Influence of Subgrade Material Type and Stiffness on Predicted Distresses Using the AASHTOWare Pavement ME Design Software for New Flexible Pavement Design

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Abstract

Experiences in North America and elsewhere have shown that good quality native and borrowed soils including granular fills provide strong support for the overlying pavement structure for increased load carrying capacity and longer service life or allow for the reduction of pavement thickness. The stiffness of subgrade soils has a significant and realistic influence on pavement thickness design using empirical design methods. The AASHTOWare Pavement ME Design (PMED) software predicts several key distresses in pavements for the variation of different design inputs including subgrade properties. However, past studies have shown that this software is unable to adequately consider the influence of subgrade soil quality, as practically experienced. As part of continued design trials since 2007 to assess the suitability of the PMED software, the Transportation Association of Canada (TAC) ME Pavement Design Subcommittee undertook this study in 2025 to verify the findings of earlier studies using the new web version of the software. The objective of this study is to evaluate how variations in subgrade stiffness and material type affect PMED software distress predictions for new flexible pavements under different climatic conditions.

Five different subgrade soil types, AASHTO classifications 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), with varied physical properties and resilient moduli values ranging from 20 MPa to 150 MPa were selected. Eleven weather stations were selected to capture the effect of varied climatic conditions across Canada on predicted performance. This led to a total of 110 design runs, which were completed using the software's default global calibration coefficients.

The analyses of results showed that bottom-up fatigue cracking decreases as subgrade stiffness increases with minimal sensitivity to soil type. Bottom-up fatigue cracking also varied with variation of climatic conditions, with substantially higher cracking predicted in colder regions. Predicted top-down fatigue cracking and thermal cracking displayed little to no sensitivity to subgrade stiffness, soil type, or climate variations. Climatic variation was the dominant factor influencing total and asphalt concrete layer rutting, outweighing the effects of subgrade material type and stiffness. Subgrade rutting generally decreased as resilient modulus increased within each soil type. However, an unexpected inverse trend was observed, where coarser-grained or lower-plasticity subgrade soils exhibited greater predicted rutting than finer-grained soils with similar resilient modulus. Climate had a pronounced effect on pavement roughness prediction. This paper presents the methods, analyses, and findings from these trials to assist highway agencies in evaluating the suitability of PMED for routine pavement design applications.

Introduction

Flexible pavement design has been increasingly transitioned toward mechanistic–empirical methods over the past two decades that aim to better represent how pavement systems behave under real traffic and environmental conditions. AASHTOWare Pavement ME Design software is a tool that is widely used to estimate long-term distresses including rutting, various cracking, and ride quality. While this represents a significant advancement over purely empirical approaches, there remains ongoing discussions and concerns in practice regarding the consistency and reliability of the predicted performance. A key parameter influencing this uncertainty is the representation of subgrade support conditions. The subgrade

is typically represented using the resilient modulus (Mr). According to NCHRP study conducted in 2004, Resilient Modulus is one of the most sensitive inputs in mechanistic-empirical design due to its direct influence on the pavement responses used to predict pavement distresses, particularly rutting [1]. Subgrade response is an output based on several input parameters that are intended to represent a soil type under varying stress and environmental conditions such as traffic and climate data.

There has been an increasing need to better understand the subgrade representation influences predicted performance and whether the assumptions carried during the design process reflect the field conditions. Depending on the geographical location, subgrade soils with similar resilient modulus values may exhibit different performance in the field due to variations in material type, moisture sensitivity, and environmental conditions. These behavioral differences are not always captured by a single design input value, yet they can significantly influence rutting development over time.

This paper is an attempt to examine the combined influence of subgrade material type and stiffness on predicted pavement distresses using AASHTOWare Pavement ME Design software. During the trials, the author(s) focused on evaluating the pavement response when subgrade type was varied across five different categories and eleven climate stations. predicted distresses such as rutting and related performance measures across eleven climate stations.

Background and Literature Review

The design of flexible pavements has evolved significantly from empirical approaches toward mechanistic-empirical (ME) methodology that accounts for material behavior, traffic loading, and various environmental conditions. The AASHTOWare Pavement ME Design software represents the current state of practice, providing a tool to the designers to predict key pavement distresses such as rutting, fatigue cracking, thermal cracking, and the International Roughness Index (IRI). The characterization of pavement layer properties is an essential part of this methodology, as predicted performance is sensitive to input parameters. Among these, the subgrade plays a critical role as the foundation supporting the pavement structure, and its representation directly influences the computed stress/strain pavement responses that result in distress predictions.

In AASHTOWare Pavement ME Design, the subbase layer is defined through a set of structural, mechanical, and environmental input parameters that collectively influence pavement response under repeated loading. These include layer thickness and resilient modulus, which govern structural capacity, as well as soil classification parameters (gradation, plasticity index, and liquid limit) that describe material type. Additional inputs such as Poisson's ratio, density, moisture content, and the soil-water characteristic curve (SWCC) are incorporated to account for stress-dependent behavior and moisture-induced variations in stiffness [2]. Many studies have identified Mr as one of the most influential input parameters in mechanistic-empirical design, particularly in its control over pavement responses used in the PMED software to predict distresses, and consequently the prediction of rutting. Therefore, increases in subgrade Mr are associated with reductions in predicted rutting and improvements in overall pavement performance.

Ahammed M.A., Podborochynski D., and Chan S. [3] compared the effect of the same subgrade types but with each one having their own single fixed modulus, the results and analysis showed that the subgrade

soil type and stiffness had minor effect on the predicted IRI, with the predicted IRI slightly decreasing for stiffer and better quality subgrade with the exception of silty sand (A-2-4) subgrade. The results also showed unexpected and inconsistent trends for the predicted total rutting (permanent deformation), bottom-up fatigue cracking, and AC layer rutting. Subgrade soil type and stiffness also had negligible or no effect on the predicted top-down fatigue cracking.

Réus and Fontenele [4] examined the effect of variations in layer thickness and resilience modulus on flexible pavement performance. The distresses predicted and considered in this study were: top-down cracking, bottom-up cracking, asphalt coating, subgrade, and total permanent deformation, and IRI. Pavement lifespan prediction was significantly sensitive to variations in asphalt layer and subbase thickness and in subgrade resilience modulus. For the AASHTO method programs, bottom-up cracking was more sensitive to variations in asphalt layer, base resilience modulus, subgrade resilience modulus, and base thickness, in that order. When it comes to sensitivity concerning fatigue cracking and permanent deformations, subgrade resilient modulus was considered significant. Regarding prediction of IRI values for the 20th project year, it was possible to observe that, for MEPDG software, the greatest influence was that of asphalt layer, followed by variations in base and subgrade resilience modulus. With the application of AASHTO ME method programs, it was found that coating and base thicknesses and base and subgrade resilient moduli are more influent in predicting distress magnitudes.

Ahammed M.A., Smith T.J., Podborochynski D. et al [5] did a study on the effects of subgrade, subbase, and base materials on the PMED Software predicted distresses in jointed plain concrete. They saw that the predicted IRI decreased as the physical properties or stiffness of native subgrade soils improved. There was a significant effect of varying climatic conditions on the PMED software predicted IRI. No design met the IRI criteria for high plastic clay (A-7-6), low plastic clay (A-6) and sandy silt (A-4) subgrade soils in cold climates but the no-freeze climate zone, e.g., in Victoria (BC), where the soil types and stiffness had minimal effect on the predicted IRI, which seemed to be due to a very low freezing index and freeze-thaw cycles in Victoria. In cold climates, subgrade soils with better physical properties such as low fines content were more helpful than the stiffer subgrade soils. Subgrade type did not provide any difference in predicted transverse cracking regardless of climatic conditions and subgrade type or stiffness. Stiffer subgrade did not have significant benefit in terms of predicted IRI and, in each climatic condition, the variations of predicted IRI among the subgrade soils were associated with their physical properties. Poor quality subbase caused a slight increase in IRI and faulting. Poor quality subbase resulted in slightly higher transverse cracking.

Islam and Gassman [6] studied three different subgrade resilient modulus for two sites with fine grained soils in South Carolina. Resilient Modulus derived from the lab, backcalculated through FWD testing results and default Mr value were used to determine various pavement responses including IRI. The study demonstrated that predicted pavement distresses are highly sensitive to subgrade resilient modulus; however, their results also showed variability in rutting and cracking predictions for similar subgrade conditions, indicating that resilient modulus alone may not fully characterize subgrade performance.

Oberez, M.E., Kass, S., Hilderman, S. et al [7] assessed the sensitivity of predicted distresses to changes in subgrade modulus by using several runs of the Pavement ME software using the maximum and minimum values of laboratory resilient modulus of the subgrade. The findings showed that for HMA overlay, the

subgrade type and resilient modulus showed very little influence in the predicted rutting, IRI and total fatigue cracking.

Shakhan, M.R., Topal, A., Şengöz, B. [8] did a study to investigate the impact of subgrade strength on flexible pavements using AASHTOWare Pavement Design v2.5.5. The results of the study showed that reducing the subgrade CBR values from 50 to 5 CBR resulted in an increase by 3.7mm in total rutting depth and 5.6% in alligator cracking magnitude. Also, the results demonstrated that the influence of subgrade strength on rutting within the asphalt concrete layers (AC rutting) is negligible. By contrast, increasing the subgrade CBR value from 5 to 50 resulted in a significant increase (65.1 to 314.7 m/km) in longitudinal cracking magnitude while the thermal (transverse) cracking was not sensitive to the variation of subgrade CBR values.

Ahammed M.A., Kass, S., Hilderman, S. [9] presented an analysis of pavement design using AASHTOWare Pavement ME to demonstrate the practical sensitivity of several inputs including subgrade strength. They found that there was an increase in predicted total rutting with an increase in the subbase layer thickness, which was not expected. An increase in the subbase layer thickness also decreased the bottom up fatigue cracking while increasing the predicted longitudinal (AC top down) cracking, transverse cracking, and, AC layer rutting, which was expected. The Pavement ME longitudinal cracking model was also found to be unreliable.

Most existing studies evaluate the influence of subgrade resilient modulus independently, while limited research has systematically examined the combined effects of material type and stiffness on predicted distresses across varying environmental conditions. To address these limitations, this study evaluates the combined influence of subgrade material type and resilient modulus on predicted pavement distresses using Pavement ME, with particular emphasis on understanding variability across different climatic conditions.

Scope, Objectives and Significance

The findings from literature review indicate that several studies focused on the evaluation of the effect of subgrade soils on the PMED software predicted distresses in pavements. A few studies focused on the global sensitivity analysis, whereas limited studies were conducted to assess the impact of each individual input parameters of subgrade soils on the predicted distresses. Research studies also noted some issues or limitations in the subgrade soil related models that are incorporated into the PMED software. As a result, the software is unable to adequately consider the influence of subgrade soil quality, as practically experienced in the field.

In 2025, the TAC ME Pavement Design Subcommittee has performed several coordinated design trials to evaluate the impact of varying the key input parameters of subgrade soils on the PMED software predicted distresses in new flexible pavements under varying Canadian climatic conditions. Five different subgrade soil types, AASHTO classifications 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), with varying physical properties and resilient moduli values ranging from 20 to 150 MPa were selected. Each subgrade soil type had two different resilient moduli values. Eleven weather stations were selected to capture the effect of varying climatic conditions across Canada on predicted distresses. This led to a total of 110 design runs for this study. The objective of this

paper is to present the details of input parameters, trial results, analysis, and findings. The presented information may help different agencies and other interested individuals in assessing the suitability of the latest (web) version of the PMED software when designing flexible pavement structures with varied subgrade soil parameters.

Software Versions and General Design Inputs

All participants utilized the PMED software version 3.0 using the global calibration coefficients in all design trials. The general input parameters for the design trials are summarized in Table 1, which remained unchanged in all design runs. The varying design inputs for different trial runs included mechanical and physical properties of typical subgrade soils that are found in Manitoba and varying climatic data from across Canada. Details of climatic data are presented in the next section. Details of varying subgrade soils input parameters are presented in the “Trial Matrix and Varying Design Inputs” section.

Table 1. General inputs for design trials

Inputs		Value Used
Climate Data		MERRA-2 from 11 weather stations across Canada
Truck Traffic		Two-way 2,500 trucks/day (1,000 trucks/day on the design lane of a four-lane divided highway) and 2% cumulative annual growth rate
Vehicle Class Distribution and Axle Load Spectra		Manitoba Level 1
Traffic Speed		100 km/h
Design Life		20 years
Initial IRI		0.9 m/km
Design Reliability		90% for all distress types
HMA Properties		Manitoba SP12.5 mix: Asphalt binder = 4.8%; density = 2,276 kg/m^3; VMA = 17.2%; AV = 6.9%; aggregates finer than 9.50 mm = 80.6%, 4.75 mm = 52.6% and 0.075 mm = 2.8% Manitoba SP19.0 mix: Asphalt binder = 4.5%; density = 2,294 kg/m^3; VMA = 16.6%; AV = 7.0%; aggregates finer than 19.0 mm = 95.3%, 9.50 mm = 67.9%, 4.75 mm = 51.8% and 0.075 mm = 3.0% Asphalt binder grade: PG 58-34 in both mixes Software default Poisons ratio, reference temperature, thermal conductivity and heat capacity for both mixes
Pavement Structures	Asphalt Concrete	Surface layer = 40 mm thick SP12.5 Base layer = 110 mm thick SP19.0
	Granular Base	150 mm thick Manitoba GBC- I; Annual representative resilient modulus (Mr) = 225 MPa
	Granular Subbase	300 mm thick Manitoba CR- M50; Annual representative Mr = 200 MPa
Subgrade Type and Properties		Vary in each trial for each climatic area

IRI = International Roughness Index; SP = Superpave; VMA = Voids in Mineral Aggregates; AV = Air Voids; PG = Performance Grade; GBC- I = Granular Base Course Type- I and CR- M50 = Crushed Rock Minus 50 mm.

Selected Weather Stations and Summary of Climate Data

MERRA-2 climate data from 11 weather stations across Canada with varying climatic input parameters were selected for the design trials presented in this study. Figure 1 shows the geographic locations of the selected weather stations. The red dots indicate relatively warmer climates, while the blue dots indicate relatively colder climates in Canadian context. Table 2 presents the list of weather stations and the summary of the key climatic parameters. It should be noted here that some of the climatic parameters (such as minimum air temperature, frost depths, and annual number of wet days) in the MERRA-2 climate database seem to be unreasonable as they do not match actual ground observations.

Figure 1. Geographic locations of weather stations across Canada

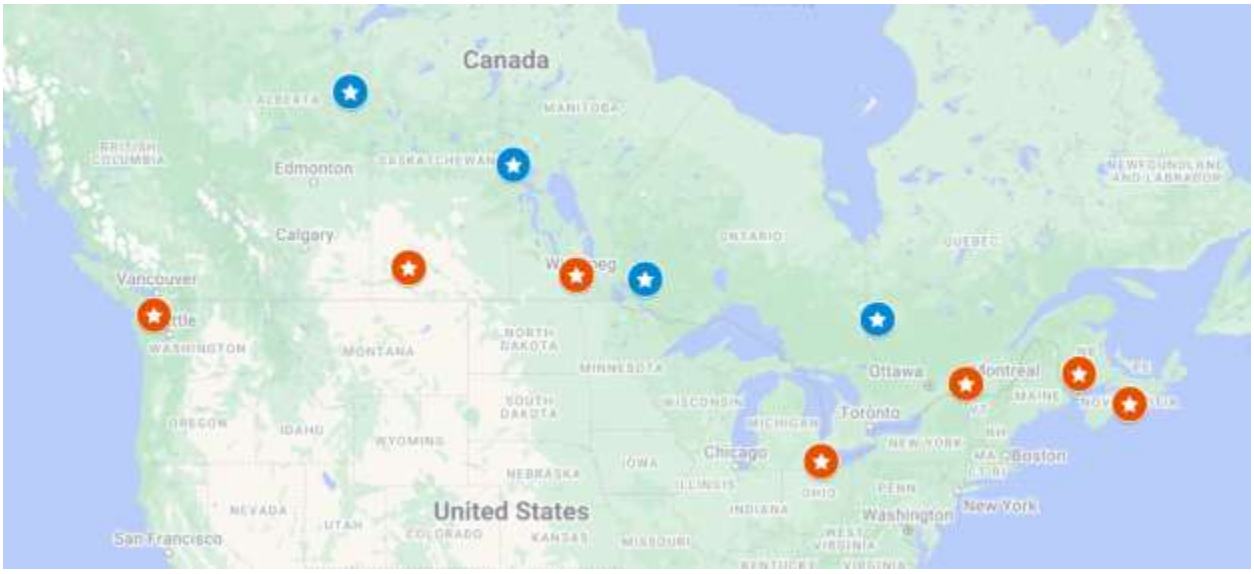


Table 2. List of weather stations and summary of key climatic parameters over the design life

Weather Station	Annual Air Temp. (°C)			Mean Annual			
	Min.	Max.	Mean	Precipitation (mm)	Number of Wet Days	FI (°C-days) (FD, m)	# of F-T Cycles
Victoria, BC	-15.4	29.4	10.9	1502	332	11 (0.5)	7.2
Fort McMurray, AB	-47.1	36.9	0.2	630	337	2081 (4.4)	66.5
Swift Current, SK	-42.1	37.9	4.9	451	274	999 (2.0)	108.6
Winnipeg, MB	-45.9	38.3	3.5	605	302	1754 (3.2)	67.6
The Pas, MB	-48.1	37.9	0.5	590	329	2357 (7.5)	58.9
Wheatley, ON	-21.7	31.6	9.6	1092	304	301 (2.0)	52.0
Waldhof, ON	-48.9	33.6	1.3	858	335	2131 (4.1)	56.8
Rouyn, QC	-45.7	31.1	2.0	1226	350	1794 (2.7)	67.3
Montreal, QC	-41.5	36.7	6.2	1379	326	1100 (2.2)	70.8
Fredericton, NB	-36.2	31.8	5.0	1389	345	1028 (1.6)	81.2
Halifax, NS	-20.1	27.1	7.3	1647	340	315 (1.1)	70.0

FI = Freezing Index, FD = Frost Depth; F-T = Freeze-Thaw

Trial Matrix and Varying Design Inputs

Subgrade type and stiffness have significant contributions to flexible pavement thickness design and field performance. This study included five typical subgrade soil types that are found in Manitoba to assess the impact of subgrade properties and stiffness on the predicted distresses. Figure 2 shows the gradations of these subgrade soils. The resilient modulus of each soil type was varied to assess the impact of subgrade stiffness for given sets of physical properties. Alternatively, each successive pair of different subgrade soil

types were assigned the same resilient modulus value to assess the impact of physical properties for a given stiffness. This led to 10 design trials for each weather station and a total of 110 design trials for 11 weather stations. Table 3 presents the design matrix for each weather station. The suitability of the PMED software in predicting pavement surface distresses, as practically expected or experienced, was also assessed through the analysis of the trends of predicted distresses.

Figure 2. Gradation of selected subgrade soils

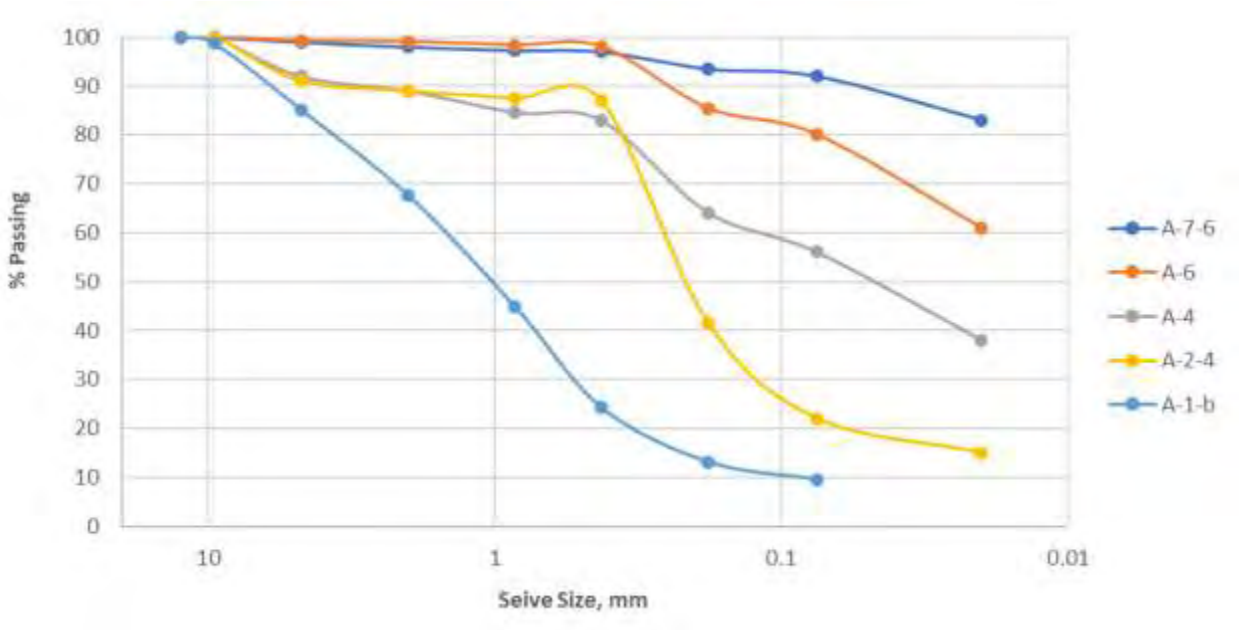


Table 3. Design trial matrix for each weather station

Trial #	Subgrade Class	Subgrade Type	Mr, MPa	LL, %	PI, %	Density, kg/m^3	MC, %
1	A-7-6	High Plastic Clay	20	79	49	1410	33.0
2	A-7-6	High Plastic Clay	30	79	49	1410	33.0
3	A-6	Low Plastic Clay	30	38	20	1650	21.5
4	A-6	Low Plastic Clay	45	38	20	1650	21.5
5	A-4	Sandy Silt	45	25	3	1780	22.5
6	A-4	Sandy Silt	65	25	3	1780	22.5
7	A-2-4	Silty Sand	65	18	3	1710	15.3
e	A-2-4	Silty Sand	100	18	3	1710	15.3
9	A-1-b	Granular Fill	100	14	0	2117	7.9
10	A-1-b	Granular Fill	150	14	0	2117	7.9

LL = Liquid Limit; PI = Plasticity Index; MC = Moisture Content

Results, Analysis and Discussion

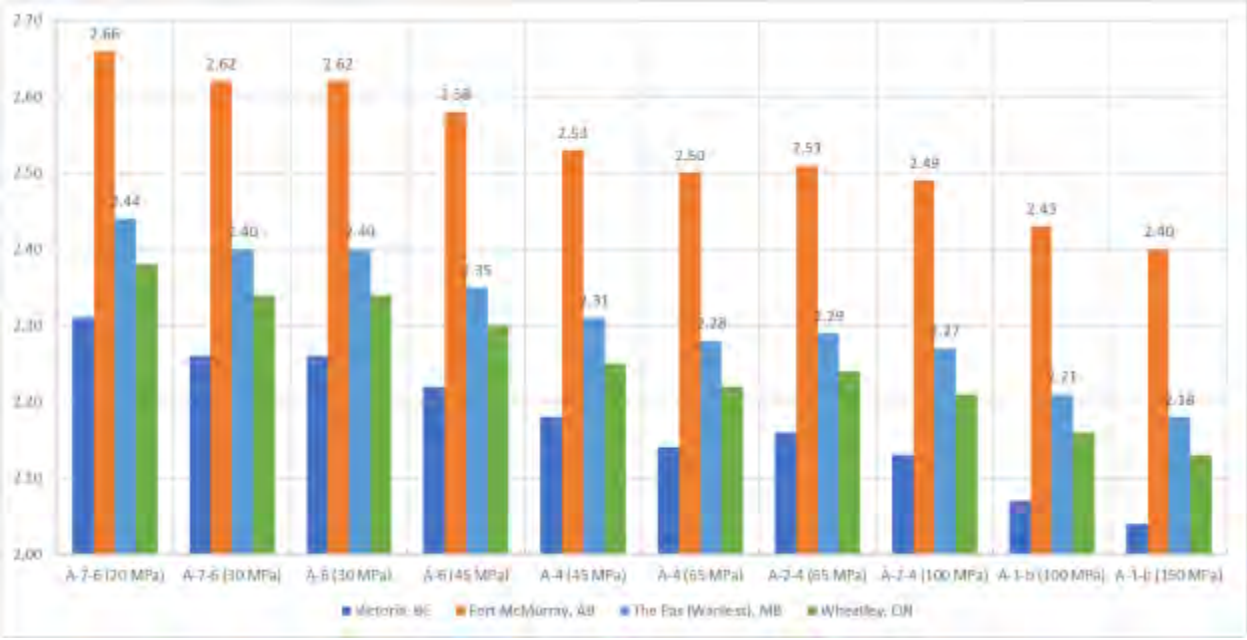
This section presents and interprets the results obtained from the PMED analyses conducted to evaluate the influence of subgrade material type and stiffness on predicted flexible pavement performance. The predicted distresses are evaluated to identify trends and relative sensitivities associated with variations in subgrade properties. The results are compared across different subgrade scenarios while maintaining consistent traffic and pavement layer thicknesses, and HMA and granular properties, allowing the isolated effects of subgrade behavior on pavement response to be assessed.

Effect of Subgrade Stiffness and Material on the Predicted IRI

Across all design scenarios, the IRI was found to decrease as subgrade stiffness increased, indicating that stronger subgrade support contributes to improved long-term pavement performance. For example, increasing the subgrade resilient modulus from approximately 20 MPa (soft clay, A-7-6) to 150 MPa (strong granular soil, A-1-b) resulted in a significant drop in terminal IRI over the 20-year design life. Variations in subgrade material type or soil properties had little to no direct impact on roughness when resilient modulus was held constant. The predicted IRI values were identical for different soils at the same Mr value, suggesting that subgrade stiffness governs roughness progression rather than soil classification. Instead, climate is shown as a dominant factor influencing IRI.

Pavements in warmer climates with highest mean temperature (e.g., Victoria, BC) consistently exhibited lower IRI values. In contrast, sections in harsh cold climates (e.g., Fort McMurray, AB and The Pas, MB, with the lowest mean annual temperatures) showed significantly higher IRI progressions through out the design life.

Figure 3. Variation in terminal IRI

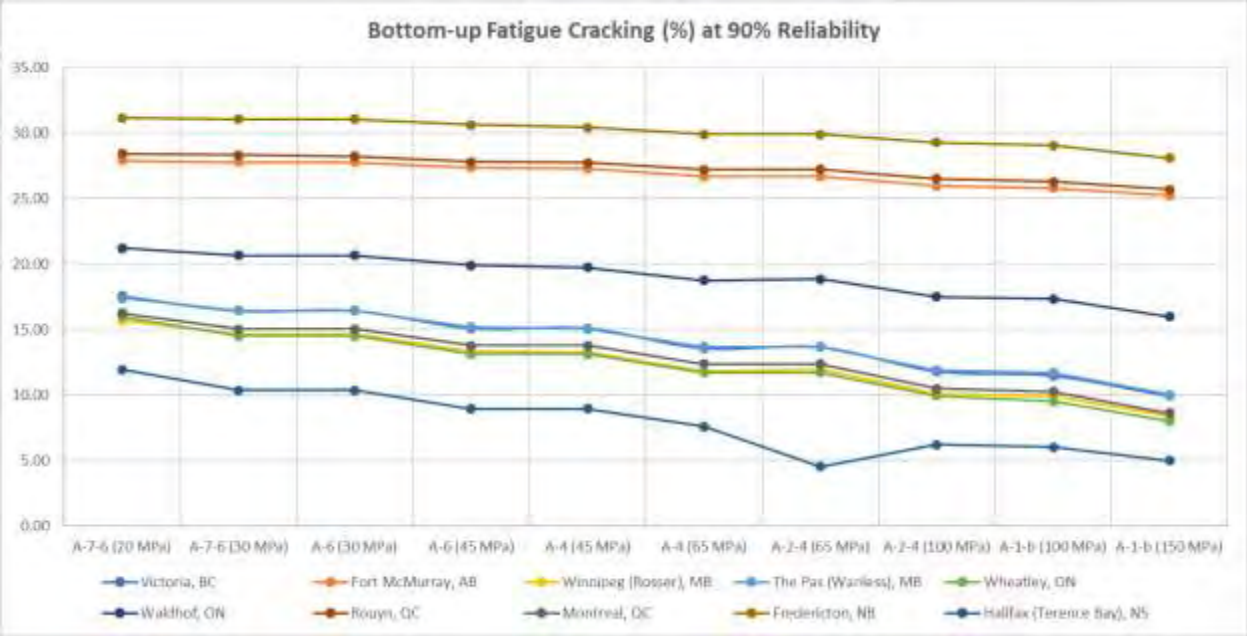


Effect of Subgrade Material Type and Stiffness on Predicted Bottom-Up Fatigue Cracking (BUFC)

The PMED analysis indicated that increasing the subgrade resilient modulus consistently reduced predicted bottom-up fatigue cracking (BUFC). This outcome aligns with expectations, a stiffer subgrade provides more rigid support and thus reduces pavement deflections and tensile strains at the bottom of the asphalt layer, thereby mitigating fatigue crack initiation and propagation. In contrast, predicted BUFC was largely insensitive to variations in subgrade material type or key index properties (e.g., subgrade dry density, liquid limit, plasticity index) when Mr was held constant.

Climatic conditions, however, had a pronounced effect on BUFC across the eleven Canadian climate stations analyzed. Pavement sections in colder regions characterized by lower mean temperatures and more severe freeze–thaw cycles exhibited substantially higher predicted fatigue cracking than those in milder climates.

Figure 4. Variations in Bottom-Up Fatigue Cracking



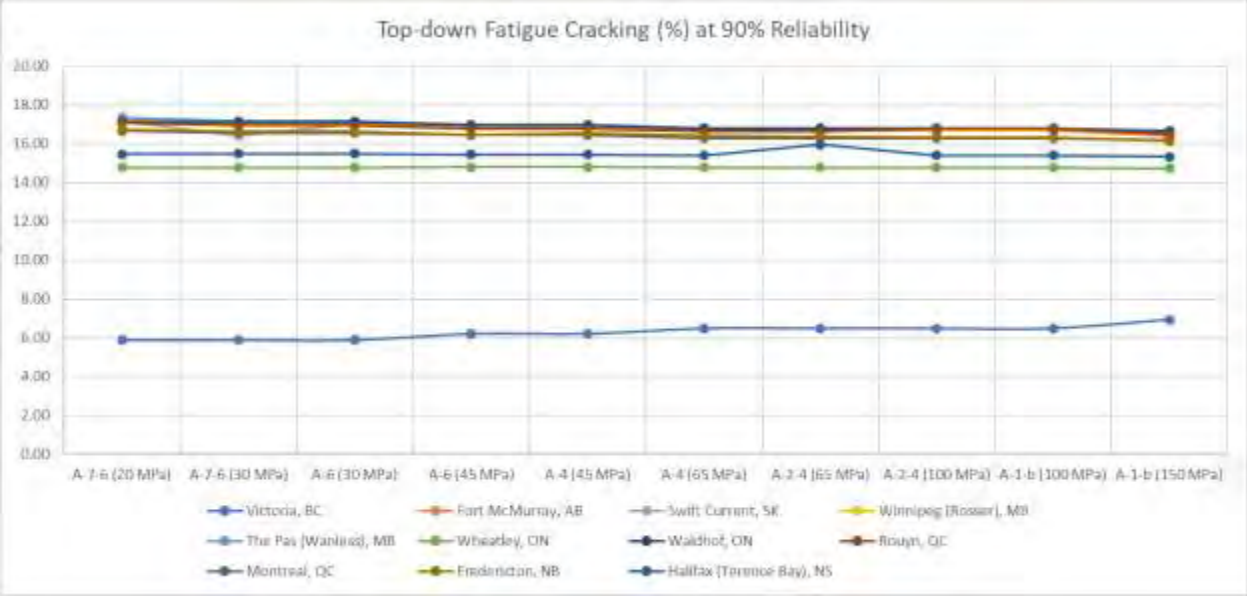
Effect of Subgrade Material Type and Stiffness on Predicted Top-Down Fatigue Cracking (TDFC)

In contrast to the pronounced subgrade-dependent trends observed for bottom-up cracking, predicted top-down fatigue cracking (TDFC) remained essentially unchanged across the range of subgrade stiffness (resilient modulus) values and soil types considered. As the subgrade resilient modulus increased from 20 MPa to 150 MPa, TDFC showed only a slight decreasing trend, indicating minimal sensitivity of the top-down cracking to subgrade stiffness. Similarly, variations in subgrade material properties including soil classification, density, and plasticity indices had negligible impact on TDFC predictions, reinforcing the conclusion that variations in subgrade characteristics did not measurably influence the effect of initiation or propagation of top-down cracks.

This insensitivity is consistent with the mechanism of TDFC, which originates at the pavement surface under high tire-contact tensile stresses and is largely governed by asphalt layer factors (surface mix

properties) rather than by the stiffness of the underlying pavement. Correspondingly, climatic differences produced only minor variation in TDFC. Nearly all climate zones yielded comparably low TDFC levels, with one notable outlier as Victoria, BC, where the predicted TDFC was only about one-third of the values observed in colder Canadian climates.

Figure 5. Variations in Top-down Fatigue Cracking

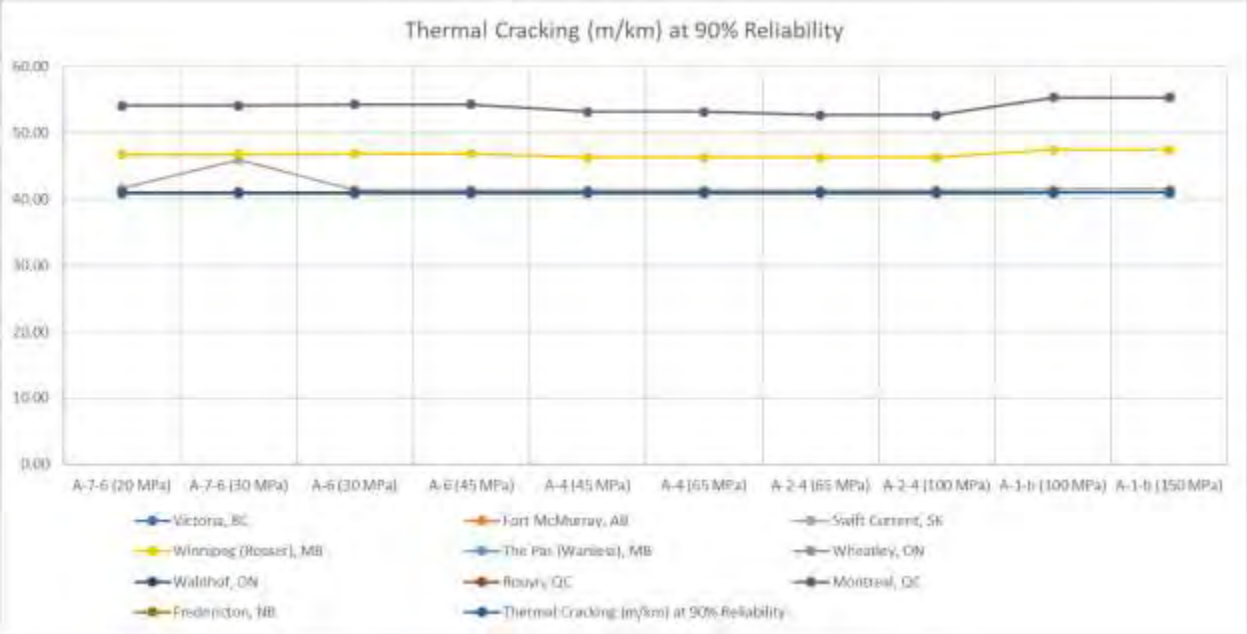


Effect of Subgrade Material Type and Stiffness on Predicted Transverse Cracking

Predicted transverse cracking showed no dependence on subgrade stiffness or material type. Across the full range of subgrade resilient moduli and soil classifications examined, the extent of thermal cracking remained nearly constant, with most scenarios showing similar crack lengths on the order of 40 m/km regardless of subgrade conditions. This indicates that subgrade improvements do not mitigate transverse cracking, a finding consistent with the understanding that thermal cracking is predominantly controlled by asphalt binder properties and temperature extremes rather than the pavement support. The influence of climate was also minimal in general, with most Canadian climate stations producing comparable transverse cracking predictions.

The cold-weather sites of Montreal and Winnipeg showed slightly higher predicted thermal crack lengths (approximately 54 m/km and 46 m/km, respectively) compared to the 40 m/km observed in other regions.

Figure 6. Variations in Transverse Cracking



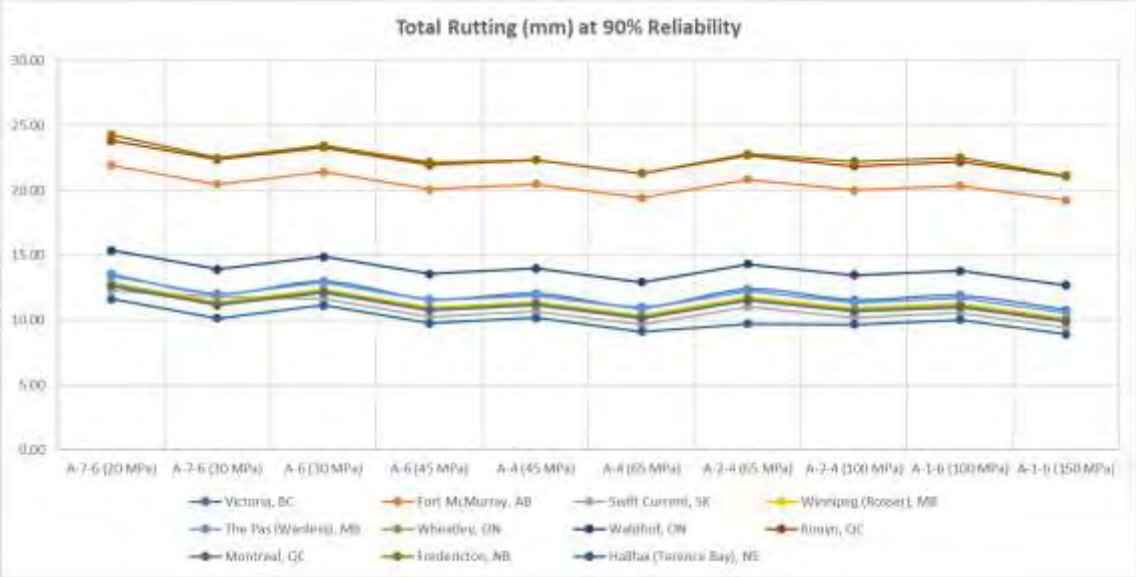
Effect of Subgrade Material Type and Stiffness on Predicted Total Rutting

The total permanent deformation of the pavement was only mildly affected by subgrade stiffness and instead was governed more by climatic conditions. Increasing the subgrade resilient modulus from very soft (20 MPa) to intermediate values (65 MPa) provided a slight reduction in overall rut depth, but the benefit diminished significantly beyond approximately 65 MPa, indicating that further stiffening of the subgrade resulted in little additional improvement in rut resistance.

However, climate variations showed much greater influence on total rutting. It was also observed that, when comparing different soil types at the same subgrade stiffness, a higher-quality, lower-plasticity soil (e.g., an A-6 silty soil) was predicted to experience greater total rutting than a high-plasticity A-7-6 clay at an equivalent Mr (≈30 MPa). This result is unexpected, as coarser and drier soils are generally considered more resistant to rutting. This suggests that, beyond a certain point, further increases in subgrade stiffness or improvements in soil classification, do not proportionally reduce total pavement rutting.

Total rutting for sections in warmer regions (e.g., Victoria) consistently showed lower accumulated rut depths, while those in severe cold climates (such as Fort McMurray, AB and Winnipeg, MB) showed substantially higher total rutting. This trend is unexpected and may reflect the influence of climatic conditions on predicted pavement response.

Figure 7. Variations in Total Rutting



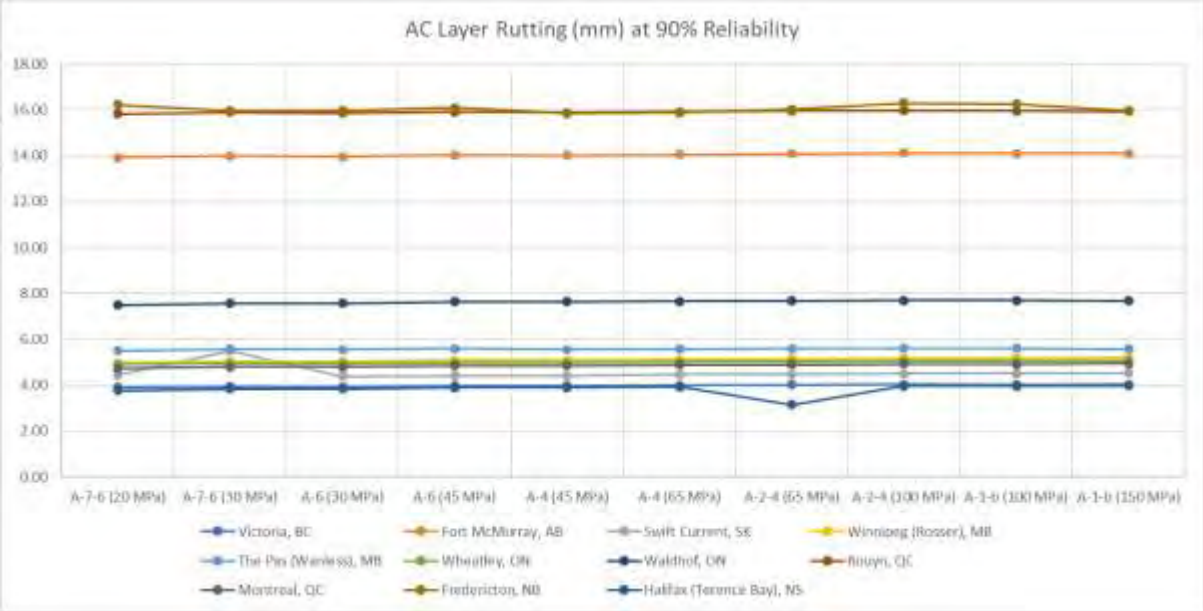
Effect of Subgrade Material Type and Stiffness on Predicted Asphalt Concrete (AC) Layer Rutting

For the asphalt concrete surface layer, the PMED results indicated minimal influence of subgrade variability on AC layer rutting, with only minor or inconsistent changes observed as subgrade stiffness and material type were varied. In general, enhancing subgrade support provided no clear reduction in the asphalt layer permanent deformation.

A slight increase in AC rutting at the highest subgrade modulus was observed, which is unexpected.

In contrast, climatic conditions had a strong influence on AC rutting. One of the warmer study sites (e.g., Fredericton, NB) exhibited measurably greater AC rut depths than the much colder The Pas, MB, as expected.

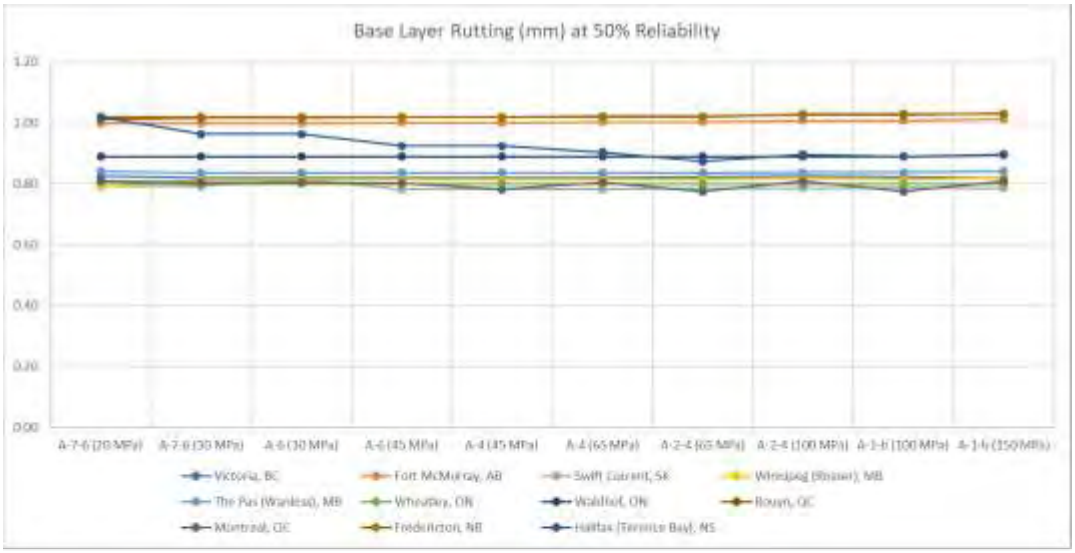
Figure 8. Variations in AC Rutting

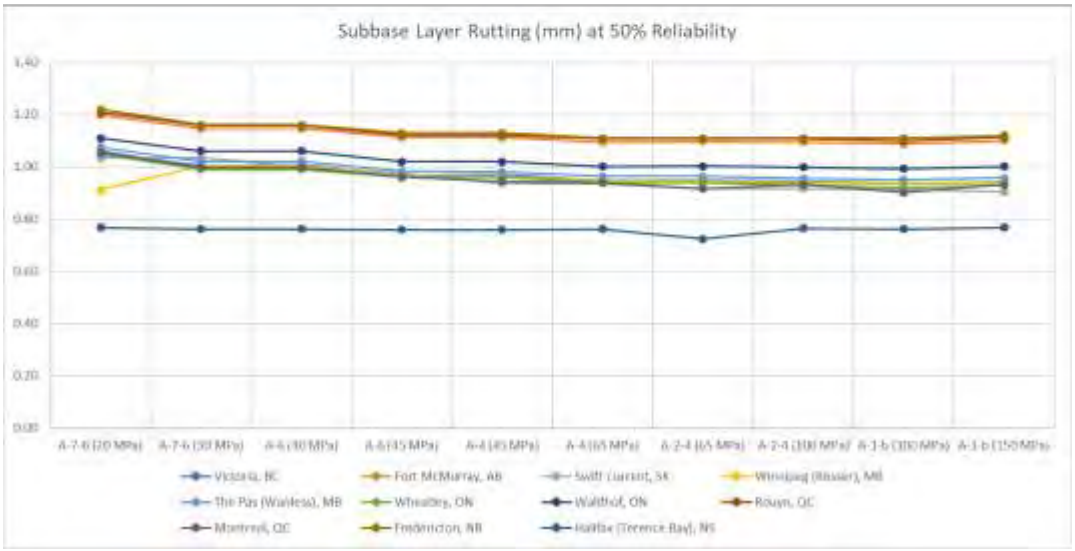


Effect of Subgrade Material Type and Stiffness on Predicted Base and Subbase Rutting

The results indicated that rutting in the granular base and subbase layers was largely unaffected by changes in subgrade stiffness or material type. Across all design cases, the rutting within the base (150 mm thick) and subbase (300 mm thick) remained essentially constant, regardless of whether the pavement was underlain by a weak A-7-6 clay subgrade or a strong A-1-b granular subgrade. Even large increases in subgrade resilient modulus (from 20 MPa up to 150 MPa) did not result in a notable change in base or subbase rutting in the PMED outputs, which is unexpected. In general, variations in subgrade material type and stiffness had a negligible impact on the predicted rutting in the base and subbase layers under the conditions evaluated.

Figure 9. Variations in Base and Subbase Rutting



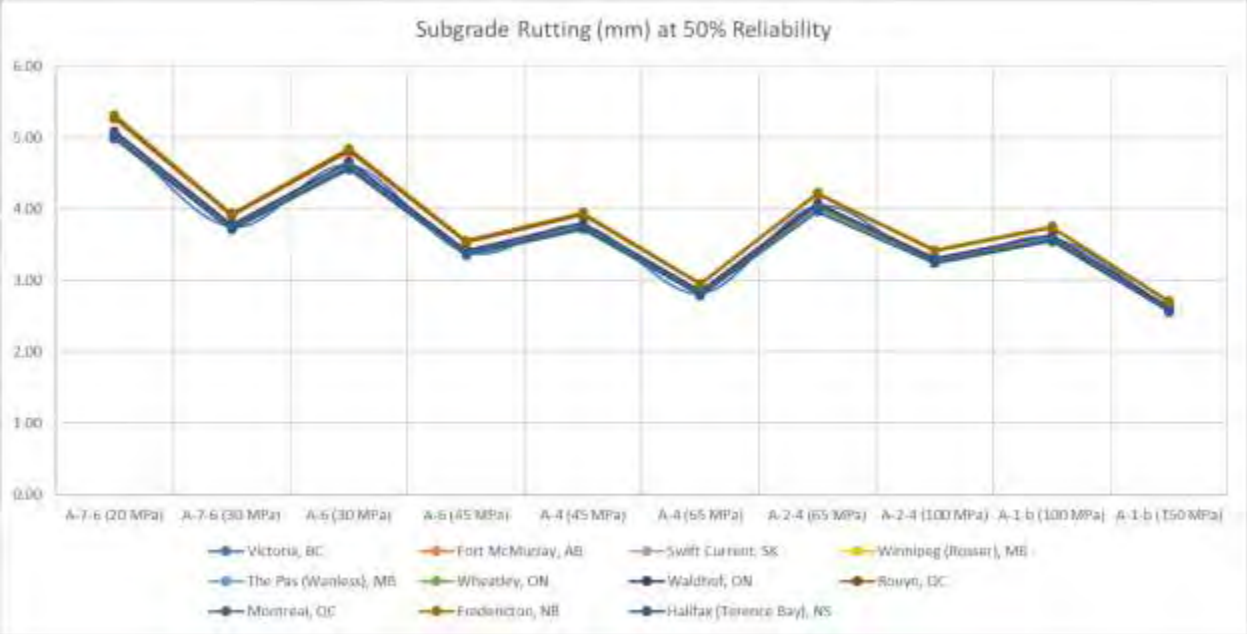


Effect of Subgrade Material Type and Stiffness on Predicted Subgrade Rutting

As expected, the subgrade rutting was inversely related to its stiffness. The PMED results showed that higher subgrade resilient modulus values consistently led to lower subgrade rutting.

However, when comparing different soil types at the same resilient modulus, coarser-grained, lower-plasticity soils exhibited more subgrade rutting than fine-grained, high-plasticity clays of identical Mr. For example, at a stiffness of 30 MPa, the model predicted greater subgrade rutting for a low plastic clay A-6 soil than for an A-7-6 high plastic clay, despite the latter being more plastic and typically considered less favorable for support. This is an unexpected trend and thus warrant further investigation.

Figure 10. Variations in Subgrade Rutting



Influence of Climate Parameters on Predicted Pavement Distresses

Based on the PMED software distress prediction models, it is expected that:

- IRI is influenced directly by freezing index and precipitation, and indirectly by predicted cracking and rutting.
- Bottom-up fatigue cracking is affected by HMA temperature and dynamic modulus, and tensile strain at the bottom of the asphalt layer.
- AC-layer rutting is influenced directly by HMA temperature and dynamic modulus.
- Total rutting combines permanent deformation within the HMA and granular aggregate layers, and subgrade. Since Level 2 annual representative resilient modulus values were used for the granular materials and subgrade, no effect of seasonal moisture variation, freezing, and thaw weakening on unbound-material stiffness was expected.

However, the predicted distresses across the climate stations did not always follow the trends expected from the annual representative climate parameters.

Summary and Conclusions

- Predicted IRI decreased significantly as subgrade stiffness increased, with almost no change due to subgrade soil type; however, roughness was strongly climate dependent, with the harsh cold climates developing significantly higher IRI over time.
- Predicted BUFC showed strong sensitivity to subgrade stiffness, decreasing noticeably as Mr increased, with minimal influence of subgrade material type and substantially higher cracking in colder climates.
- Predicted TDFC, thermal cracking, and total rutting remained very low and unchanged across all subgrade stiffnesses and soil types, exhibiting minimal sensitivity to subgrade or climate variations.
- The analysis indicates that asphalt layer rutting was independent of subgrade stiffness and material type, although climate had a noticeable impact on AC rutting, with one of the warmer locations exhibiting higher rut depths.
- Predicted rutting in the granular base and subbase layers showed negligible sensitivity to subgrade stiffness, subgrade material type, or climate, remaining nearly constant across all scenarios.
- Predicted subgrade rutting decreased significantly with increasing subgrade stiffness, as expected, with negligible differences between climates stations. However, an unexpected trend was observed, at equal Mr, a higher quality (lower-plasticity clay) soil exhibited more subgrade rutting than a high-plasticity clay.

References

[1] 501-508.AASHTO, “Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures”, NCHRP Report 1-37A, Transportation Research Board, Washington, DC, 2004.

[2] 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.

[3] Ahammed M.A., Podborochynski D., and Chan S. 2022. “Sensitivity of the Pavement ME Design Software Predicted Distresses in Flexible Pavements to Subgrade Soils and Granular Subbase Materials” Innovations in Pavement Management, Engineering and Technologies Session of the 2022 Annual Conference of the Transportation Association of Canada Edmonton, Alberta.

[4] Réus, T., Fontenele, H. 2021. "Effect of Variations in Layer Thickness and Resilience Modulus on Flexible Pavement Performance". Research, Society and Development, Volume 10, No. 8, Engineering.

[5] Ahammed M.A., Smith T.J., Podborochynski D. et al 2023. “Effect of Subgrade, Subbase and Base Materials on the PMED Software Predicted Distresses in Jointed Plain Concrete Pavement.” Prepared for presentation in Pavement Management, Engineering and Technologies Session of the 2023 TAC Conference & Exhibition, Ottawa, Ont.

[6] Islam, K. M., & Gassman, S. L. (2023). Predicting Flexible Pavement Distress and IRI Considering Subgrade Resilient Modulus of Fine-Grained Soils Using MEPDG. Materials, 16(3), 1126. https://doi.org/10.3390/ma16031126

[7] Oberez, M.E., Kass, S., Hilderman, S. et al 2015. “Estimating Base Layers and Subgrade Moduli for ME Pavement Design in Manitoba.” Prepared for presentation at the New Developments in ME Pavement Design Session of the 2015 Conference of the Transportation Association of Canada Charlottetown, PEI

[8] Shakhan, M.R., Topal, A., Cengiz, B. (2022). Impact of Subgrade Strength on Pavement Performance. DEUFMD, 24(71),

[9] Ahammed M.A., Kass, S., Hilderman, S. 2013. “Implementing the AASHTOWare Pavement ME Design Guide: Manitoba Issues and Proposed Approaches”, Prepared for presentation at the Pavement Design Innovations to Implementation (AASHTOWare Pavement ME Design Case Studies) Session of the 2013 Conference of the Transportation Association of Canada Winnipeg, Manitoba.