Assessing the Benefits of Ground Penetrating Radar Technology - Does it Improve the Accuracy of FWD Results and Overlay Design?

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Abstract

Falling Weight Deflectometer (FWD) testing is an integral component of many city's pavement and asset management programs. FWD testing is used by cities for both network and project level testing to assess the in-situ strength of the pavement structure and underlying subgrade soils. For project level testing, the correct Maintenance, Rehabilitation, or Reconstruction (M, R &R) strategy can be determined using deflection results obtained from the FWD.

One of the key data requirements for analyzing FWD data through "Backcalculation" is accurate pavement layer data. Many cities rely solely on as built data or core/bore data as an input for FWD Backcalculation. Since pavement thickness, material types, and composition can vary along the length of a roadway, some level of uncertainty is introduced in the analysis and design due to the lack of a continuous profile. More recently, Ground Penetrating Radar (GPR) technology is being used to provide a continuous layer profile and enhance FWD results.

As a part of this study, over 150 ln-km of roadways in Calgary, Alberta were surveyed with the GPR and FWD in 2010 and 2011. A number of cores were also advanced on all the surveyed roads for calibration purposes. The FWD data was backcalculated using the AASHTO 1993 methodology using three sets of pavement layer data. The first set was based solely on as built data; the second set relied on core data alone; and the third source relied on GPR data calibrated with cores. The required Overlay Thickness was calculated based on the three sets of pavement layer data and compared.

The results of the study demonstrate the benefits of using accurate pavement layer data for FWD analysis and helps reduce the chance of under or over designing the pavement M, R & R strategy. The study also demonstrates the value of collecting GPR data for municipal project level pavement evaluation.

1. Introduction

The City of Calgary is responsible for the administration of a roadway network consisting of Arterial, Collector, Local, and Industrial roads totalling approximately 4,400 centreline-kilometres. This network forms a valuable asset to be managed in a cost-effective manner in order to provide a desirable level of service to the stakeholders of the network.

Falling Weight Deflectometer (FWD) testing is an integral component of many city's pavement and asset management programs. FWD testing is used by cities for both network and project level testing to assess the in-situ strength of the pavement structure and underlying subgrade soils. For project level testing, the correct Maintenance, Rehabilitation, or Reconstruction (M, R &R) strategy can be determined using deflection results obtained from the FWD.

Pavement structural performance and rehabilitation designs are highly dependent on the in-situ layer thickness and material quality. Backcalculation analysis performed on deflection basin measurements is used to evaluate in-situ pavement structural capacity by estimating the in-situ pavement and subgrade moduli using an iterative process. Pavement layer thickness is an essential input into this analysis. Inaccurate layer thickness may lead to a significant error in the backcalculated layer moduli, and hence in the rehabilitation design [1].

Thickness of pavement layers is not constant along a project and always has some variability. Due to this variability, a certain level of uncertainty is introduced into the backcalculation and design analysis.

One issue facing pavement engineers is the availability of accurate layer thickness information that represents the in-situ conditions. Layer thickness information is obtained from as-built records or from coring/boring the pavement. Accurate as-built records cannot be easily obtained and when they are available, only general layer thickness information can be extracted from them. Cores/bores provide more accurate layer thickness information. However, the number of cores extracted per pavement section is usually limited because of the destructive nature of this operation. Also, cores/bores provide point-specific information about the in-situ layer thickness and not a continuous layer profile. Any variation in between points will not be considered as part of the analysis.

2. Objective

As a part of this study, over 150 ln-km of roadways in Calgary, Alberta were surveyed with the GPR and FWD in 2010 and 2011. A number of cores were also advanced on all the surveyed roads for calibration purposes. The FWD data was Backcalculated using the AASHTO 1993 methodology using three sets of pavement layer data. The first set was based solely on as-built data; the second set relied on core data alone; and the third source relied on GPR data calibrated with cores.

The objective of this paper is to demonstrate the benefits of using accurate pavement layer data for FWD analysis and reduce the chance of under or over designing the pavement M, R & R strategy.

3. Data Collection

Stantec Consulting Ltd. (Stantec) was retained by the City of Calgary to complete pavement data collection which includes both Ground Penetrating Radar (GPR) surveys and Falling Weight Deflectometer (FWD) testing with the intent of identifying the thickness and strength of the pavement structure for a number of roads, as presented below in Table 1.

Table 1: City of Calgary Data Collection – 2011 Test Sections

Road	To	From
1 Street SE	9 Avenue SE	17 Avenue
14 Street SW	Glenmore Trail	Anderson Road
144 Avenue NW	Rocky Ridge Road	Symons Valley Road
17 Avenue SW	14 Street W	Crowchild Trail
42 Avenue SE	Blackfoot Trail SE	Macleod Trail
50 Avenue SE	Ogden Road SE	52 Street SE
6 Avenue SW	Macleod Trail	11 Street SW
Centre Street N (Part 1)	Memorial Drive NE	24 Avenue
Centre Street N (Part 2)	64 Avenue	Beddington Trail
Centre Street SE	Riverfront Avenue SE	9 Avenue SE
Country Hill Boulevard N	Deerfoot Trail	84 Street NE
McKnight Boulevard NE	36 Street	52 Street NE
Southland Drive SW	Macleod Trail	14 Street SW

The FWD testing for the 2011 test sections was completed on August 18 to August 20, 2011. The GPR survey for the same test sections were completed on September 25, and 27, 2011.

All driving lanes between the limits were tested for each road presented in Table 1 above. The lane numbering convention as well as the locations and frequency for the GPR survey and FWD testing for the test sections are detailed below in Figure 1.

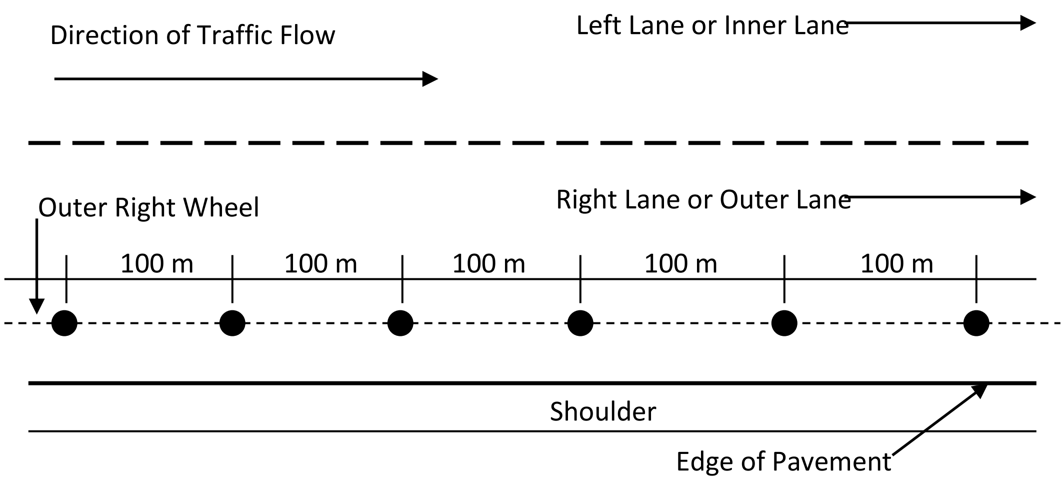

Figure 1: Lane Numbering, Test Frequency and Location

3.1. Ground Penetrating Radar Surveys

GPR testing was completed using a GPR system manufactured by Geophysical Survey Systems Inc (GSSI). It consists of a SIR-20 data acquisition system, a model 4105 2.0-GHz air coupled horn antenna, and a wheel-mounted distance measuring instrument (DMI). The GPR vehicle is equipped with a Trimble GPS system that simultaneously collects GPS coordinates. The quality of the GPS data depends on the satellite coverage within the area.

To collect high resolution GPR data for the asphalt concrete and granular layers, the antenna was set to collect at 15 nanoseconds. The transmission rate for the GPR data collection was set to 100 kHz. Data was collected at a scan rate of 6 scans per metre. The GPR data was saved to the laptop and backed up on a jump drive.

At the beginning of testing, the GPR antenna and DMI were calibrated. During data collection, the operator "flagged" the start and end of project within the data file. It is important to note that several factors can influence signal penetration and the quality of collected data. Pavements or base/subbase materials with high moisture contents adversely affect GPR signal penetration.

To limit or eliminate this problem, data was not collected during or immediately after a rain event. High frequency radio interference caused by overhead wires, cell phone towers, transmission lines, etc. can cause significant "noise" within a data file making it difficult to interpret. This problem is hard to avoid or prevent as these items are "fixed" and cannot be "removed" from the vicinity of the test section.

GPR data was processed using RADAN 6.6, GPR data reduction software developed by GSSI. GPR data is processed by identifying reflections caused by changes in the electrical properties (dielectric, electrical conductivity, etc.) of a material. The reflections are digitized and the software converts the digitized reflection into layer thicknesses. Once the layers have been identified the layer and thickness data was exported as an ASCII file. The exported GPR data was summarized and formatted as per the specifications outlined by the City of Calgary. GPR layer statistics including the minimum, maximum, average, and standard deviation are reported.

The GPR data was calibrated using ground truth information obtained by cores advanced through the pavement. The compilation of the coring data was completed by Stantec. The calibration process involves inputting a known layer thickness (core / borehole information) at a given point along the GPR survey, into the RADAN software to allow it to calculate the electrical properties for the specific pavement material present on site. RADAN selects the nearest core to calculate the electrical properties at each GPR scan. By default, the RADAN software will use an assumed average value for the electrical properties of the pavement materials if no ground truth information is available.

3.2. Core Calibration

Pavement coring on the test sections was completed and the cores obtained were used to calibrate and validate the interpreted GPR thickness data. In total, 26 cores were extracted from the test sections and used for calibration purposes.

3.3. Falling Weight Deflectometer Testing

The deflection testing was completed using a Stantec LTPP-SHRP calibrated Dynatest FWD equipped with a differential GPS. This FWD unit passed its annual FWD calibration (load cell and geophones) at the Harrisburg, Pennsylvania SHRP FWD Calibration Center in February, 2011. A relative sensor calibration was also completed in August, 2011 prior to the start of testing.

In general, FWD testing was completed in the outer right wheel path at an approximate interval of 100 m in each direction as presented in Figure 1 above. The test points were staggered between lanes and were referenced linearly to an initial starting point on the highway using a DMI, and spatially with GPS coordinates. A nine-sensor configuration was used to record the pavement deflections. The FWD sensor configuration used is presented in Table 2.

Table 2: FWD Sensor Configuration

FWD Sensor Number	1	2	3	4	5	6	7	8	9
Offset from FWD Load Plate [mm]	0	300	450	600	900	1200	1500	1800	-300

The loading sequence consists of a seating drop followed by three load applications at three target heights. The Standard Loading sequence is presented in Table 3.

Table 3: FWD Standard Loading Sequence

FWD Drop Sequence	FWD Target Height	FWD Load Level [lbf]
Seating Drop	1	40 kN
1	1	25 kN
2	2	40 kN
3	3	55 kN

The FWD being used is equipped with thermo sensors that automatically monitor air and pavement surface temperature at each test location and store them in the FWD data file. Our FWDs are also equipped with a Trimble satellite receiver that is linked to the FWDwin software. In total, over 1,400 FWD tests were completed in the test sections. As part of analysis methodology, all deflection measurements are normalized to a standard temperature of 20^{o} C and a correction factor of 0.33 was applied to the backcalculated subgrade moduli values.

4. Pavement Layer Information

The FWD data was backcalculated using the AASHTO 1993 methodology using three sets of pavement layer data. The following sources of layer information were used in the backcalculation analysis:

1. City of Calgary standard pavement sections determined by road classification
2. Core data only
3. GPR data calibrated with the extracted cores

The layer thicknesses from each data source are shown below in Table 4.

Table 4: Pavement Layer Thickness – By Data Source

Street	From	To	Case #	Asphalt Thickness (mm)				Granular Base Thickness (mm)			
				Min	Max	Avg	Std Dev	Min	Max	Avg	Std Dev
1 Street SE	9 Avenue SE	17 Avenue	1	200	200	200	-	150	150	150	-
			2	136	190	163	38.2	150	150	150	-
			3	120	307	201	43.7	193	500	329	66.6
14 Street SW	Glenmore Trail	Anderson Road	1	200	200	200	-	150	150	150	-
			2	286	307	196	14.8	150	150	150	-
			3	142	523	237	56.5	156	416	277	49.8
144 Avenue NW	Rockey Ridge Road	Symons Valley Road	1	150	150	150	-	150	150	150	-
			2	315	325	320	7.1	150	150	150	-
			3	170	394	271	53.4	131	415	276	47.8
17 Avenue SW	14 Street W	Crowchild Trail	1	200	200	200	-	150	150	150	-
			2	218	283	267	46.0	150	150	150	-
			3	77	388	236	70.9	139	434	291	63.0
42 Avenue SE	Blackfoot Trail SE	Macleod Trail	1	200	200	200	-	150	150	150	-
			2	183	264	223	57.3	150	150	150	-
			3	129	348	212	52.1	128	404	296	56.3
50 Avenue SE	Ogden Road SE	52 Street SE	1	150	150	150	-	150	150	150	-
			2	257	318	287	43.1	150	150	150	-
			3	49	534	262	66.7	131	399	276	53.5
6 Avenue SW	Macleod Trail	11 Street SW	1	200	200	200	-	150	150	150	-
			2	260	260	260	0.0	150	150	150	-
			3	23	422	232	67.2	64	405	287	58.0
Centre Street N 1	Memorial Drive NE	24 Avenue	1	200	200	200	-	150	150	150	-
			2	278	278	278	0.0	150	150	150	-
			3	155	402	251	54.9	156	362	265	55.5
Centre Street N 2	64 Avenue	Beddingt on Trail	1	200	200	200	-	150	150	150	-
			2	278	278	278	0.0	150	150	150	-
			3	106	501	300	42.2	108	406	264	48.5
Centre Street	Riverfront	9 Avenue	1	200	200	200	-	150	150	150	-

Street	From	To	Case #	Asphalt Thickness (mm)				Granular Base Thickness (mm)			
				Min	Max	Avg	Std Dev	Min	Max	Avg	Std Dev
SE	Avenue SE	SE	2	278	278	278	0.0	150	150	150	-
			3	136	378	259	80.0	147	440	303	59.4
Country Hill Boulevard N	Deerfoot Trail	84 Street NE	1	150	150	150	-	150	150	150	-
			2	208	228	218	14.1	150	150	150	-
			3	130	310	215	33.9	181	397	284	37.1
McKnight Boulevard NE	36 Street	52 Street NE	1	200	200	200	-	150	150	150	-
			2	264	302	283	26.9	150	150	150	-
			3	96	520	261	54.3	127	364	259	41.7
Southland Drive SW	Macleod Trail	14 Street SW	1	200	200	200	-	150	150	150	-
			2	177	355	221	125.9	150	150	150	-
			3	93	338	185	65.3	142	396	288	64.5

5. Analysis Results

The results of the AASHTO 1993 backcalculation and pavement evaluation analysis are presented in the following sections. The results are presented in terms of the in-situ subgrade resilient modulus (M_R), the effective pavement modulus (E_P) and the effective structural number (SN_{eff}), respectively.

5.1. Subgrade Resilient Moduli (M_R)

The backcalculated Subgrade Soil Resilient Modulus (M_R) for all sections is shown below in Table 5. A high subgrade resilient modulus is desirable to provide adequate support for the pavement structure and resist the permanent deformation under repeated traffic loading. Low subgrade resilient modulus is usually associated with weak and/or soft subgrade soil conditions.

The different layer thickness data sources had no effect on the calculation of the subgrade resilient modulus.

Table 5: Backcalculated Subgrade Resilient Modulus, M_R

Street	From	To	Source #	M_R [MPa]			
				Min	Max	Avg	Std Dev
1 Street SE	9 Avenue SE	17 Avenue	1	27	92	58	15.1
			2	27	92	58	15.1
			3	27	92	58	15.1
14 Street SW	Glenmore Trail	Anderson Road	1	25	117	57	15.7
			2	25	117	57	15.7
			3	25	117	57	15.7
144 Avenue NW	Rockey Ridge Road	Symons Valley Road	1	19	87	44	15.8
			2	19	87	44	15.7
			3	19	87	44	15.8

Street	From	To	Source #	M_R [MPa]			
				Min	Max	Avg	Std Dev
17 Avenue SW	14 Street W	Crowchild Trail	1	25	136	52	19.7
			2	25	136	52	19.7
			3	25	136	52	19.7
42 Avenue SE	Blackfoot Trail SE	Macleod Trail	1	25	189	71	30.0
			2	25	189	71	30.0
			3	25	189	71	30.0
50 Avenue SE	Ogden Road SE	52 Street SE	1	28	194	61	25.9
			2	28	194	61	25.9
			3	28	194	61	25.9
6 Avenue SW	Macleod Trail	11 Street SW	1	16	473	74	42.8
			2	16	473	74	42.8
			3	16	473	74	42.8
Centre Street N 1	Memorial Drive NE	24 Avenue	1	17	116	40	14.0
			2	17	116	40	14.0
			3	17	116	40	14.0
Centre Street N 2	64 Avenue	Beddington Trail	1	25	134	42	12.5
			2	25	134	42	12.6
			3	25	134	42	12.6
Centre Street SE	Riverfront Avenue SE	9 Avenue SE	1	38	126	72	17.8
			2	38	126	72	17.8
			3	38	126	72	17.8
Country Hill Boulevard N	Deerfoot Trail	84 Street NE	1	22	145	44	12.5
			2	22	145	44	12.5
			3	22	145	44	12.5
McKnight Boulevard NE	36 Street	52 Street NE	1	34	151	64	23.8
			2	34	151	64	23.8
			3	34	151	64	23.8
Southland Drive SW	Macleod Trail	14 Street SW	1	26	86	53	11.6
			2	26	86	53	11.6
			3	26	86	53	11.6

5.2. Effective Pavement Modulus (E_P)

The backcalculation results for the Effective Pavement Modulus of Elasticity (E_P) are below in Table 6. E_P is a representation of the overall pavement stiffness (the combined stiffnesses of all pavement layers above the subgrade) and is used to calculate the effective structural number. E_P values of new flexible pavements usually range between 1,000 to 1,700 MPa depending on the overall pavement thickness. High values of E_P indicate a stronger pavement structure.

The backcalculated E_P values were observed to be highly variable depending on the layer thickness data source used in analysis. The E_P values are dependent on the overall pavement thickness and the integrity of the pavement layers. The backcalculated values using Source #3 were observed to be more consistent overall than the other two layer thickness sources indicating a less variable pavement structure and thus a better data set.

Table 6: Backcalculated Effective Pavement Modulus, E_P

Street	From	To	Source #	E_P [MPa]			
				Min	Max	Avg	Std Dev
1 Street SE	9 Avenue SE	17 Avenue	1	396	6766	1492	1270.0
			2	446	7161	1696	1377.0
			3	336	3060	996	623.0
14 Street SW	Glenmore Trail	Anderson Road	1	232	4770	1272	642.6
			2	260	7028	1697	974.7
			3	224	3206	1129	472.6
144 Avenue NW	Rockey Ridge Road	Symons Valley Road	1	323	3314	1396	597.8
			2	278	1513	813	274.1
			3	267	1342	740	238.9
17 Avenue SW	14 Street W	Crowchild Trail	1	203	8272	1909	1491.2
			2	199	7611	1568	1277.1
			3	202	4515	1221	800.8
42 Avenue SE	Blackfoot Trail SE	Macleod Trail	1	93	3905	1201	752.9
			2	96	3890	1135	679.8
			3	100	3479	913	541.4
50 Avenue SE	Ogden Road SE	52 Street SE	1	316	6310	1633	911.3
			2	300	3277	1140	504.1
			3	290	2970	982	404.9
6 Avenue SW	Macleod Trail	11 Street SW	1	248	11783	2498	2067.8
			2	247	8159	2016	1494.2
			3	247	5626	1610	1107.6
Centre Street N 1	Memorial Drive NE	24 Avenue	1	92	15232	1543	1850.1
			2	88	10194	1157	1244.9
			3	89	7865	974	986.3
Centre Street N 2	64 Avenue	Beddington Trail	1	186	5269	1650	1255.6
			2	190	4085	1350	949.7
			3	186	2592	1017	620.1
Centre Street SE	Riverfront Avenue SE	9 Avenue SE	1	349	4382	1859	1033.2
			2	328	3198	1466	736.6
			3	325	2522	1209	563.8
Country Hill Boulevard N	Deerfoot Trail	84 Street NE	1	275	3772	1164	734.1
			2	247	2560	882	484.6
			3	230	1835	683	318.3

Street	From	To	Source #	E_P [MPa]			
				Min	Max	Avg	Std Dev
McKnight Boulevard NE	36 Street	52 Street NE	1	478	5489	1734	830.5
			2	432	3675	1348	536.8
			3	396	3279	1187	480.0
Southland Drive SW	Macleod Trail	14 Street SW	1	297	3198	1075	588.2
			2	302	3627	1082	635.7
			3	282	1889	829	361.9

5.3. Effective Structural Number (SN_{EFF})

The backcalculation results for the Structural Number are provided in Table 7. The effective strength or structural capacity of the existing pavement layers is traditionally represented by the effective structural number. Low SN_{EFF} values indicate low structural capacity of the pavement structure; while, high SN_{EFF} values indicate high structural capacity of the pavement structure.

In all but one case, the average SN_{EFF} values backcalculated, using Source #3, were higher than the SN_{EFF} values using the other two sources. This would indicate that Sources 1 and 2 both underestimate the structural number of the existing pavement and can lead to over-designing or being too conservative with a reconstruction or rehabilitation strategy.

Table 7: Backcalculated Effective Structural Number, SN_{EFF}

Street	From	To	Source #	SN_{eff}			
				Min	Max	Avg	Std Dev
1 Street SE	9 Avenue SE	17 Avenue	1	61	157	90	20.9
			2	52	155	84	22.4
			3	86	213	121	26.5
14 Street SW	Glenmore Trail	Anderson Road	1	53	158	96	17.3
			2	63	174	111	18.1
			3	69	235	125	23.3
144 Avenue NW	Rockey Ridge Road	Symons Valley Road	1	49	106	78	11.9
			2	73	129	102	11.9
			3	77	157	115	15.7
17 Avenue SW	14 Street W	Crowchild Trail	1	49	167	97	23.0
			2	60	171	108	22.6
			3	65	4515	128	28.8
42 Avenue SE	Blackfoot Trail SE	Macleod Trail	1	38	130	85	17.5
			2	45	142	89	19.1
			3	57	168	113	22.4
50 Avenue SE	Ogden Road SE	52 Street SE	1	48	131	81	13.0
			2	74	164	106	15.5
			3	70	185	124	20.3

Street	From	To	Source #	SN_{eff}			
				Min	Max	Avg	Std Dev
6 Avenue SW	Macleod Trail	11 Street SW	1	52	188	105	28.2
			2	61	195	116	28.3
			3	80	219	137	30.6
Centre Street N 1	Memorial Drive NE	24 Avenue	1	37	205	415	26.6
			2	45	219	99	27.5
			3	51	239	113	31.7
Centre Street N 2	64 Avenue	Beddington Trail	1	47	144	92	24.3
			2	58	162	106	25.7
			3	73	198	129	31.5
Centre Street SE	Riverfront Avenue SE	9 Avenue SE	1	58	135	98	19.8
			2	70	149	111	20.4
			3	80	178	138	24.6
Country Hill Boulevard N	Deerfoot Trail	84 Street NE	1	46	110	72	14.1
			2	53	122	81	14.5
			3	58	160	102	18.3
McKnight Boulevard NE	36 Street	52 Street NE	1	65	146	97	14.4
			2	74	165	112	16.4
			3	89	177	128	17.4
Southland Drive SW	Macleod Trail	14 Street SW	1	55	122	82	14.4
			2	52	138	86	17.8
			3	72	152	103	18.7

6. Case Study – 14 Street SW

14 Street SW in Calgary is a 4-lane divided road and can be classified as an arterial road. This simple case study will attempt to show the difference in using the three different layer thickness data sources to perform a rehabilitation design and highlight any differences in design and cost.

The average layer thicknesses for 14 Street SW are presented graphically in Figure 2 below. Sources 1 and 2 are fairly similar in thickness with approximately 200 mm of asphalt and 150 mm of granular base material. Source 3, on the other hand, is comprised of approximately 240 mm of asphalt and 280 mm of granular base material on average.

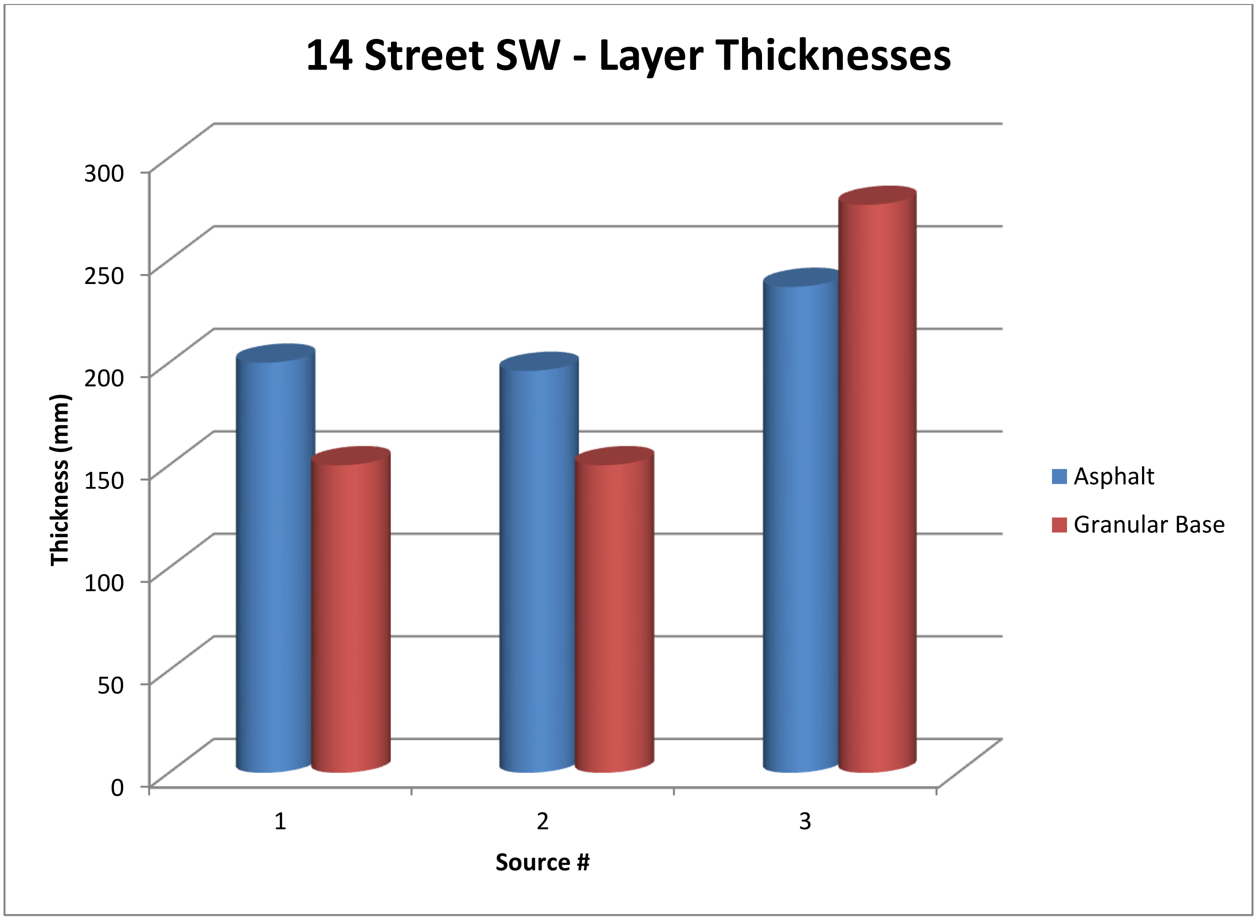

Figure 2: 14 Street SW – Layer Thicknesses by Data Source

The following parameters were used to calculate the Design Structural Number (SN_{req}) for 14 Street SW using the AASHTO 1993 empirical equations for flexible pavements:

- Total design ESALs – 10 million
- Reliability – 95%
- Initial Serviceability - 4.5
- Terminal Serviceability – 2.5

The design structural number, SN_{req}, was found to be 117. From Table 7, shown above:

Table 8: 14 Street SW – Backcalculated Effective Structural Number, SN_{EFF}

Street	From	To	Source #	SN_{eff}			
				Min	Max	Avg	Std Dev
14 Street SW	Glenmore Trail	Anderson Road	1	53	158	**96**	17.3
			2	63	174	**111**	18.1
			3	69	235	**125**	23.3

6.1. Source 1 – Overlay Design

The backcalculated SN_{EFF} using Source 1 layer thickness data was found to be 96.

$$SN(needed) = 117 - 96 = 21$$

$$Overlay\ Thickness = \frac{21}{0.42} = 50\ mm$$

Using an AASHTO 1993 layer coefficient of 0.42 for new asphalt, 14 Street SW would need approximately an AC overlay of 50 mm.

6.2. Source 2 – Overlay Design

The backcalculated SN_{EFF} using Source 1 layer thickness data was found to be 111.

$$SN(needed) = 117 - 111 = 6$$

$$Overlay\ Thickness = \frac{6}{0.42} = 14.3 \approx 15\ mm$$

Using an AASHTO 1993 layer coefficient of 0.42 for new asphalt, 14 Street SW would need approximately an AC overlay of 15 mm.

6.3. Source 3 – Overlay Design

The backcalculated SN_{EFF} using Source 1 layer thickness data was found to be 125. Since the $SN_{EFF} > SN_{req}$ no overlay is required when using Source 3 layer thickness data.

6.4. Cost Comparison

14 Street SW from Glenmore Trail to Anderson road is approximately 5 km long and has two lanes in each direction, for a total of approximately 20 ln-km. Assuming 3.8 m wide lanes, the total area of rehab is approximately 76,000 m^2.

The following unit prices and material parameters were used for cost comparison purposes:

- Superpave 12.5 FC1 - $120/t
- Superpave 12.5 FC1 unit weight – 2.55 t/m^3

6.4.1. Cost Estimate – Source 1

A total overlay of 50 mm using Superpave 12.5 FC1:

$$Source\ 1\ (cost) = \frac{\$120}{t} \times \frac{2.55t}{m^3} \times 0.05m \times 76000m^2 = \mathbf{\$1,162,800}$$

6.4.2. Cost Estimate – Source 2

An overlay of at least 30 mm using Superpave 12.5 FC1 would need to be used for the Source 2 rehabilitation strategy:

$$Source\ 2\ (cost) = \frac{\$120}{t} \times \frac{2.55t}{m^3} \times 0.03m \times 76000m^2 = \$\mathbf{697,680}$$

6.4.3. Cost Estimate – Source 3

No overlay was required when using Source 3 layer thickness data.

6.5. Cost Comparison Summary

Using accurate layer thickness data can make a significant difference during rehabilitation analysis, as shown above. Many cities rely solely on as built data or core/bore data as an input for FWD backcalculation. In the case of 14 Street SW, using these typical data sources may have cost the City of Calgary $700,000 to $1.2 million dollars depending on the source used to develop a rehabilitation strategy for 14 Street SW from Glenmore Trail to Anderson Road. Conversely, using Source 3 for rehabilitation design would have shown that 14 Street SW was structurally adequate for the design traffic of 10 million ESALs.

7. Discussion

Using the AASHTO 1993 methodology, the subgrade resilient modulus, effective pavement modulus and effective structural number were determined using backcalculation. As shown in Table 4 above, the subgrade resilient modulus was not affected by the varying pavement thicknesses when using different sources of layer information. However, there was a significant difference in the backcalculated E_P and effective structural numbers throughout every pavement section.

Large variations were observed in the backcalculated E_P data, however Source #3 (GPR data calibrated with extracted cores) had the smallest standard deviation in all cases. This would indicate a more consistent data set.

An interesting trend was observed when analyzing the backcalculated effective structural numbers of the various pavement sections. In all but one case, the effective structural number backcalculated using the GPR data calibrated with cores was observed to be higher than the backcalculated effective structural numbers using the other two sources of pavement layer data. This would indicate that backcalculation utilizing layer thicknesses extracted from standard designs and core data produces underestimated effective structural numbers, which in turn would lead engineers to designs that are too conservative. This can have a very large impact on the cost of the selected M, R & R strategy depending on the size of the network in the analysis.

8. Conclusion

Overall, the results of the study demonstrate the benefits of using accurate pavement layer data for FWD analysis to help reduce the chance of under or over designing the pavement M, R & R strategy. The study also demonstrates the value of collecting GPR data for municipal project level pavement evaluation.

References

1. Zaghloul, S. M., He, W., Kerr, B., and Vitillo, N., "Project Scoping using FWD Testing - New Jersey Experience," Transportation Research Record (TRR) 1643, Transportation Research Board (TRB), Washington, DC, 1998, page 34-43.