The Minimum Thickness of Asphalt Concrete Layer for the Design of Flexible Pavement on Low Volume Roads Using the PMED Software

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Abstract

A large portion of Canada’s highway network is low traffic volume roads with thin pavement structures. Currently, no generally accepted design method is available for these roads. As such, pavement design and/or construction methods vary widely among the jurisdictions. The AASHTO 1993 guide recommends the same design approach for thin asphalt (<100 mm asphalt) pavements as the conventional flexible pavements, but with a lower level of reliability. These design outcomes are cost prohibitive in most cases considering traffic uses. This paper examined the suitability of the AASHTOWare Pavement ME Design (PMED) software for the design of thin asphalt pavements.

In 2022, the Transportation Association of Canada (TAC) Mechanistic-Empirical (ME) Pavement Design Subcommittee completed extensive design trials for thin asphalt concrete (AC) pavements using the PMED software. These design trials used varying climate data across Canada, subgrade soil types, base/subbase thickness combinations, and asphalt concrete (AC) thicknesses that ranged 50 mm to 150 mm. The trial results have shown uniform trends of the predicted total rutting when the AC layer thicknesses were ≥60-80 mm, depending on the subgrade stiffness. Uniform trends for the predicted bottom-up fatigue cracking were observed when the AC thicknesses were ≥100-105 mm. The predicted AC layer rutting were inconsistent among the design variables. There was no noticeable effect of varying AC layer thickness on the predicted top-down fatigue cracking.

Very good correlations (with R^2 values >0.98) were observed between the AC layer thickness and the predicted IRI as well as between the AC layer thickness and the predicted total rutting. Overall, these trial results indicated that PMED software can be used to design pavements with a minimum AC thickness of approximately 100 mm (4 in.) considering all type of distresses. However, considering only the IRI and total rutting criteria and ignoring small irregularities in the trends of predicted IRI and total rutting in pavement designs for low traffic volume roads, an AC thickness of as low as 50 mm could be used when using the PMED software.

Acknowledgement

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Introduction

A large portion of Canada’s highway network is comprised of low traffic volume (simply called “low volume”) roads with thin asphalt concrete (AC) surfacing layers and pavement structures. However, the definitions of a thin AC surfacing layer and a thin pavement structure vary depending on the jurisdiction. Typically, a thin AC surfacing layer is less than 50 mm in thickness [1, 2]. Thin AC surfacing layers are used as a wearing surface course, as an alternative to chip seal (seal coat) or thick bituminous course, primarily to provide a smoother ride together with a dust free surface, and lower maintenance requirements on low traffic volume roads. They generally do not provide a considerable structural strength to the pavement structure to withstand heavy loading and are not designed for high truck traffic, especially during the spring thawing seasons. Currently, no generally accepted design method is available for these roads. As such, the pavement design methods or the selected thicknesses of surface and base layers vary widely among the jurisdictions.

Standard flexible pavement design methods such as the AASHTO 1993 (3] pavement design guide provides pavement structures with desired materials and layer thicknesses to meet certain structural number requirements, which are based on the selected design reliability, desired service quality (serviceability index) at the end of design service life, estimated axle load repetitions over the design service life and subgrade stiffness. The AASHTO 1993 [3] guide recommends a minimum of 25.4 mm (1 in.), 50.8 mm (2 in.) and 63.5 mm (2.5 in) AC surface layer for design equivalent single axle loads (ESALs) of ≤50,000, 50,001 to 150,000, and 150,001 to 500,000, respectively. However, the calculated thickness of base layer (and subbase layer, where used) with such thin AC layers to meet the structural number requirements are higher than that agencies typically use to construct these thin AC surfaced low volume roads. As such, the AASHTO 1993 pavement design method is not generally applicable to pavement design with thin AC surface layers from economic perspective, especially with the available low budgets for these roads.

As thin AC surfaces are generally not considered structural layers, the mechanics of thin AC surfacing layers are generally different from conventional (thick) AC surfacing layers. However, all AC surfaces are subject to tensile strain at the bottom of the asphalt mat, with the primary failure mode being the fatigue cracking. The tensile strain at the bottom of the AC mat increases with a reduction in asphalt thickness, which results in higher risk of fatigue cracking at the bottom of a thin AC mat that propagates quickly to the surface. While both thin and conventional thick AC surfaces are subject to fatigue cracking propagating from the bottom of the AC mat, thin AC surfaces are also subject to high shear forces at the interface of the AC mat and granular base course. Capturing this issue during the design process will help pavement engineers understand how a thin AC surface will perform in the field.

Thin AC surface layers can provide cost-effective pavement structures because they consume less asphalt binder and aggregate materials and cost less as compared to the conventional AC pavements, and reduce maintenance requirements while providing smother and dust free i.e., lower fuel consuming, more comfortable, faster and safer ride as compared to the gravel surfaced roads. In practice, there is a balance in pavement design to optimize thin AC surface layers' performance with local traffic, environmental conditions and material durability. The AASHTOWare PMED software can be used for the design and analysis of different types of pavement structures. This software is known to be more applicable to AC surfaces with a minimum thickness of 100 mm (4 in.) since the calibration coefficients were derived from flexible pavements with a minimum total AC thickness of 4 in. (100 mm) [4]. . The software enables designers to use different asphalt mix types and multiple layers in the design process. However, the suitability of this software for AC surfaces less than 100 mm in thickness is not well known. The design trials completed for this paper attempted to assess the suitability of the PMED software for the design and analysis of thin asphalt pavements.

Background

The TAC ME Pavement Design Subcommittee has been evaluating the AASHTOWare PMED software since 2007. A number of design trials were completed to assess effect of traffic loading, asphalt mix properties, asphalt binder and thickness, subgrade, subbase and base materials, and concrete slab and joint designs on the predicted distresses. The identified issues from these trials were brought forward to AASHTO PMED Task Force and the software developer, Applied Research Associates (ARA). Recently, the Subcommittee also completed additional design trials to assess the effect of subgrade, subbase and base materials and concrete mix properties on the PMED predicted distresses in rigid pavements. The results of all these trials can be found in different technical papers presented at this and other conferences.

In February and March 2022, extensive design trials were completed to assess the suitability of the PMED software for thin (<100 mm AC) flexible pavement design with different climatic inputs from 14 weather stations across Canada. The design trials included: i) two untreated native subgrade (high plastic clay and silty sand) soils with resilient moduli values of 35 and 60 MPa, respectively, ii) 100 mm granular base with 100 mm subbase and 150 mm granular base with no subbase, and iii) varying AC thickness from 50 mm to 150 mm (in 5 to 30 mm increments). This paper presents the results of these trials and discusses the issues and suitability of the AASHTOWare PMED software for the design and analysis of thin asphalt pavements for low volume roads.

Findings from Literature Review

Pavement design methods comprise two main groups: empirical methods and mechanistic-empirical methods, also called analytical or rational methods [5]. The empirical methods include those based on the subgrade engineering classification (Bureau of Public Roads), the relative shear resistance of the soil (California Bearing Ratio or CBR), and road experiments such as the WASHO Road Test (1952-1955) and the AASHO Road Test (1958-1962). These design methods consider the observed behaviour of in-service pavements under various traffic, environmental, and materials conditions [6].

Although the AASHO method has a robust empirical component, its successive versions incorporated mechanistic analysis to interpret and extrapolate the results from the original Road Test (1958-1962) on asphalt pavements. In the latest version (i.e., AASHTO 1993), the design method incorporated mechanistic concepts into a "semi-empirical" approach. As mentioned earlier, the AASHTO 1993 [3] pavement design guide recommends a minimum of 25.4 mm (1 in.), 50.8 mm (2 in.) and 63.5 mm (2.5 in.) thick asphalt surface layers for a design ESALs of ≤50,000, 50,001 to 150,000, and 150,001 to 500,000, respectively. Unlike the AASHTO method, Asphalt Institute (AI) pavement design method [7] is a mechanistic-empirical method that relies on pavement responses in terms of calculated stress, strain and deflection in pavement structures due to traffic loading and environmental conditions using theoretical response model. This procedure attempts to limit the distresses such as fatigue cracking and rutting to pavement within the desirable tolerances. Fatigue cracking and rutting are considered to be the most critical distresses for pavement failure in AI method. AI method recommends a minimum thickness of asphalt concrete, placed over an untreated base layer, of 76.2 mm (3 in.), 101.6 mm (4 in.) and 127 mm (5 in.) for a design ESALS of ≤10,000; between 10,000 and 1,000,000; and >1,000,000 respectively.

Shell design method was developed in the 1970s. It was the first mechanistic design method providing a procedure that was no longer based on codification of historical experience but instead that permitted computation of strain levels at key positions in a pavement structure [8]. Shell design method provides nominal thickness values for pavement structures. These values must be corrected in order to take into account thickness tolerances upon laying.

A review of Austroads method [9] reveals that where the asphalt thickness is less than 150 mm, the granular base layer(s) provides a substantial proportion of the load carrying capacity and both deformation and fatigue distress mechanisms of pavement failures are possible. Therefore, the asphalt and granular base materials must be of appropriate quality to ensure the intended service life results.

A study conducted in Arkansas [10] investigated flexible pavement designs for low, medium, and high-traffic volume levels at different locations using the AASHTO 1993 method and AASHTOWare PMED software. The results from the PMED software revealed that an asphalt layer of 50 mm (2 in.) over 150 mm (6 in.) of granular base is adequate for roads with low traffic volume based on the terminal IRI of 3.16

m/km, total rutting of 15 mm, and fatigue cracking of 45%. Similarly, in Louisiana, Wu et al. [11] compared the performance of flexible pavement designs with different asphalt concrete layer thicknesses using the PMED software. The study concluded that variation in the required asphalt thickness could depend on several factors, such as traffic volume, subgrade soil type and climate. Their findings showed that the minimum asphalt thickness for roads with low traffic volume ranged from 50 mm (2 in.) to 115 mm (4.5 in.) based on the terminal IRI of 3.16 m/km, total rutting of 16 mm, and fatigue cracking of 35%.

Other mechanistic-empirical (ME) design methods were also used for analysis and design of thin asphalt for low volume roads. In a study in Germany [12], a ME method was used to investigate the use of thin asphalt (10 mm chip seal to 40 mm AC) thickness, with 200 mm to 600 mm unbound granular layer (UGL), for very low traffic volume (less than 100,000 10-t standard axles). The study considered permanent deformation in the base layer and subgrade as the governing criteria. The authors concluded that an asphalt layer of less than 50 mm could be used for these roads, when proper base support is placed beneath the asphalt layer, provided that the plastic deformation or rutting in the top 300 mm of the UGL does not exceed 15 mm.

Objective, Significance and Scope

As indicated earlier, AASHTOWare PMED software focused the design and analysis of conventional flexible pavements with asphalt layer thickness of 100 mm (4 in.) or greater [4]. A limited number of studies evaluated the suitability of the PMED software for designing thin asphalt pavements for low volume roads. These studies generally indicated that the PMED software can be used for designing asphalt pavement with a thickness of as low as 50 mm based on the total rutting criteria of 15 to 16 mm and fatigue cracking of 35 to 45 percent. However, there is a need for further investigation into the application of PMED software for designing thin asphalt pavements for low volume roads considering all the distresses, particularly to limit the fatigue cracking that are typically experienced on many of these roads, in addition to the rutting.

The objectives of the design trials completed and presented in this paper are to assess, in a systemic manner, i) the effect of varying asphalt layer thickness on the predicted distresses on low traffic volume roads; ii) the effect of different subgrade, subbase and base materials on the predicted distresses on low traffic volume roads; and iii) determine the minimum asphalt thickness that can be used in the PMED software based on different distress criteria. The objective of this paper is to present the details of the completed trial results, analysis and recommendation. The presented information may help different agencies and other interested individuals understand the advantages and limitations of the PMED software and assess the suitability of the software for designing thin asphalt pavements for low traffic volume roads.

The design trials conducted in this study have strictly looked into the trends of the predicted distresses for the variations in AC, base and subbase layers as well as the climatic exposures to examine the suitability of the PMED software for the design and analysis of thin flexible pavement structures. There was no direct assessment or analysis in this study to determine the required minimum pavement structure, which will meet a specific traffic loading, subgrade stiffness and properties, and climatic condition. Such a day to day design and analysis of thin pavement structures on low traffic volume roads would generally involve the selection of a lower level of reliability, a higher initial IRI, and lower performance (higher distresses) thresholds, and also would require local calibration of different distress prediction models.

Software Versions and Trial Inputs

All trial participants used the AASHTOWare PMED software v2.6 or 2.6.1 with the default global calibration coefficients for the completed design trials. Two sets of design trials were completed to assess the suitability of this software for the design and analysis of thin flexible pavements on low volume roads: 1) general assessment and 2) in-depth assessment.

For the general assessment, the variable design inputs were: i) Climate: varying climatic data from 14 climate stations across Canada; ii) Base/Subbase Thickness: two different thickness configurations (100 mm base and 100 mm subbase or 150 mm base with no subbase); and iii) Asphalt Thickness: three different thicknesses (50 mm, 80 mm and 110 mm). A high plastic clay (A-7-6) subgrade was used in these design trial runs.

Manitoba completed the in-depth assessment only for the local climatic exposures. The variable design inputs for this assessment were: i) Climate: Two Manitoba climate stations (Winnipeg and The Pas); ii) Subgrade Type: two different subgrade types, high plastic clay (A-7-6) and silty sand (A-2-4), and iii) Asphalt Thickness: varied AC thickness from 50 to 150 mm in 5 to 10 mm increments. The thickness of both base and subbase layers remain unchanged at 100 mm.

The following input parameters were the same in all design trials/runs:

i) Truck Volume: Two-way 200 trucks/day (100 trucks/day on the design lane) with 2% annual growth rate for each classes of trucks;

ii) Vehicle Class Distribution and Axle Load Spectra (Manitoba Level 1);

iii) Asphalt Concrete Type: 12.5 mm Superpave asphalt concrete with PG 58-34 asphalt binder (Manitoba Level 3);

iv) Base/Subbase Types: Manitoba granular base (GBC-I) and granular subbase (GSB-C);

v) Design life: 20 years;

vi) Initial IRI: 0.9 m/km; and

vii) Reliability: 90%.

Selected Climate Stations

As indicated earlier, 14 MERRA climate stations across Canada with varying weather patterns were used in the general assessment design trials. Figure 1 shows the generic geographic location of these climate stations. The red dots indicate relatively warm climates while the blue dots indicate relatively cold climates in the Canadian context. Table 1 presents the list of climate stations and a summary of the key climate parameters. For the in-depth assessment, two climate stations (i.e., Winnipeg and The Pas, Manitoba) were used in the design trials. A summary of key climate parameters for these two stations is presented in Table 2.

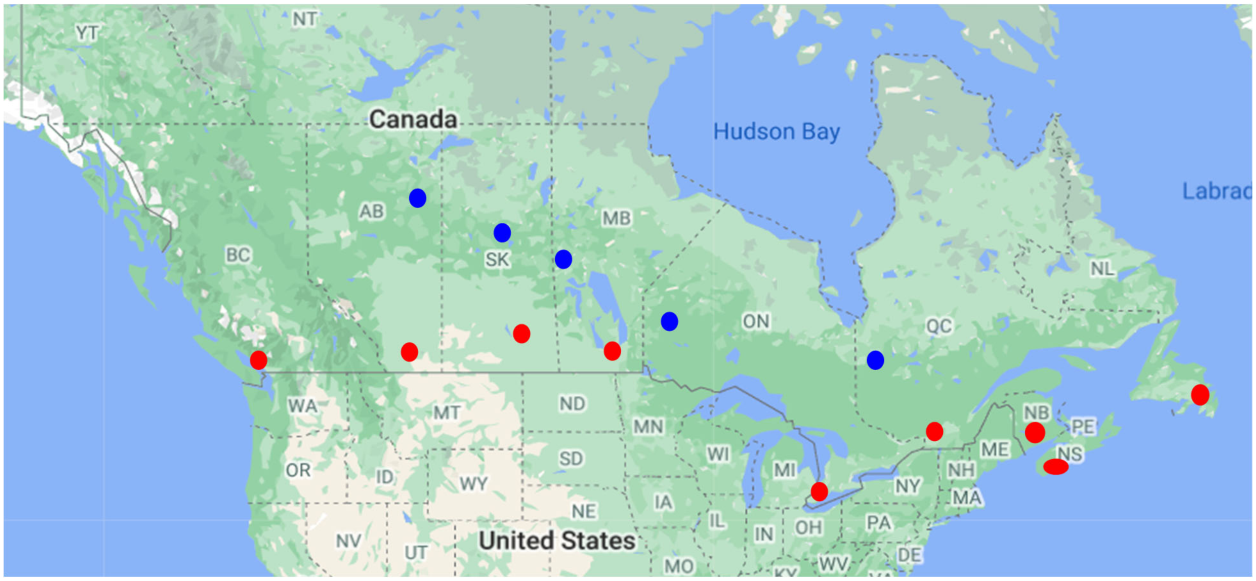

Figure 1. Geographic location of climate stations used in the PMED software trials

Table 1. List of 14 climate stations and summary of key climate data

<table>
<tr><td colspan="8">Climate Stations</td></tr>
<tr><td>Province</td><td>BC</td><td>AB</td><td>SK</td><td>MB</td><td>ON</td><td>QC</td><td>NB/NS/NL</td></tr>
<tr><td>Stations</td><td>Sechelt</td><td>Stirling, Gregoire Lake</td><td>Pilot Butte, La Ronge</td><td>Winnipeg, The Pas</td><td>Leamington, Red Lake</td><td>Montreal, Amos</td><td>Fredericton,
Halifax,
St. John’s</td></tr>
<tr><td colspan="8">Climate Data Summary</td></tr>
<tr><td>Climate Attributes/Statistics</td><td>Mean Annual Air Temp. (°C)</td><td>Mean Annual Precipitation (mm)</td><td>Mean Annual No. of Wet Days</td><td>Mean Annual Freezing Index (°C-days)</td><td>Mean Annual No. of Freeze-Thaw Cycles</td></tr>
<tr><td>Average</td><td>4.4</td><td>1102</td><td>323</td><td>1251</td><td>68</td></tr>
<tr><td>Minimum</td><td>0.2</td><td>494</td><td>259</td><td>64</td><td>41</td></tr>
<tr><td>Maximum</td><td>10.1</td><td>2697</td><td>353</td><td>2396</td><td>111</td></tr>
<tr><td>Standard Deviation</td><td>3.3</td><td>598.6</td><td>26.6</td><td>834.4</td><td>17.8</td></tr>
</table>

Table 2. Summary of key climate data for climate stations at Winnipeg and The Pas, Manitoba

Climate Station	Mean Annual Air Temp. (°C)	Mean Annual Precipitation (mm)	Mean Annual No. of Wet Days	Mean Annual Freezing Index (°C-days)	Mean Annual No. of Freeze-Thaw Cycles
Winnipeg	3.4	666	306.9	1765.8	64.4
The Pas	0.2	650	330.1	2396.1	57.4

Design and Analysis Trial Matrix

Eighty-four (six trial matrices for each climate station) and 42 (28 matrices for Winnipeg and 14 matrices for The Pas) different design runs with a specific input matrix in each run were completed for the general and in-depth assessment design trials, respectively. The details of the design trial matrix of each set are shown in Table 3 and Table 4. The gradations of granular base course (GBC), granular subbase (GSB) and subgrade materials used in the assessments are shown in Figure 2. Other physical and mechanical properties of these materials are presented in Table 5.

Table 3. General assessment design trial matrix for each climate station

Trial Matrix #	Asphalt (mm)	Granular Base (mm)	Granular Subbase (mm)	Subgrade Type
1	50	100	100	High Plastic Clay
2	80	100	100	High Plastic Clay
3	110	100	100	High Plastic Clay
4	50	150	0	High Plastic Clay
5	80	150	0	High Plastic Clay
6	110	150	0	High Plastic Clay

Table 4. In-depth assessment design matrix for two Manitoba stations

Trial Matrix #	Asphalt Thickness (mm)	Granular Base Thickness (mm)	Granular Subbase (mm)	Subgrade Type
7-20 (Winnipeg) 21-34 (The Pas)	50, 60, 70, 80, 85, 90, 95, 100, 105, 110, 120, 130, 140 and 150	100	100	High Plastic Clay
35-48 (Winnipeg)		100	100	Silty Sand

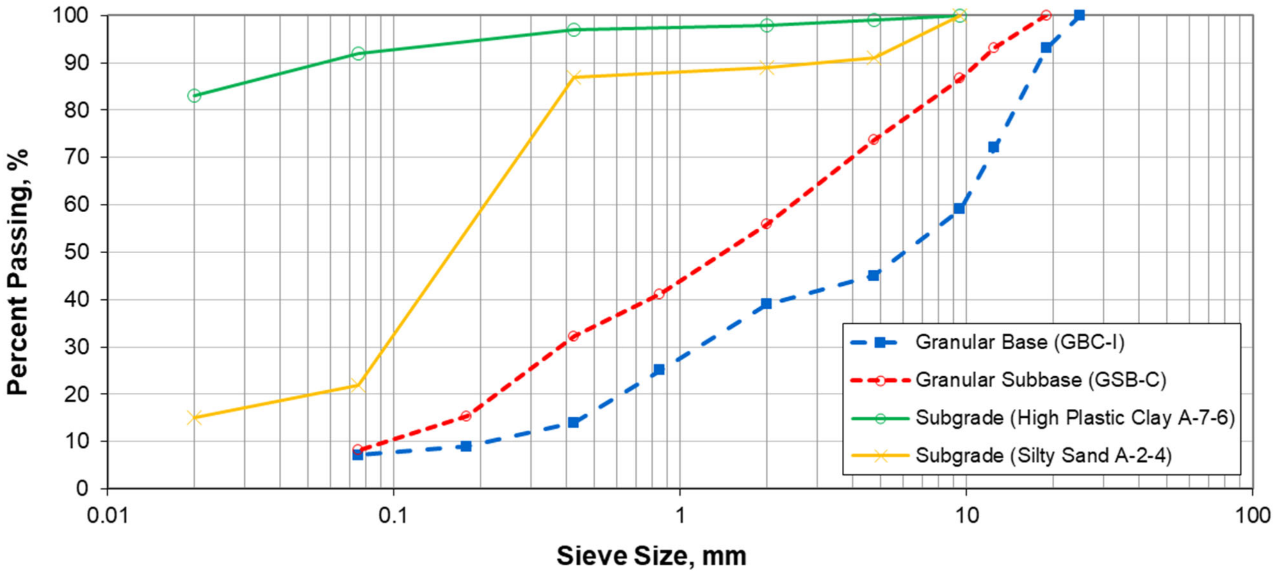

Figure 2. Gradations of granular base, subbase and subgrade materials

Table 5. Physical and mechanical properties of base, subbase and subgrade materials

Materials	Resilient Modulus (MPa)	Liquid Limit (%)	Plasticity Index (%)	Max. Dry Unit Weight (kg/m^3)	Water Content (%)
Base (GBC-I)	220	0	0	2230	6.9
Subbase (GSB-C)	105	22	4	2050	8.6
Subgrade (High Plastic Clay A-7-6)	35	79	49	1410	29.0
Subgrade (Silty Sand A-2-4)	60	18	3	1710	15.3

Results and Discussion: General Assessment

Although, trials were completed for 14 climate stations across Canada, results from selected climate stations are presented in this paper for clear visualisation of effect of each variable on the predicted distresses. As indicated earlier, a high plastic clay (A-7-6) subgrade was used in all trial runs for this assessment. The notations in the figures refer to the combination of AC and granular layers as follows:

1) 50AC-100GB-100SB = 50 mm asphalt concrete, 100 mm granular base and 100 mm granular subbase (subbase to subgrade modulus ratio of 3)
2) 80AC-100GB-100SB = 80 mm asphalt concrete, 100 mm granular base and 100 mm granular subbase (subbase to subgrade modulus ratio of 3)
3) 110AC-100GB-100SB = 110 mm asphalt concrete, 100 mm granular base and 100 mm granular subbase (subbase to subgrade modulus ratio of 3)
4) 50AC-150GB = 50 mm asphalt concrete and 150 mm granular base (base to subgrade modulus ratio of 6.3)
5) 80AC-150GB = 80 mm asphalt concrete and 150 mm granular base (base to subgrade modulus ratio of 6.3)
6) 110AC-150GB = 110 mm asphalt concrete and 150 mm granular base (base to subgrade modulus ratio of 6.3)

Effect of AC and Granular Layers on the Predicted IRI

Figure 3 shows the variations of the PMED software predicted terminal IRI for the variations of thickness of AC and granular base/subbase layers at selected climate stations. As shown in the figure, the predicted IRI decreases with an increase in AC thickness from 50 mm to 80 mm and then to 110 mm. The trends of the predicted IRI in trials with 100 mm thick granular base and 100 mm thick granular subbase (100GB-100SB) and 150 mm thick granular base (150GB) with no subbase are shown to be identical. This indicates that modulus ratio between base or subbase layer and subgrade does not have any noticeable effect on the predicted IRI in the case of thin pavements as well, as observed for the conventional flexible pavements with a thicker AC layer [12, 13]. For a given climatic condition, the effect of the increased AC thickness on the predicted IRI seems to be very small. For example, IRI decreased from 2.47 m/km for 50 mm thick AC to 2.39 m/km for 110 mm thick AC with 100 mm thick base and 100 mm thick subbase combination at Gregoire Lake.

The effect of climate on the predicted IRI seems to be more pronounced than the effect of AC layer thickness. For the same AC layer thickness, 150 mm thick base was shown to provide a lower IRI as compared to 200 mm thick base/subbase, a thicker base/subbase combination. For example, for 50 mm AC at Gregoire Lake, 100 mm thick granular base and 100 mm thick granular subbase (50AC-100GB-100SB) combination provided an IRI of 2.47 m/km whereas 150 mm thick granular base (50AC-150GB) provided an IRI of 2.43 m/km. Since granular base was stiffer (Mr = 200 MPa) than the granular subbase (Mr = 105 MPa), the stiffer base material seems to be more effective in reducing the predicted IRI as compared to the increased thickness with less stiffer materials. This trend closely resembles the trend of the predicted IRI for the conventional AC pavement with thicker AC layer and higher traffic loading, as found in a previous study by Ahammed et al. [13]. Apparently, the trends of the predicted IRI for all the design variables seem to be reasonable.

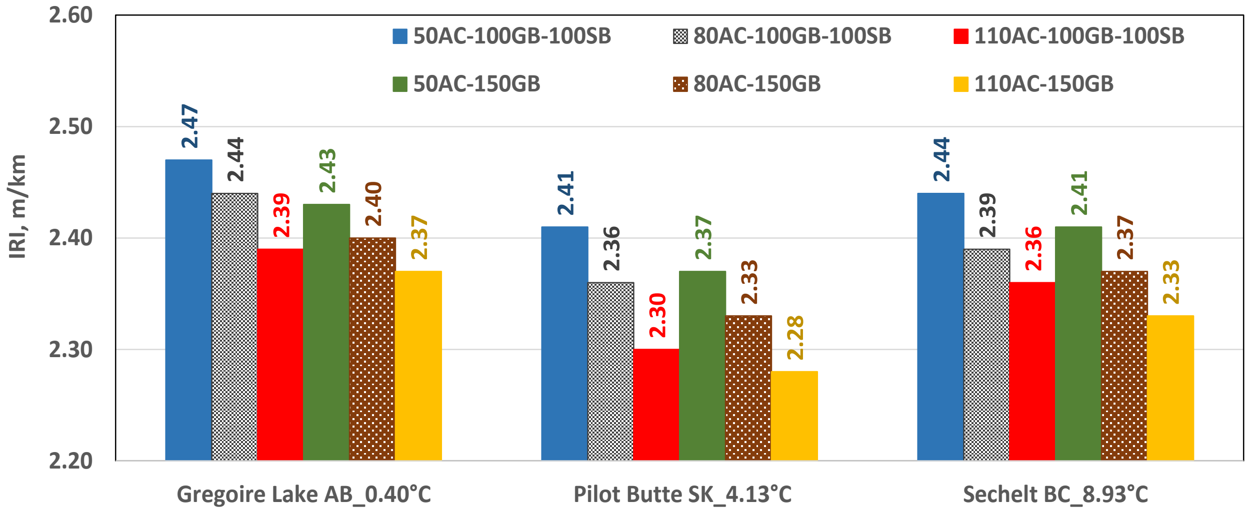

Figure 3. Variation of the predicted IRI with the variation of AC and granular layers

Effect of AC and Granular Layers on the Predicted Total Rutting

The trends of the PMED software predicted total rutting for the variations of thickness of AC as well granular base/subbase layers at selected climate stations are shown in Figure 4. As shown in the figure, the total rutting decreases with an increase in AC layer thickness from 50 mm to 80 mm and then to 110 mm. Two similar trends of the predicted total rutting are observed for both 100 mm thick granular base and 100 mm thick granular subbase (100GB-100SB) and 150 mm thick granular base (150GB) with no subbase combinations i.e., the predicted total rutting in trials with subbase and without subbase showed similar trends. This indicates that modulus ratio between base or subbase layer and subgrade does not have any noticeable effect on the predicted total rutting as well. This finding also matches with that observed for the conventional flexible pavements with a thicker AC layer [12, 13]. For a given climatic condition, there is a noticeable effect of increased AC thickness on the predicted total rutting. For example, the total rutting reduced from 15.57 mm for 50 mm thick AC to 12.04 mm for 110 mm thick AC with 100 mm thick base and 100 mm thick subbase combination at The Pas.

The variation of climate provides a noticeable variation of the predicted total rutting indicating that varying climatic conditions have considerable effect on the predicted total rutting. For the same AC layer thickness, 150 mm thick base was shown to provide a lower total rutting as compared to 200 mm thick base/subbase i.e., a thicker base/subbase combination. For example, for 50 mm thick AC at The Pas, 100 mm thick granular base/100 mm thick granular subbase (50AC-100GB-100SB) combination provided a total rutting of 15.57 mm whereas 150 mm thick granular base (50AC-150GB) provided a total rutting of 14.10 mm. It also indicates that a stiffer granular base is more effective in reducing the total rutting as compared to thicker granular layer(s) with softer materials, as observed for the predicted IRI. This trend also closely resembles the trend of the predicted total rutting for the conventional AC pavement with thicker AC layer and higher traffic loading, as found in a previous study by Ahammed et al. [13]. Apparently, the trends of the predicted total rutting for all the design variables seem to be reasonable, as observed in the case of predicted IRI.

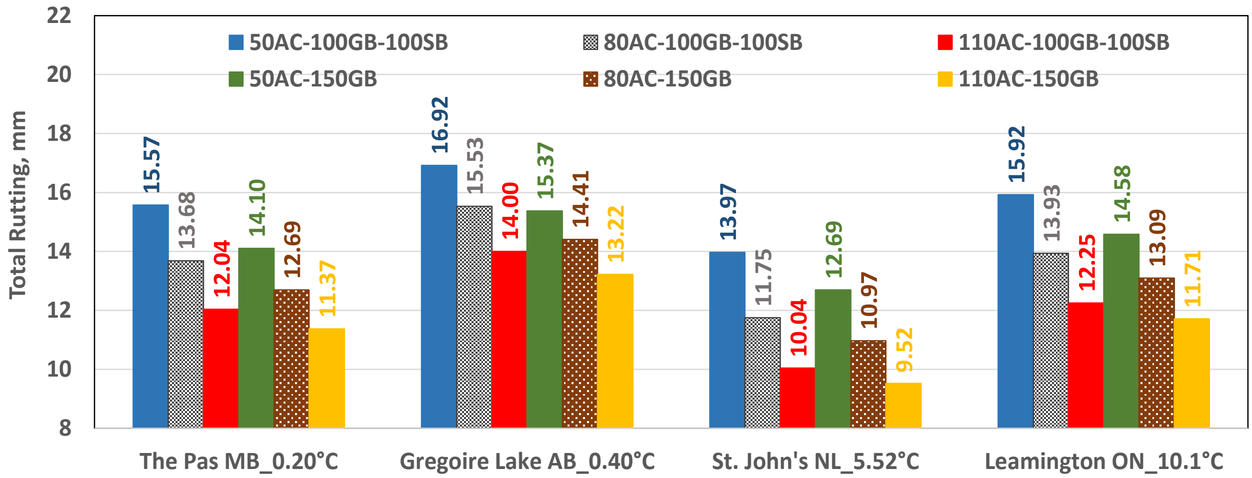

Figure 5. Variation of the predicted total rutting with the variation of AC and granular layers

Effect of AC and Granular Layers on the Predicted Bottom-Up Fatigue Cracking (BUFC)

Figure 6 shows the trends of the PMED software predicted bottom-up fatigue cracking (BUFC) for the variations of thickness of AC and granular base/subbase layers at selected climatic areas. As shown in the figure, there is an inconsistent variation of the predicted BUFC with an increase in AC thickness from 50 mm to 80 mm and then to 110 mm. For example, at La Ronge (SK), the BUFC increases from 1.53% to 5.17% for an increase AC layer thickness from 50 mm to 80 mm and then decreases to 1.63% for increase in AC layer thickness to 110 mm with 100 mm thick base and 100 mm thick subbase combination. Similar trends are observed for both 100 mm thick granular base and 100 mm thick granular subbase (100GB-100SB) and 150 mm thick granular base (150GB) with no subbase combinations. This indicates that modulus ratio between base or subbase layer and subgrade does not have any noticeable effect on the predicted BUFC, although there is an inconsistent variation of the predicted BUFC with an increase in AC layer thickness. The effect of modulus ratio in the case of thin pavements is also similar to that was observed for the conventional flexible pavements with a thicker AC layer [12, 13].

The variation of climatic conditions has shown to produce significant effect on the predicted BUFC with some inconsistent trends due to the variation in AC layer thickness within a climatic station. For the same AC layer thickness, 150 mm thick base was shown to produce a lower BUFC as compared to 200 mm (total) thick base/subbase i.e., thicker base/subbase combination. For example, for 50 mm thick AC layer at La Ronge (SK), 100 mm thick granular base-100 mm thick granular subbase (50AC-100GB-100SB) combination produced a BUFC of 1.53% whereas 150 mm thick granular base (50AC-150GB) with no subbase provided a BUFC of 1.47%. The effect of varying base/subbase thickness seems to be more pronounced with 80 mm thick AC layer as compared to 50 mm and 110mm thick AC layers. For example, the predicted BUFC is 5.17% for 80AC-100GB-100SB and 2.29% for 80AC-150GB as compared to 1.63% for 100AC-100GB-100SB and 1.53% for 110AC-150GB. Overall, the variations in predicted BUFC for different AC layer thicknesses and base/subbase seem to be inconsistent with the expected field performance.

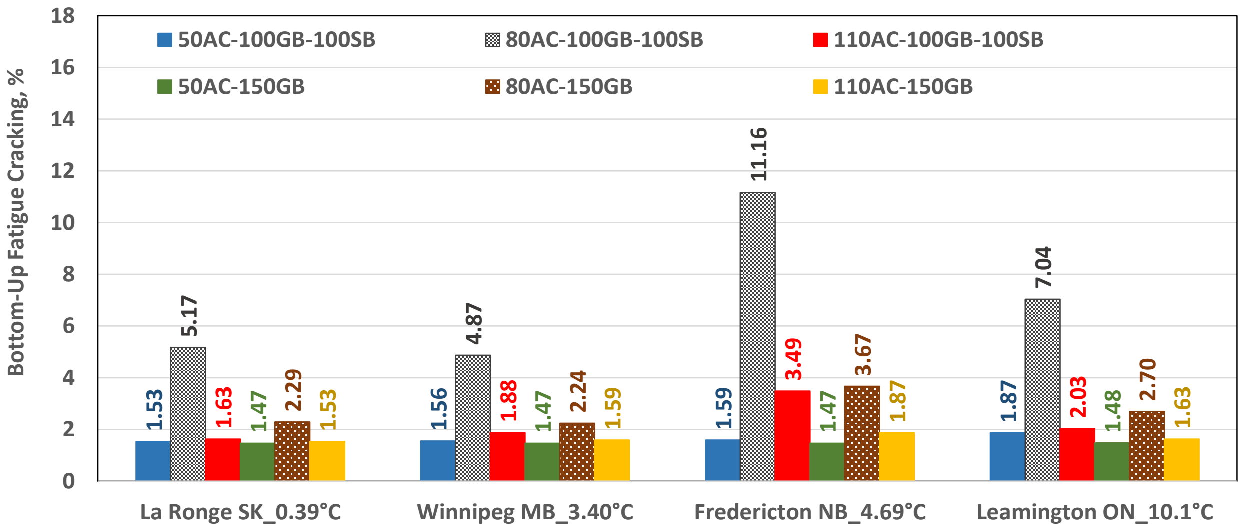

Figure 6. Variation of the predicted BUFC with the variation of AC and granular layers

Effect of AC and Granular Layers on the Predicted Top-Down Fatigue Cracking (TDFC)

The trends of the PMED software predicted top-down fatigue cracking (TDFC) for the variations of thickness of AC and granular base/subbase layers at selected climate stations are shown in Figure 7. As shown in the figure, the predicted TDFC remained unchanged at 4.69% regardless of AC layer thickness, granular base/subbase thickness and quality and climatic conditions. This indicates that the AC layer thickness, granular materials thickness and quality, and varying climatic exposures have no or minimal effect on the predicted TDFC. It is not clear why TDFC is not affected by the variation of AC and/or granular layers given that the same traffic loading is applied on different pavement structures.

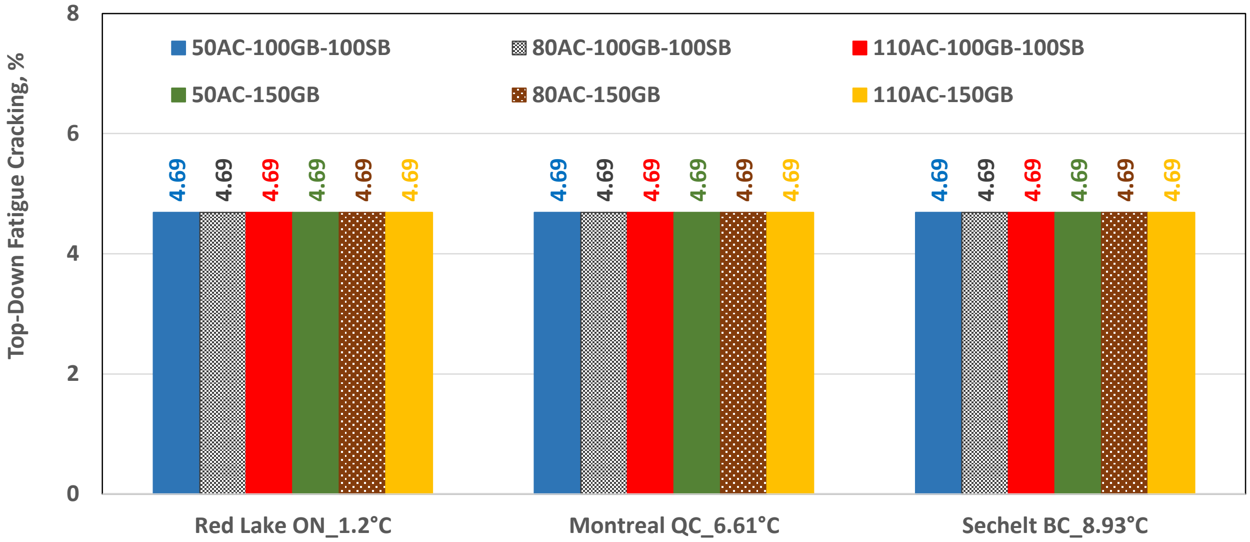

Figure 7. Variation of the predicted TPFC with the variation of AC and granular layers

Effect of AC and Granular Layers on the Predicted AC Layer Rutting

The trends of the PMED software predicted AC layer rutting, at selected climatic areas, for the variations of AC and granular base/subbase layers that were included in this study are shown in Figure 8. As shown in the figure, there is an increase in the predicted AC layer rutting with an increase in AC layer thickness from 50 mm to 80 mm. The AC layer rutting decreased when the AC layer thickness was increased from 80 mm to 110 mm. For example, the predicted AC layer rutting increased from 3.33 mm for 50AC-100GB-100SB to 3.51 mm for 80AC-100GB-100SB and then decreased to 3.22 mm for 110AC-100GB-100SB.

The trends of the predicted AC layer rutting with the variation of AC layer thickness were shown to be inconsistent between 100GB-100SB and 150GB combinations among climate stations. For example, the AC layer rutting increased from 3.84 mm for 50AC-100GB-100SB to 4.19 mm for 80AC-100GB-100SB at Amos (QC). A similar increasing AC layer rutting trend was observed between 50AC-150GB and 80AC-150GB at the same climate station. The trends were shown to be reversed for Halifax (NS) station with a reduction in AC layer rutting from 3.17 mm for 50AC-150GB to 3.09 mm for 80AC-150GB.

The variation of climate provides a noticeable variation of the predicted AC layer rutting indicating that varying climatic conditions also has considerable effect on the predicted AC layer rutting. For the same AC layer thickness, 150 mm thick base was shown to provide a higher AC layer rutting as compared to 200 mm thick base/subbase. For example, for 50 mm thick AC at The Pas, 50AC-100GB-100SB provided an AC layer rutting of 3.33 mm whereas 50AC-150GB provided an AC layer rutting of 3.37 mm. This trend indicates that stiffer granular base results in an increase in AC layer rutting. This trend is different from the variation of total rutting. Overall, the trends of the predicted AC layer rutting for all the design variables seem to be inconsistent.

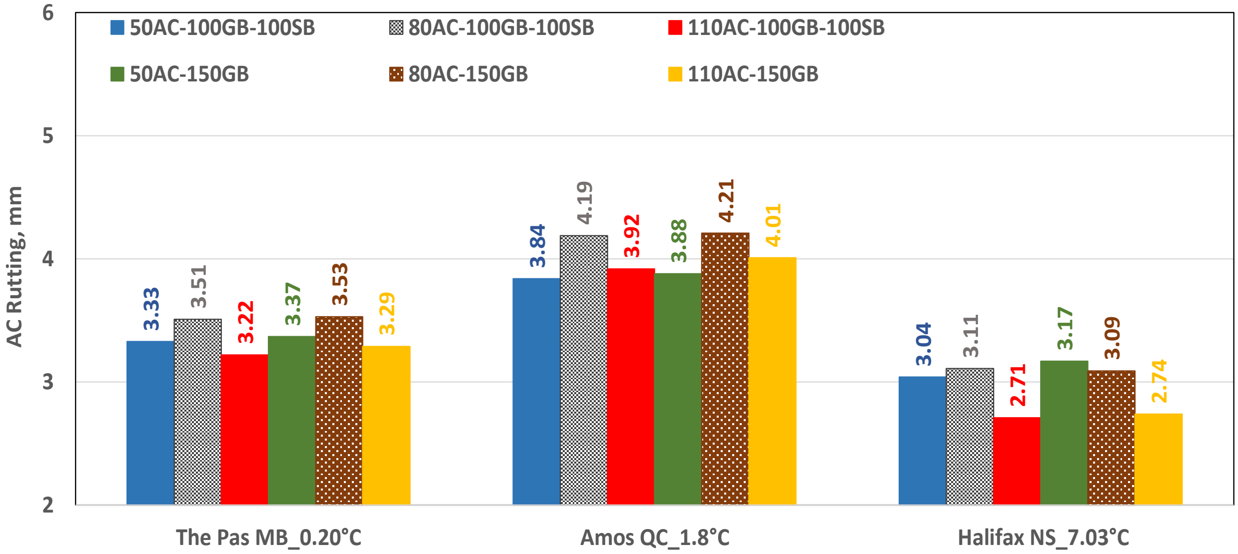

Figure 8. Variation of the predicted AC layer rutting with the variation of AC and granular layers

Effect of AC and Granular Layers on the Predicted Transverse Cracking (TC)

The trends of the PMED software predicted transverse cracking (TC) for the variation of AC and granular base/subbase layers at selected climate stations are shown in Figure 9. As shown in the figure, there is no or negligible variation of the predicted TC among the varied AC layer thickness, granular base/subbase layers and climatic conditions. This indicates that the AC layer thickness, granular materials thickness and quality, and varying climatic exposures have no or negligible effect on the predicted TC. These results seem to indicate that a PG58-34 asphalt binder is adequate to keep the TC within an acceptable limit in all areas i.e., all climatic conditions across Canada. For example, the results show approximately the same quantities of transverse cracking in cold climates like The Pas (MB) with about -40 °C in winter, and warmer climate like Leamington (ON) with about -6 °C in winter. Such predictions are not reflective of actual field observations and SuperPave performance grade binder selection criteria or requirements.

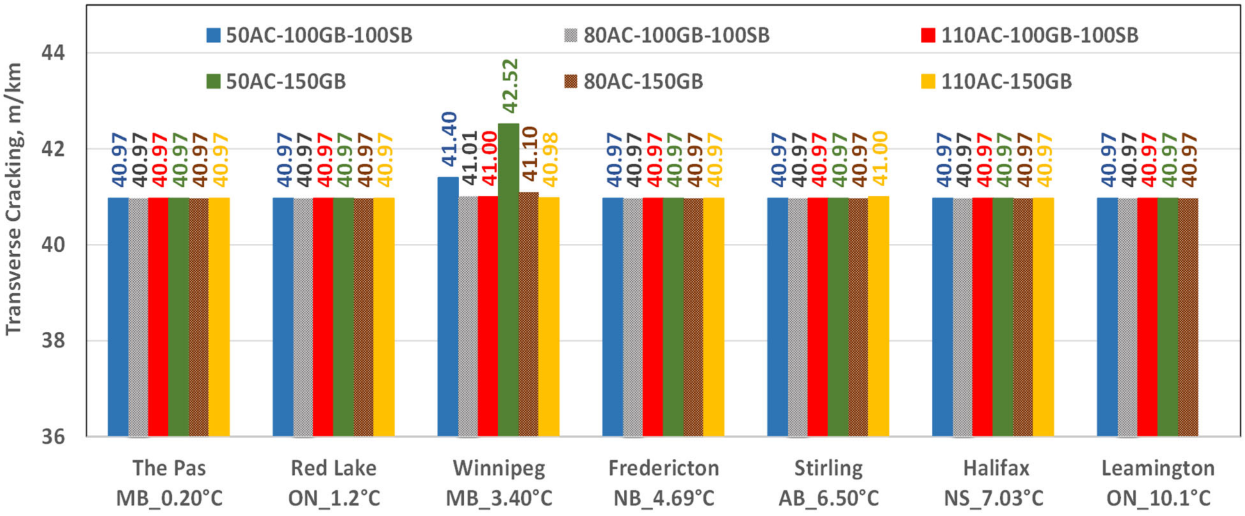

Figure 9. Variation of the predicted transverse cracking with the variation of AC and granular layers

Results and Discussion: In-Depth Assessment

As discussed in the previous section- “Results and Discussion: General Assessment”, the trends of some predicted distresses were inconsistent or unreasonable with the variations of AC layer thickness for the pavement structures analysed in that first phase. To determine the minimum thickness of AC layer that will produce reasonable trends of the predicted distresses, especially for the BUFC and total rutting, with an increase in AC layer thickness, Manitoba completed additional design trials with AC layer thickness from 50 mm to 150 mm in 5 to 10 mm increments. These trials were completed for two climate stations (Winnipeg and The Pas) in Manitoba with two different subgrade materials. This section presents and discusses the results of this additional in-depth assessment.

Variation of the Predicted IRI with AC Layer Thickness

Figure 10 shows the trends of the predicted IRI for the variations in AC layer thickness for high plastic clay (A-7-6) and silty sand (A-2-4) subgrade soil materials. As shown in the figure, although the predicted IRI generally decreases with an increase in AC layer thickness for both climate stations and subgrade materials, the trend of the predicted IRI is not uniform for any of these climatic exposures and subgrade types. However, the correlation between the AC layer thickness and the predicted IRI for each dataset of different climate and subgrade type was shown to be very good with a R^2 value of >0.98 in each case. The trends also show that stiffer (A-2-4) subgrade results in higher IRI than softer (A-7-6) subgrade for each thickness of AC layer (except for 150 mm thick AC layer), which does not seem to be reasonable. Colder climate (The Pas) results in higher IRI than warmer climate (Winnipeg), which are reasonable variations.

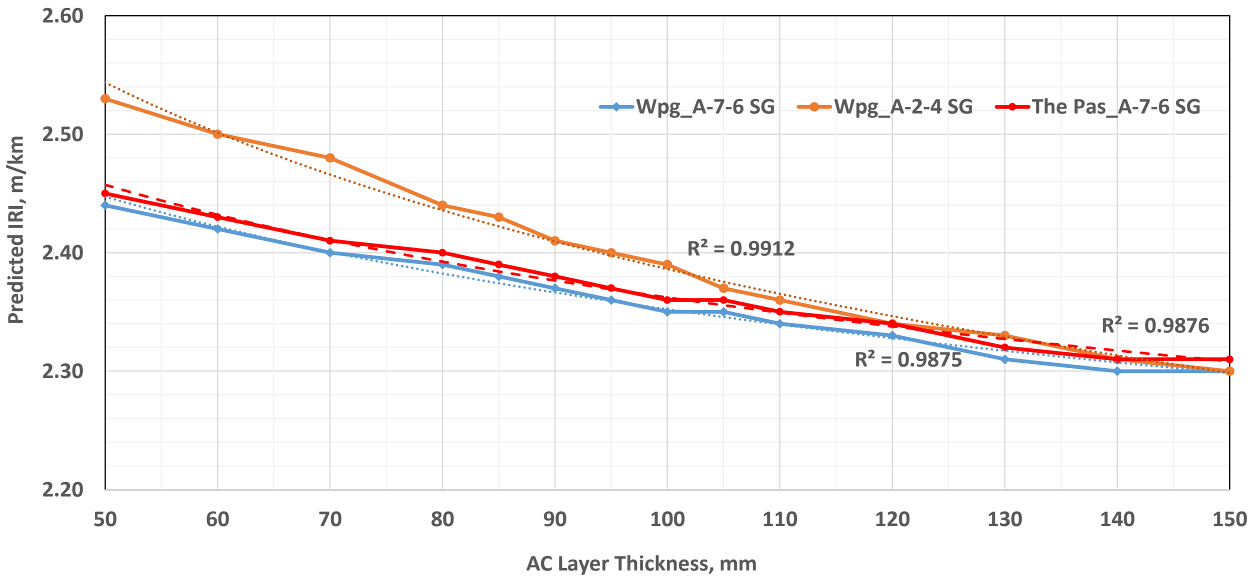

Figure 10. Trend of the predicted IRI with the variation of AC layer thickness

Variation of the Predicted Total Rutting with AC Layer Thickness

Figure 11 shows the trends of the predicted total rutting for the variations in AC layer thickness for high plastic clay (A-7-6) subgrade soil in Winnipeg and The Pas and silty sand (A-2-4) subgrade soil in Winnipeg.

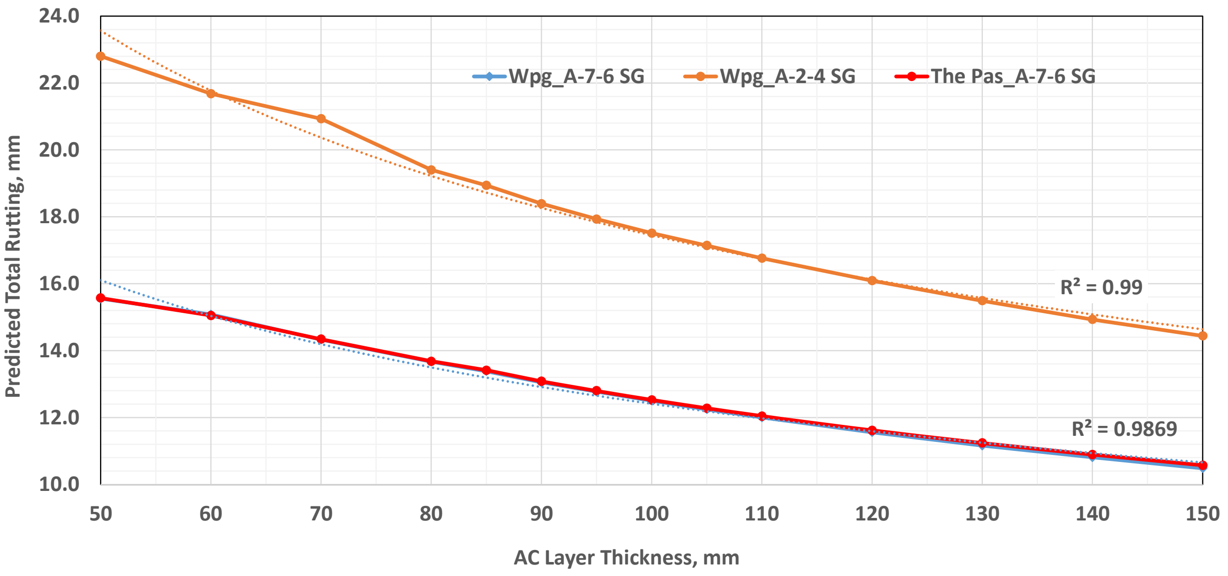

Figure 11. Trend of the predicted total rutting with the variation of AC layer thickness

As shown in Figure 11, the total rutting generally decreases with increase in AC layer thickness for both climate stations and subgrade materials. The correlation between the AC layer thickness and the predicted total rutting for each dataset of different climate and subgrade types was also shown to be very good with a R^2 value of >0.98. However, uniform trends of the predicted total rutting are observed when AC thickness is ≥60 mm in the case of high plastic clay subgrade and ≥80 mm in the case of silty sand subgrade.

The trends also show that stiffer (A-2-4) subgrade results in higher total rutting than softer (A-7-6) subgrade for each thickness of AC layer, which does not seem to be reasonable. Similar trends were also observed in the case of conventional flexible pavement with a thicker AC layer and higher traffic loading in a previous study [14]. Generally, a weaker subgrade material should result in a higher total rutting than that from a stiffer subgrade regardless of AC layer thickness. Figure 11 also shows that there is a negligible difference in predicted total rutting between two climatic areas in Manitoba for a given A-7-6 subgrade. These results also do not reflect Manitoba's local experience because in colder climates, AC layer is less susceptible to rutting and subgrade remain solidly frozen for longer duration, although AC layer is more susceptible to cracking.

Variation of the Predicted Bottom-Up Fatigue Cracking (BUFC) with AC Layer Thickness

The trends of the predicted bottom-up fatigue cracking (BUFC) for the variations in AC layer thickness for high plastic clay (A-7-6) subgrade soil in Winnipeg and The Pas, and silty sand (A-2-4) subgrade soil in Winnipeg are shown in Figure 12. As shown in the figure, the predicted BUFC increases with an increase in AC layer thickness for both climate stations and subgrade materials up to an AC layer thickness of 85 mm. The predicted BUFC generally decreases with an increase in AC layer thickness beyond 85 mm. However, uniform trends of the predicted BUFC are observed when AC thickness is ≥100 to 105 mm. The trends also show that stiffer (A-2-4) subgrade results in higher BUFC than softer (A-7-6) subgrade for AC layer thickness up to about 105 mm. There is no noticeable difference between the predicted BUFC with two different subgrade types when the AC thickness is >105 mm. As shown in Figure 12, there is a negligible difference in the predicted BUFC between two climatic areas in Manitoba.

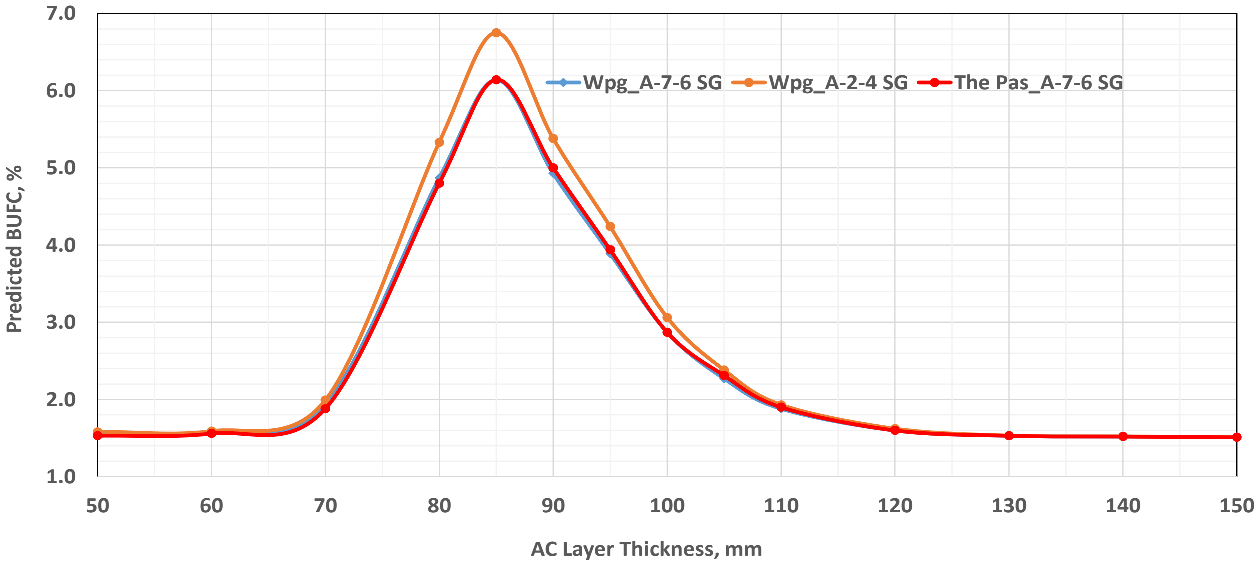

Figure 12. Trend of the predicted BUFC with the variation of AC layer thickness

Variation of the Predicted AC Layer Rutting with AC Layer Thickness

The trends of the predicted AC layer rutting for the variation of AC layer thickness for high plastic clay (A-7-6) subgrade soil in Winnipeg and The Pas, and silty sand (A-2-4) subgrade soil in Winnipeg are shown in Figure 13. Figure 13 shows inconsistent or non-uniform variations in the predicted AC layer rutting with an increase in AC layer thickness for both subgrade materials in Winnipeg up to an AC layer thickness of 105 mm. There is no noticeable difference in the predicted AC layer rutting between softer (A-7-6) and stiffer (A-2-4) subgrade soils for AC thickness of ≥105 mm (in Winnipeg area). There is a noticeable difference in the predicted AC layer rutting between two climatic areas in Manitoba with inconsistent trends. The predicted AC layer rutting in colder climate (The Pas) is lower than that in relatively warmer climate (Winnipeg) for AC layer thickness of <120 mm. The trend reversed when the AC layer thickness is >120 mm with higher AC layer rutting in The Pas than that in Winnipeg. The reasons for these inconsistent trends are difficult to explain.

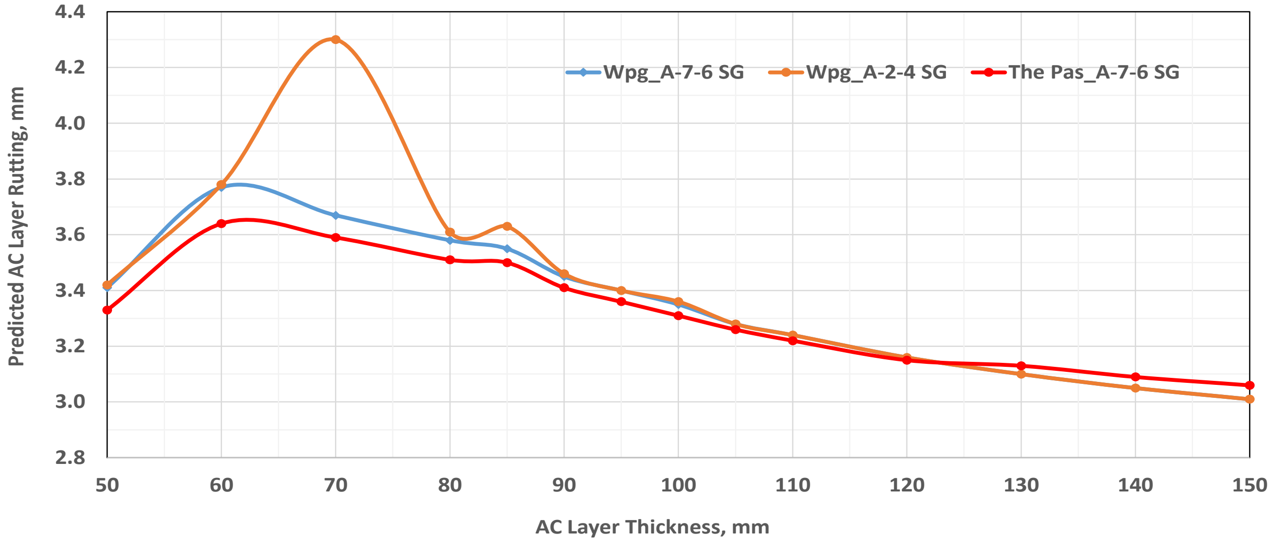

Figure 13. Trend of the predicted AC layer rutting with the variation of AC layer thickness

Summary and Conclusions

This study completed several design trials using the AASHTOWare PMED software to assess the effect of varying asphalt, base and subbase layers and subgrade on the predicted distresses on low traffic volume roads. The minimum asphalt thickness that can be used in the design and analysis using the PMED software was also determined based on various distress criteria. The trial results and analyses presented in this paper led to the following observations and conclusions:

1. The predicted distresses in trials with subbase (a low subbase to subgrade modulus ratio) and without subbase (a high base to subgrade modulus ratio) have shown similar trends indicating that the modulus ratio between subbase and subgrade or base and subgrade has no or minimal effect on the PMED software predicted distresses in the case of thin pavements as in the case of conventional thick asphalt pavements.
2. The predicted IRI generally decreases with an increase in AC layer thickness. Although the trend of the predicted IRI with increased AC thickness follows an irregular or non-uniform pattern, overall, there is a very good correlation between the AC layer thickness and the predicted IRI.
3. The predicted total rutting also decreases with an increased AC layer thickness. However, there was a uniform trend for the predicted total rutting when AC thickness was ≥60 mm for the high plastic clay subgrade with a resilient modulus of 35 MPa and ≥80 mm for the silty sand subgrade with a resilient modulus of 60 MPa. Overall, there was a very good correlation between the AC layer thickness and the predicted total rutting.
4. Illogical variations, with an increase in the predicted bottom-up fatigue cracking with an increase in AC layer thickness, were observed for AC thickness up to 85 mm. Logical but non-uniform trends

were observed for AC layer thickness in the range of 85 to <105 mm. Uniform trends for the predicted BUFC were observed when AC layer thickness was ≥105 mm. This indicates that the BUFC prediction model in the PMED software is not suitable for thin asphalt (<100 mm thick AC) pavement design.

5. The design trials showed no noticeable effect of varying AC layer thickness on the predicted top-down fatigue cracking, which is unexpected.
6. The variations of the predicted AC layer rutting with an increase in AC layer thickness were inconsistent with respect to the variations of AC layer thickness, granular base/subbase layers and climatic exposures.
7. There was no or negligible variation in the predicted transverse cracking among the varying climatic exposures across Canada despite a single asphalt binder grade was used in all trials, which does not seem to be reasonable. This prediction also does not reflect the local experience in Manitoba and different places in Canada because varied cold temperature affects the amount of thermal cracking. As such, different minus performance grade asphalt binders are used to manage the varied cold temperature exposures.
8. Overall, the selected minimum thickness of AC layer should be approximately 100 mm (4 in.) for reasonable and smooth trends of the predicted distresses using the PMED software.
9. Considering only the IRI and total rutting criteria and ignoring small irregularities in the trends of predicted IRI and total rutting in pavement designs for low traffic volume roads, an AC thickness of as low as 50 mm could be used when using the PMED software.

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