Maintenance Guide for Unpaved Roads

A Selection Method for Dust Suppressants and Stabilizers

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CARRLo Project

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1. Introduction

1.1 Background

Local roads and resource access roads make up a significant proportion of Canada's overall road network. In Quebec, for example, they add up to approximately 90% of the provincial, municipal, and private road networks. Because of the fairly low traffic on most of these roads, paving is a somewhat impractical solution that is both complex and costly. Given these conditions, the application of a granular running surface appears to be the best solution.

1.2 The issue

There is an increasing concern regarding transportation safety and productivity, resulting in the need to maintain control of unpaved roads through surface stabilization and dust control. The generation of dust brings safety issues (lower visibility) and health problems (inhalation of various kinds of particles). Furthermore, the loss of granular material inevitably results in additional resurfacing costs.

1.3 Objectives

The purpose of the CARRLo[1] research project is to come up with adapted and economical solutions for the design, rehabilitation, and maintenance of road surfaces to ensure performance, safety, and durability in Canadian conditions. The primary objective is to propose categories of stabilizers and dust suppressants for specific conditions with reference to defined objectives. Furthermore, recommended products must also be environmentally friendly.

This guide attempts to help managers of unpaved roads select an effective dust suppressant or stabilizer and achieve an optimal application rate by taking mineralogy, gradation, operating conditions, weather conditions, and product cost into account.

1.4 Generalities

This guide is intended for road network managers who want to treat unpaved roads with dust suppressants or stabilizers. It will help them select products and optimal application rates based on the characteristics of the road, or road sections, selected for treatment.

[1] CARRLo is a French acronym adopted for the project that means « roads for local and resource access ».

Proper use of this guide requires a basic knowledge of the mineralogy and gradation of the material to be treated, and knowledge of the types of vehicles that will travel on the target road. Figure 1 provides a decision-support tool for selecting a product and an application rate as a function of various criteria that characterize the road network. The flowchart leads the manager through various steps with respect to the target road in order to facilitate the identification of one or more effective solutions.

From 2005 to 2010, as part of the CARRLo project, several laboratory and field trials were conducted. A comprehensive laboratory experimental program was carried out at Laval University. First, the effects of various stabilizers and dust suppressants on the mechanical properties of various materials were studied as part of a master's program (Pelletier, 2007). A second master's project, carried out to complete the experimental program, focused on the effect of particle size gradation and mineralogy on the performance of granular material treated with a stabilizer or a dust suppressant (Beaulieu, 2011). Finally, several field studies were conducted in collaboration with FPInnovations (Pierre et al., 2007; Poulin, 2010) in order to validate laboratory results.

Results from the laboratory and field trials were reported in several publications and presentations (Beaulieu et al., 2011, 2010a, 2010b, 2010c, 2009 and 2008; Pierre et al., 2009a, 2009b, 2009c, 2008a, 2008b, 2007a and 2007b; Poulin et al., 2010 and 2008).

The solutions presented in this guide form an in-depth study of the comprehensive experimental program and the various field trials carried out as part of the CARRLo project.

2. Review of dust suppressant and stabilizer categories

Before selecting a dust suppressant or a stabilizer, it is important to have some knowledge of the available categories of products. This section provides a brief overview of those categories.

Dust suppressants and stabilizers fall into several categories, including salts and hygroscopic materials, polymers, organic products, synthetic products, petroleum-based products, electrochemical products, as well as enzyme- and cement-based products. Each category is discussed separately, focusing on its stabilization mechanism, benefits, drawbacks, and limitations.

2.1 Salts and hygroscopic products

First, it should be noted that salts and hygroscopic products act mainly as dust suppressants, even though they are sometimes used as stabilizers. According to Tingle et al. (2007), salts can induce cation exchanges. This reduces the space between particles and results in flocculation. Furthermore, the recrystallization of salts establishes physical bonds between the particles, which increase the density of stabilized materials. Moreover, by absorbing humidity from the air, this type of product forms a water film around fine-material particles. Zilionieve et al. (2007) corroborate these findings and state that the percentage of fine particles present, which significantly impacts specific surface areas, must be taken into account when calculating the quantity of a product that must be added to granular material in order to reduce dust. This type of product is well known and has been tested and used many times over.

According to Monlux et al. (2007), a calcium chloride and magnesium chloride (hygroscopic products) treatment is effective and can lower maintenance costs by a factor of eight. Furthermore, product concentration depends mostly on the quantity of water present in the soil and weather conditions. In fact, the more humid the environment, the greater the quantity of product required.

Other conclusions were drawn from this product family, following the work of Bolander et al. (1999). This team found that air must have minimum moisture content for hygroscopic products to absorb moisture and for these products to be effective. Furthermore, calcium chloride was found to be more effective than magnesium chloride in high-humidity conditions and less effective during prolonged dry conditions. This product can also lead to the corrosion of certain metals and leach out in the presence of significant quantities of water. It should be noted, however, that the environmental impacts of these products have not yet been clearly identified.

Lastly, hygroscopic products and salts can enhance compaction and increase road surface density, mainly due to good water retention.

To summarize, hygroscopic products, calcium chloride in particular, are widely used and their effectiveness as a dust suppressant has long been established. This product category can even serve as a reference (i.e., control) to determine the effectiveness of non-traditional dust suppressants that have not been tested as extensively. Furthermore, in wet weather conditions, such as those that prevail in Quebec, hygroscopic products would appear to be appropriate. Their environmental impacts, however, have received little scrutiny.

2.2 Polymers

According to Tingle et al. (2007), polymers can be used as a dust suppressant and as a stabilizer. Polymer particles are linked by strong physical bonds. Polymer polar components can be strongly adsorbed to granular material particles. Ion exchange can even occur between the polymer and the material. According to Rushing et al. (2007), polymer emulsions significantly reduce dust during the first 30 days following their application, but their effectiveness drops after 80 days and even more after 200 days. This product forms bonds with the material, but these are broken up by heavy vehicular traffic. Once broken, they cannot be re-established. The only solution is to add additional quantities of polymer emulsion. However, Pierre et al. (2007) found in their study on two types of polymers, that polymers increased and maintained higher bearing capacity even following grading operations. Based on this study, one can conclude that stabilization increases the mechanical strength of granular materials. On the other hand, Visser (2007) maintains that polymers do not really increase surface stiffness; rather, they work mainly as surface sealants, reducing surface permeability, moisture sensitivity, and abrasion due to traffic.

Furthermore, Bolander et al. (1999) claim that surface-stiffness sufficient to alleviate dust formation is difficult to achieve with polymers. They also claim that the environmental impacts of polymers are virtually non-existent.

To summarize, polymers can be effective in certain conditions, but studies do not all reach the same conclusion with respect to the limitations of this product when applied to road surfaces. It remains to be seen whether they are suitable for Canadian resource access roads, in particular, for forest access roads, which are subject to industrial traffic.

2.3 Organic products

Organic products, used mainly as dust suppressants, essentially act as binders and ensure the agglomeration of superficial particles through weak physical bonds. This family of products includes, among others, lignosulfonates and woodwaste-based resins. These products coat material particles with a thin film that keeps them together. According to Zilionieve et al. (2007), lignosulfonates reduce dust by 70 to 80%. They point out, however, that soil moisture decreases during dry periods, which affects the amount of dust produced. Zilionieve et al. (2007) even argue that the number of dry days is the key parameter affecting the amount of dust generated by vehicular traffic. Furthermore, after seven days without rain, the impact of lignosulfonates on soil moisture becomes insignificant. The use of these products is not recommended under conditions where the percentage of fine particles falls below 8%. While data on woodwaste-based resins are limited, results show that their effectiveness and usage are similar to those of lignosulfonates. Finally, lignosulfonates increase surface stiffness and offer better performance when mixed with granular materials.

Bolander et al. (1999) focused mainly on lignosulfonates, vegetable oils, and tall oil derivatives, which are an important by-product of the pulping process for softwoods such as pine. Bollander and his colleagues show that with lignosulfonates, it is hard to maintain a stiff road surface with a high bearing capacity. Furthermore, the bonds generated by the lignosulfonates can be destroyed by heavy rain. Soils treated with lignosulfonates can become muddy in high-moisture conditions and brittle in dry conditions. Their main negative environmental impact comes from the possibility of an increased biological oxygen demand in water during significant leaching periods. Vegetable oils quickly become oxidized, which makes treated soils brittle. Tall oil derivatives are effective in increasing soil strength under dry conditions; however, the bonds created by these products are weak and can even be completely destroyed by long-term exposure to heavy rain. Very little is known about their environmental impact.

It should be noted that very little research has focused on polysaccharide-based products (another type of organic product). Results published to date indicate significant leaching of these products when exposed to heavy rain (Rushing et al., 2007).

To summarize, despite the variability of the results, organic products, mainly tall oil derivatives, hold some potential given the proximity of the resource (wood). Indeed, these products could generate significant transportation savings for dust suppression purposes on forest roads, near sawmills, and around pulp and paper mills.

2.4 Synthetic products

Synthetic products foster the agglomeration of fine surface particles by creating physical bonds between individual particles. They can work as dust suppressants or stabilizers, increase surface stiffness, as well as be effective during dry periods. They usually perform better when mixed into the soil rather than simply applied to the surface. According to Rushing et al. (2007), the granular arrangement of the surface material treated with synthetic products remains relatively constant in the short term, which provides for interesting results. However, road conditions may deteriorate after 80 days, resulting in the presence of loose material and dust.

In summary, there has been little research on this category of products, but it holds potential nonetheless. It would also be useful to determine whether the products of this family are suited to heavy traffic.

2.5 Petroleum-based products

Petroleum-based products used as a dust suppressant and a stabilizing agent bind surface material by adhesion and the formation of a thin surface film. According to Tingle et al. (2007), petroleum resins create physical bonds between particles, which explains their dust suppressant properties. Many research projects have focused on this type of product. According to Zilionieve et al. (2007), under dry conditions, the effectiveness of asphaltic emulsions, which agglomerate particles, does not seem to be affected. Furthermore, they state that compared to calcium chloride and calcium lignosulfonates, asphaltic emulsions are the most effective method of suppressing dust over the long term. However, these products call for in-depth studies to ensure compliance with environmental requirements before their application on unpaved roads.

Bennett et al. (1994) studied the effect of a tall-oil pitch emulsion on Canadian forest roads. During these trials, it was noted that insufficient quantities of fine particles can diminish the adhesiveness of particles to one another, whereas excessive quantities can result in excessive moisture retention, which can lead to other problems in freezing conditions. Moreover, road treatments must be applied for at least five years in order to generate profits, by comparison with an untreated road. Finally, this product can be effective during lengthy dry periods. However, given the impermeability of roads treated with this type of product, road design must ensure appropriate surface drainage.

Bolander et al. (1999) add that the resilience of granular materials treated with petroleum-based products can diminish under dry conditions. They also add that excessive quantities of fine particles combined with a high concentration of asphaltenes trigger the formation of a crust that can be broken up by traffic or under moist conditions. Furthermore, certain products may be toxic. With this in mind, Bolander et al. (1999) suggest an in-depth ecological impact investigation in parallel with the use of the products of this family. Finally, Marshall et al. (1984), as referenced in Bergeron (1992), have noted a reduction in the bearing capacity of roads treated with asphalt-based products.

To summarize, petroleum-based products have been used and found to be effective. However, it would be interesting to determine whether any reduction of the bearing capacity of granular material treated with petroleum-based products is due only to a product-curing problem. With this in mind, the addition of small quantities of a stabilizer, such as cement, could be an interesting option to compensate for the loss of bearing capacity during the asphalt curing period. In other respects, petroleum-based products can be controversial and in-depth studies are required to ensure that they are compliant with environmental standards.

2.6 Electrochemical products

Electrochemical products used as a dust suppressant or a stabilizer reduce soil moisture and increase soil stiffness. Their use does not create physical bonds between soil particles. Rather, their effectiveness is based on chemical reactions and is particularly effective on clay soils. According to Visser (2007), sulfonated oils are highly effective and increase the strength of such soils (high CBR values). Sulfonated oils are almost ineffective on other soil types. Tingle et al. (2007) corroborate this notion by concluding that stabilization through chemical reactions is preferred for clay and silty soils, whereas stabilization through physical bonds is recommended for soils containing mainly gravel and sand.

Moreover, according to Bolander et al. (1999), the effectiveness of electrochemical products depends on soil mineralogy. Also, the effectiveness period of this type of product can be short and a relatively long conditioning period may be required in order to benefit from a product's maximum performance. The environmental impacts of electrochemical products are relatively unknown. Consequently, an evaluation of each electrochemical product is recommended.

To summarize, the chemical reactions that govern the effectiveness of electrochemical agents appear to be quite selective and small changes in site conditions diminish their effectiveness. This generates highly variable results (from "very interesting" to "poor"). Electrochemical products do not appear to be suitable when exposed to varying weather conditions. It is therefore important, before their application, to determine if weather conditions will be constant, in order to ensure their effectiveness.

2.7 Enzymes

Little information is available on enzymes used for road treatments; however, they work like electrochemical products and can be used as dust suppressants and stabilizers. Furthermore, their role is to catalyze certain reactions that are useful and effective for road stabilization or dust reduction. Tingle et al. (2007) agree and state that enzymes indeed serve as catalysts for specific chemical reactions.

Because enzymes are very sensitive to changes in surrounding conditions, their use is very limited. Furthermore, their performance can be variable ranging from good to poor.

2.8 Cement-based products

Pierre et al. (2007a, 2008b) and Henry et al. (2005) claim that cement, a traditional stabilizer, greatly improves the mechanical properties of granular material (CBR trial and unconfined compression). Pierre et al. (2007a, 2008b), however, add that cement does not significantly improve the resilient modulus of granular material.

To summarize, cement appears to be a highly effective stabilizer. Its use, however, is limited due to high costs and the fact that it must be mixed with the granular material and kept in a dry environment prior to its application. It is, nonetheless, useful and can be cost-effective for repairing severe road deterioration problems.

2.9 Other considerations

The products of each category tend to be effective in certain conditions. As mentioned by Surdahl et al. (2007), trials are frequently carried out in a single location and results are subject to certain changes, depending on the material at hand. Mokwa et al. (2007) reached the same findings. They studied various physical properties with respect to the gradation of various materials; two coarser materials used mainly for base courses, and a finer third material similar to surface material. Their study showed that coarser materials are the stiffest and most resistant. It also showed that permeability depends more on the fraction of voids between fine particles than on the type of material or the particle size. Given that there is a sufficient quantity of fine particles to fill the spaces between the coarser particles, permeability is therefore enhanced by surface material containing a greater proportion of smaller diameter particles.

Furthermore, according to Surdahl et al. (2007), the cost of the products varies greatly depending on their type and their delivery destination. Moreover, each product must be reapplied at different time intervals. Therefore, before selecting a product, it is recommended that the weather conditions, the type and number of vehicles using the roads, the environment, the budgets, and the treatment objectives be taken into consideration.

3. Using this guide

Using this guide is simple. All one has to do is follow the steps set forth in the decision-support flowchart in Figure 1. Each of the five steps in the flowchart leads to the selection of a dust suppressant or stabilizer and its application rate. Each step is briefly described in the following paragraphs, and later discussed in greater detail along with the related figures and tables.

The performance of the various dust suppressants and stabilizers, based on traffic, mineralogy, weather, and information on their environmental impacts, applicability, and cost, is presented in the form of a summary table in Appendix A.

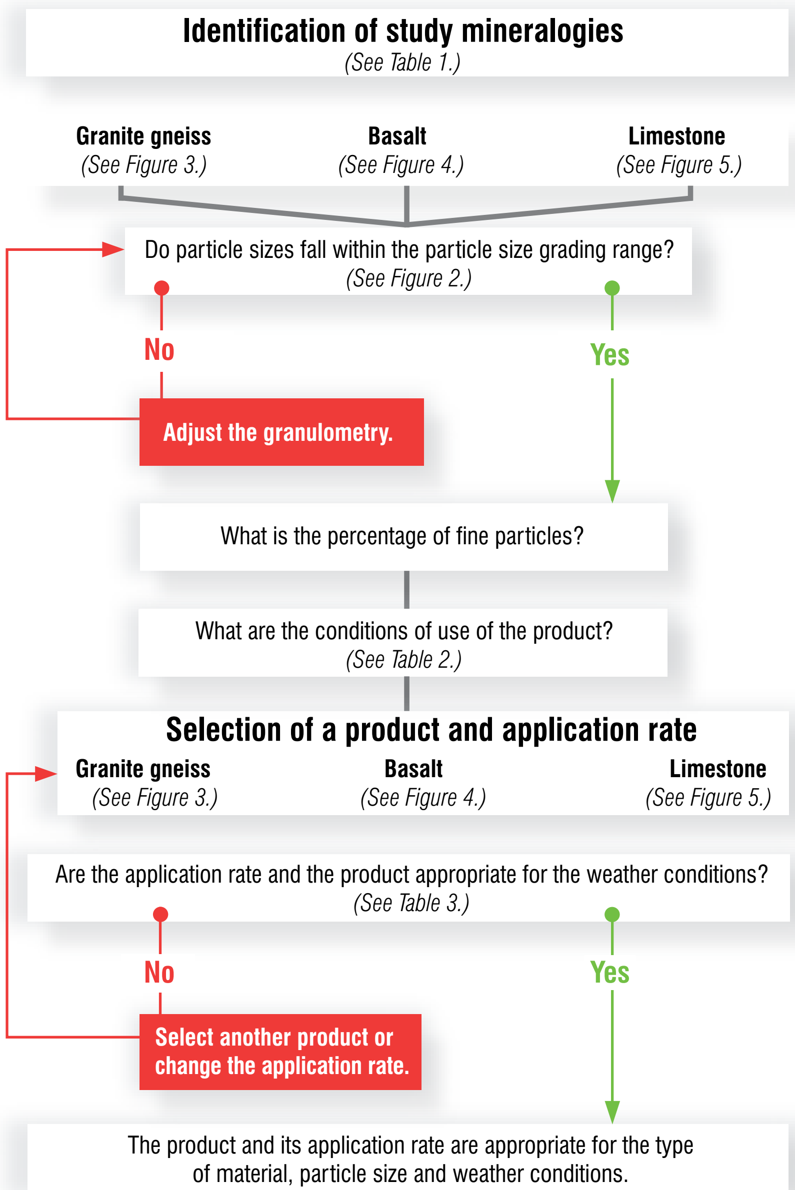


Figure 1. Decision-support flowchart.

Step 1

The mineralogy of the granular material must be determined using Table 1. The material must be composed of granite gneiss (metamorphic source), basalt (volcanic source), or limestone (sedimentary source). These are the three types of materials that were studied for the development of this guide. Appendix B presents the results of their geotechnical characterization.

Step 2

It is recommended that the particle size distribution (gradation) of the aggregate fall within the grading range suggested in Figure 2. The percentage of fine particles in the granular material must also be determined.

Step 3

The conditions for using the dust suppressant or the stabilizer must be established by consulting Table 2. Specifically, the types of vehicles using the road and location where the product is being applied must be defined.

Step 4

With the help of Figures 3 to 5, one can now select a dust suppressant or a stabilizer as well as its application rate. The user of this guide may have to choose between several products and different application rates for a given situation. However, the performance of the products can be quite similar.

Step 5

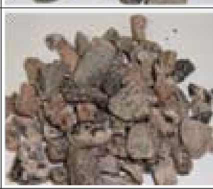
The selected product and application rate must be compatible with the weather conditions in which it will be used. For this reason, the user must determine, from Table 3, whether the product and its application rate are recommended for the weather conditions in question. It should be noted that only hygroscopic products are significantly affected by weather conditions, as described in this guide.

4. Selecting a product and an application rate

Step 1

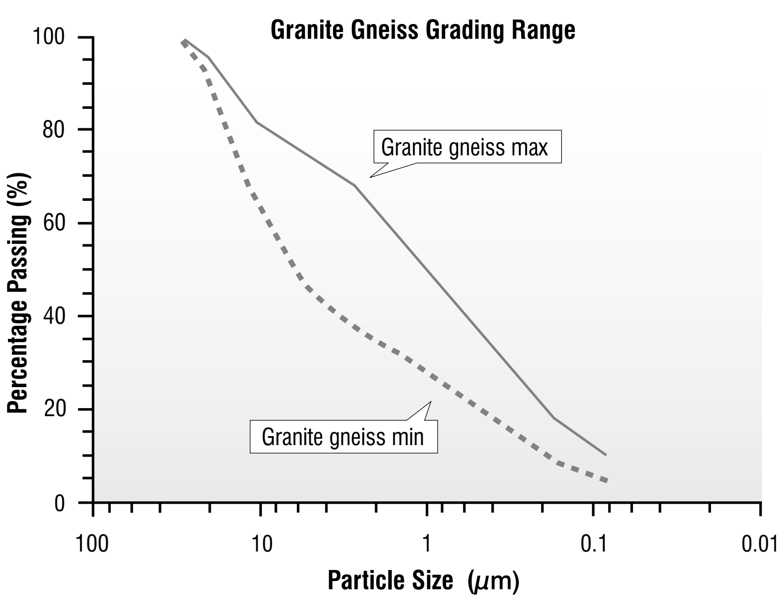
The first step consists of characterizing the mineralogy of the granular material. Table 1 shows photographs of various material sources in different states. Their characteristics are also outlined to facilitate their identification.

Table 1. Granular material mineralogy identification

Sample state	Granite gneiss	Basalt	Limestone
Non-washed and dry			
Washed and dry			
Crushed and dry			
Comments on material mineralogy characteristics	Beige and pink tints may be observed, especially when washed. Compared to basalt and limestone, the surface of the material may contain shiny spots.	Matte surface. Purplish tint, especially when wet.	Matte surface. Can break into layers; noticeable strata. Grey

Step 2

The second step consists in checking whether the gradation of the granular material falls within the recommended grading range for each type of material. For adequate performance, the grading curve of the granular material must fall within the grading envelop presented in Figure 2 for granite gneiss, basalt, or limestone. A grain-size analysis is thus required. At this step, the percentage of fine particles (particles with a diameter < 80 μm) must also be determined. Moreover, it is preferable that fine particles have a clay component (plastic) in order to increase material cohesion. It is acknowledged that adding fines with a plasticity index (PI) between 4 and 15 enhances material performance (AASHTO, 2001; Giummarra, 1993; and Tyrrell, 2000).



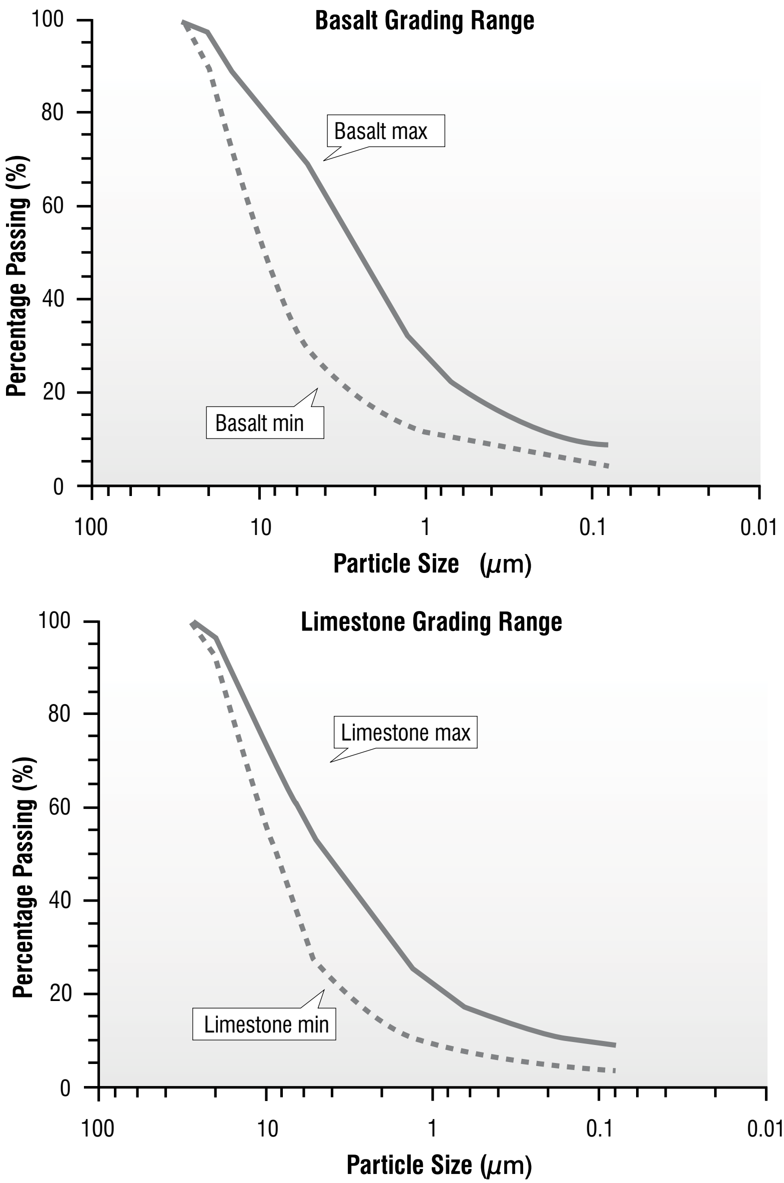


Figure 2. Optimal grading range recommended for granite gneiss, basalt, and limestone.

Step 3

In this step, the conditions in which the dust suppressant or stabilizer will be used must be determined. These include the type of traffic and the characteristics of the road or road section to be treated. Four options are available: *heavy and critical, light and critical, heavy and normal,* and *light and normal*. Table 2 presents a definition of each one.

Table 2. Definitions of the conditions of use of dust suppressants and stabilizers

Conditions of use	Definition
Heavy and critical	Condition characterized by heavy vehicle traffic (semi-trailers and off-highway vehicles) and by a critical location of the road section to be treated (steep grades, acceleration and/or braking zones, sharp curves, bridge approaches).
Light and critical	Condition characterized by traffic involving light vehicles (trucks, passenger cars, and vans) and by a critical location of the section to be treated (steep grades, acceleration and/or breaking zones, sharp curves, bridge approaches).
Heavy and normal	Condition characterized by traffic involving heavy vehicles (semi-trailers and off-highway vehicles) and by a relatively straight horizontal alignment, easy grades, no critical braking or acceleration zones, no sharp curves or bridge approaches.
Light and normal	Condition characterized by traffic involving light vehicles (trucks, passenger cars, and vans) and by a relatively straight horizontal alignment, easy grades, no critical braking or acceleration zones, no sharp curves or bridge approaches.

Step 4

After the percentage of fine particles and conditions of use determined in steps 2 and 3, step 4 leads to the selection of the appropriate dust suppressant or stabilizer and its rate of application, with the help of Figures 3, 4, or 5. The proper figure is selected based on the mineralogy characteristics determined in step 1. It should be noted that in the case of *heavy and normal* and *light and normal* conditions of use, dust suppressants are the only recommended products, whereas stabilizers are the only recommended products in the case of *heavy and critical* conditions of use. In the case of light and critical conditions of use, however, both dust suppressants and stabilizers are recommended.

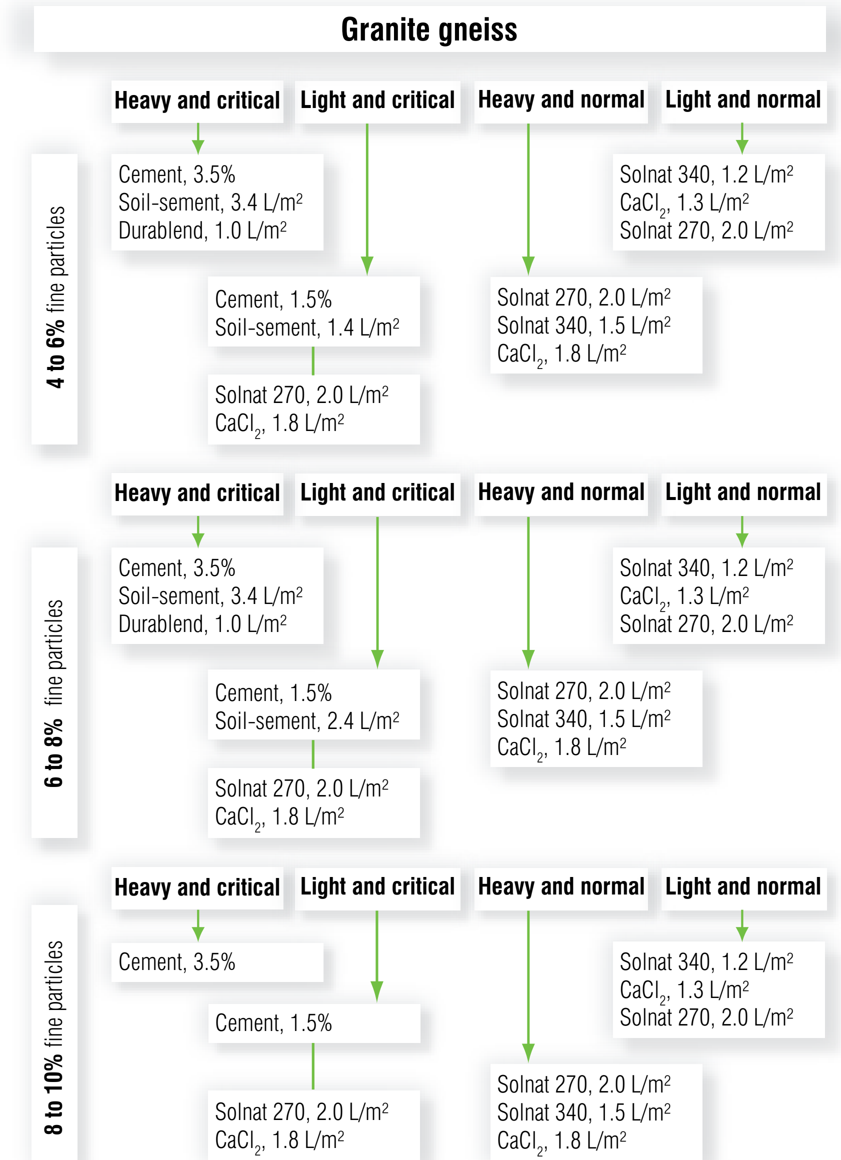


Figure 3. Selection of a dust suppressant or stabilizer for granite gneiss.

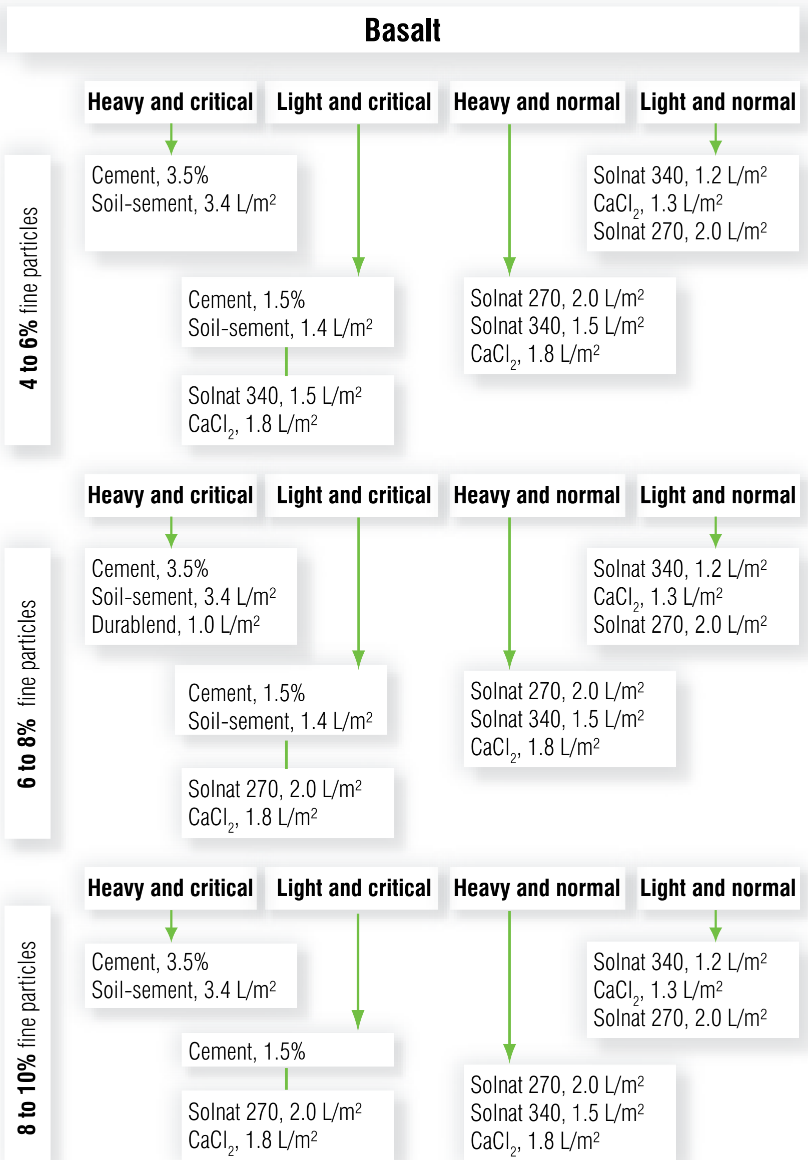


Figure 4. Selection of a dust suppressant or stabilizer for basalt.

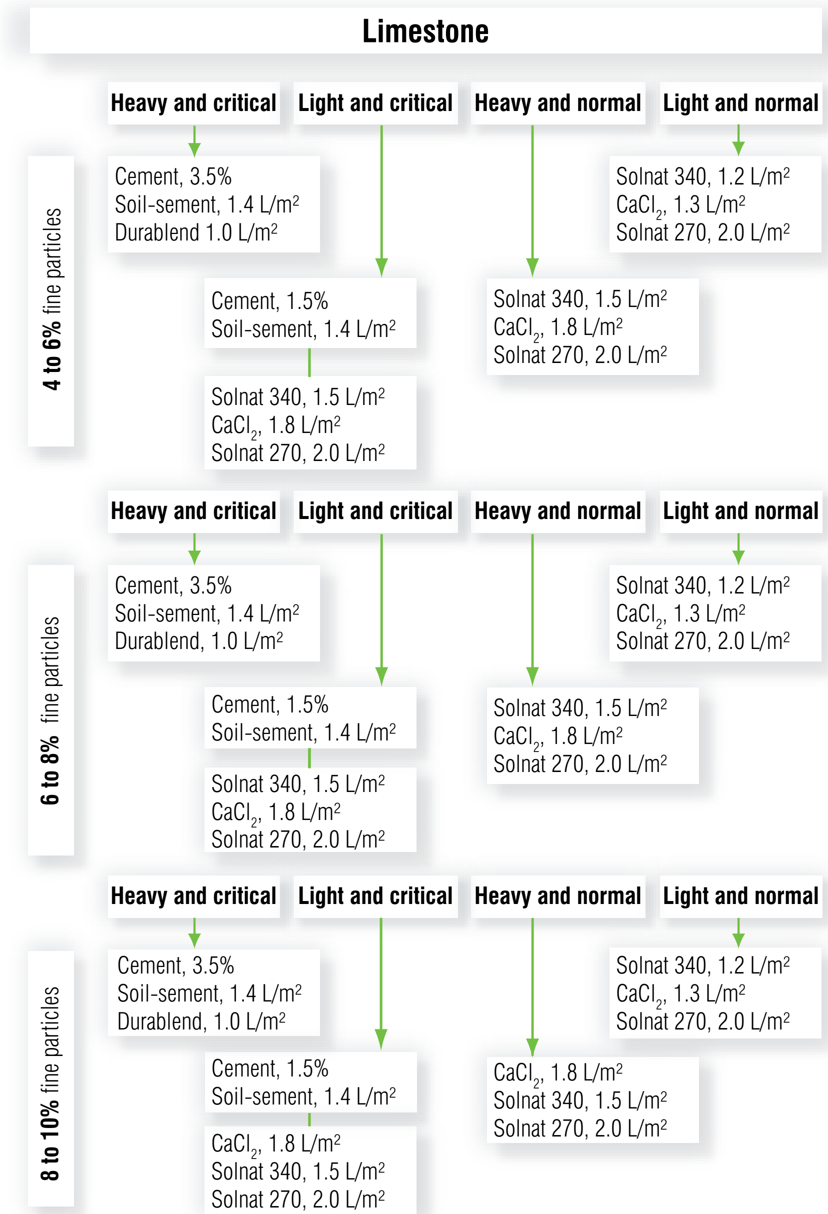


Figure 5. Selection of a dust suppressant or stabilizer for limestone.

Step 5

The purpose of the final step in this process is to determine whether the selected dust suppressant or stabilizer, and its application rate, are consistent with weather conditions. Two categories of weather conditions are proposed; dry and wet, based on the precipitations recorded from June to October. Table 3 presents the recommended application rates based on weather conditions for the various dust suppressants and stabilizers.

- Dry weather conditions: Defined as less than 500 mm of rain from June to October inclusively (average of 100 mm per month).
- Wet weather conditions: Defined as more than 500 mm of rain from June to October inclusively (average rainfall greater than 100 mm per month).

Table 3. Recommended application rate for each product for different weather conditions

		Weather Conditions	
		Wet	**Dry**
Hygroscopic products	*Calcium chloride*	1.3 to 1.8 L/m^2	1.3 to 2.3 L/m^2
	Solnat 270	1.5 L/m^2	1.8 L/m^2
	Solnat 340	1.2 to 1.5 L/m^2	1.2 to 1.8 L/m^2
	Durablend	1 L/m^2	1 L/m^2
Polymer emulsion	*Soil-Sement*	1.4 to 3.4 L/m^2	1.4 to 3.4 L/m^2
	X-hesion	3.6 L/m^2	3.6 L/m^2
Cement-based product	*Cement*	1.5 to 6%	1.5 to 6%
Organic products	*Road-Oyl*	3.4 L/m^2	3.4 L/m^2
Enzyme-based products	*Soiltac*	1.8 to 1 kg/m^2	1.8 to 1 kg/m^2
	Durasoil	0.91 to 1.63 L/m^2	0.91 to 1.63 L/m^2

5. Application considerations and costs

Road treatment products can be applied in various ways, depending on whether the product to be applied is a dust suppressant or a stabilizer.

Dust suppressants are usually applied directly onto road surfaces (Figure 6). Grading prior to applying the product is recommended in order to facilitate product penetration and to prevent leaching. Compaction of the running surface is also recommended following the spreading of a dust suppressant and reshaping of the road surface.

Figure 6. Spreading of a dust suppressant.

Stabilizers are applied differently. In order to achieve effective stabilization of the road's running surface, a layer of granular material must be removed and windrowed prior to spreading the product. This will allow the application of the stabilizer to a depth of 50 to 100 mm (Figure 7).

◀ Figure 7. Spreading of the first stabilizer layer and replacing of the granular material.

Depending on the design requirements, the stabilizers can be applied in multiple and thicker layers. The granular material must then be replaced and a second surface application of the product must be applied. Compaction of the layers is highly recommended. It is also advised to ensure that the road surface material and the product are well mixed before proceeding with grading and compaction operations.

It should be noted that with a high application rate, spreading a dust suppressant or a stabilizer can be done in several passes. For more information on product application, refer to field trials carried out in the summer of 2008 and 2009 (Pierre et al., 2009 and Poulin et al., 2010).

Table 4 summarizes various observations on product applicability and costs. Costs are presented in relative values, since they vary greatly as a function of product quantity to be applied, transportation, and availability in a given region.

Table 4. Relative cost and applicability of dust suppressants and stabilizers

		Cost	Applicability
Hygroscopic products	*Calcium chloride*	1.4	The dissolution of solid $CaCl_2$ is an exothermic reaction. This operation requires constant stirring and heat evacuation.
	Solnat 270	1	+ +
	Solnat 340	1.1	+ +
	Durablend	2.5	+ Viscous product. Thorough cleaning of spreading equipment must be carried out following its application.
Polymer emulsion	*Soil-Sement*	2.3	+ Sticky product. Thorough cleaning of spreading equipment must be carried out following its application.
	X-hesion	1.8	+ +
Cemenet-based product	*Cement*	2.1	- - A complex operation. The mixture of cement and granular material must be homogeneous. Care must be taken to protect the cement against exposure to moisture prior to its use.
Organic products	*Road-Oyl*	2.8	- Extremely sticky product. Prompt and thorough cleaning of spreading equipment must be carried out following its application.
Enzyme-based products	*Soiltac*	>3	- - Complex operation. The product-aggregate mixture must be homogeneous. Furthermore, care must be taken to protect the product against moisture prior to its use.
	Durasoil	>3	+ +

+ + Easy application.
\+ Easy application. Certain recommendations apply.
\- Specific application requiring a sequence of steps.
\- - Difficult application.

6. Environmental considerations

Several tests were carried out in order to check the quality of water running off and percolating through granular material treated with dust suppressants or stabilizers.

First, pH values represent the cologarithm of the H^+ ion concentration in liquid. The pH scale ranges from 0 to 14 and is used to determine whether water is acidic ($pH<7$), neutral ($pH=7$) or basic ($pH>7$). The pH is one of the most critical parameters to measure since it has a direct impact on several biological processes. Furthermore, pH plays a key role in the blood system of aquatic organisms. High pH fluctuations can have a serious impact on these organisms.

Second, the carbonate hardness test, also referred to as alkaline hardness, measures the acid-neutralization capacity of water. This involves measuring the presence of bicarbonate and carbonate ions, which contribute the most to the alkalinity of water. Values below 60 mg/L of $CaCO_3$ are usually associated with a low pH. This is good for fish. Carbonate hardness stabilizes water pH and is a significant source of energy for the autotrophic bacteria that contribute to the breakdown of ammonia and nitrites. Carbonates are also used by plants in photosynthesis, the process in which they replace carbon dioxide.

Third, the total hardness test represents the salts dissolved in water. These usually include calcium, magnesium, and sodium, which are all found in hygroscopic products. Values below 60 mg/L of $CaCO_3$ indicate soft water whereas values between 60 and 100 mg/L indicate slightly hard water. Values between 100 and 200 mg/L indicate moderately hard water whereas values over 200 mg/L indicate very hard water. Measurement of this parameter is required since the concentration of dissolved salts affects the osmoregulation process in fish as well as the regulation of serum calcium levels.

The last test determines the presence of ammonia in water. This can cause many problems as too high a concentration can be toxic for aquatic organisms. The level of ammonia (NH_3) should not exceed 1.2 mg/L. Concentrations over 1.2 mg/L in very alkaline water (pH of 8 or greater) are toxic for aquatic organisms. Ammonia can also be present as NH_4^+. The levels of NH_3 compared to NH_4^+ depend on pH. Bacterial flora normally converts ammonia into nitrates so as to maintain a balance.

Table 5 summarizes the results of the various tests carried out on runoff and percolation water.

There is a significant difference in the pH values for runoff water and percolation water for all products. In fact, the pH of percolation water values is somewhat neutral in all cases, whereas the pH of runoff water is acidic. This holds true for the control sample. Acid rain may have contributed to these results, which do not seem to depend directly on the nature of the products. The organic polymer (X-Hesion) and the natural brine (Solnat 270) generated the most highly acidic runoff water values, whereas no other product seemed to impact the pH of percolation water.

Carbonate hardness values should exceed 20 mg/L in order to effectively stabilize water pH. This is particularly important in this case, where runoff water is acidic. That is why average carbonate hardness values of runoff water from materials treated with the vegetal polymer (X-Hesion) and the natural brine (Solnat 270) are the lowest and correspond to the lowest pH in Table 5. Conversely, percolation water from the organic polymer (X-Hesion) tub, which posted the highest pH, had the highest carbonate hardness value. The road control sample and the road sample treated with a polymer emulsion (Soil-Sement) are the only samples with satisfactory average values for runoff water.

With respect to total hardness, hygroscopic products rich in dissolved salts had the highest values. Calcium chloride has a high average value in percolation water even though damage of the recovery system prevented sampling when the rates were highest. The two natural brine products (Solnat 270 and Solnat 340) also had high average values, greater than the 200 mg/L limit that corresponds to very hard water. Once again, runoff water and percolation water yielded different results.

Finally, with respect to ammonia, runoff water from the polymer emulsion (Soil-Sement) maintained an average value higher than the recommended limit of 1.2 mg/L.

Table 5. Result of the various tests carried out on runoff and percolation water with various dust suppressants and stabilizers

	Type of Water Tested	pH (-)	Carbonate Hardness (mg/L $CaCO_3$)	Total Hardness (mg/L dissolved salts)	Ammonia (mg/L NH_3)
Control	Runoff	6.1	21.3	35.0	0.2
	Percolation	7.2	53.3	88.3	0.0
Solnat 270	Runoff	5.3	16.7	26.7	0.3
	Percolation	7.1	40.6	1669.4	0.2
Solnat 340	Runoff	5.5	17.5	26.7	0.1
	Percolation	7.2	41.1	1702.2	0.3
$CaCl_2$	Runoff	6.0	18.9	193.3	0.2
	Percolation	6.5	34.4	4296.4	0.4
Road Oyl	Runoff	5.5	18.3	20.0	0.3
	Percolation	7.2	57.8	82.2	0.1
Soil-Sement	Runoff	6.0	52.5	90.0	2.1
	Percolation	7.1	47.8	87.8	0.0
X-Hesion	Runoff	5.3	16.7	13.3	0.1
	Percolation	7.3	87.2	227.8	0.4

Conclusion
Acknowledgements
References

This selection guide on dust suppressants and stabilizers for unpaved roads was developed through several laboratory and field tests from 2005 to 2010 as part of a NSERC Collaborative Research and Development Grant. Several publications on this work are available and highlighted in section 1.4. Close cooperation between various product manufacturers and suppliers was instrumental in the development of this project.

The guide serves as a comprehensive decision-support tool for managers of unpaved road networks. It is presented in a simple manner in an attempt to make it as user-friendly as possible. The elements likely to influence the selection of a product and an appropriate application rate – material mineralogy, gradation, the percentage of fine particles in the granular material, weather conditions, the nature and volume of traffic – are all taken into account. Since costs can vary significantly from one site to another, only relative costs are presented. The potential impact of certain products on the environment was discussed, but this whole issue warrants further research.

It is hoped that this guide will help the user make informed decisions that will enhance the performance of unpaved roads and transportation efficiency in an environmentally sensitive manner.

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Summary Table of dust suppressants and stabilizers

		Application Rate	Role	Circulation			Mineralogy		
			DS/S	Light	Moderate	Heavy	Gneiss	Lime-stone	Basalt
Hygroscopic Products	*Calcium Chloride*	1.3 L/m²	DS	++*	+*	-*	++	+	+
		1.8 L/m²		++*	++*	+*			
		2.3 L/m²		++	++	++			
	Solnat 270	2.0 L/m²	DS	++	++	++	++	+	+
	Solnat 340	1.3 L/m²	DS	++*	+*	-*	++	+	+
		1.5 L/m²		++*	++*	+*			
		1.8 L/m²		++	++	++			
	Durablend	1 L/m²	DS/S	++	++	++	++	+*	+*
Polymer Emulsion	*Soil-Sement*	1.4 L/m²	S	++*	++*	+*	++	+	+
		2.4 L/m²		++*	++*	++*			
		3.4 L/m²		++	++	++			
	X-hesion	3.6 L/m²	DS	++	++	+	+	-*	-*
Cement-based Product	*Cement*	1.5%	S	+	+	+	++	+	+
		3.5%		++	++	++			
		4.5%		++	++	++			
		6%		++	++	++			
Organic Products	*Road-Oyl*	3.4 L/m²	DS	++	++	+	+	-*	-*
Enzyme-based Products	*Soiltac*	1.8 kg/m²	S	++*	++*	+*	++	+*	+*
		1.4 kg/m²							
		1 kg/m²							
	Durasoil	0.91 L/m²	DS	++*	++*	++*	++	+*	+*
		1.16 L/m²							
		1.63 L/m²							

* Lab and field trial projections
++ Excellent performance
\+ Reasonable performance
\- Poor performance
-- Does not perform

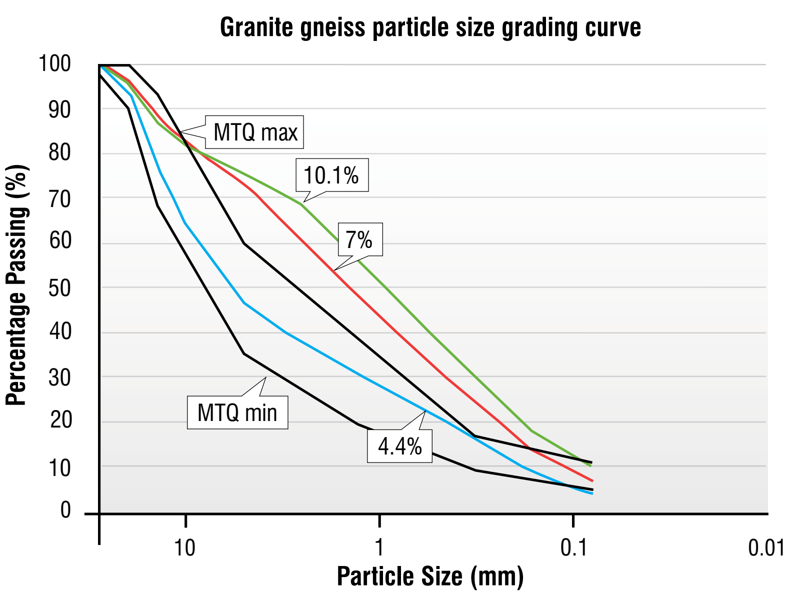
Granulometry			Weather Conditions		Environ-mental Impacts	Applicability	Costs	Overall Performance
4 to 6% fines	6 to 8% fines	8 to 10% fines	Wet	Dry				
+	+	+	++	++	++	+	$$	+
++	++	++	++	++	+	+	$$	
++	++	++	+	++	+	+	$$	
++	++	++	+	++	+	++	$	++
+	+	+	++	++	++	++	$	++
++	++	++	++	++	++	++	$	
++	++	++	++	++	+	++	$	
++	++*	+*	++	++	+*	++*	$$$	+
++	++	+	++	++	+	+	$$$	++
++	++	+	++	++	+	+	$$$	
++	++	+	++	++	+	+	$$$	
+	-*	-*	-	+	-	++	$$$	-
++	+	+	++*	++*	+	- -	$$$	++
+	++	+	++*	++*	+	- -	$$$	
+	++	+	++*	++*	+	- -	$$$	
+	++	++	++*	++*	+	- -	$$$	
+	-*	-*	-	+	+	+	$$$	-
++	+*	+*	++*	++*		- -*	$$$$	
+	++*	+*	++*	++*				
+	++*	++*	++*	++*				
-	-*	-*	++*	++*		++*	$$$$	
+	+*	+*	++*	++*				
++	++*	++*	++*	++*				

$ Low-cost $$ Affordable $$$ Expensive $$$$ Very expensive

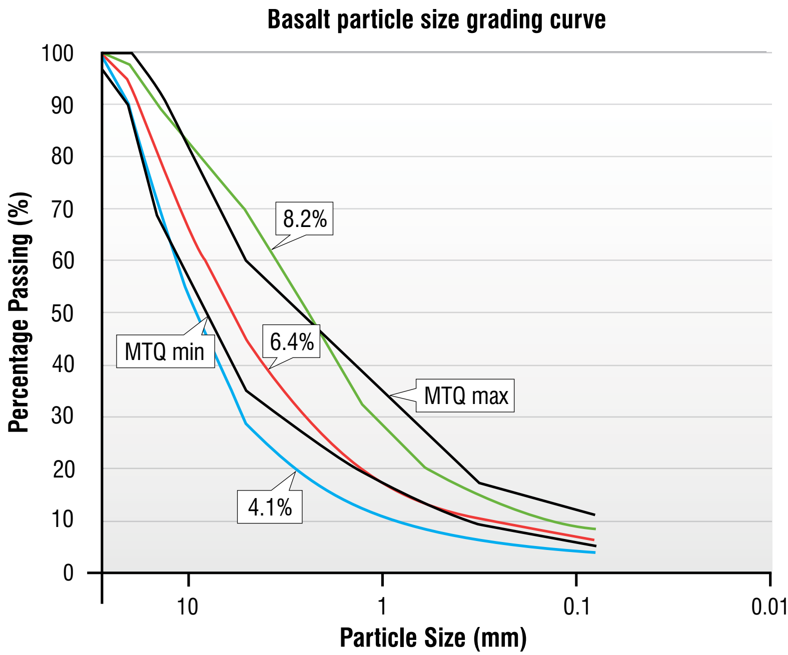
The following tests were carried out in order to characterize the granular materials selected for this study: granite gneiss, basalt and limestone:

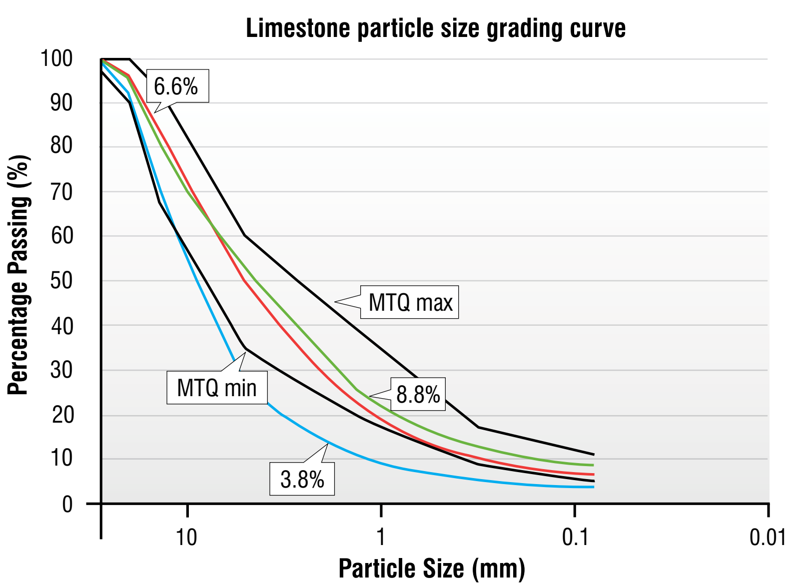
- Particle-size sieve analysis (BNQ 2560-040)
- Modified Proctor Test (BNQ 2501-255)
- Bearing capacity (modified CBR) (ASTM D 1883)
- Los Angeles (BNQ 2560-400)
- Micro-Deval (BNQ 2560-070)
- Absorption density (BNQ 2560-065 et 067)
- Methylene blue test (LC 21-255)

It should be noted that the ministère du Transport du Québec's grading range for MG-20B is shown for illustrative purposes.



Figures B1. Particle size grading curve for granite gneiss, basalt and limestone.


Basalt particle size grading curve
Percentage Passing (%)
100
90
80
70
60
50
40
30
20
10
0
8.2%
6.4%
MTQ min
MTQ max
4.1%
10
1
0.1
0.01
Particle Size (mm)


Limestone particle size grading curve
Percentage Passing (%)
100
90
80
70
60
50
40
30
20
10
0
6.6%
MTQ max
MTQ min
8.8%
3.8%
10
1
0.1
0.01
Particle Size (mm)

The granite gneiss tested in the study is characterized by the presence of very hard, wear-resistant sandy granular material that is nonetheless subject to fragmentation and abrasion. Furthermore, this material has a low percent absorption and contains few clayish particles. Basalt has a greater proportion of gross particles than gneiss and is therefore less sandy-like. Basalt has the highest absorption percentage. It contains a high proportion of clayish particles. Basalt is not as hard as gneiss. It is, however, wear-resistant, fragmentation-resistant, and abrasion-resistant. Finally, sandstone gradation is similar to that of basalt. Its percent absorption is between that of gneiss and basalt. Sandstone is also quite abrasion-resistant and fragmentation-resistant but its wear resistance, however, is quite low. It also contains a high proportion of clayish particles.

Table B-1. Results of the Proctor test for the various particle sizes of the three types of granular materials

Material (-)	Particle Size (% fine particles)	Proctor (optimal % water)	(Dry Mass Density) (kg/m³)
Granite gneiss	4.4	4.5	2,212
	7.0	6.8	2,045
	10.1	7.4	2,020
Basalt	4.1	4.5	2,180
	6.4	5.75	2,288
	8.2	6.2	2,327
Limestone	3.8	4.2	2,192
	6.6	5.6	2,220
	8.8	6.0	2,315

Table B-2. Results of the bearing capacity test for the various particle sizes of the three types of granular materials

Material	Particle Size (% fine particles)	Force at 2.5 mm (kN)	Force at 5 mm (kN)
Granite gneiss	4.4	18.4	20.7
	7.0	15.0	16.8
	10.1	15.1	18.9
Basalt	4.1	10.68	16.69
	6.4	13.77	22.35
	8.2	13.93	23.89
Limestone	3.8	10.86	14.71
	6.6	8.86	13.86
	8.8	16.34	25.64

Table B-3. Results of the abrasion resistance test using the Los Angeles abrasion testing apparatus

Material	% abrasion
Granite gneiss	50.9%
Basalt	20.1%
Limestone	26.2%
*MTQ requirements for MG-20 B**	≤ 50%

* Géolab inc., 2002

Table B-4. Results of the wear-resistance test with the micro-Deval apparatus

Material	Micro-Deval Coefficient
Granite gneiss	12.7%
Basalt	16.7%
Limestone	32.1%
*MTQ requirements for MG-20B**	≤ 25%

* Géolab inc., 2002

Table B- 5. Results of the density and absorption tests

Material	Coarse Aggregate			
-	D_{Gross} (dry)	D_{Gross} (ssd)	$D_{apparent}$	% absorption
Granite gneiss	2.64	2.66	2.70	0.82%
Basalt	2.78	2.83	2.94	1.98%
Limestone	2.61	2.65	2.72	1.51%
	Fine Aggregate			
-	D_{Brute} (dry)	D_{Brute} (ssd)	$D_{apparent}$	% absorption
Granite gneiss	2.63	2.64	2.65	0.22%
Basalt	2.66	2.72	2.85	2.54%
Limestone	2.52	2.57	2.65	1.96%

Table B-6. Results of the methylene blue tests

Material	Methylene Blue Value (cm^3/g)
Granite gneiss	0.05
Basalt	0.38
Limestone	0.60
*MTQ requirements for MG-20B**	≤ 0.20

*Géolab inc., 2002

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