	$ 46,875	$ 6,658
40	Full depth PCC repair, % area (m²)	10	750	$ 100.00	$ 75,000	$ 10,653
40	Reseal joints, % Length (m)	20	375	$ 10.00	$ 3,750	$ 533
50	Residual Value				$ 41,875	$ 3,652
	Total M&R Cost				**$ 145,625**	**$ 32,955**

Road Class **Municipal Collector HMA**
AADTT **500**
Subgrade **30 MPa (CBR=3)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design
40 mm SP 12.5
80 mm SP 19
150 mm Granular A
400 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490
Binder	Superpave 19, mm (t)	80	1,476	$ 96.00	$ 141,696
Base	Granular A, mm (t)	150	2,700	$ 18.00	$ 48,600
Subbase	Granular B, mm (t)	400	6,000	$ 15.00	$ 90,000
Excavation	Earth excavation (m^3)	670	5,025	$ 18.00	$ 90,450
	Total Initial Cost				**$ 448,236**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
10	Rout and seal, m/km (m)	250	250	$ 5.00	$ 1,250	$ 767
10	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	2	150	$ 35.00	$ 5,250	$ 3,223
20	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 4,240
20	Resurface with Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490	$ 29,205
25	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 738
30	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	375	$ 35.00	$ 13,125	$ 3,037
35	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 2,040
35	Full depth asphalt base repair, % area (m^2)	5	375	$ 45.00	$ 16,875	$ 3,059
35	Resurface with Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490	$ 14,048
40	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 355
43	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	375	$ 35.00	$ 13,125	$ 1,610
48	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 1,082
48	Resurface with Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490	$ 7,450
50	Residual value				$ 73,950	$ 6,449
	Total M&R Cost				**$ 158,155**	**$ 64,406**

Road Class **Municipal Minor Arterial PCC**
AADTT **1000**
Subgrade **30 MPa (CBR=3)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design	
200	mm PCC
200	mm Granular A
32	M Dowels
4.5	m Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	200 mm PCC pavement, 32M dowels (m^2)	200	7500	$ 49.50	$ 371,250
Base	Granular A, mm (t)	200	3600	$ 18.00	$ 64,800
Excavation	Earth excavation (m^3)	400	3000	$ 18.00	$ 54,000
	Total Initial Cost				**$ 490,050**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Reseal joints, % Length (m)	20	333	$ 10.00	$ 3,333	$ 1,856
25	Partial depth PCC repair, % area (m^2)	5	375	$ 125.00	$ 46,875	$ 13,842
25	Full depth PCC repair, % area (m^2)	10	750	$ 100.00	$ 75,000	$ 22,148
25	Reseal joints, % Length (m)	25	417	$ 10.00	$ 4,167	$ 1,230
40	Partial depth PCC repair, % area (m^2)	5	375	$ 125.00	$ 46,875	$ 6,658
40	Full depth PCC repair, % area (m^2)	15	1125	$ 100.00	$ 112,500	$ 15,980
40	Reseal joints, % Length (m)	25	417	$ 10.00	$ 4,167	$ 592
50	Residual Value				$ 54,514	$ 4,754
	Total M&R Cost				**$ 238,403**	**$ 57,553**

Road Class **Municipal Minor Arterial HMA**
AADTT **1000**
Subgrade **30 MPa (CBR=3)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design
40 mm SP 12.5 FC1
90 mm SP 19
150 mm Granular A
450 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940
Binder	Superpave 19, mm (t)	90	1,661	$ 96.00	$ 159,408
Base	Granular A, mm (t)	150	2,700	$ 18.00	$ 48,600
Subbase	Granular B, mm (t)	450	6,750	$ 15.00	$ 101,250
Excavation	Earth excavation (m^3)	730	5,475	$ 18.00	$ 98,550
	Total Initial Cost				**$ 494,748**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
10	Rout and seal, m/km (m)	250	250	$ 5.00	$ 1,250	$ 767
10	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	2	150	$ 35.00	$ 5,250	$ 3,223
15	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	10	750	$ 35.00	$ 26,250	$ 12,627
20	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 4,240
20	Resurface with Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940	$ 32,767
25	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 738
30	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	375	$ 35.00	$ 13,125	$ 3,037
35	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 2,040
35	Full depth asphalt base repair, % area (m^2)	10	750	$ 45.00	$ 33,750	$ 6,119
35	Resurface with Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940	$ 15,761
40	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 355
43	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	375	$ 35.00	$ 13,125	$ 1,610
48	Mill HMA, mm (t)	90	1688	$ 15.00	$ 25,313	$ 2,434
48	Resurface with Superpave 19, mm (t)	50	923	$ 96.00	$ 88,560	$ 8,514
48	Resurface with Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940	$ 8,359
50	Residual value				$ 167,344	$ 14,593
	Total M&R Cost				**$ 126,786**	**$ 87,998**

Road Class **Municipal Minor Arterial PCC**
AADTT **1500**
Subgrade **30 MPa (CBR=3)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design	
200	mm PCC
200	mm Granular A
32	M Dowels
4.5	m Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	200 mm PCC pavement, 32M dowels (m^2)	200	7500	$ 49.50	$ 371,250
Base	Granular A, mm (t)	200	3600	$ 18.00	$ 64,800
Excavation	Earth excavation (m^3)	400	3000	$ 18.00	$ 54,000
	Total Initial Cost				**$ 490,050**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Reseal joints, % Length (m)	20	333	$ 10.00	$ 3,333	$ 1,856
25	Partial depth PCC repair, % area (m^2)	5	375	$ 125.00	$ 46,875	$ 13,842
25	Full depth PCC repair, % area (m^2)	10	750	$ 100.00	$ 75,000	$ 22,148
25	Reseal joints, % Length (m)	25	417	$ 10.00	$ 4,167	$ 1,230
40	Partial depth PCC repair, % area (m^2)	5	375	$ 125.00	$ 46,875	$ 6,658
40	Full depth PCC repair, % area (m^2)	15	1125	$ 100.00	$ 112,500	$ 15,980
40	Reseal joints, % Length (m)	25	417	$ 10.00	$ 4,167	$ 592
50	Residual Value				$ 54,514	$ 4,754
	Total M&R Cost				**$ 238,403**	**$ 57,553**

Road Class **Municipal Minor Arterial HMA**
AADTT **1500**
Subgrade **30 MPa (CBR=3)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design
40 mm SP 12.5 FC1
100 mm SP 19
150 mm Granular A
450 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section	1000

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per km**	**Price per unit of quantity**	**Cost**
Surface	Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940
Binder	Superpave 19, mm (t)	100	1,845	$ 96.00	$ 177,120
Base	Granular A, mm (t)	150	2,700	$ 18.00	$ 48,600
Subbase	Granular B, mm (t)	450	6,750	$ 15.00	$ 101,250
Excavation	Earth excavation (m³)	740	5,550	$ 18.00	$ 99,900
	Total Initial Cost				**$ 513,810**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
10	Rout and seal, m/km (m)	250	250	$ 5.00	$ 1,250	$ 767
10	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	2	150	$ 35.00	$ 5,250	$ 3,223
18	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	10	750	$ 35.00	$ 26,250	$ 10,907
20	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 4,240
20	Resurface with Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940	$ 32,767
25	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 738
30	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	5	375	$ 35.00	$ 13,125	$ 3,037
35	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 2,040
35	Full depth asphalt base repair, % area (m²)	10	750	$ 45.00	$ 33,750	$ 6,119
35	Resurface with Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940	$ 15,761
40	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 355
43	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	5	375	$ 35.00	$ 13,125	$ 1,610
48	Mill HMA, mm (t)	90	1688	$ 15.00	$ 25,313	$ 2,434
48	Resurface with Superpave 19, mm (t)	50	923	$ 96.00	$ 88,560	$ 8,514
48	Resurface with Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940	$ 8,359
50	Residual value				$ 167,344	$ 14,593
	Total M&R Cost				**$ 126,786**	**$ 86,278**

Road Class **Municipal Major Arterial PCC**
AADTT **2,500**
Subgrade **30 MPa (CBR=3)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design
200 mm PCC
200 mm Granular A
32 M Dowels
4.5 m Slab Length
Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road, m	15.0
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	200 mm PCC pavement, 32M dowels (m²)	200	15000	$ 49.50	$ 742,500
Base	Granular A, mm (t)	200	7200	$ 18.00	$ 129,600
Excavation	Earth excavation (m³)	400	6000	$ 18.00	$ 108,000
	Total Initial Cost				**$ 980,100**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Partial depth PCC repair, % area (m²)	2	300	$ 125.00	$ 37,500	$ 20,881
12	Reseal joints, % Length (m)	25	833	$ 10.00	$ 8,333	$ 4,640
25	Partial depth PCC repair, % area (m²)	5	750	$ 125.00	$ 93,750	$ 27,685
25	Full depth PCC repair, % area (m²)	10	1500	$ 100.00	$ 150,000	$ 44,295
25	Reseal joints, % Length (m)	25	833	$ 10.00	$ 8,333	$ 2,461
40	Partial depth PCC repair, % area (m²)	5	750	$ 125.00	$ 93,750	$ 13,317
40	Full depth PCC repair, % area (m²)	15	2250	$ 100.00	$ 225,000	$ 31,960
40	Reseal joints, % Length (m)	25	833	$ 10.00	$ 8,333	$ 1,184
50	Residual Value				$ 109,028	$ 9,508
	Total M&R Cost				**$ 515,972**	**$ 136,916**

Road Class **Municipal Major Arterial HMA**
AADTT **2,500**
Subgrade **30 MPa (CBR=3)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design
40 mm SP 12.5 FC1
110 mm SP 19
150 mm Granular A
450 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road m	15.0
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	Superpave 12.5FC1, mm (t)	40	1,512	$ 115.00	$ 173,880
Binder	Superpave 19, mm (t)	110	4,059	$ 96.00	$ 389,664
Base	Granular A, mm (t)	150	5,400	$ 18.00	$ 97,200
Subbase	Granular B, mm (t)	450	13,500	$ 15.00	$ 202,500
Excavation	Earth excavation (m³)	750	11,250	$ 18.00	$ 202,500
	Total Initial Cost				**$ 1,065,744**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
5	Rout and seal, m/km (m)	200	200	$ 5.00	$ 1,000	$ 784
10	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 1,535
10	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	5	750	$ 35.00	$ 26,250	$ 16,115
20	Mill HMA, mm (t)	40	1500	$ 15.00	$ 22,500	$ 8,480
20	Resurface with Superpave 12.5FC1, mm (t)	40	1512	$ 115.00	$ 173,880	$ 65,534
25	Rout and seal, m/km (m)	1000	1000	$ 5.00	$ 5,000	$ 1,477
30	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	10	1500	$ 35.00	$ 52,500	$ 12,147
35	Mill HMA, mm (t)	90	3375	$ 15.00	$ 50,625	$ 9,178
35	Resurface with Superpave 19, mm (t)	50	1845	$ 96.00	$ 177,120	$ 32,110
35	Resurface with Superpave 12.5FC1, mm (t)	40	1512	$ 115.00	$ 173,880	$ 31,523
40	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 1,065
45	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	10	1500	$ 35.00	$ 52,500	$ 5,843
48	Mill HMA, mm (t)	40	1500	$ 15.00	$ 22,500	$ 2,163
48	Full depth asphalt base repair, % area (m²)	5	750	$ 45.00	$ 33,750	$ 3,245
48	Resurface with Superpave 12.5FC1, mm (t)	40	1512	$ 115.00	$ 173,880	$ 16,717
50	Residual value				$ 191,775	$ 16,723
	Total M&R Cost				**$ 553,480**	**$ 191,192**

Road Class	**Municipal Major Arterial PCC**
AADTT	**5,000**
Subgrade	**30 MPa (CBR=3)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design	
200	mm PCC
200	mm Granular A
32	M Dowels
4.5	m Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road, m	15.0
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	200 mm PCC pavement, 32M dowels (m^2)	200	15000	$ 49.50	$ 742,500
Base	Granular A, mm (t)	200	7200	$ 18.00	$ 129,600
Excavation	Earth excavation (m^3)	400	6000	$ 18.00	$ 108,000
	Total Initial Cost				**$ 980,100**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Partial depth PCC repair, % area (m^2)	2	300	$ 125.00	$ 37,500	$ 20,881
12	Reseal joints, % Length (m)	25	833	$ 10.00	$ 8,333	$ 4,640
25	Partial depth PCC repair, % area (m^2)	5	750	$ 125.00	$ 93,750	$ 27,685
25	Full depth PCC repair, % area (m^2)	10	1500	$ 100.00	$ 150,000	$ 44,295
25	Reseal joints, % Length (m)	25	833	$ 10.00	$ 8,333	$ 2,461
40	Partial depth PCC repair, % area (m^2)	5	750	$ 125.00	$ 93,750	$ 13,317
40	Full depth PCC repair, % area (m^2)	15	2250	$ 100.00	$ 225,000	$ 31,960
40	Reseal joints, % Length (m)	25	833	$ 10.00	$ 8,333	$ 1,184
50	Residual Value				$ 109,028	$ 9,508
	Total M&R Cost				**$ 515,972**	**$ 136,916**

Road Class **Municipal Major Arterial HMA**
AADTT **5,000**
Subgrade **30 MPa (CBR=3)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design
40 mm SP 12.5 FC1
120 mm SP 19
150 mm Granular A
600 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road m	15.0
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	Superpave 12.5FC1, mm (t)	40	1,512	$ 115.00	$ 173,880
Binder	Superpave 19, mm (t)	120	4,428	$ 96.00	$ 425,088
Base	Granular A, mm (t)	150	5,400	$ 18.00	$ 97,200
Subbase	Granular B, mm (t)	600	18,000	$ 15.00	$ 270,000
Excavation	Earth excavation (m^3)	910	13,650	$ 18.00	$ 245,700
	Total Initial Cost				**$ 1,211,868**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
5	Rout and seal, m/km (m)	200	200	$ 5.00	$ 1,000	$ 784
10	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 1,535
10	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	750	$ 35.00	$ 26,250	$ 16,115
20	Mill HMA, mm (t)	40	1500	$ 15.00	$ 22,500	$ 8,480
20	Resurface with Superpave 12.5FC1, mm (t)	40	1512	$ 115.00	$ 173,880	$ 65,534
25	Rout and seal, m/km (m)	1000	1000	$ 5.00	$ 5,000	$ 1,477
30	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	10	1500	$ 35.00	$ 52,500	$ 12,147
35	Mill HMA, mm (t)	90	3375	$ 15.00	$ 50,625	$ 9,178
35	Resurface with Superpave 19, mm (t)	50	1845	$ 96.00	$ 177,120	$ 32,110
35	Resurface with Superpave 12.5FC1, mm (t)	40	1512	$ 115.00	$ 173,880	$ 31,523
40	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 1,065
45	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	10	1500	$ 35.00	$ 52,500	$ 5,843
48	Mill HMA, mm (t)	40	1500	$ 15.00	$ 22,500	$ 2,163
48	Full depth asphalt base repair, % area (m^2)	5	750	$ 45.00	$ 33,750	$ 3,245
48	Resurface with Superpave 12.5FC1, mm (t)	40	1512	$ 115.00	$ 173,880	$ 16,717
50	Residual value				$ 191,775	$ 16,723
	Total M&R Cost				**$ 553,480**	**$ 191,192**

Road Class	**Municipal Major Arterial PCC**
AADTT	**7,500**
Subgrade	**30 MPa (CBR=3)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design	
210	mm PCC
200	mm Granular A
32	M Dowels
4.5	m Slab Length
0.5	m Widened Slab

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road, m	16.0
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	210 mm PCC pavement, 32M dowels (m²)	210	16000	$ 50.90	$ 814,400
Base	Granular A, mm (t)	200	7680	$ 18.00	$ 138,240
Excavation	Earth excavation (m³)	410	6560	$ 18.00	$ 118,080
	Total Initial Cost				**$ 1,070,720**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Partial depth PCC repair, % area (m²)	2	320	$ 125.00	$ 40,000	$ 22,273
12	Reseal joints, % Length (m)	25	889	$ 10.00	$ 8,889	$ 4,950
25	Partial depth PCC repair, % area (m²)	5	800	$ 125.00	$ 100,000	$ 29,530
25	Full depth PCC repair, % area (m²)	10	1600	$ 100.00	$ 160,000	$ 47,248
25	Reseal joints, % Length (m)	50	1778	$ 10.00	$ 17,778	$ 5,250
25	Texturize, % area (m²)	25	4000	$ 10.00	$ 40,000	$ 11,812
40	Partial depth PCC repair, % area (m²)	5	800	$ 125.00	$ 100,000	$ 14,205
40	Full depth PCC repair, % area (m²)	15	2400	$ 100.00	$ 240,000	$ 34,091
40	Reseal joints, % Length (m)	50	1778	$ 10.00	$ 17,778	$ 2,525
40	Texturize, % area (m²)	50	8000	$ 10.00	$ 80,000	$ 11,364
50	Residual Value				$ 145,926	$ 12,725
	Total M&R Cost				**$ 658,519**	**$ 170,523**

Road Class **Municipal Major Arterial HMA**
AADTT **7,500**
Subgrade **30 MPa (CBR=3)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design
40 mm SP 12.5 FC1
130 mm SP 19
150 mm Granular A
600 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road, m	16.0
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	Superpave 12.5FC1, mm (t)	40	1,613	$ 115.00	$ 185,472
Binder	Superpave 19, mm (t)	130	5,117	$ 96.00	$ 491,213
Base	Granular A, mm (t)	150	5,760	$ 18.00	$ 103,680
Subbase	Granular B, mm (t)	600	19,200	$ 15.00	$ 288,000
Excavation	Earth excavation (m³)	920	14,720	$ 18.00	$ 264,960
	Total Initial Cost				**$ 1,333,325**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
8	Rout and seal, m/km (m)	200	200	$ 5.00	$ 1,000	$ 677
8	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	5	800	$ 35.00	$ 28,000	$ 18,952
13	Rout and seal, m/km (m)	1000	1000	$ 5.00	$ 5,000	$ 2,652
13	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	15	2400	$ 35.00	$ 84,000	$ 44,547
18	Mill HMA, mm (t)	50	2000	$ 15.00	$ 30,000	$ 12,466
18	Full depth asphalt base repair, % area (m²)	10	1600	$ 45.00	$ 72,000	$ 29,917
18	Resurface with Superpave 12.5FC1, mm (t)	50	2016	$ 115.00	$ 231,840	$ 96,334
23	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 814
28	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 1,913
28	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	10	1600	$ 35.00	$ 56,000	$ 14,285
32	Mill HMA, mm (t)	90	3600	$ 15.00	$ 54,000	$ 11,333
32	Resurface with Superpave 19, mm (t)	50	1968	$ 96.00	$ 188,928	$ 39,650
32	Resurface with Superpave 12.5FC1, mm (t)	40	1613	$ 115.00	$ 185,472	$ 38,924
37	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 1,233
40	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	10	1600	$ 35.00	$ 56,000	$ 7,955
45	Mill HMA, mm (t)	50	2000	$ 15.00	$ 30,000	$ 3,339
45	Full depth asphalt base repair, % area (m²)	10	1600	$ 45.00	$ 72,000	$ 8,013
45	Resurface with Superpave 12.5FC1, mm (t)	50	2016	$ 115.00	$ 231,840	$ 25,803
50	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 654
50	Residual value				$ 194,740	$ 16,982
	Total M&R Cost				**$ 1,148,840**	**$ 342,478**

Road Class **Municipal Major Arterial PCC**
AADTT **10,000**
Subgrade **30 MPa (CBR=3)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design
230 mm PCC
200 mm Granular A
32 M Dowels
4.5 m Slab Length
0.5 m Widened Slab

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road, m	16.0
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	230 mm PCC pavement, 32M dowels (m²)	230	16000	$ 53.70	$ 859,200
Base	Granular A, mm (t)	200	7680	$ 18.00	$ 138,240
Excavation	Earth excavation (m³)	430	6880	$ 18.00	$ 123,840
	Total Initial Cost				**$ 1,121,280**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Partial depth PCC repair, % area (m²)	2	320	$ 125.00	$ 40,000	$ 22,273
12	Reseal joints, % Length (m)	25	889	$ 10.00	$ 8,889	$ 4,950
25	Partial depth PCC repair, % area (m²)	5	800	$ 125.00	$ 100,000	$ 29,530
25	Full depth PCC repair, % area (m²)	10	1600	$ 100.00	$ 160,000	$ 47,248
25	Reseal joints, % Length (m)	50	1778	$ 10.00	$ 17,778	$ 5,250
25	Texturize, % area (m²)	25	4000	$ 10.00	$ 40,000	$ 11,812
40	Partial depth PCC repair, % area (m²)	5	800	$ 125.00	$ 100,000	$ 14,205
40	Full depth PCC repair, % area (m²)	15	2400	$ 100.00	$ 240,000	$ 34,091
40	Reseal joints, % Length (m)	50	1778	$ 10.00	$ 17,778	$ 2,525
40	Texturize, % area (m²)	50	8000	$ 10.00	$ 80,000	$ 11,364
50	Residual Value				$ 145,926	$ 12,725
	Total M&R Cost				**$ 658,519**	**$ 170,523**

Road Class **Municipal Major Arterial HMA**
AADTT **10,000**
Subgrade **30 MPa (CBR=3)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design
40 mm SP 12.5 FC2
140 mm SP 19
150 mm Granular A
600 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road, m	16.0
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	Superpave 12.5FC2, mm (t)	40	1,613	$ 120.00	$ 193,536
Binder	Superpave 19, mm (t)	140	5,510	$ 96.00	$ 528,998
Base	Granular A, mm (t)	150	5,760	$ 18.00	$ 103,680
Subbase	Granular B, mm (t)	600	19,200	$ 15.00	$ 288,000
Excavation	Earth excavation (m^3)	930	14,880	$ 18.00	$ 267,840
	Total Initial Cost				**$ 1,382,054**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
8	Rout and seal, m/km (m)	200	200	$ 5.00	$ 1,000	$ 677
8	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	800	$ 35.00	$ 28,000	$ 18,952
13	Rout and seal, m/km (m)	1000	1000	$ 5.00	$ 5,000	$ 2,652
13	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	15	2400	$ 35.00	$ 84,000	$ 44,547
18	Mill HMA, mm (t)	50	2000	$ 15.00	$ 30,000	$ 12,466
18	Full depth asphalt base repair, % area (m^2)	10	1600	$ 45.00	$ 72,000	$ 29,917
18	Resurface with Superpave 12.5FC2, mm (t)	50	2016	$ 120.00	$ 241,920	$ 100,523
23	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 814
28	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 1,913
28	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	10	1600	$ 35.00	$ 56,000	$ 14,285
32	Mill HMA, mm (t)	90	3600	$ 15.00	$ 54,000	$ 11,333
32	Resurface with Superpave 19, mm (t)	50	1968	$ 96.00	$ 188,928	$ 39,650
32	Resurface with Superpave 12.5FC2, mm (t)	40	1613	$ 120.00	$ 193,536	$ 40,617
37	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 1,233
40	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	10	1600	$ 35.00	$ 56,000	$ 7,955
45	Mill HMA, mm (t)	50	2000	$ 15.00	$ 30,000	$ 3,339
45	Full depth asphalt base repair, % area (m^2)	10	1600	$ 45.00	$ 72,000	$ 8,013
45	Resurface with Superpave 12.5FC2, mm (t)	50	2016	$ 120.00	$ 241,920	$ 26,925
48	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 721
50	Residual value				$ 200,620	$ 17,495
	Total M&R Cost				**$ 1,171,184**	**$ 349,035**

Typical Ontario Municipal Pavements

LIFE CYCLE COST ANALYSIS SUMMARY

Listed by 25 Year AADTT and Pavement Type for Medium Strength Subgrade

Item	Collector			
	250 PCC	250 HMA	500 PCC	500 HMA
Initial Cost	$ 425,100	$ 412,236	$ 436,950	$ 430,236
M&R Cost (Discounted)	$ 32,955	$ 64,406	$ 32,955	$ 64,406
Total Cost	$ 458,055	$ 476,642	$ 469,905	$ 494,642
LCC Difference	4%		5%	

Item	Minor Arterial			
	1,000 PCC	1,000 HMA	1,500 PCC	1,500 HMA
Initial Cost	$ 490,050	$ 439,686	$ 490,050	$ 477,810
M&R Cost (Discounted)	$ 57,553	$ 87,998	$ 57,553	$ 86,278
Total Cost	$ 547,603	$ 527,684	$ 547,603	$ 564,088
LCC Difference	4%		3%	

Item	Major Arterial			
	2,500 PCC	2,500 HMA	5,000 PCC	5,000 HMA
Initial Cost	$ 980,100	$ 991,620	$ 980,100	$ 1,103,868
M&R Cost (Discounted)	$ 136,916	$ 200,051	$ 136,916	$ 191,192
Total Cost	$ 1,117,016	$ 1,191,671	$ 1,117,016	$ 1,295,060
LCC Difference	6%		14%	

Item	Major Arterial			
	7,500 PCC	7,500 HMA	10,000 PCC	10,000 HMA
Initial Cost	$ 1,045,440	$ 1,256,525	$ 1,070,720	$ 1,343,654
M&R Cost (Discounted)	$ 170,523	$ 342,478	$ 170,523	$ 349,035
Total Cost	$ 1,215,963	$ 1,599,003	$ 1,241,243	$ 1,692,690
LCC Difference	24%		27%	

Road Class **Municipal Collector PCC**
AADTT **250**
Subgrade **40 MPa (CBR=4)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design
180 mm PCC
200 mm Granular A
No Dowels
4 m Slab Length
Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	180 mm PCC pavement, no dowels (m²)	180	7500	$ 41.20	$ 309,000
Base	Granular A, mm (t)	200	3600	$ 18.00	$ 64,800
Excavation	Earth excavation (m³)	380	2850	$ 18.00	$ 51,300
	Total Initial Cost				**$ 425,100**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Reseal joints, % Length (m)	10	188	$ 10.00	$ 1,875	$ 1,044
25	Partial depth PCC repair, % area (m²)	2	150	$ 125.00	$ 18,750	$ 5,537
25	Full depth PCC repair, % area (m²)	5	375	$ 100.00	$ 37,500	$ 11,074
25	Reseal joints, % Length (m)	20	375	$ 10.00	$ 3,750	$ 1,107
40	Partial depth PCC repair, % area (m²)	5	375	$ 125.00	$ 46,875	$ 6,658
40	Full depth PCC repair, % area (m²)	10	750	$ 100.00	$ 75,000	$ 10,653
40	Reseal joints, % Length (m)	20	375	$ 10.00	$ 3,750	$ 533
50	Residual Value				$ 41,875	$ 3,652
	Total M&R Cost				**$ 145,625**	**$ 32,955**

Road Class **Municipal Collector HMA**
AADTT **250**
Subgrade **40 MPa (CBR=4)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design
40 mm SP 12.5
80 mm SP 19
150 mm Granular A
300 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490
Binder	Superpave 19, mm (t)	80	1,476	$ 96.00	$ 141,696
Base	Granular A, mm (t)	150	2,700	$ 18.00	$ 48,600
Subbase	Granular B, mm (t)	300	4,500	$ 15.00	$ 67,500
Excavation	Earth excavation (m^3)	570	4,275	$ 18.00	$ 76,950
	Total Initial Cost				**$ 412,236**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
10	Rout and seal, m/km (m)	250	250	$ 5.00	$ 1,250	$ 767
10	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	2	150	$ 35.00	$ 5,250	$ 3,223
20	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 4,240
20	Resurface with Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490	$ 29,205
25	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 738
30	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	375	$ 35.00	$ 13,125	$ 3,037
35	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 2,040
35	Full depth asphalt base repair, % area (m^2)	5	375	$ 45.00	$ 16,875	$ 3,059
35	Resurface with Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490	$ 14,048
40	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 355
43	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	375	$ 35.00	$ 13,125	$ 1,610
48	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 1,082
48	Resurface with Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490	$ 7,450
50	Residual value				$ 73,950	$ 6,449
	Total M&R Cost				**$ 158,155**	**$ 64,406**

Road Class	**Municipal Collector PCC**
AADTT	**500**
Subgrade	**40 MPa (CBR=4)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design	
190	mm PCC
200	mm Granular A
No	Dowels
4	m Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section, m	1000

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per km**	**Price per unit of quantity**	**Cost**
Surface	190 mm PCC pavement, no dowels (m²)	190	7500	$ 42.60	$ 319,500
Base	Granular A, mm (t)	200	3600	$ 18.00	$ 64,800
Excavation	Earth excavation (m³)	390	2925	$ 18.00	$ 52,650
	Total Initial Cost				**$ 436,950**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
12	Reseal joints, % Length (m)	10	188	$ 10.00	$ 1,875	$ 1,044
25	Partial depth PCC repair, % area (m²)	2	150	$ 125.00	$ 18,750	$ 5,537
25	Full depth PCC repair, % area (m²)	5	375	$ 100.00	$ 37,500	$ 11,074
25	Reseal joints, % Length (m)	20	375	$ 10.00	$ 3,750	$ 1,107
40	Partial depth PCC repair, % area (m²)	5	375	$ 125.00	$ 46,875	$ 6,658
40	Full depth PCC repair, % area (m²)	10	750	$ 100.00	$ 75,000	$ 10,653
40	Reseal joints, % Length (m)	20	375	$ 10.00	$ 3,750	$ 533
50	Residual Value				$ 41,875	$ 3,652
	Total M&R Cost				**$ 145,625**	**$ 32,955**

Road Class	**Municipal Collector HMA**
AADTT	**500**
Subgrade	**40 MPa (CBR=4)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design
40 mm SP 12.5
80 mm SP 19
150 mm Granular A
350 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section	1000

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per km**	**Price per unit of quantity**	**Cost**
Surface	Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490
Binder	Superpave 19, mm (t)	80	1,476	$ 96.00	$ 141,696
Base	Granular A, mm (t)	150	2,700	$ 18.00	$ 48,600
Subbase	Granular B, mm (t)	350	5,250	$ 15.00	$ 78,750
Excavation	Earth excavation (m^3)	620	4,650	$ 18.00	$ 83,700
	Total Initial Cost				**$ 430,236**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
10	Rout and seal, m/km (m)	250	250	$ 5.00	$ 1,250	$ 767
10	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	2	150	$ 35.00	$ 5,250	$ 3,223
20	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 4,240
20	Resurface with Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490	$ 29,205
25	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 738
30	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	375	$ 35.00	$ 13,125	$ 3,037
35	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 2,040
35	Full depth asphalt base repair, % area (m^2)	5	375	$ 45.00	$ 16,875	$ 3,059
35	Resurface with Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490	$ 14,048
40	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 355
43	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	375	$ 35.00	$ 13,125	$ 1,610
48	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 1,082
48	Resurface with Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490	$ 7,450
50	Residual value				$ 73,950	$ 6,449
	Total M&R Cost				**$ 158,155**	**$ 64,406**

Road Class **Municipal Minor Arterial PCC**
AADTT **1000**
Subgrade **40 MPa (CBR=4)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design	
200	mm PCC
200	mm Granular A
32	M Dowels
4.5	m Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	200 mm PCC pavement, 32M dowels (m^2)	200	7500	$ 49.50	$ 371,250
Base	Granular A, mm (t)	200	3600	$ 18.00	$ 64,800
Excavation	Earth excavation (m^3)	400	3000	$ 18.00	$ 54,000
	Total Initial Cost				**$ 490,050**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Reseal joints, % Length (m)	20	333	$ 10.00	$ 3,333	$ 1,856
25	Partial depth PCC repair, % area (m^2)	5	375	$ 125.00	$ 46,875	$ 13,842
25	Full depth PCC repair, % area (m^2)	10	750	$ 100.00	$ 75,000	$ 22,148
25	Reseal joints, % Length (m)	25	417	$ 10.00	$ 4,167	$ 1,230
40	Partial depth PCC repair, % area (m^2)	5	375	$ 125.00	$ 46,875	$ 6,658
40	Full depth PCC repair, % area (m^2)	15	1125	$ 100.00	$ 112,500	$ 15,980
40	Reseal joints, % Length (m)	25	417	$ 10.00	$ 4,167	$ 592
50	Residual Value				$ 54,514	$ 4,754
	Total M&R Cost				**$ 238,403**	**$ 57,553**

Road Class **Municipal Minor Arterial HMA**
AADTT **1000**
Subgrade **40 MPa (CBR=4)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design
40 mm SP 12.5 FC1
80 mm SP 19
150 mm Granular A
350 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section	1000

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per km**	**Price per unit of quantity**	**Cost**
Surface	Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940
Binder	Superpave 19, mm (t)	80	1,476	$ 96.00	$ 141,696
Base	Granular A, mm (t)	150	2,700	$ 18.00	$ 48,600
Subbase	Granular B, mm (t)	350	5,250	$ 15.00	$ 78,750
Excavation	Earth excavation (m^3)	620	4,650	$ 18.00	$ 83,700
	Total Initial Cost				**$ 439,686**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
10	Rout and seal, m/km (m)	250	250	$ 5.00	$ 1,250	$ 767
10	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	2	150	$ 35.00	$ 5,250	$ 3,223
15	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	10	750	$ 35.00	$ 26,250	$ 12,627
20	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 4,240
20	Resurface with Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940	$ 32,767
25	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 738
30	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	375	$ 35.00	$ 13,125	$ 3,037
35	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 2,040
35	Full depth asphalt base repair, % area (m^2)	10	750	$ 45.00	$ 33,750	$ 6,119
35	Resurface with Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940	$ 15,761
40	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 355
43	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	375	$ 35.00	$ 13,125	$ 1,610
48	Mill HMA, mm (t)	90	1688	$ 15.00	$ 25,313	$ 2,434
48	Resurface with Superpave 19, mm (t)	50	923	$ 96.00	$ 88,560	$ 8,514
48	Resurface with Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940	$ 8,359
50	Residual value				$ 167,344	$ 14,593
	Total M&R Cost				**$ 126,786**	**$ 87,998**

Road Class **Municipal Minor Arterial PCC**
AADTT **1500**
Subgrade **40 MPa (CBR=4)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design	
200	mm PCC
200	mm Granular A
32	M Dowels
4.5	m Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section	1000

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per km**	**Price per unit of quantity**	**Cost**
Surface	200 mm PCC pavement, 32M dowels (m²)	200	7500	$ 49.50	$ 371,250
Base	Granular A, mm (t)	200	3600	$ 18.00	$ 64,800
Excavation	Earth excavation (m³)	400	3000	$ 18.00	$ 54,000
	Total Initial Cost				**$ 490,050**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
12	Reseal joints, % Length (m)	20	333	$ 10.00	$ 3,333	$ 1,856
25	Partial depth PCC repair, % area (m²)	5	375	$ 125.00	$ 46,875	$ 13,842
25	Full depth PCC repair, % area (m²)	10	750	$ 100.00	$ 75,000	$ 22,148
25	Reseal joints, % Length (m)	25	417	$ 10.00	$ 4,167	$ 1,230
40	Partial depth PCC repair, % area (m²)	5	375	$ 125.00	$ 46,875	$ 6,658
40	Full depth PCC repair, % area (m²)	15	1125	$ 100.00	$ 112,500	$ 15,980
40	Reseal joints, % Length (m)	25	417	$ 10.00	$ 4,167	$ 592
50	Residual Value				$ 54,514	$ 4,754
	Total M&R Cost				**$ 238,403**	**$ 57,553**

Road Class	**Municipal Minor Arterial HMA**
AADTT	**1500**
Subgrade	**40 MPa (CBR=4)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design
40 mm SP 12.5 FC1
100 mm SP 19
150 mm Granular A
350 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940
Binder	Superpave 19, mm (t)	100	1,845	$ 96.00	$ 177,120
Base	Granular A, mm (t)	150	2,700	$ 18.00	$ 48,600
Subbase	Granular B, mm (t)	350	5,250	$ 15.00	$ 78,750
Excavation	Earth excavation (m³)	640	4,800	$ 18.00	$ 86,400
	Total Initial Cost				**$ 477,810**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
10	Rout and seal, m/km (m)	250	250	$ 5.00	$ 1,250	$ 767
10	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	2	150	$ 35.00	$ 5,250	$ 3,223
18	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	10	750	$ 35.00	$ 26,250	$ 10,907
20	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 4,240
20	Resurface with Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940	$ 32,767
25	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 738
30	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	5	375	$ 35.00	$ 13,125	$ 3,037
35	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 2,040
35	Full depth asphalt base repair, % area (m²)	10	750	$ 45.00	$ 33,750	$ 6,119
35	Resurface with Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940	$ 15,761
40	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 355
43	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	5	375	$ 35.00	$ 13,125	$ 1,610
48	Mill HMA, mm (t)	90	1688	$ 15.00	$ 25,313	$ 2,434
48	Resurface with Superpave 19, mm (t)	50	923	$ 96.00	$ 88,560	$ 8,514
48	Resurface with Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940	$ 8,359
50	Residual value				$ 167,344	$ 14,593
	Total M&R Cost				**$ 126,786**	**$ 86,278**

Road Class **Municipal Major Arterial PCC**
AADTT **2,500**
Subgrade **40 MPa (CBR=4)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design	
200	mm PCC
200	mm Granular A
32	M Dowels
4.5	m Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road, m	15.0
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	200 mm PCC pavement, 32M dowels (m^2)	200	15000	$ 49.50	$ 742,500
Base	Granular A, mm (t)	200	7200	$ 18.00	$ 129,600
Excavation	Earth excavation (m^3)	400	6000	$ 18.00	$ 108,000
	Total Initial Cost				**$ 980,100**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Partial depth PCC repair, % area (m^2)	2	300	$ 125.00	$ 37,500	$ 20,881
12	Reseal joints, % Length (m)	25	833	$ 10.00	$ 8,333	$ 4,640
25	Partial depth PCC repair, % area (m^2)	5	750	$ 125.00	$ 93,750	$ 27,685
25	Full depth PCC repair, % area (m^2)	10	1500	$ 100.00	$ 150,000	$ 44,295
25	Reseal joints, % Length (m)	25	833	$ 10.00	$ 8,333	$ 2,461
40	Partial depth PCC repair, % area (m^2)	5	750	$ 125.00	$ 93,750	$ 13,317
40	Full depth PCC repair, % area (m^2)	15	2250	$ 100.00	$ 225,000	$ 31,960
40	Reseal joints, % Length (m)	25	833	$ 10.00	$ 8,333	$ 1,184
50	Residual Value				$ 109,028	$ 9,508
	Total M&R Cost				**$ 515,972**	**$ 136,916**

Road Class	**Municipal Major Arterial HMA**
AADTT	**2,500**
Subgrade	**40 MPa (CBR=4)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design
40 mm SP 12.5 FC1
100 mm SP 19
150 mm Granular A
400 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road m	15.0
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	Superpave 12.5FC1, mm (t)	40	1,512	$ 115.00	$ 173,880
Binder	Superpave 19, mm (t)	100	3,690	$ 96.00	$ 354,240
Base	Granular A, mm (t)	150	5,400	$ 18.00	$ 97,200
Subbase	Granular B, mm (t)	400	12,000	$ 15.00	$ 180,000
Excavation	Earth excavation (m^3)	690	10,350	$ 18.00	$ 186,300
	Total Initial Cost				**$ 991,620**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
5	Rout and seal, m/km (m)	200	200	$ 5.00	$ 1,000	$ 784
10	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 1,535
10	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	750	$ 35.00	$ 26,250	$ 16,115
20	Mill HMA, mm (t)	40	1500	$ 15.00	$ 22,500	$ 8,480
20	Resurface with Superpave 12.5FC1, mm (t)	40	1512	$ 115.00	$ 173,880	$ 65,534
25	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	1000	1000	$ 35.00	$ 35,000	$ 10,336
30	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	10	1500	$ 35.00	$ 52,500	$ 12,147
35	Mill HMA, mm (t)	90	3375	$ 15.00	$ 50,625	$ 9,178
35	Resurface with Superpave 19, mm (t)	50	1845	$ 96.00	$ 177,120	$ 32,110
35	Resurface with Superpave 12.5FC1, mm (t)	40	1512	$ 115.00	$ 173,880	$ 31,523
40	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 1,065
45	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	10	1500	$ 35.00	$ 52,500	$ 5,843
48	Mill HMA, mm (t)	40	1500	$ 15.00	$ 22,500	$ 2,163
48	Full depth asphalt base repair, % area (m^2)	5	750	$ 45.00	$ 33,750	$ 3,245
48	Resurface with Superpave 12.5FC1, mm (t)	40	1512	$ 115.00	$ 173,880	$ 16,717
50	Residual value				$ 191,775	$ 16,723
	Total M&R Cost				**$ 583,480**	**$ 200,051**

2011-01-10

Road Class **Municipal Major Arterial PCC**
AADTT **5,000**
Subgrade **40 MPa (CBR=4)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design
200 mm PCC
200 mm Granular A
32 M Dowels
4.5 m Slab Length
Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road, m	15.0
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	200 mm PCC pavement, 32M dowels (m^2)	200	15000	$ 49.50	$ 742,500
Base	Granular A, mm (t)	200	7200	$ 18.00	$ 129,600
Excavation	Earth excavation (m^3)	400	6000	$ 18.00	$ 108,000
	Total Initial Cost				**$ 980,100**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Partial depth PCC repair, % area (m^2)	2	300	$ 125.00	$ 37,500	$ 20,881
12	Reseal joints, % Length (m)	25	833	$ 10.00	$ 8,333	$ 4,640
25	Partial depth PCC repair, % area (m^2)	5	750	$ 125.00	$ 93,750	$ 27,685
25	Full depth PCC repair, % area (m^2)	10	1500	$ 100.00	$ 150,000	$ 44,295
25	Reseal joints, % Length (m)	25	833	$ 10.00	$ 8,333	$ 2,461
40	Partial depth PCC repair, % area (m^2)	5	750	$ 125.00	$ 93,750	$ 13,317
40	Full depth PCC repair, % area (m^2)	15	2250	$ 100.00	$ 225,000	$ 31,960
40	Reseal joints, % Length (m)	25	833	$ 10.00	$ 8,333	$ 1,184
50	Residual Value				$ 109,028	$ 9,508
	Total M&R Cost				**$ 515,972**	**$ 136,916**

Road Class **Municipal Major Arterial HMA**
AADTT **5,000**
Subgrade **40 MPa (CBR=4)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design
40 mm SP 12.5 FC1
120 mm SP 19
150 mm Granular A
450 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road m	15.0
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	Superpave 12.5FC1, mm (t)	40	1,512	$ 115.00	$ 173,880
Binder	Superpave 19, mm (t)	120	4,428	$ 96.00	$ 425,088
Base	Granular A, mm (t)	150	5,400	$ 18.00	$ 97,200
Subbase	Granular B, mm (t)	450	13,500	$ 15.00	$ 202,500
Excavation	Earth excavation (m^3)	760	11,400	$ 18.00	$ 205,200
	Total Initial Cost				**$ 1,103,868**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
5	Rout and seal, m/km (m)	200	200	$ 5.00	$ 1,000	$ 784
10	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 1,535
10	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	750	$ 35.00	$ 26,250	$ 16,115
20	Mill HMA, mm (t)	40	1500	$ 15.00	$ 22,500	$ 8,480
20	Resurface with Superpave 12.5FC1, mm (t)	40	1512	$ 115.00	$ 173,880	$ 65,534
25	Rout and seal, m/km (m)	1000	1000	$ 5.00	$ 5,000	$ 1,477
30	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	10	1500	$ 35.00	$ 52,500	$ 12,147
35	Mill HMA, mm (t)	90	3375	$ 15.00	$ 50,625	$ 9,178
35	Resurface with Superpave 19, mm (t)	50	1845	$ 96.00	$ 177,120	$ 32,110
35	Resurface with Superpave 12.5FC1, mm (t)	40	1512	$ 115.00	$ 173,880	$ 31,523
40	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 1,065
45	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	10	1500	$ 35.00	$ 52,500	$ 5,843
48	Mill HMA, mm (t)	40	1500	$ 15.00	$ 22,500	$ 2,163
48	Full depth asphalt base repair, % area (m^2)	5	750	$ 45.00	$ 33,750	$ 3,245
48	Resurface with Superpave 12.5FC1, mm (t)	40	1512	$ 115.00	$ 173,880	$ 16,717
50	Residual value				$ 191,775	$ 16,723
	Total M&R Cost				**$ 553,480**	**$ 191,192**

Road Class	**Municipal Major Arterial PCC**
AADTT	**7,500**
Subgrade	**40 MPa (CBR=4)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design	
200	mm PCC
200	mm Granular A
32	M Dowels
4.5	m Slab Length
0.5	m Widened Slab

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road, m	16.0
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	200 mm PCC pavement, 32M dowels (m^2)	200	16000	$ 49.50	$ 792,000
Base	Granular A, mm (t)	200	7680	$ 18.00	$ 138,240
Excavation	Earth excavation (m^3)	400	6400	$ 18.00	$ 115,200
	Total Initial Cost				**$ 1,045,440**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Partial depth PCC repair, % area (m^2)	2	320	$ 125.00	$ 40,000	$ 22,273
12	Reseal joints, % Length (m)	25	889	$ 10.00	$ 8,889	$ 4,950
25	Partial depth PCC repair, % area (m^2)	5	800	$ 125.00	$ 100,000	$ 29,530
25	Full depth PCC repair, % area (m^2)	10	1600	$ 100.00	$ 160,000	$ 47,248
25	Reseal joints, % Length (m)	50	1778	$ 10.00	$ 17,778	$ 5,250
25	Texturize, % area (m^2)	25	4000	$ 10.00	$ 40,000	$ 11,812
40	Partial depth PCC repair, % area (m^2)	5	800	$ 125.00	$ 100,000	$ 14,205
40	Full depth PCC repair, % area (m^2)	15	2400	$ 100.00	$ 240,000	$ 34,091
40	Reseal joints, % Length (m)	50	1778	$ 10.00	$ 17,778	$ 2,525
40	Texturize, % area (m^2)	50	8000	$ 10.00	$ 80,000	$ 11,364
50	Residual Value				$ 145,926	$ 12,725
	Total M&R Cost				**$ 658,519**	**$ 170,523**

Road Class	**Municipal Major Arterial HMA**
AADTT	**7,500**
Subgrade	**40 MPa (CBR=4)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design
40 mm SP 12.5 FC1
130 mm SP 19
150 mm Granular A
500 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road, m	16.0
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	Superpave 12.5FC1, mm (t)	40	1,613	$ 115.00	$ 185,472
Binder	Superpave 19, mm (t)	130	5,117	$ 96.00	$ 491,213
Base	Granular A, mm (t)	150	5,760	$ 18.00	$ 103,680
Subbase	Granular B, mm (t)	500	16,000	$ 15.00	$ 240,000
Excavation	Earth excavation (m^3)	820	13,120	$ 18.00	$ 236,160
	Total Initial Cost				**$ 1,256,525**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
8	Rout and seal, m/km (m)	200	200	$ 5.00	$ 1,000	$ 677
8	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	800	$ 35.00	$ 28,000	$ 18,952
13	Rout and seal, m/km (m)	1000	1000	$ 5.00	$ 5,000	$ 2,652
13	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	15	2400	$ 35.00	$ 84,000	$ 44,547
18	Mill HMA, mm (t)	50	2000	$ 15.00	$ 30,000	$ 12,466
18	Full depth asphalt base repair, % area (m^2)	10	1600	$ 45.00	$ 72,000	$ 29,917
18	Resurface with Superpave 12.5FC1, mm (t)	50	2016	$ 115.00	$ 231,840	$ 96,334
23	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 814
28	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 1,913
28	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	10	1600	$ 35.00	$ 56,000	$ 14,285
32	Mill HMA, mm (t)	90	3600	$ 15.00	$ 54,000	$ 11,333
32	Resurface with Superpave 19, mm (t)	50	1968	$ 96.00	$ 188,928	$ 39,650
32	Resurface with Superpave 12.5FC1, mm (t)	40	1613	$ 115.00	$ 185,472	$ 38,924
37	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 1,233
40	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	10	1600	$ 35.00	$ 56,000	$ 7,955
45	Mill HMA, mm (t)	50	2000	$ 15.00	$ 30,000	$ 3,339
45	Full depth asphalt base repair, % area (m^2)	10	1600	$ 45.00	$ 72,000	$ 8,013
45	Resurface with Superpave 12.5FC1, mm (t)	50	2016	$ 115.00	$ 231,840	$ 25,803
50	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 654
50	Residual value				$ 194,740	$ 16,982
	Total M&R Cost				**$ 1,148,840**	**$ 342,478**

Road Class **Municipal Major Arterial PCC**
AADTT **10,000**
Subgrade **40 MPa (CBR=4)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design	
210	mm PCC
200	mm Granular A
32	M Dowels
4.5	m Slab Length
0.5	m Widened Slab

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road, m	16.0
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	210 mm PCC pavement, 32M dowels (m^2)	210	16000	$ 50.90	$ 814,400
Base	Granular A, mm (t)	200	7680	$ 18.00	$ 138,240
Excavation	Earth excavation (m^3)	410	6560	$ 18.00	$ 118,080
	Total Initial Cost				**$ 1,070,720**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Partial depth PCC repair, % area (m^2)	2	320	$ 125.00	$ 40,000	$ 22,273
12	Reseal joints, % Length (m)	25	889	$ 10.00	$ 8,889	$ 4,950
25	Partial depth PCC repair, % area (m^2)	5	800	$ 125.00	$ 100,000	$ 29,530
25	Full depth PCC repair, % area (m^2)	10	1600	$ 100.00	$ 160,000	$ 47,248
25	Reseal joints, % Length (m)	50	1778	$ 10.00	$ 17,778	$ 5,250
25	Texturize, % area (m^2)	25	4000	$ 10.00	$ 40,000	$ 11,812
40	Partial depth PCC repair, % area (m^2)	5	800	$ 125.00	$ 100,000	$ 14,205
40	Full depth PCC repair, % area (m^2)	15	2400	$ 100.00	$ 240,000	$ 34,091
40	Reseal joints, % Length (m)	50	1778	$ 10.00	$ 17,778	$ 2,525
40	Texturize, % area (m^2)	50	8000	$ 10.00	$ 80,000	$ 11,364
50	Residual Value				$ 145,926	$ 12,725
	Total M&R Cost				**$ 658,519**	**$ 170,523**

Road Class **Municipal Major Arterial HMA**
AADTT **10,000**
Subgrade **40 MPa (CBR=4)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design
40 mm SP 12.5 FC2
140 mm SP 19
150 mm Granular A
550 mm Granular B

Geometric Design

Design feature	Dimension
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road, m	16.0
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	Superpave 12.5FC2, mm (t)	40	1,613	$ 120.00	$ 193,536
Binder	Superpave 19, mm (t)	140	5,510	$ 96.00	$ 528,998
Base	Granular A, mm (t)	150	5,760	$ 18.00	$ 103,680
Subbase	Granular B, mm (t)	550	17,600	$ 15.00	$ 264,000
Excavation	Earth excavation (m³)	880	14,080	$ 18.00	$ 253,440
	Total Initial Cost				**$ 1,343,654**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
8	Rout and seal, m/km (m)	200	200	$ 5.00	$ 1,000	$ 677
8	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	5	800	$ 35.00	$ 28,000	$ 18,952
13	Rout and seal, m/km (m)	1000	1000	$ 5.00	$ 5,000	$ 2,652
13	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	15	2400	$ 35.00	$ 84,000	$ 44,547
18	Mill HMA, mm (t)	50	2000	$ 15.00	$ 30,000	$ 12,466
18	Full depth asphalt base repair, % area (m²)	10	1600	$ 45.00	$ 72,000	$ 29,917
18	Resurface with Superpave 12.5FC2, mm (t)	50	2016	$ 120.00	$ 241,920	$ 100,523
23	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 814
28	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 1,913
28	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	10	1600	$ 35.00	$ 56,000	$ 14,285
32	Mill HMA, mm (t)	90	3600	$ 15.00	$ 54,000	$ 11,333
32	Resurface with Superpave 19, mm (t)	50	1968	$ 96.00	$ 188,928	$ 39,650
32	Resurface with Superpave 12.5FC2, mm (t)	40	1613	$ 120.00	$ 193,536	$ 40,617
37	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 1,233
40	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	10	1600	$ 35.00	$ 56,000	$ 7,955
45	Mill HMA, mm (t)	50	2000	$ 15.00	$ 30,000	$ 3,339
45	Full depth asphalt base repair, % area (m²)	10	1600	$ 45.00	$ 72,000	$ 8,013
45	Resurface with Superpave 12.5FC2, mm (t)	50	2016	$ 120.00	$ 241,920	$ 26,925
48	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 721
50	Residual value				$ 200,620	$ 17,495
	Total M&R Cost				**$ 1,171,184**	**$ 349,035**

Typical Ontario Municipal Pavements

LIFE CYCLE COST ANALYSIS SUMMARY

Listed by 25 Year AADTT and Pavement Type for High Strength Subgrade

Item	Collector			
	250 PCC	250 HMA	500 PCC	500 HMA
Initial Cost	$ 425,100	$ 412,236	$ 436,950	$ 412,236
M&R Cost (Discounted)	$ 32,955	$ 64,406	$ 32,955	$ 64,406
Total Cost	$ 458,055	$ 476,642	$ 469,905	$ 476,642
LCC Difference	4%		1%	

Item	Minor Arterial			
	1,000 PCC	1,000 HMA	1,500 PCC	1,500 HMA
Initial Cost	$ 490,050	$ 421,686	$ 490,050	$ 459,810
M&R Cost (Discounted)	$ 57,553	$ 87,998	$ 57,553	$ 86,278
Total Cost	$ 547,603	$ 509,684	$ 547,603	$ 546,088
LCC Difference	7%		0%	

Item	Major Arterial			
	2,500 PCC	2,500 HMA	5,000 PCC	5,000 HMA
Initial Cost	$ 980,100	$ 955,620	$ 980,100	$ 1,029,744
M&R Cost (Discounted)	$ 136,916	$ 191,192	$ 136,916	$ 191,192
Total Cost	$ 1,117,016	$ 1,146,812	$ 1,117,016	$ 1,220,936
LCC Difference	3%		9%	

Item	Major Arterial			
	7,500 PCC	7,500 HMA	10,000 PCC	10,000 HMA
Initial Cost	$ 1,045,440	$ 1,218,125	$ 1,045,440	$ 1,305,254
M&R Cost (Discounted)	$ 170,523	$ 342,478	$ 170,523	$ 349,035
Total Cost	$ 1,215,963	$ 1,560,603	$ 1,215,963	$ 1,654,290
LCC Difference	22%		26%	

Road Class **Municipal Collector PCC**
AADTT **250**
Subgrade **50 MPa (CBR=5)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design	
180	mm PCC
200	mm Granular A
No	Dowels
4	m Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section	1000

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per km**	**Price per unit of quantity**	**Cost**
Surface	180 mm PCC pavement, no dowels (m^2)	180	7500	$ 41.20	$ 309,000
Base	Granular A, mm (t)	200	3600	$ 18.00	$ 64,800
Excavation	Earth excavation (m^3)	380	2850	$ 18.00	$ 51,300
	Total Initial Cost				**$ 425,100**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
12	Reseal joints, % Length (m)	10	188	$ 10.00	$ 1,875	$ 1,044
25	Partial depth PCC repair, % area (m^2)	2	150	$ 125.00	$ 18,750	$ 5,537
25	Full depth PCC repair, % area (m^2)	5	375	$ 100.00	$ 37,500	$ 11,074
25	Reseal joints, % Length (m)	20	375	$ 10.00	$ 3,750	$ 1,107
40	Partial depth PCC repair, % area (m^2)	5	375	$ 125.00	$ 46,875	$ 6,658
40	Full depth PCC repair, % area (m^2)	10	750	$ 100.00	$ 75,000	$ 10,653
40	Reseal joints, % Length (m)	20	375	$ 10.00	$ 3,750	$ 533
50	Residual Value				$ 41,875	$ 3,652
	Total M&R Cost				**$ 145,625**	**$ 32,955**

Road Class **Municipal Collector HMA**
AADTT **250**
Subgrade **50 MPa (CBR=5)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design
40 mm SP 12.5
80 mm SP 19
150 mm Granular A
300 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490
Binder	Superpave 19, mm (t)	80	1,476	$ 96.00	$ 141,696
Base	Granular A, mm (t)	150	2,700	$ 18.00	$ 48,600
Subbase	Granular B, mm (t)	300	4,500	$ 15.00	$ 67,500
Excavation	Earth excavation (m³)	570	4,275	$ 18.00	$ 76,950
	Total Initial Cost				**$ 412,236**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
10	Rout and seal, m/km (m)	250	250	$ 5.00	$ 1,250	$ 767
10	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	2	150	$ 35.00	$ 5,250	$ 3,223
20	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 4,240
20	Resurface with Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490	$ 29,205
25	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 738
30	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	5	375	$ 35.00	$ 13,125	$ 3,037
35	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 2,040
35	Full depth asphalt base repair, % area (m²)	5	375	$ 45.00	$ 16,875	$ 3,059
35	Resurface with Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490	$ 14,048
40	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 355
43	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	5	375	$ 35.00	$ 13,125	$ 1,610
48	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 1,082
48	Resurface with Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490	$ 7,450
50	Residual value				$ 73,950	$ 6,449
	Total M&R Cost				**$ 158,155**	**$ 64,406**

Road Class **Municipal Collector PCC**
AADTT **500**
Subgrade **50 MPa (CBR=5)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design	
190	mm PCC
200	mm Granular A
No	Dowels
4	m Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section, m	1000

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per km**	**Price per unit of quantity**	**Cost**
Surface	190 mm PCC pavement, no dowels (m²)	190	7500	$ 42.60	$ 319,500
Base	Granular A, mm (t)	200	3600	$ 18.00	$ 64,800
Excavation	Earth excavation (m³)	390	2925	$ 18.00	$ 52,650
	Total Initial Cost				**$ 436,950**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
12	Reseal joints, % Length (m)	10	188	$ 10.00	$ 1,875	$ 1,044
25	Partial depth PCC repair, % area (m²)	2	150	$ 125.00	$ 18,750	$ 5,537
25	Full depth PCC repair, % area (m²)	5	375	$ 100.00	$ 37,500	$ 11,074
25	Reseal joints, % Length (m)	20	375	$ 10.00	$ 3,750	$ 1,107
40	Partial depth PCC repair, % area (m²)	5	375	$ 125.00	$ 46,875	$ 6,658
40	Full depth PCC repair, % area (m²)	10	750	$ 100.00	$ 75,000	$ 10,653
40	Reseal joints, % Length (m)	20	375	$ 10.00	$ 3,750	$ 533
50	Residual Value				$ 41,875	$ 3,652
	Total M&R Cost				**$ 145,625**	**$ 32,955**

Road Class **Municipal Collector HMA**
AADTT **500**
Subgrade **50 MPa (CBR=5)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design
40 mm SP 12.5
80 mm SP 19
150 mm Granular A
300 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490
Binder	Superpave 19, mm (t)	80	1,476	$ 96.00	$ 141,696
Base	Granular A, mm (t)	150	2,700	$ 18.00	$ 48,600
Subbase	Granular B, mm (t)	300	4,500	$ 15.00	$ 67,500
Excavation	Earth excavation (m^3)	570	4,275	$ 18.00	$ 76,950
	Total Initial Cost				**$ 412,236**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
10	Rout and seal, m/km (m)	250	250	$ 5.00	$ 1,250	$ 767
10	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	2	150	$ 35.00	$ 5,250	$ 3,223
20	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 4,240
20	Resurface with Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490	$ 29,205
25	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 738
30	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	375	$ 35.00	$ 13,125	$ 3,037
35	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 2,040
35	Full depth asphalt base repair, % area (m^2)	5	375	$ 45.00	$ 16,875	$ 3,059
35	Resurface with Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490	$ 14,048
40	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 355
43	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	375	$ 35.00	$ 13,125	$ 1,610
48	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 1,082
48	Resurface with Superpave 12.5, mm (t)	40	738	$ 105.00	$ 77,490	$ 7,450
50	Residual value				$ 73,950	$ 6,449
	Total M&R Cost				**$ 158,155**	**$ 64,406**

Road Class	**Municipal Minor Arterial PCC**
AADTT	**1000**
Subgrade	**50 MPa (CBR=5)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design	
200	mm PCC
200	mm Granular A
32	M Dowels
4.5	m Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	200 mm PCC pavement, 32M dowels (m^2)	200	7500	$ 49.50	$ 371,250
Base	Granular A, mm (t)	200	3600	$ 18.00	$ 64,800
Excavation	Earth excavation (m^3)	400	3000	$ 18.00	$ 54,000
	Total Initial Cost				**$ 490,050**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Reseal joints, % Length (m)	20	333	$ 10.00	$ 3,333	$ 1,856
25	Partial depth PCC repair, % area (m^2)	5	375	$ 125.00	$ 46,875	$ 13,842
25	Full depth PCC repair, % area (m^2)	10	750	$ 100.00	$ 75,000	$ 22,148
25	Reseal joints, % Length (m)	25	417	$ 10.00	$ 4,167	$ 1,230
40	Partial depth PCC repair, % area (m^2)	5	375	$ 125.00	$ 46,875	$ 6,658
40	Full depth PCC repair, % area (m^2)	15	1125	$ 100.00	$ 112,500	$ 15,980
40	Reseal joints, % Length (m)	25	417	$ 10.00	$ 4,167	$ 592
50	Residual Value				$ 54,514	$ 4,754
	Total M&R Cost				**$ 238,403**	**$ 57,553**

Road Class **Municipal Minor Arterial HMA**
AADTT **1000**
Subgrade **50 MPa (CBR=5)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design
40 mm SP 12.5 FC1
80 mm SP 19
150 mm Granular A
300 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940
Binder	Superpave 19, mm (t)	80	1,476	$ 96.00	$ 141,696
Base	Granular A, mm (t)	150	2,700	$ 18.00	$ 48,600
Subbase	Granular B, mm (t)	300	4,500	$ 15.00	$ 67,500
Excavation	Earth excavation (m³)	570	4,275	$ 18.00	$ 76,950
	Total Initial Cost				**$ 421,686**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
10	Rout and seal, m/km (m)	250	250	$ 5.00	$ 1,250	$ 767
10	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	2	150	$ 35.00	$ 5,250	$ 3,223
15	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	10	750	$ 35.00	$ 26,250	$ 12,627
20	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 4,240
20	Resurface with Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940	$ 32,767
25	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 738
30	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	5	375	$ 35.00	$ 13,125	$ 3,037
35	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 2,040
35	Full depth asphalt base repair, % area (m²)	10	750	$ 45.00	$ 33,750	$ 6,119
35	Resurface with Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940	$ 15,761
40	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 355
43	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	5	375	$ 35.00	$ 13,125	$ 1,610
48	Mill HMA, mm (t)	90	1688	$ 15.00	$ 25,313	$ 2,434
48	Resurface with Superpave 19, mm (t)	50	923	$ 96.00	$ 88,560	$ 8,514
48	Resurface with Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940	$ 8,359
50	Residual value				$ 167,344	$ 14,593
	Total M&R Cost				**$ 126,786**	**$ 87,998**

Road Class **Municipal Minor Arterial PCC**
AADTT **1500**
Subgrade **50 MPa (CBR=5)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design	
200	mm PCC
200	mm Granular A
32	M Dowels
4.5	m Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	200 mm PCC pavement, 32M dowels (m²)	200	7500	$ 49.50	$ 371,250
Base	Granular A, mm (t)	200	3600	$ 18.00	$ 64,800
Excavation	Earth excavation (m³)	400	3000	$ 18.00	$ 54,000
	Total Initial Cost				**$ 490,050**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Reseal joints, % Length (m)	20	333	$ 10.00	$ 3,333	$ 1,856
25	Partial depth PCC repair, % area (m²)	5	375	$ 125.00	$ 46,875	$ 13,842
25	Full depth PCC repair, % area (m²)	10	750	$ 100.00	$ 75,000	$ 22,148
25	Reseal joints, % Length (m)	25	417	$ 10.00	$ 4,167	$ 1,230
40	Partial depth PCC repair, % area (m²)	5	375	$ 125.00	$ 46,875	$ 6,658
40	Full depth PCC repair, % area (m²)	15	1125	$ 100.00	$ 112,500	$ 15,980
40	Reseal joints, % Length (m)	25	417	$ 10.00	$ 4,167	$ 592
50	Residual Value				$ 54,514	$ 4,754
	Total M&R Cost				**$ 238,403**	**$ 57,553**

Road Class **Municipal Minor Arterial HMA**
AADTT **1500**
Subgrade **50 MPa (CBR=5)**

All quantities and costs are for one km of 2-lane roadway

Pavement Design
40 mm SP 12.5 FC1
100 mm SP 19
150 mm Granular A
300 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	7.5
Total width of paved shoulders, m	N/A
Total width of subject road, m	7.5
Length of section	1000

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per km**	**Price per unit of quantity**	**Cost**
Surface	Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940
Binder	Superpave 19, mm (t)	100	1,845	$ 96.00	$ 177,120
Base	Granular A, mm (t)	150	2,700	$ 18.00	$ 48,600
Subbase	Granular B, mm (t)	300	4,500	$ 15.00	$ 67,500
Excavation	Earth excavation (m^3)	590	4,425	$ 18.00	$ 79,650
	Total Initial Cost				**$ 459,810**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
10	Rout and seal, m/km (m)	250	250	$ 5.00	$ 1,250	$ 767
10	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	2	150	$ 35.00	$ 5,250	$ 3,223
18	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	10	750	$ 35.00	$ 26,250	$ 10,907
20	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 4,240
20	Resurface with Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940	$ 32,767
25	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 738
30	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	375	$ 35.00	$ 13,125	$ 3,037
35	Mill HMA, mm (t)	40	750	$ 15.00	$ 11,250	$ 2,040
35	Full depth asphalt base repair, % area (m^2)	10	750	$ 45.00	$ 33,750	$ 6,119
35	Resurface with Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940	$ 15,761
40	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 355
43	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	375	$ 35.00	$ 13,125	$ 1,610
48	Mill HMA, mm (t)	90	1688	$ 15.00	$ 25,313	$ 2,434
48	Resurface with Superpave 19, mm (t)	50	923	$ 96.00	$ 88,560	$ 8,514
48	Resurface with Superpave 12.5FC1, mm (t)	40	756	$ 115.00	$ 86,940	$ 8,359
50	Residual value				$ 167,344	$ 14,593
	Total M&R Cost				**$ 126,786**	**$ 86,278**

Road Class **Municipal Major Arterial PCC**
AADTT **2,500**
Subgrade **50 MPa (CBR=5)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design	
200	mm PCC
200	mm Granular A
32	M Dowels
4.5	m Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road, m	15.0
Length of section	1000

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per km**	**Price per unit of quantity**	**Cost**
Surface	200 mm PCC pavement, 32M dowels (m²)	200	15000	$ 49.50	$ 742,500
Base	Granular A, mm (t)	200	7200	$ 18.00	$ 129,600
Excavation	Earth excavation (m³)	400	6000	$ 18.00	$ 108,000
	Total Initial Cost				**$ 980,100**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
12	Partial depth PCC repair, % area (m²)	2	300	$ 125.00	$ 37,500	$ 20,881
12	Reseal joints, % Length (m)	25	833	$ 10.00	$ 8,333	$ 4,640
25	Partial depth PCC repair, % area (m²)	5	750	$ 125.00	$ 93,750	$ 27,685
25	Full depth PCC repair, % area (m²)	10	1500	$ 100.00	$ 150,000	$ 44,295
25	Reseal joints, % Length (m)	25	833	$ 10.00	$ 8,333	$ 2,461
40	Partial depth PCC repair, % area (m²)	5	750	$ 125.00	$ 93,750	$ 13,317
40	Full depth PCC repair, % area (m²)	15	2250	$ 100.00	$ 225,000	$ 31,960
40	Reseal joints, % Length (m)	25	833	$ 10.00	$ 8,333	$ 1,184
50	Residual Value				$ 109,028	$ 9,508
	Total M&R Cost				**$ 515,972**	**$ 136,916**

Road Class	**Municipal Major Arterial HMA**
AADTT	**2,500**
Subgrade	**50 MPa (CBR=5)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design
40 mm SP 12.5 FC1
100 mm SP 19
150 mm Granular A
350 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road m	15.0
Length of section	1000

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per km**	**Price per unit of quantity**	**Cost**
Surface	Superpave 12.5FC1, mm (t)	40	1,512	$ 115.00	$ 173,880
Binder	Superpave 19, mm (t)	100	3,690	$ 96.00	$ 354,240
Base	Granular A, mm (t)	150	5,400	$ 18.00	$ 97,200
Subbase	Granular B, mm (t)	350	10,500	$ 15.00	$ 157,500
Excavation	Earth excavation (m³)	640	9,600	$ 18.00	$ 172,800
	Total Initial Cost				**$ 955,620**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
5	Rout and seal, m/km (m)	200	200	$ 5.00	$ 1,000	$ 784
10	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 1,535
10	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	5	750	$ 35.00	$ 26,250	$ 16,115
20	Mill HMA, mm (t)	40	1500	$ 15.00	$ 22,500	$ 8,480
20	Resurface with Superpave 12.5FC1, mm (t)	40	1512	$ 115.00	$ 173,880	$ 65,534
25	Rout and seal, m/km (m)	1000	1000	$ 5.00	$ 5,000	$ 1,477
30	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	10	1500	$ 35.00	$ 52,500	$ 12,147
35	Mill HMA, mm (t)	90	3375	$ 15.00	$ 50,625	$ 9,178
35	Resurface with Superpave 19, mm (t)	50	1845	$ 96.00	$ 177,120	$ 32,110
35	Resurface with Superpave 12.5FC1, mm (t)	40	1512	$ 115.00	$ 173,880	$ 31,523
40	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 1,065
45	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	10	1500	$ 35.00	$ 52,500	$ 5,843
48	Mill HMA, mm (t)	40	1500	$ 15.00	$ 22,500	$ 2,163
48	Full depth asphalt base repair, % area (m²)	5	750	$ 45.00	$ 33,750	$ 3,245
48	Resurface with Superpave 12.5FC1, mm (t)	40	1512	$ 115.00	$ 173,880	$ 16,717
50	Residual value				$ 191,775	$ 16,723
	Total M&R Cost				**$ 553,480**	**$ 191,192**

2011-01-10

Road Class **Municipal Major Arterial PCC**
AADTT **5,000**
Subgrade **50 MPa (CBR=5)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design	
200	mm PCC
200	mm Granular A
32	M Dowels
4.5	m Slab Length
	Tied Shoulder/Curb

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road, m	15.0
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	200 mm PCC pavement, 32M dowels (m²)	200	15000	$ 49.50	$ 742,500
Base	Granular A, mm (t)	200	7200	$ 18.00	$ 129,600
Excavation	Earth excavation (m³)	400	6000	$ 18.00	$ 108,000
	Total Initial Cost				**$ 980,100**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Partial depth PCC repair, % area (m²)	2	300	$ 125.00	$ 37,500	$ 20,881
12	Reseal joints, % Length (m)	25	833	$ 10.00	$ 8,333	$ 4,640
25	Partial depth PCC repair, % area (m²)	5	750	$ 125.00	$ 93,750	$ 27,685
25	Full depth PCC repair, % area (m²)	10	1500	$ 100.00	$ 150,000	$ 44,295
25	Reseal joints, % Length (m)	25	833	$ 10.00	$ 8,333	$ 2,461
40	Partial depth PCC repair, % area (m²)	5	750	$ 125.00	$ 93,750	$ 13,317
40	Full depth PCC repair, % area (m²)	15	2250	$ 100.00	$ 225,000	$ 31,960
40	Reseal joints, % Length (m)	25	833	$ 10.00	$ 8,333	$ 1,184
50	Residual Value				$ 109,028	$ 9,508
	Total M&R Cost				**$ 515,972**	**$ 136,916**

Road Class **Municipal Major Arterial HMA**
AADTT **5,000**
Subgrade **50 MPa (CBR=5)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design
40 mm SP 12.5 FC1
110 mm SP 19
150 mm Granular A
400 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road m	15.0
Length of section	1000

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per km**	**Price per unit of quantity**	**Cost**
Surface	Superpave 12.5FC1, mm (t)	40	1,512	$ 115.00	$ 173,880
Binder	Superpave 19, mm (t)	110	4,059	$ 96.00	$ 389,664
Base	Granular A, mm (t)	150	5,400	$ 18.00	$ 97,200
Subbase	Granular B, mm (t)	400	12,000	$ 15.00	$ 180,000
Excavation	Earth excavation (m³)	700	10,500	$ 18.00	$ 189,000
	Total Initial Cost				**$ 1,029,744**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
5	Rout and seal, m/km (m)	200	200	$ 5.00	$ 1,000	$ 784
10	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 1,535
10	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	5	750	$ 35.00	$ 26,250	$ 16,115
20	Mill HMA, mm (t)	40	1500	$ 15.00	$ 22,500	$ 8,480
20	Resurface with Superpave 12.5FC1, mm (t)	40	1512	$ 115.00	$ 173,880	$ 65,534
25	Rout and seal, m/km (m)	1000	1000	$ 5.00	$ 5,000	$ 1,477
30	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	10	1500	$ 35.00	$ 52,500	$ 12,147
35	Mill HMA, mm (t)	90	3375	$ 15.00	$ 50,625	$ 9,178
35	Resurface with Superpave 19, mm (t)	50	1845	$ 96.00	$ 177,120	$ 32,110
35	Resurface with Superpave 12.5FC1, mm (t)	40	1512	$ 115.00	$ 173,880	$ 31,523
40	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 1,065
45	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	10	1500	$ 35.00	$ 52,500	$ 5,843
48	Mill HMA, mm (t)	40	1500	$ 15.00	$ 22,500	$ 2,163
48	Full depth asphalt base repair, % area (m²)	5	750	$ 45.00	$ 33,750	$ 3,245
48	Resurface with Superpave 12.5FC1, mm (t)	40	1512	$ 115.00	$ 173,880	$ 16,717
50	Residual value				$ 191,775	$ 16,723
	Total M&R Cost				**$ 553,480**	**$ 191,192**

Road Class **Municipal Major Arterial PCC**
AADTT **7,500**
Subgrade **50 MPa (CBR=5)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design	
200	mm PCC
200	mm Granular A
32	M Dowels
4.5	m Slab Length
0.5	m Widened Slab

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road, m	16.0
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	200 mm PCC pavement, 32M dowels (m²)	200	16000	$ 49.50	$ 792,000
Base	Granular A, mm (t)	200	7680	$ 18.00	$ 138,240
Excavation	Earth excavation (m³)	400	6400	$ 18.00	$ 115,200
	Total Initial Cost				**$ 1,045,440**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Partial depth PCC repair, % area (m²)	2	320	$ 125.00	$ 40,000	$ 22,273
12	Reseal joints, % Length (m)	25	889	$ 10.00	$ 8,889	$ 4,950
25	Partial depth PCC repair, % area (m²)	5	800	$ 125.00	$ 100,000	$ 29,530
25	Full depth PCC repair, % area (m²)	10	1600	$ 100.00	$ 160,000	$ 47,248
25	Reseal joints, % Length (m)	50	1778	$ 10.00	$ 17,778	$ 5,250
25	Texturize, % area (m²)	25	4000	$ 10.00	$ 40,000	$ 11,812
40	Partial depth PCC repair, % area (m²)	5	800	$ 125.00	$ 100,000	$ 14,205
40	Full depth PCC repair, % area (m²)	15	2400	$ 100.00	$ 240,000	$ 34,091
40	Reseal joints, % Length (m)	50	1778	$ 10.00	$ 17,778	$ 2,525
40	Texturize, % area (m²)	50	8000	$ 10.00	$ 80,000	$ 11,364
50	Residual Value				$ 145,926	$ 12,725
	Total M&R Cost				**$ 658,519**	**$ 170,523**

Road Class	**Municipal Major Arterial HMA**
AADTT	**7,500**
Subgrade	**50 MPa (CBR=5)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design
40 mm SP 12.5 FC1
130 mm SP 19
150 mm Granular A
450 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road, m	16.0
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	Superpave 12.5FC1, mm (t)	40	1,613	$ 115.00	$ 185,472
Binder	Superpave 19, mm (t)	130	5,117	$ 96.00	$ 491,213
Base	Granular A, mm (t)	150	5,760	$ 18.00	$ 103,680
Subbase	Granular B, mm (t)	450	14,400	$ 15.00	$ 216,000
Excavation	Earth excavation (m^3)	770	12,320	$ 18.00	$ 221,760
	Total Initial Cost				**$ 1,218,125**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
8	Rout and seal, m/km (m)	200	200	$ 5.00	$ 1,000	$ 677
8	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	5	800	$ 35.00	$ 28,000	$ 18,952
13	Rout and seal, m/km (m)	1000	1000	$ 5.00	$ 5,000	$ 2,652
13	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	15	2400	$ 35.00	$ 84,000	$ 44,547
18	Mill HMA, mm (t)	50	2000	$ 15.00	$ 30,000	$ 12,466
18	Full depth asphalt base repair, % area (m^2)	10	1600	$ 45.00	$ 72,000	$ 29,917
18	Resurface with Superpave 12.5FC1, mm (t)	50	2016	$ 115.00	$ 231,840	$ 96,334
23	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 814
28	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 1,913
28	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	10	1600	$ 35.00	$ 56,000	$ 14,285
32	Mill HMA, mm (t)	90	3600	$ 15.00	$ 54,000	$ 11,333
32	Resurface with Superpave 19, mm (t)	50	1968	$ 96.00	$ 188,928	$ 39,650
32	Resurface with Superpave 12.5FC1, mm (t)	40	1613	$ 115.00	$ 185,472	$ 38,924
37	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 1,233
40	Spot repairs, mill 40 mm/patch 40 mm, % area (m^2)	10	1600	$ 35.00	$ 56,000	$ 7,955
45	Mill HMA, mm (t)	50	2000	$ 15.00	$ 30,000	$ 3,339
45	Full depth asphalt base repair, % area (m^2)	10	1600	$ 45.00	$ 72,000	$ 8,013
45	Resurface with Superpave 12.5FC1, mm (t)	50	2016	$ 115.00	$ 231,840	$ 25,803
50	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 654
50	Residual value				$ 194,740	$ 16,982
	Total M&R Cost				**$ 1,148,840**	**$ 342,478**

Road Class **Municipal Major Arterial PCC**
AADTT **10,000**
Subgrade **50 MPa (CBR=5)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design	
200	mm PCC
200	mm Granular A
32	M Dowels
4.5	m Slab Length
0.5	m Widened Slab

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road, m	16.0
Length of section	1000

Initial Pavement Structure

Pavement layer	Description of pavement layer, Amount (Quantity)	Amount	Quantity per km	Price per unit of quantity	Cost
Surface	200 mm PCC pavement, 32M dowels (m²)	200	16000	$ 49.50	$ 792,000
Base	Granular A, mm (t)	200	7680	$ 18.00	$ 138,240
Excavation	Earth excavation (m³)	400	6400	$ 18.00	$ 115,200
	Total Initial Cost				**$ 1,045,440**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	Description of pavement layer, Amount (Quantity)	Amount	Quantity	Price per unit of quantity	Cost	Net present worth
12	Partial depth PCC repair, % area (m²)	2	320	$ 125.00	$ 40,000	$ 22,273
12	Reseal joints, % Length (m)	25	889	$ 10.00	$ 8,889	$ 4,950
25	Partial depth PCC repair, % area (m²)	5	800	$ 125.00	$ 100,000	$ 29,530
25	Full depth PCC repair, % area (m²)	10	1600	$ 100.00	$ 160,000	$ 47,248
25	Reseal joints, % Length (m)	50	1778	$ 10.00	$ 17,778	$ 5,250
25	Texturize, % area (m²)	25	4000	$ 10.00	$ 40,000	$ 11,812
40	Partial depth PCC repair, % area (m²)	5	800	$ 125.00	$ 100,000	$ 14,205
40	Full depth PCC repair, % area (m²)	15	2400	$ 100.00	$ 240,000	$ 34,091
40	Reseal joints, % Length (m)	50	1778	$ 10.00	$ 17,778	$ 2,525
40	Texturize, % area (m²)	50	8000	$ 10.00	$ 80,000	$ 11,364
50	Residual Value				$ 145,926	$ 12,725
	Total M&R Cost				**$ 658,519**	**$ 170,523**

Road Class **Municipal Major Arterial HMA**
AADTT **10,000**
Subgrade **50 MPa (CBR=5)**

All quantities and costs are for one km of 4-lane roadway

Pavement Design
40 mm SP 12.5 FC2
140 mm SP 19
150 mm Granular A
500 mm Granular B

Geometric Design	
Design feature	**Dimension**
Width of the traffic lanes, m	15.0
Total width of paved shoulders, m	N/A
Total width of subject road, m	16.0
Length of section	1000

Initial Pavement Structure

Pavement layer	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity per km**	**Price per unit of quantity**	**Cost**
Surface	Superpave 12.5FC2, mm (t)	40	1,613	$ 120.00	$ 193,536
Binder	Superpave 19, mm (t)	140	5,510	$ 96.00	$ 528,998
Base	Granular A, mm (t)	150	5,760	$ 18.00	$ 103,680
Subbase	Granular B, mm (t)	500	16,000	$ 15.00	$ 240,000
Excavation	Earth excavation (m³)	830	13,280	$ 18.00	$ 239,040
	Total Initial Cost				**$ 1,305,254**

Urban Pavement Maintenance and Rehabilitation Action Plan

Years after initial construction	**Description of pavement layer, Amount (Quantity)**	**Amount**	**Quantity**	**Price per unit of quantity**	**Cost**	**Net present worth**
8	Rout and seal, m/km (m)	200	200	$ 5.00	$ 1,000	$ 677
8	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	5	800	$ 35.00	$ 28,000	$ 18,952
13	Rout and seal, m/km (m)	1000	1000	$ 5.00	$ 5,000	$ 2,652
13	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	15	2400	$ 35.00	$ 84,000	$ 44,547
18	Mill HMA, mm (t)	50	2000	$ 15.00	$ 30,000	$ 12,466
18	Full depth asphalt base repair, % area (m²)	10	1600	$ 45.00	$ 72,000	$ 29,917
18	Resurface with Superpave 12.5FC2, mm (t)	50	2016	$ 120.00	$ 241,920	$ 100,523
23	Rout and seal, m/km (m)	500	500	$ 5.00	$ 2,500	$ 814
28	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 1,913
28	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	10	1600	$ 35.00	$ 56,000	$ 14,285
32	Mill HMA, mm (t)	90	3600	$ 15.00	$ 54,000	$ 11,333
32	Resurface with Superpave 19, mm (t)	50	1968	$ 96.00	$ 188,928	$ 39,650
32	Resurface with Superpave 12.5FC2, mm (t)	40	1613	$ 120.00	$ 193,536	$ 40,617
37	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 1,233
40	Spot repairs, mill 40 mm/patch 40 mm, % area (m²)	10	1600	$ 35.00	$ 56,000	$ 7,955
45	Mill HMA, mm (t)	50	2000	$ 15.00	$ 30,000	$ 3,339
45	Full depth asphalt base repair, % area (m²)	10	1600	$ 45.00	$ 72,000	$ 8,013
45	Resurface with Superpave 12.5FC2, mm (t)	50	2016	$ 120.00	$ 241,920	$ 26,925
48	Rout and seal, m/km (m)	1500	1500	$ 5.00	$ 7,500	$ 721
50	Residual value				$ 200,620	$ 17,495
	Total M&R Cost				**$ 1,171,184**	**$ 349,035**

2011-01-10

APPENDIX C

CONCRETE PAVEMENT SPECIFIERS GUIDELINES – MUNICIPAL EDITION

CONCRETE PAVEMENT SPECIFIERS GUIDELINES

MUNICIPAL EDITION

READY MIXED CONCRETE ASSOCIATION OF ONTARIO

August 2009

FOREWORD

Portland cement concrete (PCC) pavement refers to the rigid concrete layer of the pavement structure that is in direct contact with the traffic. Typical concrete is composed of coarse aggregate (crushed stone and gravel), fine aggregate such as sand, Portland cement, admixtures and water. Concrete can be modified in a number of ways, including the addition of cementitious materials such as Slag or Fly Ash (which are materials that are added to the mixture to enhance the properties of the fresh or hardened concrete) keeping them from landfill sites. Once the concrete has been mixed, it is placed on a prepared base coarse, consolidated and shaped.

In pavement construction, three different concrete pavement design types are commonly used: jointed plain concrete pavements (JPCP), jointed reinforced concrete pavements (JRCP), and continuously reinforced concrete pavements (CRCP). Each of these design types can provide long-lasting pavements that meet or exceed specific project requirements. Each type is suitable for new construction, reconstruction, and overlays (resurfacing) of existing roads.

With the state of our environment and the economy in the forefront of people's minds, concrete pavements provide high-quality assurance, and will continue to be more competitive in the future. Concrete pavements are cost competitive (both initial and life cycle) and are now being recognized as the environmental responsible choice among pavement alternatives for both new and rehabilitation projects. They simply last longer than flexible pavements (MTO LCCA) which means they don't need rehabilitation or reconstruction as often. Another consideration is that concrete pavements use significantly less aggregate in total than flexible pavements. This conserves our non-renewable resources and results in less truck traffic and congestion. Less soil needs to be excavated for a concrete road (when compared to the flexible alternatives) due to the rigid nature of concrete pavement allowing for thinner base cross-sections. This is a huge advantage with the increased difficulty in finding areas to dump any contaminated soils. Equally important is that longer lasting concrete helps reduce traffic congestion and vehicle emissions because there are simply fewer construction zones slowing traffic flow during the life of the pavement.

Some other advantages of concrete pavements are that they save fuel and reflect light and heat rather than absorbing it. Studies from National Research Council (Canada) show substantial savings on diesel fuel with heavy trucks, and new studies are available from Sweden and United States showing gasoline savings on cars and light vehicles. These savings result in lower vehicle operating costs and greatly reduced CO_2 emissions. Concrete pavement's ability to reflect light can lead to a 20 to 30% reduction in the cost to purchase and operate light standards, and because concrete pavements reflect heat, they also contribute to cool communities and reduce the Urban Heat Island Effect.

Every attribute of concrete can be tied back to a sustainable benefit. Concrete pavements are an excellent choice for Responsible Materials Procurement. To address sustainable materials procurement, the Ready Mixed Concrete Association of Ontario (RMCAO) has developed the "ECO CERTIFIED Concrete Facility" certification program.

MESSAGE TO SPECIFIER

This *"Concrete Pavement Specifiers Guidelines"* document is intended solely for use by professional personnel who are competent to evaluate the significance and limitations of the information provided in this document, and who will accept full responsibility for the application of this information. The Ready Mixed Concrete Association of Ontario (RMCAO) disclaims any and all responsibility and liability for the accuracy and application of the information included in this guideline document to the fullest extent permitted by law. Please note that each project will have different circumstances that the owner and/or consultant must assess due to factors such as geographical area, locally available materials, subgrade conditions, environmental conditions, traffic loading, etc.

For information on Pervious Concrete for Storm Water Management, please refer to the RMCAO's *"Pervious Concrete Specifiers Guidelines".*

For information on other products and applications please contact the RMCAO (www.rmcao.org).

DESIGN

One of the tools that can be used to assist in the design process is the ***"StreetPave"*** software program. StreetPave is the latest in concrete thickness design software for streets and local road pavements, produced by the American Concrete Pavement Association (ACPA). This software utilizes proven engineering analysis to produce optimized concrete pavement thicknesses for municipal streets and roads (collector, minor and major arterial). A "Life Cycle Cost Analysis" module also allows you to perform a detailed informed decision of your pavement design project. StreetPave is now available as a free-use online version and as a fully-featured windows version. Note: You cannot save your project files in the free online version.

"CANPav™" is another concrete pavement tool designed to offer the specifier and owner an easy initial cost comparison through material cost and design inputs. Developed by the RMCAO, this program is online starting September 2009 in collaboration with the Cement Association of Canada (CAC) and is available to anyone interested in comparing the initial construction costs of different pavement alternatives. Visit http://www.canpav.com/.

CONSIDERATIONS

- It is important to realize the capabilities and limitations of all placing equipment, when developing your initial design.
- It is also important to realize that all technologies may not be suitable for all projects. It is also important to fully understand a technology before including it in a specification.
- Joint design and details should be considered carefully, and it is recommended that you request input from the contractor.

REFERENCES

- Ontario General Contractor Association (OGCA) & RMCAO Publication "Best Practices Guidelines for Concrete Construction".
- FHWA Publication No. HIF – 07 – 004 "Integrated Materials and Construction Practices for Concrete Pavement: A State-of-the-Practice Manual".
- American Concrete Pavement Association Publication "Concrete Pavement Field Reference *Pre-Paving*".

FINAL NOTE

If you have any questions regarding the content of this document, please contact:

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pavement@rmcao.org
www.rmcao.org

1.0 GENERAL PROVISIONS

1.1 GENERAL DESCRIPTION

This document is intended for use by engineers and/or owners in preparing detailed construction specifications for Portland cement concrete pavements on municipal streets and roads (major/minor arterial and collector roads).

Specifications for subgrade and subbase construction are limited to its effects on concrete pavement construction.

A Pre-Job Meeting should be held with the owner, engineer, concrete producer, testing company and concrete paving contractor. The purpose of the meeting is to review the job specification and construction procedures to ensure that all parties understand the job requirements and to clarify responsibilities. Refer to the *“Best Practices Guidelines for Concrete Construction”* for a sample pre-job meeting form.

The contractor should develop and submit for approval a Traffic Management Plan as well as designate a qualified person to administer the safety aspects of the contract.

1.2 SCOPE

This sample specification covers the requirements for the construction of concrete pavements. Requirements for both the fixed-form and slip-form methods of concrete construction are covered. The choice between paving methods will depend on the project size, geometry, as well as accessibility and construction constraints. This document is applicable to both plain jointed undowelled and dowelled pavements.

1.3 DEFINITIONS

Alkali-Aggregate Reactivity (AAR)
AAR is the production of expansive gel caused by a reaction between aggregates containing certain forms of silica or carbonates and alkali hydroxides in concrete.

Cementing Material
Cementing material is any material having cementing properties or contributing to the formation of hydrated calcium silicate compounds. When proportioning concrete, the following are considered common cementing materials: Portland cement, blended hydraulic cements, fly ash, ground granulated blast-furnace slag, and silica fume.

Cold Weather
Those conditions when the air temperature is at or below 5˚C in the shade. It also applies when the air temperature is at or is likely to fall below 5˚C within 24 hours after concrete placement.

Concrete Pavement
A rigid pavement structure with an exposed concrete surface which may include concrete shoulders.

Curing
Maintenance of a satisfactory moisture content and temperature in concrete for a suitable period of time during its early stages (immediately following placing and finishing) so that the desired properties of the material can develop. Curing assures satisfactory hydration and hardening of the cementing materials.

D-Cracking
D-cracking is damage that occurs in concrete due to expansive freezing of water in some aggregate particles. The damage normally starts near joints to form a characteristic D-shaped crack. This problem can be reduced either by selecting aggregates that are less susceptible to freeze-thaw deterioration or, where marginal aggregates must be used, by reducing the maximum aggregate size. Also, providing drainage for carrying water away from the base may prevent saturation of the pavement.

ECO CERTIFIED Concrete Facility
The RMCAO's ECO CERTIFIED Concrete Facility is a certification program that addresses current environmental requirements such as C of A for Air, Noise, Sewage Works and Permits to Take Water. The ECO CERTIFICATION program is also designed to highlight many practices and methodologies that concrete facilities have regarding the use of SCM's, energy conservation, emissions control, water conservation and recycling and more.

Engineer
Engineer means a licensed professional engineer designated by the owner to administer the contract.

Frost Heave
Frost heave occurs when ice lenses form in the soil, which continue to attract water and expand further. The heaving itself is not a problem for concrete pavements; rather, it is the subsequent thawing and differential settling of the concrete slabs that can lead to roughness and/or cracking. For frost heave to occur, all three conditions must be present: a frost-susceptible soil, freezing temperatures that penetrate the subgrade, and a supply of water. Controlling any one of the three conditions will dramatically reduce the potential for frost heave.

Hot Weather
Those conditions when the air temperature is at or above 28˚C in the shade. It also applies when the air temperature is at or is likely to rise above 28˚C within 24 hours.

Isolation Joints
Joints placed to allow differential movement at intersecting streets, drainage structures, or other fixed objects.

Load Transfer
Is the effective transfer of traffic loads from one side of the joint to the other. Load transfer across joints is developed either by aggregate interlock and/or by using dowel bars.

Longitudinal Joints
A joint between two slabs which allows slab warping without appreciable separation or cracking the slabs. Longitudinal joints are used to relieve warping stresses and are generally needed when slab widths exceed 4.6m. Longitudinal joints should coincide with pavement lane lines whenever possible, to improve traffic operations.

Percent Within Limits (PWL)
PWL means an estimate of the percentage of the lot population that is within specification limits, determined by using the mean and standard deviation of the lot.

Standard Deviation
Standard deviation means the square root of the value found by summing the squares of the difference between each test result and the mean of the test results divided by the number of test results minus one.

Subbase
Granular material placed immediately above the subgrade.

Subgrade
The native soil upon which the subbase is to be placed.

Tining
Small grooves of specified dimension (longitudinal or transverse) which are hand or machine made in the concrete surface.

Transverse Construction Joints
Joints installed at the temporary end of a paving operation. Whenever possible, these joints should be installed at the location of a planned joint.

Transverse Contraction Joints
Joints that are constructed transverse to the centerline and spaced to control cracking from stresses caused by shrinkage, moisture and thermal differentials. Typically, transverse contraction joints are oriented at right angles to the centerline and edge of the pavement.

Unshrinkable Fill
Unshrinkable fill is a controlled density backfill material used in utility cuts and trenches. It is a mixture of cementitious materials, water, fine and coarse aggregates and may contain an air-entraining admixture. It is an extremely low-strength material with a maximum strength usually specified, rather than a minimum strength as for normal concrete (0.7MPa as per OPSS 1359).

1.4 REFERENCED STANDARDS

ACI Standards

ACI 309	Standard Practice for Consolidation of Concrete

ASTM Standards

ASTM C260	Standard Specification for Air-Entraining Admixtures for Concrete
ASTM C494	Standard Specification for Chemical Admixtures for Concrete
ASTM C666	Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing

CSA Standards

CAN/CSA A23.1	Concrete Materials and Methods of Concrete Construction
CAN/CSA A23.2	Methods of Test and Standard Practices for Concrete
CAN/CSA A3001	Cementitious Materials for Use in Concrete

Ministry of Transportation Ontario

MTO LS 101	Procedures for Calculating Percent Within Limits

Ontario Provincial Standards Specifications

OPSS 350	Construction Specification for Concrete Pavement and Concrete Base
OPSS 369	Construction Specification for Sealing or Resealing of Joints and Cracks in Concrete Pavement and Concrete Base
OPSS 904	Construction Specification for Concrete Structures
OPSS 919	Construction Specification for Formwork and Falsework
OPSS 1002	Aggregates for Concrete
OPSS 1308	Material Specification for Joint Filler in Concrete
OPSS 1350	Material Specification for Concrete – Materials and Production
OPSS 1441	Material Specification for Load Transfer Assemblies
OPSS 1442	Material Specification for Epoxy Coated Reinforcing Steel Bars for Concrete

2.0 MATERIALS

2.1 CONCRETE

Concrete and concrete materials shall be according to OPSS MUNI 1350, and be tested for compliance with the specifications in accordance with procedures given in CSA Standard A23.2, with the following amendments.

a. The coarse aggregate for concrete pavement shall have a combined gradation of nominal maximum size 37.5mm and 19.0mm aggregate and shall be according to the requirements of OPSS 1002.

b. The minimum compressive strength shall be Class C-2 32MPa with a maximum water cementitous materials ratio (W/CM) of 0.45 (as per CSA A23.1).

c. For all concrete pavement and concrete base, the air content shall be (as per CSA A23.1):

   i. 6.5% ± 1.5% when using aggregate with nominal maximum size between 14-20mm, and

   ii. 5.5% ± 1.5% when using aggregate with nominal maximum size between 28-40mm.

d. The slump shall be selected by the contractor. Acceptance ranges (as per CSA A23.1) are as follows:

   i. Less than 80mm slump $\pm$ 20mm

   ii. 80mm – 180mm slump $\pm$ 30mm

e. Concrete shall be placed with a mix temperature between 10˚C and 27˚C, as per OPSS 1350.

2.1.1 Portland Cements

Portland cement & blended hydraulic cements shall meet the requirements of CSA Standard A3001.

2.1.2 Supplementary Cementing Materials

Supplementary cementing materials and blended supplementary cementing material shall meet the requirements of CSA Standard A3001.

2.1.3 Aggregates

All coarse aggregates proposed for use shall be listed on the MTO's Aggregate Source List for Concrete Base and Concrete Pavement. Aggregates for use on concrete pavement shall not be susceptible to D-cracking and AAR. Unless field experience or prior laboratory testing have proven otherwise, aggregate for use in concrete pavement shall be tested in accordance with ASTM C666, Test Method for Resistance of Concrete to Rapid Freezing and Thawing. Testing shall be in accordance with Procedure A for a period of 350 cycles and appropriate AAR tests.

2.1.4 Water

Water used in mixing or curing shall meet the requirements of CSA A23.1.

2.1.5 Admixtures

Air-entraining admixtures shall conform to the requirements of ASTM C260. Chemical admixtures shall conform to the requirements of ASTM C494.

2.2 JOINT MATERIALS

Expansion joint filler shall be in accordance to OPSS 1308. Joint sealant material shall be in accordance to OPSS 369.

2.3 TIE BARS

Tie bars are epoxy coated deformed bars placed in longitudinal joints to prevent slabs from separating, and shall be in accordance to OPSS 1442.

2.4 DOWELS

Dowel bars are smooth, round steel bars placed across transverse joints to provide load transfer while permitting a joint to open and close. Dowels shall be in accordance to OPSS 1441.

3.0 SUBMITTALS

3.1 RMCAO CERTIFICATION OF CONCRETE FACILITIES

For the supply of concrete the contractor shall submit to the owner a valid Certification of Concrete Facilities for each concrete supply plant from the Ready Mixed Concrete Association of Ontario (RMCAO) two weeks prior to the start of the project.

3.2 ECO CERTIFICATION OF CONCRETE FACILITIES

To address sustainable materials procurements, the Contractor shall submit to the Owner a valid ECO CERTIFIED Concrete Facility certificate, from the RMCAO, for each concrete supply plant two weeks prior to the start of the project.

4.0 EQUIPMENT

4.1 BATCHING PLANT AND EQUIPMENT

Use a batching plant conforming to CSA A23.1 and the RMCAO's Audit and Check List.

4.2 MIXERS

Mix the concrete in a central-mix plant or in truck mixers conforming to CSA A23.1, and the RMCAO's Truck Certification Program. Operate all equipment within the manufacturer's recommended capacity to produce concrete of uniform consistency.

4.2.1 Central Mix Plant

Use a batching plant conforming to CSA A23.1 and the RMCAO's Audit and Check List. Combine cementitous materials, aggregates, admixtures and water in the mixer. Dispense liquid admixtures through controlled flow-meters or use dispensers with sufficient capacity to measure, at one time, the full quantity of each admixture required for a batch. If the mixture requires more than one admixture, dispense each with separate equipment.

4.2.2 Truck Mixers and Truck Agitators

Use truck mixers for mixing and hauling concrete and truck agitators for hauling central-mixed concrete that meet the requirements of CSA A23.1, and the Ready Mixed Concrete Association of Ontario's Truck Certification Program.

4.2.3 Non-Agitator Trucks

Use non-agitator trucks for hauling central-mixed concrete that meet the requirements of CSA A23.1, and the RMCAO's Truck Certification Program.

4.3 PAVING EQUIPMENT

Furnish the paving and finishing equipment applicable to the type of construction in this contract.

4.3.1 Slip-Form Machines

Where used, furnish machines capable of spreading, consolidating, screeding, and finishing the freshly placed concrete in one pass to provide a dense and homogenous pavement requiring minimal hand finishing. Equip the paving machine with the following:

a. Automatic controls to control line and grade from either or both sides of the machine, or from averaging-skis that reference the grade.

b. Vibrators to consolidate the concrete for the full width and depth of the strip of pavement being placed.

c. A positive interlock system to stop all vibration and tamping elements when forward motion of the machine stops.

4.3.2 Self-Propelled Form-Riding Machines

a. Where used, furnish mechanical, self-propelled spreading and finishing machines capable of consolidating and finishing the concrete with minimal hand finishing. Do not use machines that displace the fixed side forms.

b. Furnish internal immersed tube or multiple spud vibrators. Attach vibrators to the spreader or finishing machine, or attach them on a separate carriage that precedes the finishing machine.

4.3.3 Manual Fixed-Form Paving Machines

Where used, furnish spreading and finishing machines capable of consolidating and finishing concrete up to 200mm thick.

Note: Where the contractor wishes to place slabs greater than 200mm, authorization shall be obtained from the engineer prior to concrete placement.

Note: Slabs greater that 200mm shall be internally vibrated to provide full depth consolidation without segregation.

4.3.4 Vibrators

Concrete shall be consolidated by means of surface vibrators, internal vibrators, or a combination of both that provides full depth consolidation without segregation.

a. Furnish internal immersed tube or multiple spud vibrators for all paving more than 200mm thick. Operate the vibrators at frequencies as per manufacturer’s recommendations.

b. For the construction of irregular areas, use handheld vibrators. Operate the vibrator at a frequency in the range recommended by the manufacturer for the vibrator’s head diameter.

4.4 CONCRETE SAWS

Furnish concrete saws that are capable of sawing new concrete for crack control on all concrete pavements in this contract. Equip all saws with blade guards and guides or devices to control alignment and depth.

4.5 FORMS

Furnish straight, steel, wood or metal plate wood forms with a height equal to the nominal pavement thickness at the edge. For curved edges with radii less than 30m, furnish flexible or curved forms. Forms shall be according to OPSS 919 and conform to the following:

a. Use straight forms that are 3m minimum in length.

b. Use forms with a maximum top face deviation of 3mm in 3m.

c. Use forms with a maximum inside face deviation of 6mm in 3m.

d. Equip each form with devices to adequately secure the form to the subbase or subgrade, and to withstand operation of the paving equipment and pressure of the concrete.

e. Equip each form with devices to tightly join and lock each end to the abutting section.

4.6 JOINT SEALING

Furnish joint sealing equipment, if required, according to the sealant manufacturer's recommendations for the sealant specified in the plans.

4.7 FINISHING TOOLS

Furnish magnesium hand finishing tools.

4.8 DOWEL ASSEMBLIES FOR PRE-PLACED DOWEL BARS

Where dowel bars are required, and dowel assemblies (baskets) are used, and are fastened to the subbase using steel staking pins for granular materials or nailing clips for stabilized materials. Care must be taken in positioning the baskets so that the joints can be sawed directly over the basket and perpendicular to the centerline. Consolidation of the concrete around the dowel bars must be completed during concrete placement.

4.9 AUTOMATIC DOWEL BAR INSERTER

Where dowel bars are required, and an automatic dowel bar inserter is used, it must be capable of placing dowels as specified. The dowel bars shall be inserted to mid-depth of the slab and centered on the transverse joint locations and spaced as shown on the plans. The equipment shall be capable of consolidating the concrete around the dowel bars.

4.10 DIAMOND GRINDER

Where a diamond grinder is used, it shall be power-driven, self propelled equipment specifically designed to grind and texture concrete pavement and concrete base. It shall be equipped with a grinding head with at least 50 diamond blades per 300mm of shaft. The grinding head shall be at least 0.9m wide. The grinder shall be equipped with the capability to adjust the depth, slope and crossfall to ensure that concrete is removed to the desired dimensions and uniformly feathered and textured across the width and length of the required area. The equipment shall also include a slurry pick-up system.

5.0 CONSTRUCTION REQUIREMENTS

5.1 SUBGRADE PREPARATION

Preparation of the subgrade shall include the following activities:

a. Compacting soils shall be completed at moisture contents and densities that will ensure uniform and stable pavement support.

Note: All soft, yielding material or other portions of the subgrade that will not compact to specification shall be removed and replaced with suitable material. The subgrade shall be brought to a firm unyielding condition with a uniform density. It shall be compacted at or above optimum moisture content to 95% Standard Proctor density.

Note: High plasticity subgrade soils should be compacted at moisture contents slightly above optimum values to minimize the potential for future swelling.

b. Whenever possible, set grade lines high enough and make side ditches deep enough to increase the distance between the water table and the pavement.

c. Cross-hauling and mixing soils to achieve uniform conditions in areas where there are abrupt horizontal changes in soil types.

Note: Concrete pavements require continuous and uniform support. Subgrades having abrupt changes in material type or moisture content may result in differential movement causing non-uniform support for the pavement slab.

d. Using selective grading in cut and fill areas to place the better soils nearer to the top of the final subgrade elevation.

e. Improving extremely poor soils by treating them with lime, cement, cement kiln dust, or fly ash, or by importing better soils, whichever is more economical.

Note: When concrete is placed directly on the subgrade, it should be checked for conformity with the cross-section tolerance. The finished surface should not deviate more than 0mm above and 20mm below the specified grade and cross-section, and the surface should not deviate more than 10mm at any place on a 3m template.

Note: In areas where frost heave may be a concern, placement of a layer of insulation in the road bed to retard geothermal heat loss, thereby reducing the depth of frost penetration has been used as an economical solution to the problem of frost heave dating back to the late 1960’s. This is a technique still being used today.

5.2 SUBBASE PREPARATION

The subbase shall consist of specified material and have a compacted thickness and density of not less than that specified in the contract documents. Prior to placing concrete, the subbase shall be thoroughly wetted.

Note: Wetting of the subbase shall be carried out, such that standing water in not present.

Note: Although a subbase may not be needed for pavement structural design, it is often provided as a working surface for the concrete placement operation, to prevent subgrade pumping from heavy, frequent truck traffic, or to provide a drainage layer.

Note: For slip-form paving, it is important that the subbase travelled by the tracks of the paving machine be firm and have a smooth surface.

Note: The prepared subbase shall be checked for conformity with the cross-section and grade tolerances. The finished surface of the subbase shall not deviate more than 0mm above and 20mm below the specified grade and cross-section, and the surface shall not deviate more than 10mm at any place on a 3m template.

5.3 CURB, GUTTERS, MANHOLES AND CATCH BASINS

Manholes, catch basins and their frames shall be isolated full-depth from the mainline pavement by round-outs using the jointing procedures described in section 5.9.

5.4 FORMS AND GUIDE LINES

5.4.1 Fixed-Form Paving

a. Sideforms shall be steel, wood or metal plate wood forms. They shall be of such cross section and strength, and so secured as to resist the pressure of the concrete when placed, and the impact and vibration of any construction equipment they support without springing or settlement. For curves of 30m radius or less, flexible or curved forms should be used. Where required, forming strips for keyways should be accurately dimensioned and securely fastened against the form face.

b. Forms shall be pinned securely, tolerances of 6mm in 3m in horizontal alignment and 3mm in 3m in vertical alignment.

c. Forms should be fully and continuously supported over the subgrade or subbase by one or both of the following methods:

    i. The subgrade or subbase under the forms should be trimmed and compacted to ensure the forms are uniformly supported over their entire length at the correct level and grade.

ii. Forms should be adjusted to the correct level by the use of steel shims or wedges, and the space between the subgrade or subbase and the form should be filled solid and trimmed flush with the inside of the form.

d. Forms shall be set sufficiently in advance of concrete placement to permit inspection.

e. Forms shall be cleaned and coated with acceptable form release agent before each use.

f. Forms should remain in place until the concrete has set sufficiently to avoid damage to the pavement edge or any projecting tie-bars or dowels upon removal.

5.4.2 Stringlines for Slip-Form Paving

a. Stringlines shall be placed on both sides of the slip-form equipment. Stringlines may be omitted when abutting existing pavement.

b. Stringlines should be fixed sufficiently in advance of the paver to permit inspection.

5.5 TRANSPORTING AND PLACING CONCRETE

5.5.1 Transporting

a. The concrete mixing, delivering and spreading operations shall be coordinated to provide a uniform rate of progress of the paving equipment minimizing stopping and starting.

b. Concrete mixed at a central mixing plant shall be transported to the paving site in truck mixers, truck agitators or non-agitating trucks. When non-agitating trucks are used to haul concrete, no more than 30 minutes shall elapse from the time water is added to the mix until the concrete is deposited at the paving site. When truck agitators are used, the elapsed time should not exceed 90 minutes.

c. During mixing and transportation of concrete, truck mixers shall be operated at the speeds designated by the manufacturer, as shown on the manufacturer’s rating plate attached to the drum unit.

d. Concrete shall be transported to its final position, such that segregation or loss of slump is minimized and the concrete has the required workability at the point and time of discharge.

e. Concrete trucks or truck mixers shall not operate from previously paved lanes until the concrete has achieved a compressive strength of 20MPa, as per OPSS 350. If equipment operating in the paving lane causes rutting or displacement of the subbase or subgrade material then lighter trucks, suitable runways, tracked equipment, or combination of these procedures shall be used.

5.5.2 Placing Concrete

a. Concrete shall be placed on a dampened subgrade or subbase, and as close as possible to its final position, so as to minimize rehandling.

b. Hand spreading of concrete shall be done with a come-along or square ended shovel (rakes shall not be used).

c. Concrete shall be placed as near as possible to a dowel assembly, but shall not be dumped directly onto the assembly.

d. Concrete shall not be placed in snow or ice or on a frozen subgrade or subbase.

5.6 PAVING

5.6.1 Equipment

Place concrete with fixed-form or slip-form paving equipment. Operate the paving equipment with a continuous forward movement, as practicable, and coordinate mixing, delivering, and spreading concrete to provide uniform progress.

Note: Except in an emergency, apply no tractive force to a slipform-paving machine, except that which is controlled from the machine.

5.6.2 Reinforcing Steel

Place reinforcing steel as shown in the contract documents. Either firmly position the reinforcement on acceptable supports before placing the concrete or mechanically insert the reinforcement into the plastic concrete to the required location and alignment tolerances.

5.6.3 Irregular Areas

In irregular areas or areas inaccessible to self-propelled paving equipment, construct the pavement using fixed forms and manual fixed-form paving equipment. Thoroughly and uniformly vibrate and consolidate the concrete during placement without segregating the material. Use handheld internal vibrators along forms and around embedded objects, including dowel baskets and utility fixtures, where necessary to ensure adequate consolidation.

5.6.4 Hot and Cold Weather

When paving in extremely hot or cold air temperatures, use adequate concrete protection measures. Concrete that the engineer suspects was damaged by frost action or excessive heat is subject to additional testing to determine its quality.

5.7 CONSOLIDATING AND FINISHING

5.7.1 Consolidation

a. The sequence of operations shall be the strike-off and consolidation, floating, if necessary, straight-edging, and final surface finish.

b. Concrete shall be thoroughly consolidated against and along the face of all forms and into the face of previously placed concrete.

Note: The rate of progress of either slip-form or fixed-form paving machines should be adjusted to ensure complete consolidation of the concrete along the full width of the paver.

Note: See ACI 309, *Standard Practice for Consolidation of Concrete*, for guidance.

Note: Thorough consolidation is important and necessary for: maximum strength, sharp details at edges and joints, and good bond to tie bars.

c. For fixed-form pavers with vibrating screeds, hand-held vibrators shall be used to supplement consolidation adjacent and along the full length of the form. They should also be inserted at regularly spaced intervals along both sides of dowel assemblies. The vibrators shall not come in contact with the subgrade or subbase, forms or dowel assemblies. Vibrators shall never be operated longer than 15 seconds in any one location, as per ACI 309.

d. Speed and operation of vibrating beam pavers should be in accordance with manufacturers' recommendations.

Note: Some pavers require two passes or two beams set in tandem to achieve desired consolidation and surface profile. The speed is usually in the 0.5 to 1.0 m/min range.

e. For slip-form pavers, the concrete shall be consolidated by internal vibrators of sufficient number, spacing and frequency to provide uniform consolidation to the entire pavement width and depth. The vibrators shall not operate while the paver is stopped.

Note: For slabs up to 250mm thick, the vibrators should be mounted at mid-depth and parallel to the subgrade or subbase. For depths greater than 250mm, vibrators should be mounted with the tips a minimum of 50mm above the subgrade or subbase and the top a minimum of 50mm below the surface of the concrete.

Note: Proper consolidation has been achieved when the surface of the concrete has a uniform texture, with no mortar streaking, uniform sheen, with the coarse aggregate barely visible on or immediately below the surface.

Note: Prior to the construction of the pavement, a test section of pavement should be constructed to evaluate the paving machine operation and performance. The air void system and density of the concrete should be checked, as well as its compressive or flexural strength. Approval of the test section by the engineer should be obtained.

5.7.2 Finishing

a. Adding water to the surface of the concrete to assist the finishing operation shall not be permitted. A fine spray of water shall be permitted only to prevent drying shrinkage cracking caused by rapid evaporation of surface moisture. Only approved spray equipment may be used.

b. Following strike-off and consolidation, the concrete pavement shall be struck-off with a magnesium straightedge 3m long, equipped with a handle to permit operation from the edge of the pavement, if required.

c. The straightedge shall be drawn perpendicular to the centerline of the pavement and should be moved forward, in the direction of the paving, one-half of its length after each pass. Irregularities should be corrected by the addition or removal of concrete. All disturbed surfaces should again be straightedged.

Note: When slip-form pavers exhibit edge slumps in excess of specified tolerances, the engineer may direct that the contractor use temporary side forms for surface correction during the scraping operation.

d. The final surface texture shall be applied, as specified, following the straightedge and edging operation.

Note: A burlap drag or broom is acceptable on low speed facilities; on high-speed facilities, a burlap or astro-turf drag with a tined texture should be used.

e. A burlap drag shall be wide enough to cover the entire pavement slab and should be at least 1m long with a minimum of 500mm in contact with the concrete surface. The burlap shall be kept in a clean and damp condition, free from encrusted mortar. It should be placed on the surface and dragged in the direction the pavement was placed.

f. A broom finish shall be obtained by the use of a stiff, coarse fibre broom. A tined finish should be obtained by the use of a device having randomly spaced wire tines with spacing varying from 10 to 40mm with 50 percent of the spacings less than 25mm. The device used shall be dragged transversely across the pavement to form grooves in the surface of the pavement. The width of grooves should range from 2 to 3mm, and the depth of the grooves from 3 to 5mm. Texturing shall be delayed until the concrete is sufficiently hard to retain the ridges. Longitudinal tinning may also be specified by the owner.

g. Final texturing shall be determined in the field on the pavement to the satisfaction of the authorities having jurisdiction.

h. The contractor shall have available material to protect the surface of the plastic concrete from damage by rain. These materials may consist of burlap, cotton mats, waterproof paper or plastic sheeting. Pavement protection shall be employed when rain, sufficient to spoil the texture of the concrete surface, is expected. When slip-form construction is used the edges of the pavement shall be protected.

Note: No concrete should be placed during rain. When rain appears imminent, paving operations should cease and the necessary steps for complete protection of plastic concrete pavement surface commenced, as well as the provision of a construction joint as shown on the drawings.

5.8 CURING AND PROTECTION

5.8.1 Curing

a. The contractor shall have the material and equipment needed for adequate curing on hand and ready to install before actual concrete placement begins.

b. Curing shall be according to OPSS 904 with the following exceptions:

Note: Desirable properties of concrete pavements, such as strength, durability and wear resistance, improve with continuous hydration of the cement as a result of good curing practice.

i. Curing shall be applied to all exposed surfaces as soon after the texturing operation as can be achieved without damaging the surface.

ii. As soon as forms are removed, the sides of the exposed concrete faces shall be sprayed with the white pigmented curing compound at the specified rate of application. Curing compound shall not be applied to joint faces receiving sealant or to concrete surfaces to which concrete or mortar is to be bonded.

iii. In extremely hot temperatures, consideration should be given to adding set-retarding admixtures, early morning or evening placement, or other means to keep the concrete temperature as low as possible when placed.

iv. When concrete has been placed in cold weather and the air temperature is expected to drop below 5˚C, insulated curing blankets or other suitable material shall be placed on the concrete pavement and weighted to prevent movement. Curing shall continue until the cumulative number of days, or fraction thereof, during which the temperature of the concrete is above 10˚C, has totaled a minimum of 7 days.

Note: Corners and edges are most vulnerable to damage from freezing and should receive additional insulation protection.

v. Concrete pavement placed in cool weather shall experience a minimum 30 day air-drying period, following final curing, before the first application of de-icing salts.

Note: A period of air-drying increases the resistance of the surface of the pavement to possible damage caused by deicer applications. Membrane-forming curing compounds tend to delay air-drying. In some jurisdictions, use of membrane-forming curing compounds is not permitted following October 15.

5.8.2 Protection

a. During the seven days following placing, the concrete temperature shall not fall below 10˚C or exceed 27˚C.

b. Concrete shall not be placed in the rain. The contractor shall take all necessary precautions to protect plastic concrete from the rain.

c. Traffic, other than foot traffic, rubber-tired sawing equipment, and rubber-tired side wheels of form mounted placing and finishing equipment necessary to construct adjacent lanes, shall not be permitted on the concrete until it has attained 20MPa.

d. The concrete pavement shall be protected from damage to the surface at all times when steel-tracked equipment is used.

5.8.3 Hot Weather Concreting

a. The temperature of the concrete at the time of placement shall be between 10˚C and 28˚C.

b. The temperature of formwork, reinforcing steel or the material on which the concrete is to be placed, shall not exceed 30˚C.

5.8.4 Cold Weather Concreting

a. The temperature of the concrete at the time of placement shall be between 10˚C and 28˚C.

b. Ice and snow shall be removed from the area where concrete is to be placed. Deicing chemicals shall not be used.

c. Concrete shall not be placed on or against frozen ground. Excavations prepared for concreting and any existing concrete, reinforcing steel, structural steel, forms or other surfaces against which concrete will be placed, shall be at a minimum temperature of 5˚C for a period of 12h prior to commencement of placing concrete.

d. All cold weather protection material shall be on site prior to each concrete placement.

e. The protection system shall be designed for the worst conditions that can be reasonably anticipated from local weather records, forecasts, site conditions and past experience for the time period during which the protection is required.

f. The contractor shall monitor the conditions and modify the protection system as required.

5.9 JOINTING

Joint layout is critical for prevention of uncontrolled cracks, especially for complex geometries and intersections. Joints shall be of the type and at the location shown in the Contract, and cleaned and sealed according to OPSS 369. Load transfer devices shall be as shown in the contract.

Note: For joint layout – match existing joints or cracks; place joints to meet in-pavement structures; remember maximum joint spacing; place isolation joints where needed; understand that adjustments to joint locations can be made in the field; and be practical.

Note: Avoid – slabs less than 0.6m or greater than 4.5 wide; angles less than 60˚ (~90˚ is best, do this by dog-legging joints through curve radius points); creating interior corners; odd shapes (keep slabs near-square or pie-shaped).

5.9.1 Contraction Joints

a. Transverse contraction control joints and all longitudinal joints shall be constructed and located as indicated on the drawings.

b. Transverse and longitudinal joints shall consist of planes of weakness created by forming or cutting vertical grooves in the pavement surface.

Note: The method of constructing control joints will depend on the construction method, the size of the project and the required riding quality.

c. Transverse contraction joints shall extend to a minimum depth of 1/3 the thickness of the slab. They shall be located at a spacing not exceeding 30 times the thickness of the slab, with a maximum distance of 4.5m between joints.

i. Sawed transverse control joints shall be located on the surface of the pavement by suitable marking in advance of sawing. A standby saw and blades must be available in the event of equipment breakdown.

ii. Sawing shall commence as soon as the concrete has hardened sufficiently to permit sawing without excessive raveling (usually within 6 to 12 hours). Earlier sawing may be achieved with specialized methods if approved by owner.

Note: Air temperature, wind and humidity levels will dictate how soon sawing can commence.

iii. Sawing of any joint shall be omitted if a random crack has developed at or near the joint location before the time of sawing. Sawing should be discontinued if a crack develops ahead of the saw.

Note: When a crack occurs ahead of the sawing, usually as a result of sawing too late, remedial measures may be required, such as sawing every third or fourth joint followed by sawing the intermediate joints.

iv. Sawed grooved forming a reservoir for joint sealant shall be formed to requirements or manufacturer specifications.

v. Concurrent with the reservoir sawing operation, the grooves shall be cleaned of laitance and grit by high pressure water jets.

vi. Transverse contraction joints shall extend continuously across the mainline pavement and curb or shoulder.

5.9.2 Longitudinal Joints

a. Longitudinal joints shall consist of planes of weakness created by cutting or forming grooves in the surface of the pavement at the locations shown on the drawings. The depth of the joint shall be at least one-third the slab thickness.

i. Sawed longitudinal joints shall be constructed similar to the procedure for transverse contraction joints – Clause 5.9.1.c.i.

5.9.3 Construction Joints

a. Transverse construction joints should be made at the end of each day’s run or whenever the placing of concrete is interrupted for more than 30 minutes.

b. Longitudinal construction joints shall be of the dimension shown on the drawings. When a key is required, it shall be constructed by forming or extruding when the first lane adjacent the joint is placed. Dimensions of the keyway shall not vary more than 2mm from the dimensions shown on the drawings, and not more than plus or minus 4mm the mid-depth of the pavement.

i. Longitudinal construction joints shall be edged with a small radius edger and textured to match adjacent concrete.

5.9.4 Isolation Joints

Isolation joints shall be constructed around maintenance holes in catch basins and against existing structures or objects within or abutting the pavement, and at intersections as shown on the drawings. The isolation joint filler shall be held in a vertical position, and shall be continuous from edge to edge with no gaps, and should extend the full depth of the pavement. The joint shall be edged and textured to match the adjacent surface. The finished joints should not deviate in horizontal alignment more than from a straight line.

5.9.5 Dowel bars

Dowel bars are smooth, round steel bars placed across transverse joints. Dowel bars are used to provide load transfer while permitting a joint to open and close.

a. Dowel bars when required shall conform to the requirements of OPSS 1441.

b. Dowels shall be epoxy coated, smooth, straight and free from dirt. The free ends shall be beveled. For at least half their length, the dowels shall be coated with a bond-breaking compound, such as, oil or a form release agent, or be enclosed in a tight-fitting plastic sheath.

c. When specified, dowels shall be placed at transverse joint locations using either dowel basket assemblies or automatic dowel bar inserters.

Note: Dowel baskets shall be pinned to remain stable and undisturbed during the paving operation.

d. Tolerances for dowel placement shall be a deviation of not more than one degree from alignment of the pavement; and within a tolerance of $\pm$ 6mm in the vertical and horizontal planes of the pavement.

Note: Failure to accurately align the dowels may result in a locked joint causing cracking or spalling.

e. Dowel locations shall be visibly marked on the form, adjacent slab or by stakes or pins on the shoulder to permit accurate location for joint forming operation.

5.9.6 Tie bars

Tie bars are deformed bars used to hold adjacent pavement slabs tightly together.

a. Tie bars shall be deformed reinforcing bars. Bent tie bars may be used. Epoxy-coated tie bars shall be used and shall conform to the requirements of OPSS 1442.

b. Tie bars shall be free of any lubricant or coating which may reduce the bond with the concrete. They shall be located at the mid-depth of the slab, as shown on the drawings and installed so they do not deviate more than 20mm from mid-depth.

Note: For fixed-form paving, tie bars may be located in openings in the form face.

Note: For slip-form paving, tie bars may be inserted through temporary side forms located behind the paver, or mechanically inserted into the plastic concrete by approved devices associated with the slip-form paver.

c. Tie bars shall be inserted in such a manner that no voids are created around the tie bar, and no distortion of the pavement surface occurs.

5.9.7 Sealing Joints

a. Joint sealing shall be according to OPSS 369.

b. Joint sealants shall be installed to joint sealant manufacturer's specification.

c. Joints specified to be sealed shall be filled with joint sealing material before pavement is open to traffic.

d. Just before sealing with field-moulded sealants, joints shall be abrasive blast cleaned, followed by air-blasting with compressed air free of oil and moisture. The joint faces should be clean and dry when the sealing material is applied.

5.10 OPENING TO CONSTRUCTION EQUIPMENT

Protect previously-constructed lanes from damage by construction equipment. Only allow equipment on the previously constructed concrete after the concrete attains a compressive strength of 20MPa, as per OPSS 350.

6.0 STRENGTH TESTING AND EVALUATION

6.1 ACCEPTANCE REQUIREMENTS

Acceptance of the concrete pavement for each lot will be based on the mean and standard deviation of the lot measurements for compressive strength, slab thickness and smoothness. The engineer will calculate the Percent Within Limits (PWL) for each criterion as described in LS-101.

6.1.1 Concrete Strength Evaluation

a. Compressive strength test results shall be used as the basis for acceptance or rejection of the concrete. Performance based mix submissions shall include a correlation of compressive strength to flexural strength.

b. When cylinders are specified, the average compressive strength of all sets of three consecutive strength tests, made and tested in accordance with CSA A23.2-3C and CSA A23.2-9C, should not be less than that specified in 2.1.b of this document at age 28 days. No individual strength test should be more than 3.5MPa below the specified strength.

c. When cores are specified, the compressive strength shall be tested when the concrete is 28 to 35 days old. If the contractor elects to core prior to 28 days, the compressive strength test will be performed within two days of coring. The cores shall be stored in the laboratory at an ambient air temperature of $\geq$15˚C and $\leq$ 25˚C and moisture conditioned for 40-48 hours prior to testing. The testing shall be in accordance with CSA A23.2-9C. The PWL shall be greater than 50%, with no individual core less than 60% of the specified compressive strength, as per OPSS 350.

6.1.2 Thickness

The slab thickness will be determined based on core length for each sublot; each core shall be measured for length prior to trimming. Four measurements rounded to the nearest millimeter shall be made around the perimeter of the core to determine the actual concrete thickness. These measurements shall be taken at the ends of two perpendicular diameters. The PWL shall be greater than 50%, with no individual core less than 60% of the specified slab thickness, as per OPSS 350.

6.1.3 Smoothness

The finished surface shall be tested for smoothness by use of a 3m long straightedge placed parallel to the center line of the pavement in each wheel line.

6.1.4 Tolerance in Pavement

The surface of the concrete is to be such that when tested with a 3m long straightedge placed in any location and direction, including the edge of pavement, except across the crown or drainage gutters, there shall not be a gap greater than 3mm between the bottom of the straightedge and the surface of the pavement.

6.1.5 Frequency and Number of Tests

The frequency and number of tests for compressive strength, air content, slump and temperature of the plastic concrete shall be in accordance with CSA Standard A23.1, unless otherwise specified in the contract documents.

a. Strength: Not less than one test for every $100m^3$ of concrete placed, with no fewer than one test for each class of concrete placed on any one day.

b. Slump: A sufficient number of tests must be conducted to establish consistency. It is recommended to test the first 3 loads per mix per day, one for every strength test, and one for every air test.

c. Air Content: For classes C-XL, C-1 and C-2, every load until consistency is attained, every 3^{rd} load thereafter. An air test must be performed with every strength test.

6.2 OPENING TO TRAFFIC

The pavement may be open to traffic when specimen cylinders conforming to the requirements stated above have attained 20MPa, as per OPSS 350; or cores conforming to the requirements stated above have attained 17MPa.