Overview of Specifications for Unbound Granular Base Materials in Selected Canadian Provinces and Neighbouring States

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Abstract

Specifications for unbound granular base materials vary among transportation agencies based on the availability of materials, climatic conditions, and function. Specifications aim to provide durable materials that meet design requirements and achieve the target design life. This paper compares Manitoba Infrastructure and Transportation (MIT) specifications for unbound granular base materials with the specifications developed by selected Canadian provinces and neighbouring States. This work is part of a research project to evaluate the effect of base material gradation on performance and, if required, update current MIT specifications for unbound granular base materials. The comparison showed that MIT specifications allow a higher percentage of fines (particles passing sieve No. 200). MIT's maximum particle size (19 mm) is generally smaller than the maximum particle size in other specifications (25 to 37.5 mm).

The effect of the base material gradation and fines content on the stiffness and stability is being evaluated in the laboratory. Results of laboratory tests will be used to update current specifications, if required, and develop performance-based parameters for pavement design using the Mechanistic-Empirical Pavement Design Guide (MEPDG).

Introduction

Unbound granular materials are used in flexible and rigid pavement construction to serve as a working platform on compressible subgrade, structural layer to provide load distribution, drainage layer, and fill material [1,2]. The effective use of locally-available material and targeting long service life are important aspects for design and construction of sustainable and cost-effective pavements [2].

Physical and chemical properties of unbound granular materials determine the suitability of aggregate for different uses in pavement construction and govern aggregates durability and soundness [2]. Saeed et al. specified several laboratory tests that measure properties related to the performance of unbound granular base materials [3]. The measured properties include particle size distribution, moisture content-density relationship, Atterberg limits, toughness and abrasion resistance, soundness, elastic modulus, and shear strength.

Laboratory characterization of the performance of unbound granular materials is an essential component of the Mechanistic-Empirical Pavement Design Guide (MEPDG) [4]. Full characterization of the performance of unbound materials includes evaluation of the elastic and plastic behavior of the material. Resilient modulus of unbound materials is a measure of the elastic modulus of the material at a given stress state. Resilient modulus of unbound materials is a primary input in MEPDG for design of pavement structures. Rutting is a major flexible pavement distress that leads to uneven riding surface and a significant reduction in pavement serviceability and safety level. Pavements experience rutting failure when the pavement materials undergo an excessive amount of permanent, or plastic, deformation. Laboratory assessment of permanent deformation is an essential performance parameter for unbound granular materials.

Gradation is one of the main factors that influence the elastic and plastic behavior of unbound granular materials [5]. For the same aggregate source, base materials with coarser gradations have higher resilient modulus than finer gradations [5,6,7]. In addition to mechanical properties, gradation has an influence on the permeability and frost susceptibility of unbound base materials [8].

Type (plastic or nonplastic) and amount of fines passing No. 200 sieve in base materials influence the elastic and plastic response of base materials under traffic loading [2]. Several studies evaluated the optimum fines content that achieve maximum strength and increase permanent deformation resistance. Based on laboratory testing of local materials, Gandara et al. found that base materials with fines content ranging from 5% to 10% have higher resilient modulus and are less susceptible to moisture variation [9]. Gandara et al. recommended a fines content limit of 10% for better performance of base materials [9]. For dense-graded crushed limestone base material, Tutumluer and Seyhan recommended the optimum fines content to be 7% [10]. The optimum fines content varies based on aggregate source and gradation.

The performance of granular base materials depends on the interaction between aggregate source, gradation, and fines content. In addition to these parameters, there are other factors that have significant effect on base material performance. These factors are plasticity of fines, degree of compaction, moisture content, and aggregate shape, texture and angularity [2].

This paper summarize the results of environmental scan of current granular base material specifications of transportation agencies in Manitoba and Neighbouring Provinces and US States. This work is part of a project that aims to evaluate the performance parameters of unbound highway materials under dynamic loading. Results from the laboratory investigation and environmental scan will be used to update Manitoba Infrastructure and Transportation (MIT) specifications, if required, for granular materials and to develop reliable design input values for these materials.

Environmental Scan of Base Material Specifications

The purpose of this investigation was to compare the surveyed specifications of neighbouring jurisdictions to the specifications employed by MIT and decide whether gradations outside the current specifications should be considered for evaluation in Manitoba. The specifications investigated were for granular materials used for:

- Granular or aggregate base material
- Dense-graded base
- Base material for use directly under flexible pavement
- Unbound base material

The base course specifications of provinces across Canada were investigates. States located in the upper Midwest and West regions of the United States were also of interest due to the similar climatic condition to that of Manitoba as well as the availability of standard specifications from each state's department of transportation. The regions investigated and the specification names are shown in Figure 1 and Table 1, respectively.

Table 1: The Regions Investigated and Specification Names

Province / State	Specification Name
Ontario	Class A Granular Base Course
British Columbia	25mm (Top Layer) Well Graded Base Course
Saskatchewan	Type 31 (Top Layer), Base Course
Alberta	Class 25 Granular Base Course
Illinois	Aggregate Base Course CA 10
South Dakota	Aggregate Base Course
North Dakota	Aggregate Base
Nebraska	Crushed Rock for Base Course
Kansas	Aggregate Base AB-1

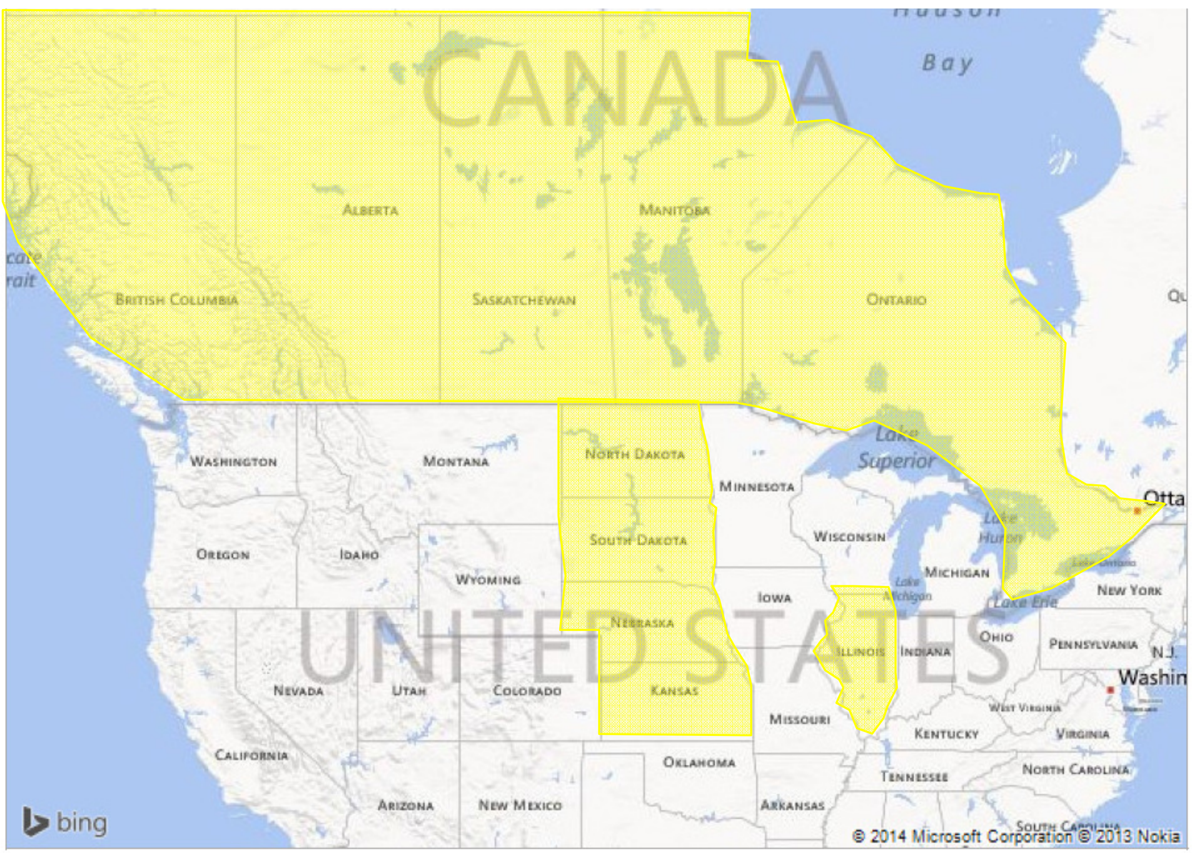

Figure 1: Map of Provinces and States Covered by the Environmental Scan

Gradation and Fines Content Limits

MIT specify two gradation limits for dense-graded base course materials: Class A gravel base and Class A limestone base. MIT gradation limits for Class A gravel base and Class A limestone base are listed in Table 2. Table 3 shows gradation limits for granular bas materials according to the specifications of the jurisdictions investigated. Figure 2 compares MIT gradation limits to the gradation limits of other Canadian provinces. Figure 3 compares MIT gradation limits to the gradation limits of neighbouring States. The gradation limits employed by MIT allow finer gradation than the average gradation limits of all other jurisdictions investigated. This is true for both the upper and lower gradation limits.

Figures 4 shows the maximum aggregate size based on the specifications of MIT and the jurisdictions investigated. The maximum particle size according to MIT specifications is 16.0 mm for Class A gravel base and 19.0 mm for Class A Limestone base, while the other jurisdictions have a maximum particle size ranging from 25.0 mm to 37.5 mm.

Fines content is one of the factor that has a significant influence on the elastic and plastic response of granular base materials under traffic loading. Fines are required in dense-graded granular base material but to a certain limit to maintain higher resilient modulus and higher resistance to permanent deformation [2]. Figures 5 shows the limits for the allowed fines content based on the specifications of MIT and the jurisdictions investigated. MIT specifications allow a higher fines content than any other jurisdiction investigated.

Results of Resilient Modulus Tests

Resilient modulus (M_R) tests were conducted on three samples of base materials collected from ongoing construction projects as a pilot basis. The three base materials are: limestone, gravel, and granite. Resilient modulus tests were conducted for each base material at two levels of moisture contents and two replicates were tested at each moisture content. Results of M_R tests showed that the resilient modulus of the tested materials is significantly lower than MEPDG default values and other M_R values reported in the literature [4,6,7]. The MEPDG default values were developed for material gradations having D_{60} (particle size at 60% passing) ranging from 12.6 to 18.2 mm, while D_{60} for the tested base materials ranged from 5.0 to 6.5 mm [4]. The finer gradation of the tested base materials explains the difference between the laboratory values of M_R and the MEPDG default values. Table 4 shows the range of M_R values recommended in the MEPDG and the lab values for the tested base materials. The lab values of M_R correspond to confining pressure (σ_3) = 35 kPa and cyclic stress (σ_1- σ_3) = 103 kPa.

Table 2: Gradation Limits for Aggregate Base Course in Manitoba

Particle Size (mm)	50	37.5	25	19	16	9.5	4.75	2.00	0.425	0.075
Gravel, Granite	100-100	100-100	100-100	100-100	80-100	63-87	40-70	25-55	15-30	8-15
Limestone	100-100	100-100	100-100	100-100	92-96	68-85	35-70	26-56	10-30	8-17

Table 3: Gradation Limits for Aggregate Base Course in the Surveyed Jurisdictions

Particle Size (mm)	50	37.5	25	19	16	9.5	4.75	2.00	0.425	0.075
Ontario	100-100	100-100	97-100	85-100	76-95	50-73	35-55	23-46	8-27	2-8
British Columbia	100-100	100-100	100-100	80-100	73-96	50-85	35-70	24-49	15-35	0-5
Saskatchewan	100-100	100-100	90-96	80-91	74-88	58-79	39-68	26-47	12-23	6-11
Alberta	100-100	96-99	70-94	61-88	55-85	43-73	31-61	22-49	10-29	2-10
Illinois	100-100	100-100	100-100	90-100	80-98	58-85	40-60	24-51	11-33	5-13
South Dakota	100-100	100-100	100-100	80-100	75-96	62-84	46-70	32-51	13-28	3-12
North Dakota	100-100	100-100	100-100	90-100	83-96	63-85	35-70	27-58	14-35	4-10
Nebraska	100-100	100-100	79-97	65-95	58-89	36-70	24-52	10-30	5-21	0-10
Kansas	100-100	90-100	72-97	60-95	56-92	43-80	25-65	14-44	5-22	2-10
Average	100-100	98-100	90-98	77-97	70-93	51-79	35-63	22-47	10-28	3-10

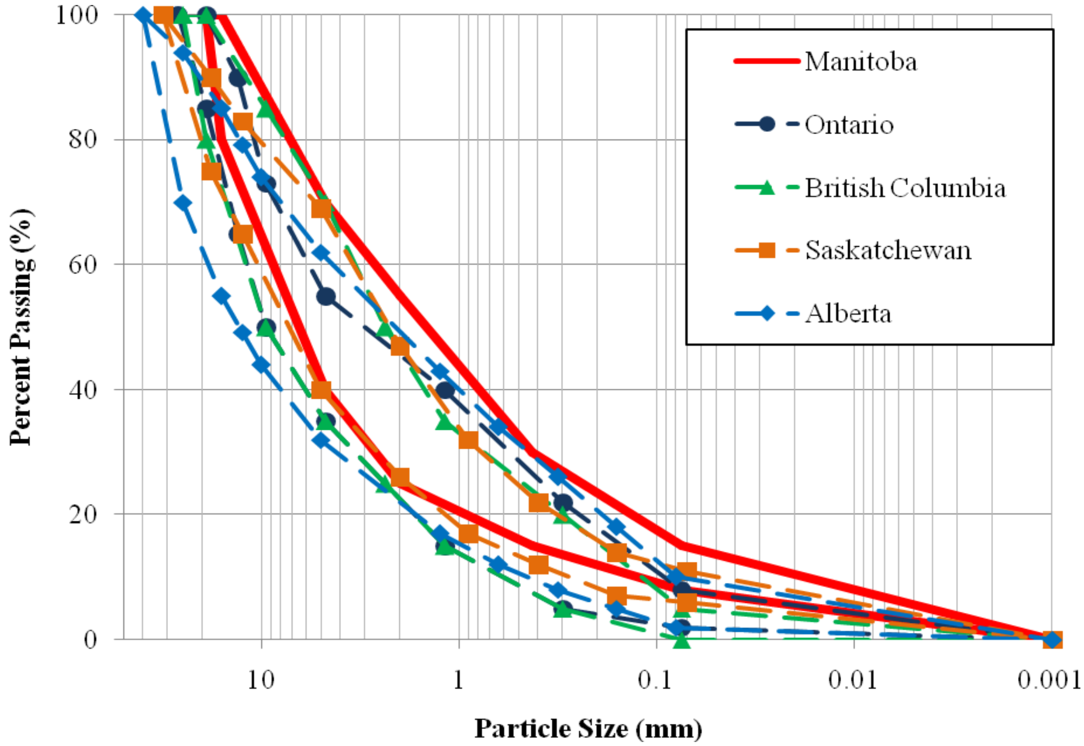

Figure 2: Gradation Limits for Aggregate Base Course: MIT vs. Surveyed Canadian Jurisdictions

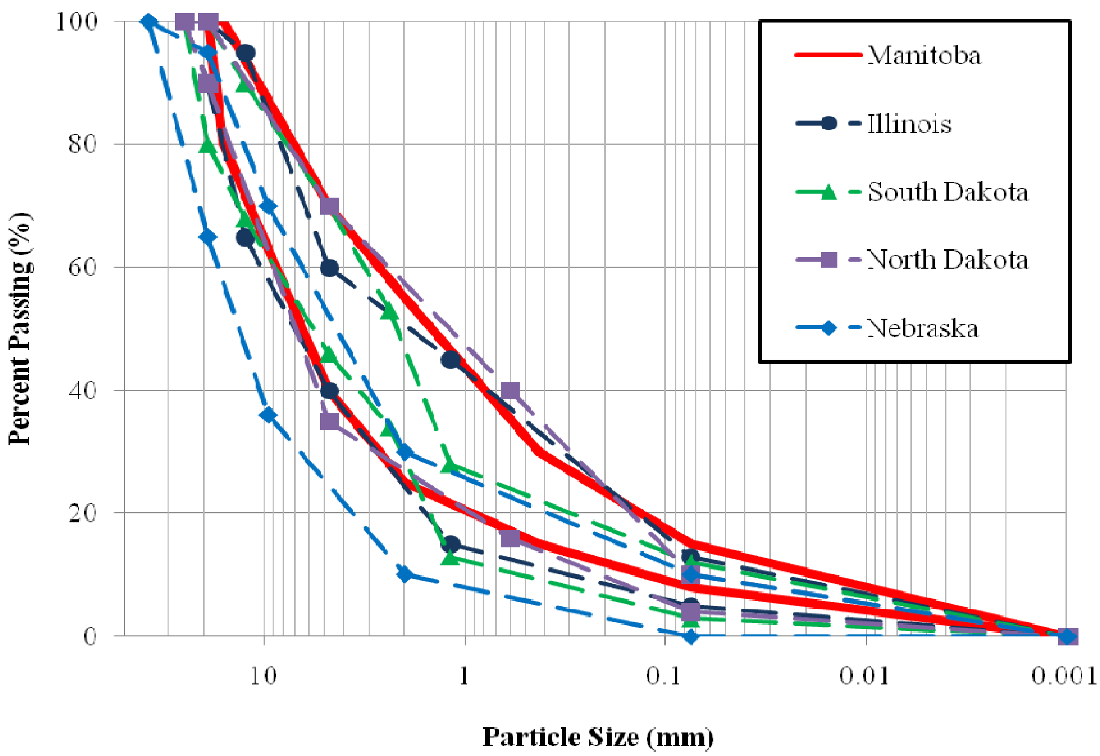

Figure 3: Gradation Limits for Aggregate Base Course: MIT vs. Surveyed US Jurisdictions

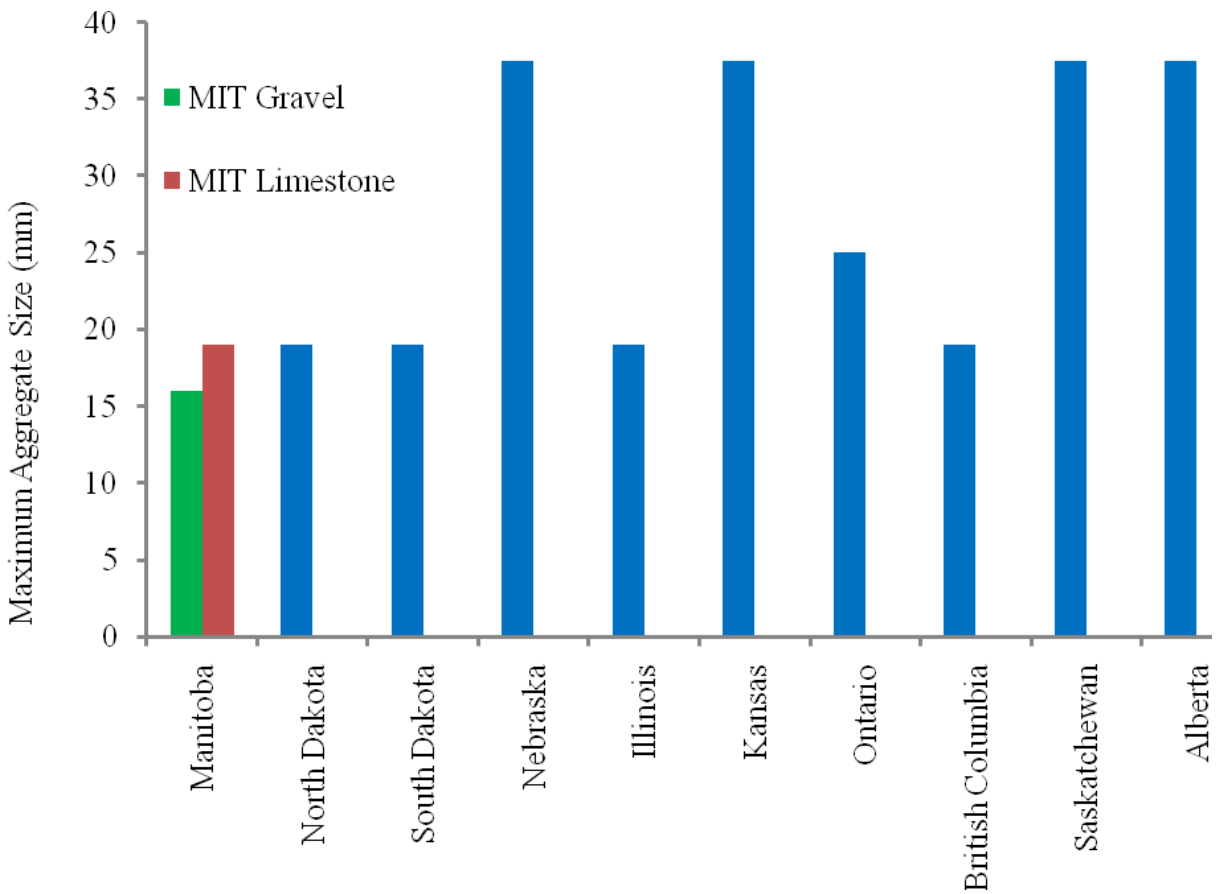

Figure 4: Maximum Aggregate Size by Jurisdiction

Table 5 provides a comparison between the M_R values for base materials obtained from the M_R tests and the M_R values reported in the literature [6,7]. The gradation of the tested base materials was finer than the gradation of other materials reported in the literature. Results showed that M_R and permanent deformation of the tested base materials is sensitive to moisture content variation.

Testing Program to Evaluate the Influence of Gradation and Fines Content on Base Material Performance

A laboratory testing program has been developed to investigate the influence of gradation and fines content on the elastic and plastic performance of granular base materials. The testing program included evaluation of resilient modulus and permanent deformation resistance for granular base material having different gradations and fines contents.

Three material samples were collected by MIT to represent three types of material: Class A limestone base, Class A gravel base, and Class A granite base. The materials were sieved into individual particle sizes. For limestone and gravel materials, the individual particle sizes were

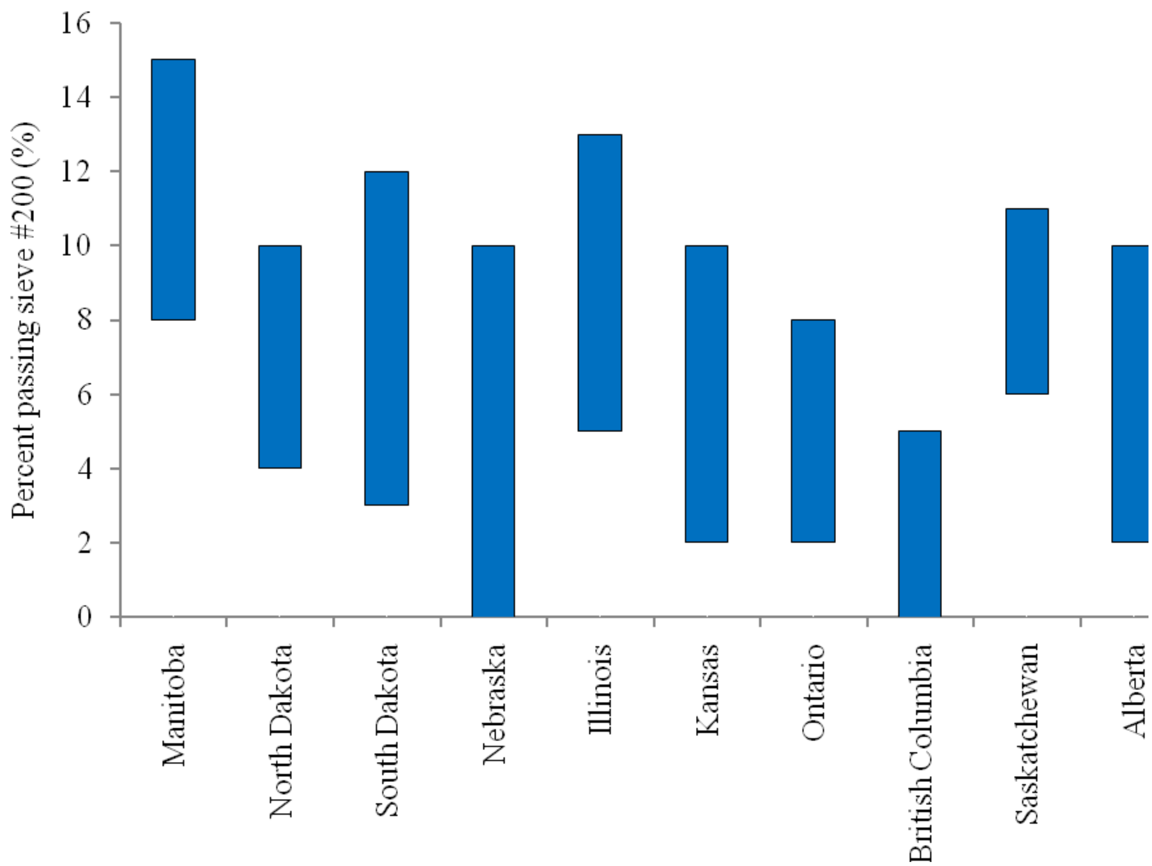

Figure 5: Limits for the Allowable Fines Content by Jurisdiction

Table 4: Typical M_R Values for the Tested Base Materials and MEPDG Default Values

Base Material Type	Fines Content (%)	Optimum M.C. (%)	M.C (%)	Lab M_R (MPa)	MEPDG Range (MPa) [a]	Ratio of Lab M_R to MEPDG default value (%)
Limestone	9.5	10.8	7.9	211.5	265.4 – 289.6	55 - 60
			10.1	158.1		
Granite	10.5	7.4	5.3	169.1	265.4 – 289.6	49 - 53
			7.3	141.3 [b]		
Gravel	10.5	8.5	6.2	156.9	265.4 – 289.6	40 - 44
			8.7	116.4 [b]		

[a] Values recommended in the MEPDG represent M_R values at optimum moisture content and maximum dry density
[b] Permanent strain exceeded 5%

Table 5: Comparison between the Lab M_R Values and Values Reported in the Literature for Louisiana and Texas Base Materials

Material Type	Location	Nominal Maximum Size (mm)	D_{60} (mm)	Optimum M.C. (%)	Dry Density (kg/m^3)	M_R (MPa)
Granite	Manitoba	16.0	6.5	7.4	2249	141
	Texas	37.5	16.0	5.6	2353	334
Limestone	Manitoba	9.50	5.0	10.8	2124	158
	Louisiana	19.0	7.0	5.9	2243	190
	Louisiana	19.0	7.0	3.2	2019	246

combined into three different gradations. The three gradations had different fines content to approximately simulate the minimum and maximum allowable fines contents and a gradation with less fines than allowable, as per MIT specifications. For gravel base, the fines contents for the three gradations were 4%, 9% and 14.5% as shown in Figure 6. For limestone base, the fines contents for the three gradations were 4.5%, 10.5% and 16% as shown in Figure 7 . Grain size analysis was performed to ensure the quality control of the mixed samples. Each sample used for testing was mixed, bagged and stored separately to ensure a consistent gradation over all samples.

Grain size analysis, standard Proctor, and Atterberg Limits tests were conducted on the base material samples. Table 6 shows the maximum dry density and the optimum moisture content for the limestone and gravel base material samples.

Table 6: Properties of Limestone and Gravel Base Materials

Material type	Fines content (%)	Optimum moisture content (%)	Maximum dry density (Kg/m^3)
Class A Limestone	4.5	7.5	2202
	10.5	7.0	2277
	16.0	6.5	2305
Class A Gravel	4.0	7.9	2170
	9.0	7.0	2223
	14.5	8.3	2203

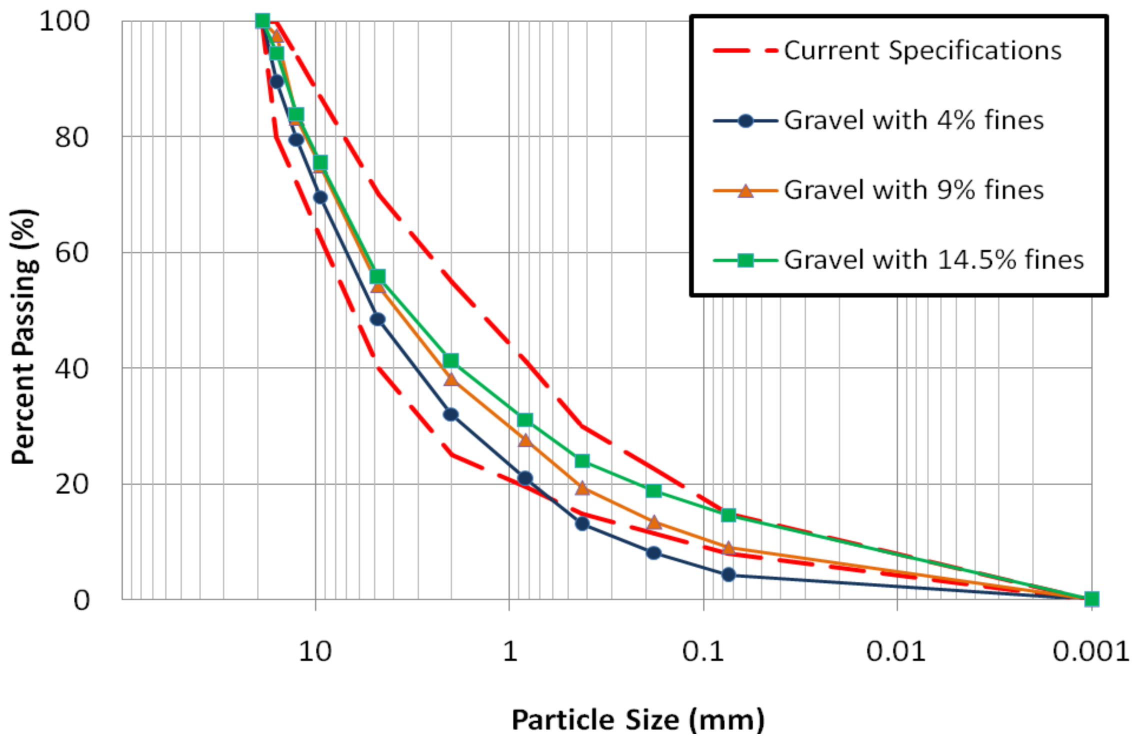

Figure 6: Particle Size Distribution for Gravel Base Material Samples

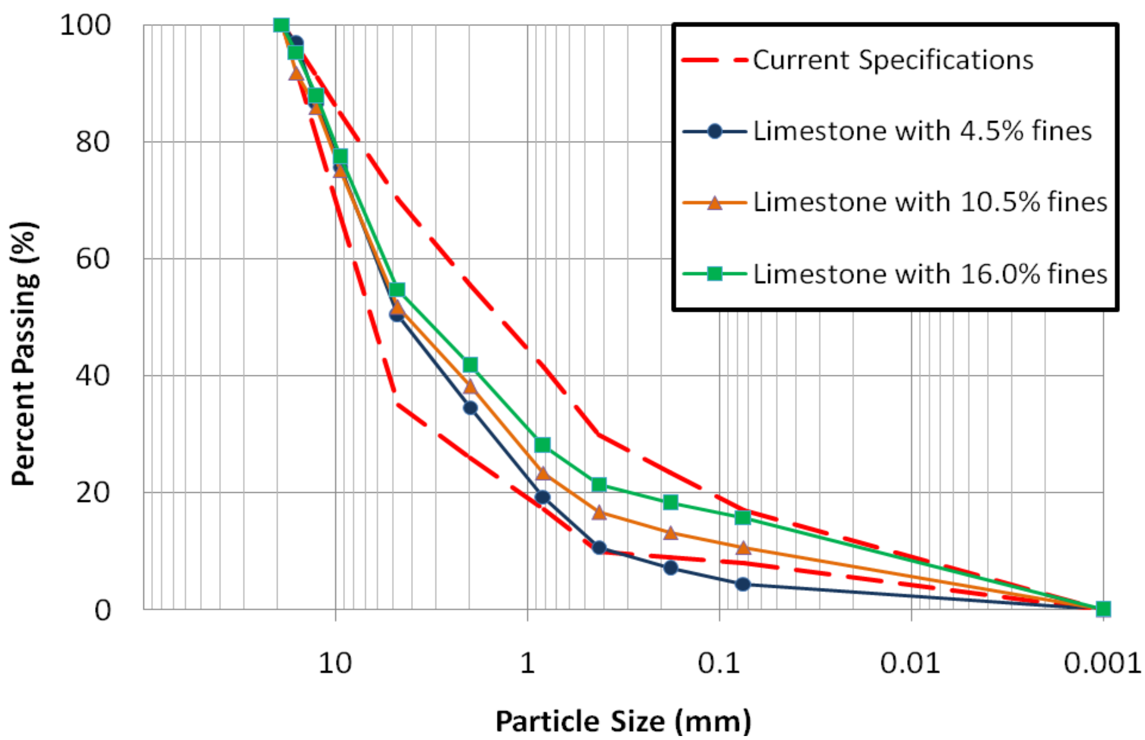

Figure 7: Particle Size Distribution for Limestone Base Material Samples

Resilient modulus and permanent deformation test specimen measures 101.6 mm in diameter and 203.2 mm in height. The test specimen is compacted in eight layers, 25.4 mm each, to reach the target moisture content. A vibration compactor, shown in Figure 8, is used to compact the specimens.

Resilient modulus tests are conducted according to the test protocol developed under NCHRP Project 1-28A [11]. After applying 1000 conditioning cycles, the test specimen is subjected to 30 loading sequences that represent different stress levels. The load pulse has a loading duration of 0.1 sec and a rest period of 0.9 sec. For each material sample, two moisture contents are selected to evaluate the sensitivity of resilient modulus to the variation in moisture content and dry density. The two moisture contents are on the dry side of the moisture-density curve and approximately at the optimum moisture content (OMC) according to standard Proctor test. Preparation and testing of samples at moisture contents above the OMC value was not feasible where sample failed during conditioning.

Permanent deformation for limestone and gravel base materials is evaluated under cyclic loading. Permanent deformation tests are conducted on same limestone and gravel base materials gradations used for resilient modulus tests (limestone with 4.5% fines, 10.5% fines, and 16.0% fines; gravel with 4.0% fines, 9.0% fines, and 14.5% fines). For each material sample, two moisture contents were selected to evaluate the sensitivity of permanent deformation to the variation in moisture content. The two moisture contents are 2.0% below the OMC and approximately at the OMC content according to standard Proctor test. The test specimen is subjected to 13,000 loading cycles with a constant stress level (cyclic stress and confining pressure). Each cycle consists of a load pulse with a loading duration of 0.1 sec and a rest period of 0.9 sec.

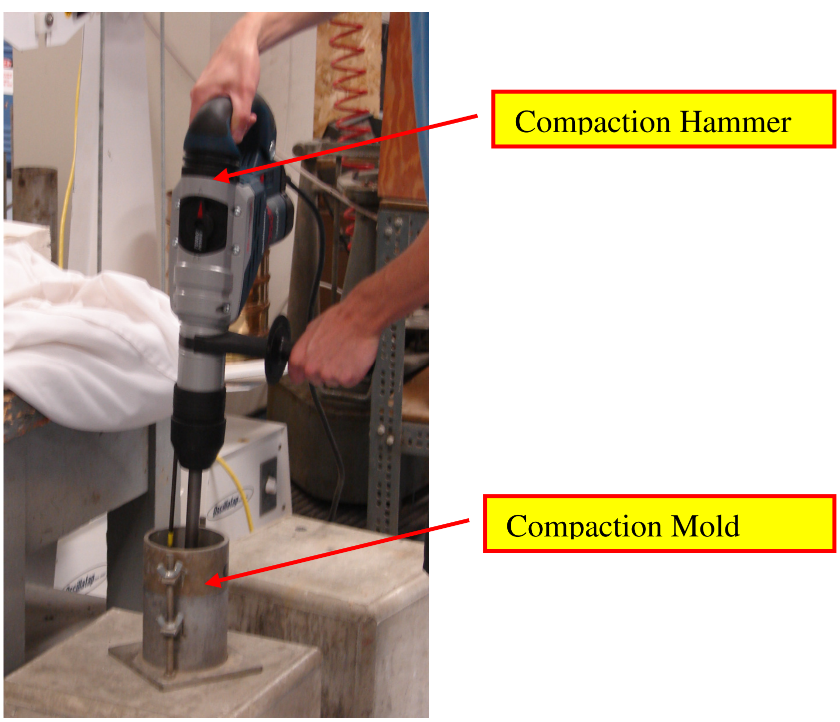

Figure 8: Vibratory Compaction (Compaction Time Varies Based on Material Type)

Summary and Findings

Physical and chemical properties of unbound granular materials determine the suitability of aggregate for different functionalities in pavement construction and govern aggregates durability and soundness. Fines content and gradation have a significant influence on the elastic and plastic response of granular base materials under traffic loading. Fines are required in dense-graded granular base material but to a certain limit to maintain higher resilient modulus and higher resistance to permanent deformation. Having performance-based specifications allow for better use of locally available granular base materials and provide a sustainable and long-lasting pavement structures.

Specifications of the allowable gradations for unbound granular base material from jurisdictions neighbouring Manitoba were investigated. The purpose of this investigation was to compare the surveyed specifications of neighbouring jurisdictions to the specifications employed by MIT and decide whether gradations outside the current specifications should be considered for evaluation in Manitoba. The gradation limits employed by MIT allow finer gradation than the average gradation limits of all other jurisdictions investigated. This is true for both the upper and lower gradation limits. The maximum particle size according to MIT specifications is 16.0 mm for Class A gravel base and 19.0 mm for Class A Limestone base, while the other jurisdictions have a maximum particle size ranging from 25.0 mm to 37.5 mm. MIT specifications allow a higher fines content than any other jurisdiction investigated.

Resilient modulus tests were conducted on three samples of base materials collected from ongoing construction projects. Results showed that the resilient modulus of the tested materials is significantly lower than MEPDG default values and other M_R values reported in the literature. The finer gradation of the tested base materials explains the difference between the laboratory values of M_R and the MEPDG default values. The current MIT specification for base materials allows 8% to 17% fines content. The fine gradation of the unbound base materials available in Manitoba and the high fines content in some materials provide a need for further laboratory testing to develop reliable design values and specifications for granular materials.

A laboratory testing program has been developed to investigate the influence of gradation and fines content on the elastic and plastic performance of granular base materials. The testing program included evaluation of resilient modulus and permanent deformation resistance for granular base material having different gradations and fines contents. Results of laboratory tests will be used to update current specifications, if required, and develop performance-based parameters for pavement design using the MEPDG.

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