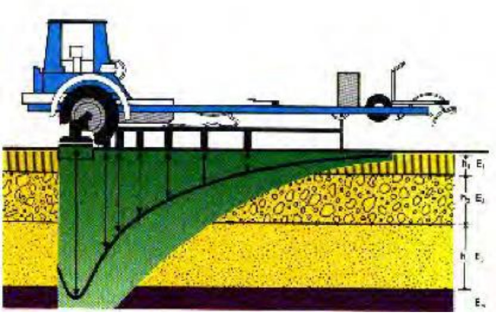
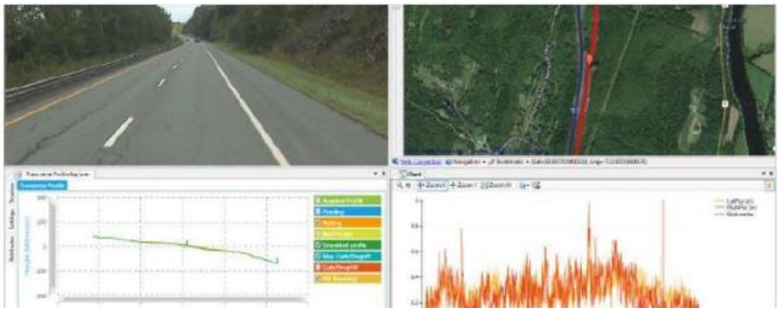
TORONTO Transportation Services

Pavement Design and Rehabilitation Guideline







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Pavement Design and Rehabilitation Guideline

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Executive Summary

For over a century, the City of Toronto's pavement infrastructure has been routinely constructed, maintained, and enhanced. Roads have been constructed using a variety of pavement structural designs depending on the location within the city, function, the soil, and traffic conditions. Over the past several decades, research and other technological advancements in the pavement engineering field have brought a gradual shift in design and construction thinking. This shift has been observed in terms of how pavements and pavement materials are designed, tested, evaluated, constructed and managed. Pavement design is steadily changing from an art to a science.

In 2006, the City published Pavement Structural Design Guideline [1] mostly focusing on the design of new pavement construction. As the City and associated infrastructure ages, the need for cost effective maintenance, repairs, rehabilitation and replacement continues to grow. Due to the gaps in the 2006 Pavement Structural Design Guideline, in April 2017, Transportation Infrastructure Management Section, Infrastructure Asset Management & Programming Unit formed a task group consisting of members from the Engineering and Construction Services and Transportation Services Division. These members collaborated for more than a year to finalize the contents within this document. Committees were formed to solicit wider feedback as the Pavement Design and Rehabilitation Guideline is applicable to other stakeholders such as Road Operations and Public Realm Section. Beginning of 2019, as part of Transportation Services divisional business transformation, the City is moving towards implementation of AASHTO 1993 pavement design guidelines [2] along with the MTO MI-183 report entitled "Adaptation and Verification of AASHTO Pavement Design Guide for Ontario Conditions" [3] for the verification of all road rehabilitation works as per best industry practices.

New revisions in this Pavement Design and Rehabilitation Guideline include Superpave Mix Design, Life Cycle Cost analysis, Enhanced/New Material tests and Non-Destructive Testing (NDT), for example Ground Penetrating Radar (GPR), Falling Weight Deflectometer (FWD), and Friction Resistance Testing. The Guideline also includes network level planning to project level design context, clarification around Laneways & Expressway design, clarity around Road Operations/Maintenance and improved pavement treatment Service Lives clarity. Finally, revisions also comprise of pavement reconstruction age triggers, clarity around other assets design and linkage with pavement design, consistent coring/boring frequency guidance,

improved focus on pavement design using the AASHTO 1993 guidelines, and a new chapter on constructability and improved drainage design.

This Pavement Design and Rehabilitation Guideline (PDRG) shall act as a guidance document to be followed by engineering consultants and City staff when engaged in design functions for City pavement and related transportation assets. Future enhancements of this guide may include pavement structural design updates to reflect the 2015 American Association of State Highway and Transportation Officials (AASHTO) Mechanistic Empirical Pavement Design (MEPD) Guide, calibrated for City, Ontario Ministry of Transportation, and Greater Toronto Area experience along with ongoing revisions reflecting best practices in materials specifications and emerging policies and regulations.

What's New?

In 2006, the Pavement Structural Design Guideline was released. As part of continued business improvements and enhancements, the new 2019 Pavement Design and Rehabilitation Guideline (PDRG) provides enhancements and additions in terms of:

1. Non-Destructive Testing (NDT), for example Ground Penetrating Radar (GPR), Falling Weight Deflectometer (FWD) and Frictional Resistance Testing, etc.
2. Enhanced/new material tests
3. Consistent and modified guidance for Coring/Boring frequency with and without NDT
4. Improved focus on pavement design using AASHTO 1993 guidelines
5. Network level planning to Project Level design context clarity
6. Pavement age reconstruction triggers
7. Clarification around Laneways & Expressways design
8. Improved guidance on pavement treatment service lives
9. Superpave Mix Design
10. Improved drainage design focus
11. Life Cycle Cost analysis to identify the best value-for-money rehabilitation alternative
12. New chapter on constructability
13. Clarity around Road Operations/Maintenance
14. Discussion of other related Assets and linkage with pavement design
15. Best practices in pavement materials, selection and specification to reflect the City's Climate Change Risk Management Policy and related Climate Change Risk Assessments

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Technical Working Committees

Focused technical working committees were formed to engage the Engineering & Construction Services (ECS) and Transportation Services (TS) Divisions to gain their input from a design, constructability and delivery perspective. A list of the technical working committee members is presented below:

Chair:
Mark Berkovitz, Infrastructure Asset Management & Programming, TS

Co-Chair and Lead:
Riaz Ahmed, Infrastructure Asset Management & Programming, TS

Coordinator (s):
Prabir Das, Infrastructure Asset Management & Programming, TS
Jawaid Choudhary, Infrastructure Asset Management & Programming, TS
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3. Jerry Higgins, Soil & Groundwater Quality, ECS
4. Michael Popik, Major Roads, ECS
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Acknowledgments

This Pavement Design and Rehabilitation Guideline demonstrates the talents and dedication of the City staff from various Divisions and Units. We would like to thank the staff of the Transportation Infrastructure Management Section, Engineering & Construction Services, Road Operations and Public Realm Section for their involvement in making this guideline a reality. The City of Toronto would like to thank Tom Kazmierowski and Michael Maher of Golder Associates Ltd. for their review in developing this guideline.

All participants were committed to creating a practical resource that will provide a practical guidance document to be followed by external engineering consultants and City staff when engaged in pavement design and rehabilitation projects so as to support the delivery of cost effective and safe road infrastructure in the City. The advice, input and participation received throughout the consultation process is gratefully appreciated.

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List of Abbreviations

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Cement
ARAN	Automated Road Analyzer
CB	Catch-basin
CBR	California Bearing Ratio
CIR	Cold In-Place Recycling
CIREAM	Cold In-Place Recycled Expanded Asphalt Mix
CRL	Crusher Run Limestone
DB	Deflection Basin
EAS	Expanded Asphalt Stabilization
ECS	Engineering & Construction Services
ESAL	Equivalent Single Axle Load
FN	Friction Number
FWD	Falling Weight Deflectometer
GBE	Granular Base Equivalency
GHG	Greenhouse Gas
GPR	Ground Penetrating Radar
GPS	Global Positioning System
HIR	Hot In-Place Recycling
HMA	Hot Mix Asphalt
IRI	International Roughness Index
JPCP	Jointed Plain Concrete Pavement
JRCP	Jointed Reinforced Concrete Pavement

LCCA	Life Cycle Cost Analysis
LT	Load Transfer
LTE	Load Transfer Efficiency
MEPDG	Mechanistic Empirical Pavement Design Guide
MH	Maintenance Hole
MPMA	Municipal Pavement Management Application
MTO	Ministry of Transportation of Ontario
NDT	Non-Destructive Testing
NMAS	Nominal Maximum Aggregate Size
OGDL	Open Graded Drainage Layer
OPS	Ontario Provincial Standard
OPSD	Ontario Provincial Standard Drawings
PC	Pervious Concrete
PCC	Portland Cement Concrete
PCI	Pavement Condition Index
PCS	Primary Control Size
PDRG	Pavement Design and Rehabilitation Guideline
PGAC	Performance Graded Asphalt Cement
PLM	Polarized Light Microscopy
PQI	Pavement Quality Index
PSI	Present Serviceability Index
PXO	Pedestrian Crossover
RAP	Reclaimed Asphalt Pavement
RCM	Reclaimed Concrete Material
R.o.W.	Right of Way

SCI	Sidewalk Condition Index
SLC	Structural Layer Coefficient
SMA	Stone Mastic Asphalt
SN	Structural Number
TAC	Transportation Association of Canada
TS	Transportation Services
TWSI	Tactile Walking Surface Indicators
U-fill	Unshrinkable Fill
VOC	Vehicle Operating Costs
WMA	Warm Mix Asphalt

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Introduction

The City of Toronto maintains a network of about 5,600 centreline-kilometres of road and over 300 centreline-kilometres of laneways. It controls an extensive network of roadways that vary in function from low volume residential roadways to controlled access highways.

The City's pavement infrastructure has been constructed, maintained, and enhanced for over a hundred years. Over the years, roads have been constructed using a variety of empirical and structural pavement designs depending on the location within the city, intended function, soil conditions, and traffic characteristics. Many of the designs have been empirical—based on past experience and observations—that have evolved and been modified over time. Some examples of pavement cross-sections from the 20th century are shown in Figure 1, Figure 2, and Figure 3.

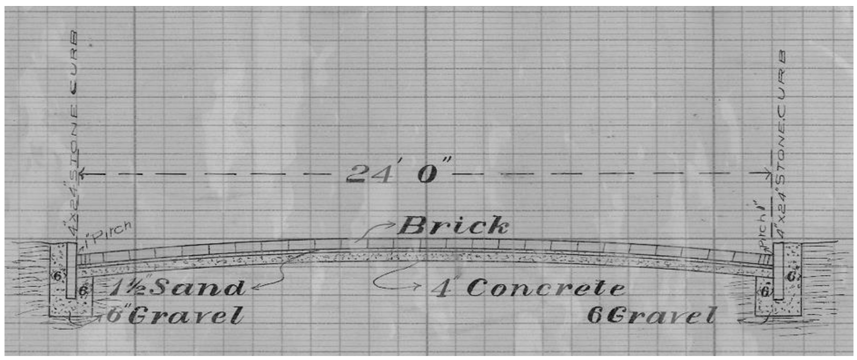


Figure 1. Carlton Street brick surfaced pavement designed in 1902

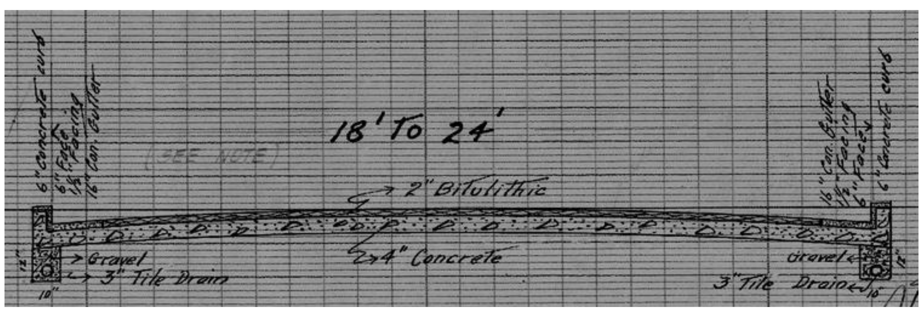


Figure 2. Highland Avenue composite pavement designed in 1909

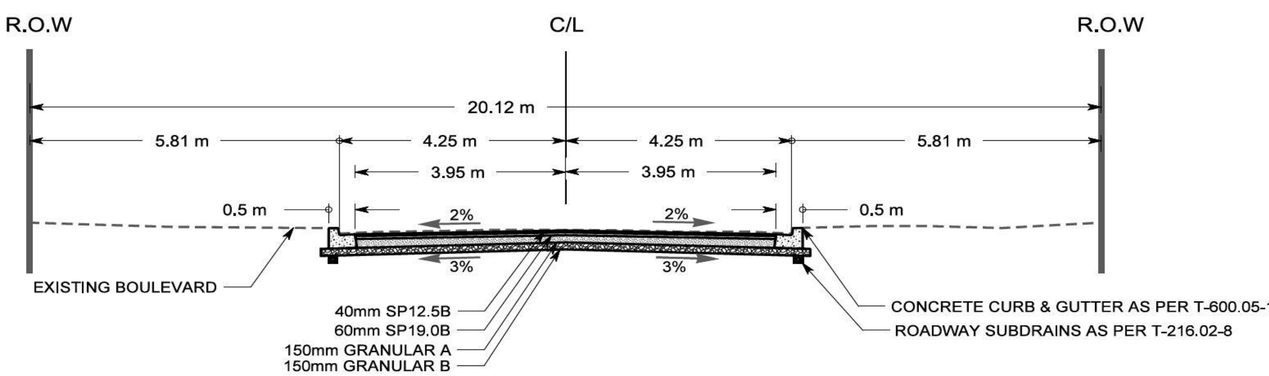


Figure 3. Whitburn Crescent flexible pavement designed in 2018

The past several decades have seen vast changes, fuelled by research and other technological advancements in the pavement engineering field. As a result, a gradual shift is being observed in terms of how pavements and pavement materials are selected, designed, tested, evaluated, constructed, and managed. As part of this effort, pavement design is transitioning from an empirical to a mechanistic-empirical realm which is based on the principles of engineering mechanics correlating to actual field performance.

The Mechanistic Empirical Pavement Design Guide (MEPDG) was developed as a major enhancement on the existing American Association of State Highway and Transportation Officials (AASHTO) 1993 Guide for Design of Pavement Structures [2]. The AASHTO 1993 design procedure was based on empirical performance models that were developed from the American Association of State Highway Officials (AASHO) Road Test of the late 1950's and early 1960's. The 1993 AASHTO procedure has been widely implemented and has been used extensively by North American agencies including the Provinces of British Columbia, Alberta, Manitoba, Ontario, Quebec, New Brunswick, and Nova Scotia. The Ministry of Transportation Ontario (MTO) has adapted and validated the procedure for Ontario conditions [3]. The City's Pavement Structural Design Guideline was first published in 2006 and included a pavement structural design matrix for new pavement construction and reconstruction projects, considering traffic volume, road classification and pavement types based on MEPDG.

Revisions in this Pavement Design and Rehabilitation Guideline (PDRG) include Superpave Mix Design, increased emphasis on Life Cycle Cost Analysis (LCCA), enhanced/new material tests and Non-Destructive Testing (NDT). Examples of these include Ground Penetrating Radar (GPR), Falling Weight Deflectometer (FWD), and friction resistance testing. The PDRG also includes network level planning to Project Level design context, clarification around laneway & expressway designs, clarity around Road Operations/Maintenance and improved clarity on Pavement Treatment Service Lives. Finally, revisions also comprise the Pavement Age Reconstruction Triggers, clarity around Other Assets design and linkage with Pavement Design, consistent guidance on coring/boring frequency, improved focus on Pavement Design using AASHTO 1993 guidelines, a new chapter on constructability and improved drainage design.

SECTION ONE – PAVEMENT EVALUATION, INVESTIGATION AND DESIGN

Chapter 1 – Pavement Evaluation

Pavement evaluations are conducted to determine functional and structural conditions of a road section for the purposes of either routine monitoring or planned corrective action. Functional condition is primarily concerned with the ride quality or surface texture of a road section. Structural condition is concerned with the structural capacity of the pavement and its ability to sustain traffic loads as measured by deflection, layer thickness, and material properties.

At the network level, routine evaluations can be used to develop performance models, prioritize maintenance or rehabilitation efforts and develop short- and medium-term capital expenditure plans. At the project level, evaluations are more focused on establishing the root causes of existing problems to determine the best rehabilitation strategies. Another essential component of collecting detailed pavement related information is for use in design and tendering and to reduce the risk of construction claims.

1.1. Pavement Condition Survey

Pavement surveys are conducted to identify pavement condition. The method used in the City of Toronto to evaluate current road condition is based on the Pavement Condition Index (PCI). PCI is a combined numerical rating out of 100 that represents the severity and extent of a wide range of pavement distress types for a designated section of road. The City has adopted the ASTM D6433 standard [4] as the basis for PCI. In the future Pavement Quality Index (PQI) will be calculated by incorporating roughness/smoothness with PCI for arterial roads and expressways. Currently, the City is using a Pavement condition model where the PQI equals PCI.

After establishing the PQI of a road section it can then be classified as Good, Fair or Poor. The PQI trigger values for the condition classification depend on the road functional class. This allows the level of service to be adjusted based on traffic volumes and posted speeds. The current PQI trigger values to assign a pavement condition classification based on road classification are listed in Table 1.

Table 1: Pavement Condition Classification Based on PQI

Road Classification	PQI Range	Pavement Condition
Expressway	PQI > 75	Good
	75 ⩾ PQI ⩾ 65	Fair
	PQI < 65	Poor
Arterial	PQI > 75	Good
	75 ⩾ PQI ⩾ 55	Fair
	PQI < 55	Poor
Collector	PQI > 70	Good
	70 ⩾ PQI ⩾ 50	Fair
	PQI < 50	Poor
Local Laneway	PQI > 65	Good
	65 ⩾ PQI ⩾ 45	Fair
	PQI < 45	Poor

Since 2017, the City has made great progress in how pavement condition surveys are completed. Manual surveys have transitioned to automated pavement condition surveys for network level data collection and for collecting detailed roadway data such as video, GPS, 3D laser and Laser Crack Measurement Sensor (LCMS) to assess pavement condition. The collected data is used to manage, maintain, value and predict the future performance of the road network. PQI values are used to evaluate pavement condition and are a key input to the City's pavement asset management tools. Construction and rehabilitation history, road classification and pavement types such as flexible, rigid and composite, along with current PQI rating play a significant role in determining the appropriate maintenance and rehabilitation strategy.

Network level pavement condition data is collected using the Automated Road Analyzer (ARAN®) survey unit for pavement asset management and capital works programming. The City collected pavement condition data for all its public road network as a base data set in 2017. The data collection cycle for expressway and arterial roads is once every two years. Collector, local roads and laneways are scheduled every four years. The ARAN® vehicle consists of an automated system for collecting pavement condition data, such as distresses, roughness and crossfall, information on other road right of way assets, digital video log and GPS (Global Positioning System) data. The collected data is available in a web based portal called iVision using linear intervals and PQI values are calculated for all sections. Network level PQI data is input to the City's pavement management software called RoadMatrix to determine projects for multiyear capital works programming and maintenance strategy. The age triggers to identify road sections needing reconstruction in capital works programming are presented in Table 2. This age trigger is used in conjunction with the PQI triggers to identify initial project scope however, proper geotechnical investigation shall identify the final scope of work.

Table 2: Initial Decision Matrix for Road Reconstruction

Pavement Type	Road Classification	PQI	Typical Age of Pavement
Flexible	Local	<45	>70
	Collector	<50	>65
	Minor Arterial	<55	>55
	Major Arterial	<55	>50
	Expressway	<65	>50
Composite/Rigid	Local	<45	>85
	Collector	<50	>80
	Minor Arterial	<55	>70
	Major Arterial	<55	>65
	Expressway	<65	>65

Using the information available in the iVision system, a cursory project level pavement inspection shall be performed to confirm any site specific conditions as part of the regular project level site visits.

1.2. Non-Destructive Testing

Properly designing a durable and economical rehabilitation strategy requires knowledge of a pavement's structural capacity. A non-destructive evaluation procedure can be utilized to assess the structural adequacy of a pavement and determine the material properties for use in designing cost effective rehabilitation strategies. Non-destructive testing can also be utilized to determine the pavement roughness and skid resistance to address road safety. A set of the most commonly used non-destructive tests are discussed below. This will guide City staff and consultants in selecting the right non-destructive test based on the project and network level specific needs.

1.2.1. Falling Weight Deflectometer

Falling Weight Deflectometer (FWD) testing is a non-destructive method for evaluating the structural capacity of a pavement. It tests the pavement to verify whether the joints can transfer the load, how much the layer is deflecting and whether significant voids exist underneath the pavement layer. The City of Toronto follows Ministry of Transportation's *Falling Weight Deflectometer (FWD) Testing Manual – MERO 053* [5] for FWD testing; consultants and City staff are advised to refer to the manual for details pertaining to the testing.

FWD testing can be performed on a wide range of pavement structures including flexible, rigid and composite pavements. There are two main types of FWD testing, Deflection Basin (DB) Test and Load Transfer (LT) Test. DB Test evaluates all types of structures. LT Test usually tests the joints and cracks of rigid and composite pavement structures.

There are two data collection scenarios applicable for FWD testing as per ASTM standard D4602-93 [6], General Project Level and Detailed Project Level. As per MERO-053, the minimum requirements for testing frequency is provided below in Table 3 [5].

Table 3: Typical Requirements for FWD Testing Frequency/Interval

Data Collection Scenario	Test Plan		
	FLEX (DB)	**JCP (DB/LT)**	**JCP (LT)**
General Project Level	Every 50 m to 200 m each lane	25% of cracks/joints	N/A
Detailed Project Level	Every 10 m to 50 m each lane	50% of cracks/joints	Required

Determination of the rigid/composite pavement rehabilitation strategies shall be based on the transverse crack severity and load transfer efficiencies (LTE). LTE can be determined from FWD load transfer test results, visual condition of the crack and joint distress severities, and loss of support/void detection analysis from FWD testing. A decision tool to assist in developing a full depth concrete pavement repair strategy based on the data from FWD testing analysis for jointed plain concrete pavement (JPCP) is shown in Table 4 [5].

Table 4: Criteria for Full Depth Concrete Repair of Transverse Crack/Joint in JPCP

Load Transfer Efficiencies (LTE)	Test Plan	
	Low Severity	**Medium and High Severity**
>70%	Consider other data to determine repair	Full Depth Repair
<= 70%	Full Depth Repair	Full Depth Repair

For any further details, the consultant should follow the MTO document MERO *053* [5].

1.2.2. Ground Penetrating Radar

Ground Penetrating Radar (GPR) is another type of field test that can provide a continuous profile of subsurface conditions [7]. The objectives of the GPR survey are to evaluate the structural condition of the existing pavement and identify subsurface discontinuities. This information is valuable in developing recommendations for rehabilitation, locating limits for treatments and in identifying locations for full depth repairs.

A GPR survey is to be performed continuously at posted speeds using ground penetrating radar equipment with both mid resolution (400-500 MHz) and high resolution (1000-1500 MHz) antennae. A higher signal frequency gives a better resolution (i.e. a more precise indication of depth) but a lower penetration (i.e. shallower investigation depth). The GPR testing shall be capable of producing site mapping as requested showing pavement and subsoil stratigraphy (asphalt pavement thickness, concrete base thickness, and granular bottom depth), shallow voids, and other anomalies close to the surface such as, buried streetcar tracks, pipes, conduit, tanks, and reinforcing bars.

Project level GPR survey requests pertain to a more site-specific needs basis, which can include longitudinal and/or lateral profiling. The longitudinal and lateral location of the GPR testing shall be determined by City staff. A longitudinal GPR survey is to be carried out using vehicle mounted equipment with both mid resolution and high resolution antennae that are positioned at multiple lateral locations on the vehicle. Lateral GPR surveys where requested should be done using appropriate portable equipment. Both longitudinal and lateral surveys can collect data using both mid and high resolution antennae in real time. Four examples of project level GPR scope requests are listed below to provide a general overview of typical City needs:

- Longitudinal GPR survey along all lanes including centre left turn lane and designated left and right turn lanes, to identify the pavement structural layer thickness such as HMA layer, concrete layer and granular layer.
- Longitudinal GPR survey along all lanes for void detection, including location and magnitude under composite and flexible pavements.
- 1 m strip longitudinal GPR survey along a bridge deck in both directions to identify locations for the installation of cycling bollards without destroying the existing waterproofing layer underneath the HMA surface.
- Lateral/transverse GPR survey at 100 m intervals to detect the presence of old buried rail track. If track is detected, the GPR survey is conducted at 20m intervals to delineate the extent of the buried track.

GPR survey results should be calibrated using borehole and pavement core data obtained in conjunction with the GPR survey. If a geotechnical investigation is already completed or scheduled to be conducted as part of a regular pavement evaluation, then these should be used for calibration of the GPR survey. Otherwise, confirmatory pavement cores and boreholes should be advanced to calibrate and validate the GPR-derived layer thicknesses. For typical project-level GPR surveys, core and bore frequency shall be based on Table 5 covering the range of material types and layer thicknesses anticipated and used for calibration. The GPR report should discuss the calibration and the anticipated accuracy of the derived GPR survey data.

The City is also in the process of integrating network level GPR data, collected during ARAN® surveys, into iVision. This network level GPR data will be calibrated against the construction history information available in the City's Pavement Management System (RoadMatrix). These GPR profiles will provide coring optimization plans whereby coring and boring is performed at only select locations where needed, to avoid unnecessary cost and work zone management issues.

1.2.3. Roughness

Pavement roughness describes the pavement characteristic that affects the ride quality, vehicle delay costs, fuel consumption, safety, road and vehicle maintenance costs, etc. [8]. Roughness is also referred to as smoothness when evaluating newly constructed or rehabilitated pavements, and it serves as a good indication of level of service for the travelling public. A key factor in the long-term performance of flexible, rigid or composite pavements is initial pavement smoothness. In general, the smoother a pavement is built initially, the smoother it remains over time and service quality is enhanced.

International Roughness Index (IRI) is the pavement roughness measurement standard used for analysis. It is a roughness measure that is valid for any road surface type and covers all levels of roughness. An IRI value of 0 mm/m (or m/km) indicates no roughness and IRI values in excess of 4 mm/m (m/km) represent very rough roads.

The City started collecting network level pavement roughness data in 2017 as part of its network level automated pavement condition data collection using the ARAN® vehicle. The vehicle uses a RoLine Laser Profilometer System, which offers an advantage over single point or multi-point methods by providing a 100 mm line spacing of data across the road surface. By seeing more of the road, RoLine allows profilers to measure accurately on all pavement types at normal operating speeds. Measurements taken with the data collection unit are converted to an accurate real-time IRI. These calculations can be made at a posted speed and as low as 25 km/h [9]. The use of IRI data is most suitable for higher speed roads such as arterial roads and expressways and may be used to affect the prioritization of projects.

1.2.4. Frictional Resistance Testing

Skid Resistance describes the friction resistance between the tires of the vehicles and the pavement. It is defined by a friction number (FN) [10]. The most widely used friction measurement standard is described in ASTM Method E274 / E274M - 15 [11].

Chapter 2 – Geotechnical Investigation

2.1. Geotechnical Investigation and Testing Requirements

The following provides the consultant with minimum requirements for geotechnical investigation and testing. It should be noted that the borehole and pavement core spacing, and material testing guidelines presented in this section are only applicable to pavement investigation. Geotechnical investigation and testing should also be conducted as per common industry practice for other road elements such as sidewalks, boulevards, and medians. In coordination with City staff, the consultant is responsible for undertaking sufficient fieldwork and laboratory testing to ensure that the geotechnical and pavement recommendations are fully supported and are consistent with existing site conditions. The testing should be performed in laboratories with CCIL Aggregate Laboratory Certification Type C, as a minimum. Deliverables required by the City for geotechnical investigation and testing can be found in Chapter 5 of this document.

2.1.1. Borehole and Pavement Core Spacing

Boreholes and pavement cores are advanced to determine the underlying material components for main alignments, passing lanes, and turning lanes. The minimum required frequency, location and depth for each test type is outlined in Table 5. For any given project, a minimum of two boreholes and three pavement cores should be advanced. It should be noted that boreholes should not be advanced on utility cut patching.

Table 5: Typical Borehole and Pavement Core Spacing – Project Level

Test Type	**Road Classification**		**Minimum Depth**
	Local/Laneway	**Arterial/Collector**	
Without any Non-Destructive Testing			
Borehole	50 to 100 m each lane	150 to 200 m each lane	1.5 m below profile grade
Pavement Core	100 to 200 m each lane	300 to 400 m each lane	To top of granular layer
With Non-Destructive Testing*			
Borehole	150 to 200 m each lane	250 to 300 m each lane	1.5 m below profile grade
Pavement Core	300 to 400 m each lane	500 to 600 m each lane	To top of granular layer

** The City is also in the process of integrating network level GPR data, collected during the ARAN pavement condition surveys, into iVision Software. This network level GPR data will be calibrated against construction history available in the City's Pavement Management System (RoadMatrix). These GPR profiles will provide coring optimization plans whereby coring and boring for pavement design purposes is performed on only select locations where needed to avoid cost and work zone management issues. Wherever such GPR coring optimization plans are available, the City will provide locations, numbers, and frequency for coring/boring.*

Project managers and consultants should consider the following site specific factors while selecting borehole and pavement core spacing:

- Pumping slabs, reflective cracks or distress from old utility cut repairs and perceived moisture issues from side slopes/edge cracking;
- Significant variation in pavement performance or condition;
- Significant changes in longitudinal or transverse pavement structure thickness that may have been caused by utility cuts, road widening, and road extension;
- Excess soil disposal requirements and for delineating the extent of asbestos containing material.

These factors should be determined through the review of site conditions including but not limited to: review of the City's iVision based pavement condition data, the completion of visual pavement condition inspections, and/or the result of non-destructive testing (ie. FWD and GPR).

2.1.2. Borehole Logs

Written logs should be prepared for all boreholes describing the materials encountered and the layer thicknesses and depths. Soil descriptions should be in accordance with the MTO Pavement Design and Rehabilitation Manual [10] and should be supported by laboratory testing. Groundwater seepage conditions should be noted.

2.1.3. Sampling and Laboratory Testing

The consultant is responsible for undertaking sufficient field sampling and laboratory testing by coordinating with City staff or as directed by City staff. Table 6 shall be used as a guideline for testing standards for existing alignments and pavement distress areas. The project manager or consultant should consider the site specific factors listed above for borehole and pavement core spacing while selecting testing frequency.

The testing requirements outlined in Table 6 provide a guideline for preparing an appropriate laboratory testing program. The testing requirements for a proposed investigation shall be established based on this guideline, as well as engineering judgement and project specific criteria in the Terms of Reference / Request for Proposal or Quotation. In addition, the consultant shall ensure that all requirements of the Environmental Protection Act are met, as applicable to geotechnical and pavement field investigations.

Table 6: Material Testing Guidelines

Material		Tests*	Standard	
Aggregates / Granular Materials	Granular Base	Sieve Analysis Moisture Content Asphalt Coated Particles Proctor (if to be used as fill) Percent Crushed Micro-Deval	LS-602 LS-701 LS-621 LS-706 LS-607 LS-618/619	[12] [13] [14] [15] [16] [17]
	Granular Subbase	Sieve Analysis Moisture Content Asphalt Coated Particles Proctor (if to be used as fill)	LS-602 LS-701 LS-621 LS-706	
Soil / Earth		Moisture Content Particle Size Analysis Atterberg Limits Proctor (if to be used as fill) Permeability	LS-701 LS-702 LS-703/704 LS-706 LS-709	 [18] [19] [20]
Organic (Topsoil, Muskeg, Swamp material)		Moisture Content Organic Content	LS-701 ASTM D 2974	[21]
Existing Concrete Base (Composite pavement)		Compressive Strength	CSA A23.2	[22]

*Laboratories performing the testing in Table 6 should have the appropriate CCIL Certifications.

Table 6 lists the typical testing undertaken as part of a routine pavement investigation. More specialized testing may be required in specific circumstances where non-standard performance problems are experienced. Any additional testing should be discussed and approved by City staff prior to initiating.

2.1.4. Asbestos Content Testing and Analysis

Depending on the road construction or rehabilitation and asbestos content history of a road section, asphalt cores may need to be analyzed to determine asbestos content as per O. Reg. 278/05 [23] in accordance with the U.S. Environmental Protection Agency Test Method EPA/600/R-93/116: Method for the Determination of Asbestos in Bulk Building Materials. June 1993 (EPA 600) [24].

Asbestos analysis, where required, should typically be done on a composite of all HMA layers found in a core sample. If asbestos is detected in the composite sample or if asbestos is already suspected in a specific layer, a separate analysis of each distinguishable HMA layer may be required.

Asbestos concentrations should be reported as a percent by weight to less than 0.50 percent asbestos content (as per O. Reg. 278/05) and also include an indication of the asbestos fibre type [23]. An asbestos fibre analysis should be done using polarized light microscopy (PLM). The asbestos fibre analysis method shall be based on EPA 600 or an approved equivalent [24].

Consultants should provide the required recommendations for the handling and disposal of excess excavated material and asbestos containing materials that will be generated during construction.

2.1.5. Soil Chemical Testing and Analysis

Laboratory tests shall be made on undisturbed soil samples where directed by City staff. Only laboratory tests which are deemed necessary by City staff shall be made.

Laboratory testing of soil samples for environmental purposes shall be performed as per the Ministry of Environment, Conservation and Parks' standards and regulations, namely, Ontario Regulation 153/04 - Records of Site Condition Part XV.1 of the Act, (as amended) and R.R.O. 1990 Regulation 347 General – Waste Management (as amended) under the Environmental Protection Act. The analytical testing will be sufficient to characterize the soil for disposal in accordance with O. Reg. 153/04, R.R.O 1990 Reg. 347, MOECC Regulations for landfill disposal [25].

At a minimum, each soil sample will be analysed for metals and inorganics and undergo representative testing for petroleum hydrocarbon (PHC) fractions F1-F4 [26]. Additional testing for parameters such as petroleum hydrocarbons (PHCs), volatile organic compounds (VOCs), and polycyclic aromatic hydrocarbons (PAHs) may also need to be undertaken based on potential contaminants of concern identified as part of the current and historical land use review.

The work program undertaken, including test results, and comments/recommendations on the suitability of excavated material for disposal options shall be provided by the consultant.

Where test results indicate that the material will not be suitable for reuse at residential/ parkland/ institutional land use or industrial/ commercial/ community land use, the consultant shall include alternative disposal options consistent with MOE Regulations for landfill disposal and be consistent with the MOE's Management of Excess Soil – A Guide for Best Management Practices, April 2016 (as amended) [27].

Chapter 3 – Pavement Design and Rehabilitation

In 2006 the City had developed Pavement Structural Design Guideline Summary that contained requirements for new and reconstructed pavement structures. The matrix was revised in 2018 to reflect the implementation of Superpave asphalt mixes along with changes for granular materials. The matrix is included in Appendix A for information and historical purposes only.

Beginning of 2019, as part of Transportation Services Division business transformation, the City is moving towards implementation of AASHTO 1993 pavement design guidelines [2] along with the MTO MI-183 report entitled "Adaptation and Verification of AASHTO Pavement Design Guide for Ontario Conditions" [3] for the verification of all road rehabilitation work as per best industry practices.

Using AASHTO 93, the material properties of the pavement structure are characterized mechanistically using elastic theory. This involves predicting the states of stress, strain and displacement within the pavement structure when subjected to a wheel load. The following sections provide a brief overview of the design input parameters used in the AASHTO 93 procedure. More detailed descriptions and design examples can be found in the MTO MI-183 report [3]. Various input parameters required for selecting an appropriate structural design that will withstand the anticipated traffic loading is described in the following subsections.

This chapter will outline detailed information on the design of an appropriate pavement structure for new construction, reconstruction or rehabilitation projects. At the project level, resurfacing vs. reconstruction options should be selected based on the current condition and service life of the pavement, pavement type, road classification and traffic. A proper geotechnical investigation and/or non-destructive testing, along with a life cycle cost analysis as part of a pavement design report is required to determine the best strategy to maintain the pavement in a good state of repair.

3.1. Functional Classification and Traffic

Roadways within Toronto are generally characterized as expressway, major and minor arterial, collector, local and laneway. Road classification system maps as well as the road classification criteria (adopted by City Council on February 2000) are available on the City's webpage [28]. Transportation Services pavement management application, Roadmatrix, provides further functional classification characterization for collector and local roads by land use that include either 'residential' or "commercial/industrial".

Recognizing that pavement damage is largely a function of traffic loading, this guideline was developed based on inputs that reflect traffic loading rather than just functional classification. Three specific inputs are required to define traffic loading conditions; functional classification, average annual daily traffic (AADT), and commercial vehicle percentage. The functional classification of individual roadways within the City have been predetermined. Consultants should be using the most up to date traffic data, the sources can be found from the City website [29] or as provided by the City project managers. The consultants are required to use traffic parameters as per industry best practices and pavement designer's experience. The consultant shall be aware of traffic estimates as they may relate to bus traffic, lane distribution factors and growth rates for the City of Toronto conditions.

3.2. Subgrade Characteristics

The subgrade is the underlying or foundation component of the total roadway pavement structure. It is usually constructed with native soil, sometimes in combination with soil imported from local borrow sources. Subgrade soils can be used as earth borrow to construct embankment fills or to replace existing unsuitable soils. The objective of the subgrade construction is to provide a uniform foundation for the pavement structure. Non-uniform subgrades lead to differential pavement performance. Where significant changes occur in subgrade support or type, transitions and adjusted designs should be incorporated. The characterization of subgrade soils in the AASHTO Guide is one of the most challenging parts of pavement design. In rigid and flexible pavement, the subgrade eventually carries the load, and pavement performance is affected by the quality of the subgrade. The subgrade characteristic input parameters in the AASHTO design process for flexible and rigid/composite pavements are different and the pavement design is very sensitive to this input [2]. Resilient modulus (M_R) is used for flexible pavements and modulus of subgrade reaction (k-value) is used for rigid/composite pavements. The frost susceptibility of the subgrade soils and the drainage conditions are other critical factors in developing a viable design.

3.2.1. Flexible Pavements

The ability of subgrade soil to support a pavement structure is characterized (for AASHTO design) by its laboratory-determined M_R. Subgrade modulus associated with soil type as per the MTO soil classification system, anticipated drainage and subgrade conditions is presented in the MTO MI-183 report [3]. The resilient modulus of subgrade soils recommended in Ontario for different soil types and anticipated long-term drainage conditions, are shown in Table 7 (adapted from reference [3]).

Table 7: Recommended Effective M_R Values and Corresponding MTO Soil Classification

Brief Description	Category No.	MTO Classification (MTO, 1980)	Drainage Characteristics	Susceptibility to Frost Action	Resilient Modulus (M_R) for Typical Subgrade Conditions, MPa		
					Good	Fair	Poor
Rock, rock fill, shattered rock, boulders/cobbles	1	Boulders/ cobbles	Excellent	None	90	80	70
Well graded gravels and sands suitable as granular borrow	2	GW, SW	Excellent	Negligible	80	70	50
Poorly graded gravels and sands	3	GP, SP	Excellent to fair	Negligible to slight	70	50	35
Silty gravels and sands	4	GM, SM	Fair to semi-impervious	Slight to moderate	50	35	30
Clayey gravels and sands	5	GC, SC	Practically impervious	Negligible to slight	40	30	25
Silts and sandy silts	6	ML, MI	Poor	Severe	30	25	18
Low plasticity clays and compressible silts	7	CL, MH	Practically impervious	Slight to severe	35	20	15
Medium to high plasticity clays	8	CI; CH	Semi-impervious to impervious	Negligible to severe	30	20	15

The City is located within the physiographic regions of Southern Ontario, mapped as the Iroquois Lake Plain and the Peel Plain [30]. The bars, beaches, and boulder fields of the lower lying Iroquois Plain stand in stark contrast to the undulating Peel Plain found further north. The soils in the lower southern Iroquois Plain are characterised by lacustrine deposits of sandy alluvium and clays. The soils of the Peel Plain are typically characterised as silt till and clay till.

Within the Greater Toronto area, the cohesive tills, clays and silt soils of the Iroquois and Peel Plains are characterised as providing "fair" subgrade support with frost susceptibility ranging from low to high depending on the actual soil matrix. The sandy alluvium soils of the Iroquois Plain are characterised as providing 'good' subgrade support. Dependant on the actual soil matrix, these soils typically have low susceptibility to frost heave. The actual soil properties should be determined from the Geotechnical Investigations Report.

For each soil group, ratings of Good, Fair, and Poor are used to indicate the range of M_R values. Because the determination of M_R for various subgrade soils was based on engineering judgment, the determination of the range of M_R values for specific soil types is perhaps even more uncertain. In general, the following four characteristics should be considered together when determining the condition of subgrade soil:

- **Moisture content of soil** - Resilient modulus of fine-grained soil is highly dependent on moisture condition and the degree of saturation. Good condition implies that soil is typically (most of the time) dry of optimum moisture content. Poor condition implies that soil is typically wet of optimum. For example, poor conditions are indicated by a high water table, shallow ditches with vegetation suggesting the frequent presence of standing water, and shallow ditches in cuts. Overall drainage conditions of the area should be considered both before and after construction. For example, the construction can lower the water table and ameliorate the pre-construction moisture conditions.
- **Presence of materials with deleterious particle size** - Good condition implies that the amount of particles with deleterious sizes is close to minimum for the soil class. For example, the amount of fines (particles less than 0.075 mm) in GW soil is well below 12 percent. This characteristic should also consider the presence of borderline coarse-grained soils containing between 5 and 12 percent fines [31].
- **Other deleterious conditions** - Other conditions that may influence engineering properties of soils include plasticity of fines and the presence of organic materials. Good condition implies that other deleterious conditions do not negatively influence engineering properties of the soil.
- **Uniformity of subgrade soil** - The condition of subgrade soil may vary within the length that is applicable for a given pavement design. The variation in the subgrade condition may be in terms of soil type, moisture content, presence of materials with deleterious particle size, and other deleterious conditions. Good condition implies that soil condition is relatively uniform within the limits of the single pavement design. If the conditions within the limits of the entire project vary, consideration should be given to subdividing the project length into sections and producing different designs for these sections as required. The differences between the pavement designs within the project length are typically accommodated by changing the thicknesses of granular materials and including an appropriate transition.

It should be noted that subgrade support value should be identified based on proper geotechnical investigation.

3.2.2. Rigid/Composite Pavements

For rigid pavement design, layer coefficients for the base and subbase material are not used. Subgrade and base/subbase support are defined in terms of the Westergaard modulus of subgrade reaction (k). This parameter is used in most concrete pavement design procedures. In the AASHTO Guide, the support a foundation provides a concrete pavement is characterized by the k-value, which represents a “dense liquid” (elastic springs) foundation. With rigid pavements, a subbase layer is usually placed on the subgrade to provide a uniform support and to improve constructability. When this is done, the k used for design is a “composite k” (k_c) that represents the combined strength of the subgrade and subbase. Recommended k-values for different types of soils, anticipated drainage characteristics, and frost susceptibility as presented in in the MTO MI-183 report [3] are summarized in Table 8.

Table 8: Recommended k values and Corresponding MTO Soil Classification

Brief Description	Category No.	MTO Classification (MTO, 1980)	Drainage Characteristics	Susceptibility to Frost Action	k-Values for Typical Subgrade Conditions, kPa/mm		
					High (Good)	Medium (Fair)	Low (Poor)
Rock, rock fill, shattered rock, boulders/cobble	1	Boulders/ cobbles	Excellent	None	140	110	100
Well graded gravels and sands suitable as granular borrow	2	GW, SW	Excellent	Negligible	120	100	80
Poorly graded gravels and sands	3	GP, SP	Excellent to fair	Negligible to slight	110	90	70
Silty gravels and sands	4	GM, SM	Fair to semi-impervious	Slight to moderate	110	70	60
Clayey gravels and sands	5	GC, SC	Practically impervious	Negligible to slight	90	60	40
Silts and sandy silts	6	ML, MI	Typically poor	Severe	80	40	20
Low plasticity clays and compressible	7	CL, MH	Practically impervious	Slight to severe	60	30	15
Medium to high plasticity clays	8	CI, CH	Semi-impervious to impervious	Negligible to severe	60	30	10

3.3. Material Characteristics

Flexible Pavements

The AASHTO Guide requires that characteristics of paving materials be expressed in terms of structural layer coefficients (a_i). The concept of structural layer coefficients is similar to Ontario's traditionally used concept of granular base equivalency (GBE) factors, in that stronger, more stable materials are assigned higher values. The layer coefficients are not used in pavement performance equations; they are only used to assemble a pavement structure that satisfies the required structural number (SN). However, in this way, a_i values directly and significantly influence the required layer thicknesses. Structural layer coefficients for various materials are presented in Table 9 as guidelines. A designer can modify the recommended layer coefficients based on the knowledge of specific material characteristics [2].

Table 9: Recommended Structural Layer Coefficients for Various Material Types

Layer Material Type	AASHTO–Ontario Structural Layer Coefficient (SLC), a_i *
Bituminous Bound Materials	
New virgin and recycled hot mix asphalt	0.42 [a]
Existing hot mix asphalt	0.14 to 0.42 [ab]
Cold recycling of RAP off-site or in-place (cold mix)	0.28 to 0.38
RAP / Granular A blend stabilized with expanded asphalt cement	0.20 to 0.25 [c]
Existing cold mix	0.11 to 0.24
Bituminous treated Granular A (with about 3% AC)	0.31
Unbound Materials	
Granular A	0.14
Granular A with up to 50% of RAP	0.14
Pulverized bituminous surface mixed with existing granular material (with up to 50% of RAP)	0.10 to 0.14
Existing Granular A with or without RAP	0.10 to 0.14
Granular B, Type I	0.09
Existing Granular B, Type I [c]	0.05 to 0.09
Granular B, Type II	0.14
Existing Granular B, Type II	0.06 to 0.14
Granular O	0.14
Rubblized PCC slab	0.14 to 0.30 [c]
Miscellaneous Materials	
Untreated OGDL material, AC stabilized or PC stabilized OGDL material	0.14
Portland cement treated base	0.28 to 0.34
Select subgrade material	n/a [d]

**The consultants are required to use these parameters as per industry best practices and pavement designer's experience.*

[a] The numbers may change as more experience is gained.

[b] Higher structural layer coefficients than SLC = 0.28 may apply to overlay projects involving existing recently placed and well-preserved hot mix asphalt. The lower limit (SLC = 0.14) may apply to reconstruction projects. Refer to Table 10, below for further details.

[c] Applies also to old Granular A. May also apply to “sand cushion” that is part of the pavement structure.

[d] Select subgrade material should be considered to be part of the subgrade.

Table 10: Typical Guideline Values for the Structural Layer Coefficient for Existing HMA

Structural Layer Coefficient	Guidelines
0.08 – 0.14	Pavement is in poor condition with extensive moderate cracking and frequent moderate alligator cracking or the HMA is severely segregated or stripped. The existing HMA is likely to be recycled rather than left in-place.
0.14 – 0.20	Pavement is in fair condition with intermittent moderate and frequent slight cracking, and with intermittent slight alligator cracking.
0.20 – 0.28	Pavement is in fairly good condition with slight cracking and a few areas of very slight alligator cracking.
0.28 – 0.42	Pavement is in good to excellent condition with very slight or slight cracking and no more than slight mix defects. Pavement is typically less than 6 years old.

<u>Rigid/Composite Pavements</u>

As per the most recent City specifications TS 3.40, new PCC construction requires a minimum 28-day compressive strength (fc’) of 32 MPa [32]. This corresponds to a flexural strength of about 3.9 MPa; it is recommended to use 28 GPa as the elastic modulus of concrete [33].

3.4. Pavement Design Serviceability and Reliability

Serviceability and reliability are key factors in ensuring the City of Toronto's road network is safe and comfortable for the public. "The serviceability can be determined, in part, by pavement evaluation or pavement condition rating which rates two different physical parameters: (1) the riding quality of the pavement surface, and (2) the extent and severity of distress manifestations." [10] Serviceability and reliability factors will vary on a project by project basis. To ensure detailed pavement design, consultants are required to refer to AASHTO 1993 guidelines, MTO MI-183 and MTO Pavement Design and Rehabilitation Manual to select the optimum serviceability and reliability factors as per the consultant's experience.

3.5. Pavement Type Selection

Pavement type selection must balance issues of both short- and long-term performance while considering initial and long-term costs. The stakeholders that City staff answer to—the travelling public—generally do not express strong feelings on the type of pavement constructed, as long as reasonable levels of service, safety, and ride quality are provided.

The dilemma facing the engineer during pavement type selection can be summarized best by the following quote from the AASHTO Guide for Design of Pavement Structures (1):

The selection of pavement type is not an exact science but one in which the highway engineer or administrator must make a judgement on many varying factors such as traffic, soils, weather, construction, maintenance, and environment. The selection process may be facilitated by comparison of alternative structural designs for one or more pavement types using theoretical or empirically derived methods. However, such methods are not so precise as to guarantee a certain level of performance from any one alternative or comparable service for all alternatives.

Also, comparative cost estimates can be applied to alternate pavement designs to aid in the decision-making process. The cost for the pavement should include not only the initial cost but also subsequent costs to maintain the service level desired. It should be recognized that such procedures are not precise since reliable data for maintenance, subsequent stages of construction, or corrective work and salvage value are not always available, and it is usually necessary to project costs to some future point in time. Also, economic analyses are generally altruistic in that they do not consider the present or future capabilities of the contracting agency.

To further cloud the issue of pavement type selection, City staff involved with the design and selection of pavements face a high degree of uncertainty regarding the types of loadings a pavement will experience over the whole service life, which is anticipated to be in the range of 65 to 100 years.

The surface type selection process consists of two principal steps:

1. Alternatives are developed and life-cycle cost analysis (LCCA) is performed[1]. If the life cycle is within a set range, generally 10 per cent, the life cycle costs are considered equivalent.

2. Alternatives with equivalent life cycle costs are then evaluated. Based on factors that may include adjoining pavement types, constructability, traffic control, subgrade support, traffic volumes, sustainability, and other design considerations to select the most appropriate alternative.

Within Toronto, composite pavement structures are the preferred design in the urban environment while flexible pavements are preferred for suburban roadways. Notwithstanding, pavement structure selection shall be based on a life cycle cost comparison considering the whole service life, operating costs, impact to the public and risk analysis. The primary advantages of a composite or rigid pavement structure over a flexible pavement structure are the abilities of the rigid concrete slab to resist deformation that may be caused by:

[1] See Section 3.17 for LCCA procedures

1. Poor subgrade soils, considering the soil type and associated drainage conditions and frost impacts;
2. High density, location or incidence of utility intrusion, that typically results in settlements in and around the utilities; and
3. Repairs associated with these noted conditions, accounting for their frequency, density and severity.
4. Excessive loading imposed on heavily trafficked truck/bus routes.

A constructability review should be performed on the recommended pavement design as per Chapter 4.

3.6. Pavement Structural Thickness

Irrespective of whether it is reconstruction, new construction, pavement widening, extension or rehabilitation, pavement designers shall follow the AASHTO 93 design procedure. In this section, typical pavement structure thicknesses for major and minor arterials, collector and local roads consider some common design parameters such as subgrade support value, functional classification, AADT, and percent commercial vehicles. Based on site specific conditions, such as higher traffic volumes, higher percentage of trucks or buses, weak subgrades, poor drainage, a heavier pavement structure might be required. Pavement designers should follow the AASHTO 93 guideline to design these high volume roadways.

While constructing pavements on challenging subgrade soils including wet clays and silts or with subgrade modulus less than 30 MPa, special considerations should be given, including but not limited to, a thicker subbase layer or using geotextile or subgrade improvement. Thinner subbase lifts may cause issues with clay and silt subgrades that will pump through when placing the next lift of granular and impairing the quality of the subbase. Therefore, the pavement designer should recommend a pavement structure based on in situ soil conditions obtained from geotechnical investigations and where necessary, recommend treatments to improve constructability; see Section 3.9.8-3.9.10 for further details.

For rehabilitation projects, the roadway must be able to withstand the expected construction loading and normal traffic loading during construction if traffic is to be permitted on milled surfaces. Designs should incorporate a minimum thickness that will allow top surface and/or binder course HMA to be removed and still sustain traffic loading without damaging the pavement during all stages of construction, especially in areas of high truck volumes servicing properties where no other access is available. After milling, the remaining HMA binder course should be examined thoroughly to identify any areas requiring repairs including rout and crack sealing prior to placing new HMA.

The following asphaltic concrete mixes are considered as standard City mixes. Designers shall reference

Table 11: Standard Asphaltic Concrete Mixes and Corresponding Asphalt Cements

Traffic Category(1)	Mix Description	Typical Use
B	SP 4.75 PG 58-28	Surface course mix for sidewalks and multi-use trails
	SP 9.5 PG 58-28	Surface course mix for driveways, raised medians and boulevards
	SP 12.5 PG 58-28	Surface course mix for interim maintenance and utility repair work on local and collector roads
	SP 12.5 PG 64-28	Surface course mix for resurfacing and reconstruction work on local and collector roads
	SP 19.0 PG 58-28	Binder course mix for all non-roadway areas including interim repair and utility cut repair work
	SP 19.0 PG 64-28	Binder course mix for resurfacing and reconstruction work on local and collector roads
C	SP 12.5 FC1 PG 64-28	Surface course mix for minor arterial roads
D	SP 12.5 FC2 PG 64-28	Surface course mix for major arterial roads
	SP 19.0 PG 58-28	Binder course mix for interim maintenance and utility repair work on minor and major arterial roads
	SP 19.0 PG 64-28	Binder course mix for resurfacing and reconstruction work minor and major arterial roads
E	SP 12.5 FC2 PG 70-28	Surface course mix for major arterial roads with heavy truck traffic
	SP 19.0 PG 64-28	Binder course mix for major arterial roads with heavy truck traffic
	SMA 12.5 (2) PG 70-28	Surface course mix for expressway
	SMA 19.0 (2) PG 70-28	Binder course mix for expressway

(1) The traffic categories are according to Table 5 of TS 1151 specification, as listed below:
Traffic category B: 0.3 to 3 million ESALs
Traffic category C: 3 to 10 million ESALs
Traffic category D: 10 to 30 million ESALs
Traffic category E: Greater than 30 million ESALs

(2) The use of SMA mixes is typically restricted to high volume roads and shall only be selected in consultation with Transportation Services' Infrastructure Asset Management & Programming Unit.

3.7. Laneways

Public laneways in the City are typically designed as a rigid pavement. Detailed concrete and granular layer thicknesses, curb, slope, drainage, construction joints, expansion joints and contraction joint details should be designed according to City standard drawing T-502.01 [34], unless the geotechnical report recommends differently.
In the case of laneway state of good repair projects the following should be considered:

- Ensure drainage by installing subdrains/storm sewer system as required.
- Reconstruction of deficient sidewalk at entrances.
- Replacement of all substandard castings.
- Installation of CB frame and MH covers at low points.
- Ensure overland drainage into laneway is unimpeded and CB's are installed at street lines of adjacent streets to prevent overland flow of water across sidewalk.

All unimproved areas immediately adjacent to lane limits should be paved with a 1.0 m wide strip of HMA with the consent of property owner in order to reduce water infiltrating under concrete pavement.

Laneways constructed using flexible pavement structures or other pavement types (for example pavers) should be assessed on a project by project basis. Such pavement structure design should be verified using the AASHTO 1993 method.

3.8. Expressways

The pavement structure for City expressways such as W. R. Allen Road, Gardiner Expressway, Don Valley Parkway and Highway 2A are not included in the PDRG. Expressway pavement structure design should be carried out by experienced pavement design engineers using the AASHTO 1993 method.

3.9. Design Considerations

There are many factors that influence the success of a pavement design. Notwithstanding the results of the design matrices presented herein, the selection of the most appropriate pavement for individual facilities will depend on a number of site-specific factors including:

- geographic and topological conditions
- environmental conditions
- physiographic setting and subgrade soil characteristics
- groundwater conditions
- projected traffic loading
- availability of construction materials and by-products
- local contractor resources
- required performance and sustainability
- climate change adaptation

- seasonal weather effects
- cost

Detailed geotechnical investigations and pavement design reports are recommended for all new and rehabilitated facilities.

While the construction materials used and layer thickness established are an important structural consideration, they are by no means the only factors that affect the performance of a pavement. Other important design considerations need to be addressed to maintain good preforming roads and consistency across the City.

3.9.1. Flexible Pavement Considerations

In general, pavements in Ontario are designed with sufficient total thickness so that subgrade overloading is typically not a problem. However, pavement surface distresses in the form of rutting, transverse cracking, fatigue cracking and distress associated with environmental impacts are nevertheless common flexible pavement problems in many municipalities across the province, including the City of Toronto.

Fatigue cracking can often be attributed to insufficient HMA layer thickness for the projected traffic loading. Mechanistic-empirical analysis methods, i.e. the MEPDG, have been found to better address the stress and strains induced at the bottom of the asphalt layer than the AASHTO 1993 method at higher traffic levels.

Plastic deformation of the HMA layers has been found to be the most common cause of wheel track rutting in flexible pavements. Important considerations include careful attention to mix volumetric, the aggregate skeleton, and selection of the appropriate performance grade of asphalt cement binder (including increases to the PGAC grading for the high temperature and for heavy, slow-moving traffic; also referred to as "bump-up", refer to Table 11.

Traditionally the City has used the Marshall method for asphaltic concrete mix designs. The Superpave mix design methodology which was one of the main outcomes from the Strategic Highway Research Program (SHRP) provides an alternative to the older Marshall method for formulating asphaltic concrete mixes. The Superpave system includes asphalt binder and aggregate selection into the mix design process, and also considers traffic and climate. The former drop hammer compaction method has been replaced by a gyratory compactor and the compaction effort in mix design is tied to expected traffic. The Superpave system is now accepted as an improved method for specifying the asphalt cement and component aggregates as well as developing the appropriate asphalt job mix formula for a particular application. The Superpave binder selection has been used by MTO and the City for a number of years. The Superpave mix design methodology was adopted by the City in 2018 and most other larger municipalities in Ontario.

The predominant HMA types for surface courses are SP 12.5, SP 12.5 FC1 and SP 12.5 FC2 and for the binder course is SP 19.0, with corresponding traffic categories of B, C, D or E. These materials are specified in City specification TS 1151 [35]. The experience to date and availability from local mix producers make Superpave mixes ideal choices for continued use.

Premium surface mixtures such as Stone Mastic Asphalt (SMA) 9.5 and SMA12.5 can also be substituted on high-priority roads where rut resistance and frictional properties are critical. Typically, SMA has been successfully used on the City's expressway pavements including the Don Valley Parkway, the Indy portion of Lakeshore Boulevard, and other high traffic arterial routes. Typical Superpave mixes are shown in Table 12 [35].

Table 12: Superpave Asphalt Mixes that Correspond with Marshall Mixes

Superpave Mix	Traditional Marshall Mix (equivalent)	Course			Traffic Category (Note1)				Typical Asphalt Cement
		Surface	Binder	Levelling/ Padding	B	C	D	E	
SP 4.75	HL2	x		x	x				PG 58-28 (2)
SP 9.5	HL3 fine	x		x	x				PG 58-28 (2)
SP 12.5	HL3/ HL4	x			x				PG 58-28 (2)
					x				PG 64-28 (3)
SP 12.5 FC1	HL1	x				x			PG 64-28 (3)
SP 12.5 FC2	DFC	x					x		PG 64-28 (3)
								x	PG 70-28 (3)
SP 19.0	HL4/HL8/ HL8(HS)		x	x	x		x	X	PG 58-28 (2)
					x		x	x	PG 64-28 (3)
SMA 12.5	DFC/OFC	x						x	PG 70-28 (3)
SMA 19.0	HL8(HS)		x					x	PG 70-28 (3)

Note:

1. The traffic categories are according to Table 5 of TS 1151 specification [35].
2. PG 58-28 asphalt cement shall be used in driveways, medians, boulevards, sidewalks, multi-use trails, utility cut repairs and interim maintenance activities.
3. PG 64-28 and PG 70-28 asphalt cement shall be used in capital works program (CWP) types of projects such as local, collector and arterial road resurfacing and reconstruction.

Minimum and maximum lift thickness

Coarse graded Superpave mixes generally tend to have lower asphalt cement contents. To promote adequate compaction in the field and for long-term durability, it is recommended that Superpave mixes be designed below the primary control sieve (PCS), that is to say the coarse gradation should be placed with a lift thickness of 3 to 4 times the nominal maximum aggregate size (NMAS). SMA mixes are designed as coarse graded mixes, therefore, SMA should also be placed at 3 to 4 times NMAS.

The pavement designer should specify the minimum and maximum suggested compacted layer thickness for each HMA type as provided in Table 13 *[36]*.

Table 13: Guideline for Minimum and Maximum HMA Layer Thickness

Pavement Layer	Hot Mix Asphalt Type	Typical Compacted Layer Thickness Range, mm(1)
Surface Course Mixes	Superpave 4.75	25 - 35
	Superpave 9.5	30 - 40
	Superpave 12.5, 12.5 FC1 and 12.5 FC2	40 - 50
	SMA 12.5	40 - 50
Base Course Mixes	Superpave 19.0	50 - 80
	SMA 19.0	60 - 80

Note:

1. The designer should be aware that the lower minimum value is for finer graded mixes and the upper minimum value is for coarser graded mixes

Warm Mix Asphaltic Concrete

Warm Mix Asphalt (WMA) is a technology whose production takes place at a relatively low temperature, which consumes less energy and causes less GHG emissions. WMA is the generic term for a variety of technologies that allow producers of HMA pavement material to lower temperatures at which the material is mixed and placed on the road. WMA technologies are numerous and in constant development, but all operate by one of three principal processes: organic additives, chemical additives, or foaming. It has been proven that this technology can reduce paving costs, extend the paving season, improve workability, improve WMA compaction, allow for WMA to be hauled longer distances and improve working conditions for paving crews. WMA mixes shall meet the requirements of City specification TS 1151 [35].

Asphalt Cement

The City currently uses performance graded asphalt cement (PGAC). These asphalt binders must comply with specified requirements at both the low and high pavement in-service temperatures, as determined on a project specific basis. For example, a binder identified as PG 64-28 must meet minimum performance criteria at a seven-day average maximum pavement design temperature of 64°C, and also at a minimum pavement temperature of -28°C. PG 64-28 is the asphalt cement grade typically specified by the City for most applications. The asphalt cement should meet the requirements of City specification TS 1101 [37]. Depending on the project specific needs, the designer may consider PGAC upgrades for heavy commercial traffic, at intersections, including approaches and steep grades, where vehicles, particularly buses, make frequent starts and stops, and slow vehicle speeds. In addition, the City's climate change risk assessment identified the bump-up of PGAC grades as a pro-active approach to the increasing temperatures anticipated in the 2030 and 2050 time horizons (add reference). The designer may increase (or bump-up) the high temperature grade according to City specification TS 1101 [37] and the Climate Risks & Adaptation Practices – For the Canadian Transportation Sector 2016 [38] to accommodate these special scenarios, as listed in Table 14.

Table 14: Guidelines for the Adjustment of PGAC High Temperature Grade Based on Roadway Classification and Traffic Conditions

Highway Type	Increase from Standard	Optional Additional Grade Increase [(a)]
Expressway	2 Grades	N/A
Major Arterial	1 Grade	1 Grade
Minor Arterial	Consider increasing by 1 grade if heavy truck traffic is greater than 20% of AADT	1 Grade
Collector **Local**	No Change	1 or 2 Grades

[(a)] Consideration should be given to an increase in the high temperature grade for roadways which experience a high percentage of heavy truck or bus traffic at slow operating speeds, frequent stops and starts, and historical concerns with instability rutting.

Note :

Upgrading of the high temperature grade is recommended for use in both surface and top binder courses, i.e., top 80 to 100 mm of HMA

Tack Coat

A tack coat should be utilized between HMA layers, on milled surfaces or between concrete and HMA layers when construction is staged or delayed and at all tie-ins and vertical surfaces. The tack coat should meet the requirements of City specification TS 3.20 [39].

3.9.2. Rigid and Composite Pavement Considerations

The current state of practice with rigid pavements includes the use of load transfer devices to reduce faulting, widened slabs to reduce edge stresses, and random perpendicular joint patterns. In the City setting most roads have a concrete curb that provides a longitudinal key for concrete road base that provides rigidity similar to widened slabs as shown in standard drawings T-600.05-1 [40] and T-600.11-1 [41].

Portland Cement Concrete (PCC) road base should meet the requirements of City specification TS 3.40 [32]. Load transfer devices in accordance with TS 3.40 [32], should be considered for all PCC pavements with thickness greater than 200 mm. The use of load transfer devices has two principal benefits: they reduce differential deflection across joints, and they reduce tensile stresses on the top of the slab. For most applications, 32 mm diameter by 450 mm long coated dowel bars spaced at 300 mm are recommended. Larger diameter bar sizes can be considered for very heavy loading applications and for thicker slabs. Standard Drawing T-216.02-4 provides the location and detail of joints for composite pavements [42], also see T-508.010-1 [43] for details on hook bolt dowel and concrete repair.

The MEPDG design procedure shows a sensitivity to the slab length in the required design thickness of concrete pavement layers. The longer slab lengths tend to show premature failure due to slab cracking because of the higher accumulation of thermal stresses in the form of curling and warping in combination with truck traffic loads. It is important for the City to monitor the deterioration of underlying concrete slabs to ensure that they are adequately distributing traffic loads to the granular subbase and subgrade soils. If excessive slab cracking is found, shorter slab lengths should be considered.

3.9.3. Utility Cut Restoration

The City has made some improvements to the Utility Cut Management Process [44]. Utility cut repair and restoration shall be carried out as directed in the City's construction specification TS 4.60 [45]. This specification covers the requirements for utility cutting, excavating, backfilling, and repair of City streets. Table 15 summarizes Superpave mix selection for any machine laid utility cut repair work. Superpave mix for any hand laid utility cut repair works shall be selected as listed in Table 15 [45].

Table 15: Superpave Mix Selection for Any Hand Laid Work Including Utility Cut Restoration

Layer	Laneway	Local	Collector	Minor Arterial	Major Arterial
Surface Course	SP 12.5 B PG 58-28			SP 12.5 FC1 C PG 58-28	
Base Course	SP 19.0 D PG 58-28				

The pavement structure for utility cut restoration shall match the existing pavement thickness

3.9.4. Concrete Bus Pad Consideration

Conventional HMA pavement is flexible, and can be deformed by the force and heat generated by braking buses, leading to wave-shaped distortions along the length of a bus stop (referred to as shoving and rutting). This issue is pronounced at high-volume stops where stopped buses further deform the roadway surface, as well as at near-side stops in mixed-traffic lanes where trucks may add to distortion and wear. As part of the City's ongoing work to improve the resilience of infrastructure to respond to its Climate Change Risk Assessment Policy, implementation of exposed concrete bus pads has been adopted at such high-volume stops to address the common issue of HMA distortion [46]. Concrete bus pads should meet the requirements of City specification TS 3.41 [47].

3.9.5. Driveways

Throughout construction works, access to driveways must be maintained unless otherwise arranged. City standard drawing T-310.050-8 [48] specifies the design thicknesses for both residential and industrial/condominium high rise/commercial driveways with a HMA or concrete surface.

The consultant engineer is to ensure the following is adhered to and monitored:

- The HMA or concrete shall be placed on the prepared base to the line, grade, dimensions, and thickness outlined in the City standard drawing T-310.050-8 [48].
- The prepared granular base shall be dry, well compacted, and approved by the geotechnical consultant.
- Forms or other approved means shall be used to obtain proper line and neat uniform edges.

3.9.6. Concrete Base Repair

During the removal and replacement of the HMA layer on the surface of composite pavements, detailed inspection of the exposed concrete base is recommended to identify maintenance and repair needs. The repair of concrete pavement and base should meet the requirements outlined in City specification TS 3.45 [49] and drawing T-508.010-1 [43]. The requirements for partial depth repairs in concrete pavement include removal of concrete, preparation of surfaces, placement of new concrete and forming joints associated with the repairs as outlined in OPSS 364 [50].

Based on the site specific condition, partial depth repair may also be required. The procedure for partial depth concrete repair is outlined below:

- Sawcutting the perimeter of the repair area vertically to a depth of 50 mm.
- The concrete within the sawcut area shall be removed to a minimum depth of 50 mm and a maximum depth of one-third the thickness of the existing concrete slab using equipment that prevents the fracture of the underlying sound concrete.
- Wire mesh, if encountered, in the concrete shall be removed to the edge of the repair area. The area shall be abrasive blast cleaned according to OPSS 929 [51].
- Immediately prior to filling the repair area with concrete, the entire surface of the repair shall be uniformly coated with cement paste.
- The repair area shall then be filled with concrete, finished flush with the adjacent surface and cured according to OPSS 350 [52].
- Where wire mesh was encountered and removed, new replacement mesh should be installed with the appropriate cover.

3.9.7. Granular Base Considerations

The City specifies Granular A Native and Granular B – Type II for granular road base and subbase.

The use of Granular B – Type I which is comprised of sand with gravel rather than crushed material, may be warranted for use as a granular road subbase in certain applications. Granular B – Type II can be substituted for Granular B – Type I on a 1:1.5 basis, that is to say 100 mm of Granular B – Type II equals 150 mm of Granular B – Type 1 from a structural support perspective [53].

Acknowledging finite mineral resources, the City is allowing the substitution of granular materials with Reclaimed Concrete Material (RCM) as a granular base and subbase, such as Granular A RCM. RCM can be substituted for Crusher Run Limestone (CRL) on a 1:1 basis. Granular A RAP (maximum 30% asphalt coated particles as per TS 1010) can also be utilized as granular base material.

While RCM is specified to meet current Toronto TS and OPS specification requirements, field observations of materials with excessive fines have been shown to exhibit poor drainage characteristics, which in turn affects pavement performance. Similarly, RCM can contain deleterious components, such as gypsum board or brick. RCM suspected of containing excessive fines or deleterious components should be subjected to increased scrutiny. This may include confirmation of process control charts and/or increased quality assurance testing.

All the base and subbase granular materials shall fulfill the requirements of City specification TS 1010 [53].

3.9.8. Challenging Subgrade Conditions

Challenging subgrade conditions are usually the result of one of the following situations or phenomena:

- The presence of very weak or compressible subgrade soils, such as organic soils, saturated silts and compressible clays.
- Rapid changes in the properties of subgrade soils, such as changes in the extent and depth of the organic deposits.
- Rapid transitions between highly frost susceptible soils and soils that are not frost susceptible.
- The presence of free water and related changes with temperature resulting in ice lens formation, frost heave and the loss of pore water pressure during spring thaw (resulting in posted Spring load restrictions on some roadways).

The usual remedial practice includes removal and replacement of weak soils to their full or partial depth, building transitional zones between different soil types and addressing frost heaving concerns by using more subbase material, and ensuring drainage of the subgrade and the pavement structure. Additional techniques may include the use of light-weight fill materials, geosynthetic materials and fabrics, building surcharge embankments for preloading and soil stabilization/modification techniques. These recommendations should be fully addressed in the Pavement Design Report. The selection of the design subgrade modulus should consider the likely result of these localized remedial measures.

3.9.9. Frost Susceptibility of Subgrade

Frost heave within or beneath a pavement structure can lead to a decrease in pavement serviceability. To reduce frost heave, frost susceptible soils should be removed to a depth of 60 to 70 percent of the frost penetration depth and replaced with soils that are non-frost susceptible or with granular materials. Construction of a good subsurface drainage system and lowering of the water table by the installation of adequate side ditches or subdrains placed at a sufficient depth are the most effective ways of dealing with potential frost heave.

Fine-grained subgrade soils such as very fine sand and silt tend to exhibit high capillarity and low cohesion. Soils exhibiting these properties tend to be moisture sensitive and susceptible to frost heaving based on a grain size analysis. Table 16 taken from the MTO Pavement Design and Rehabilitation Manual [10] identifies the following susceptibility categories based on a grain size analysis.

Table 16: Frost Susceptibility Based on Gradation

Grain Size (5-75 µm)	Susceptibility to Frost Heaving
0-40%	Low
40-55%	Moderate
55-100%	High

Frost susceptible subsoils may require subgrade replacement in the form of additional granular base or approved alternative. The requirement for subgrade replacement can be evaluated through the geotechnical investigation phase of the pavement design process, for example, to address frost susceptibility or moisture sensitive silts.

3.9.10. Geosynthetics

The generic term *geosynthetics* is used to cover a wide range of manufactured construction products, including geotextiles and geogrids. Geotextiles are permeable fabrics that are primarily used as separation layers between subgrade soils and aggregate layers. Geotextiles act as a membrane which allow water to pass but retain soil particles. Geotextiles are usually classified as either woven or non-woven. Woven fabrics have a plastic appearance and are more durable but not very porous and so are used extensively in separation and erosion control applications. Non-woven fabrics have a felt-like appearance and are used for filtration and drainage applications. Non-woven fabrics are specified by their weight and their filtration opening size (FOS), which is selected based on the characteristics of the soil that will surround it. Geogrids consist of a regular grid of durable plastic ribs with large apertures between the ribs. The principal benefit of geogrids is shear strength improvement, especially when incorporated with aggregate layers. The geogrid will also improve aggregate interlock. Biaxial geogrids are mainly used for base reinforcement, while uniaxial geogrids can be used for reinforcing slopes. The function of the openings is to allow the surrounding soil materials to interlock across the plane of the geogrid. The selection of geogrids is mainly based on their tensile strength, their elongation at break and the opening size which is partially dependent on the gradation of the material into which it will be placed.

Geosynthetics have successfully been used to improve soil conditions and for constructability. The most common uses for roadway applications include; reinforcing subgrade soils and aggregate bases, layer separation, and for improving drainage. The separation function describes the maintenance of materials of different gradations as separate and distinct materials. In the specific case of pavement application, this relates to separating unbound granular base course materials from the subgrade. The reinforcement function is very similar to the reinforcement process in reinforced concrete elements. Geosynthetics are introduced to provide elements with tensile resistance into the unbound material, especially over weak subgrades prone to large deflection under load. Frequently non-woven geotextiles are used in conjunction with geogrids to provide both reinforcement and filtration/separation functions. The use of geosynthetics may be appropriate on a project specific basis. City staff and the consultants should ensure that the appropriate type, grade and quality of geosynthetic is selected for the particular application.

3.10. Pavement Drainage Considerations

Drainage is a critical facet of roadway performance and consists of two components: surface drainage and internal drainage. Adequate drainage of the pavement structure is considered to be the most important element in ensuring the long-term pavement performance. The proper design of the drainage system for a particular pavement is of paramount importance. Reducing the moisture content of the granular layers and underlying subgrade through the use of effective drainage directly affects fatigue cracking of the HMA surfaces and thus the life of the pavement.

Efficient road surface stormwater management and internal pavement drainage, as well as groundwater control and slope drainage are essential for improved pavement performance. Surface drainage and runoff characteristics are influenced by road crown and crossfall, and surface layer permeability. When water ponds on a pavement surface, it increases water infiltration into the pavement and reduces ride safety. Internal pavement structure drainage is influenced by the permeability of the surface layers and granular materials, and by the subgrade soil type and crossfall, in combination with roadside subdrains and ditches. Most of the City roads incorporate a subdrain system and depending on the road type and location, side ditches are also used to collect and remove water from the pavement structure. Pavement designs must ensure that water cannot become trapped within the granular base and subbase layers and continuity of drainage is a major design consideration when designing road widening or additional lanes.

Subgrade permeability and the location of the water table should be evaluated since some sandy or porous subgrades may not require subdrains. The practice of backfilling to the underside of the concrete or HMA with unshrinkable fill (U-fill) is not recommended. U-fill should only be placed to the top of the subgrade and the granular layer needs to be reinstated to allow drainage. Any pockets of isolated subgrade repairs must be able to drain to a subdrain or ditch. Installation of additional subdrains or French drains may be required if the excavation is not extended to the subdrain or ditch.

3.10.1. Subdrains placed under a roadway or within its right-of-way

Subdrains consisting of flexible perforated or slotted plastic pipe commonly 150 mm in diameter wrapped with a geotextile are the most common type of collector system used [54]. The drains are normally installed in shallow, narrow trenches, to ensure that the pavement granular layers are positively drained. In urban cross sections, continuous longitudinal subdrains, minimum 150 mm diameter, should be installed at least 300 mm below the top of subgrade under the curb line. The subdrains should be on a positive grade and connected to appropriate outlets. Roadway subdrains should be placed as detailed according to standard drawing T-216.02-8 [55] and according to specification TS 405 [54].

Where continuous subdrains cannot be installed due to conflicts with underground utilities, or in areas with permeable sand subgrade soils, consideration should be given to the installation of stub drains. These stub drains should be a minimum of 10 m in length and extend longitudinally in either direction along the roadway from all catch-basins.

The ditch system is mostly used in areas where there are no space constraints and no storm sewer system is available to collect and remove excess surface water. In earth cut sections the ditch is located directly adjacent to the road and the ditch invert must be at least 0.5 m below the top of subgrade. In fill sections the ditch invert should extend at least 0.25 m below the base of the fill and should be separated from the toe of the fill by a 1.5 m plateau. Specified ditching sections are provided in the 200 series of the Ontario Provincial Standard Drawings (OPSD).

The laboratory testing of soil samples shall be performed as per the Ministry of the Environment, Conservation and Park’s standards and regulations, and as described under the Soil Chemical Testing and Analysis Section in Chapter 1.

The designer shall also consider the following guidelines during pavement drainage design:

- Toronto Green Streets Technical Guidelines [56]
- Wet Weather Flow Management Guidelines [57]
- Low Impact Development (LID) Stormwater Management Planning and Design Guide [58]
- Toronto Complete Street Guidelines [59]
- Design Criteria for Sewers and Watermains [60]

3.10.2. Catchbasins

This section refers mainly to catchbasins on urbanized roads as some roads with rural cross-section may occasionally have "ditch-inlet catchbasins" where the ditch ends and the receiving drain connects to a storm sewer. This is very common throughout the former Etobicoke area of the City (Wards 1,2 & 3). Catchbasins help to collect drainage from both pervious and impervious areas. The engineer should limit the number of catch-basins connected to each section of sewer so that the system is not overloaded.

At street intersections, catchbasins should generally be located immediately upstream of sidewalk or pedestrian crosswalks where the road grade falls towards the intersection. Catchbasins should not be located within one metre of a driveway or walkway curb depression. Catchbasins and their lead connections need to be designed to capture the expected maximum flow. Double catchbasins are required when drainage is received from more than one direction.

For a single catchbasin, the minimum lead connection diameter is 200 mm with minimum 1.0 percent grade. For details and additional design information on single catchbasins, see City standard T-705.010 [61].

For double catchbasins, the minimum lead connection diameter should be 250 mm with the minimum 0.7 percent grade. Double catchbasins should be constructed at sag points when the catchment area is greater than 100 square metres and received from more than one direction in the road way or in cul-de-sacs. For details and additional design information, see City standard T-705.020 [62].

Catchbasins should be provided at adequate intervals to ensure that all the road drainage can be intercepted up to the capacity of the storm sewer. This should be the basis to determine the type, location, and spacing of the catchbasins. The spacing may vary with the road width, grade, and cross fall and with the design storm frequency. The spacing is also affected by the location of pedestrian crossing points, intersections, major depression points, driveway depressions, and so on. The recommended maximum spacing is shown Table 17 [60].

Table 17: Recommended Maximum Catchbasin Spacing

Pavement Width	Grade < 4 % grade	Grade > 4 % grade
7.3 m–8.5 m	90 m	60 m
8.5 m–9.8 m	82 m	55 m
9.8 m–12.2 m	73 m	50 m
12.2 m–14.0 m	60 m	40 m

The spacing of catch-basins may be altered for grades greater than 4 percent, by using side inlet catch-basins. The desired maximum distance between catch-basins from a crest in a road to a catch-basin is 90 metres, measured along the curb line for each side of the road. The maximum area to be serviced by any catch-basin shall be 0.2 hectare of paved area or half hectare of sodded area [60].

3.11. Rehabilitation Strategies

Rehabilitation strategies are designed to help extend the life of an existing pavement; there are two types major and minor. The City of Toronto practices various types of routine rehabilitation for flexible, rigid and composite pavements. Table 18 displays the various types of routine rehabilitation techniques, not all methods are currently practiced with in the City of Toronto.

Table 18: Routine Rehabilitation Techniques

Routine Flexible Rehabilitation	Routine Rigid Rehabilitation
- Full depth removal and resurfacing - Full depth reclamation / pulverization and resurfacing - Pulverization with expanded asphalt stabilization and resurfacing - Partial reconstruction for multi-lane roads - Unbonded concrete overlays - Cold and Hot In-place recycling	- Bonded concrete overlays - Unbonded concrete overlays - Full depth slab repair - Precast concrete slab repair - Hot mix asphalt resurfacing - Remove & replace concrete pavement - Crack and seal with HMA overlay - Rubblization with HMA overlay

3.11.1. Resurfacing

Full-depth removal and resurfacing is considered to be a major form of rehabilitation, this is done when the HMA layer is severely distressed. The HMA layer is milled off fully; if the pavement is flexible, the exposed granular base is assessed and repaired by adding more granular material if needed. Partial-depth removal and resurfacing is minor form of rehabilitation and it is done when a pavement has surficial defects such as ravelling and segregation. The HMA layer is milled, the depth of milling is dependent on the severity of the distresses, and a new HMA layer is paved.

3.11.2. Full Depth Reclamation

Full Depth Reclamation (FDR) is a rehabilitation method used for flexible pavements with severe distresses. When total roadway reconstruction seems to be the only option, FDR should be considered since it removes all existing HMA distresses. FDR consists of pulverizing the surface layers of the pavement and a portion of underlying granulars up to 300 mm in depth. The desired reclaimed HMA and granular (coated to uncoated particles) blend is a 50:50 (or higher percentage for granular fraction), in other words, the pulverized mix should contain a maximum of 50% coated particles. This mixture can be used as a granular base for a new HMA surface. The pulverized mix can also be stabilized using bituminous materials, hydraulic cement, lime or calcium chloride. Additional materials are added depending on the condition of the pulverized mix, to further increase the structural capacity. This method is environmentally friendly due to the 100% reuse of existing materials [10]. The consultant should refer to OPSS 330 [63] and OPSS.MUNI 330 [64] for construction specifications.

3.11.3. Full Depth Reclamation with Expanded Asphalt Stabilization

A further development in FDR is Expanded Asphalt Stabilization (EAS), which uses the same pulverization process except that expanded (foamed) asphalt cement is added to stabilize the material. In the foaming process, a small amount of water is added to the hot asphalt cement, which vaporizes causing it to rapidly “foam” and improve coating of the aggregate particles with asphalt cement. Expanded asphalt is a more efficient binder than emulsion and produces higher resilient modulus values and a mix more resistant to moisture [10]. The consultant should refer to OPSS.PROV 331 [65] and OPSS.MUNI 331 [66] for construction specifications.

3.11.4. In-Place Recycling

In-place recycling is a rehabilitation technique that involves scarification of the existing pavement surface, in-place processing of the scarified materials, possibly adding binder with or without additives to improve the binder properties and simultaneous placement of the processed material. This operation can be completed by several different methods and various types of equipment, either hot or cold. Regardless of the process selected, candidate sections for in-place recycling should be thoroughly evaluated. Corrective procedures prior to placement of the in-place recycled mix may be needed to ensure the new pavement functions at full capacity.

3.11.5. Cold In-place Recycling

Cold-in-place recycling (CIR) is a rehabilitation technique where an existing HMA layer with distresses is milled, screened, processed and mixed with an asphalt recycling agent and compacted with a paver. To complete cold-in-place recycling, equipment such as emulsion tanker, milling machine and paver are needed. The Asphalt Institute's Manual "Asphalt Cold-Mix Recycling" [67], summarizes the general procedures involved and discusses the problems that can occur. A construction specification for CIR is provided in OPSS.MUNI 333 [68].

Cold in-place recycling can also use expanded (foamed) asphalt cement rather than an asphalt emulsion to bind the mix. This method is known as Cold in-place Recycled Expanded Asphalt Mix (CIREAM). The current CIR method needs a minimum of 14 days for the emulsion to break and is restricted to warmer, drier months. Whereas when using CIREAM the new HMA surface can be paved in as little as three days and is less dependent on weather conditions. A construction specification for CIREAM is provided in OPSS.MUNI 335 [69]. Not all existing HMA is suitable for CIREAM treatment and trial mixes should be prepared in advance of construction.

3.11.6. Hot In-place Recycling

Hot in-place recycling (HIR) is an onsite rehabilitation method where the HMA surface layer is heated, rejuvenated, and repaved in-situ, therefore, eliminating the use of virgin materials. This method is practiced using a train system where there is a pre-heating unit followed by a heating unit that scarifies the HMA, immediately followed by an auger that mixes the heated rejuvenated materials which are then levelled off with a screed. Finally, conventional compaction equipment is used to compact the newly recycled pavement. The advantage with this method is that the use of new materials is minimized since no new aggregate is added, only adding a rejuvenator (recycling agent). HIR recycles only the top 50 mm of pavement and is not suitable for a pavement that consists of various HMA mixes, heavily spray patched, crack sealed, or with structural distresses. Emissions from this procedure can be quite high and should be regulated on site. A construction specification for HIR can be found in OPSS.PROV 332 [70].

3.11.7. Bonded Concrete Overlays

Bonded overlays have been successfully used in many parts of North America as a rehabilitation method, the main function of a bonded overlay is to act as one monolithic structure with the underlying layer. For a bonded overlay to be constructed, the underlying layer must be in good to excellent condition. A bonded overlay requires the existing pavement to be clear of full depth distresses and any working cracks to be repaired. If there are distresses beyond repair, such as material related distresses and the layer has structurally failed, the pavement is considered to be in poor condition and a bonded overlay cannot be placed. Bonded overlays rely on the underlying layer for flexural support and increases the overall structural capacity, therefore proper bondage is crucial. If the underlying pavement is PCC, then the joints on the bonded overlay must be matched exactly, otherwise, reflective cracking will immediately propagate to the overlay. The City of Toronto currently does not use bonded overlays as a type of rehabilitation method.

3.11.8. Unbonded Concrete Overlays

Unlike bonded overlays, unbonded does not rely on the underlying concrete for flexural support, it acts as a separate entity. However, it does use the layer as a stable base which results in an increased overall structural capacity. A concrete that is significantly deteriorated will have working cracks, spalling, shattered slabs and pumping as some of the distresses. Due to the existing concrete being significantly deteriorated, a separation layer must be placed between the concrete and the overlay to prevent the distresses from propagating and to provide a smooth base for the overlay. The separation layer can either be a thin HMA layer (<25mm) or non-woven fabric such as geotextile (<3mm) [71]. Since a separation layer is used in-between, the jointing of the overlay is not required to match the joints of the underlying concrete. This City of Toronto has one location where this method of rehabilitation has been implemented.

3.12. Transition Treatments

All widenings for bus bays, turn tapers, and so on must be constructed with tie-ins that ensure effective drainage from the bottom of the existing granular subbase. This can be achieved by constructing the base of the new pavement granular at or below the base of the existing granular. For instances where existing pavement sections differ from pavement sections proposed in the new guidelines, the thicker of the two pavement sections should be used. For general pavement widening the type of pavement structure should match the existing.

3.13. Perpetual Pavements

Perpetual pavements (also called long-life pavements) are essentially deep strength, full depth pavements that are designed for long life. Perpetual pavements are designed to limit the stresses and strains at the bottom of the HMA layer in an effort to eliminate fatigue cracking.

The perpetual pavement concept incorporates a premium wearing surface, rut resistant intermediate layers, and an AC rich fatigue resistant bottom layer. A properly designed and constructed perpetual pavement would only require rehabilitation or replacement of the wearing surface for an anticipated service life up to 50 years.

Recent improvements in materials technology including PG asphalt cements, more stringent screening of aggregates, use of polymers and fibres in asphalt mixes, Superpave mix design methodology and SMA mixes; as well as more advanced pavement analysis and design methodologies, have made possible these long-life pavements.

The Don Valley Parkway is an example of a perpetual pavement with HMA layers in the order of 500 mm thick. At traffic levels consistent with the minor arterial non-truck route classification, a perpetual pavement could potentially have HMA layers in excess of 350 mm thick.

The consideration of the use of perpetual pavements should be on a project specific basis and in conjunction with a detailed life cycle cost analysis. Their advantages to the City is a reduction in the number of major maintenance interventions with associated reduction in traffic disruption and inconvenience for the public and local businesses.

3.14. Sustainability

Sustainability is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [72]. The City of Toronto has many initiatives in place to ensure a well-functioning street network that support and sustain the quality of life. Currently the City is encouraging the Complete Street approach for all newly built and reconstructed roads, and a guideline has been developed to aid designers. The purpose of the Complete Street approach is to consider the needs of all users at the design stage in an integrated manner, and to improve environmental sustainability and safety [59]. The City encourages designers to consider sustainability principles when evaluating alternative rehabilitation treatments such as:

- Maximizing reuse and recycling where it does not impair pavement performance

- Minimizing waste generation
- Minimizing Greenhouse Gases (GHG), noise, and dust emissions
- Sourcing local materials and minimizing material haul distances
- Ensuring long term value for money

To properly understand the implication of pavements on the environment a Life Cycle Assessment (LCA) needs to be completed. Concrete and asphalt are the most commonly used materials in pavement structures. A comparison of LCA for both materials can help a user determine the more sustainable solution. This is further discussed in sections 3.15 and 3.16.

3.15. Economic Evaluation

Roadways are an integral part of the City's infrastructure and are expensive to construct and maintain. To maximize serviceability and minimize costs, it is important to choose the most suitable construction materials as well as appropriate and timely maintenance practices.

It is necessary to review and update cost data on a regular basis to determine its effect on the pavement asset's life cycle cost. A sensitivity analysis of various factors such as current inflation and interest rates should also be included in the comparison of alternatives. This will assist in the selection of preferred pavement structures and rehabilitation alternatives.

It is very important to conduct economic evaluations and analyses, as they provide insight into many benefits such as cost-effective design and construction, best return on investment, better understanding of risks for complex projects and documentation of the decision process. This information is critical for project related decision making.

3.16. Life Cycle Costs

Life cycle cost analysis (LCCA) is a systematic economic evaluation process which considers all identifiable costs to an agency and is used as a decision support tool. Conducting a LCCA forces an organization to place values on not only present expenditures, but also on future investments, and therefore make more rational decisions. When expenditures for roadway infrastructure are spread over the life of the road then a better understanding of the trade-offs in investments is understood. Life cycle costs refer specifically to the direct financial costs associated with a project. When comparisons are made between roadway options (whether for capital construction or routine maintenance), the analysis considered is typically limited to technical costs such as design, contract administration and construction. It is also necessary to relate all costs to a common benchmark. To facilitate this, the influence of interest or discount rate as well as inflation must be considered. The key components of a life cycle cost analysis are detailed in MTO's Pavement Design and Rehabilitation Manual [10] and are also listed below:

Initial Construction Costs – developed for the selected initial designs. Initial cost of each design is based on local unit prices extrapolated to the anticipated construction date.

Rehabilitation Costs – associated with future rehabilitation or other upgrading when the Pavement Condition Index (PCI) reaches a specified minimum level of acceptability, known as the Terminal Serviceability Level. The PCI minimum level is dependent on road function and classification.

Maintenance Costs – are associated with items directly affecting pavement performance. Annual maintenance costs increase with pavement age.

User Costs – are related to vehicle operating costs (VOCs), user travel time costs, traffic delay costs due to construction, collision costs, discomfort costs and environmental costs. User costs are affected by riding condition, vehicle speed, as well as safety features like site distance. These costs are often difficult to quantify. An example of a user cost is that required for additional TTC bus service. In 2017 these costs amounted toa about $3 million for road and bridge works on arterial roads.

Direct Benefits – result from any improvement to the road network such as reduced travel times and improved accessibility to property and building developments adjacent to the improvement works.

Indirect Benefits – are those associated with salvage of materials, greater than anticipated life expectancy, and lower construction bids. It is important not to double-count these items.

Analysis Period – in order to understand the long-term effects of a decision and to assess the impact on costs over time, it is important to choose an ideal analysis period. The analysis period should be long enough to include at least one future rehabilitation event for each alternative. For new roads, an analysis period of more than 40 years is required to properly assess the cost, whereas for rehabilitation projects a minimum analysis period of 30 years is recommended.

Discount Rate – when completing LCCA, it is necessary to incorporate factors that account for changes in the value of money over the analysis period such as inflation and potential interest rates. A discount rate is used to bring all future expenditures to the same time reference point. The unit of time used is typically years, but for some cases months can be used. As time goes by the costs of future work become lower, or are discounted, relative to today’s costs.

Salvage Value – salvage value or residual value is often included in LCCA to account for differences in the condition of each alternative at the end of the analysis period. The salvage value represents the remaining value of pavement materials—at the end of its service life—that can be reused for future construction. The salvage value appears as a negative number in the life-cycle cost analysis since it accounts as a credit in value. It is usually estimated to be 5 per cent of the initial construction cost.

A simplified rehabilitation and maintenance toolbox in relation to current pavement condition is presented in Table 19.

Table 19: Simplified Rehabilitation and Maintenance Toolbox

Activity Category	Activity Name	Activity Description	Estimated Service Life (Yrs)
Construction	Reconstruction	Rebuild entire pavement structure, improve drainage	30 for flexible pavement 30 for rigid pavement
Construction	Partial Pavement Reconstruction	Rebuild flexible/rigid pavement layers	25 for flexible 30 years for rigid
Rehabilitation	Cold Recycling (Flexible Pavements on local roads)	Recycle in-place HMA layers (full depth)	20-25+
Rehabilitation	Resurfacing	Replace 2 lifts HMA and base repairs	20 - 25
Rehabilitation	*'Mill and Pave'* (1 lift)	Replace 1 lift of HMA	18 - 22
Rehabilitation	Overlay (1 lift)	Place 1 lift HMA over existing surface	10 - 20

3.17. Recommended LCCA Method

There are a number of economic models that can be used to predict costs and benefits associated with different pavement design strategies. To make realistic comparisons, it is necessary to identify the differences in the worth of money over time [10]. It is recommended to use the present worth method for LCCA.

The present worth method forecasts the purchasing power of today's funds. It is commonly used in the transportation field and is applicable to the pavement sector. This method considers costs, benefits, or cost and benefits together. It discounts all future sums to the present, using an appropriate discount rate [10].

It is a common industry practice to use the simplified present worth procedure (deterministic approach) for routine life cycle cost analysis. The input values such as initial construction costs are single values representing the mean value and do not account for variability or uncertainly of the inputs [10]. This analysis includes only initial rehabilitation, first overlay costs, and salvage return costs. Steps for the simplified procedure are listed below.

The City will follow the simplified LCCA method developed by MTO. This method is described in the MTO Pavement Design and Rehabilitation Manual [10] as follows.

i. Obtain costs for various rehabilitation schemes.

ii. Based on the anticipated life expectancy (service life) of each scheme, assign an initial life cycle (time to first overlay) in years to each scheme.
iii. Design and cost a first overlay treatment for each scheme which would be applied at the end of the life cycle.
iv. Using the societal discount rate prescribed by the Ministry of Finance (5%) calculate present worth of the overlay treatment, the City PM will confirm the value. The discount rate accounts for the nominal rate of inflation and the cost of borrowing money.
v. Calculate the salvage return years and factored salvage costs based on the excess life of the schemes beyond the 30-year analysis period. Discount the salvage return costs to their present value from the end of the analysis period.
vi. The present worth cost of an overlay plus the initial rehabilitation costs less the discounted salvage costs are calculated to give the life cycle cost.

The LCCA analysis should be reported in the Pavement Design Report. For reconstruction and major rehabilitation projects, LCCA should be carried out on at least three viable design alternatives and the results presented in the report with a recommendation as to the preferred scenario.

Chapter 4 – Constructability Review

The Constructability process has been described as “the optimum use of construction knowledge and experience in planning, engineering, procurement, and field operation to achieve overall project objectives.” [73].

For major infrastructure projects in Canada, a Constructability Review process is frequently implemented to help identify construction inefficiencies or design components likely to unreasonably increase the cost of a project by making the construction process or project staging overly complicated. It is sometimes implemented in conjunction with a Value Engineering review. In the formal application of the process, the concept is to involve a team of experienced individuals with extensive construction experience to address the question, “Is this the best way to construct and deliver this project?”

The purpose of a constructability review of a project is to ensure that the project meets the following guidelines:

- Fulfills the entire technical and legal requirements, required to advertise the project for bidding competition.
- Confirms that the project is practically possible to construct within the specified budget and time.
- Confirms that the project is cost-effective.
- Confirms that the project is maintainable with minimum cost and time.

It is very important to perform a continued constructability review throughout the design phase and to the various construction phases. This review will help the design and construction team to minimize the risks, which may create problems during construction and ultimately will result in increased project cost and extended completion schedule.

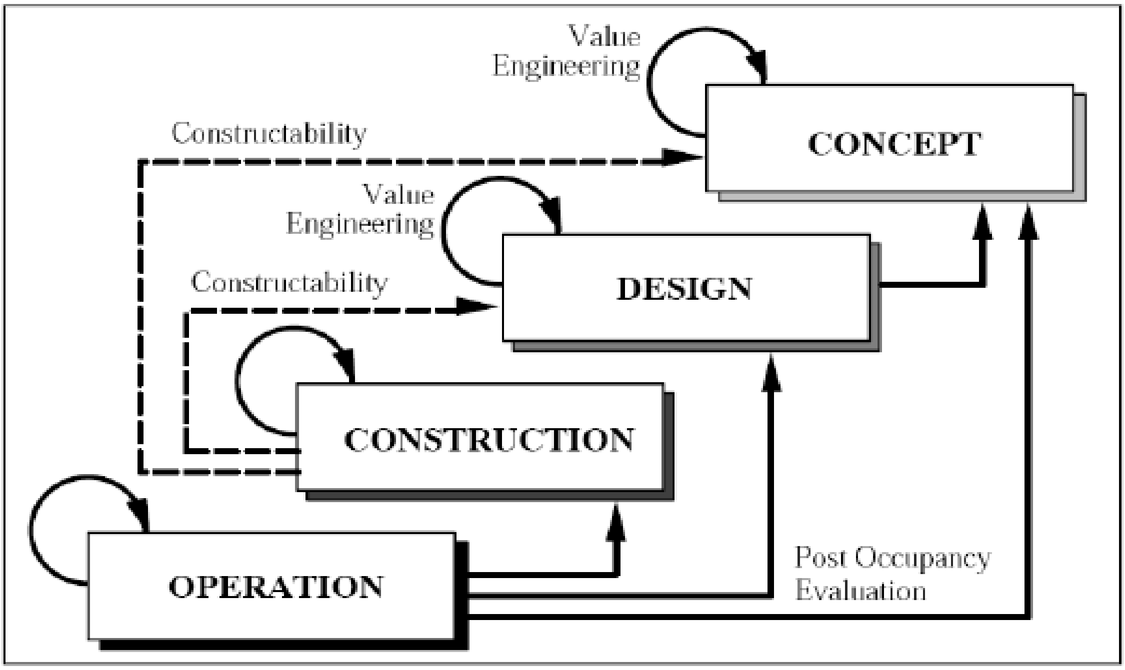


Figure 4: Constructability Feedback Channels in Project Life Cycle

Figure 4 taken from "Constructability Knowledge-Intensive Database System" [74], discusses a process for enhancing the Constructability review process by taking advantage of feedback from previous project experience. Continued feedback based on lessons learned, brain storming and professional construction expertise are the main components of the constructability review process.

It is the responsibility of an Asset Owner (Transportation Agency) to define a clear scope of work in terms of the main project deliverables so that the design and construction team (Engineering & Construction Services, ECS) can gather the necessary information required for the design and construction of any project in a focused and efficient manner. The constructability process starts with clearly defined project goals and objectives.

The Design team or Project Engineer should highlight all constructability based technical/non-technical issues or concerns at a very early stage to allow the asset owner to review, and discuss possible mitigation options and provide guidance for resolution.

Examples of possible Technical Constructability issues are:

- **Scope changed**: needs more technical information, budget and time or project needs to be re-scheduled in future.
- **Relocation of utilities**: relocation of hydro poles, gas main, and fibre cables etc., for an intersection improvement project to enhance the safety of motorists and

pedestrians. A decision may be made to undertake the relocations as an advance contract to minimize schedule and cost impacts on the main contract.

- **Topography:** earth cuts needed to construct a new sidewalk may merit a review of optimum slopes for stability and erosion control, as well as considering a range of partial or full earth retaining structure options.
- **Technical drawings**: should be clear, unambiguous and easy to follow so that the construction team can implement the design with minimum effort and input from the design team. High quality drawings and specifications will minimize construction errors and non-conformances.
- **Appropriate construction techniques**: road grading length and width need to be compatible with the equipment required to construct the road. CIR and HIR recycling methods are not recommended for small sections of road, or small local cul-de-sac roads. Occasionally, bundling of smaller projects may be feasible to reduce construction costs, especially mobilization charges.
- **Enhanced underground utility locates**: encountering unexpected underground utilities during construction increases cost and schedule. To reduce this risk, consideration can be given to daylighting utilities by hydro-vac methods in advance of construction so as to reduce the constructability issues arising during the construction phase.
- **Rationalization:** Opportunities may exist to reduce the range of materials and products in a construction bid with a view to achieving better unit prices. For example, if a design indicates three or four HMA mix types, efficiencies can be achieved by eliminating one of the mix types, especially where the quantities are small.
- **Improving staging:** A major construction consideration in busy City road corridors is construction staging. Opportunities may exist to improve constructability and reduce construction duration by optimizing staging in the form of innovative temporary traffic detours or by allowing extended working hours.

Examples of possible non-Technical Contractibility issues are:

- **Land acquisition:** some modifications may require land adjacent to the R.o.W. Therefore, initiating this process at an early design stage will help reduce delays at the construction phase.
- **Coordination with other agencies:** Road work which is not in the City’s R.o.W. may require permissions from and negotiations with other agencies, such as the MTO, CN/CP Rail, Metrolinx, etc. These negotiations should be initiated early so that other agencies’ design and construction requirements can be integrated early in the design and minimize future construction impacts.
- **Constructor issues:** Under Ministry of Labour requirements, two separate contractors cannot work closer than 500 m to each other [75]. Internal coordination

is necessary between City departments to avoid future conflicts that could require a construction contract being delayed after award. Potential neighbourhood or community activity conflicts also need to be identified in advance.

- **Stakeholder engagement:** Any special instructions or constraints during construction, from schools, hospitals, senior citizen homes and transit systems, etc. need to be addressed early to avoid contract cost and delay impacts.

In addition to the above mentioned constructability related issues, the safety of motorists, cyclists, pedestrians and workers should also be considered during the constructability review of every project. Selection of construction methods, equipment and schedule can play an important role and can reduce the risk related to constructability.

- School closure during the summer break is the best time for road rehabilitation with CIR/HIR methods.
- Appropriate selection of construction equipment and methods in residential and built-up areas so as to minimize vibration, noise and dust.
- Selection of appropriate equipment based on the subsurface conditions identified in the geotechnical report to minimize construction delays. This is particularly important for projects involving deep excavations, piling, and significant groundwater control measures.
- Smooth and unimpeded movement of emergency vehicles through work zones must be assured at all times and fire routes must be kept clear.
- Provision should be made for emergency pull-offs of construction equipment where and when needed.
- Consideration must be given for suitable locations for construction materials and vehicle storage, for safe equipment/materials loading and off-loading and for safe entry and exit from construction sites.
- Contractors need to ensure that construction sites are secure and that all equipment is demobilized and secured during off-work periods.
- Where sidewalks or bicycle paths are impeded by construction, alternative safe routes need to be provided.

Also, a Constructability review on the proposed pavement design should be performed as per best industry practices and as per comments from the City's Project Manager and team. Other considerations which may change the decision of pavement resurfacing to reconstruction or vice versa, for example, including but not limited to:

- If the curb height does not meet the City's minimum standard as per TAC Geometric Design Guidelines [76] , then an analysis of the most economical way to meet that standard should be performed and could include reconstructing the curb and boulevard, the road or both.

- If sidewalks are too narrow and do not meet the City's minimum standards, then an analysis of the most economical way to meet that standard should be performed and could include widening the sidewalk within the boulevard space or narrowing the road as per geometric design analysis using TAC Guidelines; noting that narrowing the road may result in the need to reconstruct the pavement to achieve proper grading for drainage.
- Road realignment due to safety, operation, and geometric design issues may change the pavement resurfacing scope to reconstruction.
- If recommending Cold or Hot in-Place Recycling alternatives, site specific conditions, for example, street length, detours, inconvenience to the residents and availability of machinery shall be assessed.

Chapter 5 – Geotechnical Investigation Report and Pavement Design Report

Geotechnical Investigation and Pavement Design reports for the City of Toronto are crucial documents that allow City engineers to make well informed decisions for Toronto's road network. Geotechnical investigations are conducted prior to project design, so that the designer can confirm important elements such as the structure of the road base and the requirements for trench backfill. Geotechnical Investigation Reports (GIR) are included in the construction tender packages so that contractors can determine their material disposal requirements before bidding. During construction, material testing and quality assurance services are performed in order to help ensure that the City's construction standards and specifications are being followed by the contractor. On a project by project basis, the Geotechnical Investigation Report should summarize pavement evaluation, investigation and testing requirements as per Chapter 1 and 2 of this document.

Pavement Design Report (PDR) deliverables will be determined on a project by project basis however, general guidelines for a PDR are listed below:

1. PDR shall consider all factual information about exiting pavement structure and subsoil conditions as identified in the GIR.
2. PDR shall summarize the findings and recommendations based on Chapter 2 – Pavement Design, and Economic Evaluation using the simplified life cycle cost analysis (LCCA) approach based on the MTO Pavement Design Manual (9).
3. The recommendation shall include a minimum of three alternative options.
4. Detailed LCCA analysis based on the simplified LCCA approach as described in Section 3.16 of this Guide should be appended in the report.
5. A description of the pavement design and analysis software as per AASHTO 1993 shall be appended in the report. Based on the field condition, a road section may need to be divided into sub-sections and recommendations for each sub-section should be listed separately. Traffic volumes (AADT) required for the pavement design will be supplied by the City as described in Section 3.1.
6. Pavement materials recommended in the pavement design report shall be referred to in accordance with City specifications and drawings.
7. The final pavement design report shall address all the comments provided on draft reports and shall recommend, with appropriate justification, one clear final recommendation to the City for the pavement rehabilitation.
8. If the recommendation is resurfacing, explicit resurfacing treatments, for example Mill 1 and Pave 1, Mill 2 and Pave 2, One Lift Overlay, In-Place Recycling etc.; shall be clearly recommended.

9. If the recommendation is full reconstruction, the report shall clearly recommend the pavement type in terms of Flexible Pavement or Composite Pavement based on LCCA analysis and constructability. There may be instances whereby the recommended pavement type could be exposed concrete, for example, an industrial area with high traffic volumes and commercial loading with no utility issues.
10. For standalone road rehabilitation projects, not including public realm infrastructure scope as per Chapter 6 of this document, condition assessment of sidewalks, boulevards, curbs, median, TTC bus pads and other associated items must be provided.
11. Considerations which may change the decision of pavement resurfacing to reconstruction or vice versa, as detailed in Chapter 4.
12. As per Chapter 4, a Constructability Review on the proposed design as per best industry practices and as per comments from the City's Project Manager and team must be provided.

SECTION TWO – PAVEMENT MAINTENANCE AND PUBLIC REALM INFRASTRUCTURE

Chapter 6 – Pavement Maintenance

The key to long term, cost effective pavement performance is the use of appropriate rehabilitation, preservation, and routine maintenance options at the right time during the service life of the pavement, in conjunction with coordination between all departments within the City. The benefits of timely and appropriate application of these options are realized in the form of lower costs, longer serviceability and less disruption to the travelling public. An important component of the pavement rehabilitation process is estimating the remaining life of the in-service pavements. Remaining life should be defined in terms of both structural capacity and functional serviceability. Figure 5 is a graphical illustration of the typical loss in pavement serviceability over time along with the various pavement rehabilitation, preservation and routine maintenance strategies utilized by the City.

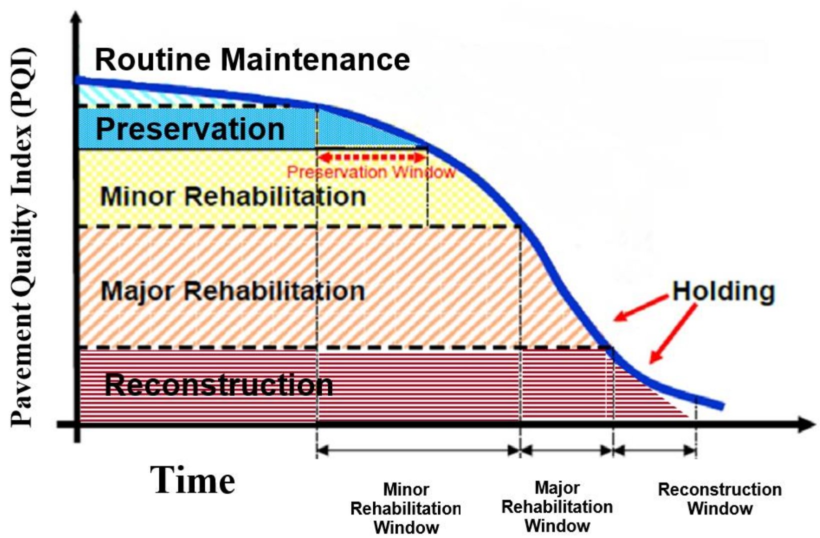


Figure 5: Loss in Pavement Quality Index (PQI) Over Time and Role of Pavement Maintenance and Rehabilitation

As illustrated in Figure 5, a wide range of intervention types are available for road preservation and maintenance. To maximize return on investment, the interventions need to be timely and appropriate. Extensive research over the past 30 years has demonstrated that the timely application of relatively low cost routine maintenance and preservation treatments are six times more cost effective than waiting until the PQI has deteriorated so that only costly major rehabilitation or reconstruction will restore serviceability.

As the City and its associated infrastructure ages, the need for maintenance, repairs, servicing, upgrades and replacement of utilities continues to grow. The timing and frequency of these various events fluctuates significantly. Consequently, pavements can be disturbed at any time during the year and sometimes different utilities may need access to their infrastructure on a shorter frequency cycle – less than 5 years – resulting in pavements that have been cut into and repaired many times. Cuts made during the winter months can exacerbate pavement damage because of infiltration of moisture, the resulting freeze/thaw action and the complications with quality restoration during cold weather.

Classification of Maintenance Interventions

The purpose of this chapter is to discuss three maintenance interventions: preservation, routine maintenance and holding. The City recognizes the role of these strategies in its approach to maintaining its road network. A brief overview of the two types of maintenance interventions is provided below.

Preservation – treatments designed to be proactive, applied while the pavement is still in good condition and maintain a high level of service. They are planned strategies that extend the life of the pavement. These treatments preserve the system, retard deterioration, and maintain or improve the functional condition of the system (without increasing structural capacity).

Routine Maintenance – planned, reactive and preventive work completed on a routine basis to address immediate problems. This form of maintenance is done to ensure full functionality and to maintain the condition of the road at a satisfactory level for a longer period of time.

Holding – "A short term strategy that prolongs the life of a pavement to maintain acceptable levels of functionality or safety until rehabilitation or reconstruction can be completed" [10]. A holding strategy is frequently used where, say major sewer replacement works are proposed beneath a road in 5 years and it is necessary to extend the service life until the sewer work is undertaken at which time the pavement would be reconstructed.

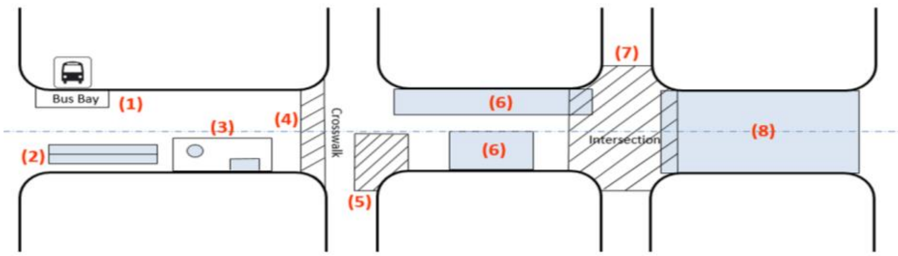
Examples of routine maintenance and preservation techniques for flexible and composite pavements are shown in Table 20.

Table 20: Routine Maintenance and Preservation Techniques

	Flexible	Rigid/Composite
Routine Maintenance and Holding Techniques	- Pothole repairs - Roadside maintenance - Drainage maintenance - Spray patching - Localized distortion repair - Localized HMA patching	- Pothole repairs - Partial depth slab repairs with HMA - Full depth slab repair with HMA - Pavement "Blow ups"repairs - Localized distortion repair - Drainage maintenance - Localized HMA patching
Preservation	- Rout and crack sealing - Hot mix patching - Surface sealing (seal coat, slurry seal, micro surfacing, chip seal/ surface treatment) - Texturization (micro-milling, shot blasting, sand blasting) - Asphalt strip repairs / full depth patching - Thin lift HMA resurfacing - Partial depth removal (milling) and resurfacing - Distortion correction / localized resurfacing - Drainage improvements / subdrain retrofit - Frost treatments - Ultra-thin resurfacing	- Resealing and sealing of joints and cracks - Load transfer retrofit - Full depth joint repair - Full depth stress relief joints - Milling/grinding of stepped joints and distortion - Subsealing, slab jacking and joint stabilization - Surface texturization / diamond grinding - Drainage improvements / subdrain retrofit - HMA overlay

6.1. Routine Maintenance Activities

At present, there are routine maintenance activities including critical interim repairs carried out on an annual basis by the Transportation Services division and contract staff. Figure 6 shows the types of critical interim repairs completed within the Transportation Services division. In making the determination of which repairs are the most critical and the procedures to be used to make the repairs, one should not lose sight of the fact that the distress is often only the visual effect of the problem and not the cause of it. For instance, cracking along a curb line may be improved by sealing the cracks but the problem may be due to the presence of excessive moisture in the subgrade and the lack of pavement edge subdrains. The pavement failures can often be assisted by treating the effect but this is generally only a short term solution.



Number	Type of PCIR
1	Bus Bay
2	Construction Joint
3	Maintenance Chamber/Catchbasin
4	Crosswalk
5	Partial Intersections
6	Partial Pavements
7	Full Intersection
8	Full Width

Figure 6: Pavement Critical Interim Repair – Type/Location of Repair

The current pavement maintenance and critical interim repairs activities used by Transportation Services are as follows:

- Milling and overlay
- Patch repairs
- Deep patching
- Pothole repair
- Curb replacement
- Catch-basin repair
- Bus bay and bus stop repairs
- Crack sealing
- Gutter sealing
- Boulevard repairs

A Pavement Critical Interim Repair form (Appendix B) is used to identify the location and extent of repair. The form requires identification of the type of activity and where it is required. If the full intersection or full width of the pavement needs repair, a special approval is required. Descriptions of the repair activities can be found below:

Milling and Overlay

The milling and overlay maintenance activity is generally used to address localized pavement surface distortions. A surface distortion is any deviation of the pavement surface from its original shape. Generally, these distortions result from rutting, rippling, shoving, settlement, volume changes due to moisture or temperature and frost heaving. In the predominantly urban Toronto environment, the most common pavement distortion is rutting due to traffic loading. Rutting is a longitudinal depression (channel) in the wheel paths after repeated load applications. It results from the compaction/densification in any of the pavement layers or transverse flow of the HMA pavement. While rutting can occur over the entire length of a pavement section, it is generally more prevalent in high stop areas such as intersections and in bus bays. Rutting over the entire length of a pavement section is not to be considered a pavement maintenance activity unless it becomes a serious safety concern. If rutting over an entire section is identified as a serious concern, the pavement maintenance engineer/staff or consultant should consult the Transportation Services division to determine when the section is scheduled for pavement rehabilitation so that any pavement maintenance is coordinated with the planned future rehabilitation of the pavement. Rutting in localized areas should be identified for maintenance.

Other less prevalent surface defects that can be treated by milling and overlay include bleeding and ravelling. Bleeding is the result of free asphalt migrating upward to the pavement surface and usually occurs in the wheel tracks particularly during hot weather. The repair of localized areas of bleeding, particularly in high stopping areas such as intersections should be considered a high priority and safety concern, as bleeding can result in reduced pavement frictional resistance. Ravelling is the progressive loss of pavement material—usually coarse aggregate loss—from the top downward. Ravelling can occur over the entire pavement surface but the wheel tracks are generally the worst areas because of traffic action.

Patch Repairs

The patch repair maintenance activity is generally used to complete final repair to utility cut restorations or to address surface deflections in previous patches. Patch repairs can be completed by either milling the HMA surface or replacing it with new HMA, or by using equipment such as the Patch Master to reheat and rework the existing HMA. Patch repairs may also be used to address other surface defects such as depressions and settlements, wide cracks and severe ravelling.

Deep Patching

The deep patching maintenance activity is only used to address pavement failure areas. Deep patch repairs are completed by saw-cutting around the affected area, removing the concrete or granular base and subbase materials and then reinstating the pavement. Deep patching is used to address severe pavement distress such as alligator cracking.

Pothole Repair

Potholes are created when water penetrates the top layer of HMA through cracks in the road. When temperatures drop the moisture freezes and expands, sections of the pavement are pushed up. The weight of vehicles passing over this section of road breaks the pavement and the HMA pieces are forced out. Potholes are more frequent in the spring, after the freeze/thaw action during winter.

Repairing potholes is an affordable way to maintain the road network. The City's crews routinely monitor road conditions and identify areas that need repairs. Road users and business owners can help by reporting potholes through online or by calling 311. Crews place HMA and rake it into the pothole. Then they tamp down the HMA and smooth it out until the road surface is improved.

Curb Replacement

The curb replacement maintenance activity is used to complete localized repairs to damaged curbs. Curbs may have been damaged due to environmental degradation such as freeze/thaw action or physically damaged due to snow plow impact. Care must be taken when identifying curb for replacement to ensure that the roadway section has not been identified for rehabilitation within the 5 year program. In general, most roads with a PQI between 55 and 65 will be scheduled for resurfacing within 5 years.

Catch Basin Repair

The catch basin repair maintenance activity is used to repair cracked or broken catch-basins. It can also be used to complete adjustments to the height of catch basin covers to assist pavement surface drainage. Catch basins / storm drains will either settle or deteriorate over time. This is because as water enters the joints between the steel casting and block or the mortar joints, it causes the water to disintegrate the mortar. When this happens, especially during the colder months, the water will expand and contract causing the mortar to “pop out”. The criteria for identifying catch-basin repairs are as follows:

- cracked or broken cover
- settled catch basin (> 50 mm) in heavy traffic area
- catch basin heave or road settlement resulting in the catch-basin being higher than the surrounding pavement causing drainage problems.

Bus Bay and Bus Stop Repair

The bus bay repair maintenance activity is used to identify repairs necessary within bus bays or on-roadway bus stop areas. The most prevalent bus bay distress is rutting in the stop areas. In some cases, bus bays have been constructed using a concrete surface. Severe cracking of the concrete could also trigger the bus bay repair maintenance strategy. For rutted bus bay pavements, the repair procedure is usually milling of several layers of HMA followed by replacement with high stability HMA materials.

Routing and Sealing of Cracks

The purpose of crack sealing is to prevent moisture from penetrating the base and subgrade thereby weakening the roadway structure. It also prevents material spalling from the edges of cracks. Pavement cracks on Toronto roads are generally routed to a required reservoir, blown clean with hot compressed air and sealed using a hot-poured rubberized asphaltic crack sealant.

Boulevard Repairs

Boulevard repair activity is used to identify locations where remedial maintenance is required on the boulevard. The type of boulevard repair is not specified under this item. The repair may be to the paved HMA surface, impressed concrete, or grassed boulevard.

The boulevard repair should be as per the most recent Public Realm Guidelines and City standards.
Note: the City does not include the sidewalk area within the definition of boulevard.

6.2. Maintenance Work Responsibilities

The purpose of this section is to identify the current business process pertaining to maintenance of roads and road peripherals. When other non-Transportation related Capital Works projects are performed and road related maintenance work is required.

1. **Road Operations** section is responsible for performing maintenance work identified as part of the Pavement Critical Interim Repair form (Appendix B) and all road peripheral assets identified by **Engineering and Construction Services (ECS)** as part of their capital works delivery. Once the maintenance work is outlined by ECS, the work will then be provided to Road Operations to complete in coordination with ECS's capital projects delivery. Further discussions will be required to determine the details of work as well as the maintenance work timeline for Operations and Maintenance. In certain cases, ECS may carry out the maintenance work identified.
2. **Transportation Infrastructure and Management** section is responsible for overviewing the maintenance work identified by ECS and determining the optimal solution by conducting in-house research. The solution may either be to forward the maintenance work to Road Operation section or request a change in scope of work if required (resurfacing or reconstruction) which would then be carried out by ECS.

Chapter 7 – Public Realm Infrastructure

Public Realm is defined as the "space around, between and within buildings that are publicly accessible, including streets, parks and open spaces which promote public life and social interaction." [77]. As part of the Complete Streets approach, the City of Toronto is undertaking Public Realm Transformation. The purpose of this transformation is to enhance the public realm assets and create an environment for the public to use safely. When improving pavements and the street network, it is also part of the Complete Street approach to improve public realm assets such as sidewalks, walkways, crosswalks, boulevards, multi-use trails/paths, bike lanes and cycle tracks, permeable pavements, TTC street car tracks and concrete pavers. For further information regarding these assets, the designer is requested to refer to the Complete Streets Guideline [59].

7.1. Sidewalk

There are three typical layouts for sidewalks and curbs in Toronto. They include: the monolithic sidewalk and curb, the boulevard separated sidewalk and curb, and the keyed sidewalk and curb. Monolithic sidewalk and curb, as the name implies is comprised of sidewalk and curb constructed as one unit structure. Separated sidewalks are independent structures. They are separated from the curb or edge of road by a boulevard. A keyed sidewalk structure is similar to a monolithic sidewalk and curb with the major difference being the construction method. Keyed sidewalks are built adjacent to but independently of the curb. The sidewalk is supported by a ledge built into the curb to support the sidewalk and thus reduce the chance for settlement of the curbside. Keyed sidewalks should only be placed on curb and gutter systems to prevent rotation of stand-alone curbs. Standalone curbs can be integral (keyed) to the concrete base in concrete or composite pavements, but stand-alone curbs should not be used adjacent to flexible pavements.

The City constructs permanent sidewalks using concrete based on City specification TS 3.70 [78]. The City also uses HMA for temporary sidewalks using City specification TS 3.30 [79]. HMA is a very useful material because it is inexpensive, and easily installed. However, HMA is not as durable as concrete, and is more prone to settlements/distortions, making it less favourable for long term use. For this reason permanent sidewalks are not constructed using HMA. Instead, temporary sidewalks and temporary repairs of sidewalks are made pending permanent replacement with concrete.

Existing sidewalk condition is the most important parameter from a repair and maintenance scheduling perspective. The condition of a sidewalk is recorded using a standard scale called the Sidewalk Condition Index (SCI). SCI values are a measure of the ability of the sidewalk to provide service to the public and they are used to identify the overall network conditions and needs. The quality of a sidewalk and its SCI value is evaluated for a given length. The SCI calculation model employs a deduct value system; all recorded distresses contribute to the value to be deducted from a maximum rating. SCI values range from 0 to 10 and can relate to condition descriptions ranging from Very Poor to Excellent. The City's Sidewalk Survey Guideline available upon request from the City should be used for accepted standards of construction, inventory, condition evaluation and rehabilitation of sidewalks. Below is the list of criteria for sidewalk removal and replacement for resurfacing and reconstruction projects:

- Backfall;
- Ponding;
- Displacement at joints (in excess of 10 mm);
- Excessive slopes causing a fall hazard (Any slope greater than 4% is considered to be excessive);
- Cut repairs as per TS 4.60 **[45]**;
- Scaling/Cracking, including all hairline cracks;
- Severe spalling, foot prints, polished surface, exposed aggregates which could be a tripping hazard;
- Driveway ramps with HMA placed in gutter are to be reconstructed when the difference in elevation cannot be easily corrected with new paving, after confirmation that ramp is legal;
- Sidewalks should extend across driveways;
- Driveway ramps which are found to be illegal, abandoned or have legal requests from TS for widening;
- Project Lead to confirm all driveway alterations with TS Right of Way management;
- Expansion joint to expansion joint removal limits as per specifications;
- Do not leave single bays between areas of repair (floating bays);
- If the sidewalk width is 1.5 m or less, then the whole sidewalk should be replaced;
- The sidewalk may need to be removed and widened at localized areas where pinch points result in a clearway less than 1.2 m;
- All missing or interrupted sections of sidewalk;
- Full block reconstruction when 50-70% of non-continuous sidewalk requires reconstruction depending on bay by bay approach using common sense;
- Controlled and uncontrolled crossings that do not have proper sidewalk ramps must be removed and replaced;
- New sidewalk ramps at pedestrian crossings must include tactile walking surface indicators;
- Ensure depressed curbs and curb ramps align with crosswalk markings; and
- Remove severe jogs or kinks along the sidewalk and replace with flatter transitions, if feasible.

Sidewalk Widths

- The legislated requirement is to provide a minimum 1.5 m clearway on exterior paths of travel that are outdoor sidewalks or walkways designed and constructed for pedestrian travel.
- The City Standard is to provide a minimum 2.1 m clearway on arterial and collector roads, and a minimum 1.8 m clearway on local roads, where possible.
- Generally, all sidewalks that are less than 1.5 m in width or have a pedestrian clearway less than 1.5 m in width should be reconstructed to provide a minimum 1.5 m pedestrian clearway if the sidewalk falls within project limits.
- Sidewalks that meet the minimum legislated requirement but do not meet the City Standard width will be assessed on a case by case basis.
- ECS should identify all sidewalks within project limits that do not meet minimum legislated requirements and identify any barriers to widening the existing sidewalk to meet minimum legislated requirements and City Standard widths.

Tactile Walking Surface Indicators (TWSIs)

Tactile walking surface indicators (TWSIs) are intended to be detectable underfoot when walking or by a long white cane. They are used to alert people with low or no vision of potential hazards, such as moving vehicular traffic.

- The minimum legislated requirement is to install TWSIs at sidewalk ramps that are being newly constructed or redeveloped.
- TWSIs should be installed at all sidewalk ramps that are part of an exterior path of travel within the project limits for all road reconstruction and road resurfacing projects.
- TWSIs should be installed at all corners of an intersection even if not all corners of an intersection fall within project limits.

7.2. Walkway

Walkways typically play a minor transportation role for motor and transit vehicles, but a significant role for pedestrians and cyclists. Cycling and walking is prevalent, and should be welcomed, prioritized and made safe, especially for the most vulnerable. Cyclists may have a separate facility such as a lane or path, but may also mix in the general use of the street. In areas with higher recreational use, cyclists and pedestrians should be separated to improve safety, accessibility and enjoyment. Walkways development and design should be in line with Toronto Complete Street Guidelines [59].

7.3. Crosswalk

Designated pedestrian crossings are found at intersections of streets, at midblock locations on long blocks, and at key destinations, such as schools, transit stops or stations, offices, or shopping plazas, that generate pedestrian crossing demand. Pedestrian crossings are facilitated by traffic signals, mid-block pedestrian signals, pedestrian crossovers also known as PXOs and pedestrian crossing islands or refuge islands.

Pedestrian Signals: Traffic control signals that provide pedestrians with a protected crossing opportunity at intersections or midblock locations by requiring motorists to stop at the signal.

Pedestrian Crossover (PXO): Pedestrian crossovers are identified by specific signs, pavement markings, illuminated overhead lights, and pedestrian push buttons. Under provincial laws, drivers and cyclists must wait until pedestrians have completely crossed the road.

Pedestrian Crossing Island or Refuge Island: An area protected by curbs (i.e., a raised concrete island) between two directions of traffic, where pedestrians can wait for a gap in vehicular traffic or rest while crossing streets mid-block.

All crosswalk development and design should be in line with Toronto Complete Street Guidelines [59].

Pavement Markings

- Current Signs and Markings' policy requires installation of stop bars, tails, and crossing lines at controlled crosswalks.
- Current practice is to install pavement markings only where they existed previously.
- ECS should install stop bars with tails at all stop signs and crossing lines at all controlled crossings within project limits.

7.4. Boulevard

The boulevard typically described the area between the street and the property line, and the sidewalk may or may not be included [80]. The City has three different standard drawings for boulevards, as listed below:

T-310.010-2 Concrete Sidewalk with Boulevard [81]
T-310.010-9 Concrete Boulevard Edge [82]
T-561.030-4 Detail of Boulevard Paving [83]

- Typically, boulevards greater than 1.0m in width should be sod and boulevards less than 1.0m in width should be concrete.
- Existing sod boulevards that are less than 1.0m in width that are in good condition should be reinstated and not replaced with concrete.
- ECS should identify all HMA boulevards within project limits for review by Beautiful Streets.

7.5. Multi-Use Trails/Paths

Toronto's multi-use trails are utilized by residents and visitors throughout the year and form a dense network throughout the city. Taken together with the City's parks and open spaces, sidewalks and on-road bicycle facilities; this trail network forms part of a greater network of active transportation and recreation choices for Toronto's residents and visitors. Within this network, each trail, park, bicycle lane or other component has a particular role to play. As a result, each trail needs to have certain characteristics to ensure that it can perform appropriately. Three classes of trails are identified by their role in the network: primary trails, secondary trails and high-capacity trails.

All multi-use trail construction and maintenance work throughout the City should be conducted as per Toronto Multi-Use Trail Guidelines [84]. The guidelines speak to the urban context of Toronto's trails and their varied locations in City boulevards, ravines, parkland, rail and hydro corridors. These guidelines are consistent with current, relevant City and Provincial guidelines and policy documents, as well as the current North American and international best practices. In some cases, these guidelines make recommendations that exceed existing guidelines and best practices, in order to create truly world-class multi-use trails for Toronto's residents and visitors.

Multi-use trails in the City mainly consist of flexible pavement. Detailed HMA mixture requirements and details of minimum thickness of granular layers should be designed according to City standard drawing T-221.01 [85], unless a geotechnical report recommends differently. Any multi-use trail pavement structure design should be carried out using the AASHTO 1993 method, if required.

7.6. Bike Lanes and Cycle Tracks

The City has a network of designated cycling facilities across the City. The cycling network includes many types of infrastructure including cycle tracks, bicycle lanes, contraflow lanes, shared roadway routes and multi-use trails. Toronto's cycling routes are used for both commuter and recreational cycling.

Shared lane pavement markings, or "sharrows", help guide cyclists on and between cycling routes and remind motorists to share the road. Sharrows highlight the best position for cyclists on the road and provide wayfinding between cycling routes. If a street is wide enough for cyclists and motorists to safely travel side by side in a single lane, then sharrows will be placed to direct cyclists and motorists to travel within the lane, side-by-side. If a street is too narrow to allow side-by-side use, sharrows are placed in the centre of the lane, directing road users to travel single file.

Designated bicycle lanes and cycle tracks are by-lawed, dedicated parts of the roadway, for the exclusive use of cyclists. Cycle tracks are separate lanes for bicycles that are adjacent to the roadway, but separated from vehicular traffic. Cycle tracks help distinguish the area for cycling from motor vehicle traffic. Other road users may not lawfully drive, stand, stop or park in a designated bicycle lane. The diamond marking in bicycle lanes and cycle tracks is used to indicate a ‘reserved lane’ for cyclists. Contraflow bicycle lanes allow cyclists to travel in two directions on a street, which is one-way for all other vehicles. Cyclists travel in one direction in the designated bicycle lane. When travelling in the opposite direction, the cyclist will travel in the mixed-use traffic lane

Specific cycling related issues should be referred to the City's cycling webpage for details [86].

7.7. Permeable Pavement

Permeable pavements are an alternative to traditional pavement surfacing that are relatively impermeable. They allow stormwater to drain through the surface and into a crushed stone reservoir below where it can be slowly infiltrated into the underlying native soil or temporarily detained. They are only suitable for low volume roads, parking lots, driveways, pedestrian plazas and walkways. Permeable pavements are ideal for sites with limited space for other surface stormwater best management practices. The Low Impact Development (LID) Stormwater Management Planning and Design Guide [58] identifies typical types of permeable pavement as listed below:

- permeable interlocking concrete pavers, such as block pavers;
- plastic or concrete grid systems, such as grid pavers;
- pervious concrete; and
- porous asphalt.

Depending on the native soils and physical constraints, the system may be designed with no underdrain for full infiltration, with an underdrain for partial infiltration, or with an impermeable liner and underdrain for a no infiltration or detention and filtration only practice. Permeable paving allows for filtration, storage, or infiltration of runoff, and can reduce or eliminate surface stormwater flows compared to traditional impervious paving surfaces like concrete and HMA. Permeable pavement specifications and application details are listed in Low Impact Development Stormwater (LID) Management Planning and Design Guide [58] and Toronto Complete Street Guidelines [59].

The American Society of Civil Engineers (ASCE) 2016 “Permeable Pavements” manual provides an excellent and comprehensive guide for the overall design, installation, and maintenance of permeable pavements [87].

7.8. TTC Street Car Track Allowance

The Toronto Transit Commission's (TTC) extensive streetcar network covers a vast area of the city with 11 routes and approximately 82 kilometres of service [88] . The network is concentrated primarily in downtown Toronto and in proximity to the City's waterfront. Much of the streetcar route network dates from the 19th century. Most of City's streetcar routes operate on street trackage shared with vehicular traffic, and streetcars stop on demand at frequent stops like buses. The street car track allowance is solely maintained and operated by TTC. For any TTC street car track allowance, pavement designers should be referred to corresponding City specifications and standard drawings.

City specification TS 3.75 [89] covers the requirements for the construction of the streetcar track pavement and the foundation slab. TTC streetcar track allowance cross-section is specified in City standard drawing T-216.02-11 [90].

7.9. Brick and Precast Concrete Pavers

Brick and precast concrete pavers are commonly used decorative methods of creating a pavement surface or hard-standing surface. The main benefit of bricks and precast pavers over other materials is that individual bricks or pavers can later be lifted up and replaced. Typical areas of use would be for driveways, pavement, patios, town centres and more commonly in road surfacing. There are many different laying patterns that can be achieved using brick or precast pavers. The most common of these is the herringbone pattern. This pattern is the strongest of the block paving as it offers the most interlock, therefore making it a good choice for driveways and road surfacing. A herringbone pattern can be created by setting the blocks at either 45 degrees or 90 degrees to the perpendicular. City specification TS 3.80 [91] covers the requirements for the installation of concrete unit pavers. The serviceability and aesthetic appearance of pavers is highly dependent on the competence and uniformity of the supporting base, which can comprise concrete or granular base.

The City has four different standard drawings on the use of unit pavers:
T-310.020-2 Sidewalk Paved with Unit Paver Band at Curb [92]
T-310.050-2 Vehicular Crossing of Sidewalk with Unit Paver Installation [93]
T-561.030-1 Unit Pavers on Concrete Base Non-Vehicular Locations [94]
T-561.030-2 Unit Pavers on Granular Base Non-Vehicular Locations [95]

References

[1] Applied Research Associates, Inc. , "Pavement Structural Design Guideline," City of Toronto, Toronto, 2006.

[2] American Association of State Highway and Transportation Officials, AASHTO Guide for Design of Pavement Structures, Washington: AASHTO, 1993.

[3] Ministry of Transportation Ontario, "MTO MI-183 Adaptation and Verification of AASHTO Pavement Design Guide for Ontario Conditions," MTO, 2008.

[4] ASTM International, "ASTM D6433-18 Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys," ASTM International, West Conshohocken, 2018.

[5] Ministry of Transportation Ontario, "Falling Weight Deflectometer (FWD) Testing Manual," in *MERO-053*, MTO, 2018.

[6] ASTM International, ASTM D4602-93 Standard Guide for Non-destructive Testing of Pavements Using Cyclic-Loading Dynamic Deflection Equipment, West Conshohocken: ASTM International, 2015.

[7] Pavement Interactive, Ground Penetrating Radar, 2019.

[8] Pavement Interactive , Roughness, 2019.

[9] City of Toronto, "Data Extraction of Other Assets within the Right-Of-Way Pilot Summary Report," City of Toronto, Toronto, 2018.

[10] Ministry of Transportation Ontario, Pavement Design and Rehabilitation Manual, vol. Second Edition , MTO, 2013.

[11] ASTM International, ASTM E274 / E274M-15 Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire, West Conshohocken: ASTM International, 2015.

[12] Ministry of Transportation Ontario, LS-602 Method of Test for Sieve Analysis of Aggregates, MTO , 2017.

[13] Ministry of Transportation Ontario, LS-701 Method of Test for Determination of Moisture Content of Soils, MTO, 1996.

[14] Ministry of Transportation Ontario, LS-621 Method of Test for Determination of Amount of Asphalt-Coated Particles in Coarse Aggregate, MTO , 2015.

[15] Ministry of Transportation Ontario, LS-706 Method of Test for Moisture-Density Relationship of Soils Using 2.5 kg Rammer and 305 mm Drop, MTO, 2015.

[16] Ministry of Transportation Ontario , LS 607 Method of Test for Determination of Percent Crushed Particles in Processed Coarse Aggregate, MTO, 2001.

[17] Ministry of Transportation Ontario, LS-618 Method of Test for the Resistance of Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus, MTO , 2001.

[18] Ministry of Transportation Ontario, LS-702 Method of Test for Determination of Particle Size Analysis of Soils, MTO, 2018.

[19] Ministry of Transportation Ontario, LS-703/704 Method of Test for Liquid Limit, Plastic Limit, and Plasticity Index of Soils, MTO, 2018.

[20] Ministry of Transportation Ontario , LS-709 Method of Test for Determination of Permeability of Granular Soils, MTO, 1999.

[21] ASTM International, ASTM D2974-14 Standard Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils, West Conshohocken: ASTM International, 2014.

[22] CSA Group, CSA A23.1 -14 / A23.2-14, Concrete Materials and Methods of Concrete Construction/ Test Methods and Standard Practices for Concrete, Mississauga, 2014.

[23] Government of Ontario, Ontario Regulation 278/05: Designated Substance - Asbestos on Construction Projects and in Buildings and Repair Operations, Government of Ontario, 2018.

[24] United States Environmental Protection Agency, EPA/600/R-93/116: Test Method - Method for the Determination of Asbestos in Bulk Building Materials, United States Environmental Protection Agency, 1993.

[25] Government of Ontario, Ontario Regulation 153/04: General – Waste Management, Government of Ontario, 2017.

[26] Canadian Council of Ministers of the Environment, Guidance Manual for Environmental Site Characterization in Support of Environmental and Human Health Risk Assessment, vol. Volume 4 Analytical Methods, Canadian Council of Ministers of the Environment, 2016.

[27] Ontario Ministry of the Environment and Climate Change, Management of Excess Soil – A Guide for Best Management Practices, Ontario Ministry of the Environment and Climate Change, 2016.

[28] City of Toronto, "Attachment 1: Road Classification Criteria (adopted by City Council)," 1 March 2000. [Online]. Available: https://www.toronto.ca/wp-content/uploads/2018/12/95ba-TS_Road-Classification_Criteria.pdf. [Accessed 2019].

[29] City of Toronto, "Transportation - Data Catalogue," [Online]. Available: https://www.toronto.ca/city-government/data-research-maps/open-data/open-data-catalogue/transportation/. [Accessed March 2019].

[30] Ontario Geologic Survey, The Physiography of Southern Ontario, vol. Special Volume 2, Ontario, 1984.

[31] ASTM International, ASTM D2487-17 Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), West Conshohocken: ASTM International, 2017..

[32] City of Toronto, "TS 3.40 Construction Specification for Concrete Road Base," September 2017. [Online]. Available: https://www.toronto.ca/wp-content/uploads/2017/11/9160-ecs-specs-roadspecs-TS_3.40_Sep2017.pdf. [Accessed March 2019].

[33] S. H. Kosmatka, W. C. Panarese, K. D. Gissing and N. F. MacLeod, Design and Control of Concrete Mixtures, vol. Sixth Canadian Edition , Portland Cement Association , 1995.

[34] City of Toronto, Standard Drawing T-502.01 Concrete Pavement for Lanes, Toronto, 2014.

[35] City of Toronto, TS 1151 Amendment to OPSS.MUNI 1151 (Apr 2018) - Material Specification for Superpave and Stone Mastic Asphalt Mixtures, Toronto: City of Toronto, 2018.

[36] Ontario Provincial Standard Specification, OPSS.MUNI 1151 Material Specification for Superpave and Stone Mastic Asphalt Mixtures, OPSS, 2018.

[37] City of Toronto, TS 1101 Amendment to OPSS.MUNI 1101 (Nov 2016) - Material Specification for Performance Graded Asphalt Cement, Toronto, 2017.

[38] J. Casello and W. Towns, Climate risks and adaptation practices for the Canadian transportation sector 2016 (pp. 264-309), Ottawa: Government of Canada, 2017.

[39] City of Toronto, TS 3.20 Construction Specification for Track Coat, Toronto, 2017.

[40] City of Toronto, T-600.11-1 Concrete Curb Standard Drawing, Toronto, 2014.

[41] City of Toronto, T-600.05-1 Concrete Curb and Gutter Standard Drawing, Toronto, 2014.

[42] City of Toronto, T-216.02-4 Location and Detail of Joints for Composite Pavements, Toronto, 2018.

[43] City of Toronto, T-508.010-1 Anchored Hook Bolt Dowel and Concrete Repair Detail, Toronto, 2014.

[44] City of Toronto, Improvements to the Utility Cut Management Process, Toronto, 2010.

[45] City of Toronto, TS 4.60 Construction Specification for Utility Cut and Restoration, Toronto, 2017.

[46] City of Toronto, Resilient City - Preparing for a Changing Climate Status Update and Next Steps, Toronto, 2016.

[47] City of Toronto, TS 3.41: Construction Specification for Concrete Bus Pad, Toronto, 2017.

[48] City of Toronto, T-310.050-8 Driveway Thickness Standard Drawing, Toronto, 2014.

[49] City of Toronto, TS 3.45 Construction Specification for the Repair of Concrete Pavement and Base, Toronto, 2014.

[50] Ontario Provincial Standards for Roads and Public Works, OPSS.MUNI 364 Construction Specification for Partial Depth Repairs in Concrete Pavement, 2017.

[51] Ontario Provincial Standards for Roads and Public Works, OPSS.MUNI 929 Construction Specification for Abrasive Blast Cleaning – Concrete Construction, 2017.

[52] Ontario Provincial Standards for Road and Public Works, OPSS 350 Construction Specification for Concrete Pavement and Concrete Base, 1998.

[53] City of Toronto, TS 1010 Amendment to OPSS.MUNI 1010 (Apr 2013) – Material Specification for Aggregates – Base, Subbase, Select Subgrade, and Backfill Material, Toronto, 2017.

[54] City of Toronto, TS 405 Amendment to OPSS 405 (Nov 2008) – Construction Specification for Pipe Subdrains, Toronto, 2017.

[55] City of Toronto, T-216.02-8 Roadway Subdrains Standard Drawing, Toronto, 2014.

[56] City of Toronto, Toronto Green Streets Technical Guidelines, vol. Version 1.0, Toronto, 2017.

[57] City of Toronto, Wet Weather Flow Management Guidelines, Toronto, 2016.

[58] Toronto and Region Conservation Authority and Credit Valley Conservation, Low Impact Development Stormwater Management Planning and Design Guide, vol. Version 1.0, Toronto, 2010.

[59] City of Toronto, Toronto Complete Street Guidelines, vol. Edition 1. Volume 1 , Toronto, 2017.

[60] City of Toronto, Design Criteria for Sewers and Watermains, vol. First Edition , Toronto, 2014.

[61] City of Toronto, T-705.010 Precast Catch Basin with Sump, Toronto, 2013.

[62] City of Toronto, T-705.020 Precast Double Catch Basin with Sump, Toronto, 2013.

[63] Ontario Provincial Standard Specification, OPSS 330 Construction Specification for In-Place Full Depth Reclamation of Bituminous Pavement and Underlying Granular, 2011.

[64] Ontario Provincial Standard Specification , OPSS.MUNI 330 Construction Specification for In-Place Full Depth Reclamation of Bituminous Pavement and Underlying Granular, 2014.

[65] Ontario Provincial Standard Specification , OPSS.PROV 331 Construction Specification for Full Depth Reclamation with Expanded Asphalt Stabilization, 2015.

[66] Ontario Provincial Standard Specification , OPSS.MUNI 331 Construction Specification for Full Depth Reclamation with Expanded Asphalt Stabilization, 2016.

[67] Asphalt Recycling and Reclaiming Association, Basic Asphalt Recycling Manual, Annapolis, 2001.

[68] Ontario Provincial Standard Specification, OPSS.MUNI 333 Construction Specification for Cold In-Place Recycled Mix, 2015.

[69] Ontario Provincial Standard Specification, OPSS.MUNI 335 Construction Specification for Cold In-Place Recycling with Expanded Asphalt, 2009.

[70] Ontario Provincial Standard Specification, OPSS.PROV 332 Construction Specification for Hot In-Place Recycling and Hot In-Place Recycling with Integral Overlay, 2016.

[71] D. Harrington and G. Fick, Guide to Concrete Overlays: Sustainable Solutions for Resurfacing and Rehabilitating Existing Pavements, Washington: American Concrete Pavement Association (ACPA), 2014.

[72] IISD, "Sustainable Development," 2017. [Online]. Available: http://www.iisd.org/topic/sustainable-development.

[73] Construction Industry Institute , Constructability Concepts File, Publication 3-3, Austin, 1987.

[74] M. Katram, K. Al-Reshaid and H. Askar, Constructability Knowledge-Intensive Database System - Durability of Building Materials and Components, Ottawa: Institute of Research in Construciton, 1999.

[75] Ministry of Labour, Employment Standards, 2019.

[76] Transportation Association of Canada, Geometric Design Guide for Canadian Roads, 2017.

[77] Ministry of Municipal Affairs and Housing , Growth Plan for the Greater Golden Horseshoe, 2017.

[78] City of Toronto, TS 3.70 Construction Specification for Concrete Sidewalk and Concrete Raised Median, Toronto, 2016.

[79] City of Toronto, TS 3.30 Construction Specification for Hot Mix Asphalt Sidewalks, Boulevards and Driveways, Toronto, 2017.

[80] City of Oshawa, Boulevards and Sidewalks, Oshawa, 2019.

[81] City of Toronto, T-310.010-2 Concrete Sidewalk with Soft Boulevard or Concrete Sidewalk Adjacent to Curb, Toronto, 2017.

[82] City of Toronto, T-310.010-9 Concrete Boulevard Edge, Toronto, 2017.

[83] City of Toronto, T-561.030-4 Detail of Boulevard Paving, Toronto, 2014.

[84] City of Toronto, Toronto Multi-Use Trail Design Guidelines, Toronto, 2015.

[85] T-221.01 Asphalt Paving for Multi-Use Pathways Standard Drawing, Toronto, 2016.

[86] City of Toronto, "Cycling in Toronto," City of Toronto, 2019. [Online]. Available: https://www.toronto.ca/services-payments/streets-parking-transportation/cycling-in-toronto/.

[87] American Society of Civil Engineers , Permeable Pavements, 2016.

[88] Toronto Transit Commission, TTC Toronto's Streetcar Network, Toronto, 2019.

[89] City of Toronto, TS 3.75 Construction Specification for Streetcar Track Pavement and Foundation Slab, Toronto, 2017.

[90] City of Toronto, T-216.02-11 Concrete Pavement in TTC Track Allowance Detail Standard Drawing, Toronto, 2014.

[91] City of Toronto, TS 3.80: Construction Specification for Concrete Unit Pavers, Toronto, 2017.

[92] City of Toronto, T-310.020-2 Sidewalk Paved With Unit Paver Band At Curb, Toronto, 2017.

[93] City of Toronto, T-310.050-2 Vehicular Crossing of Sidewalk With Unit Paver Installation, Toronto, 2016.

[94] City of Toronto, T-561.030-1 Unit Pavers On Concrete Base Non-Vehicular Locations, Toronto, 2018.

[95] City of Toronto, T-561.030-2 Unit Pavers On Granular Base Non-Vehicular Locations, Toronto, 2018.

Appendix A - Historical Pavement Structural Design Matrix

Pavement Structural Design Matrix, Revised 2018 – City of Toronto

TORONTO

		30,000		40, 000		50,000		60,000		75,000	
		30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa
Major Arterial	Non-Truck Routes (5% Commercial Vehicles)	40 mm SP12.5 FC2 D 110 mm SP19.0 D 150 mm Granular A 200 mm Granular B* 500 mm Total	40 mm SP12.5 FC2 D 90 mm SP19.0 D 150 mm Granular A 200 mm Granular B* 480 mm Total	40 mm SP12.5 FC2 D 125 mm SP19.0 D 150 mm Granular A 200 mm Granular B* 515 mm Total	40 mm SP 12.5 FC2 D 100 mm SP19.0 D 150 mm Granular A 200 mm Granular B* 490 mm Total	40 mm SP12.5 FC2 D 135 mm SP19.0 D 150 mm Granular A 200 mm Granular B* 525 mm Total	40 mm SP12.5 FC2 D 110mm SP 19.0 D 150 mm Granular A 200 mm Granular B* 500 mm Total	40 mm SP12.5 FC2 D 145 mm SP 19.0 D 150 mm Granular A 200 mm Granular B* 535 mm Total	40 mm SP12.5 FC2 D 120 mm SP19.0 D 150 mm Granular A 200 mm Granular B* 510 mm Total	40 mm SP 12.5 FC2 D 155mm SP19.0 D 150 mm Granular A 200 mm Granular B* 545 mm Total	40 mm SP12.5 FC2 D 125 mm SP19.0 D 150 mm Granular A 200 mm Granular B* 515 mm Total
	Truck Routes (7.5% Commercial Vehicles)	40 mm SP12.5 FC2 D 130 mm SP19.0 D 150 mm Granular A 250 mm Granular B* 570 mm Total	40 mm SP12.5 FC2 D 110 mm SP 19.0 D 150 mm Granular A 250 mm Granular B* 550 mm Total	40 mm SP12.5 FC2 D 150 mm SP19.0 D 150 mm Granular A 250 mm Granular B 590 mm Total	40 mm SP 12.5 FC2 D 130 mm SP19.0 D 150 mm Granular A 250 mm Granular B* 570 mm Total	40 mm SP12.5 FC2 D 155 mm SP19.0 D 150 mm Granular A 250 mm Granular B* 595 mm Total	40 mm SP12.5 FC2 D 135 mm SP19.0 D 150 mm Granular A 250 mm Granular B* 575 mm Total	40 mm SP12.5 FC2 E 160 mm SP 19.0 E 150mm Granular A 250 mm Granular B* 600 mm Total	40 mm SP12.5 FC2 E 145 mm SP19.0 E 150 mm Granular A 250 mm Granular B* 585 mm Total	40 mm SP 12.5 FC2 E 170 mm SP19.0 E 150 mm Granular A 250 mm Granular B* 610 mm total	40 mm SP12.5 FC2 E 150 mm SP19.0 E 150 mm Granular A 250 mm Granular B* 590 mm Total
	Truck Routes (10% Commercial Vehicles)	40 mm SP12.5 FC2 D 150 mm SP19.0 D 150 mm Granular A 250 mm Granular B* 590 mm Total	40 mm SP12.5 FC2 D 125 mm SP 19.0 D 150 mm Granular A 250 mm Granular B* 565 mm Total	40 mm SP12.5 FC2 D 160 mm SP19.0 D 150 mm Granular A 250 mm Granular B* 600 mm Total	40 mm SP 12.5 FC2 D 135 mm SP19.0 D 150 mm Granular A 250 mm Granular B* 575 mm Total	40 mm SP12.5 FC2 E 170 mm SP19.0 E 150 mm Granular A 250 mm Granular B 610 mm Total	40 mm SP12.5 FC2 E 145 mm SP19.0 E 150 mm Granular A 250 mm Granular B* 585 mm Total	40 mm SP12.5 FC2 E 175 mm SP 19.0 E 150 mm Granular A 250 mm Granular B* 615 mm Total	40 mm SP12.5 FC2 E 155 mm SP19.0 E 150 mm Granular A 250 mm Granular B* 595 mm Total	40 mm SP 12.5 FC2 E 185 mm SP19.0 E 150 mm Granular A 250 mm Granular B* 625 mm Total	40 mm SP12.5 FC2 E 165 mm SP19.0 E 150 mm Granular A 250 mm Granular B* 605 mm Total

		20,000		25,000	
		30 MPa	50 MPa	30 MPa	50 MPa
Minor Arterial	Non-Truck Routes (4% Commercial Vehicles)	40 mm SP12.5 FC1 C 95 mm SP19.0 D 150 mm ranular A 150 mm Granular B* 435 mm Total	40 mm SP12.5 FC1 C 80 mm SP19.0 D 150 mm Granular A 150 mm Granular B* 420 mm Total	40 mm SP12.5 FC1 C 105 mm SP19.0 D 150 mm Granular A 150 mm Granular B* 445 mm Total	40 mm SP 12.5 FC1 C 85 mm SP 19.0 D 150 mm Granular A 150 mm Granular B* 425 mm Total
	Truck Routes (7.5% Commercial Vehicles)	40 mm SP12.5 FC1 C 135 mm SP19.0 D 150 mm Granular A 150 mm Granular B* 475 mm Total	40 mm SP12.5 FC1 C 110 mm SP 19.0 D 150 mm Granular A 150 mm Granular B* 450 mm Total	40 mm SP12.5 FC1 C 140 mm SP19.0 D 150 mm Granular A 150 mm Granular B* 480 mm Total	40 mm SP 12.5 FC1 C 120 mm SP19.0 D 150 mm Granular A 150 mm Granular B* 460 mm Total

		5,000		7,500		10,000		15,000	
		30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa
Collector	Comm./Ind. (5% Commercial Vehicles)			40 mm SP12.5 B 105 mm SP19.0 B 150 mm Granular A 150 mm Granular B* 445 mm Total	40 mm SP12.5 B 75 mm SP19.0 B 150 mm Granular A 150 mm Granular B* 415 mm Total	40 mm SP12.5 B 115 mm SP19.0 B 150 mm Granular A 150 mm Granular B* 455 mm Total	40 mm SP12.5 B 85 mm SP19.0 B 150 mm Granular A 150 mm Granular B* 425 mm Total	40 mm SP12.5 B 125 mm SP 19.0 B 150 mm Granular A 150 mm Granular B* 465 mm Total	40 mm SP12.5 B 95 mm SP19.0 B 150 mm Granular A 150 mm Granular B* 435 mm Total
	Residential (3% Commercial Vehicles)	40 mm SP12.5 B 70 mm SP19.0 B 150 mm Granular A 150 mm Granular B* 410 mm Total	40 mm SP12.5 B 60 mm SP19.0 B 150 mm Granular A 150 mm Granular B* 400 mm Total	40 mm SP12.5 B 85 mm SP19.0 B 150 mm Granular A 150 mm Granular B* 425 mm Total	40 mm SP12.5 B 60 mm SP19.0 B 150 mm Granular A 150 mm Granular B* 400 mm Total	40 mm SP12.5 B 95 mm SP19.0 B 150 mm Granular A 150 mm Granular B* 435 mm Total	40 mm SP12.5 B 60 mm SP19.0 B 150 mm Granular A 150 mm Granular B* 400 mm Total		

	2,500		3,000		4,500	
	Local Residential (3% Commercial Vehicles)		Local Industrial (10% Commercial Vehicles)		Local Throughway (3% Commercial Vehicles)	
	30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa
Local	40 mm SP12.5 B 60 mm SP19.0 B 150 mm Granular A 150 mm Granular B* 400 mm Total		40 mm SP12.5 B 80 mm SP19.0 B 150 mm Granular A 150 mm Granular B* 420 mm Total	40 mm SP12.5 B 60 mm SP19.0 B 150 mm Granular A 150 mm Granular B* 400 mm Total	40 mm SP 12.5 B 60 mm SP 19.0 B 150 mm Granular A 150 mm Granular B* 400 mm Total	

		All Traffic & Subgrade
Composite Pavements	Major Arterial	40 mm Surface layer** 50 mm Base layer** 250 mm PCC Concrete 150 mm Granular A 490 mm Total
	Minor Arterial - Bus/Truck Route	40 mm SP 12.5 FC1 C 50 mm SP 19.0 D 250 mm PCC Concrete 150 mm Granular A 490 mm Total
	Local Collector - Bus/Truck Route	50 mm SP 12.5 B 200 mm PCC Concrete 150 mm Granular A 400 mm Total
	Local Collector - Non Bus/Truck Route	50 mm SP 12.5 B 150 mm PCC Concrete 150 mm Granular A 350 mm Total

Notes:

AADT
Subgrade

* Subbase is Granular B - Type II as specified in TS 1010

** Surface and base layer asphalt mixe types for Major Arterial composite pavements should be selected based on the AADT as prescribed for flexible pavements

Appendix B - Pavement Critical Interim Repair Form

Pavement Critical Interim Repair (PCIR) Request Form

TORONTO Transportation Services

Requestor Contact Information:

Contact Name: | Phone Number: | Email:

Project Information: *(if multiple project locations, please provide all locations on a separate sheet with this form)*

Street Name

From Street

To Street

Year

Project Length (m)

Capital Project planned on the same location?

☐ Yes ☑ No

(If Yes, please provide the following information)

Capital Project Year

Capital Project Work Type

Type of PCIR:

☐ Bus Bay (1)

☐ Construction Joint (2)

☐ Maintenance Chamber / Catchbasin (3)

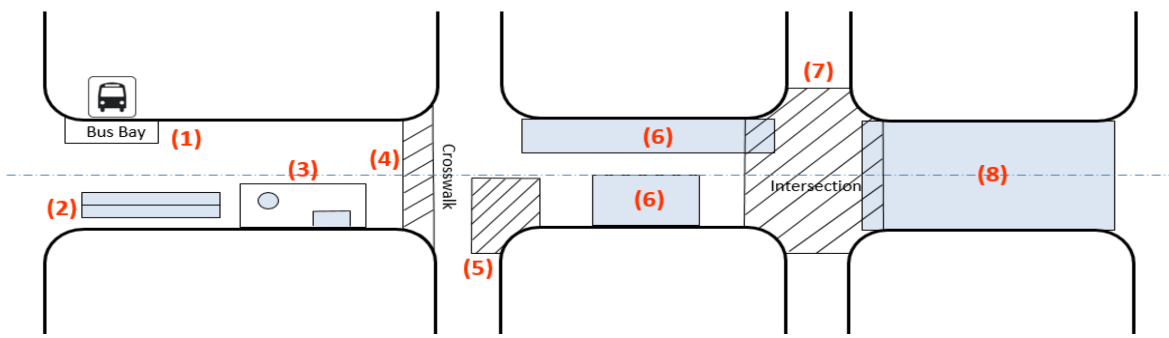
☐ Crosswalk (4)

☐ Partial Intersections (5)

☐ Partial Pavements (6)

☐ Full Intersections (7)

☐ Full Width (8)



Reason for the PCIR:

** Director's approval is required only for interim repair treatment # **7 & 8**.

Director, Transportation Infrastructure Management

Name (Please Print) | Signature | Date

Director, Road Operations

Name (Please Print) | Signature | Date