Sensitivity of the Pavement ME Design Software Predicted Distresses in Flexible Pavements to Granular Base Materials

Principal Author:
M. Alauddin Ahammed, Ph.D. P. Eng.
Manager, Pavement and Materials Engineering Section
Manitoba Transportation and Infrastructure
1420- 215 Garry Street, Winnipeg, Manitoba R3C 3P3
Tel.: (204) 792 1338
Email: Alauddin.Ahammed@gov.mb.ca

Co-Authors:
Julie Roby, M.A.Sc., P.Eng.
Pavement Design Engineer
Ministère des Transports
800, rue d'Youville, 14e étage
Québec (Québec) G1R 3P4
Tel. (418) 643-0800 x24065
E-mail: Julie.Roby@transports.gouv.qc.ca

Mohammad Karim, M.A.Sc., P.Eng.
Surfacing Standards Specialist
Alberta Transportation
2nd floor Twin Atria Building, 4999-98 Avenue NW, Edmonton, AB T6B 2X3
Tel.: 780-643-2812
E-mail: Mohammad.Karim@gov.ab.ca

Sam Esfandiarpour, Ph.D., P.Eng.
Pavement Engineer
Thurber Engineering Ltd.
Suite 11 – 1815 Ironstone Manor, Pickering, Ontario L1W 3W9
Tel.: 905 829 8666 x5233, 647 954 1575 (D)
E-mail: sesfandiarpour@thurber.ca

Paper prepared for presentation
at the Innovations in Pavement Management, Engineering and Technologies Session
of the 2022 Annual Conference of the
Transportation Association of Canada
Edmonton, AB

Abstract

Granular base materials constitute a considerable portion of flexible pavement structures. In empirical design methods, 1 mm of asphalt concrete (AC) thickness generally equates to 3-4 mm of granular base thickness with no concern related to pavement performance. Experience has also shown that an increased base layer thickness and a stiffer base material can significantly enhance the performance of flexible pavements. However, 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 materials properly.

Between May and November 2021, Transportation Association of Canada (TAC) ME Pavement Design Subcommittee completed five sets of design trials to assess the sensitivity of the PMED software predicted distresses to the physical and mechanical properties of granular base materials. The design trials included: i) six different granular base specifications with varying physical and mechanical properties with no subbase layer, ii) six different granular base specifications with varying physical and mechanical properties with a subbase layer, iii) six different sources of granular base materials with varying stiffness with two different gradations, iv) three different granular base gradations with constant stiffness value, and v) varying base layer thickness for two different materials. The results have shown negligible to excessive sensitivity of the predicted distresses to the variation of base material stiffness, gradations and thickness with some inconsistencies.

Acknowledgement

The authors would like to acknowledge and thank the persons, listed herein, for their participation in design trials and/or discussion: Susanne Chan and Fiona Leung (Ministry of Transportation Ontario), Jhuma Saha and John Crockett (Alberta Transportation), Diana Podborochynski (Saskatchewan Ministry of Highway and Infrastructure), Qingfan Liu, Arma Dhaliwal and Remi Oyediji (Tetra Tech), and Yasir Shah and Marcus Wong (Manitoba Transportation and Infrastructure).

Introduction

Unbound (i.e., granular) base materials constitute a considerable portion of conventional pavement structures, especially for the flexible pavements and unpaved roads in Canada and elsewhere. In conventional flexible pavements, a 100 to 300 mm thick base layer with additional subbase, as required depending on the subgrade stiffness as well as frost susceptibility and design traffic loading, underlies asphalt concrete (AC) layer. Some jurisdictions (e.g., Alberta) design and construct their flexible pavements with only a single base layer below the surfacing layer (no subbase underneath the base layer) and the thickness of base layer could be up to 600 mm. The required AC and subbase (where used) thickness are also affected by stiffness of the base material.

In the widely used AASHTO 1993 Design method [1], 1 mm of asphalt concrete (bituminous) thickness typically equates to 3-4 mm of granular base thickness, depending on the structural layer coefficients of AC (typically 0.40-0.48) and base materials (typically 0.12-0.14). Such conversions have been extensively used in different jurisdictions to convert the calculated total (design) structural number into the thickness of various layer materials. The properly designed and constructed flexible pavements following this approach performed well, if a certain minimum thickness of AC layer is placed over the base (and subbase) layer(s) depending on the design traffic loading.

Experience has shown that an increased base layer thickness and a stiffer base material have enhanced the performance of flexible pavements due to increased structural capacity. They also provided economic pavement structures. In cold climate like Canada, a thicker and good quality base layer can provide extra protection from frost and freeze/thaw related damages, and enhance pavement drainage performance leading to a longer service life of all 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 adequately consider the effect of the granular base thickness and stiffness as expected based on past performance experience. This study was undertaken to verify the findings of earlier studies using the latest version of the software.

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 (flexible/rigid pavements); 2) effect of asphalt mix, binder and thickness; and 3) effect of concrete slab and joint designs. The identified issues from these trials were brought forward to AASHTO Pavement ME Task Force and the software developer, Applied Research Associates (ARA). Between May and November 2021, design trials have been completed with different climatic inputs from 14 to 17 weather stations across Canada to assess the sensitivity of the predicted distresses to the physical and mechanical properties of granular base materials. The design trials and analysis included: i) six different granular base specifications from several provinces of Canada with varying physical and mechanical properties with no subbase layer, ii) six different granular base specifications from several provinces of Canada with varying physical and mechanical properties with a subbase layer, iii) six different sources (gravel, limestone and granite) of granular base materials with varying stiffness (Mr = 103 to 310 MPa) with two different gradations, iv) three different granular base gradations with constant stiffness (Mr = 250 MPa), and v) varying base layer thickness (200 to 500 mm) for two different materials (Mr = 220 MPa and 120 MPa). This paper presents the results of these trials and discusses the issues and suitability of the AASHTOWare PMED software for modeling the effect of granular base materials.

Findings from Literature Review

Several studies [2, 3 and 4] have reported that AASHTOWare PMED procedure is less sensitive to base layer compared to AASHTO 1993. Masad and Little [2] indicated that unbound layers exhibit anisotropic properties, and it is not considered in the MEPDG (PMED) software. A sensitivity analysis (in Texas) noted that base modulus and thickness have significant influence on the predicted IRI and longitudinal cracking. The effect on alligator cracking is about half of that on longitudinal cracking. Granular base properties have been found to have almost no influence on the predicted permanent deformation (total rutting). Through a sensitivity analysis (in Iowa), Coree et al. [3] noted that: i) base properties are sensitive for longitudinal cracking and very sensitive for alligator cracking with an extreme sensitivity for the modulus, ii) base properties are very sensitive for AC rutting, but are not sensitive to subbase or subgrade rutting, iii) base modulus is sensitive for IRI, but thickness is not, and iv) base modulus has more impact than thickness on the predicted distresses. Luo et al. [4] found that total rutting is marginally sensitive to resilient modulus of unbound layer and insensitive to thickness. Although resilient modulus, shear strength and permanent deformation are key factors, PMED models lack: i) moisture-dependency of the modulus, shear strength and permanent deformation, ii) stress-dependency of the modulus and permanent deformation, and iii) cross-anisotropy of the modulus.

In a study at West Virginia University, Orobio [5] found that base material stiffness significantly affects IRI, rutting and cracking. However, in a study at the University of Maryland, Schwartz and Carvalho [6] found that base layer thickness has little influence on performance with MEPDG software when compared to the AASHTO 1993. Bottom-up fatigue (alligator) cracking has little sensitivity and rutting is insensitive to base layer thickness. Although performance is expected to be better when increasing base thickness, MEPDG provides the opposite results. An improved performance is expected with a stiffer base, but rutting is not as sensitive as fatigue cracking because of the effect of asphalt to base modulus ratio. Base resilient modulus variation only has little influence on AC elastic deformations (vertical strains) and thus on AC rutting. However, it has a bigger effect on horizontal tensile strains at the bottom of AC layer, thus on bottom-up fatigue cracking.

Several studies [7, 8 and 9] indicated that with the AASHTO 1993 guide [1], granular base and subbase layers could contribute up to 50 % of overall structural capacity of a pavement structure, but unbound granular layer is less sensitive with the new MEPDG approach. The NCHRP Project 1-47 report indicated that: i) resilient modulus and thickness of base layer are very sensitive for longitudinal cracking and alligator cracking with resilient modulus being the most sensitive between the two; ii) for rutting (AC or total) and IRI, properties of base layer are not very sensitive, and iii) MEPDG design process is dominated by the AC layer and is less sensitive to base layer compared to AASHTO 1993.

A NCAT study [10] indicated that an increased thickness of unbound aggregate base in the MEPDG has limited impact on AC thickness. However, AC thickness can be decreased by increasing resilient modulus (Mr) of the aggregate base. A study in Minnesota [11], found that the use of locally available and somewhat marginal materials might be quite cost-effective in terms of fatigue and rutting life expectancies by using stress dependent Mr models in Minnesota's mechanistic empirical pavement design software (MnPAVE). Using an advanced three-dimensional finite element (FE) model that captures the nonlinear cross-anisotropic behaviour of granular material, Wang and Li [12] also found that fatigue cracking and subgrade rutting are more affected by changes of aggregate base layer properties.

Dawson [13] identified the micro-scale properties of the individual particles of the granular material as a profound influencer on the behaviour of the material. The study concluded that the non-linearity of granular material is an important characteristic when used as pavement base course with a thin bound surface. Overall response of a pavement with the same aggregate in the same type of structural layer will differ depending on the thickness and condition of the layers overlying and underlying the aggregate and there will be an associated change in granular material response, which contributes to this change in the pavement response.

An analysis in Manitoba [14] found that 5 mm AC could be replaced with 200 mm granular base up to a maximum base thickness of 250 mm in the MEPDG software. The base layer exceeding 250 mm is shown to produce no practical influence on the required asphalt thickness. Although the total rutting decreases with an increase in base thickness, the increased AC thickness required for an increase of traffic volume (e.g., 500 to 1000 trucks/day) cannot be replaced with any amount of base (or subbase). The bottom-up fatigue cracking decreases while the predicted longitudinal (AC top-down) cracking, transverse cracking and AC layer rutting increase with an increase in base thickness. The resilient moduli of base was shown to produce significant influences on the predicted distresses. A design example showed that the AC thickness could be reduced by 10 mm with an increase in base Mr from 140 MPa to 280 MPa.

Objective and Significance

Some past studies conducted global sensitivity analysis of the PMED software predicted distresses to granular base properties without a in-depth logical analysis, while some other studies indicated a low to high sensitivities to granular modulus but no or negligible sensitivities to base layer thickness. Some also questioned the adequacy of the PMED software models for unbound materials. The objectives of the TAC PMED Subcommittee design trial is to assess further the effect of granular base properties on the predicted distresses using the latest version of the software in Canadian context. The objective of this paper is to present the details of the completed trial results and analysis. The presented information may help different agencies and other interested individuals in assessing the suitability of the current version of the PMED software when designing pavement structures with granular base materials and/or develop an appropriate process for design and construction.

Software Versions and and Trial Inputs

All participants used the PMED software v 2.6 or 2.6.1 with the global calibration coeffiecnts for the design trials. The variable design inputs were: i) Climate: varying climates data from 14-17 climate stations across Canada, and ii) Granular base material: varying specifications, sources/modulus, gradations and layer thicknesses. All other input parameters remain unchanged in all trials: i) Truck volume: 500 trucks/day on the design lane with 2% growth, ii) Vehicle class distribution and Axle Load Spectra (ALS): Manitoba Level 1; iii) Surface layer: 150 mm SuperPave (SP) 12.5 asphalt (with PG 58-34) surface (MB Level 3); iv) Subbase (where used): Manitoba GSB-C, 300 mm thick layer and 105 MPa resilent modulus; v) Subgrade materials: High Plastic Clay (AASHTO A-7-6), 35 MPa resilent modulus; vi) Design Life: 20 years, vii) Initial IRI: 0.9 m/km; and viii) Design reliability: 90%.

Selected Climate Stations:

As indicate ealier, 14-17 MERRA climate stations across Canada with variying weather patterns were used in these trials. Figure 1 shows the geographic location of the climate stations. The red dots indicate relatively warmer while the blue dots indicate relatively colder climates in Canadian context. Table 1 presents the list of climate stations and the summary of the key climate parameters.

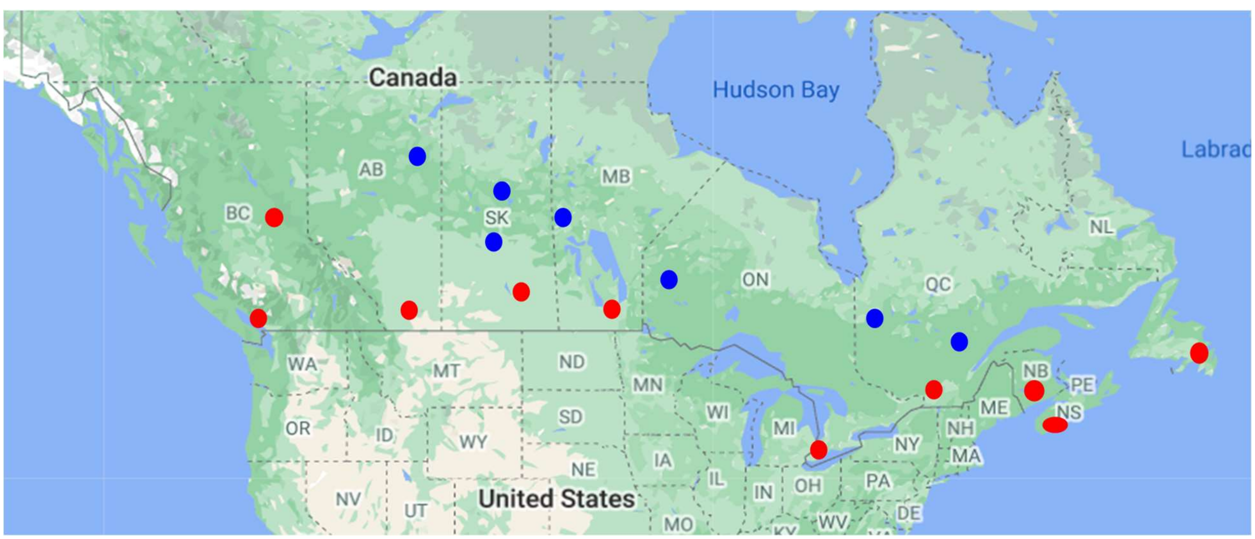

Figure 1. Geographic location of climate statiions used in the PMED software trials

Table 1. List of climate stations and climate data summary

Climate Stations							
Province	BC	AB	SK	MB	ON	QC	NB/NS/NL
Stations	Sechelt/ Prince George	Stirling, Gregoire Lake	Pilot Butte, Prince Albert/ La Ronge	Winnipeg, The Pas	Leamington, Red Lake	Montreal, Saguenay/ 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 (17 stations)			4.1	1071	324	1321	68
Minimum (17 stations)			0.2	494	259	64	41
Maximum (17 stations)			10.1	2697	351	2396	111
Standard Dev. (17 stations)			3.1	574.4	25.8	790.7	16.7

Design Trial Matrix and Demonestration of Results

The design trials for granular base included five different sets of trials with a specific matrix for each set of trial. The variables in each trial set including their rationale are discussed in the results and discussion section for the convenience of understanding. 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/visualization of the effect of each variable.

Results and Discussion- Trials 1A and 1B: Effect of Modulus Ratio, Climate and Granular Base Types

Trial Sets 1A and 1B included six different granular base materials with varying modulus and physical properties. The granular base thickness was 300 mm in Trial 1A with no subbase resulting in a granular base to subgrade modulus ratio of 3.4 to 7.1. In Trial 1B, 200 mm granular base and 300 mm subbase were used. The granular base to subbase modulus ratios were 1.1 to 2.4 while the subbase to subgrade modulus ratio was 3.0. The purposes of these two sets of trials were to i) evaluate the effect of granular base or subbase to subgrade modulus ratio and varying climate on the predicted distresses; ii) evaluate the effect of granular base specifications based on combined physical and mechanical properties. Figure 2 shows the gradations of base materials and Table 2 shows the summary of granular base material properties. Gran A-MB (old) is a fine graded granular base material that Manitoba have been using in the past, while GBC I-MB (New) is Manitoba's new granular base material which is coarser, stiffer, more stable and more drianable than Gran A. Type 33-SK, MG 20-QC, Type 25-AB and Gran A-ON are granular base speccifications of Sastaktchewan, Quebec, Alberta and Ontario, respectively.

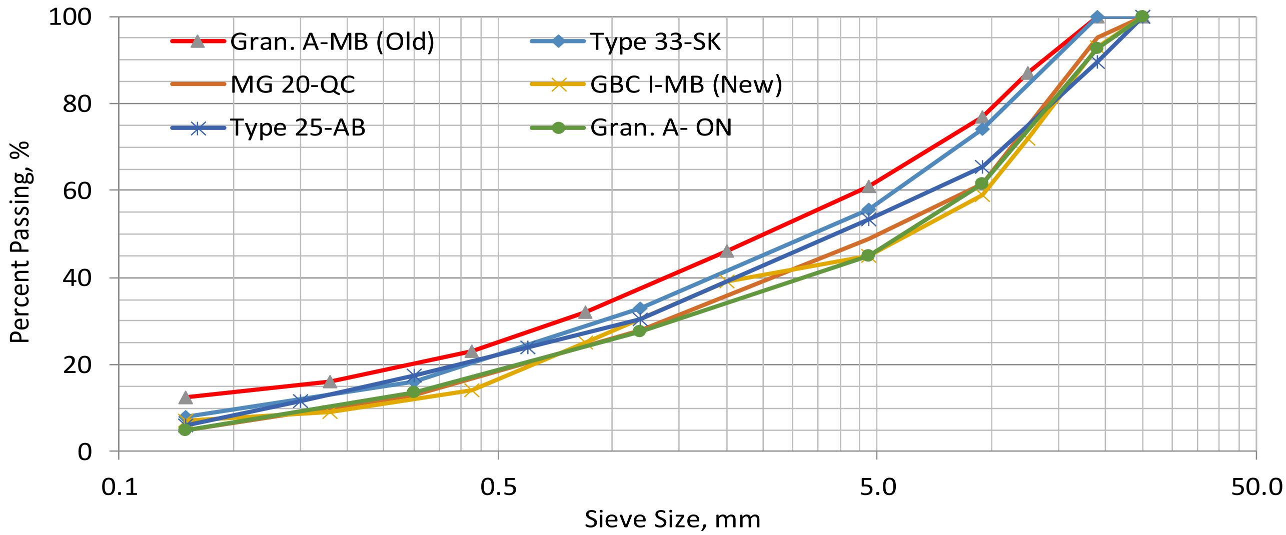

Figure 2. Gradations of granular base materials used in Trials 1A and 1B

Table 2. Granular base material properties in Trials 1A and 1B

Granular Base Materials	Resilient Modulus (MPa)	Liquid Limit (%)	Plasticity Index (%)	Max. Dry Unit Weight (kg/m3)	Water Content (%)
Gran A (MB Old)	120 (Measured[1])	20	4	2240	8.5
Type 33 (SK)	200 (Estimated)	12	3	2150	7.0
MG 20 (QC)	200 (Measured[2])	20	5	2190	6.2
Type I (MB New)	220 (Measured[1])	0	0	2230	6.9
Type 25- Des. 2 (AB)	250 (Estimated)	6	0	2160	5.0
Gran A (ON)	250 (Estimated)	6	0	2240	5.7

[1]NCHRP 1-28A; [2]MTQ's method LC 22-400 (based on AASHTO T307 and NF EN 13286–7 Part 7)

Effect of Modulus Ratio and Climate on Predicted Distresses

Figures 3 through 8 show the comparative variation of predicted distresses between trials without (Trial 1A) and with (Trial 1B) subbase layer. As shown in Figure 3, the trends of the predicted IRI are almost similar (with some inconsistencies among climate stations) for both trials implying no considerable effect of modulus ratio on the predicted IRI. Figures 4, 5 and 8 show that the variation of total permanent deformation, bottom-up fatigue (alligator) cracking and AC layer rutting for trials without and with subbase layer follow similar trends with no noticeable effect of modulus ratio. Climate has significant effect on the predicted IRI, total rutting, bottom-up fatigue cracking and AC layer rutting, but the effect of climate on bottom-up fatigue cracking is the most significant.

Figure 6 shows that the variation of predicted top-down fatigue (longitudinal) cracking is inconsistent with the variation of climate. Although modulus ratio has no noticeable effect on thermal cracking (Figure 7), varying climates have also shown no effect on the predicted thermal cracking despite there was no change in asphalt mix and binder to suit local climate requirement. This appears to be software glitch. As such, all subsequent discussion excluded the assessment of thermal cracking prediction.

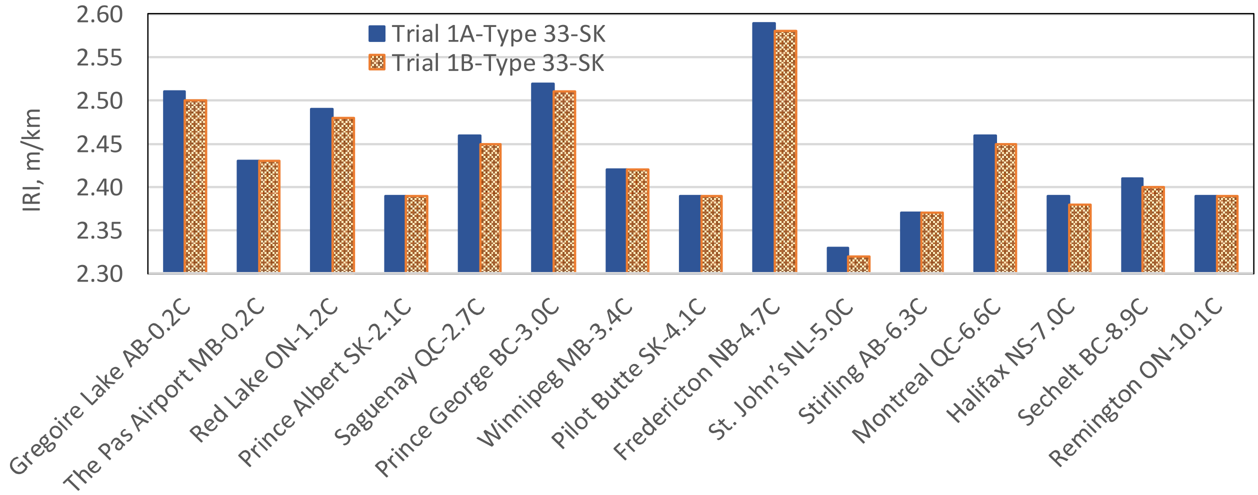

Figure 3. Effect of modulus ratio and climate on the predicted IRI (Trials 1A and 1B)

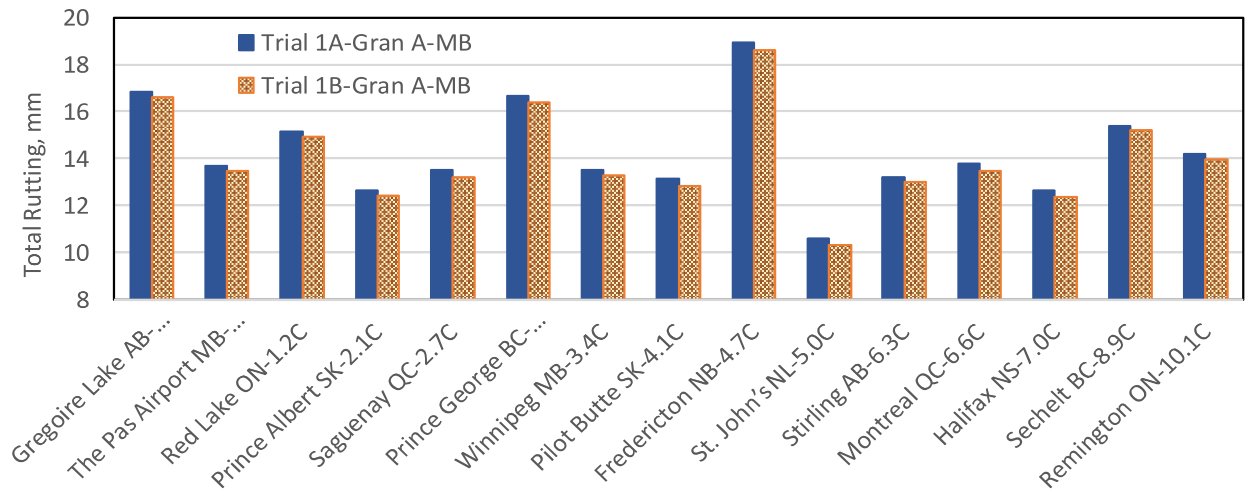

Figure 4. Effect of modulus ratio and climate on the predicted total rutting (Trials 1A and 1B)

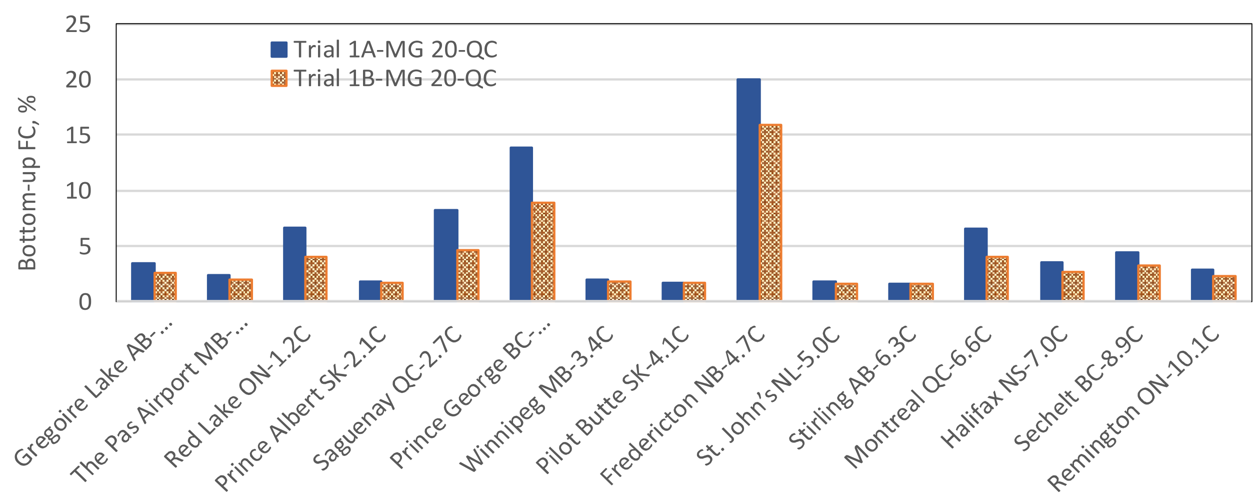

Figure 5. Effect of modulus ratio and climate on bottom-up fatigue cracking (Trials 1A and 1B)

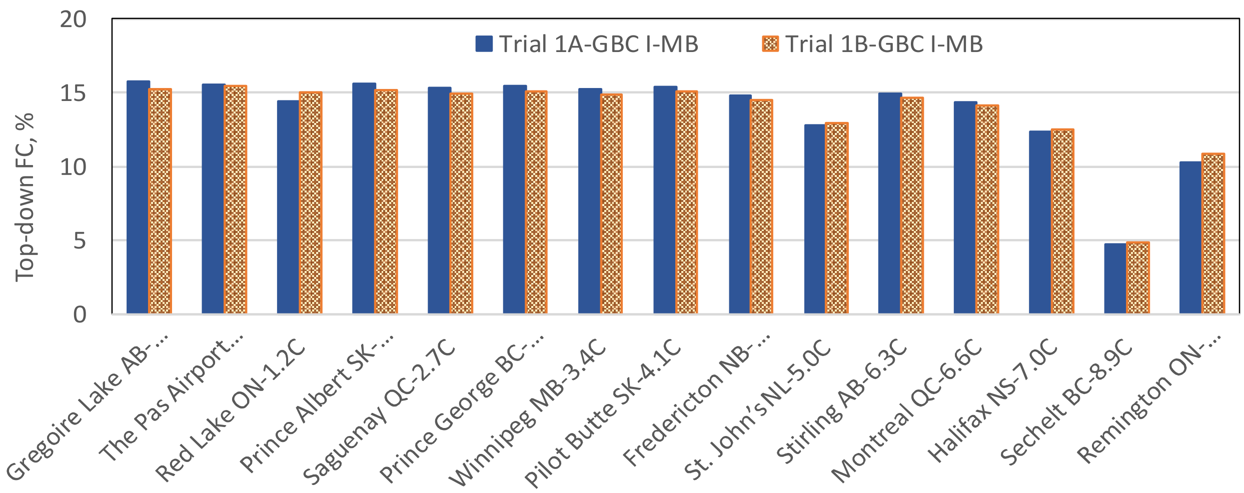

Figure 6. Effect of modulus ratio and climate on top-down fatigue cracking (Trials 1A and 1B)

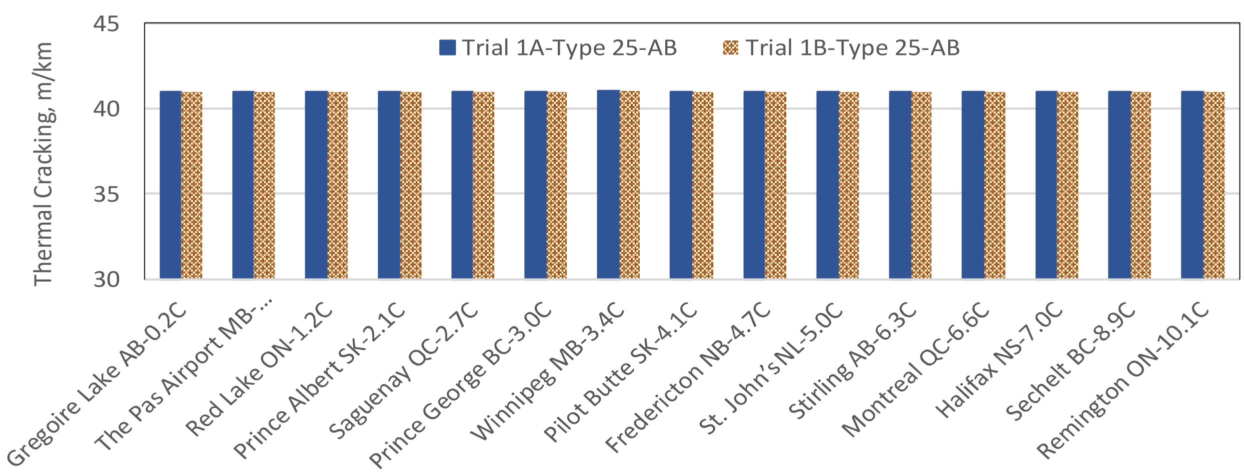

Figure 7. Effect of modulus ratio and climate on the predicted thermal cracking (Trials 1A and 1B)

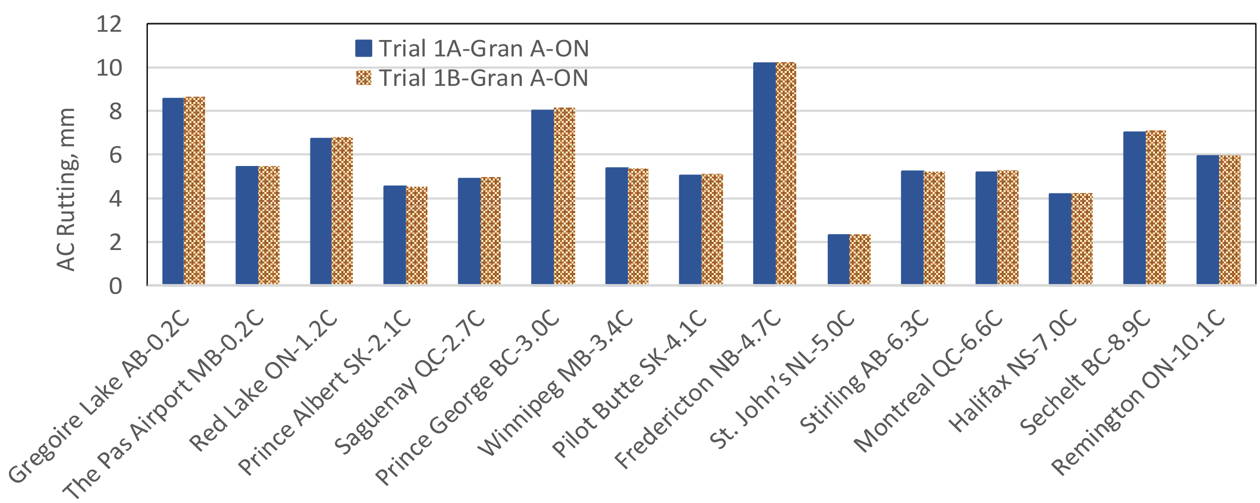

Figure 8. Effect of modulus ratio and climate on the predicted AC layer rutting (Trials 1A and 1B)

Effect of Base Material Types (Specifications) on the Predicted Distresses (Trial 1B)

Figures 9 through 13 show the variation of predicted distresses for different types of granular base used in several jurisdictions in Canada. Figures 9 and 10 show that base material type has minor effect on the predicted IRI and slight effect on the predicted total rutting. The trend in Figure 11 shows that base material type has significant effect on the predicted bottom-up (alligator) fatigue cracking, especially for weak material. Figure 12 shows that the base material type has a negligible effect on the predicted top-down fatigue (longitudinal) cracking with an inconsistent variation among climate stations. Figure 13 shows that the base material type has a negligible effect on the predicted AC layer rutting.

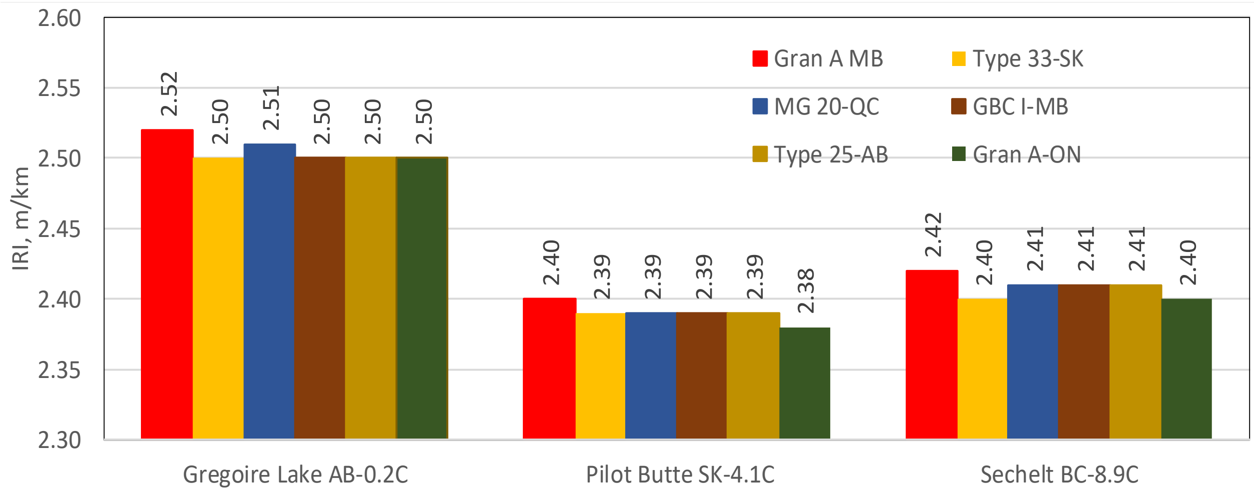

Figure 9. Effect of base material types (specifications) on the predicted IRI (Trial 1B)

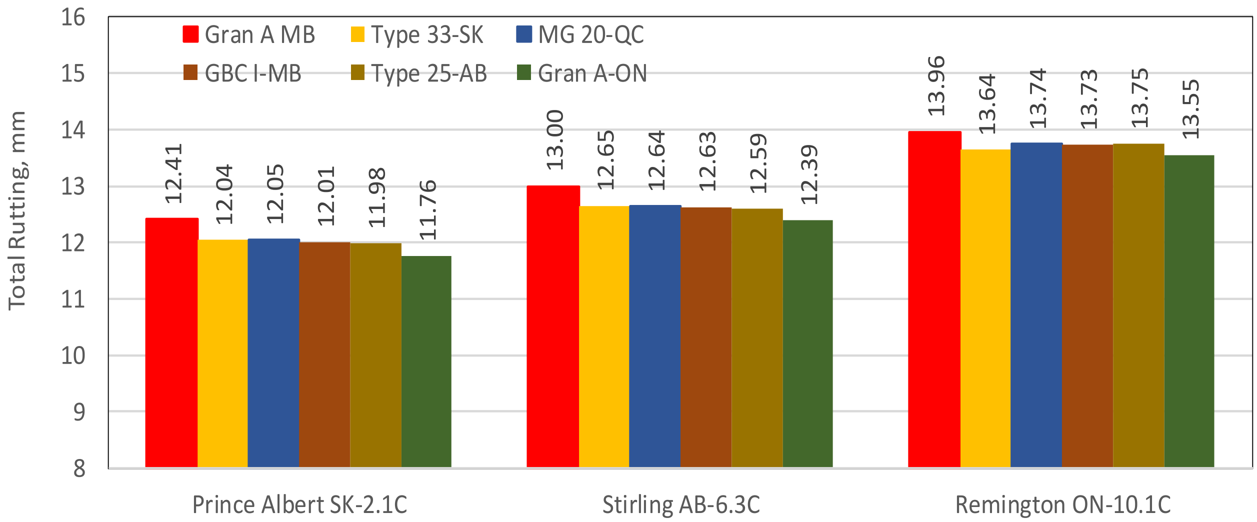

Figure 10. Effect of base material types (specifications) on the predicted total rutting (Trial 1B)

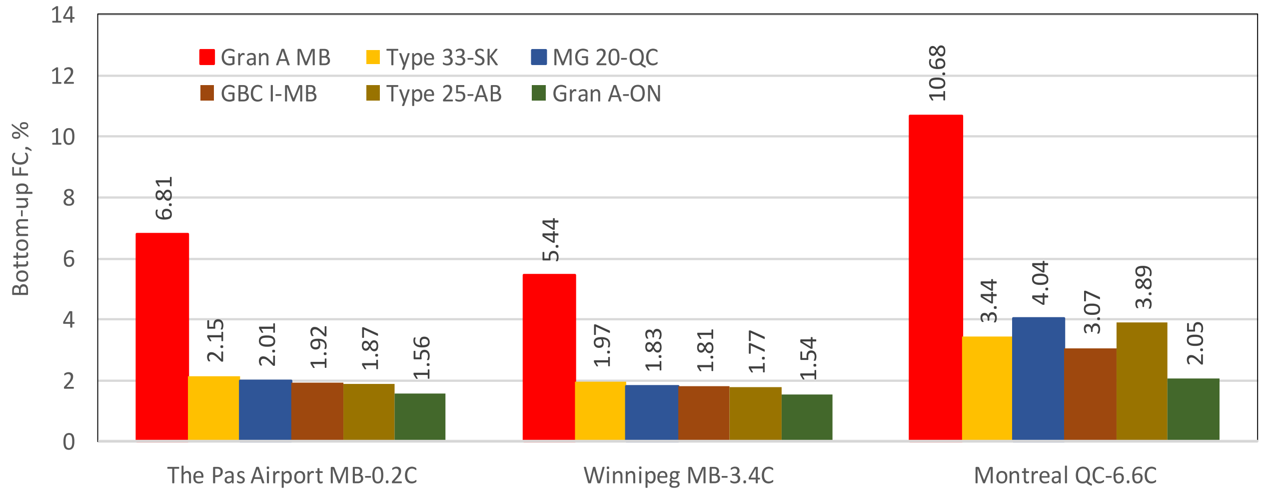

Figure 11. Effect of base material types (specifications) on bottom-up fatigue cracking (Trial 1B)

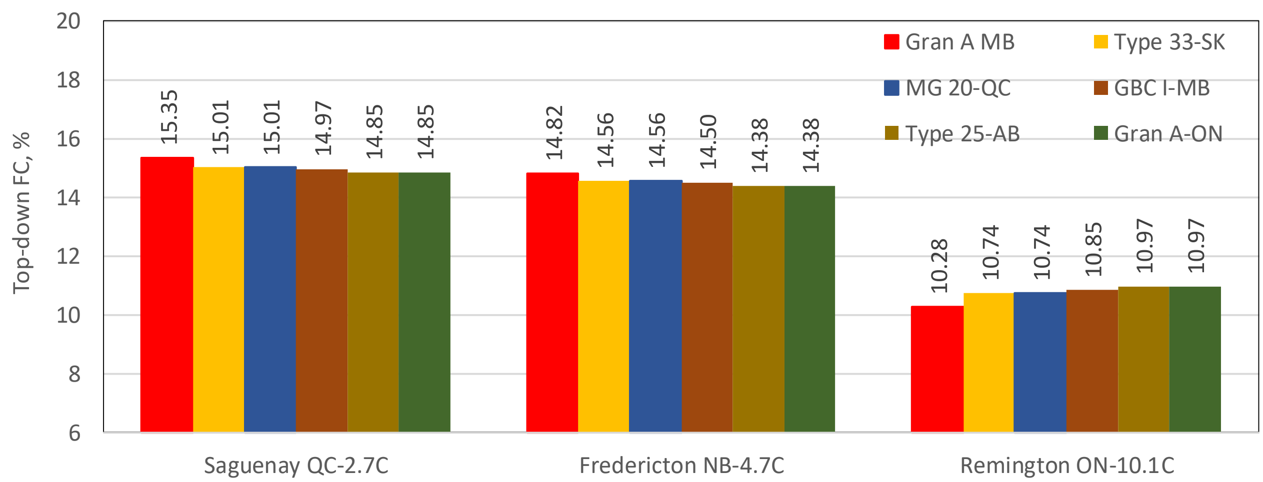

Figure 12. Effect of base material types (specifications) on top-down fatigue cracking (Trial 1B)

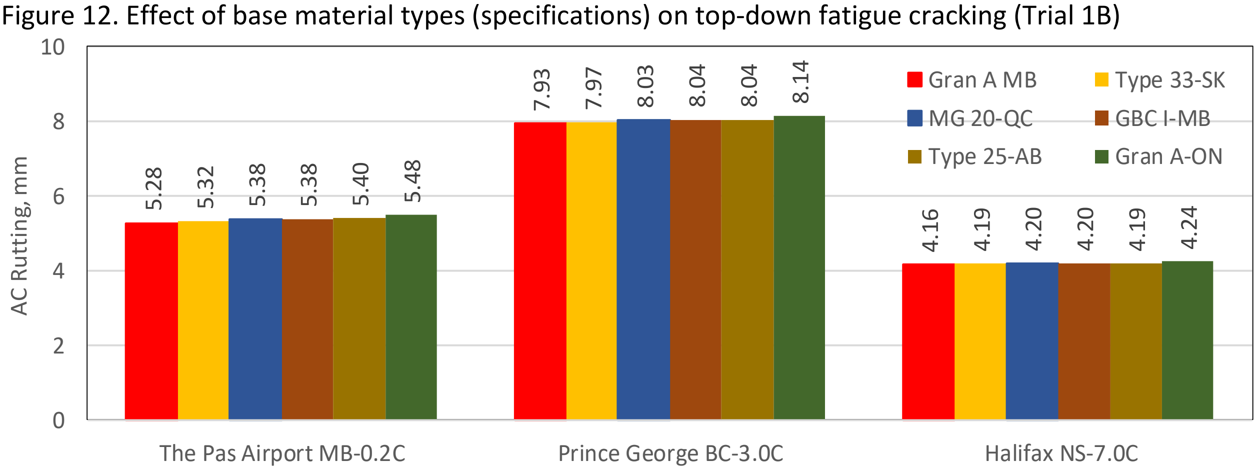

Figure 13. Effect of base material types (specifications) on AC layer rutting (Trial 1B)

Results and Discussion- Trial 2A: Effect of Granular Base Mineralogy and Source

Trial Set #2A included granular base materials from six different sources with varying aggregate mineralogy in two different gradation bands. The stiffness of the matrials varied depending on the source/mineralogy. A 200 mm granular base and a 300 mm subbase layers were used in this trial set. The purpose of this trial set was to evaluate the effect of granular base aggregate mineralogy and source on the predicted distresses. Table 3 shows the summary of granular base material properties and source types. The first three materials are PMED software default base materials with same gradation. The last three materials are Manitoba's new granular base specification. The variation of source and mineralogy mainly affected the stiffness of the materials in this trial set.

Table 3. Granular base sources/properties (Trial 2A)

Granular Base Materials	Mr (MPa)	LL (%)	PI (%)	Unit Wt. (kg/m^3)	Water Content (%)
River Run Gravel (Default)	103	6	1	2038	7.4
Crushed Gravel (Default)	172	6	1	2046	7.4
Crushed Stone (Default)	207	6	1	2046	7.4
Crushed Limestone (MB GBC- I)	235	12	0	2259	7.8
Crushed Gravel (MB GBC- I)	265	13	1	2260	7.1
Crushed Granite (MB GBC- I)	310	0	0	2186	6.0

Figures 14 through 18 show the variation of predicted distressess for different base materials used in this trial set. As shown in the figures, stiiffer and better quality granular base cause minor reduction in the predicted IRI and a slight reduction in the predicted total rutting. An increased modulus from 103 MPa to 310 MPa (three times increase in stiffness) results in about 1 mm reduction in total rutting. Granular base stiffness has a highly significant effect on the bottom-up fatigue cracking with a decrease in predicted cracking as modulus values increases from 103 MPa to 207 MPa. The predicted fatigue cracking remain uncahnged for modulus values of 235 MPa and higher. The effect of granular base stiffness on the predicted longitudinal (top-down fatigue) cracking is minor and inconsistent. AC layer rutting slightly increases with increased base layer stiffness which is logical.

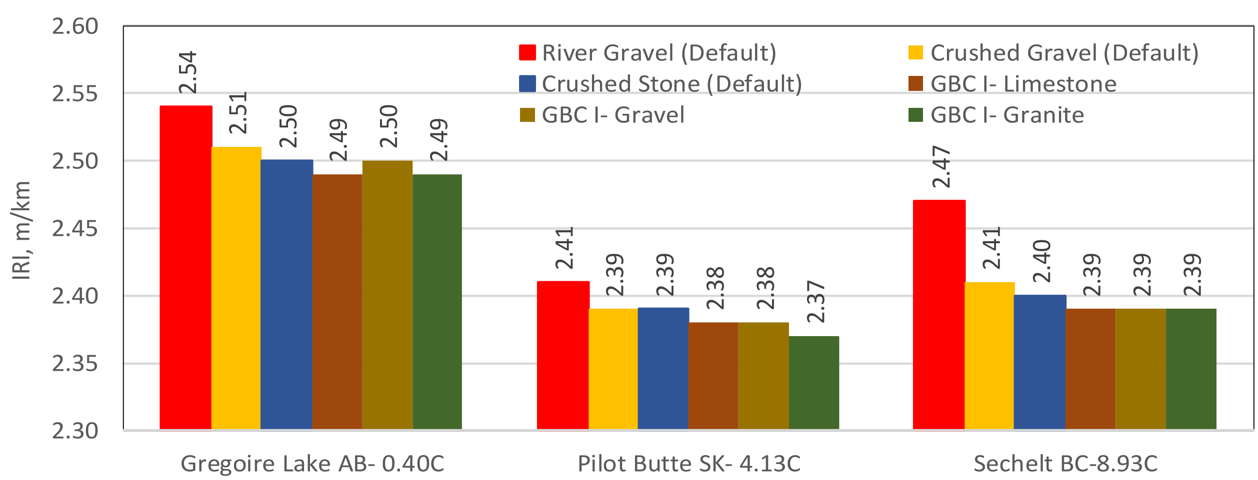

Figure 14. Effect of granular base mineralogy and source on the predicted IRI (Trial 2A)

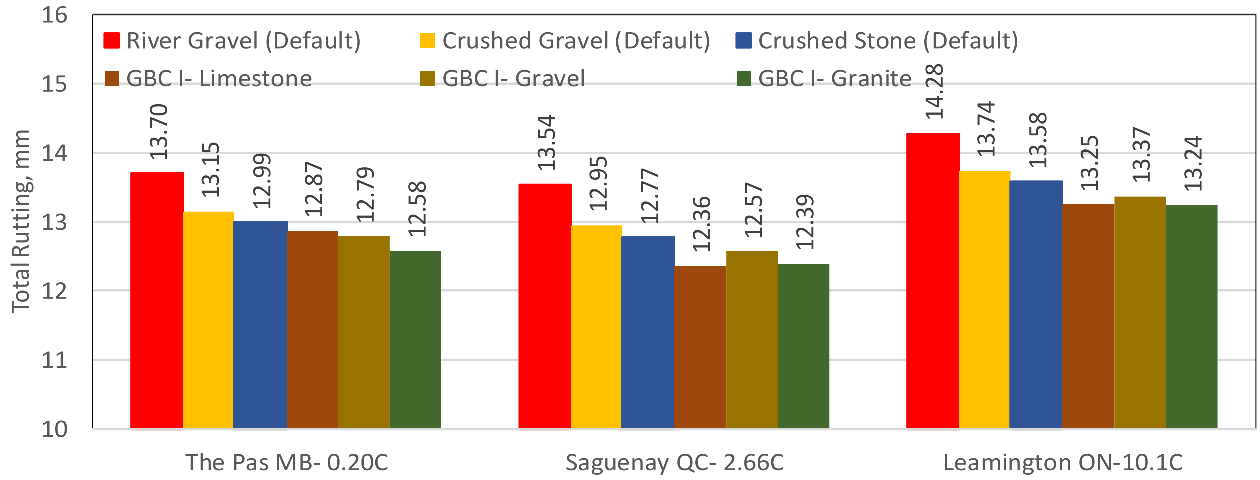

Figure 15. Effect of granular base mineralogy and source on the predicted total rutting (Trial 2A)

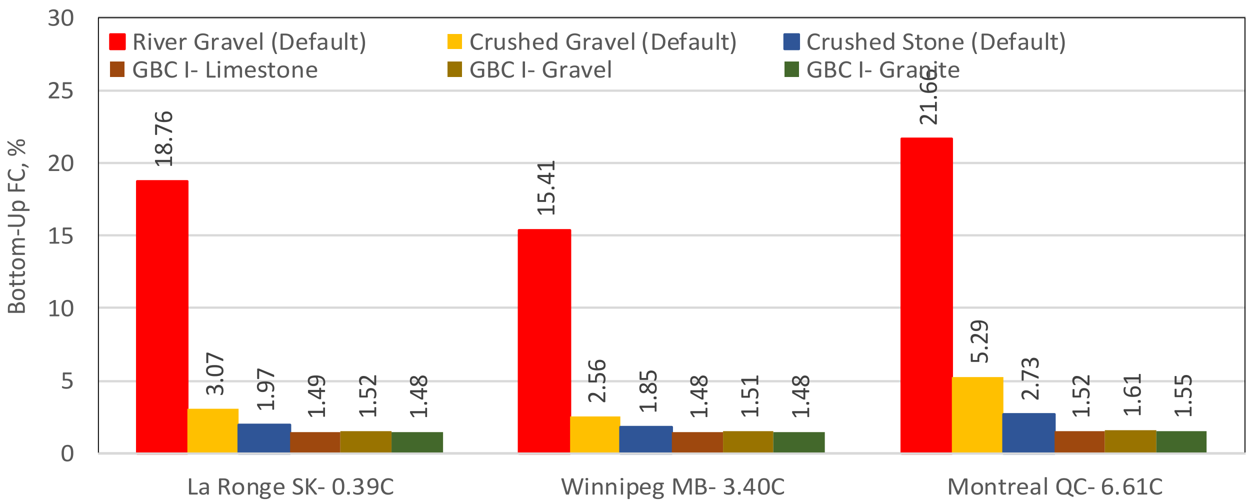

Figure 16. Effect of granular base mineralogy and source on the predicted bottom-up FC (Trial 2A)

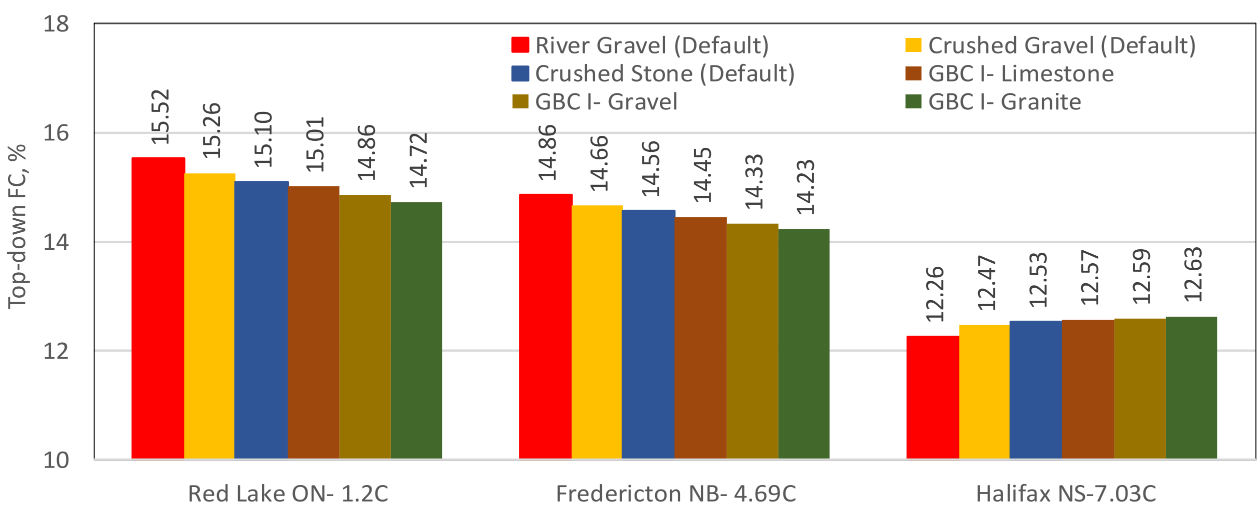

Figure 17. Effect of granular base mineralogy and source on the predicted top-down FC (Trial 2A)

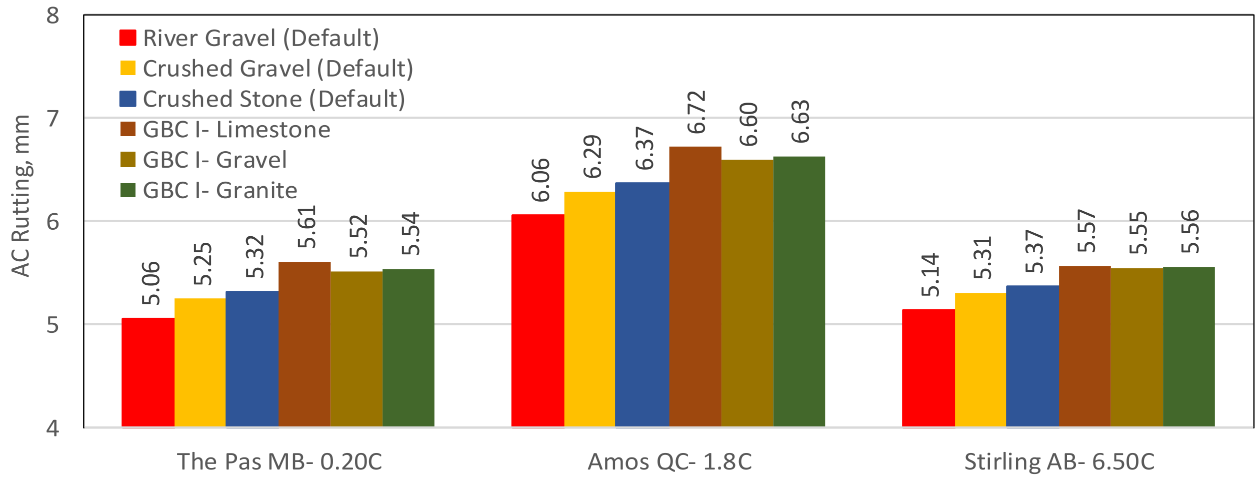

Figure 18. Effect of granular base mineralogy and source on the predicted AC layer rutting (Trial 2A)

Results and Discussion- Trial 2B: Effect of Granular Base Gradation

Trial Set #2B included granular base materials with three different gradations as shown in Figure 19. These gradations reflect Manitoba's new GBC-I (coarse gradation and premium quality), GBC-M (medium gradation and good quality) and GBC-S (fine gradation and moderate quality) materials. The resilient modulus (250 MPa), density (2260 kg/m^3) and moisture content (7.4%) intentionally made fixed for all three gradations to assess the impact of gradation alone.

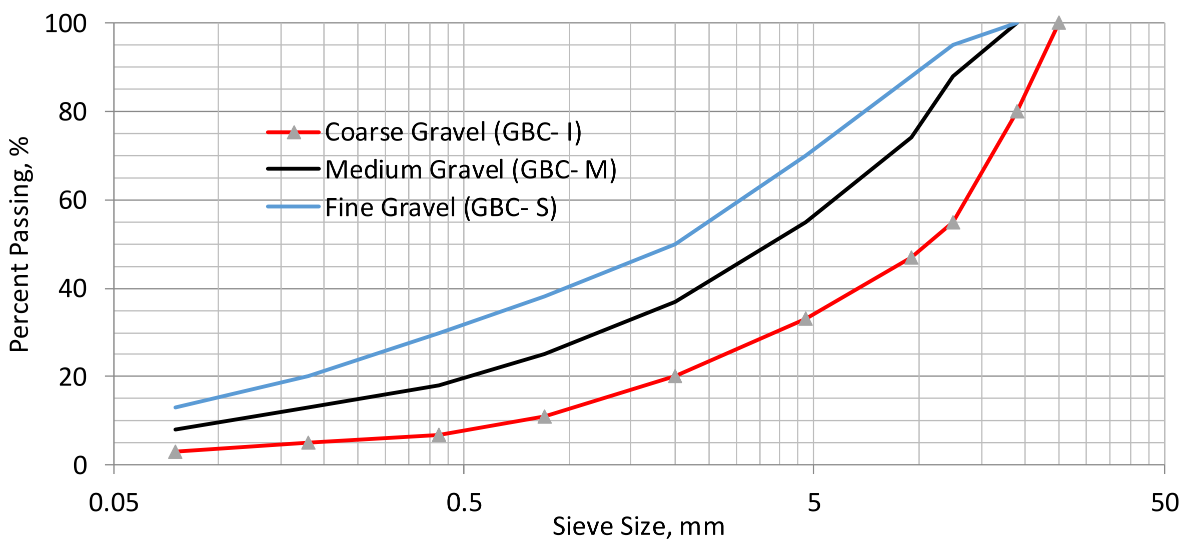

Figure 19. Gradations of granular base for Trial 2B

Figures 20 through 24 show the trends of predicted distressess for different gradations of base material. As shown in the figures, gradations alone do not have any effect on the predicted distresses when the modulus is fixed and entered as an annual representative in the software. Since modulus vary seasonally due to changes in moisture, freezing and thawing, gradations have effect on the seasonal modulus values. As a result, if the modulus is allowed to vary seasonally in the software, gradations show some effects on the predicted distresses. As shown in Figures 25 and 26, the predicted total rutting and bottom-up fatigue cracking increase as the base material become finer when the modulus is allowed to vary seasonally.

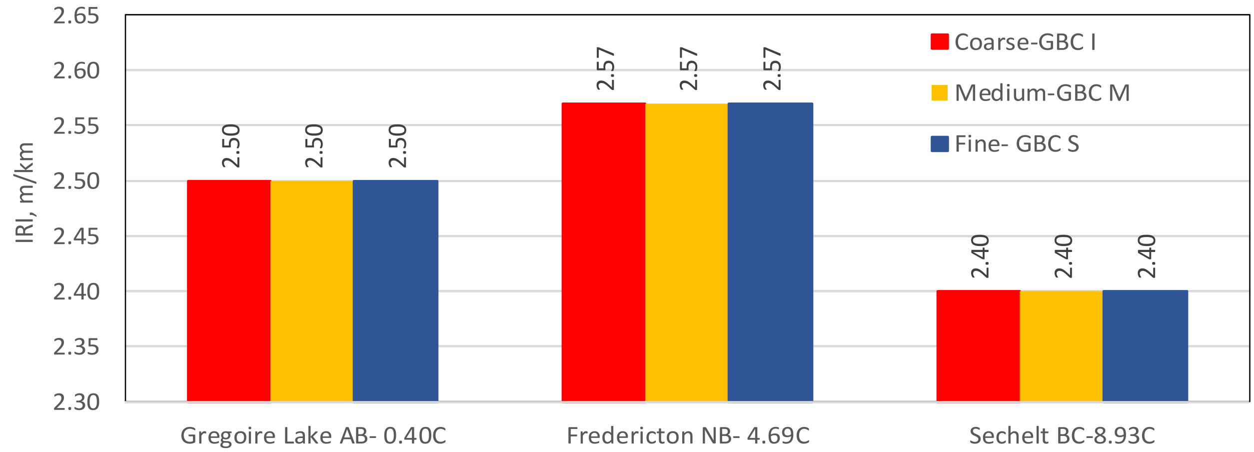

Figure 20. Effect of GBC gradations on the predicted IRI (Trial 2B)

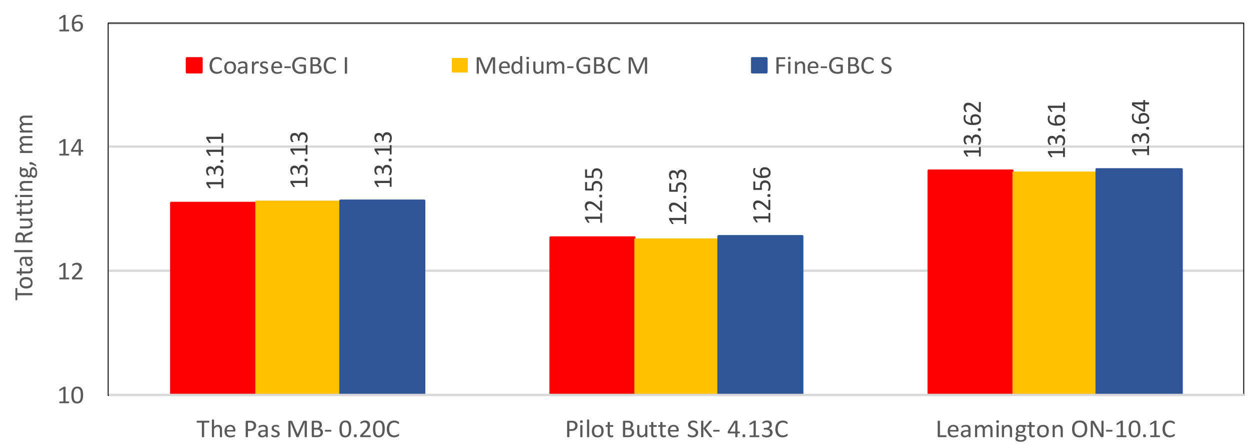

Figure 21. Effect of GBC gradations on the predicted total rutting (Trial 2B)

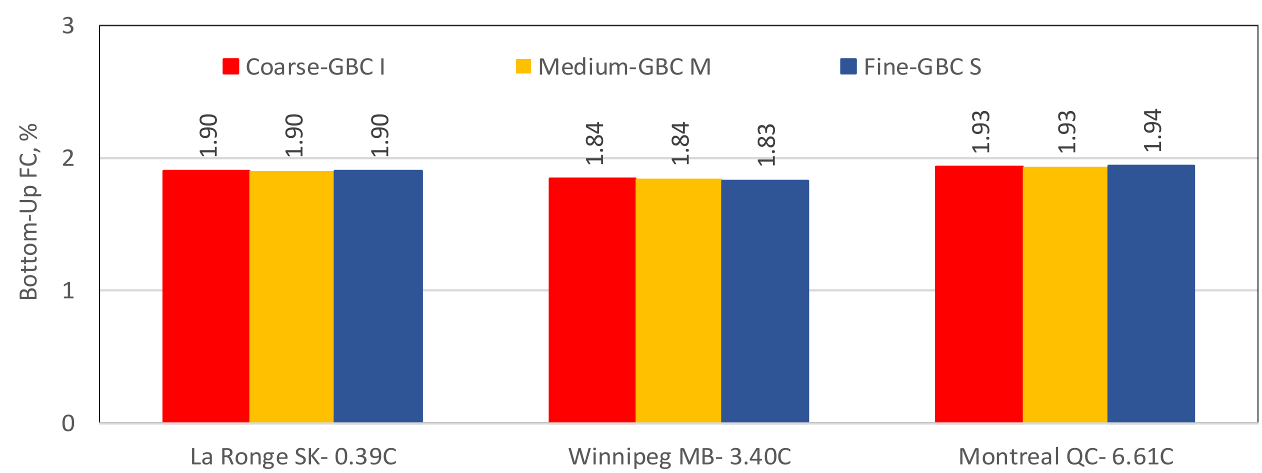

Figure 22. Effect of GBC gradations on the predicted bottom-up fatigue cracking (Trial 2B)

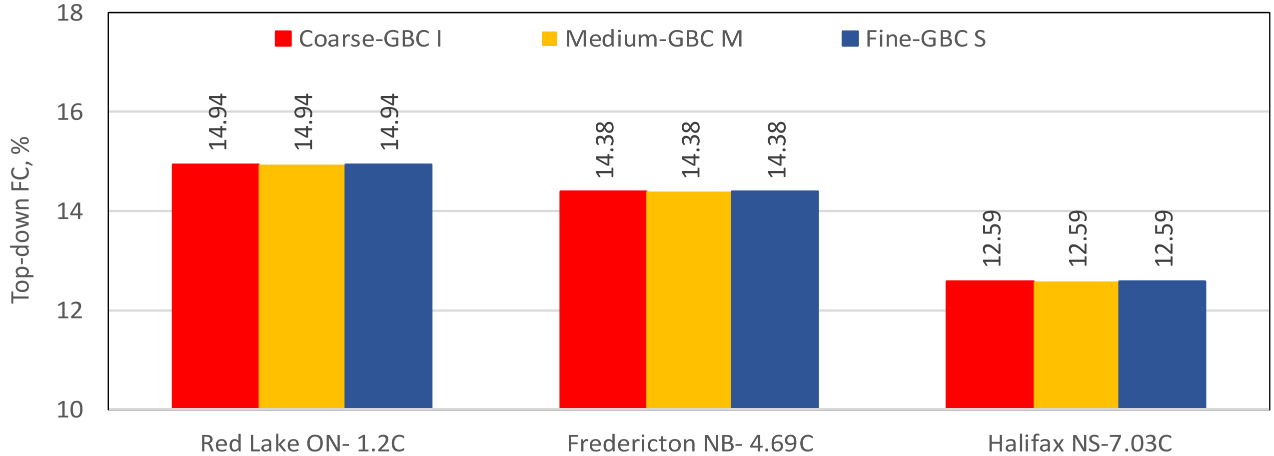

Figure 23. Effect of GBC gradations on the predicted top-down fatigue cracking (Trial 2B)

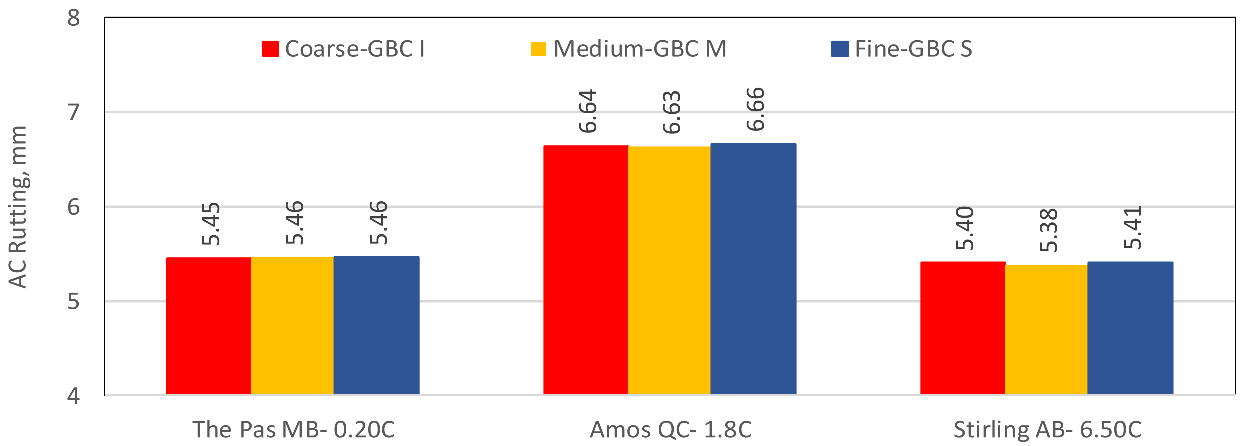

Figure 24. Effect of GBC gradations on the predicted AC layer rutting (Trial 2B)

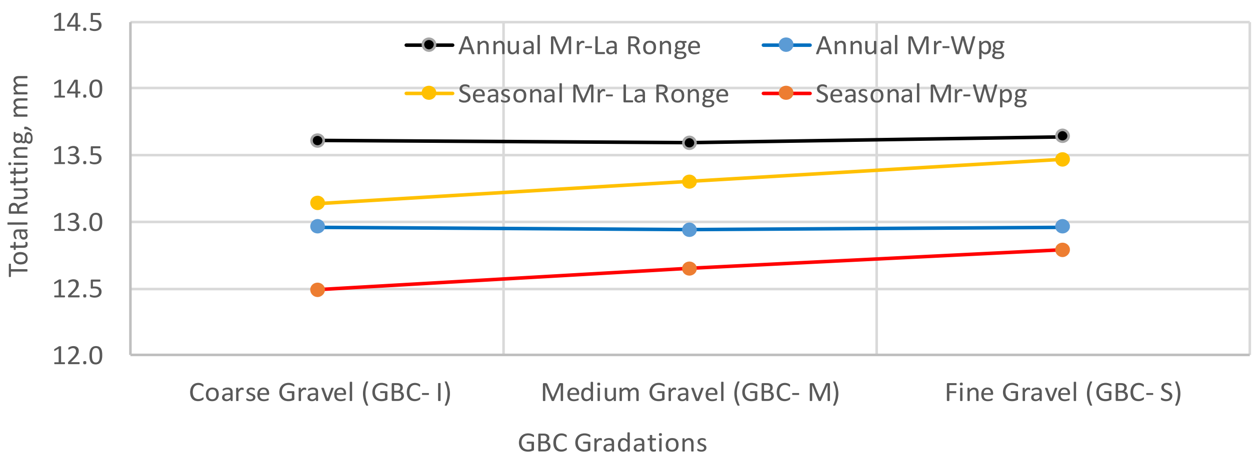

Figure 25. Effect of GBC gradations with seasonally varied modulus on total rutting (Trial 2B)

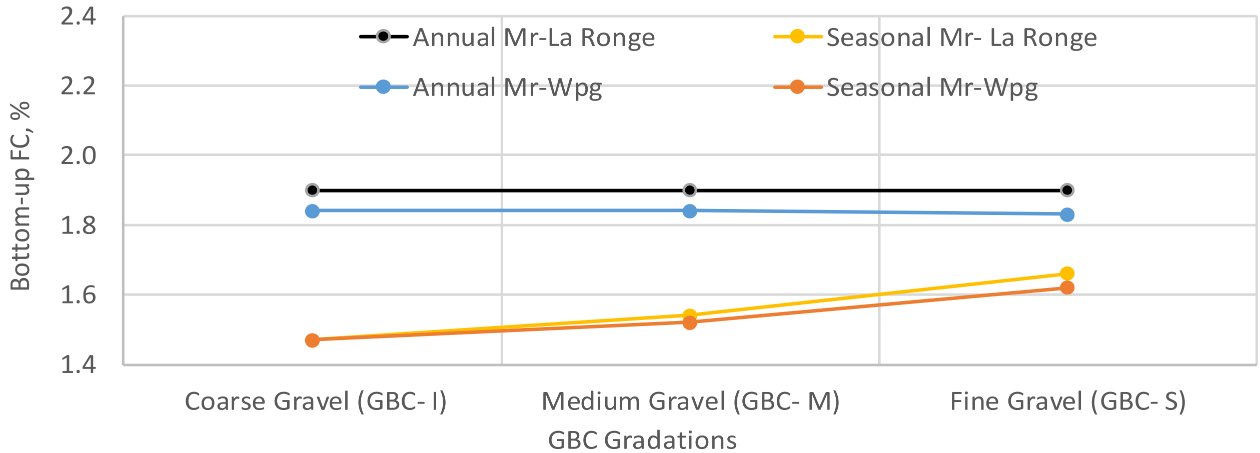

Figure 26. Effect of GBC gradations with seasonally varied modulus on bottom-up FC (Trial 2B)

Results and Discussion- Trial 3: Effect of Granular Base Thickness

In Trial Set #3, granular base thickness was varied from 200 mm (with subbase) or 300 mm (with no subbase) to 500 mm for two gradations (coarse and fine) to determine the effect of increased GBC thickness on the predicted distresses. Table 4 shows the matrix of variables used in this trial set.

Table 4. Trial 3 matrix

Base Type	Base Mr	Base Thickness	Subbase Thickness
GBC- I (Coarse)	220 MPa	200mm and 500mm	300 mm
GBC- I (Coarse)	220 MPa	300mm and 500mm	No SB
GBC- S (Fine)	120 MPa	200mm and 500mm	300 mm

Figures 27 through 31 show the trends of predicted distressess for the variation of base materials thickness. As shown in the figures, there is a negligible (avg. 0.02 m/km) decrease in IRI with an increase in granular base thickness from 200 mm to 500 mm. An increase in GBC thickness from 200 mm to 500 mm results in average 0.5 mm decrease in total rutting which is not good enough to reduce asphalt thickness even by 5 mm. There is a significant decrease in bottom-up fatigue cracking with an increase in GBC thickness, especially for base material with a low stiffness. Top-down fatigue cracking slightly decrease with increase in GBC thickness from 200 mm to 500 mm. AC layer rutting slightly increases with an increase in base thickness. The variation of different distresses in trials with and without subbase followed similar trends indicating no noticeable impact of base to subgrade or subbase, and subbase to subgrade modulus ratio on the predicted distreses.

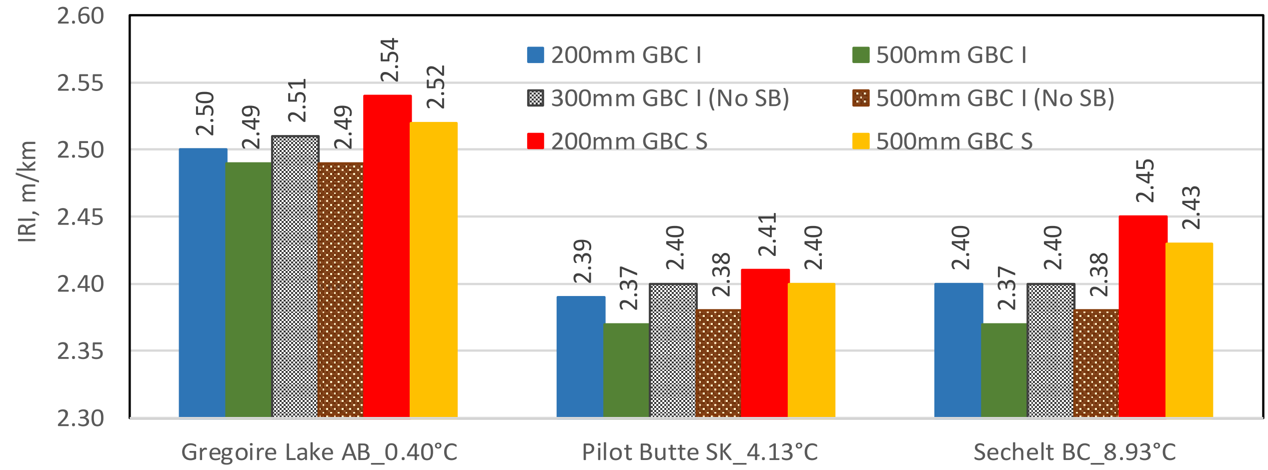

Figure 27. Effect of GBC thickness on the predicted IRI (Trial 3)

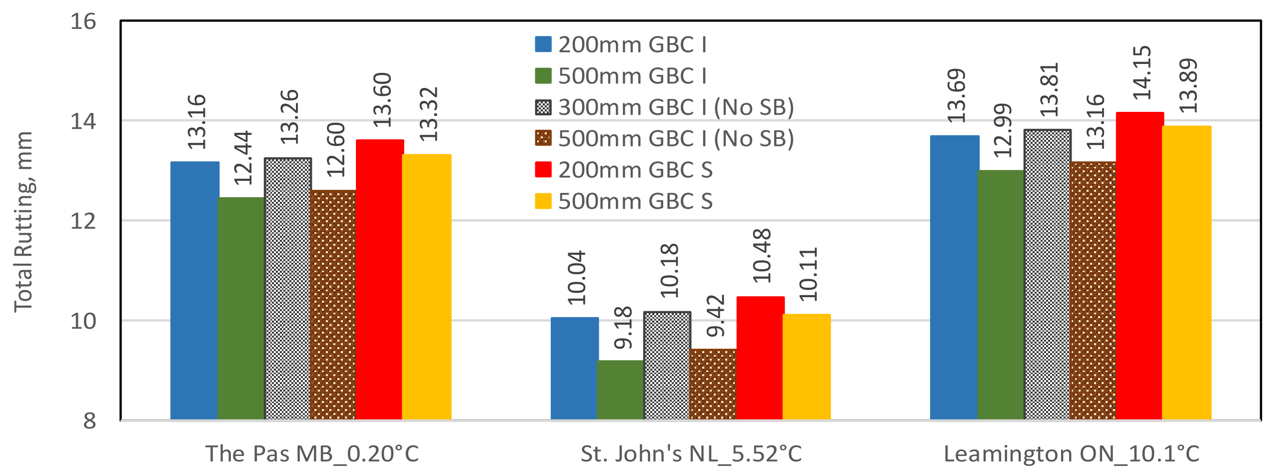

Figure 28. Effect of GBC thickness on the predicted total rutting (Trial #3)

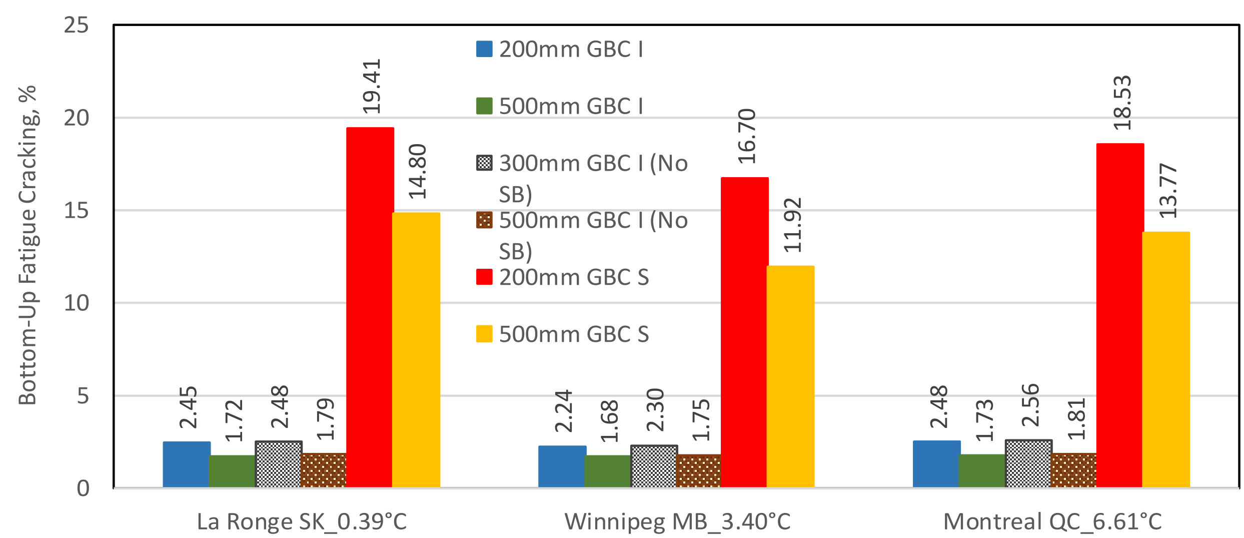

Figure 29. Effect of GBC thickness on the predicted bottom-up fatigue cracking (Trial #3)

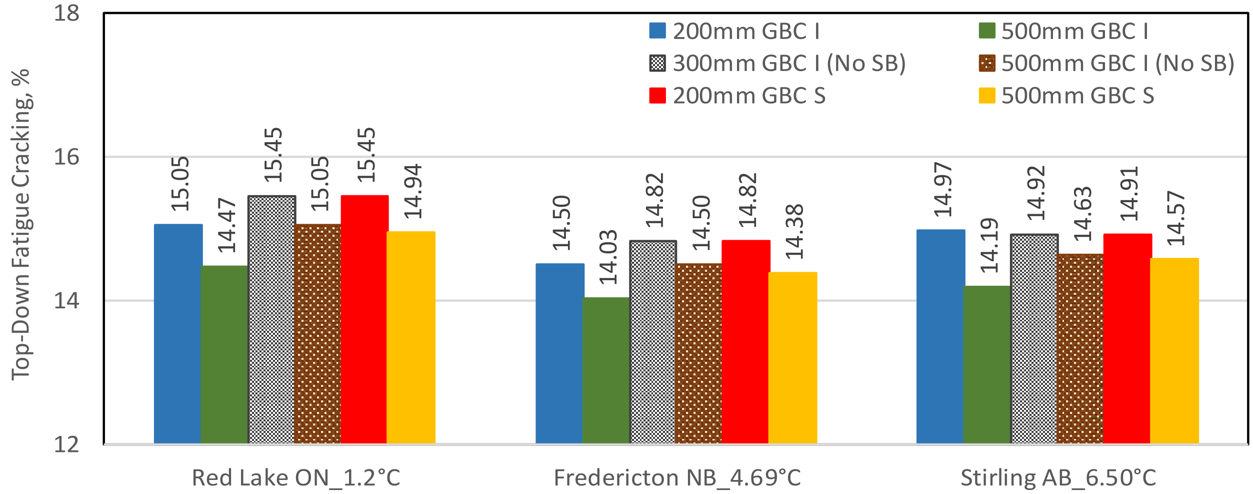

Figure 30. Effect of GBC thickness on the predicted top-down fatigue cracking (Trial #3)

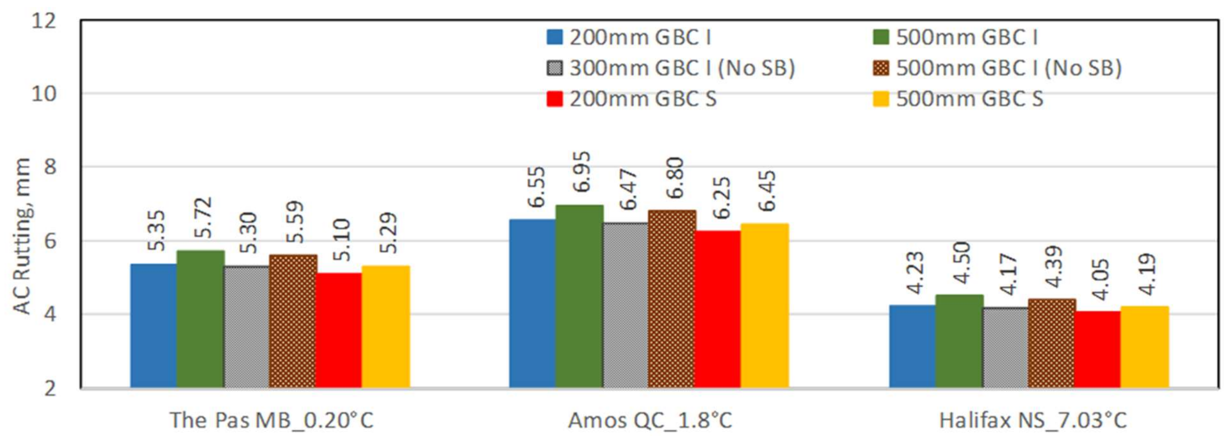

Figure 31. Effect of GBC thickness on the predicted AC layer rutting (Trial #3)

Summary and Conclusions

The results and analyses have shown that the combined physical and mechanical properties of granular base material (base types) have slight impact on the predicted total rutting and noticeable impact on the alligator (bottom-up fatigue) cracking. The granular base or sub-base to subgrade modulus ratios do not have noticeable effect on the predicted distresses for flexible pavements while, climate conditions affect all distresses. Aggregate stiffness (based on source and mineralogy) has a minor effect on IRI, a noticeable effect on total rutting and a significant effect on alligator cracking, especially for weak base materials. It should be noted that a high modulus ratio between AC and base layers could produce a high tensile strain at the bottom of AC layer leading to a high amount of alligator cracking, especially for weak base materials. To limit the amount of predicted alligator cracking, the base layer modulus should be high enough, preferably not less than 200 MPa. Gradation alone does not have any noticeable effect on the predicted distresses. However, it has notable impact on the seasonal variation of modulus, which can affect the predicted distresses. Granular base thickness has a negligible effect on the predicted IRI, small effect on the total rutting, small effect on longitudinal cracking, a significant effect on alligator cracking and a minor effect of AC layer rutting. Some inconsistencies in the predicted distresses were also noted. Overall, PMED software is not yet able to consider the effect of granular base materials, as expected.

References

1. AASHTO 1993. "*AASHTO Guide for Design of Pavement Structure*." American Association of State Highway and Transportation Officials, Washington, D.C.
2. Masad, S.A. and Little, D. N. 2004. "*Sensitivity Analysis of Flexible Pavement Response and AASHTO 2002 Design Guide to Properties of Unbound Layers*". International Center for Aggregates Research (ICAR), Report 504-1, Austin, Texas.
3. Coree B. et al. 2005. "*Implementing the Mechanistic-Empirical Pavement: Technical Report*". Iowa Highway Research Board (IHRB) Project TR-509. Center for Transportation Research and Education, Iowa State University, Iowa.
4. Luo, X. et al., 2017. "*Mechanistic-Empirical Models for Better Consideration of Subgrade and Unbound Layers Influence on Pavement Performance"*. Elsevier, Science Direct. Transportation Geotechnics, Volume 13. pp 52-68.
5. Orobio, A. 2010. "*Sensitivity analysis of flexible pavement performance parameters in the mechanistic-empirical design guide*". Doctor's degree dissertation, Department of Civil and Environmental Engineering, West Virginia University, Morgantown, West Virginia.
6. Carvalho, R.L. and Schwartz, C.W. 2007. *"Implementation of the NCHRP 1-37A Design Guide. Final Report, Volume 2: Evaluation of Mechanistic-Empirical Design Procedure".* MDSHA Project No. SP0077B41, Department of Civil and Environmental Engineering, University of Maryland, College Park, MD.
7. Schwartz, C.W. et al. 2011. "*Sensitivity Evaluation of MEPDG Performance Prediction*". Final Report NCHRP Project 1-47, Transportation Research Board, Washington, D.C.
8. Li, R. et al. 2012. "*Local Sensitivity of Mechanistic-Empirical Flexible Pavement Performance Predictions to Unbound Material Property Inputs*". Proceedings of the GeoCongress 2012: State of the Art and Practice in Geotechnical Engineering, American Society of Civil Engineering (ASCE), Oakland, California.
9. Schwartz C.W. et al., 2013. "*Global Sensitivity Analysis of Mechanistic-Empirical Performance Predictions for Flexible Pavements*". Transportation Research Board, Washington D.C., Transportation Research Record, No. 2368, pp.12-23.
10. Tran, N. et al. 2017. "*Pavement ME Design-Impact of Local Calibration, Foundation Support and Design and Reliability Thresholds*". NCAT Report 17-08, National Center for Asphalt Technology, Auburn University, Auburn.
11. Xiao Y. et al. 2011. "*Mechanistic–Empirical Evaluation of Aggregate Base and Granular Subbase Quality Affecting Flexible Pavement Performance in Minnesota*". Journal of the Transportation Research Board, Washington D.C., Transportation Research Record Volume 22227, Issue 1, pp 97-106.
12. Wang, H. and Li, M. 2019. "Evaluation of Effects of Variations in Aggregate Base Layer Properties on Flexible Pavement Performance". Journal of the Transportation Research Board, Washington D.C., Transportation Research Record, Volume 2524, Issue 1, pp 119-129.
13. Dawson, A.R. 2022. "*Implications of Granular Material Characteristics on the Response of Different Pavement Constructions*". https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.561.7994&rep=rep1&type=pdf (Accessed April 2022)
14. Ahammed, M.A. et al. 2013. "*Implementing the AASHTOWare Pavement ME Design Guide: Manitoba Issues and Proposed Approaches*". Pavement Design Innovations to Implementation (AASHTOWare Pavement ME Design Case Studies) Session, 2013 Conference of the Transportation Association of Canada, Winnipeg, Manitoba.