Asphalt Mix Design Improvements at Toronto Pearson

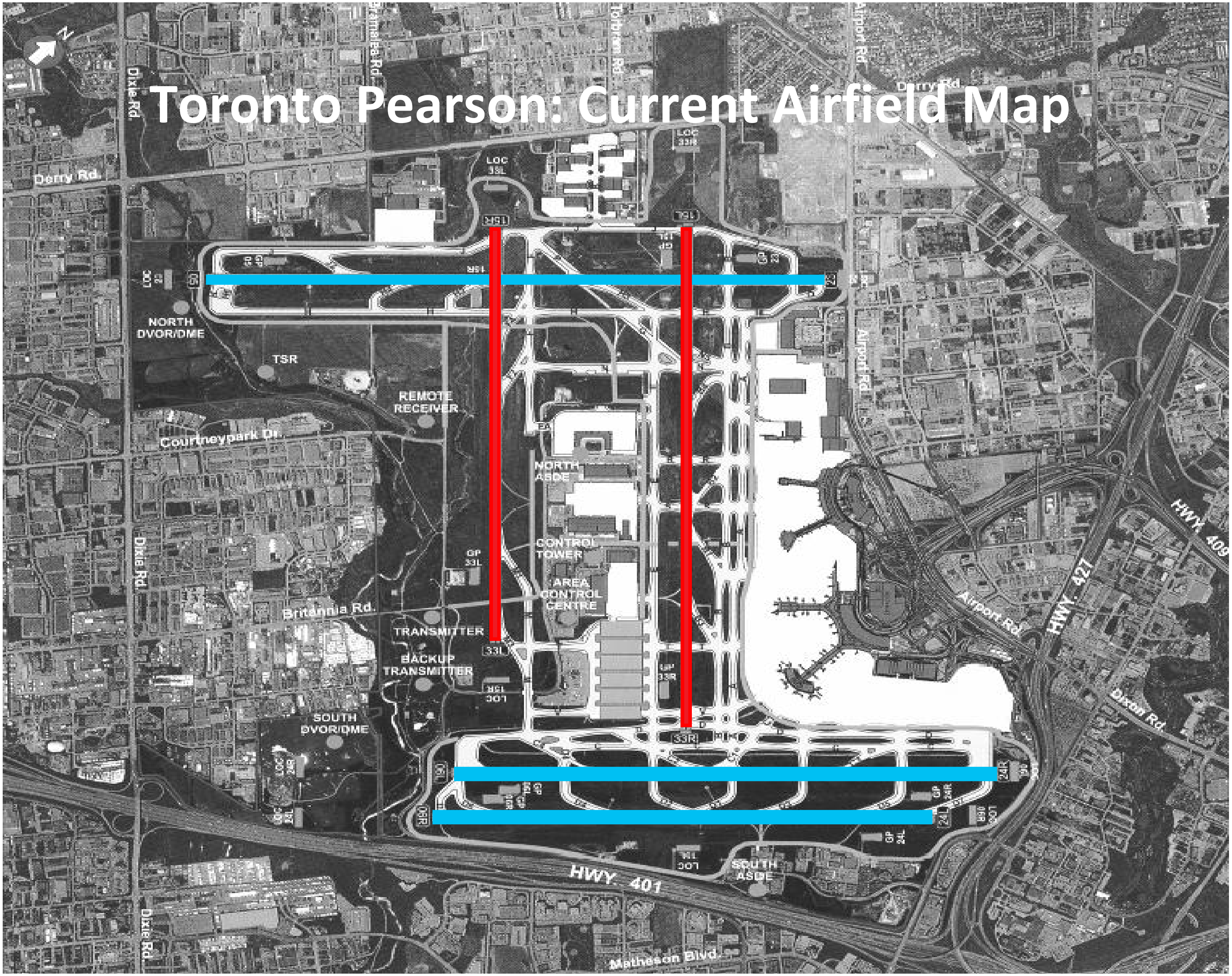
September 12, 2013

GTAA

For You. The World.

Toronto Pearson
International Airport | Aéroport International

Toronto Pearson: Current Airfield Map



Toronto Pearson Airport – Canada's Largest Airport

- 2012 Passenger Volume: 34.9 Million PAX.
- Ranking in North America: 12th busiest airport
  (in terms of passenger volume)
- Total airside paved areas: approx. 4,700,000 m2
- Layout: 5 runways
- # aircraft movements: approx. 433,990 annually
- Cargo processed in 2012: over 500,000 kg

Overview

The goal of this presentation is to show:

- Issues/problems that Pearson had encountered
- Contributing factors to asphalt deformation
- Mix design improvement to meet current and future needs

Issues/Problems

Distress Photos

Slippage of asphalt away from the inset light

Pavement shoved at runway holdline position

Distress Photos

Asphalt rutting along taxiway wheel path area

Asphalt Sliding

Distress Photos


Asphalt Shoving at reflection joint on a taxiway

Asphalt slippage & shoving over PCC

Case Study 1 – Taxiway Shoving

Background

1.Taxiways A & H were constructed in 1984 and upgraded to low visibility routing in 2001 & 2002 by adding additional inset lights in between the existing ones and then overlaying with asphalt.

2.Pavement was subjected to very heavy aircraft and slow moving traffic with frequent stop and go movement. e.g. Antonov An 124

Case Study 1 – Taxiway Shoving con’t

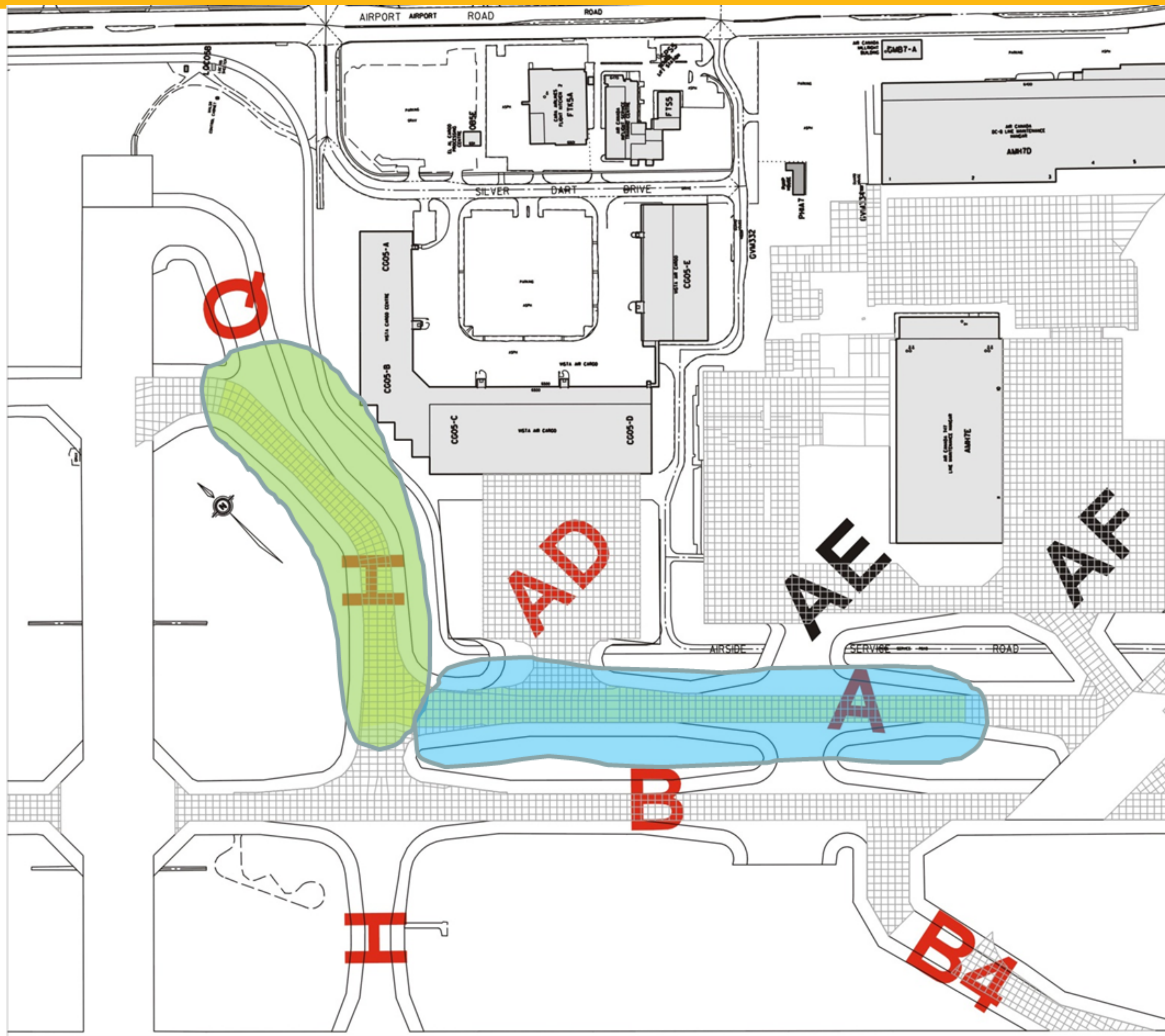
3. Pavement Structure:

Upgrade:	[HMAC	125mm <--- 2001 - 2002
Existing:	PCC	380mm <--- 1984
	CSB	200mm <--- 1984
	Subbase	250mm <--- 1984

4. Northern part of Taxi A was overlaid in October 2001 and eastern part of Taxi H was overlaid in May 2002.

5. Pavement shoving was first noticed after July 1st long weekend in 2002.

Case Study 1 – Locations of Shoving



Case Study 2 – Runway Shoving

Background

1. Runway 06R-24L was constructed in 2001. A blend of crushed limestone and trap rock was used in the surface course.

2. Pavement Structure:

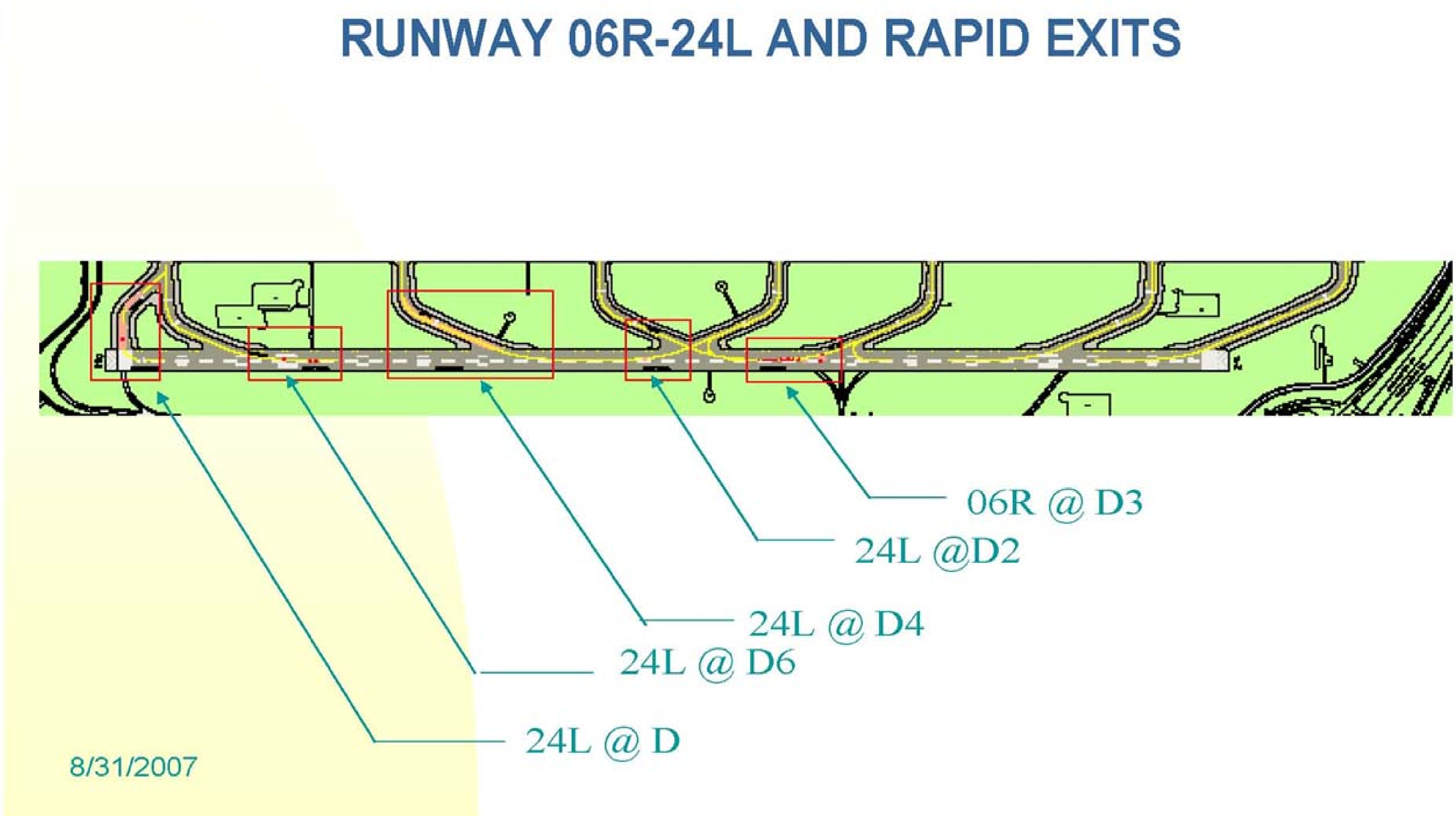
	HMAC	125mm <--- 2001
Existing:	Base	300mm <--- 2001
	Subbase	900mm <--- 2001

3. August 6, 2007, an irregular piece of surface course asphalt peeled off from the lower course of asphalt pavement on the runway between D1 and D3.

Case Study 2 – Runway Shoving con’t

4. Asphalt slipping and shoving were also observed at different locations on the runway and taxiway exits (i.e. 24L @ D, 24L @ D6, 24L @ D4 and 24L @ D2). This was very noticeable at the interface with inset lights and at the runway holdlines.

Case Study 2 – Locations of Shoving



Contributing Factors

Case Study 1 – Contributing Factors

- In situ air voids as low as 2.2%
- AC content as high as 5.75% by mass of aggregate or 5.45% by mass of total mix
- Record high ambient temperature of 36^{o}C on July 1, 2002
- Pavement surface temperature was 56^{o}C to 58^{o}C
- Improper cleaning of milled surfaces
- Heavy aircraft such as Antonov An 124 travelled on the newly paved taxiway carrying rolls of steel from Japan to Toronto frequently in the summer of 2002.
- High tack coat application rate
- Where GlassGrid installed, sliding was more prominent

Case Study 2 – Contributing Factors

1. High ambient temperatures during the week of August 6, 2007, ranging from 30^{o}C to 32^{o}C.
2. Pavement surface temperature was 50^{o}C to 52^{o}C as recorded by the surface weather detection system.
3. Heavy traffic on Runway 24L due to closure of Runway 06L-24R which was under construction and only a few crossing exits were operational.
4. Heavy aircraft braking in order to use the nearest open exit (since some of the exits were closed due to the construction on adjacent Runway 06L-24R).
5. The slippage was produced by the original asphalt surface course sliding over the base asphalt course of the pavement.

Case Study 2 – Contributing Factors con’t

6. The asphalt cement PG64-28 used in 2000/2001 for the surface asphalt had a lower viscosity at higher temperatures than it has now.
7. The asphalt content specified at that time (2000/2001) for surface course was up to 5.8%.
8. The specified minimum Marshall Stability was 10kN.
9. The aggregate used in 2001 was a blend of crushed limestone and trap rock. The abrasion loss by mass was max 25%.

Asphalt Mix Design Improvements

Asphalt Mix Design Development

- In April 1998, Ontario Hot Mix Producers Association (OHMPA) on behalf of the Ministry of Transportation of Ontario (MTO) / Ontario Road Builders Association (ORBA) established grade equivalencies of PG asphalt cement with respect to penetration asphalt. PG 58-28 grade was set to be equivalent to 85-100 penetration asphalt.

- Prior to Year 2000 all airfield pavements were designed according to Transport Canada standards with the asphalt mix using asphalt penetration 85-100 for Southern Ontario and having a Marshall Stability value of 10kN.

Asphalt Mix Design Development con't

- Since Year 2000, Performance Grade (PG) asphalt began to replace the Penetration Grade asphalt in the Canadian market.

- Because of TPIA's heavy traffic, the asphalt grade for the surface course was bumped up one grade to PG 64-28. At that time all other criteria of the asphalt mix design remained the same with only minor changes to the quality of coarse aggregate requirements.

Asphalt Mix Design Development con't

- It was observed that the crushed limestone aggregates were not able to meet the surface aggregate criteria of maximum abrasion loss by mass of 25 % when tested for Los Angeles Degradation in accordance with ASTM C131.

- Therefore, around Year 2000 a blend of crushed limestone and traprock was recommended to meet the loss by mass criterion as soft aggregates may polish with time causing potential lower friction values. Inclusion of traprock crushed aggregates also demanded the use of an anti-stripping additive.

Asphalt Mix Design Development con't

- In 2002, the asphalt grade for the surface course was bumped again to PG 70-28 to accommodate the global warming effect of high ambient temperature and heavy aircraft such as Antonov An124 and Boeing B777-300ER.

- In 2006, polymer modified asphalt was introduced to increase the stiffness of the asphalt at high temperatures which will further reduce the concern of rutting and shoving.

History of Mix Design Development

Items	Prior to 2000	2000/2001	2002	2006 to Present
Asphalt Cement **- Penetration Grade** **- Performance Grade**	85-100	PG 64-28	PG 70-28	PG 70-28 PMA
Asphalt Content	5.5-5.8%	5.5-5.8%	4.8-5.2%	4.8-5.2%
Aggregate	Limestone	Blend of Limestone & Trap rock	Traprock	Traprock
Marshall Stability	10kN	10kN	14kN	14kN
Tack Coat (L/m^2)				
- On existing asphalt surface	RS-1, max 0.5	RS-1 max 0.5	RS-1, 0.3-0.4	RS-1, 0.3-0.4
- On rough concrete surface	RS-1, max 0.5	RS-1 max 0.5	CRS-2P, 0.2-0.3	CQS-1HP, 0.3-0.4
- Between new lifts	RS-1, max 0.2	RS-1 max 0.2	RS-1, 0.15-0.25	RS-1, 0.15-0.25

Asphalt Mix Design Development con’t

- In 2012, specification review was undertaken primarily to address rutting and shoving concerns in holding areas induced by heavy and slow moving aircraft. Recycled asphalt pavement (RAP) and Sasobit Warm Mix Asphalt (WMA) technology were evaluated using Superpave mix design method.
- Work includes:
  - comparing current Marshall design to Federal Aviation Administration (FAA) Engineering Brief No. 59A Item P-401 Plant Mix Bituminous Pavement (Superpave)

Asphalt Mix Design Development con’t

- selecting PGAC based on AASHTO M 320 and MP 19 Performance-Graded Asphalt Binder using Multiple Stress Creep Recovery (MSCR) test and confirming moisture susceptibility to AASHTO T-283 Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage test
- determining Polished Stone Value (PSV) to BS 812 Part 114
- determining Dynamic Modulus and Flow Number using the IPC Global Asphalt Mixture Performance Tester (AMPT)
- evaluating mix design using Asphalt Pavement Analyzer (APA) rut tester

Step 1 – N-Equivalent Analyses

- Determine the equivalent number of gyrations (N_{equiv}) required to produce a comparative Marshall mix at 75 blows per side.

- Based on the evaluation results, the N-equivalent for the 12.5mm surface course was 86 gyrations and for the 19mm lower course was 78, therefore, we adopted the FAA criteria as per Table 1 in EB-59A Item P-401 Superpave Criteria where N_{des} is based on 85 gyrations.

N-equivalent for Surface Course Marshall Mix

Determination of N-equivalent for the GTAA Surface Course Marshall Mix

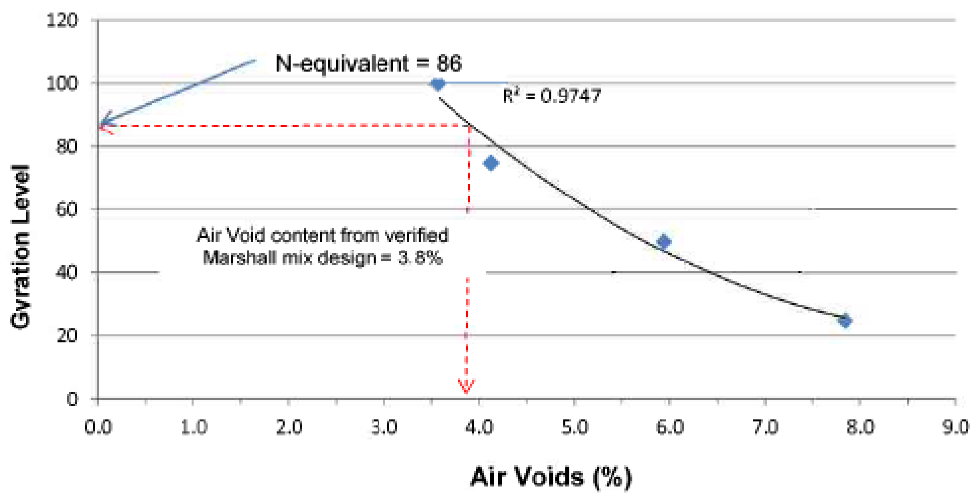
Project No.:	*11-1900-10*	Mixing / Compaction Temper.:	*165 / 150 °C*
Client:	*Great Toronto Airport Autority*	Asphalt Binder:	*McAsphalt / PGAC 70-28 P*
Mix Type:	*Marshall Surface Course / SP 12.5 mm*	Target Air Void Content (%):	*3.7*
Mix Design No.:	*Surface Course*	Percentage of Additive:	*N / A*

Maximum Specific Gravity - Gmm			Bulk Specific Gravity - Gmb								
Sample No.:	Sample A	Sample B	Specimen No.:	Spec. at 25 Gyr.		Spec. at 50 Gyr.		Spec. at 75 Gyr.		Spec. at 100 Gyr.	
Flask No.:	11	12	No. of Gyratation	25		50		75		100	
Flask & Mix - Air:	2634.4	2667.7	Wt in Air	5051.5	5048.6	5240.0	5240.0	5323.9	5320.7	5324.3	5332.4
Flask in Air:	652.9	609.1	Wt - SSD	5082.5	5089.9	5258.3	5259.5	5333.7	5331.7	5331.7	5338.6
Mix in Air:	1981.5	2058.6	Wt in H2O	3092.1	3077.8	3222.5	3226.3	3312.8	3298.1	3315	3319.5
Flask & Mix - H_2O:	1828.4	1838.9	Volume	1990.4	2012.1	2035.8	2033.2	2020.9	2033.6	2016.7	2019.1
Flask in H_2O:	570.3	532.3	BRD	2.538	2.509	2.574	2.577	2.634	2.616	2.640	2.641
Mix in H_2O	1258.1	1306.6	% Air Voids	7.3	8.4	6.0	5.9	3.8	4.5	3.6	3.6
Volume	723.4	752.0	Ave. % Air Voids	7.8		5.9		4.1		3.6	
MRD	2.739	2.738									
Average MRD	2.738										

Verified Marshall Mix Design

AME Marshall Mix Desiogn # 8797

Mix Property	Selected	Verified
BRD (Gmb)	2.655	2.633
MRD (Gmm)	2.758	2.738
% Air Voids (Va)	3.7	3.8
% VMA	16.2	16.8
Stability (KN)	21,400	16083
Flow (0.25 mm)	15	13.5



N-equivalent for Lower Course Marshall Mix

Determination of N-equivalent for the GTAA Lower Course Marshall Mix

Project No.:	*11-1900-01*	Mixing / Compaction Temper.:	*165 / 150 °C*
Client:	*Great Toronto Airport Autority*	Asphalt Binder:	*McAsphalt / PGAC 70-28 P*
Mix Type:	*Marshall Lower Course / SP 19.0 mm*	Target Air Void Content (%):	*3.6*
Mix Design No.:	*Lower Course*	Percentage of Additive:	*N / A*

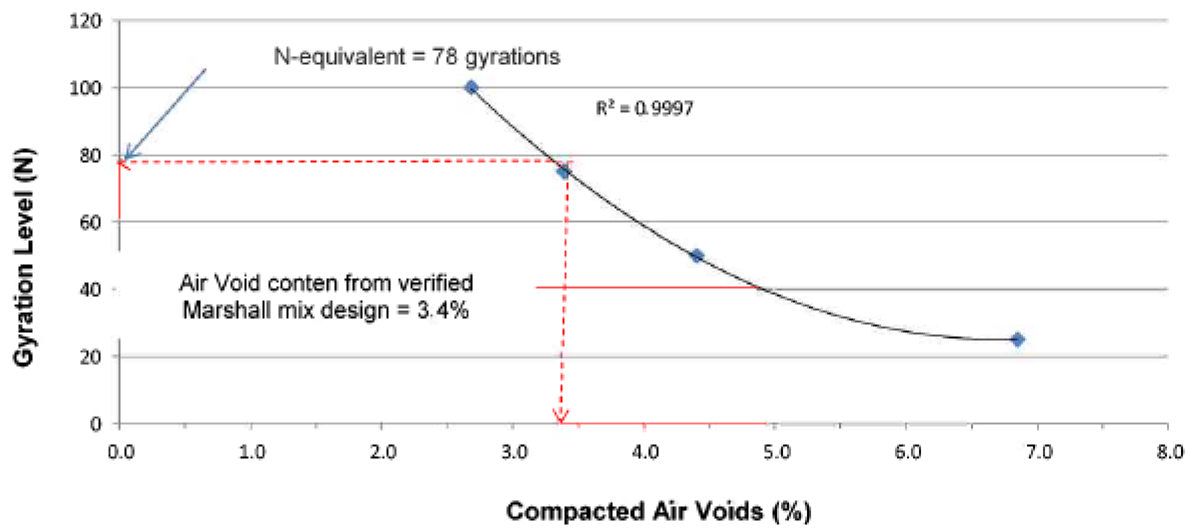
Maximum Specific Gravity - Gmm		
Sample No.:	Sample A	Sample B
Flask No.:	11	12
Flask & Mix - Air:	2591.0	2700.7
Flask in Air:	652.9	609.1
Mix in Air:	1938.1	2091.6
Flask & Mix - H_2O:	1750.8	1807.2
Flask in H_2O:	570.3	532.3
Mix in H_2O	1180.5	1274.9
Volume	757.6	816.7
MRD	2.558	2.561
Average MRD	2.560	

Bulk Specific Gravity - Gmb								
Specimen No.:	Spec. at 25 Gyr.		Spec. at 50 Gyr.		Spec. at 75 Gyr.		Spec. at 100 Gyr.	
No. of Gyratation	25		50		75		100	
Wt in Air	4777.0	4785.8	4940.7	4937.0	4999.4	4998.2	5041.7	5040.7
Wt - SSD	4806	4810.3	4955.5	4947.3	5006	5009.3	5051.3	5047.8
Wt in H2O	2799	2806.4	2928.4	2937.4	2988.2	2984	3023	3028.4
Volume	2007	2003.9	2027.1	2009.9	2017.8	2025.3	2028.3	2019.4
BRD	2.380	2.388	2.437	2.456	2.478	2.468	2.486	2.496
% Air Voids	7.0	6.7	4.8	4.0	3.2	3.6	2.9	2.5
Ave. % Air Voids	6.9		4.4		3.4		2.7	

Verified Marshall Mix Design

DBA Marshall Mix Desiogn # 1870

Mix Property	Selected	Verified
BRD (Gmb)	**2.479**	**2.474**
MRD (Gmm)	**2.571**	**2.560**
% Air Voids (Va)	**3.6**	**3.4**
% VMA	**13.6**	**13.8**
Stability (KN)	**15,000**	**18483**
Flow (0.25 mm)	**10.7**	**13.2**



Superpave Design Criteria EB-59A Item P-401

TABLE 1
SUPERPAVE DESIGN CRITERIA
Pavements for gross aircraft weights of 60,000 pounds or more.

Test Property	Design Criteria for Nominal Maximum Aggregate Size: 3/4" Nom. (19 mm Nom.)	Design Criteria for Nominal Maximum Aggregate Size: 1/2"Nom. (12.5 mm Nom.)
Initial Number of Gyrations (N_{ini})	8	8
Design Number of Gyrations (N_{des})	85	85
Maximum Number of Gyrations (N_{max})	130	130
Air voids @ N_{des}	4.0	4.0
Voids in Mineral Aggregate @ N_{des}, %	13.0 min.	14.0 min
Voids filled with Asphalt @ N_{des}, %	65-78	65-78
Dust proportion	0.6-1.2	0.6-1.2
Dust proportion (coarser gradations[1])	0.6-1.6	0.6-1.6
Fine Aggregate Angularity	45 min.	45 min.
$\%G_{mm}$ @ N_{ini}	$\leq$90.50	$\leq$ 90.50
$\%G_{mm}$ @ N_{max}	$\leq$98.00	$\leq$ 98.00

Step 2 – Performance Grade Asphalt Cement (PGAC) testing

- The PGAC was tested in accordance with AASHTO M 320 and AASHTO MP 19 Performance-Graded Asphalt Binder using the Multiple Stress Creep Recovery (MSCR) test
  - PG 70-28 PMA
  - PG 70-28 WMA with Sasobit additive
- MSCR test has been recommended to improve the high temperature characterization and performance grade of asphalt cements.
- Based on the anticipated traffic levels at TPIA, the non-recoverable creep compliance J_{nr}, has been selected for Extremely Heavy Traffic "E" Grade. All testing should be

Step 2 – Performance Grade Asphalt Cement (PGAC) testing con't

done at the pavement environmental grade temperature to reflect response at actual operating temperatures. In southern Ontario, the J_{nr} is tested at 58^{o}C.

- The results indicate that the PG used for this study met the specification requirements of M 320 and MP 19 (MSCR). The continuous grade of PG 70-28 PMA was graded as PG 73.4-32.4 and PG 70-28 PMA with Sasobit WMA additive was graded as PG 76.7-28.4.

Summary of PGAC testing

Test	Criteria	Test Temperature °C	PG 70-28 PMA	PG 70-28 WMA w/sasobit
		Original Binder		
Rotational Viscosity	AASHTO T 316, max 3 Pa.s	**135**	**1.04**	**0.93**
Dynamic Shear Rheometer (DSR)	AASHTO T 315, G*/sinδ, min 1.00 kPa	58 64 **70** 76	 **1.48** 0.94	 **2.08** 1.28
		Rolling Thin Film Oven Residue		
Dynamic Shear Rheometer (DSR)	AASHTO T 315, G*/sinδ, min 2.20 kPa	58 64 **70** 76	 **2.94** 1.77	 **4.03** 2.33
Multiple Stress Creep Recovery (MSCR)	AASHTO TP 70, Extremely Heavy Traffic "E" Grade $J_{nr3.2}$, max 0.5 kPa^{-1},	**58**	**0.11**	**0.17**
	J_{nrdiff}, max 75 %,		**10**	**13.3**
	Average % Recovery, $_{R3.2}$		**52.5**	**46.8**
		Pressureized Aging Vessel Residue		
Dynamic Shear Rheometer (DSR)	AASHTO T 315, "H", "V", "E" Grades G* x sinδ, max 6000 kPa	28 **25** 22 19	 **1230** 1880	 **1375** 2120
Creep Stiffness (S)	AASHTO T 313, S, max 300 MPa/ m-value, min 0.300,	-12 **-18** -24 -30	 **158/0.360** 351/0.296	 **182/0.302** 357/0.269
		Grade		
Grade	AASHTO M 320 AASHTO MP 19		PG 70 - 28 PG 58 - 28 "E" Grade	PG 70 - 28 PG 58 - 28 "E" Grade
		Continuous Grade		
Continuous Grade			**PG 73.4 - 32.4**	**PG 76.7 - 28.4**

Step 3 – Superpave Mix Design

- Four mix designs were evaluated using the Superpave method - three for the surface course and one for the lower course:
  - Surface SP 12.5A Coarse mix with 48.9% passing 4.75 mm sieve (SP 12.5A HMA)
  - Surface SP 12.5B Fine mix with 57.9% passing 4.75 mm sieve and RAP 15% (SP 12.5B HMA, RAP)
  - Surface SP 12.5B Fine mix with 57.9% passing 4.75 mm sieve, Sasobit WMA 1.5% and RAP 15% (SP 12.5B WMA, RAP)
  - Lower SP 19.0 and Sasobit WMA 1.5% (SP 19.0 WMA)

Summary of Superpave Mix Design Properties

Property		SP 12.5A	SP 12.5B RAP	SP 12.5B RAP WMA	SP 19.0 WMA
		12.5 mm Nom.	12.5 mm Nom.	12.5 mm Nom.	19.0 mm Nom.
Gradation % Passing	Sieve size (mm)	DBA Mix ID # 2073	DBA Mix ID # 2074	DBA Mix ID # 2075	DBA Mix ID # 2076
	25.0	100.0	100.0	100.0	100.0
	19.0	100.0	100.0	100.0	97.3
	16.0	100.0	100.0	100.0	93.2
	12.5	97.9	98.3	98.3	85.0
	9.5	78.1	82.8	82.8	70.2
	4.75	48.9	57.9	57.9	48.5
	2.36	41.3	51.0	51.0	38.9
	1.18	25.9	33.0	33.0	26.0
	0.600	17.3	22.0	22.0	16.5
	0.300	11.0	13.7	13.7	10.2
	0.150	6.2	7.5	7.5	6.8
	0.075	3.3	3.8	3.8	4.5
Binder Content, wt %		5.0	5.0	5.0	4.8
Design Air Voids, vol %		4.0	4.0	4.3	3.8
Design VMA, vol %		15.8	16.8	15.9	13.6
Design VFA, vol %		74.8	76.1	72.6	71.7
Mix Bulk Densit, G_{mb}		2.626	2.605	2.595	2.473
Maximum Specific Gravity, G_{mm}		2.735	2.714	2.713	2.572
Aggregate Bulk Specific Gravity		2.963	2.931	2.931	2.724
Effective binder content, vol %		12.5	10.3	10.3	11.5
Dust / Binder Ratio		0.7	0.8	0.8	1.1
Design Gyrations		85	85	85	85
% Gmm at N_{ini}		87.4	88.0	87.7	88.3
% Gmm at N_{max}		97.9	96.5	96.5	97.6

Step 3 – Superpave Mix Design con't

- Moisture susceptibility (Tensile Strength Ratio, TSR %) of the mixes were tested in accordance with AASHTO T-283 to avoid any stripping issue. The criterion for TSR is 80% minimum.
- Polished Stone Value (PSV) of the aggregate was tested in accordance with BS 812 Part 114 to ensure the aggregate has excellent micro-texture and high skid resistance. The PSV value shall be equal to or greater than 50.

Testing	Criteria	SP 12.5A, 12.5 mm Nominal	SP 12.5B, RAP, 12.5 mm Nominal	SP 12.5B WMA, RAP, 12.5 mm	SP 19.0 WMA, 19 mm Nominal
Moisture Susceptibility testing (Tensile Strength Ratio, TSR %)	AASHTO T-283, EB-59A Superpave, min 80%	91.3	87.1	84.6	95.1
Corrected Polished Stone Value (PSV)	BS 812 Part 114	50	50	50	50

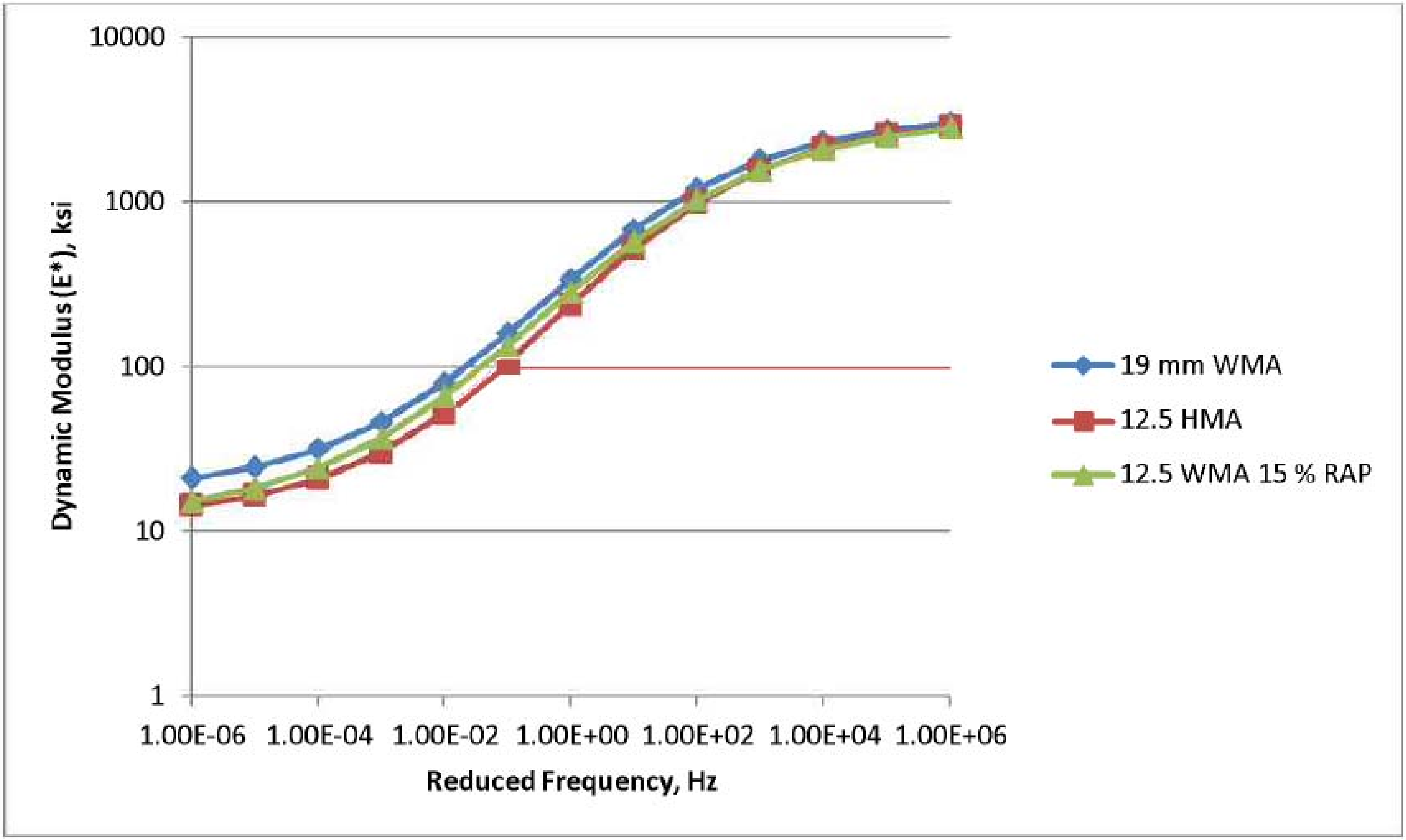
Step 4 – Performance Testing

- The performance testing was conducted using the IPC Global Asphalt Mixture Performance Tester (AMPT) and the Asphalt Pavement Analyzer (APA).
- Dynamic Modulus testing was performed using the AMPT to establish the rutting and fatigue resistance of the mixes. Samples were prepared in accordance with AASHTO PP 60-09. The mixtures were tested in accordance with AASHTO TP 79-09 with the temperatures and frequencies recommended by AASHTO PP 61-09.

Step 4 – Performance Testing con't

- The Dynamic Modulus Master Curves generated for this study are summarized in the following graph. The data in this graph shows the change in stiffness of the HMA and WMA across a full range of testing temperatures and loading frequencies for the SP 12.5A HMA versus the SP 12.5B WMA w/RAP and the SP 19.0 WMA.
- At the lower-temperature, faster frequency end of the curve (right-hand side of the curve) the SP 12.5A HMA, SP 12.5B WMA w/RAP and SP 19.0 WMA appear to have similar stiffness. As the temperatures increase and frequency of loading is reduced (left-hand side of the curve), both the WMA mixes become stiffer than the HMA.

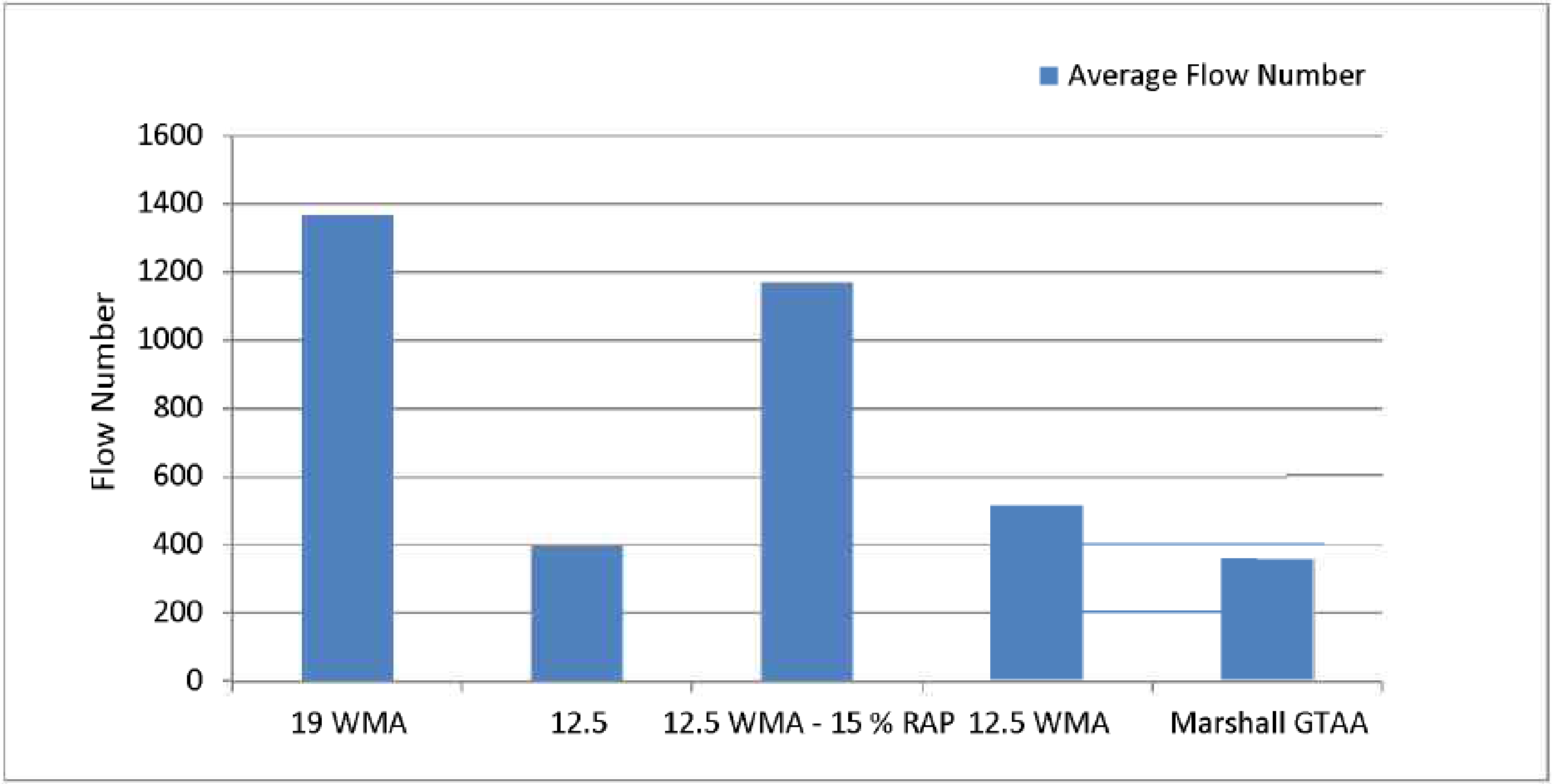
Dynamic Modulus Master Curve by Mix Type



Step 4 – Performance Testing con't

- Flow Number testing was performed using the AMPT to establish the number of load cycles corresponding to the minimum rate of change of permanent axial strain. Specimens were prepared and tested in accordance with AASHTO PP 60-09 and TP 79-09 respectively.
- A summary of the average Flow Number for each mix is presented in the following chart. Based on the mixes tested, it is evident that the WMA mixes exceed the Highways Superpave criterion for the minimum flow number of 415 for traffic level greater than 30 million ESAL.

Average Flow Number by Mix Type



Step 4 – Performance Testing con't

- APA testing was conducted to further assess the rutting resistance of the new mixes. Replicate samples of the surface mix were tested at 58°C in accordance with AASHTO TP 63-09. The results are summarized in the following table and are less than the maximum allowable permanent deformation of 5 mm.

Mix Type	DBA Mix No.	Permanent Deformation (mm)
SP 19 mm WMA	2076	3.4
SP 12.5	2073	4.4
SP 12.5 WMA 15 % RAP	2075	3.8

Summary of Key Findings

- The N-equivalent analysis confirmed that the FAA EB-59A Superpave Criterion (i.e. N_{des} of 85 gyrations) is suitable for the combination of materials used in this study for both the surface and lower course mixes evaluated.
- The addition of 1.5% Sasobit to the PG 70-28 PMA increased the high temperature grade by approx. 3^{o}C and lowered the low temperature by approx. 4^{o}C.
- The Sasobit modified (WMA) and standard PG 70-28 PMA both met the Extremely High Traffic "E" Grade based on the MSCR test and exhibited excellent elastic response and strain tolerance based on the non-recoverable creep compliance.

Summary of Key Findings con’t

- The Superpave mixes (both the HMA and WMA) designed to meet the FAA criteria are achievable with typical materials specified in the GTAA airfield specifications.
- The performance testing indicates that the mixes tested provide excellent rutting resistance. SP 19.0 WMA, SP 12.5B WMA w/RAP and SP 12.5A are ranked from highest to lowest in terms of rutting resistance.
- All mixes tested met the tensile strength ratio of 80% indicating good resistance to stripping.
- The PSV of the traprock tested with a value of 50 is considered to be representative of Ontario based traprock.

Conclusions

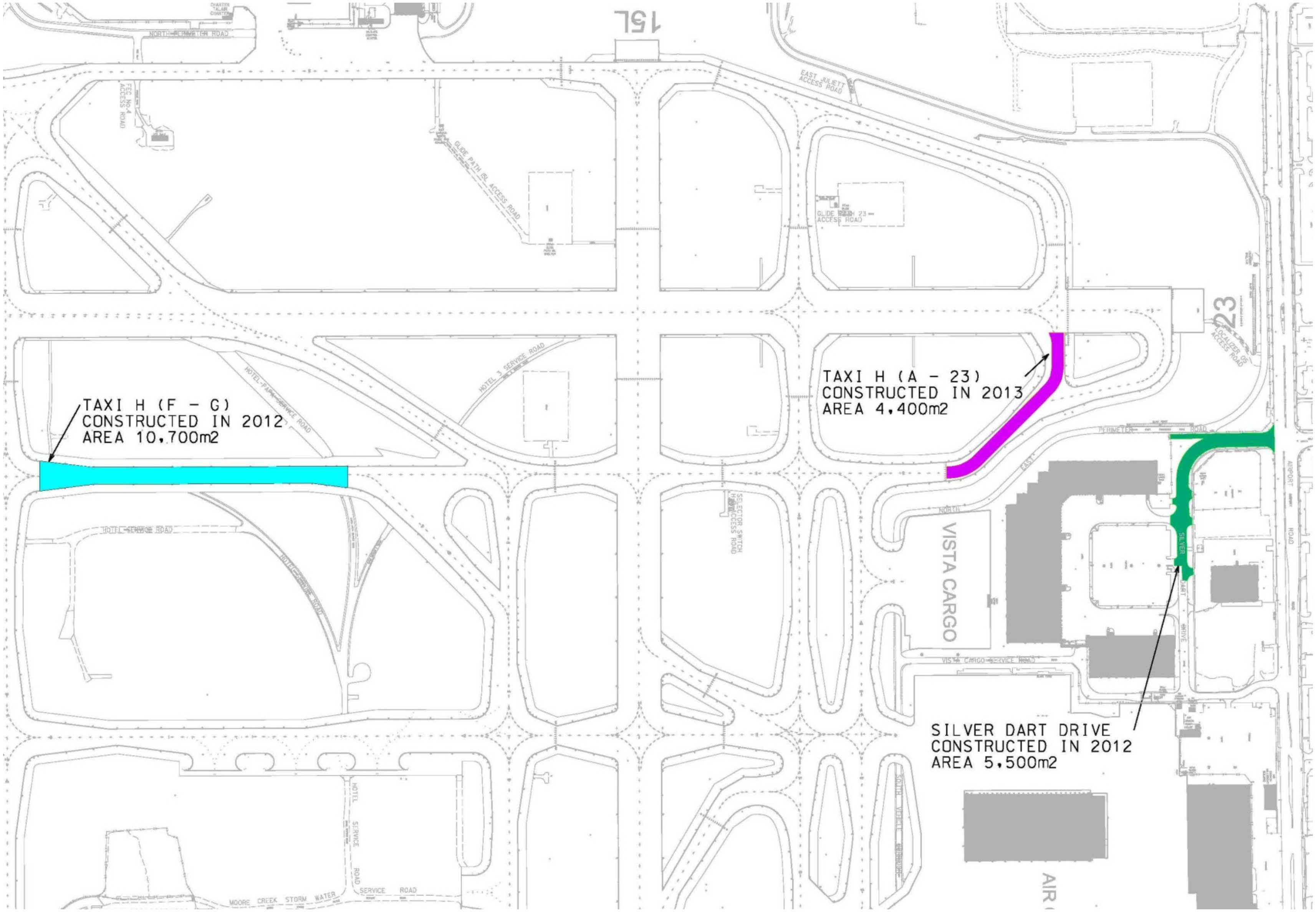
Based on this study, it is apparent that adopting Superpave specifications is feasible for the GTAA.

The results show that suitable mixes can be produced with local materials and the warm mix asphalt technology is also available for implementation.

The mixes tested show excellent rutting resistance and are expected to perform adequately on pavements in the holding areas with heavy and slow aircraft movements.

Field trials have been conducted at Silver Dart Drive and Taxi H in 2012 and 2013 respectively. Currently, the trial mix - SP 12.5B WMA w/RAP is performing well.

Field Trials – Locations Map



GTAA

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