EXPANDING THE REALM OF POSSIBILITY

Structural Pavement Design Guidelines

City of Toronto
December 14, 2006

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S1SP ARA0127-1

Project Scope

- To review existing City of Toronto pavement design procedures
- Evaluate the existing standards using mechanistic – empirical methodologies
- Consolidate the design standards and procedures of the former municipalities
- Develop new pavement structural design guidelines

Seminar Goals

- Why is this study important?
- How was the study completed?
- What is the outcome of the study?
- How will this study affect you?

Agenda

- Study background
- Brief introduction to pavement design
- Introduction to the M-E PDG
- Use of the new pavement design guidelines

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Background

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Background

- 5,200 centreline kilometres of roadways
- 250 centreline kilometres of laneways
- Network is over 100 years old

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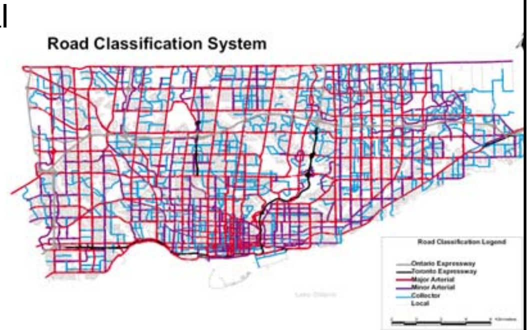
Functional Classification

- Arterial Roads
  - Primary, Secondary, Local, Major, Minor, etc
- Collector Roads
  - Industrial, Residential
- Local
  - Industrial, Residential
- Lanes

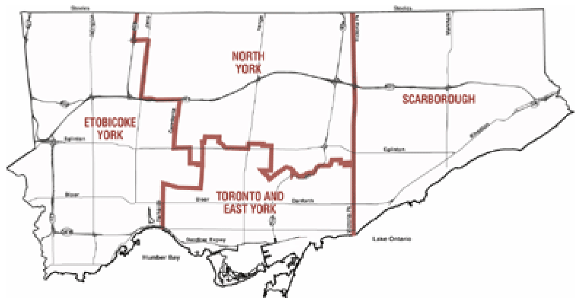


Existing Pavement Types

- Two primary pavement types throughout the City:
  - Asphalt Concrete over Aggregate Base
  - Asphalt Concrete over Concrete Base

Existing Pavement Standards

- The City of Toronto comprises 7 former cities and municipalities
  - East York
  - Etobicoke
  - Metro
  - North York
  - Scarborough
  - Toronto
  - York



Existing Pavement Designs

RIMS Road Classification	Former Cities & Municipality										
	Etobicoke		East York		Metro		North York		Scarborough	Toronto	York
	Flexible	Rigid	Flexible	Rigid	Flexible	Rigid	Flexible - Asphalt	Flexible - Granular	Flexible	Rigid	Flexible
Arterial Roads	Primary 40 mm HL1 225 mm HL8(HS) 40 mm Granular A* 260 mm Granular B T = 565 mm EGT = 830 mm Secondary 40 mm HL1 200 mm HL8(HS) 40 mm Granular A* 260 mm Granular B T = 540 mm EGT = 780 mm	Primary 40 mm HL1 40 mm HL8(HS) 225 mm 25 MPa PCC 150 mm Granular A T = 455 mm EGT = 985 mm Secondary 40 mm HL1 40 mm HL8(HS) 200 mm 25 MPa PCC 150 mm Granular A T = 430 mm EGT = 910 mm	Local Arterial 50 mm HL3 100 mm HL8 150 mm Granular A 300 mm Granular B T = 600 mm EGT = 750 mm	Local Arterial 50 mm HL3 100 mm HL8 200 mm Concrete T = 350 mm EGT = 900 mm	Deep Strength (Flex.) 35 mm HL1 240 mm HL8(HS) 150 mm Granular A T = 425 mm EGT = 700 mm Selection of hot-mix asphalt type is dependent on each project. Others: SMA, DFC, LSBC	Composite* 30 mm HL1 40 mm HL6 200 mm 25 MPa PCC 150 mm Granular A T = 420 mm EGT = 890 mm Concrete base thickness to taper from 200 at CL to 250 mm at EP by adjusting grade from 3% on subbase to 2% on base.	Heavy-Duty 35 mm HL1 250 mm HL8 50 mm Granular A* 100 mm Granular B* T = 435 mm EGT = 720 mm	Heavy-Duty 25 mm HL2 100 mm HL8 50 mm Granular A* 250 mm Granular B* 150 mm Granular A T = 575 mm EGT = 650 mm	Major Arterial & Minor Arterial 40 mm HL1 125 mm HL8 50 mm Granular A 400 mm Granular B T = 615 mm EGT = 780 mm	Composite (Heavy)* 50 mm HL1 200 mm 25 MPa PCC 150 mm Granular A T = 400 mm EGT = 850 mm Or Other** 40 mm HL1 40 mm HL6 200 mm 25 MPa PCC 150 mm Granular A T = 430 mm EGT = 910 mm	Standard "C" 40 mm HL1 85 mm HL6 200 mm Concrete 150 mm Granular A T = 475 mm EGT = 1000 mm
Collector Roads	Industrial 40 mm HL3 175 mm HL8 40 mm Granular A* 260 mm Granular B T = 515 mm EGT = 730 mm Residential 40 mm HL3 150 mm HL8 40 mm Granular A* 260 mm Granular B T = 490 mm EGT = 680 mm	Industrial 40 mm HL3 40 mm HL8 200 mm 25 MPa PCC 150 mm Granular A T = 430 mm EGT = 910 mm Residential 40 mm HL3 40 mm HL8 200 mm 25 MPa PCC 150 mm Granular A T = 430 mm EGT = 910 mm	Collector 50 mm HL3 50 mm HL8 150 mm Granular A 225 mm Granular B T = 475 mm EGT = 575 mm	Collector 50 mm HL3 50 mm HL8 200 mm Concrete T = 300 mm EGT = 800 mm	NA	NA	Medium-Duty 35 mm HL1 175 mm HL8 50 mm Granular A* 100 mm Granular B* T = 360 mm EGT = 570 mm	Medium-Duty 25 mm HL2 75 mm HL8 50 mm Granular A* 175 mm Granular B* 150 mm Granular A T = 475 mm EGT = 525 mm	Collector 40 mm HL3 (mod) 125 mm HL8 50 mm Granular A 250 mm Granular B T = 515 mm EGT = 630 mm	Composite (Heavy)* 50 mm HL1 200 mm Concrete 150 mm Granular A T = 400 mm EGT = 850 mm	Standard 'A' 40 mm HL3 85 mm HL8 200 mm Granular A 300 mm Granular B T = 625 mm EGT = 750 mm
Local Roads	Industrial 40 mm HL3 150 mm HL8 40 mm Granular A* 260 mm Granular B T = 490 mm EGT = 680 mm Residential 40 mm HL3 100 mm HL8 40 mm Granular A* 260 mm Granular B T = 440 mm EGT = 580 mm	Industrial 40 mm HL3 40 mm HL8 200 mm 25 MPa PCC 150 mm Granular A T = 430 mm EGT = 910 mm Residential 40 mm HL3 40 mm HL8 150 mm 25 MPa PCC 150 mm Granular A T = 380 mm EGT = 760 mm	Local 50 mm HL3 50 mm HL8 150 mm Granular A 225 mm Granular B* T = 475 mm EGT = 575 mm	Local 50 mm HL3 50 mm HL8 150 mm Concrete T = 250 mm EGT = 650 mm	NA	NA	Light Duty 25 mm HL2 125 mm HL8 50 mm Granular A* 100 mm Granular B* T = 300 mm EGT = 450 mm	Light Duty 25 mm HL2 50 mm HL8 50 mm Granular A* 100 mm Granular B* 150 mm Granular A T = 375 mm EGT = 400 mm	Local Comm/Ind Same as Collector Local Residential 25 mm HL3 (mod) 75 mm HL8 50 mm Granular A 250 mm Granular B T = 400 mm EGT = 500 mm	Composite (Light)* 50 mm HL1 150 mm Concrete 150 mm Granular A T = 350 mm EGT = 700 mm	Standard 'B' 40 mm HL3 50 mm HL8 200 mm Granular A 250 mm Granular B T = 540 mm EGT = 630 mm
Comments	All granulars are crushed. * This layer placed for constructability Structures also specified for bus bays.		All granulars are crushed. * This layer only required if subgrade is in poor condition. Concrete strength not specified.		All hot-mix asphalt is high stability. Thickness of surface course asphalt should be 35 mm.		* Crushed granular.		All granulars are crushed	** As shown in plans.	All granulars are crushed
Specification Information	City of Etobicoke table for "Pavement Thickness for Different Road Types"		Borough of East York Engineering Department Drawings		Recent Practices	* MT Dwg 288 Jan. 14, 1983	STD. – 605 94/01/06	STD. – 606 94/01/07	Dwg S-250, S-252, S-253, S-254, S-259, dated June 1981	* Dwg. RE-1567M Nov. 1, 1991	Pavement Rehab Contract 00D1-16RD May 2000

Lack of Commonality

- Etobicoke Arterial
  - 40 mm HL1
  - 225 mm HL8(HS)
  - 40 mm Granular A
  - 260 mm Granular B
- Scarborough Arterial
  - 40 mm HL1
  - 125 mm HL8
  - 50 mm Granular A
  - 400 mm Granular B

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Pavement Design Methodologies

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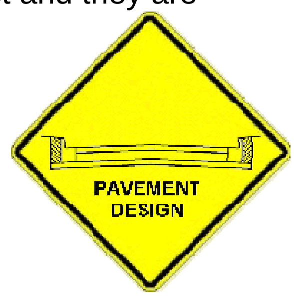
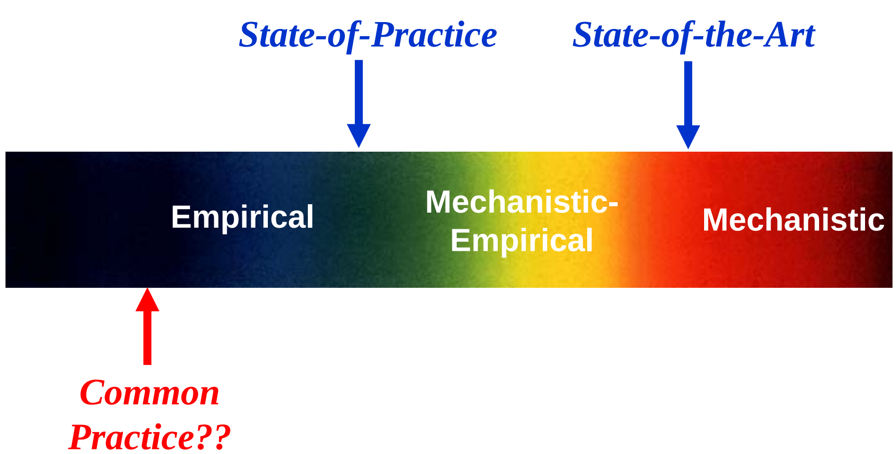
Pavement Design Methods

- There are many different design procedures in use around the world
- The theory behind the design procedures varies immensely between agencies
- A variety of different techniques exist and they are generally categorized as:
  - Empirical
  - Mechanistic
  - Mechanistic-Empirical

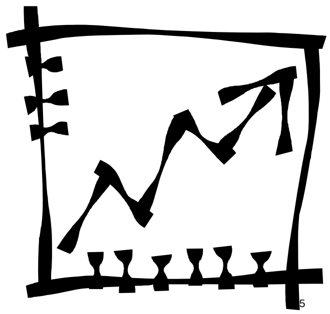


State of Practice/Art



Empirical Design

- Empirical design is based on correlations with existing experience
- Most widely used design method because people have developed confidence in the existing methods
- You need a lot of existing data to have confidence in the results
- Results are limited to the scope of the testing



Empirical – Basic Methods

- Early trial and error methods
- Successful designs are copied and repeated
- Designs often related to pavement thickness and compared using equivalent granular thickness (EGT) or granular base equivalency (GBE)
- Typical GBE or EGT factors
  - 1 mm HMA ~ 2 mm base ~ 3 mm subbase

Empirical – More Advanced

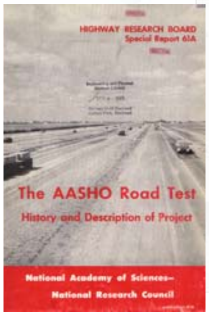
- Most common empirical design procedure in North America is the 1993 AASHTO Guide for Design of Pavement Structures
- Been validated for Ontario and widely used across Canada
- Based on in-service pavements therefore empirically based
- No procedure for innovative/improved technologies

Brief History of the AASHTO Design Guide

- AASHO Road Test (1958-60)
- 1961 – AASHO Interim Guide for the Design of Rigid and Flexible Pavements
- 1972 – Revised Interim Guide
- 1981 - Revised Interim Guide for PCC
- 1986 AASHTO Guide for the Design of Pavement Structures
- 1993 AASHTO Guide for the Design of Pavement Structures
- 1998 Supplement to the AASHTO Guide (PCC)
- 2002 Guide to utilize mechanistic **principles**

Experience

AASHO Road Test (late 1950's)



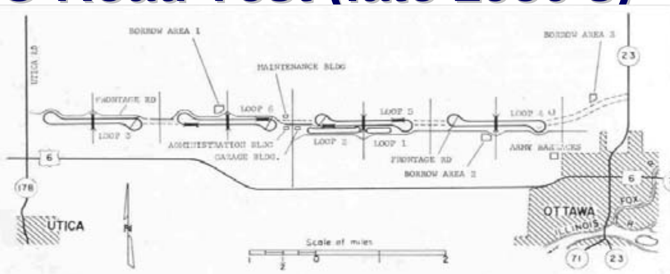
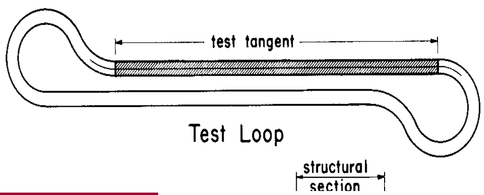


Figure 11. Map of AASHO Road Test.



(AASHO, 1961)

Loading of the AASHO Road Test

- A fleet of 70 to 126 vehicles
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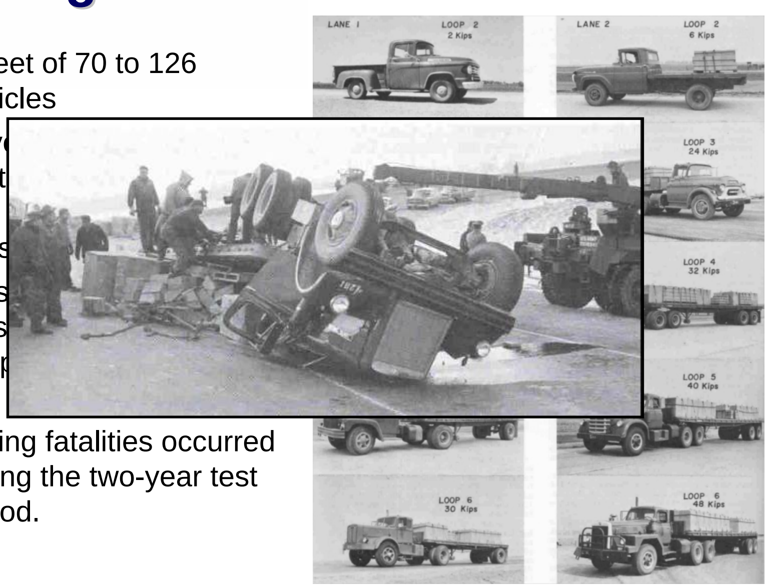
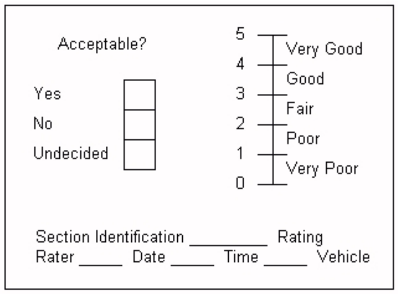
  driving fatalities occurred during the two-year test period.



Evaluation of Road Condition

- Road was evaluated in terms of the **Pavement Serviceability Rating** (PSR)
  - "The judgment of an observer as to the current ability of a pavement to serve the traffic it is meant to serve"



Results of the AASHO Road Test

- A better understanding of the difference in damage caused by different types and weights of trucks (ESALs)
- A better understanding of what users consider to be a good performing roadway (PSI)
- Design equations to relate the traffic with the damage seen on the roads

$$\log_{10}(W_{18}) = Z_R * S_0 + 7.35 * \log_{10}(D+1) - 0.06 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.511.5}\right]}{1.0 + \frac{1.624*10^7}{(D+1)^{8.46}}} + (4.22 - 0.32p_t) * \log_{10}\left[\frac{S'_c * C_d\left[D^{0.75} - 1.132\right]}{215.63 * J\left[D^{0.75} - \frac{18.42}{(E_c / k)^{0.25}}\right]}\right]$$

Using the AASHTO Data Today

- What has changed since the AASHO Road Test?
  - Significant changes to the types of materials used in pavement construction
  - Increase in traffic volume and vehicle weight
  - Large advancements in the construction practices
  - Other design factors (ie. drainage, friction, etc…)
- Our understanding of the materials and the mechanisms of the deterioration is greatly advanced

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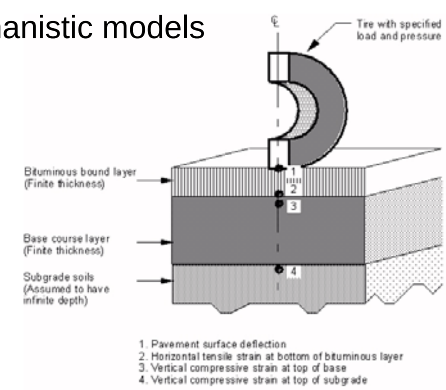
Mechanistic Design

- Relates stress/strain states to failures
- If modeled correctly can be very accurate
- Long history of existing mechanistic models
  - Boussinesq
  - Burmister
  - Linear Elastic Analysis
  - Finite Element Analysis



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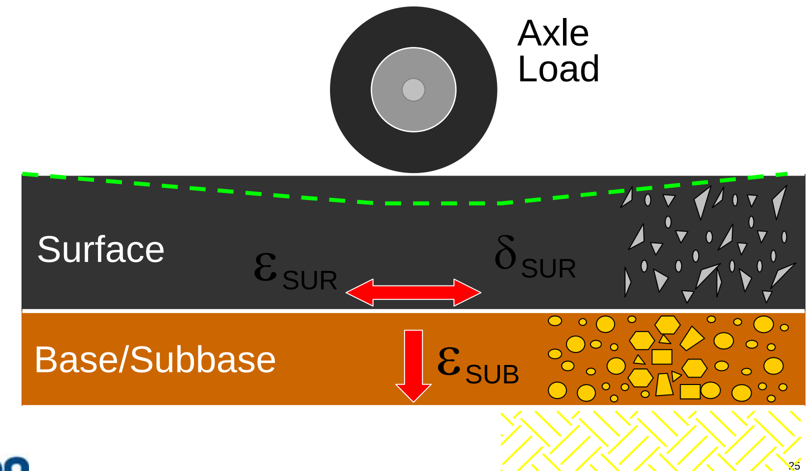
Pavement Response Under Load



Why Not Use Mechanistic Design?

- Pavement systems are VERY complicated to try and model
  - Asphalt concrete is a **non-homogenous thermal-viscoelastic** material and has properties that change with age
  - Variability in materials along a project
  - A pavement is only as good as it is constructed
  - A pavement is designed for predicted traffic
- Early attempts to predict service life were very poor
- Relationships between stress/strain and failure modes are still being developed (ride quality, structural failure, rutting, etc…)

Mechanistic-Empirical Design

- Mechanistic Design uses models to predict the effect of materials, traffic, and environment on the expected performance
- Empirical calibration ensures that it matches what is seen in the field
- A large data set is used to calibrate pavement models used to predict various methods of pavement deterioration
- The larger amount of data and mechanistic component allows for a more accurate reliability component

Mechanistic-Empirical Pavement Design Guide

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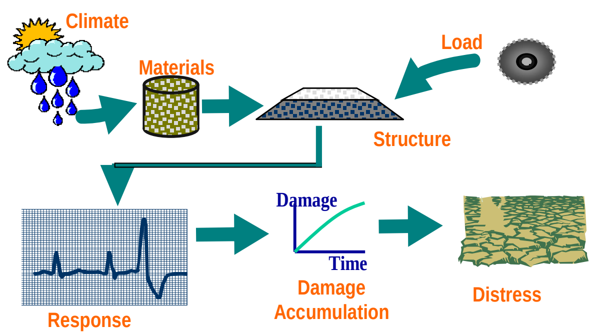
Mechanistic-Empirical Pavement Design Guide (M-E PDG)

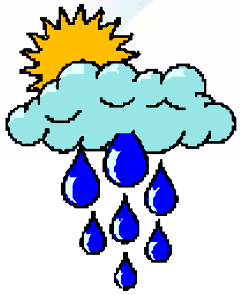
- Uses advanced inputs to predict the mechanisms of failure (structural and functional).
- Correlated with field results to ensure the models are accurate.

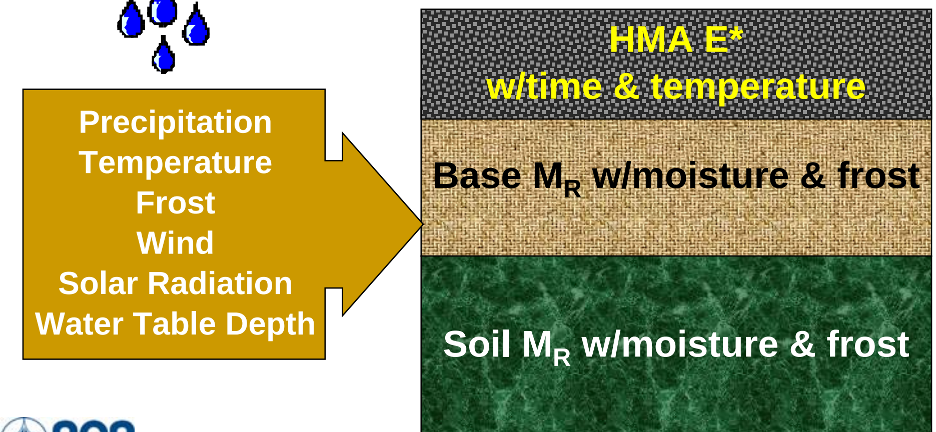
M-E PDG Design Inputs

- Climate Conditions
- Traffic Conditions
- Layer Materials and Thickness



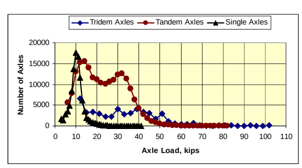
Integrated Climatic Model





Truck Traffic Inputs

- Moving away from Equivalent Single Axle Loads (ESALs)
- M-E PDG models the damage caused be individual axle loads for each pavement section
- Traffic is also distributed by time of the year and by time of the day to better account for the relationship between climate and load.



M-E PDG Material Inputs

- No longer based on standard co-efficients for each material class (SN coefficients, GBE coefficients)
- Detailed material properties and performance characteristics are needed
  - Layer moduli
  - Gradation
  - Mix Volumetrics
  - Drainage

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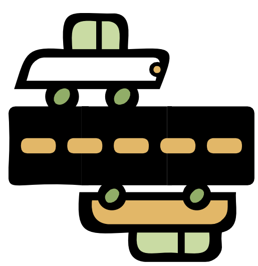
Mechanistic Models

- All inputs are combined to predict stress-strain relationships for all load combinations at different times of the day and year
- Models used for predicting distresses include:
  - Finite element analysis for flexible pavements
  - Neural network for rigid pavements
- Results in a prediction of performance for a potential cross-section



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National Calibration of Models

- The models were calculated based on research sites all over the U.S.A. and Canada.
- Advanced testing and routine monitoring was completed as a part of the Long Term Pavement Performance (LTPP) project.
- Test sites were located on states built and monitored by State and Provincial Agencies
- It was recommended that local calibration be considered to ensure that models matched local conditions, materials, loads, and construction practices.

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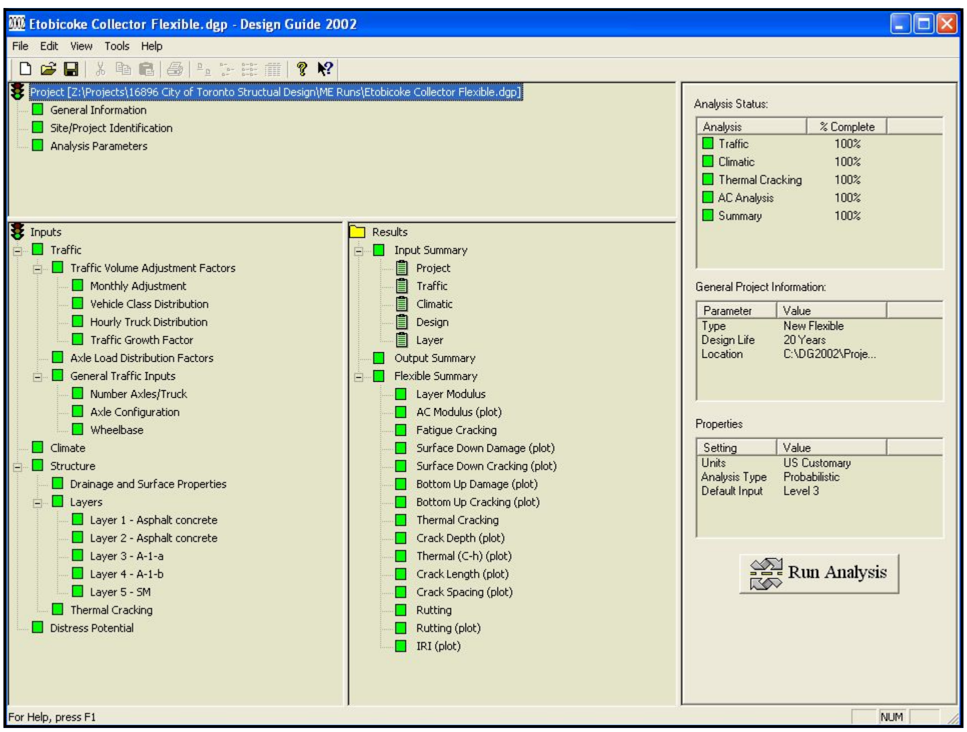
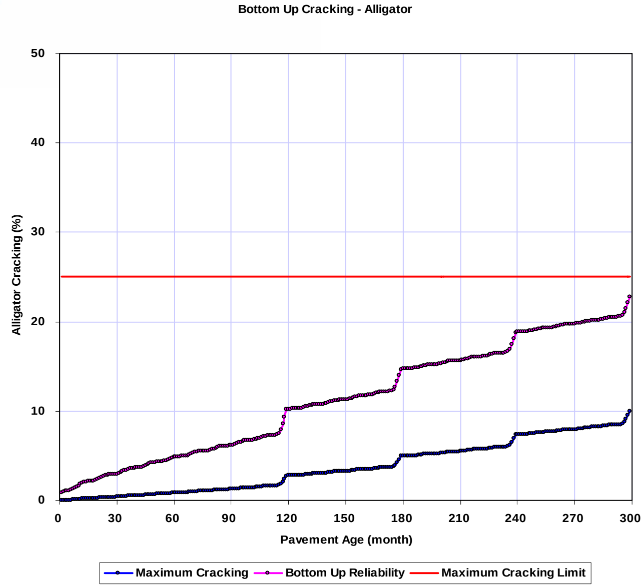


Flexible Distress Prediction

- The following distresses are predicted for flexible pavements:
  - Thermal (transverse) cracking
  - Bottom-Up fatigue (alligator) cracking
  - Top-Down fatigue (longitudinal) cracking
  - Rutting
  - IRI

Typical Prediction Outcome



Rigid Distress Prediction

- The following distresses are predicted for rigid pavements:
  - Faulting
  - Slab cracking
  - Joint load transfer
  - IRI

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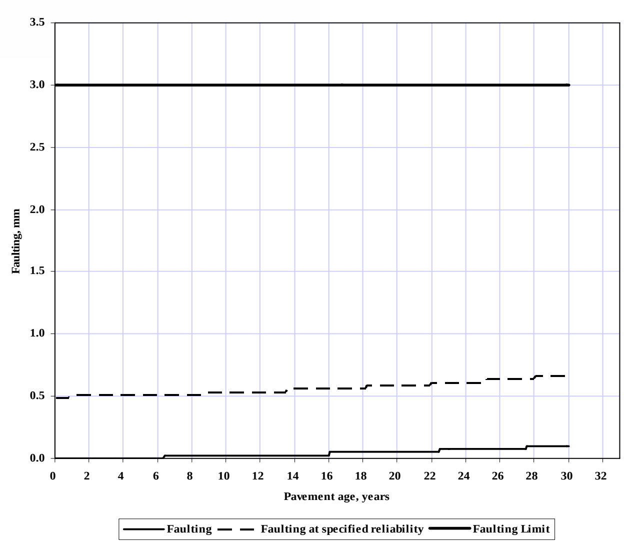
Typical Prediction Outcome

Figure 3. Predicted Faulting



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M-E PDG Calibration for The City of Toronto

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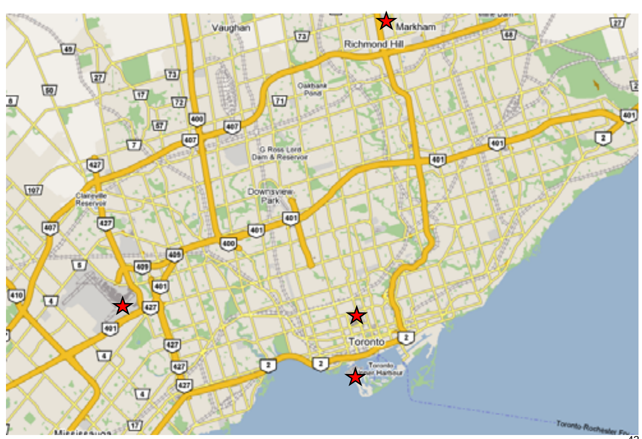
Climate Inputs

- A composite station was necessary to combine information from the 4 available weather stations
- Depth of water table was assumed to be constant for all locations



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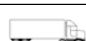
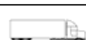
Traffic Inputs

FHWA Class	Truck Type	Local (Residential)	Local (Commercial / Industrial.)	Local (Residential Throughway)	Collector (Residential)	Collector (Commercial / Industrial.)
4		15 %	25 %	20 %	20 %	25 %
5		30 %	25 %	30 %	30 %	25 %
6		45 %	40 %	40 %	40 %	40 %
7		5 %	5 %	5 %	5 %	5 %
8		5 %	5 %	5 %	5 %	5 %
Total		100 %	100 %	100 %	100 %	100 %

Traffic Inputs

FHWA Class	Configuration	Minor Arterial (Non-Truck Route)	Minor Arterial (Truck Route)	Major Arterial (Non-Truck Route)	Major Arterial (Truck Route)
4		20 %	25 %	35 %	35%
5		30 %	25 %	30 %	15%
6		40 %	40 %	30 %	14%
7		5 %	5 %	0 %	2%
8		5 %	5 %	5 %	14%
9		0 %	0 %	0 %	20%
Total		100 %	100 %	100 %	100 %

Construction Material Inputs

- Standard pavement mixtures are used through out the city
- Typical mix design reports were available for volumetric and mix properties

JOB MIX FORMULA — GRADATION PERCENT PASSING*													
% A.C / Sieve Sizes (mm)	% A.C	26.5	19.0	16.0	13.2	9.5	4.75	2.36	1.18	0.600	0.300	0.150	0.075
JMF	4.9	100	97.8	91.2	82.5	66.2	50.0	46.6	28.3	16.5	9.4	5.6	4.1

MARSHALL		REQUIREMENTS	SELECTED
% VOIDS	(min.)	3.5	4.2
	(max.)	4.5	
FLOW (min) [0.25 mm]@ 3.5 A.V:		8	10.5
STABILITY (min) (N)		14,000	14717
% V.M.A (min)		13.5	14.5

% CA #1	26.5	% RAP	–
% CA #2	26.0	%A.C RAP	–
% FA #1	47.5	RAP PEN	
% FA #2	–	BRIQ. BRD	2.423
% FA #3	–	MRD	2.529
Gb	2.696	MRD (SD)	2.529

ASPHALT CEMENT	
SUPPLIER	PENETRATION
Bitumar	PG 58-28

ADDITIVE		
SUPPLIER	TYPE	AS % OF A.C
-	–	–

AGGREGATE TYPE	AGGREGATE SOURCE / INVENTORY NO.		AGGREGATE TYPE	AGGREGATE SOURCE / INVENTORY NO.	
COARSE	19 mm Stone		FINE	–	
AGG. # 1	Lafarge/Brechin	0	AGG. # 2	–	–
COARSE	Hi-3 Stone		FINE	–	
AGG. # 2	Lafarge/Brechin	0	AGG. # 3	–	–
FINE	Manufactured Sand		RAP	–	
AGG. # 1	Lafarge/Dundas	0		–	–

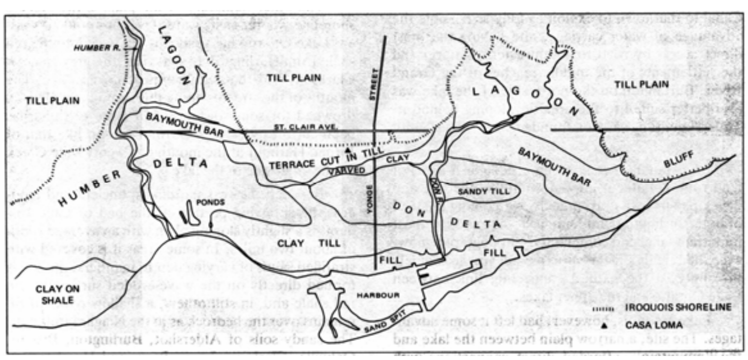
AGG. TYPE	BULK REL. DENSITY	ABSORPTION %	AGGREGATE GRADATION — PERCENT PASSING											
			26.5	19.0	16.0	13.2	9.5	4.75	2.36	1.18	0.600	0.300	0.150	0.075
CA #1	2.682	0.57	100.0	91.7	66.7	36.3	10.1	3.8	3.2	3.0	2.9	2.8	2.7	2.4
CA #2	2.678	0.68	100.0	100.0	100.0	97.7	61.8	3.0	2.1	1.9	1.8	1.6	1.3	1.1
FA #1	2.713	1.32	100.0	100.0	100.0	100.0	100.0	99.9	93.5	54.5	29.4	14.4	6.6	3.5
FA #2														
FA #3														
RAP CA														
RAP FA														

* FINES RETURNED TO MIX (1.5%)

REMARKS:
1 The pass 4.75mm portion of the blend gradation has been adjusted for fines returned to mix.
2 The briquettes were compacted with a manual hammer (75 BPS) @ 135° C
3 No SSD air void correction is required. The original mix design (mix # 600) was completed in August, 2004
4 Recompaction temperature is 135° C, Briquette weight is 1250 g

Subgrade Material Inputs

- The subsoils within the City limits comprise predominately till and delta sands



Empirical Model Calibration

- A calibration of the M-E PDG was performed as a part of this project.
- Testing was completed on 117 sections composed of:
  - 67 Flexible
  - 41 Composite
  - 6 JPCP
- Visual surveys and laser profiler testing were completed on all sections

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Calibration Results

- The distresses were predicted and then compared to the measured distresses
- Not all of the performance models were designed for municipal pavements.
- The traditional distresses used for a structural analysis (ie. alligator cracking) were centered around the national calibration models.

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Calibration Highlights

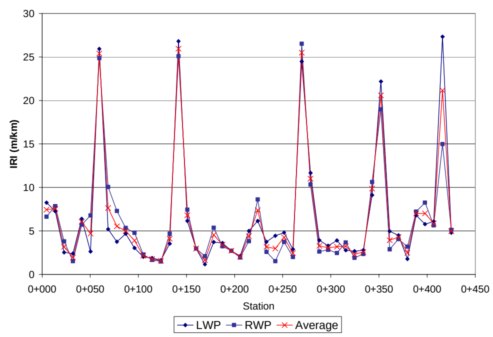
- Thermal (transverse) cracking
  - Dependent on binder type
  - PGAC has helped mitigate
  - Reflection cracking is not easily modeled
- Bottom-Up fatigue (alligator) cracking
  - Most reliable model
  - Basis of previous design methodologies
- Top-Down fatigue (longitudinal) cracking
  - Difficult distress mechanism to accurately predict

Calibration Highlights

- Rutting
  - The rutting predicted was significantly worse than that measured in the City of Toronto
  - Rutting issues encountered are related to the asphalt mix volumetrics
- Roughness (IRI)
  - Roughness measured tended to be significantly higher than predicted
  - IRI models were calibrated based on highway conditions and do not include municipal road hardware effects

Roughness Calibration…

- Pavement roughness is used to ensure that the road is safe to drive at reasonable speeds.
- IRI model didn't predict street hardware and traffic calming devices.



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EXPANDING THE REALM OF POSSIBILITY

M-E PDG and Existing Toronto Pavement Sections

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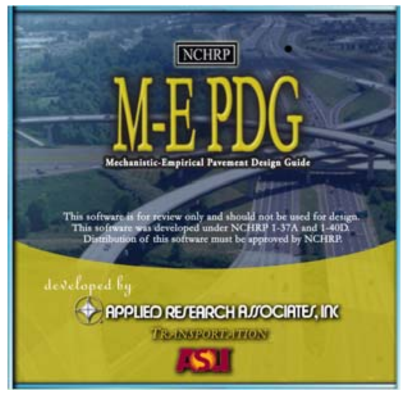
S1SP ARA0127-52

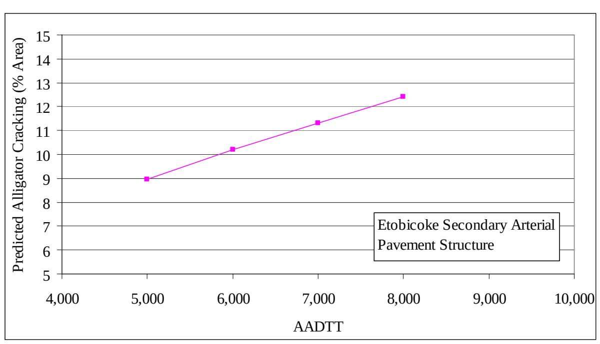
Pavement Design with the M-E PDG

- The designs were based on:
  - Common City of Toronto materials
  - Experience of design and construction staff
  - Functional classifications
  - Limiting fatigue cracking

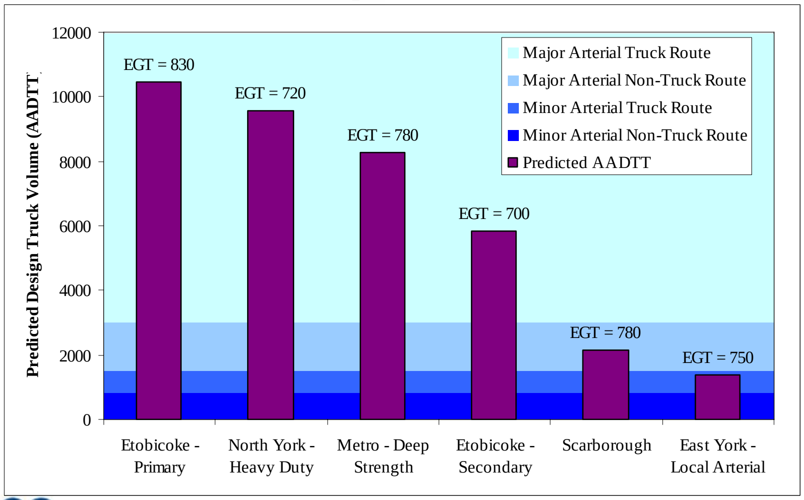


Evaluation of Existing Sections

- The M-E PDG was used to evaluate the existing cross-sections used by the former municipalities
- The Toronto specific design inputs were used
- The results of the analysis were the expected truck traffic

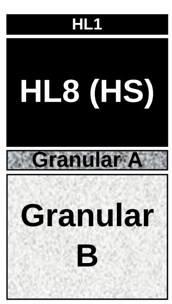


Evaluation of Existing Sections (Arterial Roads)

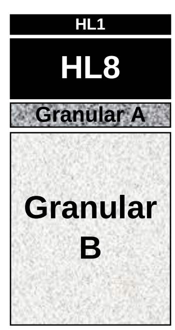


Two Arterial Sections

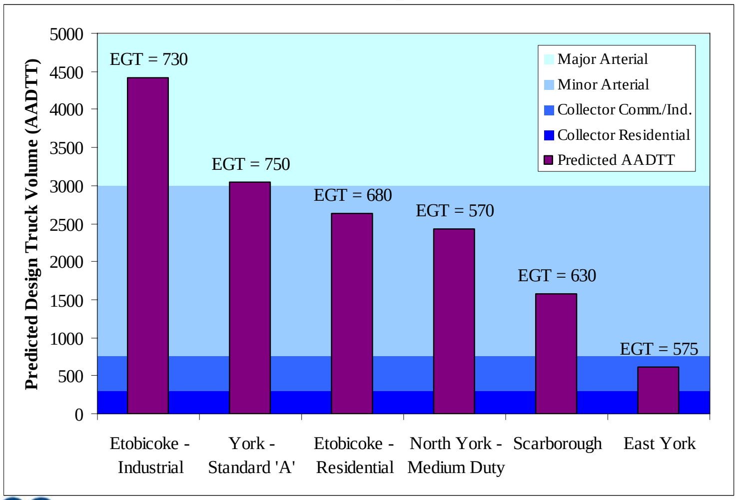
- Etobicoke Arterial
  - 40 mm HL1
  - 225 mm HL8(HS)
  - 40 mm Granular A
  - 260 mm Granular B



- Scarborough Arterial
  - 40 mm HL1
  - 125 mm HL8
  - 50 mm Granular A
  - 400 mm Granular B

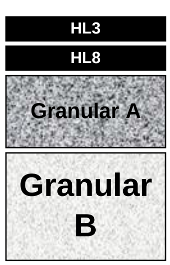


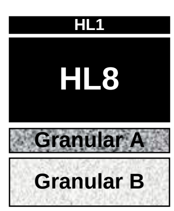
Evaluation of Existing Sections (Collector Roads)



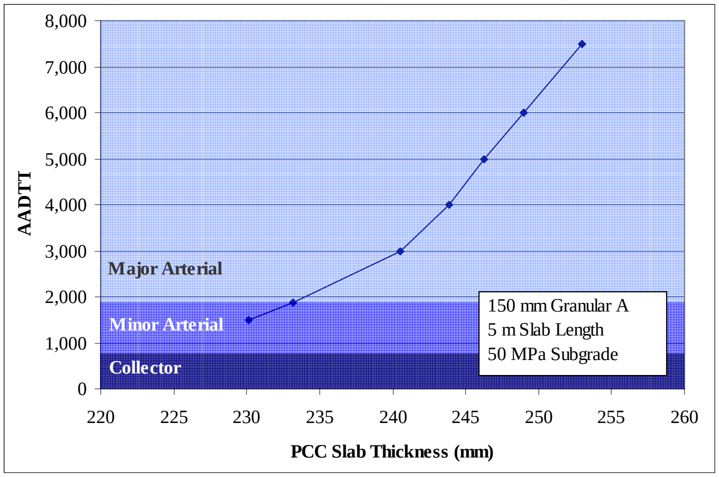
Issues with Existing Designs

- East York Collector
  - 50 mm HL3
  - 50 mm HL8
  - 150 mm Granular A
  - 225 mm Granular B
- North York Collector
  - 35 mm HL1
  - 175 mm HL8
  - 50 mm Granular A
  - 100 mm Granular B





Evaluation of Existing Sections (Composite Pavements)



Development of New Guidelines

- New designs were based on the existing designs and experience with them
- Some things were reduced:
  - Fewer materials
  - Less variability in material thickness
- Some things added:
  - More flexibility in traffic levels
  - Some consideration of subgrade type

Granular Material

- Existing guidelines use:
  - Granular A – 40-150 mm
  - Granular B – 100-400 mm
- The granular material is used to:
  - Provide frost protection
  - Allow adequate drainage
  - Provide suitable construction platform

Recommended Granular Material

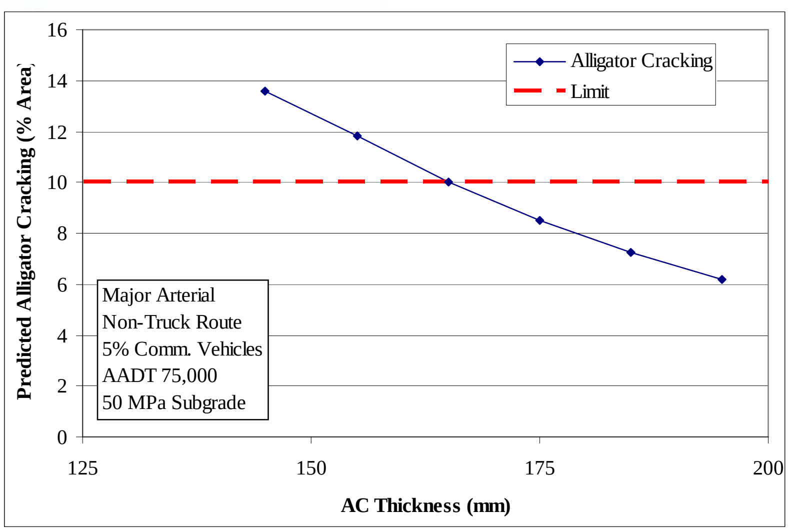
- Granular A is recommended at 50 mm
- Granular B Type II is recommended to provide adequate angularity and support

Functional Class	**Granular A**	**Granular B Type II**
Major Arterial (Truck Route)	50 mm	350 mm
Major Arterial (Non-Truck Route)	50 mm	300 mm
Minor Arterial	50 mm	250 mm
Collector	50 mm	250 mm
Local	50 mm	250 mm

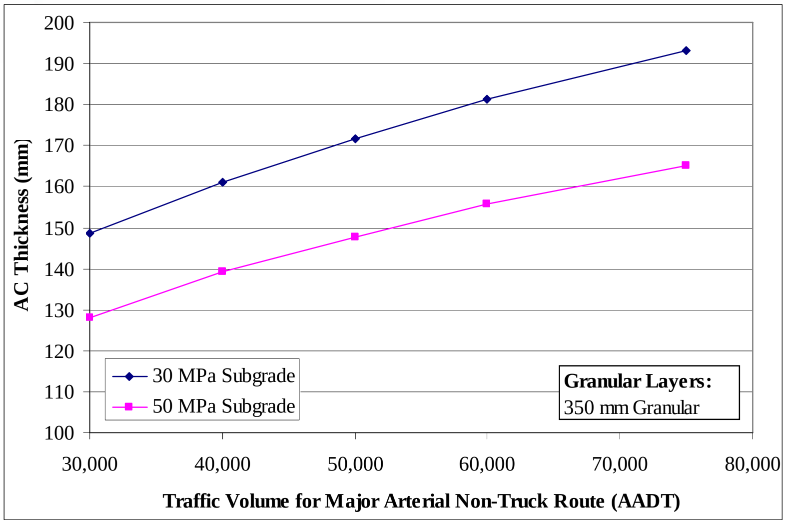
Asphalt Material

- The designs focus on four common mixes:
  - HL-1
  - HL-3
  - HL-8
  - HL-8 (HS)
- Thickness was provided for different traffic levels within functional classifications

Optimum AC Thickness (fatigue)



Asphalt Thickness (traffic)



Updated Pavement Designs

Major Arterial

	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
Non-Truck Routes (5% Commercial Vehicles)	40 mm HL-1 110 mm HL8 (HS) 50 mm Granular A 300 mm Granular B * 500 mm Total	40 mm HL-1 90 mm HL-8 (HS) 50 mm Granular A 300 mm Granular B * 480 mm Total	40 mm HL-1 125 mm HL8 (HS) 50 mm Granular A 300 mm Granular B * 515 mm Total	40 mm HL-1 100 mm HL-8 (HS) 50 mm Granular A 300 mm Granular B * 490 mm Total	40 mm HL-1 135 mm HL8 (HS) 50 mm Granular A 300 mm Granular B * 525 mm Total	40 mm HL-1 110 mm HL-8 (HS) 50 mm Granular A 300 mm Granular B * 500 mm Total	40 mm HL-1 145 mm HL8 (HS) 50 mm Granular A 300 mm Granular B * 535 mm Total	40 mm HL-1 120 mm HL-8 (HS) 50 mm Granular A 300 mm Granular B * 510 mm Total	40 mm HL-1 155 mm HL8 (HS) 50 mm Granular A 300 mm Granular B * 545 mm Total	40 mm HL-1 125 mm HL-8 (HS) 50 mm Granular A 300 mm Granular B * 515 mm Total
Truck Routes (7.5% Commercial Vehicles)	40 mm HL1 130 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 570 mm Total	40 mm HL1 110 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 550 mm Total	40 mm HL1 150 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 590 mm Total	40 mm HL1 130 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 570 mm Total	40 mm HL1 155 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 595 mm Total	40 mm HL1 135 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 575 mm Total	40 mm HL1 160 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 600 mm Total	40 mm HL1 145 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 585 mm Total	40 mm HL1 170 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 610 mm Total	40 mm HL1 150 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 590 mm Total
Truck Routes (10% Commercial Vehicles)	40 mm HL-1 150 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 590 mm Total	40 mm HL-1 125 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 565 mm Total	40 mm HL-1 160 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 600 mm Total	40 mm HL-1 135 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 575 mm Total	40 mm HL-1 170 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 610 mm Total	40 mm HL-1 145 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 585 mm Total	40 mm HL-1 175 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 615 mm Total	40 mm HL-1 155 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 595 mm Total	40 mm HL-1 185 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 625 mm Total	40 mm HL-1 165 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 605 mm Total

Minor Arterial

	20,000		25,000	
	30 MPa	50 MPa	30 MPa	50 MPa
Non-Truck Routes (4% Commercial Vehicles)	40 mm HL-1 95 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 435 mm Total	40 mm HL-1 80 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 420 mm Total	40 mm HL-1 105 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 445 mm Total	40 mm HL-1 85 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 425 mm Total
Truck Routes (7.5% Commercial Vehicles)	40 mm HL-1 135 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 475 mm Total	40 mm HL-1 110 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 450 mm Total	40 mm HL-1 140 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 480 mm Total	40 mm HL-1 120 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 460 mm Total

Collector

	5,000		7,500		10,000		15,000	
	30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa
Comm./Ind. (5% Commercial Vehicles)			40 mm HL3 105 mm HL-8 50 mm Granular A 250 mm Granular B * 445 mm Total	40 mm HL-3 75 mm HL-8 50 mm Granular A 250 mm Granular B * 415 mm Total	40 mm HL-3 115 mm HL-8 50 mm Granular A 250 mm Granular B * 455 mm Total	40 mm HL-3 85 mm HL-8 50 mm Granular A 250 mm Granular B * 425 mm Total	40 mm HL-3 125 mm HL-8 50 mm Granular A 250 mm Granular B * 465 mm Total	40 mm HL-3 95 mm HL-8 50 mm Granular A 250 mm Granular B * 435 mm Total
Residential (3% Commercial Vehicles)	40 mm HL-3 70 mm HL-8 50 mm Granular A 250 mm Granular B * 410 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 85 mm HL-8 50 mm Granular A 250 mm Granular B * 425 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 95 mm HL-8 50 mm Granular A 250 mm Granular B * 435 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total		

Local

	2,500		3,000		4,500	
	30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa
	Local Residential (3% Commercial Vehicles)		Local Industrial (10% Commercial Vehicles)		Local Throughway (3% Commercial Vehicles)	
Local	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 60 mm HL8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 80 mm HL-8 50 mm Granular A 250 mm Granular B * 420 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total

Composite Pavements

	All Traffic & Subgrade
Major Arterial	40 mm HL-1 50 mm HL-8 (HS) 250 mm PCC Concrete 150 mm Granular 'A' 490 mm Total
Minor Arterial - Bus/Truck Route	40 mm HL-1 50 mm HL-8 (HS) 250 mm PCC Concrete 150 mm Granular 'A' 490 mm Total
Local Collector - Bus/Truck Route	50 mm HL-1 of HL-3 200 mm PCC Concrete 150 mm Granular 'A' 400 mm Total
Local Collector - Non Bus/Truck Route	50 mm HL-1 or HL-3 150 mm PCC Concrete 150 mm Granular 'A' 350 mm Total

Notes: AADT
Subgrade

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

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How to Use the New Guidelines

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S1SP ARA0127-67

Pavement Design Procedure

Determine the functional classification

Determine traffic parameters

Determine subgrade support value

Use design matrix table to select pavement sections

Life cycle cost analysis

Recommended pavement design

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Determine Functional Classification

- Refer to the City Road Classification System

http://insideto.toronto.ca/wes/transportation/rc/index.htm

- If classification is unknown or undetermined contact
  - Operational Planning and Policy Unit
    Transportation Infrastructure
    Management Transportation Services

General Functional Classifications

Characteristic	Locals	Collectors	Minor Arterials	Major Arterials	Expressways
Traffic movement versus property access	Property access primary function	Traffic movement and property access of equal importance	Traffic movement primary consideration; some property access control	Traffic movement primary consideration; subject to property access control	Traffic movement primary consideration; no property access
Typical daily motor vehicle traffic volume (both directions)	# 2,500	2,500 - 8000	8,000 - 20,000	> 20,000	> 40,000
Minimum number of peak period lanes (excluding bicycle lanes)	One (one-way streets) or two	One (one-way streets) or two	Two	Four	Four
Desirable connections	Locals, collectors	Locals, collectors, arterials	Collectors, arterials	Collectors, arterials, expressways	Major arterials, expressways
Flow characteristics	Interrupted flow	Interrupted flow	Uninterrupted except at signals and crosswalks	Uninterrupted except at signals and crosswalks	Free-flow (grade separated)
Legal speed limit, km/h	40 - 50	40 - 50	40 - 60	50 - 60[1]	80 – 100
Accommodation of pedestrians	Sidewalks on one or both sides	Sidewalks on both sides	Sidewalks on both sides	Sidewalks on both sides	Pedestrians prohibited
Accommodation of cyclists	Special facilities as required		Wide curb lane or special facilities desirable		Cyclists prohibited
Surface transit	Generally not provided	Permitted	Preferred	Preferred	Express buses only
Surface transit daily passengers	Not applicable	# 1,500	1,500 - 5,000	> 5,000	Not applicable
Heavy truck restrictions (e.g. seasonal or night time)	Restrictions preferred	Restrictions permitted	Generally no restrictions	Generally no restrictions	No restrictions
Typical spacing between traffic control devices[2], m	0 - 150	215 - 400	215 - 400	215 - 400	Not applicable
Typical right-of-way width, m	15 - 22	20 - 27	20[3] – 30[4]	20[3] – 45[4]	> 45[4]

Determine the Traffic

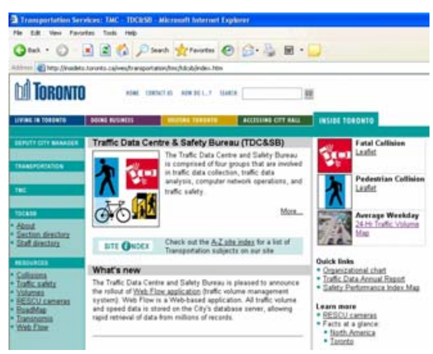
- The type of vehicles greatly affect the service life of a vehicle.
- The traffic data needed for the design guidelines includes:
  - AADT
  - Commercial Vehicles

Traffic Data

- Refer to the City's Traffic Management Centre (TMC), Volume Maps, or Turning Movement Summaries

http://insideto.toronto.ca/wes/transportation/tmc/tdcsb/volumes/index.htm

- If there is no traffic data, a traffic count request can be made through
  - Traffic Data & Safety Bureau
    Traffic Management Centre
    Transportation Services



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City of Toronto - Traffic Data Centre & Safety Bureau

TURNING MOVEMENT COUNT SUMMARY REPORT

Printed on: 09-JUN-2004 | Survey Date: 2004-JUN-02 (Wednesday)

INTERSECTION OF CARLAW AV AT LAKESHORE BV | Survey Type: Routine Hours

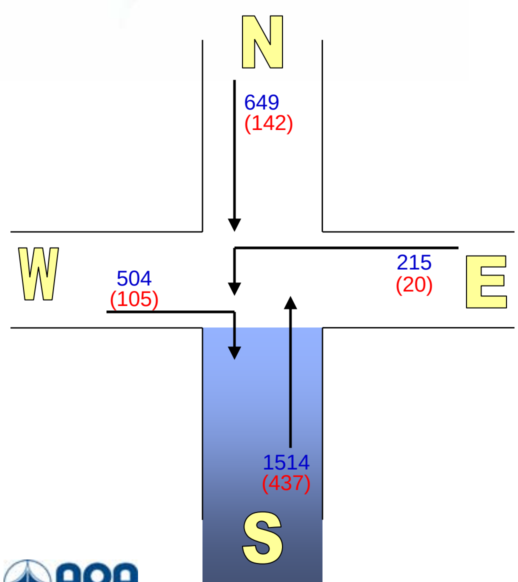
Time	Vehicle		NORTHBOUND					EASTBOUND					SOUTHBOUND					WESTBOUND						
Period	Type	Exits	Left	Thru	Right	Total	Exits	Left	Thru	Right	Total	Exits	Left	Thru	Right	Total	Exits	Left	Thru	Right	Total		Peds	Bike	Other
08:00-09:00	CAR	408	44	47	25	116	887	344	848	32	1,224	130	14	90	328	432	3,108	8	2,736	17	2,761	N	77	0
AM PEAK	TRK	42	40	17	6	63	91	21	84	9	114	19	1	9	14	24	168	1	114	4	119	S	9	0
	BUS	5	2	5	0	7	1	0	1	0	1	6	0	6	0	6	2	0	0	0	0	E	6	0
TOTAL		455	86	69	31	186	979	365	933	41	1,339	155	15	105	342	462	3,278	9	2,850	21	2,880	W	1	0
16:30-17:30	CAR	777	67	109	4	180	2,317	644	2,297	56	2,997	153	16	65	186	267	1,206	32	933	24	1,009	N	65	0
PM PEAK	TRK	23	14	5	0	19	53	15	33	6	74	16	0	10	10	20	85	0	61	3	64	S	16	0
	BUS	4	1	3	0	4	2	1	2	4	7	8	0	4	0	4	3	0	2	0	2	E	5	0
TOTAL		804	82	117	4	203	2,372	660	2,352	66	3,078	177	16	79	196	291	1,294	32	1,016	27	1,075	W	24	0
	CAR	423	56	54	10	120	1,010	346	974	41	1,361	128	26	57	209	292	1,346	30	1,081	23	1,134	N	26	0
OFF HR AVG	TRK	56	38	17	2	57	90	37	86	16	139	39	2	19	21	42	150	4	91	2	97	S	7	0
	BUS	3	1	3	0	4	2	0	2	1	3	5	0	4	0	4	3	0	2	0	2	E	5	0
TOTAL		482	95	74	12	181	1,102	383	1,062	58	1,503	172	28	80	230	338	1,499	34	1,174	25	1,233	W	3	0
07:30-09:30	CAR	772	88	92	33	213	1,664	653	1,605	106	2,364	303	26	166	676	868	5,695	31	4,931	27	4,989	N	121	0
2 HR AM	TRK	106	75	49	8	132	153	52	143	20	215	41	2	19	31	52	279	2	173	5	180	S	13	1
	BUS	13	8	13	0	21	1	0	1	1	2	11	0	10	1	11	10	0	1	0	1	E	9	0
TOTAL		891	171	154	41	366	1,818	705	1,749	127	2,581	355	28	195	708	931	5,984	33	5,105	32	5,170	W	6	0
16:00-18:00	CAR	1,540	150	232	7	389	4,585	1,267	4,543	129	5,939	288	35	113	366	514	2,411	46	1,895	41	1,982	N	118	0
2 HR PM	TRK	55	27	10	0	37	106	42	104	11	157	29	2	15	24	41	161	3	110	3	116	S	34	0
	BUS	11	1	9	0	10	3	2	3	6	11	14	0	8	1	9	7	0	5	0	5	E	13	0
TOTAL		1,606	178	251	7	436	4,694	1,311	4,650	146	6,107	331	37	136	391	564	2,579	49	2,010	44	2,103	W	36	0
07:30-18:00	CAR	4,001	461	538	78	1,077	10,287	3,302	10,045	399	13,746	1,101	164	507	1,877	2,548	13,487	195	11,149	161	11,505	N	341	0
8 HR SUMM	TRK	382	254	125	14	393	617	243	591	94	928	223	12	109	140	261	1,040	20	646	14	680	S	73	1
	BUS	35	12	32	0	44	10	3	10	11	24	44	0	33	3	36	28	0	13	0	13	E	42	1
TOTAL		4,418	727	695	92	1,514	10,914	3,548	10,646	504	14,698	1,368	176	649	2,020	2,845	14,555	215	11,808	175	12,198	W	52	1

Total 8 Hour Vehicle Volume: 31,255 | Total 8 Hour Bicycle Volume: 3 | Total 8 Hour Intersection Volume: 31,258

Comment: OTHER = E/B & W/B U TURNS

Page 1 of 1

Determine AADT from Intersection



- 8 Hour Traffic
  1514 + 649 + 215 + 504
  = 2882 Vehicles
- Commercial Vehicles
  437 + 142 + 20 + 105
  = 704 C.V.
- 24% Commercial Vehicles
- AADT
  2882 * **2.1** = 6052

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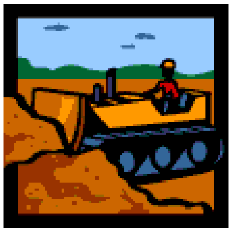
Expanding the Realm of Possibility

Subgrade Support

- The subgrade soil is the native material that the roadway is built on.
- The purpose of the pavement structure is to adequately protect the subgrade from the traffic loads
- The subgrade support is defined in terms of the Resilient Modulus (M_r)



Subgrade Support Classes

- Cohesive soils
  - Tills, clays, silts, etc
  - Low to high frost susceptibility depending on the actual soil matrix
  - Fair subgrade support with an M_r of 30 MPa
- Sandy Alluvium Soils
  - Sand bars, beaches, and boulder fields of the lower lying Iroquois Plain
  - Low frost susceptibility
  - Good subgrade support with an M_r of 50 MPa

Select Appropriate Cross Section

Major Arterial	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
Non-Truck Routes (5% Commercial Vehicles)	40 mm HL-1 110 mm HL8 (HS) 50 mm Granular A 300 mm Granular B * 500 mm Total	40 mm HL-1 90 mm HL-8 (HS) 50 mm Granular A 300 mm Granular B * 480 mm Total	40 mm HL-1 125 mm HL8 (HS) 50 mm Granular A 300 mm Granular B * 515 mm Total	40 mm HL-1 100 mm HL-8 (HS) 50 mm Granular A 300 mm Granular B * 490 mm Total	40 mm HL-1 135 mm HL8 (HS) 50 mm Granular A 300 mm Granular B * 525 mm Total	40 mm HL-1 110 mm HL-8 (HS) 50 mm Granular A 300 mm Granular B * 500 mm Total	40 mm HL-1 145 mm HL8 (HS) 50 mm Granular A 300 mm Granular B * 535 mm Total	40 mm HL-1 120 mm HL-8 (HS) 50 mm Granular A 300 mm Granular B * 510 mm Total	40 mm HL-1 155 mm HL8 (HS) 50 mm Granular A 300 mm Granular B * 545 mm Total	40 mm HL-1 125 mm HL-8 (HS) 50 mm Granular A 300 mm Granular B * 515 mm Total
Truck Routes (7.5% Commercial Vehicles)	40 mm HL1 130 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 570 mm Total	40 mm HL1 110 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 550 mm Total	40 mm HL1 150 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 590 mm Total	40 mm HL1 130 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 570 mm Total	40 mm HL1 155 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 595 mm Total	40 mm HL1 135 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 575 mm Total	40 mm HL1 160 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 600 mm Total	40 mm HL1 145 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 585 mm Total	40 mm HL1 170 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 610 mm Total	40 mm HL1 150 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 590 mm Total
Truck Routes (10% Commercial Vehicles)	40 mm HL-1 150 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 590 mm Total	40 mm HL-1 125 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 565 mm Total	40 mm HL-1 160 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 600 mm Total	40 mm HL-1 135 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 575 mm Total	40 mm HL-1 170 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 610 mm Total	40 mm HL-1 145 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 585 mm Total	40 mm HL-1 175 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 615 mm Total	40 mm HL-1 155 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 595 mm Total	40 mm HL-1 185 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 625 mm Total	40 mm HL-1 165 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 605 mm Total

Minor Arterial	20,000		25,000	
	30 MPa	50 MPa	30 MPa	50 MPa
Non-Truck Routes (4% Commercial Vehicles)	40 mm HL-1 95 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 435 mm Total	40 mm HL-1 80 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 420 mm Total	40 mm HL-1 105 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 445 mm Total	40 mm HL-1 85 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 425 mm Total
Truck Routes (7.5% Commercial Vehicles)	40 mm HL-1 135 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 475 mm Total	40 mm HL-1 110 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 450 mm Total	40 mm HL-1 140 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 480 mm Total	40 mm HL-1 120 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 460 mm Total

Composite Pavements	All Traffic & Subgrade
Major Arterial	40 mm HL-1 50 mm HL-8 (HS) 250 mm PCC Concrete 150 mm Granular 'A' 490 mm Total
Minor Arterial - Bus/Truck Route	40 mm HL-1 50 mm HL-8 (HS) 250 mm PCC Concrete 150 mm Granular 'A' 490 mm Total
Local Collector - Bus/Truck Route	50 mm HL-1 of HL-3 200 mm PCC Concrete 150 mm Granular 'A' 400 mm Total
Local Collector - Non Bus/Truck Route	50 mm HL-1 or HL-3 150 mm PCC Concrete 150 mm Granular 'A' 350 mm Total

Collector	5,000		7,500		10,000		15,000	
	30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa
Comm./Ind. (5% Commercial Vehicles)			40 mm HL3 105 mm HL-8 50 mm Granular A 250 mm Granular B * 445 mm Total	40 mm HL-3 75 mm HL-8 50 mm Granular A 250 mm Granular B * 415 mm Total	40 mm HL-3 115 mm HL-8 50 mm Granular A 250 mm Granular B * 455 mm Total	40 mm HL-3 85 mm HL-8 50 mm Granular A 250 mm Granular B * 425 mm Total	40 mm HL-3 125 mm HL-8 50 mm Granular A 250 mm Granular B * 465 mm Total	40 mm HL-3 95 mm HL-8 50 mm Granular A 250 mm Granular B * 435 mm Total
Residential (3% Commercial Vehicles)	40 mm HL-3 70 mm HL-8 50 mm Granular A 250 mm Granular B * 410 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 85 mm HL-8 50 mm Granular A 250 mm Granular B * 425 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 95 mm HL-8 50 mm Granular A 250 mm Granular B * 435 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total		

Local	2,500		3,000		4,500	
	30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa
	Local Residential (3% Commercial Vehicles)		Local Industrial (10% Commercial Vehicles)		Local Throughway (3% Commercial Vehicles)	
	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 60 mm HL8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 80 mm HL-8 50 mm Granular A 250 mm Granular B * 420 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total

Notes: AADT

Subgrade

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

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Using the Design Matrix

- The design matrix is setup in groups of functional classes
- For each functional classification, find the specific design by using the expected traffic and subgrade support value.

Minor Arterial	20,000		25,000	
	30 MPa	50 MPa	30 MPa	50 MPa
Non-Truck Routes (4% Commercial Vehicles)	40 mm HL-1 95 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 435 mm Total	40 mm HL-1 80 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 420 mm Total	40 mm HL-1 105 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 445 mm Total	40 mm HL-1 85 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 425 mm Total
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Expanding the Realm of Possibility

Composite Pavements

- Selected only by Functional Classification
- Pavement structure isn't as sensitive to traffic volume.

Composite Pavements		All Traffic & Subgrade
	Major Arterial	40 mm HL-1 50 mm HL-8 (HS) 250 mm PCC Concrete 150 mm Granular 'A' 490 mm Total
	Minor Arterial - Bus/Truck Route	40 mm HL-1 50 mm HL-8 (HS) 250 mm PCC Concrete 150 mm Granular 'A' 490 mm Total
	Local Collector - Bus/Truck Route	50 mm HL-1 of HL-3 200 mm PCC Concrete 150 mm Granular 'A' 400 mm Total
	Local Collector - Non Bus/Truck Route	50 mm HL-1 or HL-3 150 mm PCC Concrete 150 mm Granular 'A' 350 mm Total

Pavement Type Selection

- City of Toronto uses two pavement types:
  - Flexible (Asphalt) pavement
  - Composite (Asphalt and Concrete) pavement
- Many factors to consider
  - Long term performance
  - Short term performance
  - Serviceability
  - Life Cycle Cost

Life Cycle Cost

- A procedure to account for all costs over the whole life of a pavement
- Costs for both alternative pavement types are calculated and compared
- Recommended whole life
  - Arterial Roads – 100 years
  - Collector Roads – 75 years
- Recommended rehabilitation analysis period
  - 50 years (30 years minimum)

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Life Cycle Cost Considerations

- Select appropriate whole life maintenance plan
- Calculate costs of all maintenance and rehabilitation activities for each alternative
- Calculate life cycle costs for each alternative
- Summarize and compare the Net Present Value for all alternatives
- If the life cycle cost is within 10 percent, they are considered equivalent (other factors must then be considered)

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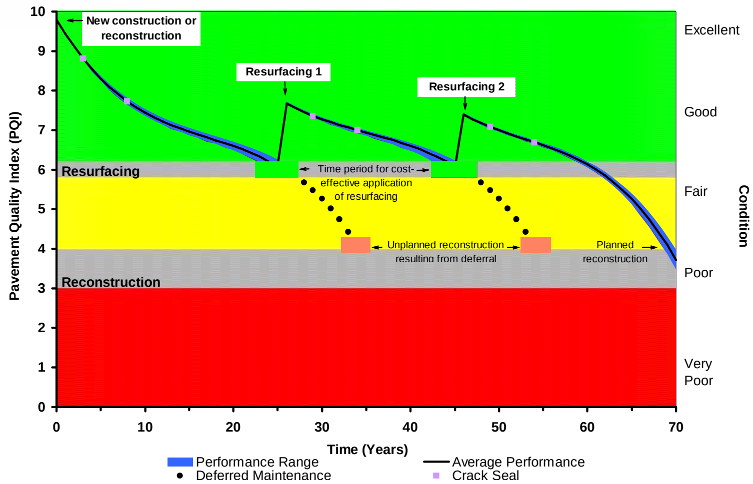
Expanding the Realm of Possibility

Whole Life Maintenance Plan

Composite Pavement Performance for Major and Minor Arterial Roads



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Pavement Unit Costs

Pavement Material Unit Prices for 2005 and 2006

Item Description	Unit	Unit Price 2005 Average	2005 Std Dev	2006 Average	2006 Std Dev	Percent Change
Hot-Mix Asphalt HL1 PGAC 58-28	Mg	$64.68	$3.76	$97.86	$20.60	51%
Hot-Mix Asphalt HL3 and HL3 MOD PGAC 58-28	Mg	$58.96	$9.77	$87.54	$31.08	48%
Hot-Mix Asphalt HL8 PGAC 58-28	Mg	$50.24	$5.63	$63.79	$10.50	27%
Hot-Mix Asphalt HL8(HS) PGAC 58-28	Mg	$62.14	$8.00	$78.69	$23.78	27%
Granular A Crushed Limestone	Mg			$27.11	$13.16	
Granular A Recycled Concrete	Mg			$26.71	$10.96	
Granular A (All Items)	Mg	$19.58	$8.49	$26.98	$12.30	38%
Granular B Crushed Limestone (Type II)	Mg			$29.29	$14.07	
Granular B Recycled Concrete	Mg			$21.03	$7.78	
Granular B	Mg			$18.73	$1.96	
Granular B (All Items)	Mg	$18.58	$3.46	$24.00	$10.69	29%
Concrete Base 150 mm Thick	m^2	$32.00		$35.40	$4.51	11%
Concrete Base 200 mm Thick	m^2	$42.67		$53.88	$0.76	26%
Concrete Base 250 mm Thick (Estimated)	m^2	$53.33		$75.70	na	42%

Source: Transportation Infrastructure Asset Management and Programming Unit

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Typical LCCA Format

DETAILED LIFE-CYCLE COST ANALYSIS
Composite Major and Minor Arterial Road per 1 km LCCA Maintenance Plan

YEAR	MAJOR ACTIVITY		MINOR ACTIVITY		TOTAL INITIAL COST	DISCOUNT FACTOR	PRESENT WORTH
	DESCRIPTION	INITIAL COST	DESCRIPTION	INITIAL COST			
0	Intitial Construction	$1,534,250			$1,534,250	1.000	$1,534,250
3			Crack Seal	$8,000	$8,000	0.844	$6,750
8			Crack Seal	$6,400	$6,400	0.636	$4,069
26	Resurfacing	$611,052			$611,052	0.229	$140,203
29			Crack Seal	$8,000	$8,000	0.194	$1,549
34			Crack Seal	$6,400	$6,400	0.146	$934
46	Resurfacing	$611,052			$611,052	0.074	$45,183
49			Crack Seal	$8,000	$8,000	0.062	$499
54			Crack Seal	$6,400	$6,400	0.047	$301
69	Reconstruction	$1,534,250			$1,534,250	0.020	$30,849
72			Crack Seal	$8,000	$8,000	0.017	$136
77			Crack Seal	$6,400	$6,400	0.013	$82
95	Resurfacing	$611,052			$611,052	0.005	$2,819
98			Crack Seal	$8,000	$8,000	0.004	$31

Sub-total $1,767,653
Salvage Value (5% of Construction Cost) -$30,553 -$106

Life-Cycle Cost for 68 Year Road Life **$1,733,631**

100 Year Life-Cycle
Residual Value (15/20 of last Rehabilitation) -$1,150,688 -$4,000
Total Life-Cycle Cost - 100 Years **$1,763,547**

CALCULATION OF DISCOUNT RATE
Annual Interest Rate = 9 %
Annual Inflation Rate = 3 %
Discount Rate = 5.83 %

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Preferred Alternative

- The pavement structural design should be based on
  - Life Cycle Cost Analysis
  - Operating Costs
  - Impact to the Public
  - Risk Analysis

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Expanding the Realm of Possibility

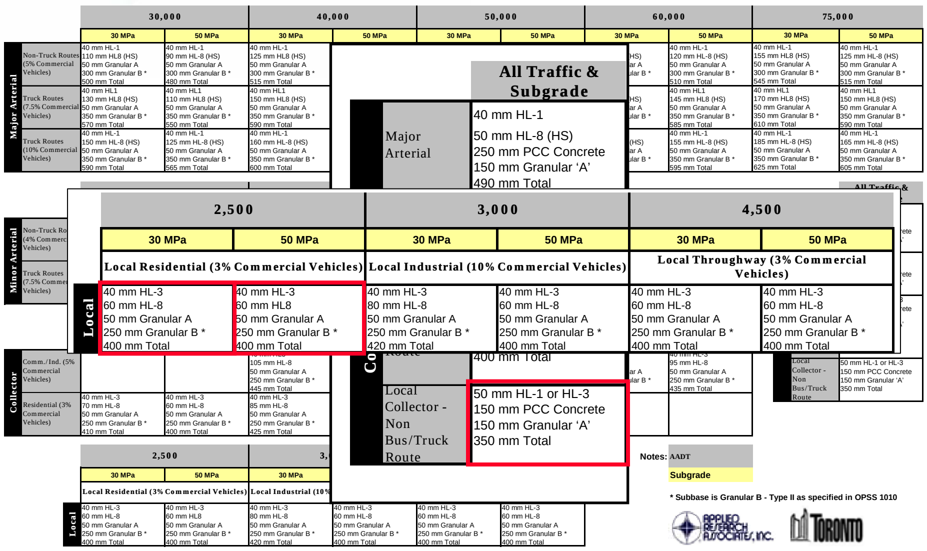
General Considerations

- Flexible Pavements
  - Typically lower initial cost
  - Shorter service life
- Composite Pavements
  - Longer service life
  - More resistant to heavy loads
  - Typically less expensive to maintain

Design Example - 1

- Local Road Rehabilitation of Existing Flexible Pavement
  - Princess Anne Crescent and surrounding streets (Oldham Rd, Cheviot Pl, Orkney Cr, Byland Rd, Grimsby Ct)
- Road Classification:
  Local Residential Roads
- Traffic Level:
  AADT <2,500;
  <3% Commercial Vehicles
- Assumed sandy silt till subgrade; support 30 MPa

Design Example 1 – Princess Anne Cr.



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But We're Not Reconstructing!

- Must consider appropriate rehabilitation strategies
  - Partial reconstruction (pulverize, regrade, new HMA)
  - Cold Recycling and Overlay
  - Full Reconstruction Flexible
  - Full reconstruction Composite
- Treatment selection should be based on LCCA

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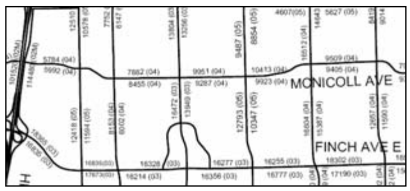
Design Example - 2

- Reconstruction of McNicoll Avenue (Program Year 2006/07)
  - From Pharmacy Ave to Warden Ave
- Road Classification: Minor Arterial Road
- Traffic Level: AADT ~ 16337 (2004); Non-Truck Route, Bus Route
- Assumed silty clay subgrade; support 30 MPa



Design Example 2 – McNicoll Avenue

Minor Arterial	20,000		25,000	
	30 MPa	50 MPa	30 MPa	50 MPa
Non-Truck Routes (4% Commercial Vehicles)	40 mm HL-1 95 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 435 mm Total	40 mm HL-1 80 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 420 mm Total	40 mm HL-1 105 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 445 mm Total	40 mm HL-1 85 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 425 mm Total
Truck Routes (7.5% Commercial Vehicles)	40 mm HL-1 135 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 475 mm Total	40 mm HL-1 110 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 450 mm Total	40 mm HL-1 140 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 480 mm Total	40 mm HL-1 120 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 460 mm Total

All Traffic & Subgrade	
Major	40 mm HL-1 50 mm HL-8 (HS)
Local Collector - Non Bus/Truck Route	50 mm HL-1 or HL-3 150 mm PCC Concrete 150 mm Granular 'A' 350 mm Total

Notes: AADT

Subgrade

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

APPLIED RESEARCH ASSOCIATES, INC. TORONTO

Design Example 2 Summary

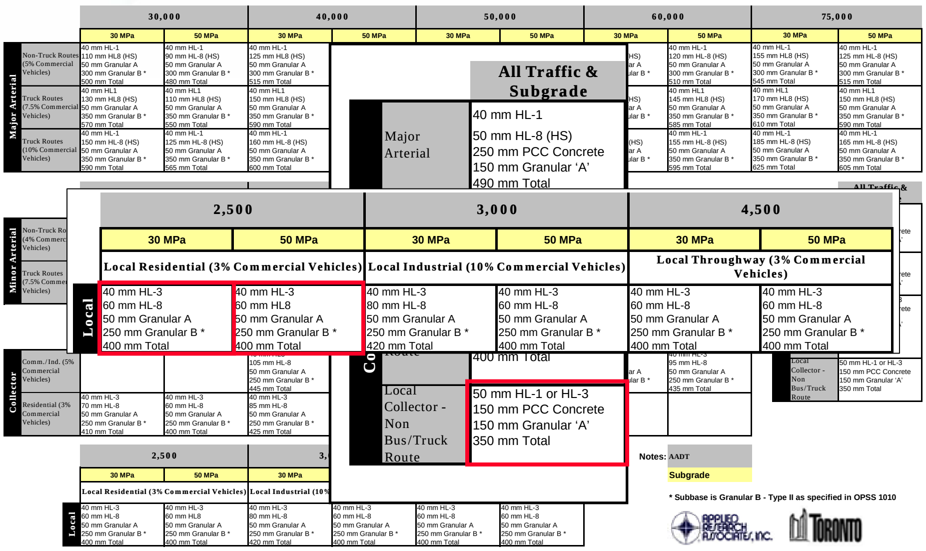
- Flexible Cross-section
  40mm HL-1
  95mm HL-8 (HS)
  50mm Granular A
  250mm Granular B – Type II
- Composite Cross-section
  40mm HL-1
  50mm HL-8 (HS)
  250mm PCC Concrete
  150mm Granular A

- Complete LCCA
- Other Considerations:
  - Urban cross-section with four lanes

Design Example 3

- New Development
  - Rouge Hills (single family -detached, semi and -row housing)
- Road Classification:
  Local Residential Roads
- Traffic Level:
  2,500 AADT
- Assumed silty clay subgrade; support 30 MPa

Design Example 3 – Rouge Hills



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Design Example 3 Summary

- Flexible Cross-section
  40mm HL-1
  60mm HL-8
  50mm Granular A
  250mm Granular B – Type II
- Composite Cross-section
  50mm HL-1 of HL-3
  150mm PCC Concrete
  150mm Granular A

- Complete LCCA
- Other Considerations:
  - Primarily residential use

Expanding the Realm of Possibility

Design Example - 4

- New Development
  - East Bayfront (condominium)
- Road Classification:
  Local Throughway
- Traffic Level:
  4,500 AADT
- Assumed sand subgrade; support 50 MPa

Design Example 4 – East Bayfront

	2,500		3,000		4,500	
	30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa
	Local Residential (3% Commercial Vehicles)		Local Industrial (10% Commercial Vehicles)		Local Throughway (3% Commercial Vehicles)	
Local	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 60 mm HL8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 80 mm HL-8 50 mm Granular A 250 mm Granular B * 420 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total

	All Traffic & Subgrade
Major Arterial	40 mm HL-1 50 mm HL-8 (HS) 250 mm PCC Concrete 150 mm Granular 'A' 490 mm Total
Local Collector - Non Bus/Truck Route	50 mm HL-1 or HL-3 150 mm PCC Concrete 150 mm Granular 'A' 350 mm Total

Notes: AADT

Subgrade

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

Design Example 4 Summary

- Flexible Cross-section
  40mm HL-1
  60mm HL-8
  50mm Granular A
  250mm Granular B – Type II
- Composite Cross-section
  50mm HL-1 of HL-3
  150mm PCC Concrete
  150mm Granular A

- Complete LCCA
- Other Considerations:
  - Primarily residential use (access to condominiums)

Design Example - 5

- Reconstruction of Carlaw Avenue (Program Year 2007)
  - From Commissioners Street to Lake Shore Blvd East South Branch
- Road Classification:
  Collector Road
- Traffic Level:
  AADT 6050 (2004);
  24% Commercial
  (Major truck route)
- Assumed sand subgrade;
  support 50 MPa

Design Example 5 – Carlaw Avenue

Major Arterial

	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
Non-Truck Routes (5% Commercial Vehicles)	40 mm HL-1 110 mm HL8 (HS) 50 mm Granular A 300 mm Granular B * 500 mm Total	40 mm HL-1 90 mm HL-8 (HS) 50 mm Granular A 300 mm Granular B * 480 mm Total	40 mm HL-1 125 mm HL8 (HS) 50 mm Granular A 300 mm Granular B * 515 mm Total	40 mm HL-1 100 mm HL-8 (HS) 50 mm Granular A 300 mm Granular B * 490 mm Total	40 mm HL-1 135 mm HL8 (HS) 50 mm Granular A 300 mm Granular B * 525 mm Total	40 mm HL-1 110 mm HL-8 (HS) 50 mm Granular A 300 mm Granular B * 500 mm Total	40 mm HL-1 145 mm HL8 (HS) 50 mm Granular A 300 mm Granular B * 535 mm Total	40 mm HL-1 120 mm HL-8 (HS) 50 mm Granular A 300 mm Granular B * 510 mm Total	40 mm HL-1 155 mm HL8 (HS) 50 mm Granular A 300 mm Granular B * 545 mm Total	40 mm HL-1 125 mm HL-8 (HS) 50 mm Granular A 300 mm Granular B * 515 mm Total
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Minor Arterial

	20,000		25,000	
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Non-Truck Routes (4% Commercial Vehicles)	40 mm HL-1 95 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 435 mm Total	40 mm HL-1 80 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 420 mm Total	40 mm HL-1 105 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 445 mm Total	40 mm HL-1 85 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 425 mm Total
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Composite Pavements

	All Traffic & Subgrade
Major Arterial	40 mm HL-1 50 mm HL-8 (HS) 250 mm PCC Concrete 150 mm Granular 'A' 490 mm Total
Minor Arterial - Bus/Truck Route	40 mm HL-1 50 mm HL-8 (HS) 250 mm PCC Concrete 150 mm Granular 'A' 490 mm Total
Local Collector - Bus/Truck Route	50 mm HL-1 of HL-3 200 mm PCC Concrete 150 mm Granular 'A' 400 mm Total
Local Collector - Non Bus/Truck Route	50 mm HL-1 or HL-3 150 mm PCC Concrete 150 mm Granular 'A' 350 mm Total

Collector

	5,000		7,500		10,000		15,000	
	30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa
Comm./Ind. (5% Commercial Vehicles)			40 mm HL3 105 mm HL-8 50 mm Granular A 250 mm Granular B * 445 mm Total	40 mm HL-3 75 mm HL-8 50 mm Granular A 250 mm Granular B * 415 mm Total	40 mm HL-3 115 mm HL-8 50 mm Granular A 250 mm Granular B * 455 mm Total	40 mm HL-3 85 mm HL-8 50 mm Granular A 250 mm Granular B * 425 mm Total	40 mm HL-3 125 mm HL-8 50 mm Granular A 250 mm Granular B * 465 mm Total	40 mm HL-3 95 mm HL-8 50 mm Granular A 250 mm Granular B * 435 mm Total
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Local

	2,500		3,000		4,500	
	30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa
	Local Residential (3% Commercial Vehicles)		Local Industrial (10% Commercial Vehicles)		Local Throughway (3% Commercial Vehicles)	
Local	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 60 mm HL8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 80 mm HL-8 50 mm Granular A 250 mm Granular B * 420 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total

Notes: AADT

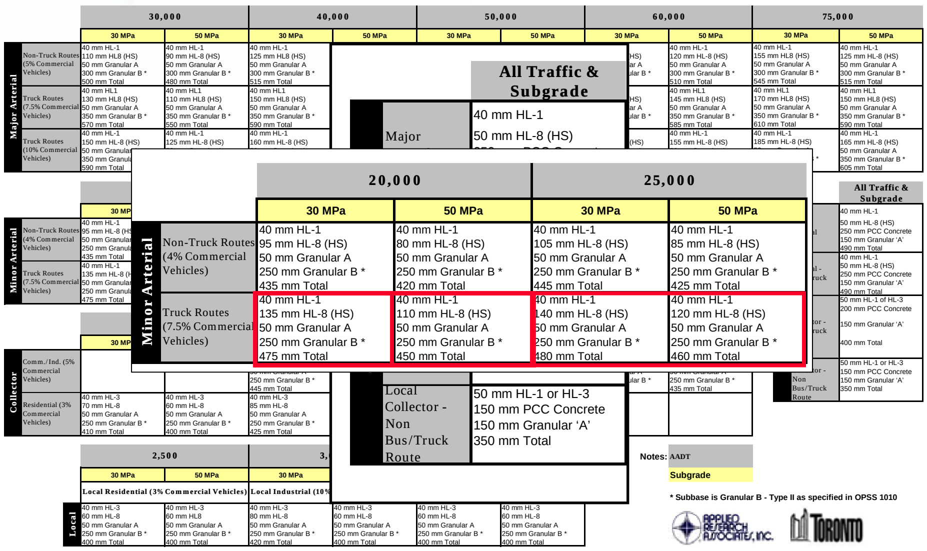
Subgrade

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

Design Example – 5 issues

- There is no option for a Collector Road with 6050 AADT and 24% commercial vehicles
- Consider Annual Average Daily Truck Traffic (AADTT)
  - Truck & Buses 1450
- Similar truck traffic loading as minor arterial
  - 1500 AADTT (20,000 AADT with 7.5% commercial)

Design Example 5 – Carlaw Avenue



Minor Arterial	20,000 – 30 MPa	20,000 – 50 MPa	25,000 – 30 MPa	25,000 – 50 MPa
Non-Truck Routes (4% Commercial Vehicles)	40 mm HL-1 95 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 435 mm Total	40 mm HL-1 80 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 420 mm Total	40 mm HL-1 105 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 445 mm Total	40 mm HL-1 85 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 425 mm Total
Truck Routes (7.5% Commercial Vehicles)	40 mm HL-1 135 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 475 mm Total	40 mm HL-1 110 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 450 mm Total	40 mm HL-1 140 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 480 mm Total	40 mm HL-1 120 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 460 mm Total

Design Example 5 Summary

- Flexible Cross-section
  40mm HL-1
  135mm HL-8 (HS)
  50mm Granular A
  250mm Granular B – Type II
- Composite Cross-section
  40mm HL-1
  50mm HL-8 (HS)
  250mm PCC Concrete
  150mm Granular A

- Complete LCCA
- Other Considerations:
  - Heavy truck route
  - Existing section shows significant rutting

EXPANDING THE REALM OF POSSIBILITY

Design Considerations

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An Employee-Owned Company

S1SP ARA0127-105

Design Considerations

- There is more to pavement design than just the thickness of the layers
  - Asphalt Mix Design
  - Concrete Base Design
  - Recycled Crushed Concrete Base
  - Drainage
  - Sensitive Soils
  - Geotextiles
  - Perpetual Pavements

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Expanding the Realm of Possibility

Asphalt Mix Design

- Asphalt mix design can have a very large impact on the performance of a pavement
- Common mixes used in Toronto
  - HL-1
  - HL-3
  - HL-8
  - HL-8 (HS)
- Premium Mixes
  - Superpave
  - SMA

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Expanding the Realm of Possibility

Performance Graded Asphalt Cement (PGAC)

- Evolution of grading asphalt binder:
  - Penetration grades
  - Viscosity grades
  - PGAC
- For the City of Toronto temperatures:
  - Typical Surface Course – PG 64-28
  - Typical Binder Course – PG 58-28
  - Premium – PG 70-28

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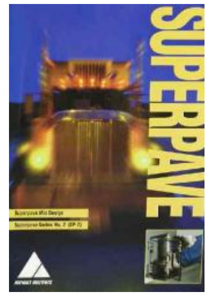
Expanding the Realm of Possibility

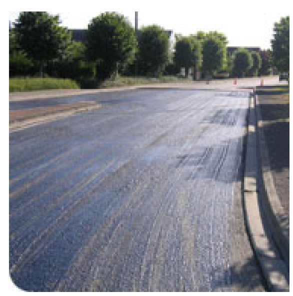
Superpave Mix Design



- Superpave vs. Marshall Mix Design
  - Same ingredients
  - Same construction
  - Just different mix design criteria
- Equivalent mixes:

HL Designation	Comparable Superpave Designation
SMA	SMA
DFC	Superpave 12.5FC2
HL-1	Superpave 12.5FC1
HL-3	Superpave 12.5
HL-8/HL-8(HS)	Superpave 19.0
LSBC	Superpave 37.5

Tack Coat



- A tack coat is used to ensure that overlays properly adhere to underlying layers.
- Should be used for all tie-ins, and vertical surfaces
- Horizontal surfaces should be tack coated if construction is staged.

Concrete Base Construction

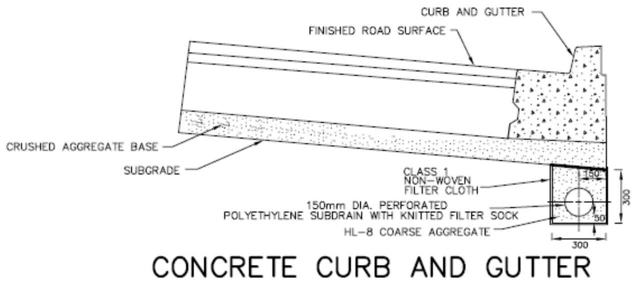
- Concrete Base
- When asphalt is removed during rehabilitation:
  - Inspect the exposed concrete slabs
  - Repair shattered slabs
  - Repair joints for poor load transfer

Recycled Crushed Concrete

- Recycled crushed concrete is a cost effective material that can be used as a base for roadways
- Typically graded to meet OPSS Granular A
- Can be substituted for Granular A on a 1:1 basis
- Proper quality control is necessary to ensure there are no excess fines

Pavement Drainage

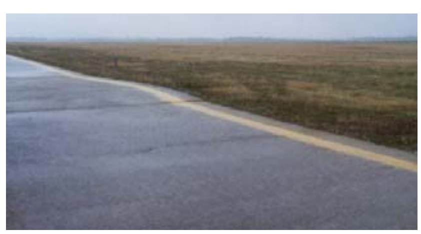
- Poor drainage can greatly reduce the service life of a pavement
- In urban situations, continuous drains should be used whenever possible
- Stub drains my be considered in cases where permeable soils are present



City of Toronto Standard Drawing T-216.02-8

Sensitive Subsoils

- Portions of the City have fine grained subgrade soils that are moisture sensitive and susceptible to frost heave
- Requires subgrade replacement or additional granular material for frost protection



Geotextiles

- Geotextiles are synthetic sheets (woven and non-woven) that are used typically to separate granular layers
- Adds tensile strength to layer
- Supports layers and improves drainage
- Tend to be expensive and should be considered on a project specific basis

Perpetual Pavements

- Perpetual pavements are designed to limit the stress and strains at the bottom of the asphalt layer
- Designed to withstand fatigue cracking
- Only requires occasional resurfacing for a long service life
- Pavements have been placed at an HMA thickness of 500mm
- Typically limited to freeway applications

Maintenance and Rehabilitation

- Not many new streets are being constructed anymore
- Most work done is either a reconstruction or a repair of an existing road
  - Preventative maintenance
  - Repair of utility cuts
  - Localized repairs
  - Resurfacing

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Expanding the Realm of Possibility

Crack Treatments

- Prevents water and debris from entering individual cracks in the HMA pavement surface

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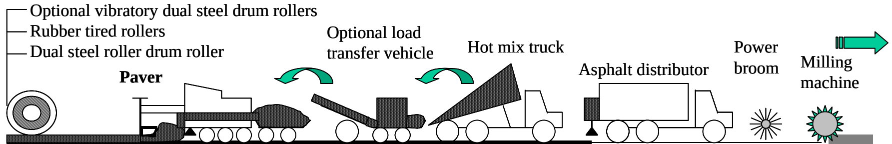
Expanding the Realm of Possibility

Patching

- Address localized areas of distress
- Correct surface discontinuities
- Seal the pavement from moisture infiltration

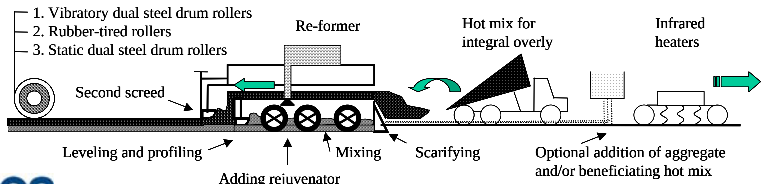
Resurfacing

- Wearing course
- Level pavement
- Improve friction
- Seal pavement
- Fills ruts



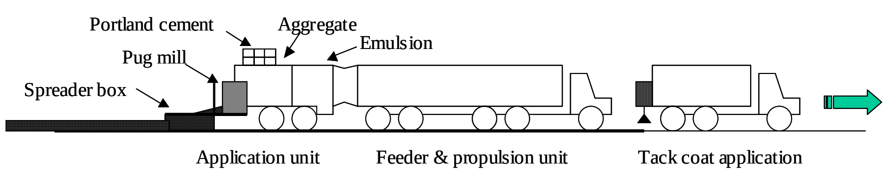
Hot In-Place Recycling

- Reduce rutting
- Reduce roughness
- Improve friction
- Reduce distress



Microsurfacing

- Level pavement surface
- Fill ruts
- Restore surface friction

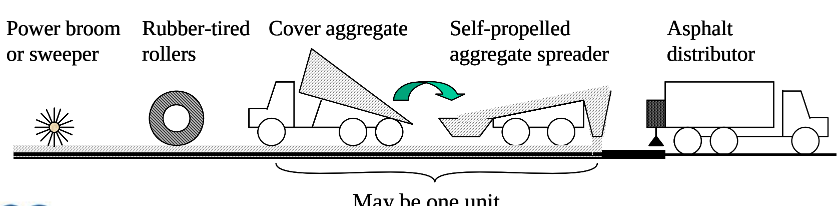


Surface Seals

- Seal pavement surface
- Rejuvenate oxidized HMA
- Provide delineation
- Improve friction

Asphalt Chip Seal

- Wearing course
- Improve surface friction
- Seal pavement
- Eliminate dust



Questions?

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Expanding the Realm of Possibility