

## **Subgrade Soil Frost Susceptibility Assessment for Pavement Design in Manitoba**

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## **Abstract**

Frost susceptible subgrade soils, when exposed to moisture and freezing condition, cause frost heaving on road surfaces. In cold climates, like Manitoba, many road sections experience surface roughness and pavement deterioration due to seasonal frost heaving and melting. Subgrade soils frost heave remedial measures such as removal and replacement, embankment construction using non-frost susceptible materials, soil stabilization or thick pavement structures are generally very costly and/or impractical. Moreover, available guidelines or study results for characterizing soils as frost susceptible and classifying into different severity levels vary widely. Remedial measures or management of frost heave issues also vary among highway agencies. All these variations or factors hinder the selection of an appropriate approach to deal with this issue.

In Manitoba, in the past, a subgrade soil was characterized as frost susceptible if it met several characteristics. If a soil was characterized as frost susceptible, the calculated structural number (SN) was increased by 25%. The historical basis for such characterization and a fixed adjustment is unknown. Manitoba has now adopted the “value for money analysis approach” for all design, construction and operational practices. This led to a review of the appropriateness of these method/practice and revise to meet Manitoba’s current needs. Manitoba has completed major changes to frost susceptibility characterization/classification and pavement structure design/analysis for frost susceptible subgrade soils. This led to a more cost-effective and reasonable pavement structure design and management. This paper presents the comparison of various frost susceptibility characterization and classification, Manitoba’s past practice and recent changes, and the impacts of these changes. This paper and presentation may be an educational opportunity for interested individuals or agencies.

## **Introduction**

Subgrade soils frost heaving, and associated pavement distress and surface roughness i.e., pavement serviceability loss are common phenomenon in cold climate. Frost heaving occurs due to an increase in volume of the soil-water matrix as water turns into ice during the winter and early spring. Subgrade soils containing silt particles are known to be frost susceptible as they readily allow formation of ice lenses when exposed to moisture and freezing temperature. Other soils such as clay, soil containing organics and peat that are exposed to a high level of moisture may also undergo frost heaving when soil freezing occurs. If the subgrade soil contents and moisture exposure are uniform along a pavement section, the frost heaving will be uniform. This is not likely to be very detrimental, as the entire section will rise at the same time when freezing occurs and settle at the same when thawing occurs. Such ideal scenario usually does not exist anywhere, and therefore a differential frost heave and settlement are observed, which produce a non-uniform pavement surface. This is due to the variation of soil properties, composition and moisture exposure along a road section.

Three conditions must coincide for frost heave to occur: a frost susceptible soil, a freezing condition, and a moisture source [1]. In cold climate like Manitoba, freezing of the subgrade is common by nature. Frost susceptible soils are present in almost all areas of the province. However, it is more prevalent in south-western region (Region 3). Where above-mentioned all three factors, including moisture exposure coincide, frost heaving, thaw settlement, road surface roughness and pavement deterioration results. Removal or treatment of the frost susceptible material is ideal solution to avoid frost related road surface roughness and pavement deterioration. However, these are generally cost prohibitive and/or an impractical option for highways in Manitoba.

Several guidelines are available for characterizing soils as frost susceptible with recommendations for remedial measures such as proper drainage, insulation and replacement. Few agencies adjust pavement thickness to provide additional overburden and insulating layer. Soils frost susceptibility classification also varies among agencies and published documents that hinders the selection of an appropriate approach.

## **Objectives**

The objectives of this paper are to compare various frost susceptibility characterization and classification of subgrade soils including Manitoba's past practice and recent changes, and to present examples of soil characterization/classification, frost susceptibility classification and incorporation into pavement design/analysis. This paper and presentation are expected to be an educational opportunity for interested individuals and/or agencies.

## **Soil Classification, Frost Susceptibility and Frost Conditions**

Table 1 presents the soil classification system used in Manitoba. In general, gravel and sand, AASHTO classification A-1-a, A-1-b and A-3 are rated as excellent to good subgrade soils. Silty or clayey gravel and/or sand, and silty soils, AASHTO classification A-2 (A-2-4, A-2-5, A-2-6, A-2-7), A-4 and A-5, are considered as potentially frost susceptible subgrade soils. Clayey soils, AASHTO classification A-6 and A-7 (A-7-5, A-7-6), are rated as fair to poor subgrade soils. However, when designing pavement structures, a subgrade soil was classified as frost susceptible if it had following characteristics [2]:

- 1) The quantity of material passing the 75  $\mu\text{m}$  (No. 200) sieve is 20% or greater.
- 2) The plasticity index is 12 or less.
- 3) The clay (particle size  $<0.005$  mm) content is 25% or less.
- 4) The combined silt (particle sizes  $<0.075$  mm to  $0.005$  mm) and fine sand (particle sizes  $<0.425$  mm to  $0.075$  mm) content is 60% or greater.
- 5) The combined coarse sand (particle sizes  $<2.00$  mm to  $0.075$  mm) and coarse aggregate (retained on 2.00 sieve) is 20% or less.

All organic soils were also considered frost susceptible. The above stated characterization system categorized soils as frost susceptible or non-frost susceptible without subgrouping into different frost heave severity groups. The historical basis for above characterization approach is unknown.

The AASHTO 1993 [3] pavement design guide [3] states that a reliable method for recognizing material as frost susceptible for site specific conditions has not yet identified. However, some guidelines are available in literature. For example, the U.S. Army Corps of Engineers reported that, for pavement design purposes, most inorganic soils containing 3% or more particles finer than 0.02 mm size are considered frost susceptible (3, 4). In AASHTO 1993 pavement design guide [3], the frost susceptibility classification and frost heave rates of different soils that were developed by Kaplan [5] are used to consider frost heave related pavement damage (serviceability loss) in pavement design. The frost severity classification varies from negligible to very high depending on unified soil classification and percentage of material, by weight, finer than 0.02 mm.

Table 1. Manitoba's soil classification system based on AASHTO designation M 149-91 with local modification.

General Classification	Granular Materials (35% or less passing No. 200 sieve)						Silty-Clay materials (more than 35% passing No. 200 sieve)				
AASHTO Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
AASHTO Group Classification	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve Size (% Passing) 2.0 mm 0.425 mm 0.075 mm	50 max 30 max 15 max	50 max 25 max	51 max 10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Liquid Limit Plasticity Index	6 max		NP	40 max 10 max	41 min 10 max	40 max 11 min	41 min 11 min	40 max 10 max	41 min 10 max	40 max 11 min	41 min 11 min
Modified AASHTO Group Index	0		0	0		4 max		8 max	12 max	16 max	20 max
Usual types of significant constituent materials	Gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General Rating as a subgrade	Excellent to Good			Potentially Frost Susceptible					Fair to Poor		

NP = Non-Plastic

The TAC PADMG [1] presented the nomograph developed by Chamberlain [6] for characterizing the frost susceptibility of subgrade soils. Ontario's limiting grain size values for sand, clay and silt is then superimposed on Chamberlain's nomograph to classify soils into acceptable, borderline or unacceptable materials. According to MTO guide [7], fine-grained soils that have high capillarity and low cohesion characteristics are more prone to frost heaving than other soils. The percentage of soil material with grain size between 5 and 75 microns is used to classify soils into low ( $\leq 40\%$  material within this size range), moderate (40 to 55% material within this size range) and high (55 to 100% material within this size range) frost susceptibility groups.

FHWA Reference Manual NHI-05-037 [8] states four conditions associated with a high frost hazard potential. These include the presence of: a) a water table within 3 m of the pavement surface; b) observed frost heaves in the area; c) inorganic soils containing 3% or more, by weight, materials finer than 0.02 mm; and d) a potential for the ponding of surface water. The conditions associated with a low frost hazard potential include: a) a water table greater than 6 m below the pavement surface; b) low natural moisture content in the frost zone; c) embankment surfaces more than 1 – 2 m above the adjacent grades that provides some insulation and weight to resist heave; and e) treatment for frost issue.

### **Consideration of Subgrade Frost Heave into Pavement Design**

The U.S. FHWA Policy Guide [9] for pavement design states that a uniform, stiff, moisture and frost resistant foundation is the most important aspect of pavement structural design. The guide recommended stabilizing the upper 300-600 mm of fine-grained clay or silt subgrade soils and using 200 to 600 mm thick non-frost susceptible granular subbase layer where frost penetration occurs. It also recommended using a free draining base layer.

TAC PADMG [1] specified the desirable heights of the top of subgrade above the high water level (HWL) as a function of the subgrade soil type. Where the maximum water level is known, the subgrade top should be at a minimum of 0.6 m for clean gravel/rock and 1.2 m for silt/clay above the maximum water level.

MTO [7] recommends utilizing uniform subgrade soils, using reduced subgrade soil strength during the spring thaw period, preventing water from entering into the area by providing adequate side ditches and/or sub-drains and using paved shoulders and/or edge sub-drains to prevent surface water from entering into the subgrade. Other treatments includes soil replacement to prevent differential frost heaves and using expanded extruded polystyrene.

For new construction and reconstruction projects, Manitoba increased the calculated structural number by 25% if a soil was classified as a frost susceptible. There was no frost heave severity classification in use. The minimum increase in granular base/sub-base thickness was 100 mm. Geotextiles were used and is still in use as a separator between subgrade and subbase, and as a reinforcement for frost susceptible subgrade soils. However, for rehabilitation designs using the Benkelman Beam Rebound (BBR) deflection method, no adjustment for subgrade soils frost heave was applied. In fact, no soil survey was done for rehabilitation designs using the BBR deflection method. This appears to be justified because BBR data were collected during the spring thawing period when the pavements are at its weakest condition. As Manitoba discontinued the use of BBR deflection method in 2016, a need for a new approach to consider frost heave in the rehabilitation design/analysis has also arose.

The engineering and design manual developed by the U.S. Army Corps of Engineers [10] provided two alternative approaches to consider subgrade soils frost heave into pavement designs. They are: a) limited

subgrade frost penetration method; and b) reduced subgrade strength method. The first method is meant to control frost heave and associated pavement deterioration by providing an adequate thickness of pavement structure (surface, base and subbase). This will limit the penetration of frost into the frost-susceptible subgrade. The manual also states that the prevention of frost penetration into the subgrade soils is uneconomical in almost all scenarios and unnecessary. The manual recommends that the limited subgrade soil frost penetration method should be only used in locations where less thickness than the reduced subgrade strength method is required.

The reduced subgrade strength method determines the thickness of pavement structures that are required to carry the design traffic loads considering occasional subgrade weakening due to frost melting. This method is applicable to a road section where the subgrade soil composition and moisture exposure are uniform throughout the section. This approach is not suitable where differential heaving due to frost penetration and differential settlement due to frost melting occur [10]. As mentioned earlier, such ideal condition (uniform frost heave and settlement) rarely exists.

The use of reduced subgrade strength for subgrade melting and weakening is a standard practice for pavement design in cold climate where spring thaw weakening is a normal phenomenon for all pavements and subgrade soils. For example, Manitoba uses a low subgrade modulus value for spring season, which is equivalent to 50% of the summer/fall modulus values, to determine the effective (annual representative) subgrade modulus. The pavement structure based on this reduced subgrade strength is adequate to carry traffic loading during the critical spring thawing period. This method may not be adequate to address the differential frost heaving and thawing, and the associated road surface roughness or serviceability loss. The reason is that any additional subgrade weakening due to frost melting, which is specific to the frost susceptible soils, may not be fully accounted for by the general 50% reduction for spring condition. MI has started a research project to investigate/analyze this issue. For now, Manitoba is in need of a cost-effective approach to limit frost penetration where subgrade soil is frost susceptible and conditions for frost heave exist or manage the frost heave issue differently.

FHWA Reference Manual NHI-05-037 [8] recommended several alternatives to improve subgrade when frost-susceptible soils are encountered that include the following:

1. Remove the frost susceptible soils that are in Groups F3 and F4 (see Figure 1) and replace with non-frost susceptible material(s) up to the depth of frost penetration;
2. Place non-frost susceptible materials of a thickness that prevent freezing of frost susceptible soils that are in Groups F2, F3 and F4 (see Figure 1);
3. Remove isolated pockets of frost-susceptible soils to eliminate abrupt changes in subgrade conditions;
4. Stabilize the frost-susceptible soil by: a) mechanically removing fines or treating with cementitious materials, b) reducing/preventing moisture migration, or c) altering the freezing point of the soil moisture; and
5. Increase the pavement thickness to account for the subgrade strength reduction during the spring-thawing period for frost-susceptible soils that are in Groups F1, F2 and F3 (see Figure 1).

AASHTO 1993 Guide [3] states that it is feasible to control frost heave by increasing thickness of pavement structure with non-frost susceptible materials. The most acceptable practice is to remove the frost susceptible materials and replace with non-frost susceptible materials to a depth of one-half of the frost

depth. If frost mitigation measure has been taken, the serviceability loss due to frost heave should be ignored in pavement design. However, AASHTO 1993 Guide [3] does not recommend increasing pavement thickness for frost heave issue. The guide recommends a pavement design for reduced service life considering the serviceability losses due to frost heave and the traffic loading. If frost heave is to be considered in the design, in terms of serviceability loss due to frost, AASHTO 1993 [3] recommends an approach similar to stage construction. However, the AASHTO 1993 Guide [3] approach can be used to increase pavement structure for a higher service life of the initial pavement considering the estimated loss due to the frost heave and the loss available for traffic loading. In MI's judgement, this approach is more appropriate for a cost effective pavement design and construction in Manitoba. The general practice is frost heave management, not frost heave protection i.e., no increase in pavement thickness, with some exceptions. This is termed as a modified stage construction approach for Manitoba with an initial pavement minimum service life of 10 years.

### **Comparison of Frost Susceptibility Classification for Typical Subgrade Soils**

Table 2 presents several examples of subgrade soils including their gradations, soil index properties, and AASHTO and Unified soil classifications. The last four columns show the frost susceptibility classification according to AASHTO 1993 [3], MI [2], TAC [1] and MTO [7] guides or manuals for each soil samples. It shows that soil characterization as frost susceptible and classification into frost susceptibility (severity) groups vary widely among the referenced four guides/manuals. Field observation in Manitoba showed a mixed results where some subgrade soils were classified as frost susceptible, as per MI Pavement Design Manual [2], but no frost heaving were experienced. This could be related to erroneous frost susceptibility identification/classification system that was in use in Manitoba and/or related to the absence of moisture exposure. Alternatively, severe frost heaves were experienced in some areas, but subgrade soils were classified as non-frost susceptible as per MI pavement design manual. Furthermore, Manitoba's frost susceptibility characterization does not distinguish among frost heave severity levels (frost heave rates) for various soil classes and compositions. These observations, together with a demand for a cost-effective pavement structures, triggered this initiative to review MI's frost susceptibility classification.

A limited investigation of actual field experience of frost issues including its severity level and testing/analysis of subgrade soils showed that soil properties and actual frost heave conditions more closely match with the frost severity classification presented in the AASHTO 1993 guide [3]. MI started a research project to verify the frost severity classification, frost heave rates and corresponding field experience.

### **New Frost Susceptibility Classification for Pavement Design/Analysis in Manitoba**

Considering the opportunity to classify soils into different frost susceptibility levels for varying level of adjustments/ options for pavement structures and a closer match with the field experience of frost issues, MI adopted the classification system presented in the AASHTO 1993 guide [3] as an interim basis. In AASHTO 1993 guide [3], subgrade soils frost susceptibility classification is based on the unified soil classification, percentage by weight of particles finer than 0.02 mm and the frost heave rate. Figure 1 shows a chart for estimating the frost heave rate for roadbed soils [10]. This chart has been adopted to estimate the frost heave rates for the subgrade soils that are found in Manitoba.

The S1 and S2 soil groups include gravelly (GW, GP, GW-GM and GP-GM) and sandy (SW, SP, SW-SM and SP-SM) soils, respectively. The frost-susceptibility of these soils are considered to be very low to medium. These materials are considered to be suitable as subbase as they will exhibit less frost heave and higher strength after freeze-thaw cycles than similar subgrade soils in F1 or F2 groups.

Table 2. Comparison of subgrade soils frost susceptibility classification.

Soil Type	% Passing							Soil Properties		Soil Classification			Frost Susceptibility					
	Sieve Size	4.75mm	2.00mm	0.425mm	0.075mm	0.05mm	0.02mm	0.005mm	LL, %	PL, %	AASHTO	ASTM/Unified Soil Classification		GI	AASHTO	MI	TAC	MTO
Fine Sand	74.0	71.0	68.0	25.0	23.0	18.0	11.0	NP	NP	A-2-4	SM	Silty Sand with Gravel		0	High	X	X	Low
Silty Sand	98.0	97.0	93.0	29.0	24.0	19.0	9.0	NP	NP	A-2-4	SM	Silty Sand		0	High	FS	X	Low
Gravel	51.0	36.0	21.0	8.0	7.0	6.0	3.0	NP	NP	A-1-a	GW-GM	Well Graded Gravel with Silt and Sand		0	Medium	X	X	Low
Fine Sand	100.0	100.0	100.0	11.0	10.0	7.5	4.0	NP	NP	A-3	SP-SM	Poorly Graded Sand with Silt		0	High	X	X	Low
Sandy Silt	91.8	89.0	83.0	55.0	50.0	37.0	18.0	16	2	A-4	ML	Sandy Silt		4	High	FS	B	Low
Sandy Silt	91.8	89.0	83.0	56.0	51.0	39.5	22.0	16	6	A-4	CL-ML	Sandy Silty Clay		4	Medium	FS	X	Low
Silt	98.0	97.0	95.0	66.0	60.0	48.0	30.0	17	2	A-4	ML	Sandy Silt		6	Very High	X	X	Low
Silt	100.0	100.0	100.0	99.0	89.0	66.0	32.0	NP	NP	A-4	ML	Silt		8	Very High	X	FS	High
Silt	98.0	97.0	96.0	75.0	66.0	48.0	19.0	16	2	A-4	ML	Silt with Sand		8	Very High	FS	FS	High
Sandy Clay	97.0	96.0	93.0	60.0	56.0	47.0	33.0	34	18	A-6	CL	Sandy Lean Clay		8	Medium	X	X	Low
Low Plastic Clay	99.0	99.0	98.0	67.0	63.0	53.0	38.0	37	20	A-6	CL	Sandy Lean Clay		10	High	X	X	Low
Low Plastic Clay	100.0	100.0	100.0	93.0	84.0	64.0	33.0	32	14	A-6	CL	Lean Clay		10	High	X	FS	High
Low Plastic Clay	98.5	98.0	98.0	75.0	71.0	63.0	52.0	38	20	A-6	CL	Lean Clay with Sand		12	Very High	X	X	Low
Low Plastic Clay	100.0	100.0	100.0	94.0	86.0	69.0	42.0	36	19	A-6	CL	Lean Clay		12	High	X	B	Moderate
Low Plastic Clay	100.0	100.0	100.0	93.0	86.0	70.0	46.0	43	24	A-7-6	CL	Lean Clay		14	High	X	B	Moderate
High Plastic Clay	100.0	100.0	100.0	80.0	74.0	62.0	43.0	45	23	A-7-6	CL	Lean Clay with Sand		14	Very High	X	X	Low
High Plastic Clay	97.0	96.0	95.0	85.0	81.0	74.0	62.0	76	49	A-7-6	CH	Fat Clay with Sand		20	Very Low	X	X	Low
High Plastic Clay	100.0	100.0	100.0	98.0	96.0	92.0	86.0	81	49	A-7-5	CH	Fat Clay		20	Negligible	X	X	Low

*LL = Liquid Limit;*

*PI = Plastic Limit;*

*NP = Non-Plastic;*

*AASHTO = American Association of State Highway and Transportation Officials;*

*ASTM = American Society of Testing and Materials;*

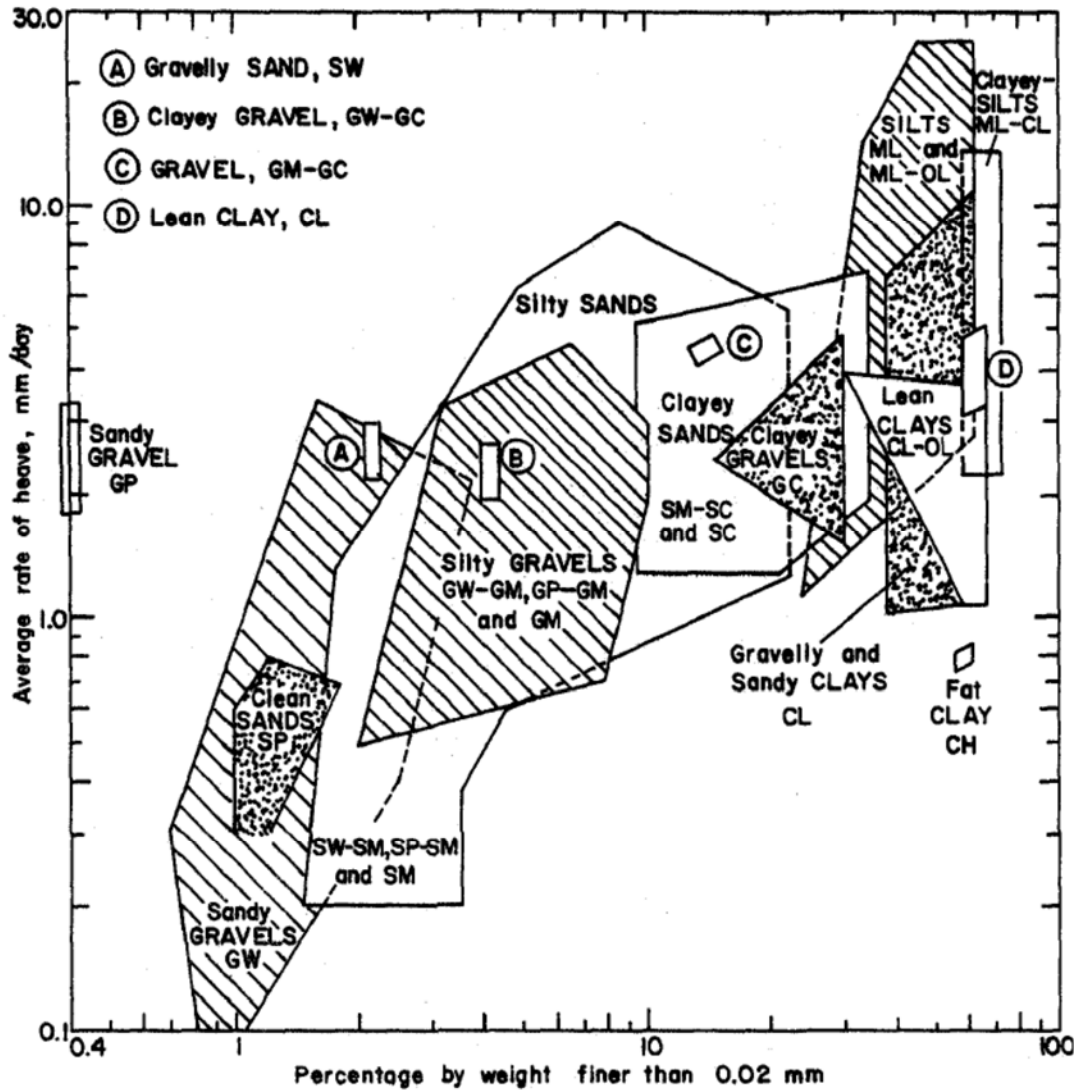
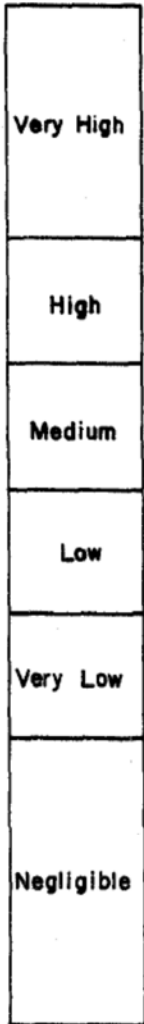
*TAC = Transportation Association of Canada;*

*MI = Manitoba Infrastructure;*

*MTO = Ministry of Transportation Ontario.*



**Frost Susceptibility Classifications**



**E. Summary Envelopes**

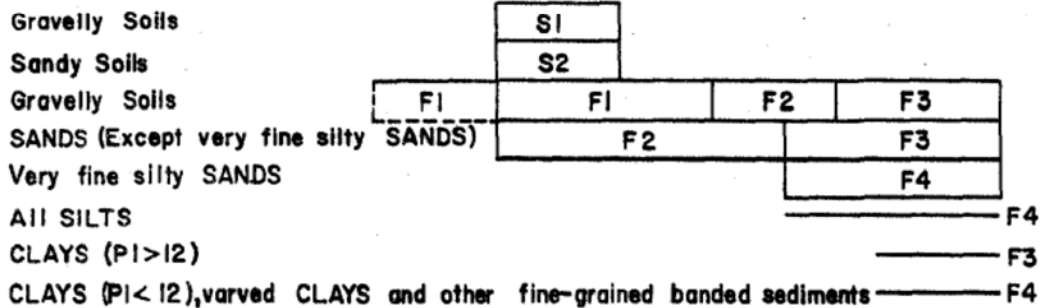


Figure 1. Subgrade soil frost classification and frost heave rate [10].

Subgrade soils in Manitoba are generally fine sand to silt and clay materials. Manitoba now does not make any adjustment to pavement design nor does an analysis for frost susceptibility of gravelly and sandy soils containing less than 6% particles, by weight, finer than 0.02 mm. The corresponding soil classes are GW, GP, GW-GM, GP-GM, SW, SP, SW-SM and SP-SM. This approach is acceptable to Manitoba because these materials are considered to be suitable as subbase. Table 3 presents the details of F1 to F4 frost groups, excluding the above-mentioned soils classes that are suitable as subbase, for which frost heave analysis are conducted. Furthermore, since the chart (Figure 1 above) presented in the AASHTO 1993 Guide [3] was developed based on frost heave measured in the laboratory on remolded soil samples, Manitoba's local field observation of frost severity is being used in the actual design and analysis.

Table 3. Frost design soil classification [10].

Frost Group	Types of Soils	% finer than 0.02 mm by weight	Typical Classification (Unified System)
F1	Gravelly soils	6 – 10	GW-GM, GP-GM, GM
F2	Gravelly soils	10 – 20	GW-GM, GP-GM, GM
	Sands	6 – 15	SW-SM, SP-SM, SM
F3	Gravelly soils	>20	GM, GC
	Sands, except very fine silty sands	>15	SM, SC
	Clays with PI > 12	-	CL, CH
F4	All silts	-	ML, MH
	Very fine silty sands	>15	SM
	Clays with PI < 12	-	CL, CL-ML

*PI = plasticity index*

## Pavement Design and Analysis

### Design Serviceability Loss due to Frost Heave

The design environmental serviceability loss due to frost heave is estimated based on potential maximum serviceability loss due to frost, frost heave probability, frost heave rate and time (service life). AASHTO 1993 Guide [3] provided a chart for estimating the design environmental serviceability loss due to frost heave. For pavement design/analysis purposes, MI uses the following equation, provided in the AASHTO 1993 Guide, Appendix G [3], to estimate the serviceability loss due to frost heave.

$$\Delta PSI_{FH} = 0.01 * \Delta PSI_{MAX} * P_F * [1 - e^{-(0.02 * \varphi * t)}] \quad (1)$$

Where,

$\Delta PSI_{FH}$  = Design environmental serviceability loss due to frost heave;

$\Delta PSI_{MAX}$  = Potential maximum serviceability loss due to frost heave;

$P_F$  = Frost heave probability;

$\varphi$  = Frost heave rate, mm/day; and

$t$  = Design (service) life or performance period.

**Potential Maximum Serviceability Loss Due to Frost Heave:** The potential maximum serviceability loss due to frost heave is a function of subgrade materials drainage quality and frost depth. The subgrade soils in Manitoba are generally fine graded materials with poor drainage quality. The depth of frost penetration into the subgrade varies with location. The following guideline (Table 4) has been developed for determining the frost penetration into subgrade based on observed frost depths in different climate zones (Figure 2) in Manitoba and correlation with the freezing indices. The potential maximum serviceability loss due to frost heave can be estimated from graph provided in the AASHTO 1993 Guide, Figure G.7 Graph for Estimating Maximum Serviceability Loss Due to Frost Heave [3] knowing the frost penetration depth and subgrade drainage quality. Figure 3 and associated equation have been developed (based on AASHTO 1993) for estimating the potential maximum serviceability loss due to frost heave for Manitoba subgrade soils that has poor drainage quality.

Table 4. Maximum frost depth and frost penetration into the subgrade

Climate Zone	Total Frost Depth	Frost Penetration into Subgrade
Zone 1 (South of The Pas)	2.0 m	Total frost depth minus the estimated thickness of pavement structure.
Zone 2 (The Pas Area)	2.2 m	
Zone 3 (Thompson Area)	2.5 m	

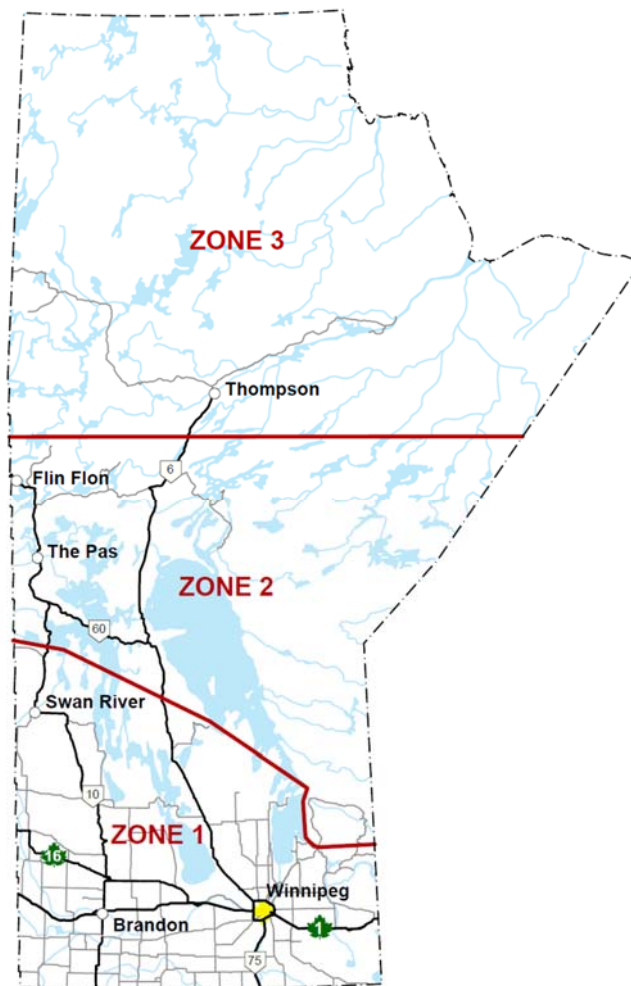


Figure 2. Climate zones in Manitoba.

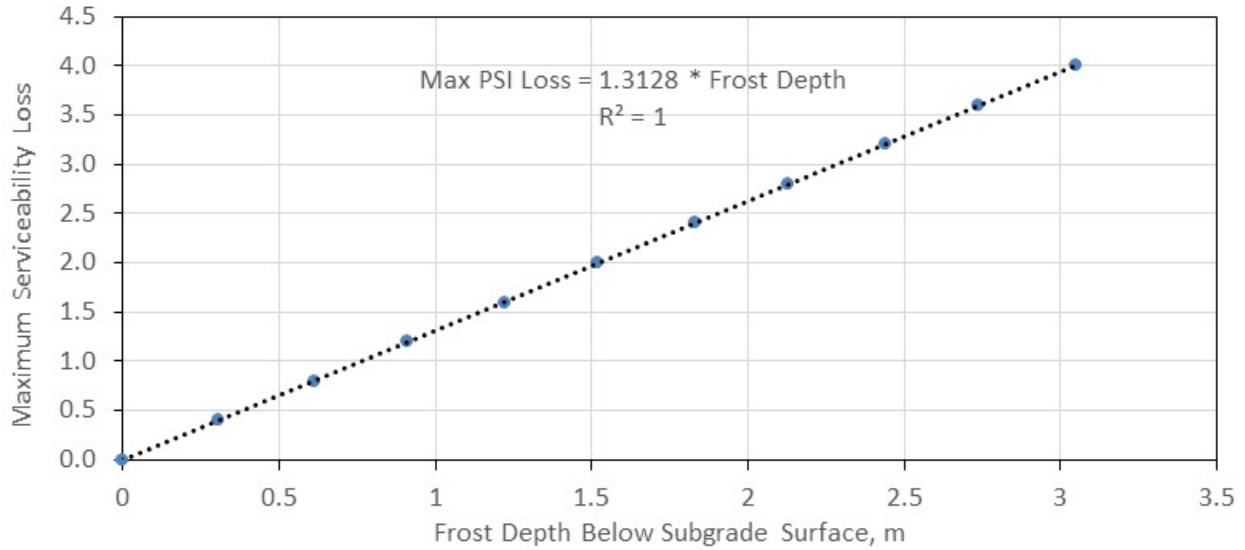


Figure 3. Maximum serviceability loss due to frost heave, redeveloped from AASHTO 1993 [3].

**Frost Heave Probability:** By simple definition, frost heave probability is an estimate of percentage of the project area that is affected by frost heave. However, as per AASHTO 1993 Guide [3], it depends on several factors that include: a) the extent of frost susceptible soils, b) moisture availability, c) pavement drainage quality, d) number of freeze-thaw cycles in a year, and e) the depth of frost penetration. There is no clear-cut method to estimate the frost heave probability and designers should rely heavily on local experience. Therefore, Manitoba has developed its own guideline to estimate the frost heave probability as a function of locally observed extent of frost heave and its time frequency of occurrence. These two factors take into account all the factors stated in AASHTO 1993 Guide [3]. The frost heave probability is calculated as:

$$P_F = Ext_{FH} * Freq_{FH} \quad (2)$$

Where,

$P_F$  = Frost heave probability in percentage;

$Ext_{FH}$  = Extent of frost heaving; and

$Freq_{FH}$  = Time frequency factor for frost heave occurrence.

The extent of frost heave is estimated based on the average distance internal of the frost heave along a road section that experiences frost heaving issue. The extent is estimated based on the local criteria shown in Table 5.

Table 5. Estimation of the frost heave extent in Manitoba.

Frost Heave Interval, m	>250	150-250	100-150	75-100	50-75	30-50	20-30	10-20	<10
$Ext_{FH}$ , %	0*	30	40	50	60	70	80	90	100

\*Take localized measure, no frost heave consideration in design/analysis.

The time frequency factor for frost heave occurrence is a function of time interval between successive annual frost heaving experiences within the functional or design life of a pavement, which is estimated as follows (Table 6):

Table 6. Estimation of time frequency factor for frost heave occurrence in Manitoba.

Occurrence	Always (Every year)	Frequent (Every 2-3 years)	Sometimes (Every 4-5 years)	Rare or Never
Frequency	1.0	0.50	0.25	0

From Tables 5 and 6, if the average distance interval between frost heaves is 75 to 100 m and frost heave occurs every 2-3 years, the probability of frost heave occurrence is estimated as  $50 \times 0.5 = 25\%$ .

**Frost Heave Rate:** Frost heave rate refers to the rate of increase in road roughness, in millimetre per day, which is associated with frost heaving of subgrade soils. The frost heave rate depends on soil classification, percentage of particles by weight finer than 0.02 mm, subgrade soils frost group, soil frost severity classification and plasticity index as shown in Figure 1. Estimating the frost heave rate using this chart is somewhat subjective and complex due to overlapping blocks of each frost group, frost heave rate and soil classes. To ease or simplify the design/analysis process for frost susceptible soils, Manitoba has developed a table for the selection of reasonable frost heave rate for different soils. As mentioned earlier, gravelly and sandy soils, containing less than 6% particles by weight finer than 0.02 mm, which are considered suitable as subbase materials, are excluded from frost heave consideration in pavement design/analysis.

The frost susceptibility classification is selected based on field observation of the severity of frost heave and settlement due to frost melting. Table 7 presents the guideline for frost severity classification, which is in use in Manitoba to estimate the frost heave severity. However, Manitoba has started a research/investigation project to determine the prospect of developing a quantitative guideline.

Table 7. Manitoba frost susceptibility (severity) classification.

Frost Susceptibility (Severity)	Field Description
Very severe	Very high frost heave and settlement issues causing extreme concern and most (very frequent) complains.
Severe	High frost heave and settlement issues causing major concern and frequent complains.
Medium	Moderate frost heave and settlement issues causing significant concern and occasional complains.
Low	Noticeable frost heave and settlement issues causing some concern and considerable complains.
Negligible or very Low	No noticeable or minor frost heave and settlement issues. Causing no considerable concern and no or rare complains.

The selected frost heave rates for different soils are shown in Table 8. The very low frost heave issues with a frost heave rate of 1.0 mm/day or less for existing pavements is expected to be eliminated with the construction of overlays (additional thickness) or reconstruction and, therefore they are ignored in pavement design and analysis.

Table 8. Selected frost heave rates for different subgrade soils in Manitoba [3, 10].

Frost Group	Unified Soils Classification	% finer than 0.02 mm by weight	Frost Susceptibility Classification	Average Frost Heave Rate, mm/day
F1/F2	GW-GM, GP-GM and GM	6 – 20	Low	1.5
			Medium	3.0
			High	4.5
F2	SW-SM, SP-SM, SM	6 – 15	Low	1.5
			Medium	3.0
			High	6.0
			Very High	9.0
F3	GM, GC, GM-GC	>20	Low	1.8
			Medium	3.0
			High	4.5
	SM-SC, SC	>15	Low	1.8
			Medium	3.0
			High	5.5
	CL, CH (PI ≥ 12)	-	Low	1.5
			Medium	3.0
			High	6.0
			Very High	9.0
F4	ML, MH	-	Low	2.0
			Medium	4.0
		<30	High	8.0
			Very High	15.0
	>30	Very High	20.0	
		SM	>15	Low
	Medium			3.0
	High			6.0
	CL, CL-ML (PI<12)	-	Low	1.5
			Medium	3.0
High			6.0	
Very High			10.0	

**Performance Period:** Performance period is the service life of a pavement structure considering serviceability loss due to traffic loading and environmental serviceability loss due to the frost heave.

### **Design and Analysis Steps**

AASHTO 1993 Guide [3] does not recommend an increase in pavement structure thickness to account for the serviceability loss due to frost heave because the increased structural number (SN) has relatively small effect on minimizing the frost heave (and/or swelling). The maximum SN is recommended to be the one which is derived based on traffic loading without considering the frost heave (and/or swelling). The guide provides a trial and error approach to estimate the service life considering above-mentioned two

serviceability losses such that service life based on traffic loading is not less than service life based on frost heave criteria. The steps are as follows [3]:

- 1) Select the standard/usual performance period (service life) for the initial pavement following the local design practice. Determine the required (design) SN considering no frost heave issue using the applicable traffic loading, subgrade  $M_{R_v}$ , reliability and total serviceability loss.
- 2) Select a reduced performance period (less than the initially selected performance period) as a trial performance period which is expected under the frost heave condition. A lower performance period is expected for greater loss (based on frost severity and probability) due to the frost heave.
- 3) Calculate the serviceability loss ( $\Delta PSI$ ) due to the frost heave using Equation 1.
- 4) Calculate the available serviceability loss due to the traffic loading ( $\Delta PSI_{TR}$ ) as total serviceability loss ( $\Delta PSI$ ) minus the serviceability loss due to the frost heave ( $\Delta PSI_{FH}$ ).
- 5) Reversely calculate the allowable ESALs for the available serviceability loss due to the traffic loading ( $\Delta PSI_{TR}$ ) based on the design SN which was calculated in step 1.
- 6) Calculate the performance period that corresponds to the allowable ESALs which was determined in step 5.
- 7) Compare the trial performance period selected in step 2 with the calculated performance period in step 6. Repeat steps 2 to 6 until the difference between the trial and calculated service periods is less than one year. Use the average of the trial and calculated performance periods from preceding step as new trial performance period in each successive trial(s). Once the difference is less than one year, it is considered that convergence is reached. Take the average of the trial and calculated years as the expected performance period under frost heave and traffic conditions.

It should be noted that the actual reliability for pavement performance would be higher than the one that is used for both of the initial pavement and overlay because an overlay is expected when pavement actually reaches the terminal serviceability under both traffic loading and frost heave conditions.

### ***Pavement Thickness Adjustment and Frost Management***

As indicated earlier, AASHTO 1993 Guide [3] does not recommend increasing the SN for frost problem than the one required for the usual service life for traffic loadings only. However, the selected pavement structure (i.e., SN) under the frost heave condition is, in fact, higher than the one which is required for the traffic loading alone for the expected (reduced) performance period under both frost heaving and traffic loading conditions. This implies that this approach may be used to increase the pavement thickness for a higher performance period than the one obtained following the approach presented earlier. This will allow for balancing the service life between expected performance period (as calculated using the earlier described approach) and the time when an overlay may be required or planned to place. Furthermore, the earlier described approach may result in a performance period less than five years when the frost severity and probability are high. Although removal of frost susceptible soils and replacement with non-frost susceptible materials or constructing a thick embankment using non-frost susceptible materials are options, they are not considered economically feasible in Manitoba, other than isolated locations. Manitoba has adopted the following practices to manage the frost heave issues including a reasonable timing of the expected overlay, instead of costly treatment or control.

1. General Practice: Determine the required pavement structure for 20 years performance period without considering the serviceability loss due to frost heave. Determine the expected performance period of this structure under combined traffic loading and frost heave condition, as outlined earlier. If the expected performance period is less than 10 years, increase the thickness to obtain a minimum performance period of 10 years for the initial pavement.
2. New construction and reconstruction: Increase the granular layer thickness up to a maximum of 300 mm, if practical, and determine the initial pavement performance period (should be 20 years or less) considering both traffic loading and frost heave.
3. Rehabilitation: Increase the thickness, if required, to ensure a minimum performance period of 10 years. Increase the bituminous thickness to match the desired lift thickness (depends on maximum size of the aggregates), if required, and determine the performance period considering both traffic loading and frost heave.
4. Isolated locations: Remove frost susceptible soils and replace with non-frost susceptible granular fill or subbase.

### **Impact of Changes: Design and Analysis Examples**

Four design examples are presented in Tables 9 through 12 from recent projects in Manitoba. In the first example (Table 9), the subgrade soils frost susceptibility is classified as medium with a 50% frost probability. The options are to build 570 mm structure (Trials 1 and 2) and manage the frost heave issue (e.g., place an overlay) when it is experienced. Pavement is expected to provide acceptable performance for 11.8 years if frost heave occurs as expected. Otherwise, pavement will perform >11.8 to 20 years, depending on the actual frost heave related deterioration. The other option is to build 750 mm structure (Trial 3) i.e., 180 mm additional subbase. This will certainly reduce the frost heave issue but may not be a complete remedy depending on the future exposure to frost conditions or may not be required at all if frost heave does not occur as expected. Therefore, the recommended structure is 150 mm bituminous, 150 mm granular A base and 300 mm C base to save some money on the initial pavement structure. An overlay will be placed in year 13 if pavement serviceability reaches to an unacceptable level. However, Regions can decide to go with 750 mm structure as shown for Trial 3, if they prefer because of the opportunity to add more structure now and the past frost heave experience. In the past (Past Practice Trial), the calculated total SN required for 20 years performance period without considering serviceability loss due to the frost heave was increased by 25% to determine the adjusted total SN to account for serviceability loss due to the frost heave.

For the area of PTH 15 (Example 2, Table 10) with a high frost susceptibility of subgrade soils, the estimated frost heave rate is 6 mm/day. The required SN (Trial 3) for a 20- year service life is 124.9 mm considering serviceability loss due to the frost heave and traffic. Then 525 mm C base will be required instead of 270 mm (Trial 1) which is required without considering the serviceability loss due to the frost heave. For the SN (Trial 1) estimated for a 20-year service life without considering the serviceability loss due to the frost, the expected performance period of the initial pavement is 9.2 years if frost occurs as expected (Trial 2). To achieve a 10-year performance from the initial pavement, the required thickness of C base is 300 mm. The recommended thickness is 150 mm bituminous, 200 mm A base 300 mm C base (total 800 mm).



Table 9. Design example #1: Design for pavement reconstruction (medium frost susceptibility).

Highway = PTH 15 (Region 1) Truck traffic volume = two-way 270 truck/day Subgrade soils = silty clay soil with some organics; $M_R = 35.5$ MPa; Frost group = F3/CL Frost heave severity = medium; frost probability = 50% Average rate of frost heave = 3.0 mm/day. Initial serviceability = 4.3 and terminal serviceability = 2.4				
Attributes	Trial 1	Trial 2	Trail 3	Past Practice
Frost penetration below subgrade surface, m	2.0	2.0	1.8	N/A
Maximum potential serviceability loss	2.6	2.6	2.4	N/A
Total serviceability loss	1.9	1.9	1.9	1.9
Initial pavement performance period i.e., time, years	20	11.8	20	N/A
Serviceability loss due to frost heave	0.00	0.67	0.83	N/A
Serviceability loss due to traffic	1.90	1.23	1.07	N/A
Calculated structural number, mm	100.3	100.3	117.1	125.3
Allowable ESALs, million	1.273	0.671	1.273	1.273
Estimated performance period, years	20	11.8	20	20
Bituminous Thickness, mm	150	150	150	150
Granular A base thickness, mm	150	150	150	150
Granular C base thickness, mm	270	270	450	550
Pavement total thickness, mm	570	570	750	850

Table 10. Design example #2: Design for pavement reconstruction (high frost susceptibility).

Highway = PTH 15 (Region 1) Truck traffic volume = two-way 270 truck/day Subgrade soils = silty clay soil with some organics; $M_R = 35.5$ MPa; Frost group = F3/CL Frost heave severity = high; frost probability = 50% Average rate of frost heave = 6.0 mm/day. Initial serviceability = 4.3 and terminal serviceability = 2.4				
Attributes	Trial 1	Trial 2	Trail 3	Past Practice
Frost penetration below subgrade surface, m	2.0	2.0	1.7	N/A
Maximum potential serviceability loss	2.6	2.6	2.2	N/A
Total serviceability loss	1.9	1.9	1.9	1.9
Initial pavement performance period i.e., time, years	20	9.2	20	N/A
Serviceability loss due to frost heave	0.00	0.88	1.01	N/A
Serviceability loss due to traffic	1.90	1.23	0.89	N/A
Calculated structural number, mm	100.3	100.7	124.9	125.3
Allowable ESALs, million	1.273	0.505	1.273	1.273
Estimated performance period, years	20	9.2	20	20
Bituminous Thickness, mm	150	150	150	150
Granular A base thickness, mm	150	150	150	150
Granular C base thickness, mm	270	270	525	550
Pavement total thickness, mm	570	570	825	850

In the third example (Table 11), the options are to place 180 mm bituminous overlay (Trials 1 and 2) and manage frost heave issue when it is experienced. Pavement is expected to provide an acceptable performance for 10.8 years if frost heave occurs as expected. Otherwise, pavement will perform >10.8 years to 20 years, depending on the actually observed frost heave related deterioration. Additional 50 mm (i.e., total 230 mm) bituminous (Trial 3) can be placed to extend the initial pavement service life to 20 years under frost heave conditions. However, this may not be very effective to remedy the frost heave issue or may not be required if frost heave does not occur as expected. The recommended option is to place 180 mm bituminous over the pulverized asphalt base to save some money. An overlay will be placed at year 12, if pavement serviceability reaches to an unacceptable level.

Table 11. Design example #3: Design for pavement rehabilitation (medium frost susceptibility).

Highway = PTH 83 (Region 3)				
Truck traffic volume = two-way 160 truck/day				
Subgrade soils = silty clay soil with some organics; $M_R = 29.7$ MPa; Frost group = F3/CL				
Frost heave severity = medium; frost probability = 50%				
Average rate of frost heave = 3.0 mm/day.				
Existing pavement = 110 mm bituminous and 250 mm granular base.				
Initial serviceability = 4.4 and terminal serviceability = 2.5				
Attributes	Trial 1	Trial 2	Trail 3	Past Practice
Frost penetration below subgrade surface, m	2.0	2.0	1.9	N/A
Maximum potential serviceability loss	2.6	2.6	2.5	N/A
Total serviceability loss	1.9	1.9	1.9	1.9
Initial pavement performance period i.e., time, years	20	10.8	20	N/A
Serviceability loss due to frost heave	0.00	0.63	0.87	N/A
Serviceability loss due to traffic	1.9	1.27	1.03	N/A
Calculated overlay structural number, mm	106.1	106.2	126.6	132.7
Calculated overlay structural number, mm	50.1	50.2	85.1	76.6
Allowable ESALs, million	1.233	0.648	1.233	1.233
Estimated performance period, years	20	10.8	20	20
Overlay bituminous thickness, mm	180	180	230	245
Pulverized asphalt base thickness, mm	110	110	110	110
Existing granular base thickness, mm	250	250	250	250
Pavement total thickness, mm	540	540	590	605

In the 4<sup>th</sup> example presented in Table 12, the options are to place 140 mm bituminous overlay (Trials 1 and 2) and manage frost heave issue when experienced. Pavement is expected to provide acceptable performance for 10.4 years if frost heave occurs as expected. Otherwise, pavement will perform >10.8 to 20 years, depending on the actually experienced frost heave related deterioration. Additional 85 mm (i.e., total 225 mm) bituminous (Trial 3) can be placed to extend the initial pavement service life to 20 years under frost heave conditions. This may not be fully effective to eliminate the frost heave issue or may not be required if frost heave damage does not occur as expected. The recommended option is to place 150 mm bituminous overlay on the milled surface to limit fatigue cracking to an acceptable level which is the required minimum bituminous thickness based on layer elastic analysis. Pavement will perform 12 years, if frost heave occurs as expected.

As mentioned earlier, in the past practice scenarios, the increase in SN from the base case (Trail 1, in examples 1-4) was 25% for all cases. Using the new practice (Trial 3, in examples 1-4), the percent increase

in SN from the base case (Trial 1) to achieve 20 years performance of the initial pavements varied based on frost severity levels and subgrade soil classifications.

Table 12. Design example #4: Design for pavement rehabilitation (high frost susceptibility).

Highway = PTH 59 (Region 1)				
Truck traffic volume = two-way 200 truck/day				
Subgrade soils = Fine sand and sandy silt ; $M_R = 84.0$ MPa; Frost group = F4/ML				
Frost heave severity = high; frost probability = 50%				
Average rate of frost heave = 8.0 mm/day.				
Existing pavement = AST (chip seal) and 100 mm granular base.				
Initial serviceability = 4.3 and terminal serviceability = 2.5				
Attributes	Trial 1	Trial 2	Trail 3	Past Practice
Frost penetration below subgrade surface, m	2.25	2.25	2.25	N/A
Maximum potential serviceability loss	3.0	3.0	3.0	N/A
Total serviceability loss	1.8	1.8	1.8	1.8
Initial pavement performance period i.e., time, years	20	10.4	20	N/A
Serviceability loss due to frost heave	0.00	1.20	1.42	N/A
Serviceability loss due to traffic	1.80	0.60	0.38	N/A
Calculated total structural number, mm	70.9	70.8	105.4	88.6
Calculated overlay structural number, mm	50.6	50.5	85.1	68.3
Allowable ESALs, million	0.997	0.476	0.997	0.997
Estimated performance period, years	20	10.4	20	20
Overlay bituminous thickness, mm	140	140	225	185
Mill and relay AST- net thickness, mm	0	0	0	0
Existing granular base thickness, mm	100	100	100	100
Pavement total thickness, mm	240	240	325	285

### Risks and Benefits of Design Changes

The risks associated with the changes in design include:

1. Insufficient pavement thickness to withstand the traffic loading during the spring melting period if an increased thaw weakening occurs in areas with frost susceptible soils than other areas with non-frost susceptible soils.
2. May generally require an earlier intervention than that used to be in the past due to expected lower performance period of the initial pavements.

Benefits with design changes include:

1. Informed decision when selecting a pavement structure option.
2. Pavements may not experience the same frost heave issues in the future as experienced in the past due to changes in weather, moisture exposure and construction materials, and the increased thickness. The higher initial construction costs associated with the thicker pavements with adjustment for frost heave issues may not be well utilized or value added, in such cases.
3. Option is available to construct thicker pavements based on the actual needs, rather than blanket 25% increase only based on soil classification, to extend the service life of the initial pavements.
4. There is always opportunity to go back and place another overlay, if/when needed.

5. Use of technically more sound and consistent approach.
6. Any cost savings on initial pavements can be utilized on other projects. This will help to improve the network health.

### Concluding Remarks

The available guidelines and study results for characterizing soils as frost susceptible including their severity levels and recommended measures vary widely. Based on the local experience, Manitoba's past approaches to characterize subgrade soils as frost susceptible and a fixed 25% increase in pavement structures for subgrade soils classified as frost susceptible also did not appear to be applicable to many cases. The AASHTO 1993 design guide approach is found to more suitable for Manitoba conditions. Accordingly, Manitoba has completed a major change to its design practice for frost susceptible subgrade soils. This led to a more cost-effective and reasonable pavement structure design and management. Further data collection, analysis, verification and update are in progress.

### References

1. Transportation Association of Canada. 2012. *"Pavement Asset Design and Management Guide"*. Ottawa, Ontario.
2. Manitoba Department of Infrastructure and Transportation. 2004. *"Pavement Design Manual"*. Winnipeg, Manitoba.
3. AASHTO. 1993. *"AASHTO Guide for Design of Pavement Structure."* American Association of State Highway and Transportation Officials, Washington, D.C.
4. Linell, K.A., Hennion, F.B. and Lobacy, E.F. 1963. "Corps of Engineers' Pavement Design in Areas of Seasonal Frost". In *Highway Research Record 33*, pp 76-133.
5. Kaplan, C.W. 1974. *"A Laboratory Freezing Test to Determine the Relative Frost Susceptibility of Soils."* Report TR 250. Cold Regions Research and Engineering Laboratory (CRREL). U.S. Army Corps of Engineers.
6. Chamberlain, E.J. 1982. *"Identification and Classification of Frost-Susceptible Soils."* Paper presented at the spring convention of the American Society of Civil Engineers, Reston, VA.
7. Ministry of Transportation Ontario (MTO), 2013. *"Pavement Design and Rehabilitation Manual – Second Edition"*. Materials Engineering and Research Office, Downsview, ON.
8. Christopher, B. R., Schwartz, C., and Boudreau, R. 2006. *"Geotechnical Aspects of Pavements"*. Publication No. FHWA NHI-05-037 (Reference Manual FHWA NHI's Course No. 132040), National Highway Institute, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.
9. US FHWA 1999. *"Federal-aid Policy Guide Non-Regulatory Supplement NS 23 CFR."* Part 626, April 8, 1999, Transmittal 25, Order 1321.1C. Washington D.C.
10. U.S. Army Corps of Engineers. 1984. *Engineering and Design, Pavement Criteria for Seasonal Frost Conditions, Mobilization Construction*. Engineer Manual No. 1110-3-138. Department of the Army, Washington, D.C. 20314.
11. NCHRP 1-37A. 2004. *"Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures."* Final Report, National Cooperative Highway Research Program NCHRP Project 1-37A, Transportation Research Board, National Research Council, Washington, D.C.