Sensitivity of the Pavement ME Design Software Predicted Distresses in Flexible Pavements to Subgrade Soils and Granular Subbase Materials

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Abstract:

Subgrade is the foundation of a pavement structure and ultimately bears the stress from the applied traffic load. Based on the historical design methods and agency experiences, subgrade soils including granular fills and their stiffness have significant impact on the design and construction of pavements. Alternatively, granular subbase and base material constitute significant portions of flexible pavement structures. In empirical design methods, 1 mm of asphalt concrete (AC) equates to 3-5 mm of granular subbase thickness. By substituting a part of AC layer with additional granular subbase, agencies could design and construct economic pavement structures that provide adequate structural capacity with improved drainage and frost protection. There are concerns that the newest pavement design and analysis tool, named the AASHTOWare Pavement ME Design (PMED) software, is not yet able to consider the effect of unbound base, subbase and subgrade materials properly.

Between November 2021 and January 2022, Transportation Association of Canada (TAC) ME Pavement Design Subcommittee completed two sets of design trials to assess the sensitivity of PMED software predicted distresses to the physical and mechanical properties of different subgrade and subbase materials. The design trials included: i) four different untreated native subgrade soils and a select granular fill with varying physical and mechanical properties, and ii) three different subbase material types with varying stiffness, thickness and gradation. The results have shown negligible to high sensitivity of the predicted distresses to the variation of subgrade types and their stiffness as well as the subbase material stiffness, thickness and gradation with some inconsistencies.

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Introduction

Subgrade is the foundation of pavement structures. The stress from applied traffic load is ultimately transferred to the native subgrade or embankment constructed out of native and/or borrowed soils, and/or select fill materials. In historical design methods, including the widely used AASHTO 1993 [1] pavement design procedure, subgrade soil including fill material types and their stiffness have significant impact on the design of pavement structures. For example, 5.3 million equivalent single axle loads (ESALs) repetitions equate to a design lane traffic loading of 500 trucks per day (as used in these trials) over 20 years. Using the AASHTO 1993 method, a total structural number (SN) of 141 mm is required to withstand the 5.3 million ESALs for a high plastic clay subgrade with an effective resilient modulus (M_r) value of 25 MPa. Keeping all other inputs unchanged, the required total SN will be 106 mm for silty sand subgrade with an effective M_r value of 60 MPa. This equates to a 35 mm difference in the required SNs or 80 to 90 mm difference in typical asphalt concrete (AC) layer thickness (with a structural layer coefficient values of 0.40 to 0.44). Highway agencies in Canada are satisfied with such design outcomes as well as the construction and performance experiences of those pavement structures.

Alternatively, granular base and subbase constitutes significant portions of flexible pavement structures in Canada. In conventional flexible pavements, base and subbase layers help to distribute the applied traffic load on pavement surface onto a wider area of subgrade/embankment to avoid overstressing and failure of pavement foundations. In properly designed conventional flexible pavements, 100 to 700 mm or more subbase is placed below the base layer depending on the subgrade stiffness and frost susceptibility, drainage conditions, design traffic loading, surfacing AC layer thickness and the base layer thickness.

Traditional empirical design methods have well accounted the effect of granular subbase materials. Based on the structural layer coefficients or granular base equivalency, 1 mm of asphalt thickness typically equates to 3- 5 mm of granular subbase, depending on the stiffness of both materials. In cold climates like Canada, a thicker and good quality subbase layer provides added protection from frost, freeze/thaw related damages, and enhanced pavement drainage (subgrade wetting-up) performance leading to a longer service life of all types of pavement structures.

However, studies in different jurisdictions have shown that the AASHTOWare PMED software, which is the latest and most sophisticated pavement design and analysis tool, is unable to consider the effect of the subbase thickness and subgrade as well as subbase stiffness as expected based on the past design and performance experience.

Background

The TAC ME Pavement Design Subcommittee has been evaluating the AASHTOWare PMED software since 2007. Trials completed in the past include: 1) effect of traffic loading (AC/PCC pavements); 2) effect of asphalt mix, asphalt binder and thickness; and 3) effect of concrete slab and joint designs. 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 has also completed design trials to assess the effect of granular base types, source and mineralogy (stiffness), gradations and layer thickness on the predicted distresses using the PMED software. Results of all these trials can be found in different technical papers presented at this and other conferences.

Between November 2021 and January 2022, TAC ME Pavement Design Subcommittee completed design trials with varying climatic inputs from 14 different weather stations across Canada to assess the sensitivity of the PMED software predicted distresses to the physical and mechanical properties of different subgrade soil and subbase materials. The trials included the following: i) five different subgrade soils with varying physical and mechanical properties (Mr = 25 to 90 MPa), and ii) three different subbase materials with varying stiffness (70 to 300 MPa) and thickness (200 mm and 500 mm). This paper presents the results of these trials and discusses the issues and suitability of the PMED software for modeling the effect of subgrade and subbase materials.

Findings from Literature Review

In the AASHTO PMED software, the subbase layer is defined by its thickness, resilient modulus, soil classification that include physical properties such as gradation, plasticity index and liquid limit, Poisson's ratio, density, moisture content and soil water characteristic curve (SWCC). Based on a literature review, Luo et al. [2] identified the parameters that affect an unbound layer's influence on pavement performance including material properties such as modulus and shear strength, material behaviours responding to traffic and environmental conditions (e.g., temperature, moisture and erosion), and structural characteristics. The PMED model assumes that subbase moisture condition and stress state are independent and that the subbase is an elastic layer. As a result, PMED software is unable to consider adequately the influence of unbound materials in pavement performance prediction. The study concluded that the Mechanistic-Empirical Pavement Design Guide (MEPDG), which is the fundamental analysis method (also referred to by this name in the earlier version) of PMED software, shows little or no sensitivity to unbound layers, including base and subbase.

Ahammed et al. [3] conducted an analysis of the MEPDG software by varying input parameters, including subbase layer thickness and subgrade type. The study found that there was no practical reduction in AC layer thickness with an increase in subbase layer thickness, which was unexpected. The analysis also showed that the total rutting increased with an increase in the subbase layer thickness, which was surprising. The study found that longitudinal (top-down fatigue) cracking, transverse cracking and AC layer rutting increases, and the bottom-up fatigue (alligator) cracking decreases with an increase in subbase layer thickness. The study also found that resilient modulus of subgrade produces significant influence on the predicted distresses and roughness.

In 2017, Su et al. [4] reviewed the MEPDG design inputs and their effects on pavement performance. The study found that the MEPDG is not sensitive to the thickness and resilient modulus of the subbase layer except that the longitudinal (top-down fatigue) cracking increases slightly with an increase in subbase layer thickness.

Réus and Fontenele [5] examined the sensitivity of the MEPDG and found that varying subbase layer thickness and resilient modulus values did not significantly affect the MEPDG software predicted distresses including bottom-up fatigue cracking, top-down fatigue cracking, subgrade rutting, AC rutting, and roughness.

The two key inputs in PMED software for subgrade are as follows: i) resilient modulus value and ii) soil classification and characteristics. These two factors are used to characterize the stress-strain behaviour of subgrade and its frost susceptibility. They also represent the elastic behaviour and load carrying capacity of subgrade soils under dynamic traffic loading in the Pavement ME model. A study by Orobio and Zaniewski [6] examined each of the pavement material characteristics in MEPDG and determined the sampling-based sensitivity of the material inputs. Different pavement structures analyzed in this study revealed that smoothness (IRI), rutting and cracking performance are significantly impacted by subgrade resilient modulus, and it has the largest effect on the rutting prediction.

Wu and Yang [7] used the PMED software (version 1.1) to evaluate the performance of the flexible pavements in Louisiana. The study found that subgrade resilient modulus has significant impact on rutting and in fact, it over-predicted the rutting performance. The impact was more pronounced when a weaker subgrade was used in the analysis.

Rahman and Gassman [8] conducted research using PMED v 2.2.4 to determine the effect of resilient modulus of soils, which varied from 32 to 75 MPa, on subgrade rutting. The subgrade rutting produced from the four resilient modulus inputs were different, and a consistent trend was observed where higher resilient modulus resulted in lower subgrade rutting. This research concluded that the resilient modulus is sensitive to rutting, and accurate quantification of resilient modulus is required to achieve an optimum pavement thickness.

Schwartz et al. [9] found that the AASHTOWare PMED shows low or no sensitivity to unbound layers and subgrade. Total rutting is marginally sensitive to resilient modulus and soil-water characteristic curve (SWCC) of unbound layers and subgrade, and insensitive to thickness of unbound layers. Load-related cracking in flexible pavement is insensitive to SWCC of unbound layers, and marginally sensitive to SWCC of subgrade. Ahammed et al. [3] also found that the predicted roughness and surface distress are identical for the two soil types, which means the PMED software was not able to analyse the impact of frost susceptible soils.

Uddin et al. [10] completed a sensitivity analysis of mechanistic-empirical (ME) design considering climate impacts to layer modulus. The analysis found that if seasonally adjusted monthly modulus values of pavement layers were not simulated, it would affect the output accuracy of ME design methods. The study concluded that neglecting the large spatial variability in subgrade soils would result in poor performance and early deterioration of pavements.

Through a sensitivity analysis (in Iowa), Coree et al. [11] found that all type of distresses in flexible pavements are insensitive to change subbase resilient modulus. The predicted longitudinal cracking has low sensitivity while all other distresses are insensitive to changes in subbase thickness. Longitudinal cracking is extremely sensitive, alligator cracking has low sensitivity, transverse cracking is insensitive, and the total rutting and smoothness have no to low sensitivity to changes in subgrade type.

Objective and Significance

Overall, the literature confirmed that the PMED software is not sensitive or provides unexpected results for the variation of thickness and resilient modulus of subbase materials. Some global sensitivity analysis indicated that subgrade resilient modulus affects all distresses including the smoothness (IRI) with most impact being on the rutting criteria while other studies indicated issues with the software when it comes to modeling the effect of subgrade materials. The global sensitivity analysis conducted in several research studies encompassing all design inputs as variables may not reflect the true effect of individual inputs. As such, further systematic analysis with one variable at a time is desired to determine the true impact of each input.

The objectives of the TAC ME Pavement Design Subcommittee design trials are to assess further, in systemic manner, the effect of subbase material properties and layer thicknesses, and the effect of varying subgrade types on the predicted distresses in Canadian context using the latest version of the PMED software. The objective of this paper is to present the above stated trial results and analysis. 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 current version of the software.

Software Versions and Trial Inputs

All participants used the PMED software v 2.6 or 2.6.1 with the default global calibration factors for the design trials. The variable design inputs were as follows: i) Climate: varying climates data from 14 climate stations across Canada, ii) Subgrade: five different types of soil/fill materials with varying modulus, gradations and properties, and iii) Subbase: three different subbase materials with varying modulus, gradation, properties and thickness. Manitoba granular base (GSB-I) with 220 Mpa resilient modulus was used in both trials, but thickness varied in trials with different subgrade types.

The following input parameters were the same for both set of trials: i) truck volume: 500 trucks/day on the design lane with 2% annual growth rate, ii) vehicle class distribution and axle load spectra: Manitoba

Level 1; iii) surface layer: 150 mm 12.5 mm Superpave asphalt concrete with PG 58-34 asphalt binder (Manitoba Level 3); iv) design life: 20 years, v) intial IRI: 0.9 m/km; and vi) reliability: 90%.

Selected Climate Stations

As indicated ealier, 14 MERRA climate stations across Canada with varying weather patterns were used in these design trials. Figure 1 shows the geographic location of these climate stations. The red dots indicate relatively warm climates while the blue dots indicate relatively cold climates in Canadian context. Table 1 presents the list of climate stations and a summary of the key climate parameters.

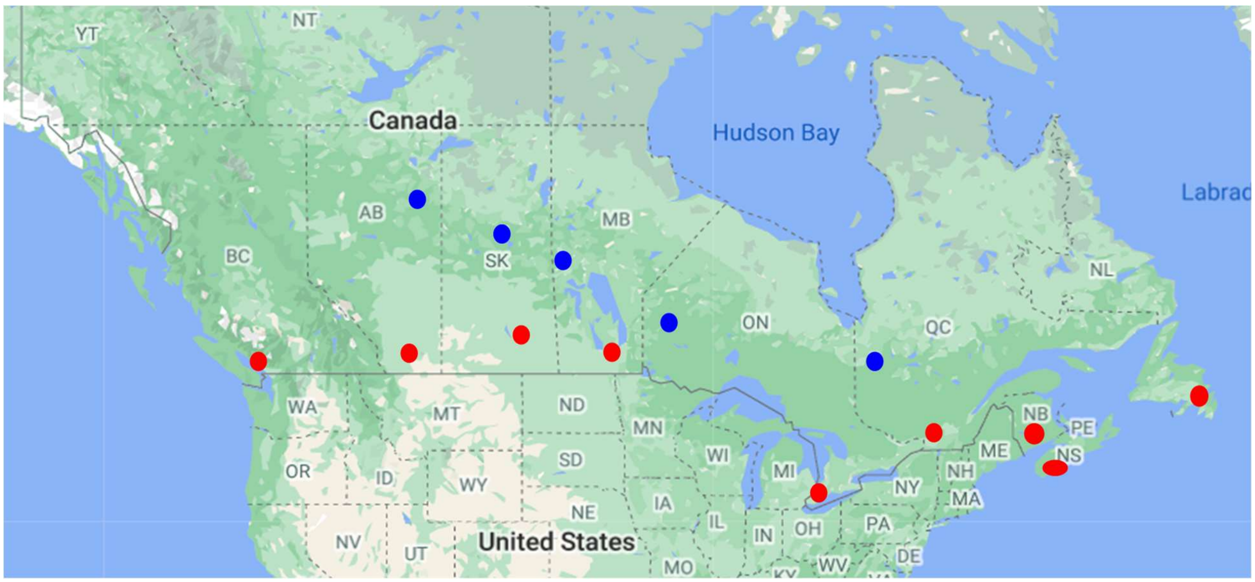


Figure 1. Geographic location of climate statiions

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

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

Design Trial Matrix

The design trials were divided into two different sets with a specific matrix of variable inputs for each trial set. The variables in each trial set including their rationale are presented in the results and discussion section for the convenience of understanding.

Results and Discussion: Effect of Subgrade Types and Stiffness (Trial Set A)

As indicated earlier, five different types of subgrade were used in this trial set to assess the effect of subgrade type and stiffness on the PMED software predicted distresses in different climates across Canada. The soil types were: A-7-6 (high plastic clay), A-6 (low plastic clay), A-4 (sandy silt), A-2-4 (silty sand), and A-1-b (gravelly sand granular fill). A 200 mm base and 300 mm subbase layers were used for all trials with the above listed subgrade soil types. An additional design trial was conducted for A-1-b (gravelly sand granular fill) subgrade with 500 mm base layer and no subbase layer.

The puposes of these trials were as follows:i) to evaluate the effect of combined physical and mechanical properties of different subgrade types, ii) to analyse effect of subgrade properties with a fixed stiffness value for A-6 and A-4 subgrades, and iii) to evaluate any adverse effect of using only two layers, asphalt and base (no subbase), on the PMED software predicted distresses.

Table 2 shows the summary of subgrade material properties and resilient modulus (Mr) values, which reflect typical properties and values for soils encountered in Manitoba. The A-1-b subgrade is Manitoba's select granular fill (GSB-F) material based on the new specifications. The resilient moduli of subgrade varied from 25 MPa to 90 MPa. The resilient moduli of A-6 (Low Plastic Clay) and A-4 (Sandy Silt) subgrade were the same because of the encountered frost susceptibility with sandy silt subgrade. It also allowed for the assessment of the effect of subgrade physical properties with a constant modulus value. The resilient moduli were allowed to vary seasonnally based on moisture and temperature in all design trials.

Table 2. Subgrade types and properties (Trial Set A)

Subgrade Classification	Mr, MPa	Minus 4.75mm, %	Minus 0.075mm, %	Density, kg/m^3	MC, %	LL, %	PI, %
A-7-6 (HP Clay)	25	99.0	92.0	1410	33.0	79	49
A-6 (LP Clay)	40	99.2	80.0	1650	21.5	38	20
A-4 (Sandy Silt)	40	92.0	56.0	1780	22.5	25	3
A-2-4 (Silty Sand)	60	91.0	22.0	1710	15.3	18	3
A-1-b (Gran. Fill)	90	81.0	8.4	2075	8.5	14	0
A-1-b (Gran. Fill) - No SB	90	81.0	8.4	2075	8.5	14	0

Effect of Subgrade Material Types and Stiffness on the Predicted Distresses (Trial Set A)

Figures 2 through 7 show the variation of predicted distresses for different subgrade types. All these figures show that climate conditions affect all type of distresses with the exception of thermal cracking. The issue with thermal cracking prediction seems to be a software limitation, which needs further investigation. Figure 8 shows an example of subgrade rutting variation for two subgrades. Table 3 presents a summary of subgrade rutting for different subgrade types.

Due to a large number of climate stations in the trials, only selected climate stations are used to demonstrate the variation of each predicted distress for a clear understanding and visualization of the effect of each variable. As shown in Figure 2, the predicted IRI decreases slightly for stiffer and better quality subgrade with the exception of silty sand (A-2-4) subgrade. Silty sand subgrade with 60 MPa resilient modulus value provides higher IRI than the low plastic clay (A-6) and sandy silt (A-4) subgrades with a resilient modulus value of 40 MPa. Sandy silt (A-4) subgrade, which is typically frost susceptible material, provides lower IRI than that for the low plastic clay (A-6) subgrade with the same resilient modulus value. Design trials for A-1-b (granular fill) subgrade with and without a subbase layer show similar trends in predicted IRI indicating no issues with design/analysis when a subbase layer is not used.

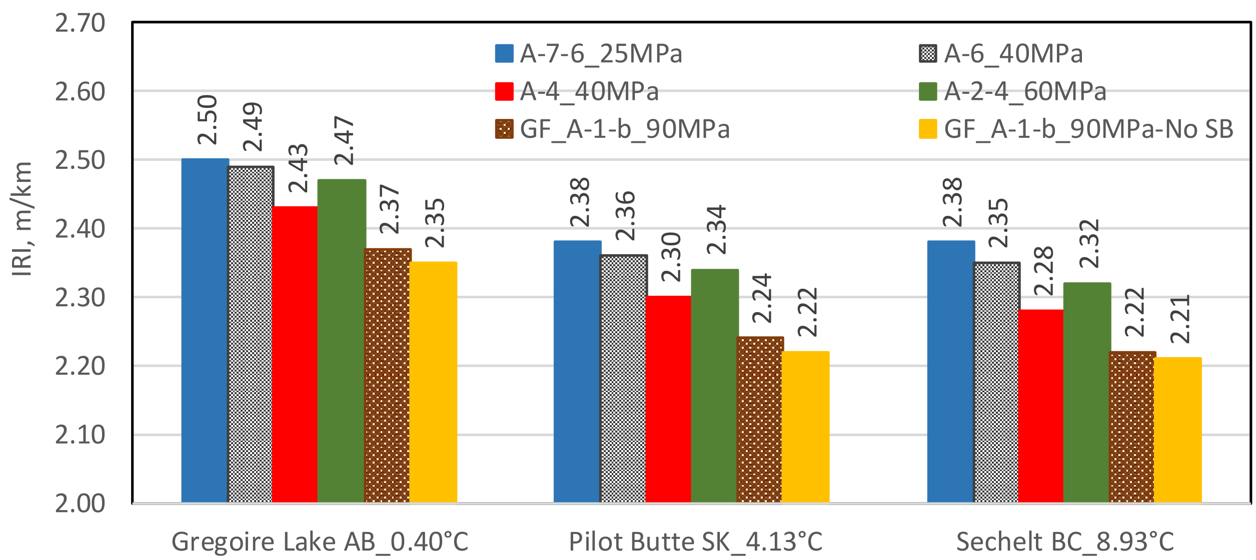


Figure 2. Effect of subgrade material types and stiffness on the predicted IRI (Trial Set A)

Figure 3 shows that the predicted total rutting is inconsistent among the subgrade types with a general trend of increased total rutting for stiffer and better-quality subgrade with most significant increase for sandy silt subgrade. Design trials for A-1-b (granular fill) subgrade with and without subbase layer show similar trends of predicted total rutting resembling the trends for the predicted IRI.

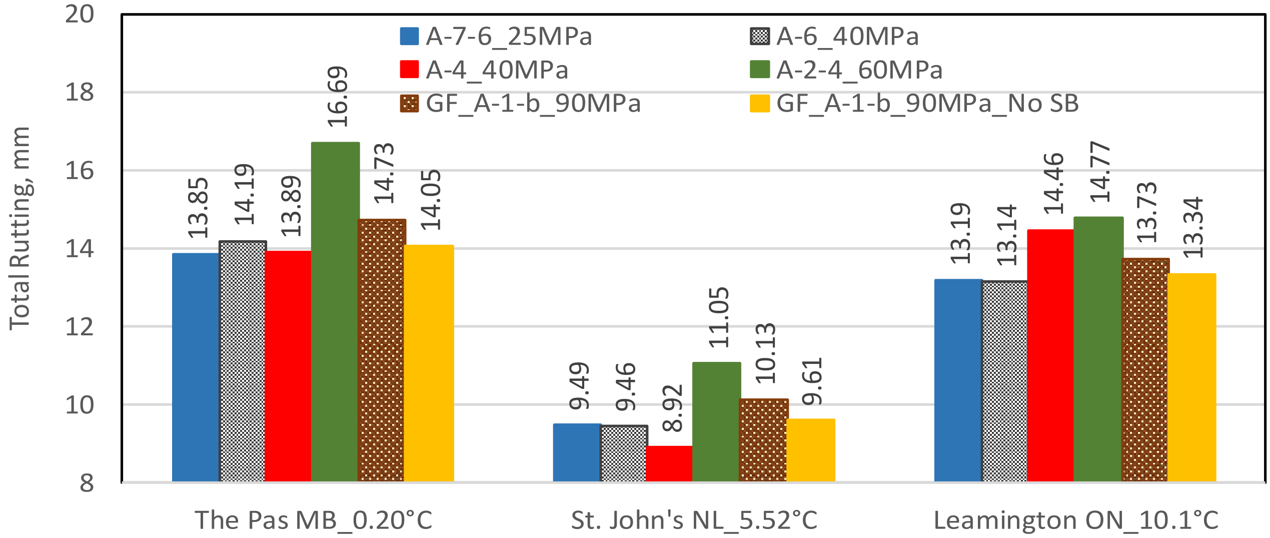


Figure 3. Effect of subgrade material types and stiffness on the predicted total rutting (Trial Set A)

Figure 4 also shows that the predicted alligator (bottom-up fatigue) cracking is inconsistent among the subgrade types, especially for silty sand (A-2-4) subgrade. Sandy silt (A-4) subgrade, which is typically a frost susceptible material, provides less bottom-up fatigue cracking than that for the low plastic clay (A-6) subgrade with the same resilient modulus value. It seems that subgrade properties such as gradation, density, moisture, plasticity, etc. have some influence on the predicted alligator cracking. However, further design trials and analysis are required to confirm this trend. Design trials for A-1-b (granular fill) subgrade with and without subbase layer show similar trends of the predicted alligator cracking resembling the trends for the predicted IRI and total rutting.

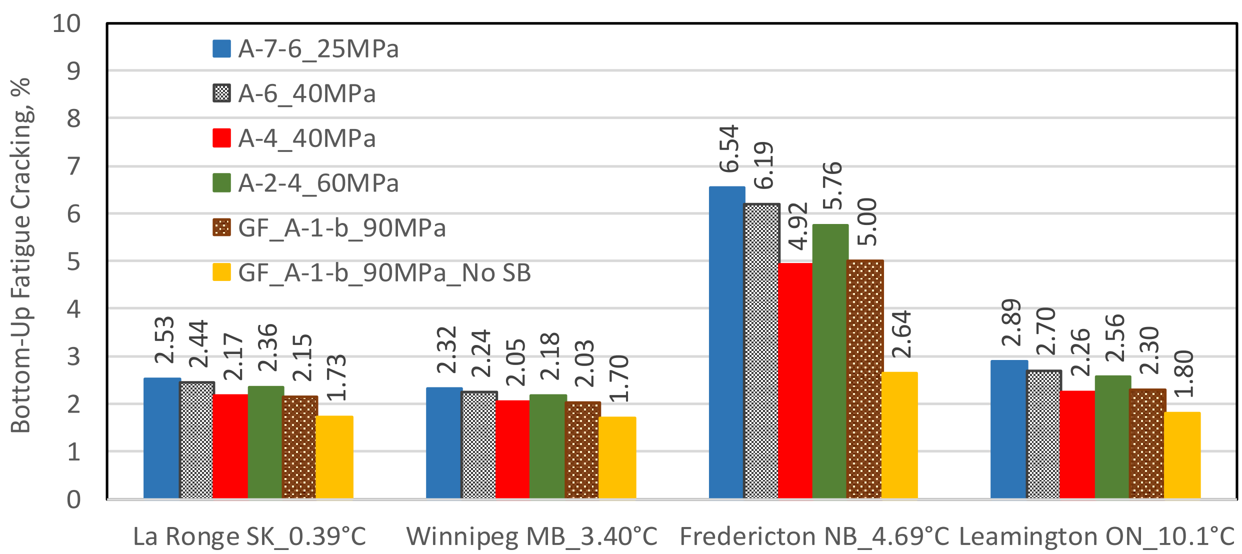


Figure 4. Effect of subgrade material types and stiffness on the predicted bottom-up FC (Trial Set A)

As shown in Figure 5, subgrade quality and stiffness have no or negligible effect on the predicted top-down fatigue cracking with some inconsistency. Design trials for A-1-b (granular fill) subgrade with and without subbase layer show same trends of the predicted longitudinal cracking.

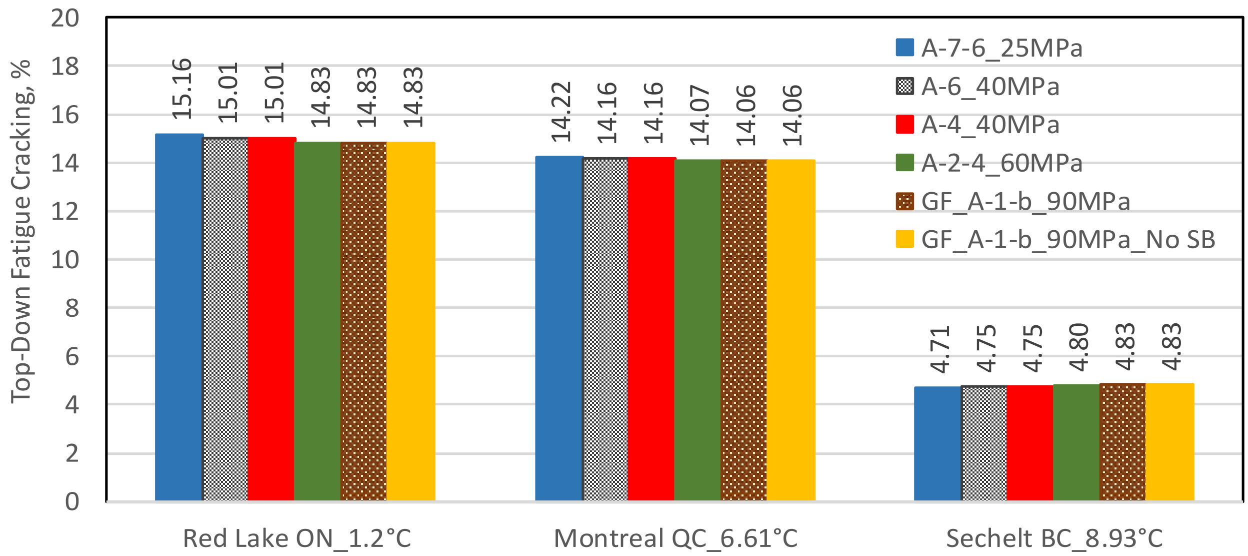


Figure 5. Effect of subgrade material types and stiffness on the predicted top-down FC (Trial Set A)

Figure 6 shows that the predicted AC layer rutting is inconsistent among the subgrade types. Design trials for A-1-b (granular fill) subgrade with and without subbase layer show similar trends of predicted AC layer rutting resembling the trends for the total rutting.

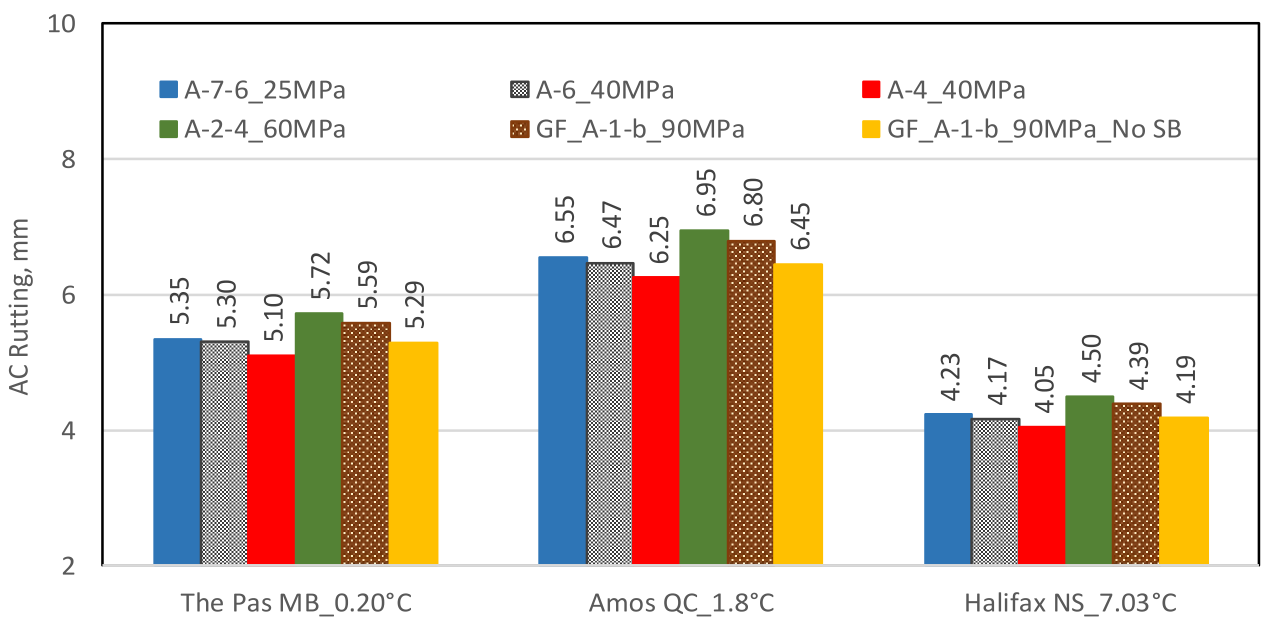


Figure 6. Effect of subgrade material types and stiffness on the predicted AC layer rutting (Trial Set A)

Figure 7a shows no noticeable difference in the predicted thermal cracking among the subgrade types and climate stations despite a significant variation of winter temperature among the climate stations and the use of single asphalt mixture and binder in all design trials. There was no year-to-year variation of the predicted thermal cracking to determine the time to reach the limiting value for a climate station and then compare among the climate stations. Examples of the predicted thermal cracking trends for Winnipeg and The Pas climate stations are presented in Figure 7b.

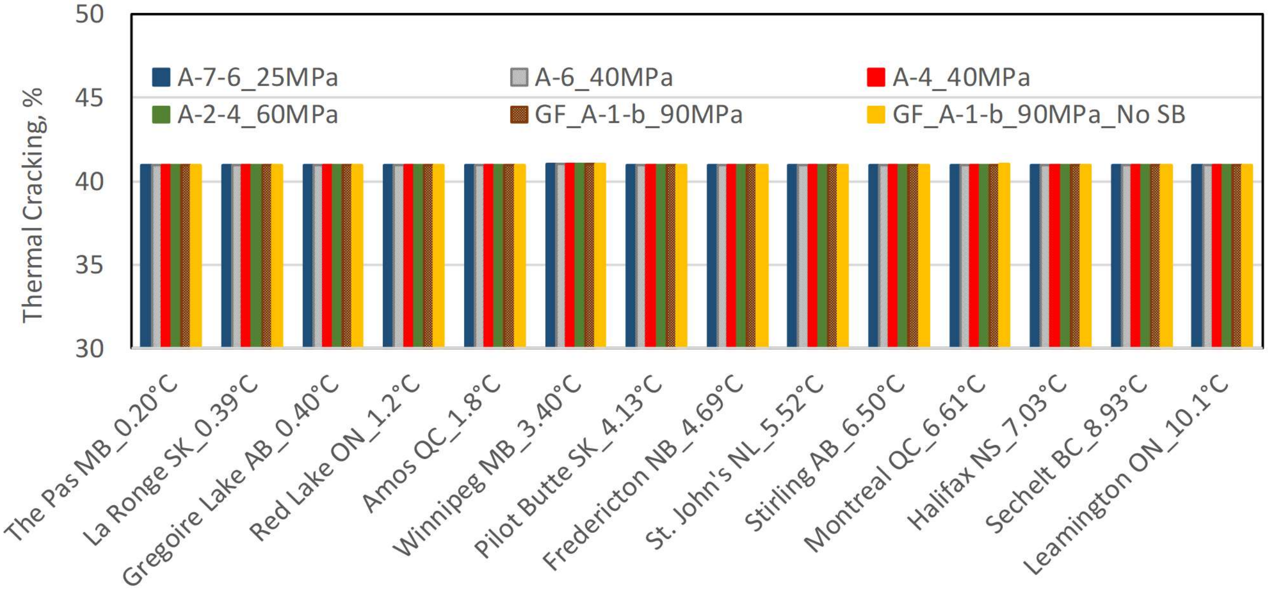
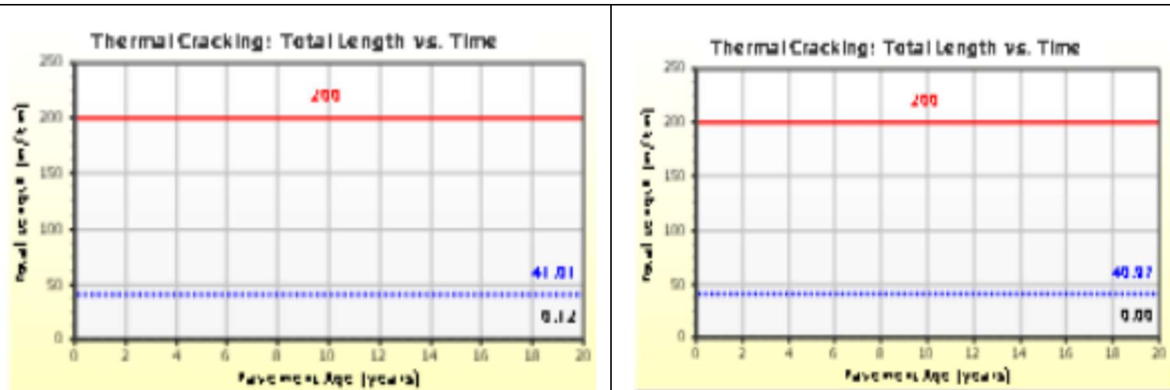


Figure 7a. Effect of subgrade material types and climate on the predicted thermal cracking (Trial Set A)



i) Winnipeg, MB

ii) The Pas, Manitoba

Figure 7b. Examples of the predicted thermal cracking trends over the design life (Trial Set A)

Figure 8 shows an example of predicted subgrade rutting trends in Winnipeg, MB climate for two subgrade materials: i) high plastic clay (A-7-6) and ii) gravelly sand (A-1-b). These two materials reflect the weakest and strongest subgrades among the subgrade types used in these trials with resilient moduli values of 25 MPa and 90 MPa, respectively. The figure indicates that stiffer subgrade results in higher subgrade rutting than that with the weaker subgrade. Table 3 shows the summary of PMED software predicted subgrade rutting for all five subgrade materials in Winnipeg climate where all other inputs remain the same. Table 3 also shows a generally increasing trend for subgrade rutting with stiffer and better quality subgrade with some inconsistency.

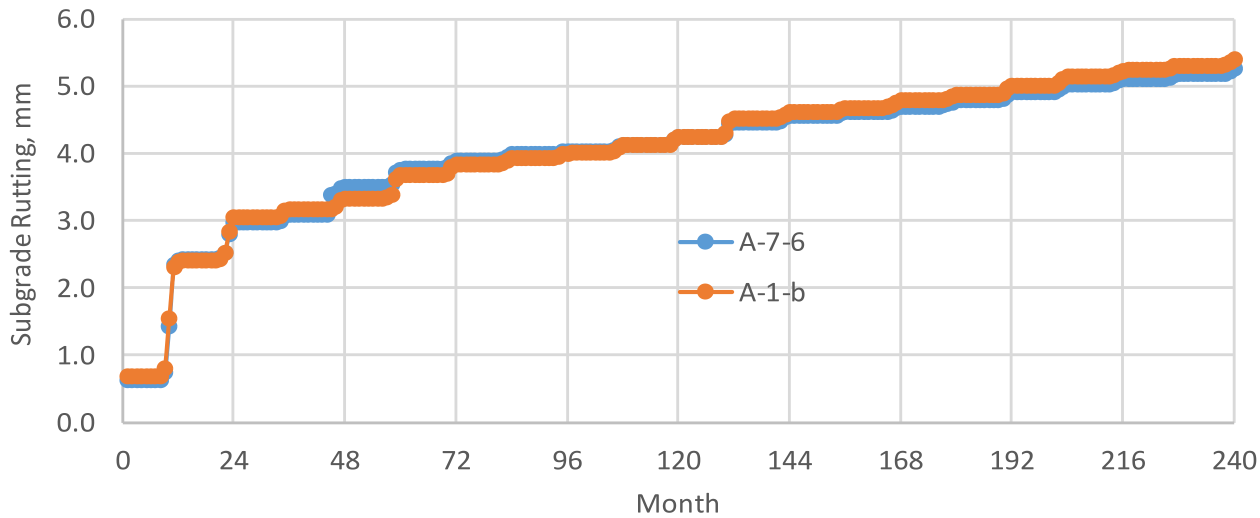


Figure 8. Variation of subgrade rutting for two different subgrades in Winnipeg climate (Trial Set A)

Table 3. Summary of predicted subgrade rutting for different subgrades in Winnipeg climate

Subgrade Type	Subgrade Resilient Modulus (Mr), MPa	Subgrade Rutting, mm
High Plastic Clay (A-7-6)	25 MPa	5.24
Low Plastic Clay (A-6)	40 MPa	5.15
Sandy Silt (A-4)	40 MPa	5.30
Silty Sand (A-2-4)	60 MPa	5.23
Gravelly Sand (A-1-b)	90 MPa	5.38

Results and Discussion: Effect of Subbase Types, Stiffness and Gradations (Trial Set B)

To assess the impact of subbase materials on the PMED software predicted distresses, three different types of subbase materials were used that include the following: i) GSB-CR-M50 (MB), ii) GSB-C (MB), and iii) SK-GSB. GSB-CR-M50 (MB) is a coarse graded minus 50 mm crushed rock granular subbase material meeting Manitoba's new specifications. It has a resilient modulus value of 300 MPa. GSB-C (MB) is Manitoba's typical subbase material based on new specifications. It is a medium graded granular subbase material with a resilient modulus value of 105 MPa. SK-GSB is a fine graded subbase material used in Saskatchewan. The estimated resilient modulus value for this subbase material is 70 MPa. Figure 9 shows the gradation of these three subbase materials. The physical properties and stiffness values of these materials are listed in Table 4.

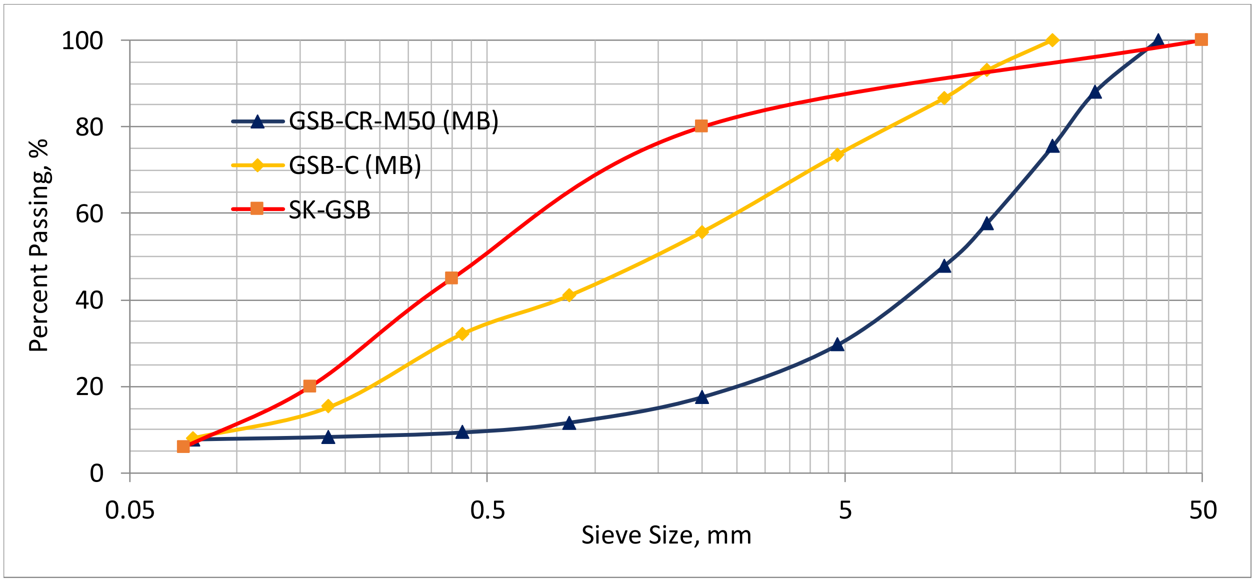


Figure 9. Gradations of granular subbase materials used in Trial Set B

Table 4. Subbase types and properties (Trial Set B)

Subbase Type	Max. Size, mm	% Passing 19mm	% Passing 4.75mm	% Passing 0.075mm	LL, %	PI, %	Density, kg/m3	MC, %	Mr, MPa
GSB-CR M50 (MB)	37.5	75.5	29.6	7.8	0	0	2065	6.8	300
GSB- C (MB)	19	100.0	73.6	8.1	22	4	2050	8.6	105
SK-GSB	50	94.0	87.0	7.0	25	6	1989	9.2	70

Effect of Subbase Thickness and Material Types/Stiffness on the Predicted Distresses (Trial Set B)

To determine the effect of granular subbase thickness and types/stiffness on the PMED software predicted distresses, all participants used a 200 mm thick granular base (GBC-I with a resilient modulus value of 220 MPa) layer above the subbase layer and a high plastic clay subgrade with a resilient modulus value of 35 MPa in all trials. The varied thickness of subbase were 200 mm and 500 mm.

Figures 10 through 14 show the variation of predicted distresses for the variation of subbase thickness and stiffness/types. Once again, due to a large number of climate stations used in these trials, only selected climate stations are used to demonstrate the variation of each predicted distress for clear understanding/visualization of the effect of each variable. The figures show that climate has a significant effect on the predicted distresses, except thermal cracking (not shown here). The predicted thermal cracking remained unchanged regardless of climate conditions as shown in the case of Trial Set A.

Figure 10 shows the variation of the predicted IRI. It shows that the predicted IRI decreases slightly with an increase in subbase thickness from 200 mm to 500 mm for CR-50, which is a coarse and stiff material.

The trends are opposite for medium (GSB-C) and fine (SK-GSB) graded subbase materials with an increase in IRI for an increase in thickness from 200 mm to 500 mm. This inconsistent variation of predicted IRI for the increased subbase thickness is unexpected and does not align with agency experiences. Figure 10 also shows that the predicted IRI increases slightly for weaker subbase materials with some inconsistency.

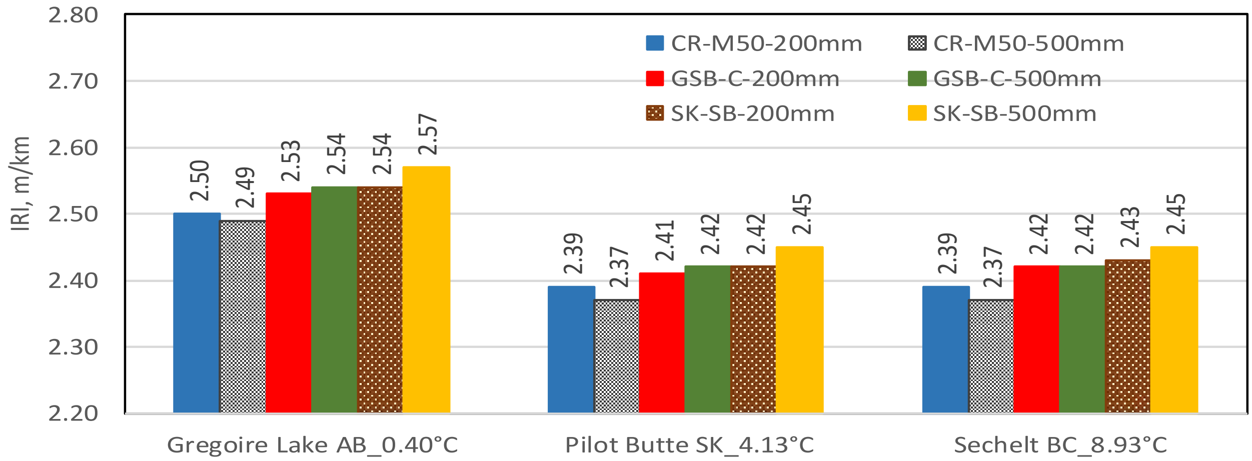


Figure 10. Effect of subbase material on the predicted IRI (Trial Set B)

Figure 11 shows the variation of predicted total rutting for the variation of subbase thickness and stiffness/type. As shown in the figure, the predicted total rutting decreases with an increase in subbase thickness from 200 mm to 500 mm for CR-50 (a coarse and stiff material). The trends are opposite (negative), with an increase in total rutting, for medium (GSB-C) and fine (SK-GSB) graded subbase materials for an increase in thickness from 200 mm to 500 mm. This inconsistent variation of predicted total rutting for the increased subbase thickness is also unexpected and does not align with agency experiences. Figure 11 show a positive trend for the predicted rutting with some increase in total rutting for weaker subbase materials.

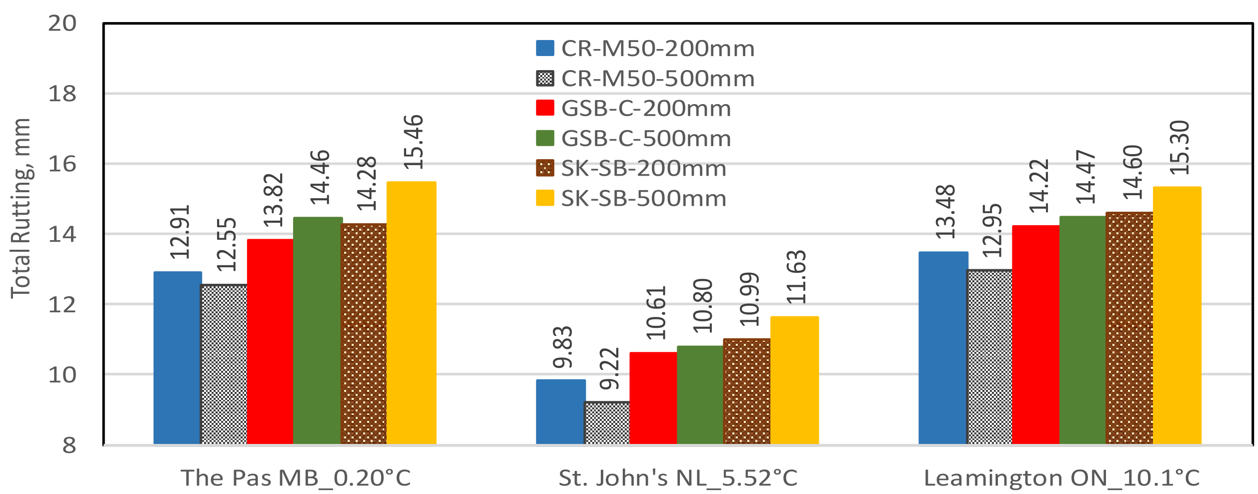


Figure 11. Effect of subbase material on the predicted total rutting (Trial Set B)

Figure 12 shows the variation of predicted bottom-up fatigue cracking for the variation of subbase thickness and stiffness/type. As shown in the figure, the predicted alligator cracking decreases with an increase in subbase thickness from 200 mm to 500 mm for CR-50 (a coarse and stiff material) and GSB-C (a medium graded subbase). The variation of alligator cracking for increased thickness is inconsistent for fine graded SK-GSB subbase material. This inconsistent variation of predicted alligator cracking for the increased subbase thickness is also unexpected. Figure 12 shows subbase stiffness has significant effect on the predicted bottom-up fatigue cracking and the effect is highly significant for weaker subbase.

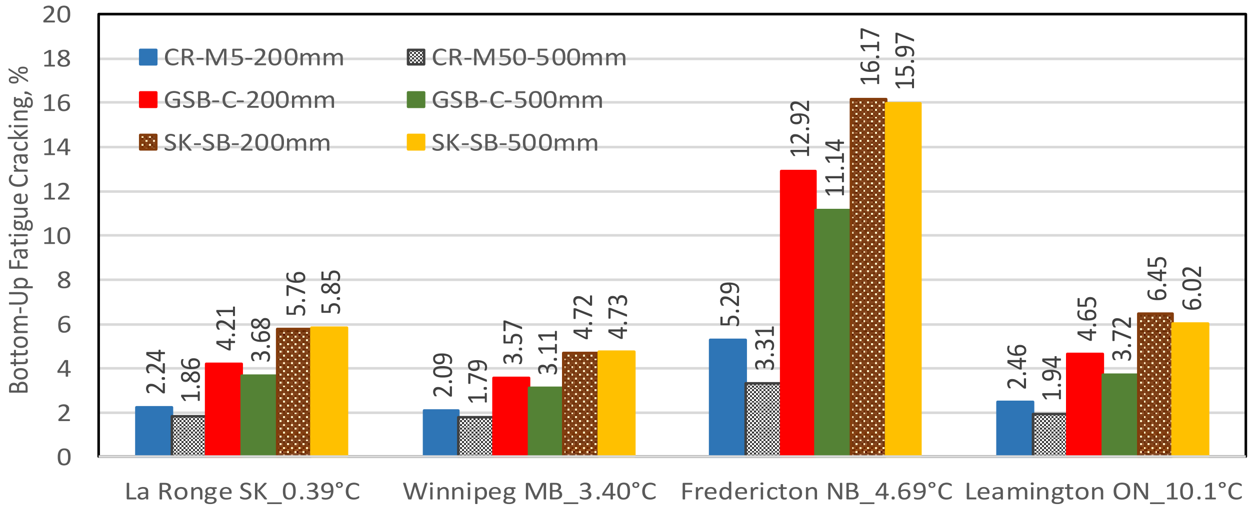


Figure 12. Effect of subbase material on the predicted bottom-up fatigue cracking (Trial Set B)

Figure 13 shows an inconsistent variation of the predicted top-down fatigue (longitudinal) cracking among climate stations for the variation (increase) of subbase thickness and stiffness, which have no effect on the predicted top-down fatigue cracking.

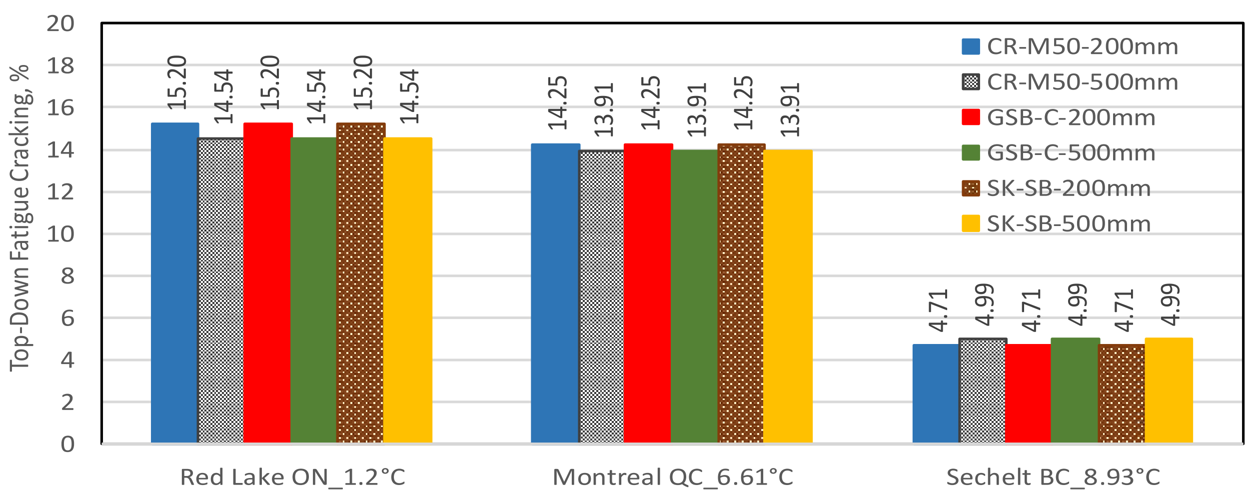


Figure 13. Effect of subbase material on the predicted top-down fatigue cracking (Trial Set B)

Figure 14 shows the variation of predicted AC layer rutting for the variation of subbase thickness and stiffness/type. As shown in the figure, the predicted AC layer rutting increases slightly for an increase in subbase thickness from 200 mm to 500 mm for CR-50 (a coarse and stiff material) and GSB-C (medium graded subbase). The variation is inconsistent for the fine graded subbase (SK-GSB) material. Figure 14 also shows that AC layer rutting decreases as the subbase material become weaker.

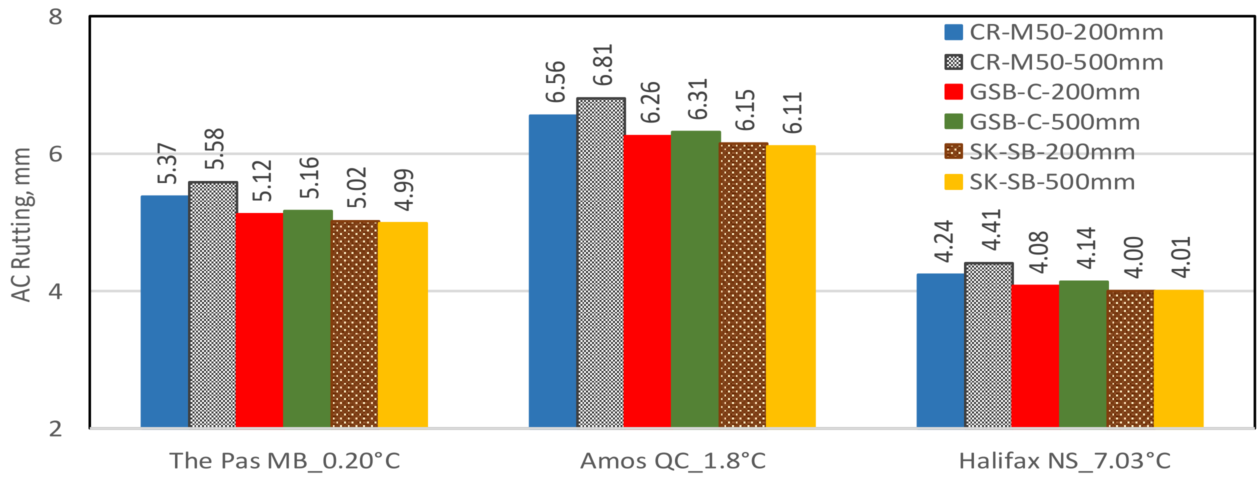


Figure 14. Effect of subbase material on the predicted AC layer rutting (Trial Set B)

Minimum Subbase Stiffness for a Positive Trend of Predicted Distress for Subbase Thickness

As indicated in the previous section, increased subbase thickness has an inconsistent (positive or negative) effect on the predicted distresses depending on the stiffness of the subbase materials. To determine the breakpoint of the subbase modulus value that will provide a positive trend of the predicted distresses, Manitoba conducted several additional design trials with 200 mm and 500 mm layer thickness for the GSB-C material. In these additional design trials, the subbase modulus varied from 70 MPa to 200 MPa. Figures 15 through 19 show the variation of the PMED software predicted distresses corresponding to varying moduli values for both 200 mm and 500 mm subbase layer thickness.

Figure 15 shows that there is no noticeable difference in the predicted IRI between 200 mm and 500 mm subbase layers when the subbase modulus is 150 MPa and higher. Although negligible, the thicker subbase provides higher IRI, a negative trend, when the subbase modulus value is lower than 150 MPa.

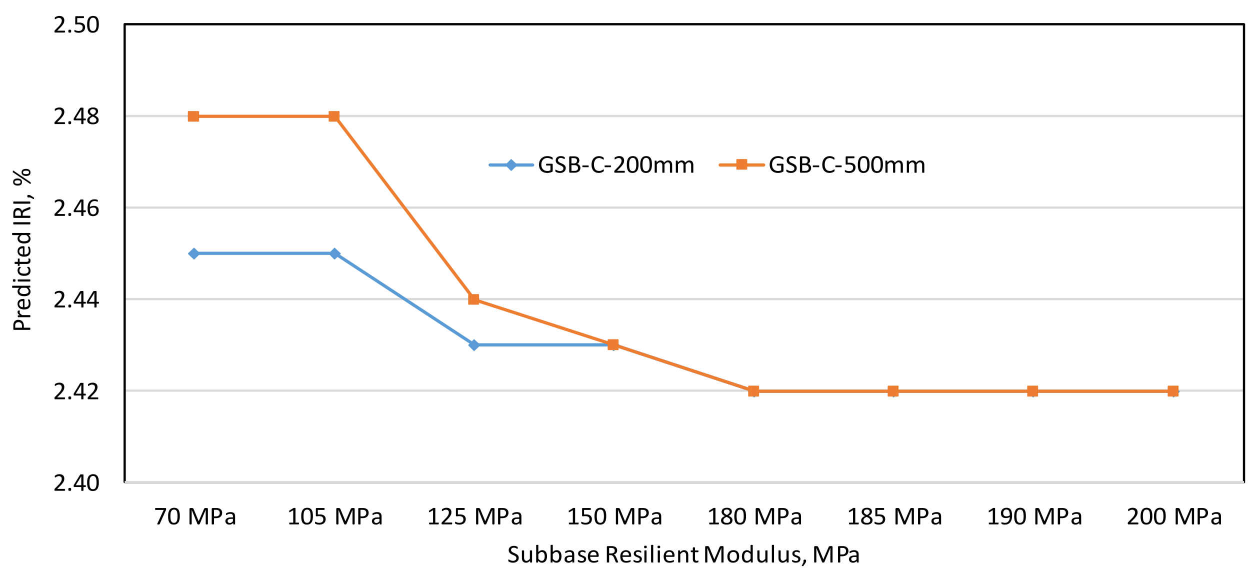


Figure 15. Variation of predicted IRI with the variation of subbase (GSB-C) stiffness

Figure 16 shows that the predicted total rutting follows a negative trend with higher rutting for the subbase layer thickness of 500 mm as compared to that for the subbase layer of 200 mm when the subbase modulus is 180 MPa and lower. A positive (and expected practical) trend is observed for increased subbase thickness when the subbase modulus value is 185 MPa or higher.

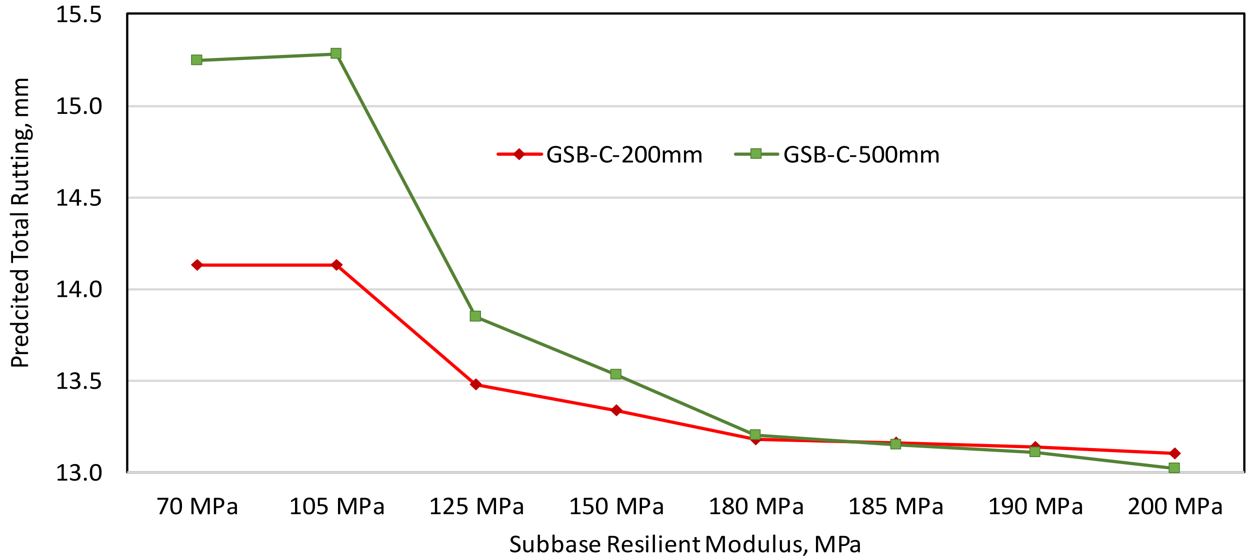


Figure 16. Variation of predicted total rutting with the variation of subbase (GSB-C) stiffness

Figure 17 shows that the predicted bottom-up fatigue (alligator) cracking is identical for 200 mm and 500 mm subbase layers when the subbase modulus value is 105 MPa and lower. A positive (expected practical) trend is observed for increased subbase layer thickness when the subbase modulus value is higher than 105 MPa.

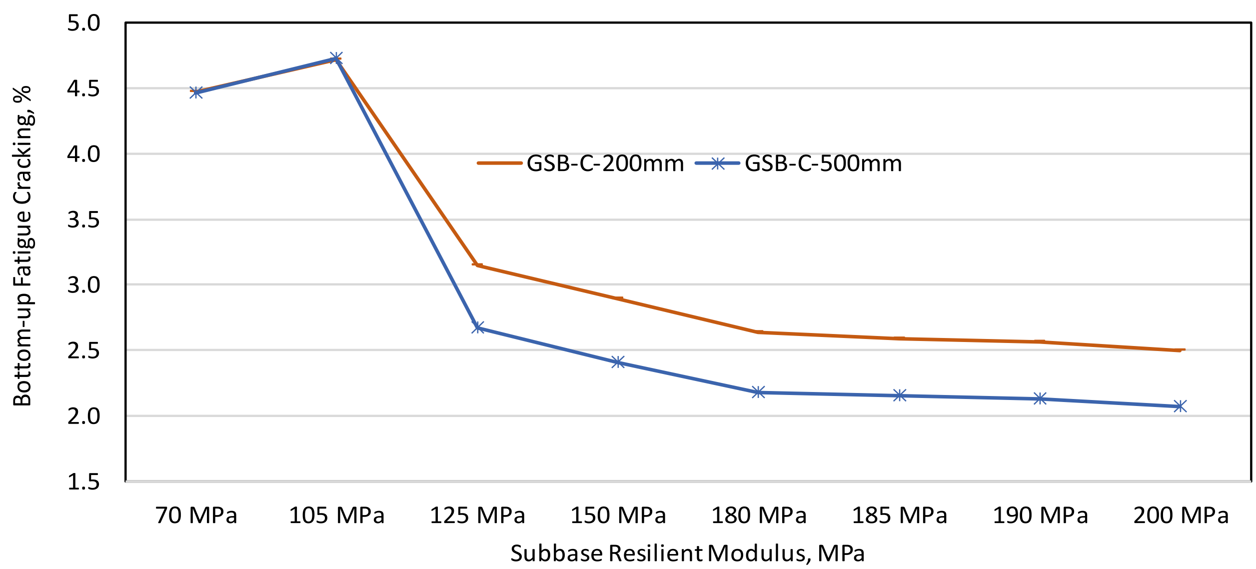


Figure 17. Variation of predicted bottom-up fatigue cracking with the variation of subbase stiffness

Figure 18 shows that the predicted AC layer rutting follows a negative or inconsistent trend for increased subbase thickness, when the subbase modulus value is less than about 180 MPa. A positive and consistent (expected practical) trend is observed for increased subbase layer thickness when the subbase modulus value is approximately 180 MPa and higher.

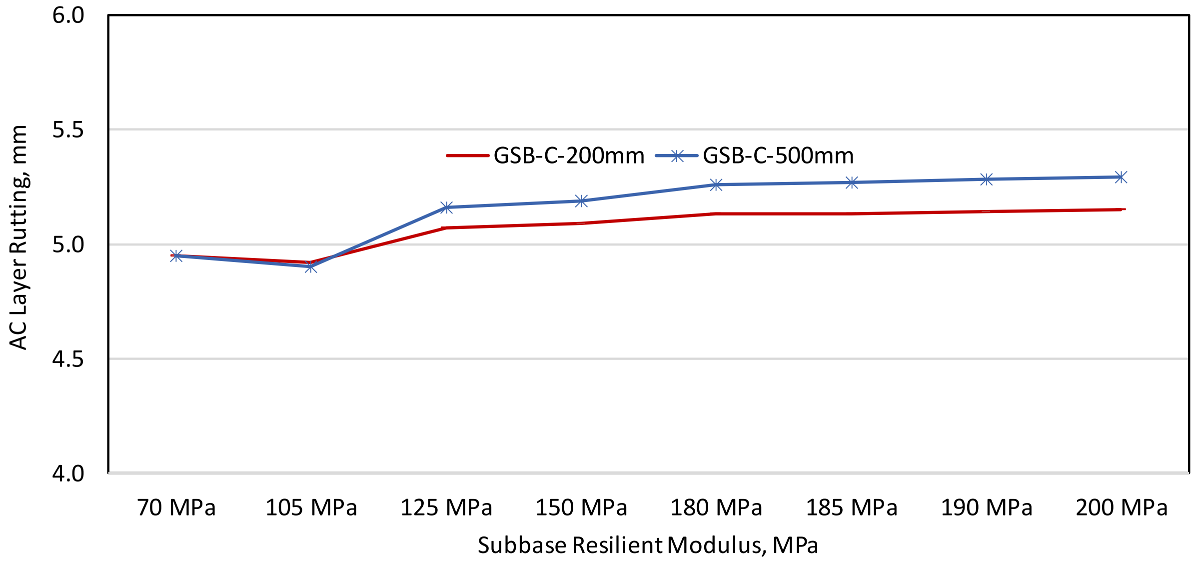


Figure 18. Variation of predicted AC layer rutting with the variation of subbase stiffness

Effect of Subbase Gradations on the Predicted Distresses

To determine the effect of subbase material gradations on the PMED software predicted distresses, Manitoba conducted additional design trials with a subbase layer thickness of 200 mm for two gradations. In these additional trials, the modulus value of GSB-C was increased from typical 105 MPa to 300 MPa and the modulus value of GSB-CR-M50 modulus was decreased from typical 300 MPa to 105 MPa. The results of these trials are presented in Table 5. As shown in the table, there is a negligible effect of subbase gradations on the predicted distresses.

Table 5. Summary of predicted distresses for different gradations

Gradation (Thickness)	Resilient Modulus	IRI, m/km	Total Rutting, mm	BUFC, %	Thermal Cracking, %	TDFC, %	AC Rutting, mm
CR- M50 (200mm)	300 MPa	2.41	12.78	2.09	41.01	15.04	5.25
GSB-C (200mm)	300 MPa	2.41	12.79	2.11	41.01	15.04	5.23
CR- M50 (200mm)	105 MPa	2.44	13.66	3.49	41.01	15.04	5.04
GSB-C (200mm)	105 MPa	2.44	13.68	3.57	41.01	15.04	5.02

Summary of Observations

Effect of Subgrade Types/Stiffness (Trial Set A)

The results and analysis of the design trials completed by the TAC ME Pavement Design Subcommittee have shown that the subgrade soil type and stiffness have minor effect on the predicted IRI. The results also show unexpected and inconsistent trends for the predicted total rutting (permanent deformation), bottom-up fatigue cracking and AC layer rutting. Subgrade soil type and stiffness have negligible or no effect on the predicted top-down fatigue cracking. The effect of subgrade type/stiffness on the predicted subgrade rutting is inconsistent with a general trend of increased subgrade rutting with stiffer subgrade.

Effect of Subbase Thickness, Types/Stiffness and Gradations (Trial Set B)

The results and analysis of the design trials completed by the TAC ME Pavement Design Subcommittee have shown that the variation of PMED software predicted IRI is negligible and inconsistent with the variation of subbase thickness and stiffness. The predicted total rutting increases for weaker subbase material but the effect of increased subbase thickness is inconsistent. Weaker and thinner subbase results in a significant increase of the predicted fatigue cracking. Subbase stiffness has no effect on the top-down fatigue cracking, but increased subbase thickness results in a moderate reduction in top-down fatigue cracking. Stiffer and thicker subbase results in an increased AC layer rutting.

For positive and consistent trends of the predicted distresses for increased subbase thickness, the subbase modulus value should be 185 MPa or higher as governed by the predicted total rutting. This high modulus requirement seems to be unreasonable and impractical for most cases based on local performance experience and availability of aggregate materials. Subbase gradations have a negligible effect on the predicted distresses using the PMED software.

Concluding Remarks

Based on the completed trial results, it appears that the current version of the AASHTOWare PMED software does not adequately consider the effect of unbound materials as well as subgrade type/stiffness. As such, an optimum or economic pavement design utilizing a stiffer subbase and/or subgrade and a thicker subbase is impractical by using the PMED software. Agencies interested in using the PMED software should develop a catalogue for desired thickness of unbound base and subbase layer(s) based on experience with local subgrade materials (stiffness, frost susceptibility, swelling, etc.) and drainage. The PMED software then can be used to determine the required AC layer thickness. A local calibration/verification of the software may also be beneficial for reliable determination of AC layer thickness in different climate and traffic loading scenarios.

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