Technical Paper

ISSN 1997-1400 Int. J. Pavement Res. Technol. 7(1):60-68

Performance Evaluation of Asphalt overlays in Alberta using Long Term Pavement Performance Specific Pavement Study 5 Sections

Meisam Norouzi[1], Somayeh Nassiri[1+], Negar Tavafzadeh Haghi[1], and Alireza Bayat[1]

Abstract: Performance data collected for the Long Term Pavement Performance program (LTPP)'s Specific Pavement Studies (SPS) 5 in Alberta was used to investigate overlay performance in Alberta's climate conditions. Comparison of peak deflection during the Falling Weight Deflectometer (FWD) test for different overlay sections with respect to the control section in seven test years showed that all overlays improved structural capacity of the pavement. The overlay thickness was found to be the most statistically significant factor to the pavement's structural response in comparison to pre-overlay conditions (milling) and asphalt mixture type. Further, overlay thickness and mixture type were found to be the most effective factors to alligator and transverse cracking, respectively. The Mechanistic Empirical Pavement Design Guide (MEPDG)-predicted International Roughness Index (IRI) was higher than the measured values in most years. The MEPDG-predicted pavement rutting was most sensitive to pavement structural design.

DOI:10.6135/ijprt.org.tw/2014.7(1).60

***Key words**: FWD, LTPP, Overlay, Pavement performance, Response, SPS 5.*

Introduction

Alberta Transportation invests nearly 50 percent of its annual budget to rehabilitate and maintain Alberta's highway network [1]. Based on the latest data available in Alberta Transportation's Pavement Management System (PMS) in 2010 approximately 50 percent of Alberta's highway network length was overlaid between year 1985 and 2010, implying that overlay construction is commonly practiced in Alberta as a rehabilitation strategy. Further, the average age of the network is 15.6 years [2], with 56 percent of the entire network length being 10 years or older, requiring rehabilitation in the future. Investigation and evaluation of in-service overlay performance over the years can greatly benefit the province's future decisions concerning several design factors, such as asphalt mixture, pavement structure and construction practices. A valuable source of information for such study is the Long-Term Pavement Performance (LTPP) program's (SPS) 5 in Alberta. The SPS 5 sections in Alberta joined the LTPP program in 1990 and has been regularly monitored and tested since.

Each SPS 5 section in the LTPP program consists of nine 152.4-m sections (500-ft) (Sections 501 to 509). The first section (501) is the control section, which receives no treatments during the monitoring period, while the other eight sections are overlaid with two different asphalt mixtures, at two different thicknesses and under two different pre-overlay conditions (milled and not milled). Table 1 presents a summary of the overlay characteristics for the nine sections. In this table, the Reclaimed Asphalt Pavement (RAP) is an asphalt mixture which includes 30 percent reclaimed asphalt material.

Several studies have been conducted on the SPS 5 sections across North America to investigate the effect of different overlay strategies on pavement performance. West et al. [3] used the latest recorded data for all the SPS 5 sections (total of 16 states in the United Sates and two provinces in Canada) to statistically compare the distresses observed for the nine sections. It was concluded in their study that mixture type and milling prior to overlay construction can greatly affect the pavement performance in terms of fatigue, transverse and longitudinal cracking. Their study also showed that overlay thickness does not have a significant effect on longitudinal cracking. In another study, Hall et al. [4] used the most recently updated measurements of the International Roughness Index (IRI) for all the SPS 5 sections across North America. Their study revealed that no significant difference exist between long-term IRI for the RAP versus virgin, as well as milled versus not-milled overlay sections. The effect of pre-overlay IRI, overlay age and average annual temperature was found to be considerable on long-term IRI. They also identified a correlation between the annual precipitation and the increase in long-term IRI for the virgin overlays. According to Hall et al. [4] the factors affecting long-term cracking are pre-overlay cracking, age and traffic loads during the

Table 1. Overlay Type and Thickness for Each SPS 5 Section in the LTPP Program.

Section No.	Overlay Asphalt Mixture Type	Overlay Thickness(mm)	Milled Prior to Overlay
501	Control Section- No treatment		
502	RAP	50	No
503	RAP	125	
504	Virgin	125	
505	Virgin	50	
506	Virgin	50	Yes
507	Virgin	125	
508	RAP	125	
509	RAP	50	

[1] University of Alberta, Markin/CNRL Natural Resources Engineering Facility, 9105 116th St, Edmonton, AB Canada T6G 2W2.

[+] Corresponding Author: E-mail somayeh@ualberta.ca

Note: Submitted January 22, 2013; Revised June 06, 2013; Accepted June 10, 2013.

service life; while mixture type or milling proved to have no effect on long-term cracking. In another effort to investigate the SPS 5 sections' performance, Carvalho et al. [5] used the distress data available over the pavement's life from Arizona's SPS 5 sections. They reported that in the long-run, sections overlaid with the virgin mixture are smoother than those overlaid with the RAP mixture. The latter sections also demonstrate higher rutting and longitudinal cracking. They also concluded that milling prior to overlay construction improves fatigue cracking performance and found that thin overlays (50 mm) demonstrate better short-term rutting; while thick overlays (150 mm) outperform the thin overlays in terms of long-term rutting and all other performance indicators.

The present study provides an in-depth evaluation of the performance of the SPS 5 sections in Alberta, using the Falling Weight Deflectometer (FWD) test data and distress records available for the sections between 1990 and 2006. The available data is implemented to first, investigate the statistical difference between the structural responses of different overlays to FWD loads in different years. Second, briefly compare long-term pavement performance in terms of alligator, transverse and longitudinal cracking and IRI for the nine sections. Lastly, the SPS 5 sections are simulated using the MEPDG to compare the MEPDG predictions to the distresses collected in the field for the SPS 5 sections in Alberta.

SPS 5 SectionS IN ALBERTA

The LTPP SPS 5 sections in Alberta are located in the westbound truck lane of Highway 16, Control Section 6, at approximately 3.5 km west of junction with Highway 32 and 36 km east of Edson [6]. The road section is considered a rural principal arterial intestate according to the LTPP database DVD Version 26 [7]. Table 2 presents the nine test sections in their order of appearance in the field along with the coordinates of the starting point and also the pavement structure for each section.

Existing Asphalt Concrete (AC) layer thickness (including the milled and replaced thickness for the milled sections) varies between 4.6 to 7 in. (117- to 178 mm) among the nine sections. Also, Sections 503, 504, 506 and 507 include a 1.9 to 2.8-in. (50- to 80-mm) Asphalt Treated Base (ATB) layer, while Sections 502, 508 and 509 do not include this layer. In addition, the Granular Base Course (GBC) varies from 11.6 to 14.9 in. for different sections. To consider the effect of variation in different layers of the pavement on the analysis conducted in this study, the concept of Structural Number (SN) from the American Association of Highway & Transportation Officials (AASHTO) 1993 Design Guide was employed [8]. In doing so, SN for each section was established using the following relation:

$$SN = a_{ol}D_{ol} + a_1 D_1 + a_2 D_2 + a_3 D_3 m_3 \tag{1}$$

a_{ol} = Structural coefficient for the overlay,
D_{ol} = Overlay thickness (inch),
a_i = ith layer coefficient,
D_i = ith layer thickness (inch),
m_i = ith layer drainage coefficient.

Overlay structural coefficient was defined as 0.4, based on the recommendations in Alberta Transportation (AT)'s Pavement Design Manual for a new AC layer in Alberta. The layer coefficient for the existing AC layer, a1, was defined as 50 percent of a new AC layer according to AASHTO Design Guide recommendations, since no distress record was available for the exiting AC layer. It should be noted that for the new sections, the layer coefficient of 0.4 was used for the portion of the existing AC layer that was milled and replaced with new AC. Other layers' coefficients, a2 and a3, were defined as 0.23, 0.14 for ATB and GBC, respectively, based on AT's design manual. The drainage coefficient was considered as 1.0 based on AT's recommendations for Alberta climate. The final SN for each section is provided in Table 2 As expected, the lowest SN of 3.6 was obtained for the control section, followed by SN of 4.0-4.2 for Sections 502, 505, 506 and 509 with thin overlays. Sections 503, 504, 506 and 507 with the thick overlay show the highest range of 4.9-6.4 for SN.

As part of the LTPP program, traffic data in terms of the Equivalent Single Axle Load (ESAL) was available for the test sections on the LTPP DVD Version 26 for the period between 1999 and 2008. As seen in Fig. 1, the kESAL/year is consistent for all the nine sections in each year. As shown in Fig. 1, kESAL/year for all the sections varies between 233 and 461 over the 10 years, with a one-percent average growth rate.

The SPS 5 sections in Alberta joined the LTPP program in May 1990 and the construction of the new overlay was completed in September 1990 (again, the control section did not receive an overlay). Since the completion of the overlay construction, each of the eight sections received different maintenance depending on their conditions. The most common treatments applied to the sections were crack sealing and pothole patching. Two of the sections, 502 and 509, reached the end of their service life in 2006, 16 years

Table 2. Coordinates and Pavement Structure for each SPS 5 Section in Alberta.

Section	Section Description	Latitude	Longitude	Pavement Structure	SN
501	Control section	53.58721	-116.02	6.3" AC/2.9" TB/11.6" GBC	3.6
505	VIR-2-N	53.58657	-116.022	2.1" AC overlay/6.1" Existing AC/2.3" TB/11.6" GBC	4.2
506	VIR-2-M	53.58586	-116.025	2.1" AC overlay/4.6" Existing AC/2" TB/13" GBC	3.7
507	VIR-5-M	53.58504	-116.027	4.7" AC overlay/5.6" Existing AC/1.9" TB/13" GBC	4.9
504	VIR-5-N	53.58277	-116.032	4.8" AC overlay/6.3" Existing AC/2.5" TB/11" GBC	6.0
503	RAP-5-N	53.58179	-116.034	5" AC overlay/5" Existing AC /2.8" TB/12.9" GBC	6.4
508	RAP-5-M	53.5808	-116.037	4.9" AC overlay/6.2" Existing AC/14.9 GBC	5.6
509	RAP-2-M	53.57963	-116.042	1.8" AC overlay/7" Existing AC/13.5" GBC	4.3
502	RAP-2-N	53.57894	-116.045	2" AC overlay/5.4" Existing AC/15" GBC	4.0

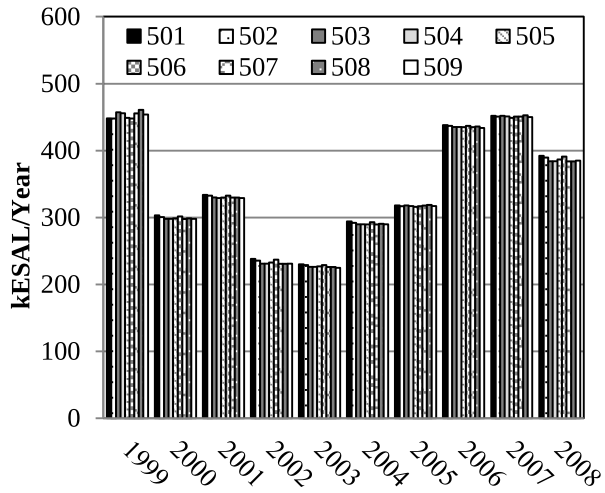

Fig. 1. kESAL/year from 1999 to 2008 for each SPS 5 in Alberta Extracted from LTPP Database.

after the overlay construction and were overlaid in fall 2006. This study focuses on the evaluation of the test sections during the period between 1990 and 2006. Alberta is located in Dry-Freeze climate zone. A summary of major climatic indices including mean monthly temperature, rainfall and snowfall and freezing index (FI), based on the weather data from 1971 to 2000 from a weather station located in Edson, Alberta is provided in Table 1 [9].

Effect of Overlay on Structural Response

Every two years, FWD tests were performed on Alberta's LTPP SPS 5 sections, since the completion of the overlay construction in 1990. The deflection measurements during the FWD tests were used herein to investigate the effects of different overlays on pavement structural responses. For this purpose, peak FWD deflection (measured underneath the plate load) was used as the structural response indicator for the pavement. The FWD tests on SPS 5 sections were performed at approximately 15-meter intervals at four different drop heights, resulting in four impact loads. Deflections corresponding to the 40 kN load drop, equal to one ESAL, were used for the analysis in this study. The deflections were normalized prior to analysis, whenever the applied load deviated from the target load by more than five percent, according to the American Standard for Testing and Materials (ASTM) D5858, Standard Guide for Calculating In Situ Equivalent Elastic Moduli of Pavement Materials Using Layered Elastic Theory [10].

To compare the deflections measured on each section to other sections, or to those for the control section, it was important to make sure that asphalt temperature remained the same for all FWD tests. Variation in asphalt temperature during FWD testing can greatly affect the peak deflections. For each section, asphalt temperature at different depths was measured once during each test and at one location. The time of temperature records for each section matched very well with the time of FWD testing for that section. Table 4 shows asphalt mid-depth temperature records for all nine sections in each of the test years. As seen in the table great variation is evident among the sections in one test year.

To isolate the effect of temperature on the peak deflections, asphalt mid-depth temperatures in Table 4 were used to adjust all the deflections to a reference temperature of 20°C. To do so, the model developed by Chen et al [11], as shown in Eq. (2) was used.

$$W_{T_w} = W_{T_c}\left(\frac{1.0823^{-0.0098\times t}}{0.8631}\right) \times T_w^{0.8316} \times T_d^{-0.8419} \qquad (2)$$

W_{T_w}: Deflection adjusted to temperature T_w(mm);
W_{T_c}: Deflection measured in the field (mm);

Table 3. Major Climatic Indices for Edson, Alberta from Environment Canada.

Climatic Index/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Temperature (°C)	-11.8	-9.2	-3.3	3.5	8.9	12.6	14.6	13.7	8.8	3.4	-6	-11.2	2
Rainfall (mm)	1.4	0.5	3	12.9	52.2	106.7	106.2	82.2	56.7	11.4	2.5	0.7	436.3
Snowfall (cm)	35.8	22.3	25.8	13.8	6.4	0	0	0.1	6.7	13.4	22.3	30	176.5
FI (°C-days)	369	263	131	22	0	0	0	0	1.3	28	197	355	1365

Table 4. Asphalt Mid-depth Temperature Records, Extracted from the LTPP Database.

	Asphalt Mid-Depth Temperature (°C)								
Section / Year	501	502	503	504	505	506	507	508	509
Section Description	Control Sections	RAP-2-N	RAP-5-N	VIRGIN-5-N	VIRGIN -2-N	VIRGIN -2-M	VIRGIN -5-M	RAP -5-M	RAP -2-M
1993	18.5	28.2	16.7	27.7	22.1	26.7	26.4	19.5	23.4
1995	15.7	24.3	18	13.8	19.5	23.6	23.3	19	23.1
1997	27.3	16.1	18.7	31.1	32.1	33.7	33.4	19.2	16.4
1999	17.6	16.8	20.6	18.7	24.9	28.1	35.5	21.8	13.8
2001	20.6	22.7	19.4	16.3	22.6	31.5	30.5	21.9	20.1
2003	22.6	31.1	27.6	26.5	25.5	26.9	24.6	25	27.2
2005	22.6	27.8	23.2	21.8	23.4	23.9	19	17.7	23.1

t: Asphalt thickness (mm);

T_d : Mid-depth asphalt temperature at time of FWD data collection (˚C);

T_w: Temperature to which deflection is adjusted (˚C).

The average temperature-adjusted peak deflection for each section in every test year is presented in Table 5. The control section (Section 501) shows higher average peak deflection in each year, when compared to the overlaid sections in the same year, except for Section 502 in 1997. The seven-year average peak deflection is also provided in Table 5 for all sections. The seven-year average peak deflection for the control section is 382 micron, which is higher than all other sections, showing the effectiveness of all overlay strategies on pavement structural response. Based on the seven-year average deflections, Section 508 (RAP-5"-Milled) is the most effective strategy showing a 54 percent decrease in deflection in comparison to the control section. The minimum overlay effect is observed for Section 502 (RAP-2"-Not Milled), which shows ten percent less deflection compared to the control section.

Next, the test sections were divided into three sets of pairs to investigate the effect of: asphalt mixture type (virgin versus RAP), overlay thickness (2-in. versus 5-in.) and milling before overlay construction on the pavement's structural response. To do so, a series of paired t-tests were conducted on each year's average peak deflection for each section; followed by another paired t-test on the seven-year average peak deflections to investigate the effect and significance of each overlay strategy on the pavement structural response during the monitoring period. Paired t-test can be used to establish whether two paired sets of data are significantly different from each other, with the assumption that the sets are independent and normally distributed. The Student's t-distribution confidence intervals can be used to determine the significance level of the difference. A large t-stat value yields a correspondingly small significance level (p-value). The acceptable p-value of 0.05 was used in this study. Therefore, the pairs resulting in p-values smaller than 0.05 were identified as significantly different from one another. The results of the t-tests for each pair are provided in Table 7 through Table 9.

First, the effect of asphalt mixture type on FWD deflections was investigated. As described previously, of the eight overlaid sections, four sections were made with the RAP and the other four sections comprised of the virgin mixture. Properties of both mixtures were extracted from the LTPP database and are summarized in Table 8. Penetration test results were slightly different between the two mixtures. Based on test results available in the LTPP online database, penetration was 66 for all the sections with the virgin mixture. Penetration test results were available only for one section with the RAP mixture and the values vary between 58 and 62. Asphalt gradation for the two mixtures is presented in Table 8 and is very similar between the RAP and virgin mixtures. Other properties of the two mixtures including binder content and air voids were similar for the two mixtures.

Table 7 presents the results of the t-tests performed on the four pairs with virgin and RAP asphalt mixtures for the two overlay thicknesses (thin: 2 in. and thick: 5 in.) and two pre-overlay conditions (milled and not-milled). Of the four pairs tested in Table 6, Case 502 vs. 505 shows the highest t-stat value at p-value equal to zero. This behaviour does not necessarily reflect the differences between the RAP and virgin mixtures. As seen in Table 5, Section

Table 5. Average Temperature-corrected Peak Deflections for each Section in each Test Year.

	Average Peak Deflections (μm)								
Section / Year	501	502	503	504	505	506	507	508	509
Section Description	Control Sections	RAP-2-N	RAP-5-N	VIRGIN-5-N	VIRGIN-2-N	VIRGIN-2-M	VIRGIN-5-M	RAP-5-M	RAP-2-M
1993	419	340	237	237	249	292	219	192	267
1995	420	328	190	205	229	269	182	170	254
1997	343	379	204	220	194	267	208	176	311
1999	428	361	213	201	210	277	208	178	295
2001	358	328	192	198	217	247	195	164	253
2003	362	339	238	212	215	303	247	176	280
2005	345	343	206	194	219	309	266	171	265
Average	382	345	211	210	219	281	218	175	275

Table 6. Properties of Asphalt Mixture for the RAP and Virgin Mix.

Asphalt Mixture Property	Value from LTPP Online Database		
Asphalt Grade	Pen 60-70 for Both RAP and Virgin		
		RAP	Virgin
Asphalt Aggregate Gradation	Cumulative % Retained 3/4 in. Sieve	0.0	0.0
	Cumulative % Retained 3/8 in. Sieve	16.0	19.0
	Cumulative % Retained #4 Sieve	22.0	17.0
	% Passing #200 Sieve	12.4	8.6
Asphalt Percentage Air Void	3.1% for RAP and 3.2% for Virgin		
Binder Content	5.4% for Both RAP and Virgin		

502 shows particularly high FWD deflections in comparison to all other sections and was one of the sections that received another overlay in 2006. No distress records were available to evaluate the pre-overlay conditions of the sections, however as it will be discussed in later sections (Fig. 2), Section 502 showed a relatively high IRI of 2.14 m/km before overlay construction. For the other three sections, no significant difference is evident between the FWD deflections for RAP and virgin mixtures.

When comparing two sections with similar asphalt mixtures and different overlay thicknesses, the thicker overlay is expected to perform better under any applied load. Table 7 shows the result of the comparison between the thick and thin overlay sections. The difference between the thin and thick overlays is very well observed for three of the four pairs. Only the 504 vs. 505 pair does not reflect the effect of a thicker overlay in reducing the deflections. The reason for this behaviour is potentially the pre-overlay conditions of Section 504. As seen in Fig. 2 Section 504 shows the highest IRI record of 2.6 m/km, when compared to all other sections.

Table 8 present the effect of milling on the pavement structural response for the sections overlaid with the virgin and RAP mixtures and at the two thicknesses of 50 and 125 mm. According to Table 2, of the four pairs tested, three show significant differences between the FWD deflections for the not-milled and milled sections. Two of the pairs prove that milling reduces the FWD deflections;

Table 7. Effect of Asphalt Mixture Type (RAP Versus Virgin) on Pavement Structural Response.

Overlay Thickness	FWD Test Year	t-Test Results for RAP Versus Virgin			
		Not Milled (Section 502 vs. 505)		Milled (Section 509 vs. 506)	
		t-stat	p-value	t-stat	p-value
Thin	1993	7.71	0.000	-1.94	0.013
	1995	11.10	0.000	-1.32	0.059
	1997	17.65	0.000	3.37	0.003
	1999	11.51	0.000	0.98	0.000
	2001	11.64	0.000	0.46	0.649
	2003	11.84	0.000	-1.21	0.124
	2005	12.84	0.000	-2.74	0.000
	Seven-year Average	11.89	0.000	-0.60	0.569
Thick		(Section 503 vs. 504)		(Section 508 vs. 507)	
	1993	-0.02	0.987	-4.57	0.000
	1995	-1.92	0.084	-3.32	0.007
	1997	-2.27	0.045	-5.37	0.000
	1999	1.35	0.207	-4.63	0.000
	2001	-0.47	0.648	-5.84	0.000
	2003	2.58	0.027	-9.60	0.000
	2005	1.17	0.270	-14.60	0.000
	Seven-year Average	0.37	0.721	-4.46	0.003

Table 8. Effect of Overlay Thickness (2 Versus 5-in.) on Pavement Structural Response.

Overlay Thickness	FWD Test Year	t-Test Results for Thin Versus Thick Overlays			
		Not Milled (Section 502 vs. 503)		Milled (Section 509 vs. 508)	
		t-stat	p-value	t-stat	p-value
RAP	1993	8.15	0.000	15.99	0.000
	1995	10.77	0.000	19.97	0.000
	1997	15.00	0.000	16.31	0.000
	1999	9.51	0.000	29.42	0.000
	2001	10.67	0.000	16.05	0.000
	2003	6.55	0.000	17.50	0.000
	2005	9.46	0.000	27.89	0.000
	Seven-year Average	15.96	0.000	14.94	0.000
Virgin		(Section 505 vs. 504)		(Section 506 vs. 507)	
	1993	1.44	0.179	7.10	0.000
	1995	4.23	0.002	6.52	0.000
	1997	-2.70	0.022	4.93	0.000
	1999	1.02	0.331	4.62	0.000
	2001	1.84	0.096	4.08	0.002
	2003	0.24	0.818	2.97	0.014
	2005	2.58	0.027	2.87	0.016
	Seven-year average	1.63	0.145	13.00	0.000

Table 9. Effect of Milling Prior to Overlay Construction on Pavement Structural Response.

Overlay Thickness	FWD Test Year	t-Test Results for Not-Milled Versus Milled Sections			
		Virgin Mixture (Section 505 vs. 506)		RAP Mixture (Section 502 vs. 509)	
		t-stat	p-value	t-stat	p-value
Thin	1993	-5.71	0.000	5.09	0.000
	1995	-3.84	0.000	6.40	0.000
	1997	-7.47	0.000	5.20	0.000
	1999	-5.05	0.00	4.08	0.000
	2001	-2.81	0.020	10.79	0.000
	2003	-6.14	0.000	3.82	0.000
	2005	-7.48	0.000	6.58	0.000
	Seven-year Average	-7.82	0.000	33.28	0.000
Thick		(Section 504 vs. 507)		(Section 503 vs. 508)	
	1993	1.86	1.739	9.41	0.000
	1995	4.00	0.003	5.38	0.000
	1997	1.53	0.157	5.05	0.000
	1999	-0.94	0.372	5.98	0.000
	2001	0.27	0.795	5.85	0.000
	2003	-3.06	0.012	8.01	0.000
	2005	-7.57	0.000	5.26	0.000
	Seven-year Average	-0.75	0.479	8.04	0.000

Table 10. Effect of Different Overlay Strategies on Alligator, Transverse and NWP Longitudinal Cracking in 2006.

Distress Type	Asphalt Mixture		Milling		Overlay Thickness	
	RAP	Virgin	Milled	Not-Milled	Thin	Thick
Average Alligator Cracking (% area)	34	25	26	32	34	24
Average Trans. Cracking (No. of Cracks/Section)	39	70	48	60	58	50
Average NWP Long. Cracking (m)	112	110	109	113	100	122

however Case 505 vs. 506 shows an opposite trend. The reason for the latter case's behavior is that as seen in Table 2, Section 506 although was milled and replaced with new AC has a SN of 3.7, compared to a SN of 4.2 for Section 505, which was not milled. The reason for the low SN for Section 506 is the thin existing AC layer. As for Case 504 vs. 507, again the poor pre-overlay conditions for Section 504 could have influenced the t-test results. It can be concluded based on the two compatible pairs (502 vs. 509 and 503 vs. 508) that milling prior to overlay can result in lower FWD deflections.

Effect of Overlay on Pavement Distresses

Based on the availability of data in the LTPP database, alligator, transverse and Non-Wheel Path (NWP) longitudinal cracking, as well as IRI for the pavement sections were used in the study to compare the performance of different overlaid sections. Distress records were not available for the control section, therefore, this section was only included in the IRI analysis. The effect of mixture type, overlay thickness and milling prior to overlay construction on long-term alligator, transverse and NWP longitudinal cracking is presented in Table 10.

The average 2006-alligator cracking for all four sections with the virgin mixture are compared to the four RAP sections in Table 10. The sections with the RAP mixture show approximately 10 percent more alligator cracking in comparison to the sections with the virgin mixture. This behaviour is not explained by the structural differences among the sections, since the average SN for the sections with the RAP mixture is higher than the virgin mixture by 0.4. The not-milled sections show approximately 6 percent more alligator cracking with respect to the milled sections. Lastly, the thinner sections show approximately 10 percent more alligator cracking compared to the thick sections.

Average transverse cracking in 2006 for all the four sections with the RAP mixture were proven to be almost half of that for the sections with the virgin mixture. Also, the sections which were not milled prior to the overlay construction, demonstrated 20 percent more transverse cracking in comparison to the sections which were milled. The thinner sections show 8 percent more transverse cracking with respect to the thick sections.

The effect of asphalt mixture type, milling prior to overlay and overlay thickness on NWP longitudinal cracking in 2006 was also investigated in Table 10. The sections made with the RAP and virgin mixtures demonstrate nearly similar amounts of longitudinal cracking. Milling too does not show much effect on longitudinal cracking. Finally, thick sections show nearly 20 percent more longitudinal cracking with respect to the thin sections.

Fig. 2 shows the IRI development in the outer wheelpath for the SPS 5 sections. Based on the Annual Average Daily Traffic (AADT) for the road section, Alberta Transportation uses an IRI trigger value of 1.9 m/km to identify the pavements to be considered for rehabilitation [12]. As seen in Fig. 2, of the nine sections, four sections (including the control section) demonstrate IRI values above 1.9 m/km in 2005 and 2006. For the rest of the sections and

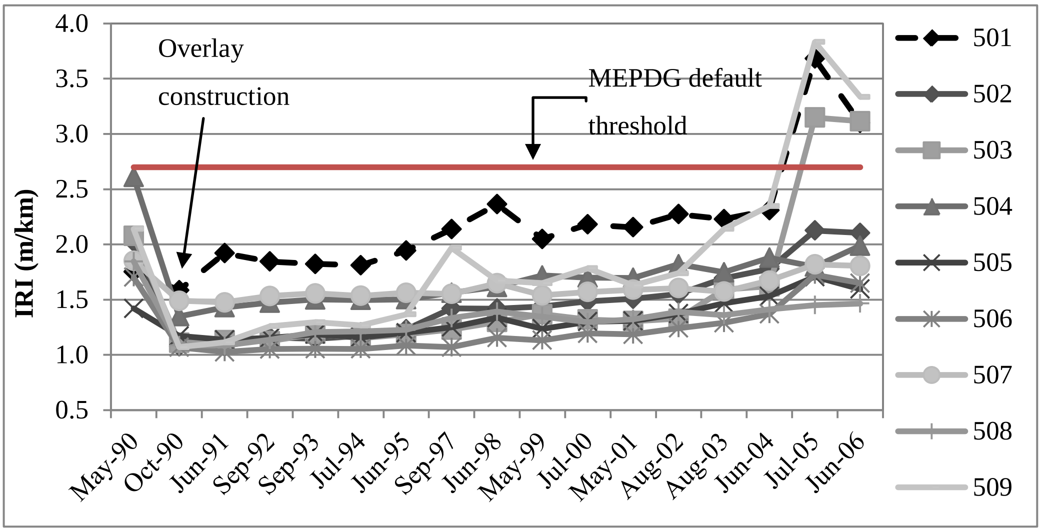

Fig. 2. IRI Measurements over Time for the Nine SPS 5 Sections in Alberta.

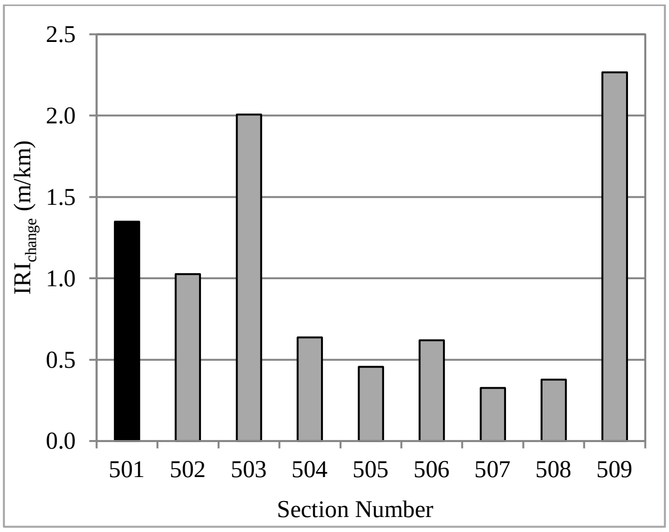

Fig. 3. IRI_{change} for the Nine SPS 5 Sections from 1990 to 2006.

years IRI is well within the acceptable range. The control section shows the highest IRI of all the section over the monitoring period, since it never received an overlay. As seen in Fig. 2 the post-overlay IRI values in 1990 are not the same for all the sections. In order to eliminate the effect of initial IRI on long-term IRI, IRI_{change} which is the difference between IRI in 2006 and the post-overlay IRI in 1990 was used to create Fig. 2.

Fig. 3 shows IRI_{change} for the nine sections. Three sections which received overlays with the RAP mixture (502, 503 and 509) demonstrate the highest IRI_{change} of 1, 2 and 2.27 m/km, respectively. Section 508, which was overlaid with the RAP mixture, is an exception from this trend and does not show a high IRI_{change} relative to the other sections. On the other hand, those sections that received the virgin mixture demonstrate considerably lower IRI_{change} of approximately 0.5 m/km. This agrees with Carvalho et al.'s findings that the sections with the virgin mixture are smoother in the long-term in comparison to the RAP sections. No special trend is evident in IRI_{change} to reflect the effect of overlay thickness or milling before paving.

COMPARISON with MEPDG Predictions

MEPDG Simulations

The test sections on the LTPP program played a key role in the development of the MEPDG performance models and are the best source for local calibration of the models. In this section the MEPDG Version 1.1 was used to predict the pavement performance for the Alberta's SPS 5 sections. The correspondence between the MEPDG-predicted performance indicators and those observed in the real world for the nine sections was investigated. The nine different sections were simulated using the MEPDG, based on the information presented in Table 1 for their structure. The default values available in the MEPDG were used to define all the required design inputs except for those listed in Table 11.

MEPDG Predictions

The MEPDG-predicted alligator cracking was obtained as zero for all the sections, which does not comply with the measured cracking of between 24 to 34 percent measured on the sections (Table 10). Fig. 4 shows the MEPDG-predicted versus observed IRI in each year from 1990 to 2006 for all the sections. It can be seen in Fig. 4 that the MEPDG mainly over-estimates the IRI values for the sections.

The MEPDG-predicted total pavement rut depth progression over the design life is presented in Fig. 5 for all the nine sections. Fig. 5 shows that none of the sections reached the MEPDG rut failure criterion of 19 mm. Overall, the MEPDG-predicted rutting is more sensitive to the pavement structure than the overlay mixture or pre-overlay conditions. Sections 502 and 509, which are thin overlay and do not have a TB layer in the pavement structure show similar trends. Additionally, Sections 505 and 506 with thin overlays and a TB layer demonstrate similar trends together. The best performing sections are Sections 503, 504 and 507 with thick overlays and an ATB layer. Section 508, another thick overlay section, which does not have a TB in the structure, shows a slightly

Table 11. Design Inputs and Their Values Used in the MEPDG.

Design Input	Value	Notes
Construction Year	Control Section:1976 Overlaid Sections:1990	From the LTPP DVD Version 26 and Alberta Transportation PMS
Initial AADT	8,000	AADT in 1990 was Backcalculated Based on 2010 AADT of 9,980 in 2010 PMS Report and Using the average Growth Rate from Fig. 1.
Condition Before Overlay	Fair or Poor	Defined Based on the Pre-overlay IRI for each Section
Milling Thickness	50 mm (2 in.)	From the LTPP DVD Version 26
Climate Data	Edson Weather Station Available in the MEPDG	The Climate Data Covers the Period Between 1960 and 1969. The Weather Station is Located 36 km West of the Test Section.
Initial IRI	1.07-1.59 m/km	IRI was Measured after Overlay Construction for each Section, from LTPP DVD Version 26.

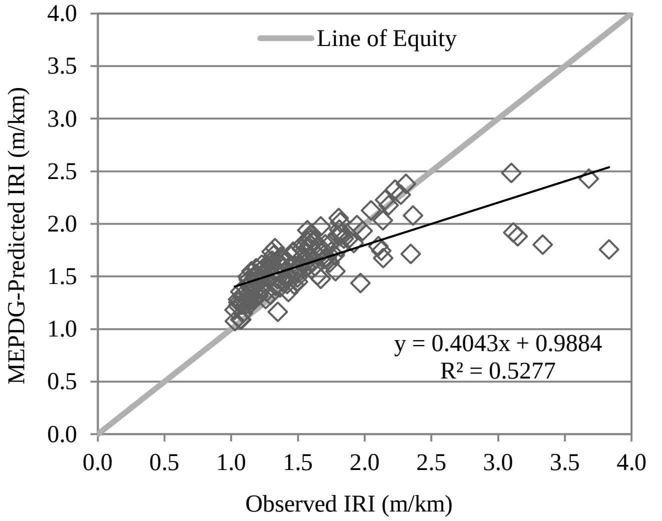

Fig. 4. Comparison of the MEPDG-predicted and Observed IRI in each Year for all Sections.

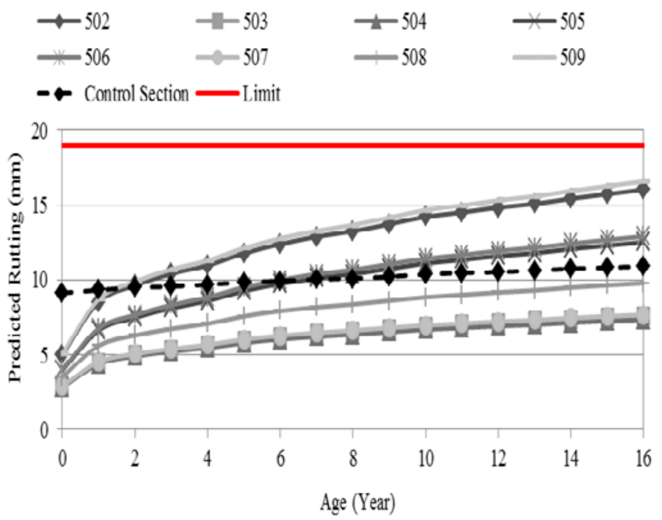

Fig. 5. MEPDG-predicted Total Pavement Rutting for the Monitoring Period.

higher rutting than the other three thick sections. The Control section has been in place since 1976. In 1990 the predicted rutting for the control section was reported as approximately nine mm, which increased by only one mm during the next 16 years as seen in Fig. 5.

Conclusions

The data available for the LTPP SPS 5 sections were used to investigate the performance of asphalt overlays in Alberta's climate conditions. The FWD deflection data was used to compare the effect of each overlay strategy on the structural response of the pavement. The long-term performance of each overlay strategy was also investigated using the distress data obtained from the LTPP database. Lastly, Alberta's SPS 5 sections were simulated using the MEPDG to investigate the accuracy of the performance predicted by MEPDG. The following conclusions were drawn from the study.

1. The control section showed higher FWD peak deflections for seven years of testing in comparison to the overlaid sections, which shows the effectiveness of all overlays.
2. Results of t-tests between paired overlay sections showed that thicker overlays show significantly smaller deflections under the FWD load. Milling reduced FWD deflections. Also, no significant difference was observed between the sections with the RAP and virgin mixtures in terms of FWD deflections. Pre-overlay conditions and variations in pavement structure along the road should be considered when comparing different sections' performances.
3. The sections with the RAP mixture showed half long-term transverse cracking than those with the virgin mixture, while they showed 10 percent more alligator cracking than the virgin mixture. Milling proved to decrease transverse and alligator cracking by 25 and six percent, respectively. The sections with thin overlays showed 10 percent more alligator cracking and 8 percent more transverse cracking with respect to the thick sections. The thin sections, however showed 22 m less non-wheelpath longitudinal cracking.
4. Higher IRI increase was observed for the sections with the RAP mixture in comparison to the sections with the virgin mixture, with the exception of one thick, milled section with RAP (508), which showed the same behaviour as the corresponding section with the virgin mixture.
5. The MEPDG-predicted IRI was higher than the observed IRI in all years for all the sections. Also, total pavement rutting predicted by the MEPDG were sensitive the pavement structure and overlay thickness rather than overlay HMA mixture or pre-overlay conditions.

Acknowledgment

The authors would like to acknowledge Mr. Chuck McMillan from Alberta Transportation for providing advantageous guidance in collecting some of the data for the Long Term Pavement Performance Sections in Alberta.

References

1. Soleymani, H.R., Keettikkal, T.P., and Igorevich, T.M. (2002). Serviceability Evaluation of the Primary Highways in Alberta. Annual Conference of the Canadian Society for Civil Engineering, 5-8 June, Quebec, Canada.
2. Gagnon, M., Gaudreault, V., and Overton, D. (2011). Age of Public Infrastructure: A Provincial Perspective. Statistics Canada, Investment and Capital Stock Division. Catalogue No. 11-621-MWE. No. 90. Published by the Minister responsible for Statistics Canada. © Minister of Industry A.
3. West, R., Michael, J., Turochy, R., and Maghsoodloo, S. (2011). Use of Data from Specific Pavement Studies Experiment 5 in the Long-Term Pavement Performance Program to Compare Virgin and Recycled Asphalt Pavements. *Transportation Research Record*, No. 2208, pp. 82–89.
4. Hall, K.T., Correa, C.E., and Simpson, A.L. (2003). Performance of Flexible Pavement Rehabilitation Treatments in the LTPP SPS-5 Experiment. Prepared for presentation at the 2003 Annual Meeting of the Transportation Research Board. Washington, DC, USA.
5. Carvalho, R., Ayres, M., Shirazi, H., Selezneva, O., and Darter, M. (2011). Impact of Design Features on Pavement Response and Performance in Rehabilitated Flexible and Rigid Pavements. Publication *FHWA-HRT-10-066*, Federal Highway Administration, U.S. Department of Transportation.
6. Kwan, A., and Stoski, R. (2007). Alberta Infrastructure and Transportation (Inftra) Technical Standards Branch (TSB) Newsletter, 6(1), pp. 1–8.
7. Long Term Pavement Performance. DataPave Online. www.datapave.com. Accessed September 7, 2012 and May 16, 2013.
8. American Association of State Highway, & Transportation Officials (1993). *AASHTO Guide for Design of Pavement Structures:* 1993 (Vol. 1), AASHTO, Washington, DC, USA.
9. Environment Canada (2013). Weather. Online. Available at: http://weather.gc.ca/canada_e.html. Accessed: January 2013.
10. ASTM Standard D5858 (2008). Standard Guide for Calculating In Situ Equivalent Elastic Moduli of Pavement Materials Using Layered Elastic Theory. West Conshohocken, PA: ASTM International. doi:10.1520/D5858-96R08
11. Chen, D.H., Bilyeu, J., Lin, H.H., and Murphy, M. (2000). Temperature correction on falling weight deflectometer measurements. *Transportation Research Record*, No. 1716, pp. 30-39.
12. Guidelines for Assessing Pavement Preservation Treatments and Strategies (2006). Alberta Infrastructure and Transportation. Edmonton, AB, Canada.