Geosynthetics Design Guide

REINFORCEMENT SOLUTIONS FOR UNPAVED ROADS
ACKNOWLEDGEMENTS

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If you require assistance to implement these research findings, please contact FPIinnovations at solutions@fpinnovations.ca.
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INTRODUCTION

Need
Extreme road construction conditions — such as on very weak soils, mid-winter thaws and early spring breakup — can have an impact on transportation and mill inventories as well as access to fibre. FPInnovations’ members across Canada have identified fibre access under these difficult conditions as a key challenge.

Road reinforcement and design solutions using geosynthetics for these critical road sections are needed to reduce negative impacts on operational efficiency. Structural design with these products, however, remains poorly understood. Products such as geogrids, geotextiles, and geocells can provide significant reinforcement when properly designed and matched with compatible materials. There is a need to bridge the knowledge gap and make geosynthetic reinforcement accessible to all.

Objective
This guide addresses two major issues regarding critically weak road sections: reduced transportation efficiency which can limit access to fibre, as well as access to good-quality materials which has an impact on construction cost. Roads built over weak soils may reduce allowable truck payloads, inhibit vehicle traction, pose a safety hazard, and lead to higher road maintenance costs over time. In addition, good-quality road materials are not always accessible or cost-effective to transport over long distances.

This guide provides users with easy-to-use charts to assist with the design of geosynthetic-reinforced unpaved roads over weak soils. It permits the estimation of key input parameters through simple procedures and judgment based on experience. Further optimization of designs may however be possible through detailed calculations and lab testing which are encouraged whenever feasible.

Designers that might have traditionally only considered unreinforced design will now be presented with a multitude of reinforcement options that they can compare amongst each other and quantify potential gravel and hauling cost savings. This tool allows users to better design critical road sections, thus improving access to fibre while reducing transportation and construction costs.
SCOPE

This guide focuses on subgrade stabilization of critical unpaved road sections through the use of geosynthetic mechanical reinforcement. The reinforcement options provided strengthen the load-carrying capacity of the road subgrade and allow for a reduction in required aggregate thickness compared to an unreinforced design.

Figure 1 shows a typical roadway design cross-section for this guide. It consists of a native soil subgrade, a base course layer, and a thin wearing course surface layer. It is important to note that the design thickness charts pertain only to the base course layer. The geosynthetic layer is placed at the interface between the subgrade and base course. The running surface, or wearing course, is a required fixed layer of ideally a well-graded aggregate with a higher degree of fines in order to provide a smooth running surface for driver comfort, potential dust control and to account for gravel loss (U.S. Department of Transportation, Federal Highway Administration, 2015). Unlike the base course, its structural value is not taken into consideration.

The critical sections under consideration for this guide are very low-strength areas with very poor subgrades. This includes primarily fine-grained clays and silts, and organic soils. Weakness of these sections is primarily due to the type of soil and its physical, mechanical, and hydraulic properties. These soil conditions are typically found in lowland and wetland areas where the soil is often partially or completely saturated. Climatic conditions, such as heavy rainfall and freeze-thaw cycles, also have a big impact on the soils ability to sustain loads and traffic. Poorly designed roads built over weak soils can result in deep rutting, poor traction, and other difficult driving conditions. These conditions require more severe interventions in order to ensure acceptable levels of performance. This includes the need for geosynthetic reinforcement and separation as well as mechanical compaction. Design charts are also provided for less critical areas with less strict design requirements. Critical sections can be found in any road class such as tertiary and block roads as well as on primary and secondary roads. The design methodology does not change based on the road designation and is rather governed by the site conditions. Figure 2 highlights a typical critical road section.

Figure 1. Design cross-section showing positioning of the geosynthetic.

Figure 2. Typical critical road section.
Geosynthetics considered
The geosynthetics considered in this guide include geotextiles, geogrids, and geocells, all of which can provide varying degrees of mechanical reinforcement.

Geotextiles
Geotextiles offer soil and base course confinement, resulting in greater load distribution and robust damage resistance for moderate to severe stress installations as shown in Figure 3. They are placed at the interface between the subgrade and base course (Holtz, Christopher, & Berg, 1997). In addition to reinforcement, geotextiles can provide drainage and separation between the subgrade and base course layers. This prevents the weaker subgrade from contaminating the base course through capillary raise and maintains the structural integrity of the road matrix (Koerner, 1997).

There are two types of geotextiles: woven and non-woven. Non-woven geotextiles are used for separation, whereas woven textiles can provide both separation and reinforcement.

High-strength woven geotextiles can be an effective choice on very weak subgrades. Wicking geotextiles have special hydrophilic and hygroscopic yarn that provides wicking action through the plane of the geosynthetic, which helps remove water from the road section and further improves its load-carrying abilities (Tencate Geosynthetics Americas, 2015b). In road applications, non-woven geotextiles are typically used in conjunction with geogrids and geocells. Figure 4 illustrates the difference between non-woven and woven geotextiles.

Figure 4. Non-woven vs. woven geotextile.

Geogrids
Geogrids are also placed between the subgrade and the base course (Holtz, Christopher, & Berg, 1997). They provide reinforcement by interlocking aggregate (Figure 5) inside their openings. In comparison to geotextiles, they do not provide separation. They are not recommended for use on critically weak subgrades. They can, however, be a cost-effective solution for

Figure 3. Geotextile reinforcement mechanism.
subgrades of moderate strength. They should be used in conjunction with a non-woven geotextile for separation.

Two types of geogrids are considered in this catalogue: biaxial and triaxial. Biaxial geogrids have rectangular grids, while triaxial geogrids have triangular openings as shown in Figure 6. Geogrids require more care in the selection of the base course material (Koerner, 1997). The particle sizes of the chosen base aggregate must be smaller than the geogrid’s opening or aperture size. This is to allow for the interlocking mechanism to take place. If the particles are too large, the geogrid will not function as intended. The maximum particle size as well as the gradation of a base course material must be verified in order to choose an appropriate geogrid.

Geocells

Geocells come in different heights and cell sizes. The higher the cell and the smaller the opening, the greater the level of reinforcement provided. Geocells are typically between 5 and 20 cm high. They provide cellular confinement and therefore increased reinforcement compared to geogrids (Pokharel, 2010). They do not provide separation, so it is always recommended to use a non-woven geotextile underneath. The design cross-section is shown in Figure 7. It consists of the separation layer placed as usual on top of the subgrade. The geocell is then placed on top of the separation geotextile and a fill material or aggregate is placed inside and on top of the geocell. Geocells can be perforated, which improves drainage.

Geocells allow for more flexibility in the choice of aggregate material. In fact, it is most common for geocells to be filled with low-quality, low-strength sand. Good quality aggregate should nevertheless be used for the base thickness above the geocell. The geocell and fill effectively act as a second structural layer in addition to the base course above. Another separation geotextile may also be used between...
these two layers on top of the geocell. Geocells deliver a higher level of support than geogrids by fully confining the material placed inside them, which significantly increases the load-carrying capacity (Kief, Schary, & Pokharel, 2015). They are primarily recommended for critically weak soils with minimal bearing capacity and where access to good base material is an issue. Figure 8 shows a geocell being installed.

Figure 8. Geocell installation. Photo from PRS geo-technologies (Canfor mill yard upgrade project- Fort Saint-John, BC).

Table 1 provides a summary of the different functions and relative cost for each of the geosynthetic options considered in this guide.

**Subgrade strength**

This guide uses the California Bearing Ratio (CBR) concept to quantify the bearing or load carrying capacity of the soils and road building material (Christopher, Schwartz, & Boudreau, 2006). The CBR can either be determined through standard laboratory or in-field test procedures, or by using the soil classification and associated CBR table provided in the design guide. The higher the CBR value, the higher the bearing capacity of the soil. This guide focuses on the stabilization of subgrade soils with minimal CBR values. Other parameters exist for quantifying the bearing capacity of a soil, such as the resilient modulus and the penetration index. The CBR is a simple and widely used measure in the design of roads.

The CBR of the subgrade is a key input for the use of the design charts. Many

Table 1. Summary of geosynthetics considered.

<table>
<thead>
<tr>
<th>Function</th>
<th>Non-woven geotextile</th>
<th>Woven geotextile (polypropylene yarns)</th>
<th>High-strength woven geotextile (polypropylene fibres)</th>
<th>Geogrid</th>
<th>Perforated geocell</th>
<th>Wicking geotextile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filtration</td>
<td>✔✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td>✔✔</td>
</tr>
<tr>
<td>Drainage</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td></td>
<td></td>
<td>✔✔</td>
</tr>
<tr>
<td>Separation</td>
<td>✔✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>✔✔</td>
</tr>
<tr>
<td>Confinement</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Wicking</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Reinforcement</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Purchase price</td>
<td>$</td>
<td>$</td>
<td>$$</td>
<td>$</td>
<td>$$</td>
<td>$$</td>
</tr>
</tbody>
</table>
factors can affect its value (Christopher, Schwartz, & Boudreau, 2006). The most critical factors are the hydraulic conductivity or the drainage capacity of the soil, the physical parameters, and the seasonal conditions. Permeable soils that provide good drainage, such as well-graded gravels and sands with low fines content, make for good subgrades. Soils with high amounts of fines on the other hand, such as silts and clays, have little to no permeability, meaning that they have very poor drainage. These soils, when saturated, have very low bearing capacities. In addition, silty and clayey soils are highly susceptible to frost heave. The environmental conditions can also have a significant impact on subgrade CBR as well. The local ground water table and the geometry of the road will greatly affect the soil’s moisture conditions. Lastly, the CBR values chosen should represent the worst case scenario of a soil’s condition over the entire range of its design life and across all seasons during which transportation is permitted.

**Design methodology**
The Giroud and Han method (Giroud and Han, 2004a, 2004b) was chosen for use in this design guide because it is the industry standard for subgrade stabilization of unpaved roads. It has the benefit of being able to produce unreinforced designs as well as geotextile and biaxial geogrid-reinforced designs. For the design of triaxial geogrids, the curves were generated using the SpectraPave software developed by the Tensar International Corporation (2019). It is important to note that the Giroud and Han method outputs the required base course thicknesses once compacted. The necessity and benefits of compaction will be discussed later on in this guide.

The Pokharel design methodology (Pokharel, 2010) was used for the geocell-reinforced design thicknesses. This method modifies the Giroud-Han formula in order to work with three-dimensional geocells. It also outputs compacted base course thicknesses.

**Limitations of the design charts**
The Giroud and Han design method has some limitations. This design method assumes that a base course material cannot be compacted to its full strength when designing over extremely weak subgrade soils. In these situations, the benefit of using a higher quality base course material is not properly demonstrated and leads to having just one design chart for both a high quality and low quality base course aggregate. A similar limitation applies to the Pokharel design methodology (Pokharel, 2010) and leads to the same result for geocells over critically weak soils.

The chosen design methodologies are only intended to be used for weak subgrades. Therefore, design charts are plotted for subgrade CBR values of 6 or less. This limitation, however, does not pose a problem, as geosynthetic reinforcement is needed most for subgrade CBR values below 4.

Another limitation of the design charts is the use of one single traffic input.
In road design, traffic impact is an important input parameter. However, a simplified approach to traffic is proposed in this guidebook. Rather than having multiple traffic cases, a single conservative value is used for all design charts. This decision was made after conducting a sensitivity analysis of different traffic input data. Results showed that traffic had varying degrees of impact on the final design when using different reinforcement options. In general, the higher strength geosynthetic products are less sensitive to changes in traffic input. With one traffic value used, lower strength options are overdesigned to a certain degree. This, however, was not deemed significant enough to warrant multiple traffic inputs. This simplified approach to traffic assumes that regular maintenance is being performed on the road to eliminate surface rutting and restore road section geometry.
BEST PRACTICES

This design catalogue focuses on the mechanical reinforcement of unpaved roads. However, geosynthetic reinforcement alone is not enough to guarantee a good, durable road section. There are certain best practices that must be followed in addition to using reinforcement.

Geosynthetic reinforcement is not the solution to all unpaved road performance issues. It is an additional step to take when general best practices in unpaved road design are being followed and problems persist. Without adequate road section geometry and drainage, wearing course, compaction, and regular maintenance, good road performance will not be achieved even when using geosynthetics. In addition, proper installation techniques for each geosynthetic product must be followed. This guide assumes that these best practices are being obeyed.

Geometric design

One of the most critical aspects of road building is ensuring proper geometric design and alignment (U.S. Department of Transportation, Federal Highway Administration, 2015). Adequate crowning of the road surface as well as foreslopes should be provided in order to ensure proper drainage. A crown makes the centreline of the road alignment the highest point, which prevents water from puddling on the road surface and drains it to the sides. Side slopes on either side of the road section also help provide good drainage. It is also highly recommended to have side ditching wherever possible to collect drained water and carry it away. Figure 9 shows an example of a good geometric design for an unpaved road.

![Figure 9. Geometric design of road section.](image)

Compaction

The design methodologies used in this guide output compacted base course thicknesses (Giroud & Han, 2004a, 2004b); (Pokharel, 2010). They do not output uncompacted thicknesses. Therefore, compaction is mandatory when designing on all subgrade strengths considered. Compaction level has a significant impact on a material’s strength (Barksdale, 1991). It is always advised to perform compaction regardless of the severity of the design. The benefit of compaction is quantified by the significant reduction in required thickness. This is because an uncompacted material will never achieve its full strength and will therefore require more thickness to provide the same load support. An example of the benefits of compaction is given in Appendix B.

It is recommended to always compact the road with proper compaction equipment (U.S. Department of Transportation, Federal Highway Administration, 2015). Truck trafficking is not enough to achieve proper levels of compaction because it will be limited to the vehicle wheel path. Compaction equipment must be used (Keller & Sherar, 2003). Smooth drum rollers...
(Figure 10) and pneumatic rollers are used for coarse-grained granular materials which are typically base courses. Sheepsfoot compactors may also be used to compact and improve fine-grained soil subgrades. Compaction equipment can either be in the form of a separate dedicated machine or an attachment that can be mounted to the front or back of existing machinery.

**Wearing course**

This guide requires the use of a fixed wearing course on top of the base course to act as the rolling surface of the road. This material should be a coarse-grained aggregate material of similar or better quality than the base course. A higher degree of fines is, however, permitted for the wearing course because this provides a smoother rolling surface and increases driver comfort (U.S. Department of Transportation, Federal Highway Administration, 2015). With a higher degree of fines, the wearing course is less permeable. Silt and clay materials should not be used as a wearing course.

The wearing course ensures that the structural base layer remains intact after maintenance. Resurfacing results in a certain amount of gravel loss upon each grader passage. Without a wearing course, gravel loss will take effect at the base layer and reduce the road’s structural integrity. A general rule of thumb is to assume a gravel loss of 25 mm per year. This will, however, ultimately depend on the frequency of grading. Typically, 100 mm of wearing course is recommended.

In situations where typical wearing course material is unavailable, it is recommended to use an added amount of the base course material to account for the wearing course. This may not have the best characteristics in terms of driver comfort but will effectively protect the road structure from gravel loss.
Regular maintenance
Regular maintenance is always recommended on any unpaved road (U.S. Department of Transportation, Federal Highway Administration, 2015). Grading should be performed to restore the road section geometry and remove surface rutting caused by vehicle traffic. Maintenance can be performed when needed or at regular intervals based on the expected traffic impact. The most optimal maintenance frequency will depend on the traffic impact. More grading will be required on roads with high traffic levels or very damaging vehicles. Even well-designed roads will experience performance and durability challenges if maintenance is not performed regularly.

Risk tolerance
Another element to consider when approaching the design is the level of risk tolerance for the road section in question. This will depend on many factors such as the expected level of traffic, the road users or stakeholders involved, and the availability of alternate routes. If many stakeholders are involved and frequently using the road — and there are no alternate routes available — the tolerance to road failure will be very low. Conditions such as these may justify a certain amount of over design and the use of higher cost options. Conversely, if the risk tolerance is high, lower cost options may be favored.
**DESIGN PROCESS**

Design charts are organized by design range, type of geosynthetic, and base course quality. The charts are used to determine the required compacted base course aggregate thickness as a function of the subgrade CBR value. The subgrade soil must be identified along with its condition, as well as an estimate of its CBR value. The subgrade CBR value will dictate whether the design range is critical, intermediate, or non-critical. The base course material should then be selected based on its quality and availability. The type of geosynthetic must be chosen based on the severity of the design as well as the base material restrictions. The traffic impact must be estimated to confirm that it falls within the scope of this guide. The correct design chart can then be selected, and the required compacted base course thickness can be determined. A flow chart and tables are provided to help the user estimate these required input parameters. Figure 11 outlines the decision process for selecting the appropriate design chart based on input data. A design example is also provided (Appendix C) to illustrate the entire process. A glossary of terms is available at the end of the guide to help clarify key parameters and concepts.

### Key Input Parameters

1. **Subgrade soil classification**  
   (Table 2, Table 3, Table 4)

2. **Subgrade strength (CBR estimation)**

3. **Subgrade strength design range**  
   (Table 6)

4. **Base course material selection and classification**  
   (Table 2, Table 5, Table 7, Table 8)

5. **Base course strength (CBR estimation)**

6. **Traffic impact estimation**  
   (Table 9)

7. **Required compacted base course thickness**  
   (Figures 13 to 20)

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**Figure 11. Decision support flowchart.**
Step 1: Subgrade soil classification

The first step in the design is the identification of the subgrade soil on which the road is to be built or rehabilitated. Tables 2 and 3 are adapted from the identification and classification chart provided by Holtz and Kovacs (1981) for sands and gravels and for silts and clays, respectively. It helps the user identify and classify subgrade soils according to the USCS classification system through a series of simple questions and visual descriptors or tests. Soil lab testing can also be performed to identify the soil.

Table 2. Coarse-grained soil classification

<table>
<thead>
<tr>
<th>Major divisions</th>
<th>Description</th>
<th>Field Identification (do not consider particles larger than 75 mm and base fractions on estimated weights)</th>
<th>USCS classification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gravels</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(more than half of coarse particles are larger than 5 mm)</td>
<td>Clean gravels (little to no fines)</td>
<td>Wide range of grain sizes and substantial amounts of all intermediate particle sizes</td>
<td>GW</td>
</tr>
<tr>
<td></td>
<td>Poorly graded gravel, gravel-sand mixtures, little or no fines</td>
<td>Predominantly one size or a range of sizes with some intermediate sizes missing</td>
<td>GP</td>
</tr>
<tr>
<td></td>
<td>Silty gravels, gravel-sand-silt mixtures</td>
<td>Gravel is mixed with non-plastic fine particles with low plasticity. Fines are of ML type</td>
<td>GM</td>
</tr>
<tr>
<td></td>
<td>Clayey gravels, gravel-clay mixtures</td>
<td>Gravel is mixed with plastic fine particles with high plasticity. Fines are of CL type</td>
<td>GC</td>
</tr>
<tr>
<td><strong>Sands</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(more than half of material is visible to the naked eye)</td>
<td>Clean sands (little to no fines)</td>
<td>Wide range of grain sizes and substantial amounts of all intermediate particle sizes</td>
<td>SW</td>
</tr>
<tr>
<td></td>
<td>Poorly graded sands, little or no fines</td>
<td>Predominantly one size or a range of sizes with some intermediate sizes missing</td>
<td>SP</td>
</tr>
<tr>
<td></td>
<td>Silty sands, sand-silt mixtures</td>
<td>Sand mixed with non-plastic fines or fines with low plasticity. Fines are of ML type</td>
<td>SM</td>
</tr>
<tr>
<td></td>
<td>Clayey sands, sand-clay mixtures</td>
<td>Sand mixed with plastic fines or fines with high plasticity, fines are of CL type</td>
<td>SC</td>
</tr>
</tbody>
</table>

Note: Adapted from "An Introduction to Geotechnical Engineering" by R.D. Holtz and W.D. Kovacs, 1981, p. 52. Copyright 1981 by Prentice-Hall.
### Table 3. Fine-grained soil classification

<table>
<thead>
<tr>
<th>Major divisions</th>
<th>Description</th>
<th>Field Identification</th>
<th>USCS classification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fine-grained soils</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Silts and clays</strong></td>
<td>Liquid limit less than 50</td>
<td>Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity</td>
<td>None to slight</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inorganic clays of low plasticity, gravelly clays, sandy clays, silty clays, lean clays</td>
<td>Medium to high</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic silts and organic silty clays of low plasticity</td>
<td>Slight to medium</td>
</tr>
<tr>
<td></td>
<td>Liquid limit more than 50</td>
<td>Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts</td>
<td>Slight to medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inorganic clays of high plasticity, fat clays</td>
<td>High to very high</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic clays of medium to high plasticity, organic silts</td>
<td>Medium to high</td>
</tr>
<tr>
<td><strong>Highly organic soils</strong></td>
<td></td>
<td>Peat and other highly organic soils</td>
<td>Identifiable by colour. Odour, spongy feel, and fibrous texture</td>
</tr>
</tbody>
</table>

**Note:** Adapted from “An Introduction to Geotechnical Engineering” by R.D. Holtz and W.D. Kovacs, 1981, p. 52. Copyright 1981 by Prentice-Hall.
As a further guide towards classifying on-site subgrade soil, pictures and associated USCS classifications are provided for some common soils in Table 4.

**Table 4. Typical weak subgrades**

<table>
<thead>
<tr>
<th>USCS classification</th>
<th>Description</th>
<th>Condition/quality</th>
<th>Source</th>
<th>Illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td>OH</td>
<td>Organic clay, high plasticity</td>
<td>Very weak subgrade, unacceptable as base course</td>
<td>Natural soil with organic material</td>
<td></td>
</tr>
<tr>
<td>CL</td>
<td>Inorganic clay, low plasticity</td>
<td>Weak subgrade, unacceptable base course even at low water content</td>
<td>Natural soil in dry area</td>
<td></td>
</tr>
<tr>
<td>CL</td>
<td>Inorganic clay, low plasticity</td>
<td>Weak subgrade, unacceptable base course, critically weak when saturated</td>
<td>Natural soil in wet area or after rainfall</td>
<td></td>
</tr>
<tr>
<td>Pt</td>
<td>Peat</td>
<td>Extremely weak, mostly composed of organic material</td>
<td>Accumulation of decaying vegetation</td>
<td></td>
</tr>
</tbody>
</table>

**Step 2: Subgrade strength**

Once the soil type has been identified, the CBR value can be estimated from Table 5. The estimation should take into account whether the soil conditions are poor, fair, or excellent. When not certain, it is always advised to assume poor conditions in order to be conservative. The CBR values are colour-coded to give a general indication of the strength. Values in red indicate weak subgrades requiring reinforcement while values in green do not. The CBR value of a soil may also be determined through laboratory or field testing methods.
### Table 5. Soil CBR values and relevant parameters

<table>
<thead>
<tr>
<th>USCS classification</th>
<th>Value as roadway material</th>
<th>Value as base course</th>
<th>Hydraulic properties and susceptibilities</th>
<th>Physical characteristics</th>
<th>CBR range and condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Potential frost susceptibility</td>
<td>Compressibility and expansion</td>
<td>Drainage characteristics</td>
</tr>
<tr>
<td>GW</td>
<td>Excellent</td>
<td>Good to excellent</td>
<td>None to very slight</td>
<td>Almost none</td>
<td>Excellent</td>
</tr>
<tr>
<td>GP</td>
<td>Very good</td>
<td>Poor to fair</td>
<td>None to very slight</td>
<td>Almost none</td>
<td>Excellent</td>
</tr>
<tr>
<td>GM</td>
<td>Very good</td>
<td>Fair to good</td>
<td>Slight to medium</td>
<td>Very slight</td>
<td>Fair to poor</td>
</tr>
<tr>
<td>GC</td>
<td>Good to very good</td>
<td>Poor</td>
<td>Slight to medium</td>
<td>Slight</td>
<td>Poor to practically impervious</td>
</tr>
<tr>
<td>SW</td>
<td>Fair to good</td>
<td>Poor</td>
<td>None to very slight</td>
<td>Almost none</td>
<td>Excellent</td>
</tr>
<tr>
<td>SP</td>
<td>Fair to good</td>
<td>Poor to not suitable</td>
<td>None to very slight</td>
<td>Almost none</td>
<td>Excellent</td>
</tr>
<tr>
<td>SM</td>
<td>Fair to good</td>
<td>Poor</td>
<td>Slight to high</td>
<td>Very slight</td>
<td>Fair to poor</td>
</tr>
<tr>
<td>SC</td>
<td>Poor to fair</td>
<td>Not suitable</td>
<td>Slight to high</td>
<td>Slight to medium</td>
<td>Poor to practically impervious</td>
</tr>
<tr>
<td>ML</td>
<td>Poor</td>
<td>Not suitable</td>
<td>Medium to very high</td>
<td>Slight to medium</td>
<td>Fair to poor</td>
</tr>
<tr>
<td>CL</td>
<td>Poor</td>
<td>Not suitable</td>
<td>Medium to very high</td>
<td>Medium</td>
<td>Practically impervious</td>
</tr>
<tr>
<td>OL</td>
<td>Poor</td>
<td>Not suitable</td>
<td>Medium to very high</td>
<td>Medium to high</td>
<td>Poor</td>
</tr>
<tr>
<td>MH</td>
<td>Poor</td>
<td>Not suitable</td>
<td>Medium to very high</td>
<td>High</td>
<td>Fair to poor</td>
</tr>
<tr>
<td>CH</td>
<td>Poor</td>
<td>Not suitable</td>
<td>Medium to very high</td>
<td>High</td>
<td>Practically impervious</td>
</tr>
<tr>
<td>OH</td>
<td>Poor</td>
<td>Not suitable</td>
<td>Medium to very high</td>
<td>High</td>
<td>Practically impervious</td>
</tr>
<tr>
<td>Pt</td>
<td>Poor</td>
<td>Not suitable</td>
<td>Slight</td>
<td>Very high</td>
<td>Fair to poor</td>
</tr>
</tbody>
</table>

Note: Table structure and data from ERES Consultants Inc. (2004); Christopher, Schwartz, & Boudreau (2006); Hamilton (2000); Asphalt Paving Association of Iowa (n.d.); NSW Government (2018). Optimum moisture content data from Shoop, Diemand, Wieder, Mason, & Seman (2008). Note: CBR values in red indicate weak to very weak subgrade soil where reinforcement is required, CBR values in yellow indicate moderately weak subgrade soil, and CBR values in green indicate strong to very strong subgrade soils where reinforcement is not required.
**Step 3: Subgrade strength design range**

Once the subgrade CBR has been estimated, a strength design range can be determined using Table 6. The design range is considered critical for a CBR of 1.5 or less, intermediate for a CBR between 1.5 and 4, and non-critical for a CBR above 4. Geosynthetic product options are given for each design range. These are based on the performance and cost of each product type. Specification guidelines for product selection are provided in Appendix A. A separation layer in the form of a non-woven geotextile is mandatory for all design ranges. Reinforcement is mandatory in the critical and intermediate design ranges. In the non-critical range, geogrid reinforcement is recommended, however, a non-woven geotextile may be used on its own.

---

**Step 4: Base course selection and classification**

The base course material can be identified using Table 2 and Table 8. Table 7 presents the useful criteria for the selection of base materials when multiple options are available, whereas Table 5 provides guidance on a material's general suitability as a base course. Fine grained and organic soils are not suitable as base courses. It is recommended to assume that the base course is of low quality if uncertain of its condition. For the purposes of this guide, most pit-run materials found on or near site generally fall under the low-quality designation, although exceptions are possible. Usually only imported manufactured gravels fall under the high-quality designation. Naturally occurring well-graded gravel is possible but is rare. It is always highly recommended to use the best aggregate available, cost permitting. USCS classification alone is not enough to determine an aggregate's quality; the full spectrum of conditions must be examined (Bilodeau, J. P., 2009).

---

**Table 6. Design ranges and recommendations**

<table>
<thead>
<tr>
<th>Design recommendations</th>
<th>Subgrade CBR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Critical range</td>
</tr>
<tr>
<td></td>
<td>0.5 to 1.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reinforcement</th>
<th>Mandatory</th>
<th>Mandatory</th>
<th>Recommended</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended geosynthetics</td>
<td>Geocells, woven geotextiles, or wicking geotextiles</td>
<td>Geogrids, woven geotextiles</td>
<td>Non-woven geotextiles, biaxial geogrids</td>
</tr>
</tbody>
</table>
Table 7. Base course quality conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>High-quality</th>
<th>Low-quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Materials</td>
<td>GW, manufactured aggregates</td>
<td>Gravel and sand pit-run aggregates</td>
</tr>
<tr>
<td>Gradation</td>
<td>Good to excellent</td>
<td>Poor to fair</td>
</tr>
<tr>
<td>Fines content</td>
<td>2% - 12%</td>
<td>12% - 50%</td>
</tr>
<tr>
<td>Moisture content</td>
<td>At or near optimum</td>
<td>High water content</td>
</tr>
<tr>
<td>Particle angularity</td>
<td>Angular</td>
<td>Smooth/rounded</td>
</tr>
<tr>
<td>Abrasion resistance (based on geological source)</td>
<td>High resistance</td>
<td>Low resistance</td>
</tr>
<tr>
<td>Compaction</td>
<td>Well compacted</td>
<td>Little to no compaction</td>
</tr>
</tbody>
</table>

It is well understood that using high-quality material is not always a cost-effective solution. The choice of base material should be made by examining the quality of pit-run available within a reasonable radius of the construction site and determining whether there is a suitable option. If only low-quality material is available, one may decide to use a reinforcement option that permits its use or to import high-quality aggregate. The opportunity cost of choosing either scenario should be weighed and compared.

Another factor to consider when selecting a base course material is its compatibility with the chosen geosynthetic. Geogrids require that the average particle size of the base aggregate not be larger than the grid opening size. If too high a percentage of the particles are larger than the grid openings, the geogrid reinforcement mechanism will not function properly. This is demonstrated in Figure 12.

Figure 12. Aggregate particle not properly matched to geogrid opening.
Step 5: Base course strength
The base course's USCS classification and conditions will determine whether it is a high-quality or a low-quality material. The CBR value of the base course material can be estimated using Table 5, whereas Table 8 shows examples of some typical base course materials and associated conditions. Low-quality base course materials are defined as having a CBR value of between 15 and 60 (not included). It is assumed that if proper construction practices are being followed including material selection and compaction, a minimum CBR value of 15 will be achieved. Most on site pit-run materials will fall under the low-quality designation. High-quality materials are defined as having a CBR value of 60 or more. This is reserved for gravels of the highest quality which meet all the quality criteria. This includes imported manufactured aggregate and well-graded gravel pit-runs which are rare but possible in some areas. MG-20 is an example of a high-quality manufactured aggregate from Quebec (Bureau de normalisation du Québec, 2014). All province’s have their own equivalent high-quality road construction aggregates under different designations but with similar specifications.
<table>
<thead>
<tr>
<th>USCS classification</th>
<th>Description</th>
<th>Condition/quality</th>
<th>Source</th>
<th>Example picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>GW</td>
<td>Well-graded gravel, MG-20, or equivalent, ¾ inch or less particle size</td>
<td>High quality</td>
<td>Imported manufactured aggregate</td>
<td></td>
</tr>
<tr>
<td>GW</td>
<td>Well-graded gravel, MG-56, or equivalent, 2-inch or less particle size,</td>
<td>High quality</td>
<td>Imported manufactured aggregate</td>
<td></td>
</tr>
<tr>
<td>GW</td>
<td>Well-graded gravel</td>
<td>High quality</td>
<td>Pit-run</td>
<td></td>
</tr>
<tr>
<td>GP</td>
<td>Poorly graded gravel</td>
<td>Moderately low-quality, angular particle shape increases quality</td>
<td>Pit-run</td>
<td></td>
</tr>
<tr>
<td>GP</td>
<td>Poorly graded gravel</td>
<td>Low-quality, smooth rounded particle shape further decreases the strength of the material</td>
<td>Pit-run</td>
<td></td>
</tr>
<tr>
<td>SP</td>
<td>Poorly graded sand, beach sand</td>
<td>Low-quality, smooth rounded particle shape further decreases the strength of the material</td>
<td>Pit-run</td>
<td></td>
</tr>
</tbody>
</table>
**Step 6: Traffic impact estimation**

The traffic impact must be estimated by considering not just the number of truck-passes, but also the impact per vehicle type. Different truck configurations will inflict varying levels of damage to the road. The impact of a vehicle on a road is defined using the equivalent single axle load (ESAL) concept (American Association of State Highway and Transportation Officials, 1993). The equivalent of 100,000 ESALs was chosen as the single traffic input for the design charts. This value is higher than what is typically used but will ensure a conservative design. The design life will depend on the period of time over which the road will experience 100,000 ESALs worth of traffic. Detailed ESAL calculations are welcome but are not required.

Table 9 equates the chosen traffic input to estimations of the number of passes of some common trucks used in the forest industry. The number of passes is given in two ways: number of fully loaded trips, and number of roundtrips which equates to one loaded and one unloaded pass. This can be compared with actual traffic count data or estimations of expected traffic. Since the traffic input is conservative, most traffic scenarios will fall under the scope of this design guide. If the road section in question is expected to see these amounts of traffic or less, the design catalogue can be used. If multiple configurations are expected on the road section, an estimate can be made based on each truck type’s relative proportion of the total truck fleet. If the traffic volume exceeds that shown below or extremely damaging truck configurations are being used, this catalogue is not applicable, and a different design methodology is required. This simplified approach to traffic input is only valid if regular maintenance is being performed on the road.
Table 9. Traffic count estimations for common truck configurations

<table>
<thead>
<tr>
<th>Truck configurations</th>
<th>Assumed gross vehicle weight (tonnes)</th>
<th>Maximum payload (t)</th>
<th>Tare weight (t)</th>
<th>Truck traffic for 100,000 ESALs</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-axle tridem drive/tridem semi-trailer</td>
<td>54.3</td>
<td>33.3</td>
<td>21.0</td>
<td>18600</td>
</tr>
<tr>
<td>7-axle tandem drive/quad semi-trailer</td>
<td>55.5</td>
<td>37.0</td>
<td>18.5</td>
<td>16600</td>
</tr>
<tr>
<td>8-axle super B-train</td>
<td>63.5</td>
<td>44.3</td>
<td>19.2</td>
<td>14700</td>
</tr>
<tr>
<td>8-axle tridem-drive B-train</td>
<td>63.5</td>
<td>43.5</td>
<td>20.0</td>
<td>13900</td>
</tr>
<tr>
<td>8-axle tridem-drive/quad-axle wagon</td>
<td>63.5</td>
<td>44.4</td>
<td>19.1</td>
<td>14000</td>
</tr>
<tr>
<td>9-axle tridem-drive B-train</td>
<td>72.5</td>
<td>51.0</td>
<td>21.5</td>
<td>12500</td>
</tr>
<tr>
<td>10-axle B-train</td>
<td>80</td>
<td>56.8</td>
<td>23.2</td>
<td>12600</td>
</tr>
<tr>
<td>4-axle twin steer/tandem drive dump truck</td>
<td>34</td>
<td>17.0</td>
<td>17.0</td>
<td>15400</td>
</tr>
<tr>
<td>5-axle tandem drive/tandem semi-trailer</td>
<td>40</td>
<td>24.3</td>
<td>15.7</td>
<td>18400</td>
</tr>
<tr>
<td>6-axle tandem drive/tridem semi-trailer</td>
<td>48</td>
<td>31.5</td>
<td>16.5</td>
<td>18600</td>
</tr>
</tbody>
</table>

Note: Equivalent number of passes and trips calculated using Transportation Association of Canada (2003) ESAL formulas.
Step 7: Required compacted base course thickness

Once the input parameters and the design range are known, the appropriate design chart can be selected and used. All charts provide the required compacted structural base course thickness. The road will not perform as intended if the structure is not compacted using proper compaction techniques.

A minimum base course thickness of 100 mm should be respected at all times, regardless of the severity of the design. An added 100 mm thickness of appropriate wearing course material or of the same material as the base course must be added to the thickness obtained from the design charts. This added layer functions as the rolling surface and prevents the base course layer from being structurally compromised due to gravel loss. The total thickness between the base course and the wearing course should never be less than 200 mm.

Unreinforced thicknesses are also provided to serve as a comparison to the reinforced design. In all cases, reinforcement leads to significant reductions in required aggregate thickness. The charts can be used to perform a cost benefit analysis between an unreinforced design and a reinforced design. They can also be used to compare different geosynthetic products amongst each other.

As previously mentioned, different geosynthetic product options are provided depending on the subgrade strength design range. High-strength high-cost options will generally be used over the weakest subgrades where their performance justifies their cost. Lower strength, low-cost options are typically favored once the subgrade strength becomes less critical because they allow for savings in required thickness while remaining cost effective.

Critical range design charts

The following design charts pertain to the critical design range. Geotextile and geocell reinforcement options are provided. Geocells should be used in conjunction with non-woven textiles. Due to the stated limitation of the design methodology, the charts are plotted for a single base course. This however does not mean that poor materials can be used in the critical subgrade strength range. It is always recommended to use the highest quality gravel for the base course whenever possible, especially when designing on critically weak subgrades.

Geotextiles
The chart in Figure 13 was developed using the Giroud and Han method (Giroud and Han, 2004a, 2004b).

Geocells
The chart in Figure 14 provides the required base thickness above the geocell. This does not include the thickness of the geocell itself, which should be filled with an appropriate fill material. A non-woven geotextile should be used underneath the geocell to provide separation. Charts are produced using the Pokharel method Pokharel (2010).
Figure 13. Required compacted base course thickness when using geotextiles in critical subgrade strength range.

Figure 14. Required compacted base course thickness when using geocells in critical subgrade strength range.
Intermediate range
The following charts represent the design thicknesses for the intermediate range. Geotextile and geogrid options are provided. Two sets of graphs are given, one for a low-quality base material and one for a high-quality base material. It is always recommended to use a high-quality gravel whenever possible. However, the low quality base course charts should be used when high quality material is unavailable or when the quality of the pit-run is uncertain. Since most pit-runs do not meet the high-quality standards, it is safer to assume the base course is of low-quality.

Geotextiles
The following charts were developed using the Giroud and Han method (Giroud and Han, 2004a, 2004b).

LOW-QUALITY BASE COURSE (CBR = 15)

Figure 15. Required compacted base course thickness when using geotextiles with low-quality base course in intermediate subgrade strength range.
High-Quality Base Course (CBR = 60)

![Graph showing required compacted base course thickness for high-quality base course in intermediate subgrade strength range.]

Figure 16. Required compacted base course thickness when using geotextiles with high-quality base course in intermediate subgrade strength range.

Geogrids

The following charts were developed using the Giroud and Han method (Giroud and Han, 2004a, 2004b). SpectraPave by Tensar International Corporation (2019) was used to generate values for triaxial geogrids. Geogrids should be used in conjunction with a non-woven geotextile to provide separation.

Low-Quality Base Material (CBR = 15)

![Graph showing required compacted base course thickness for low-quality base course in intermediate subgrade strength range.]

Figure 17. Required compacted base course thickness when using geogrids with low-quality base course in intermediate subgrade strength range.
**Non-critical range**

The following charts pertain to non-critical subgrades. Reinforcement is not mandatory. If forgoing reinforcement, a non-woven geotextile should be used to provide a separation layer. Biaxial geogrids in conjunction with non-woven geotextiles may be a cost effective solution. Woven geotextile and geocell reinforcement options are not recommended for these subgrade strengths because they are generally no longer cost effective. However, if gravel is in short supply or costs are a key concern, high-strength reinforcements options may be considered to further reduce aggregate quantities.

The charts provide unreinforced, non-woven geotextile and biaxial geogrid (with non-woven textile) design options for both low-quality and high-quality base materials. Design thicknesses are once again compacted values. The Giroud and Han method (Giroud and Han, 2004a, 2004b) was used to generate the values.

![Figure 18. Required compacted base course thickness when using geogrids with high-quality base course in intermediate subgrade strength range.](image-url)
LOW-QUALITY BASE COURSE (CBR = 15)

Figure 19. Required compacted base course thickness when using low-quality base course in non-critical subgrade strength range.

HIGH-QUALITY BASE COURSE (CBR = 60)

Figure 20. Required compacted base course thickness when using high-quality base course in non-critical subgrade strength range.
**Aggregate:** Combination of different particle sizes that include sand, gravel and/or crushed stone. Used as road building material, most typically for the base course. Can either be naturally occurring pit-run or manufactured.

**Axle load:** The load transferred to the vehicle axle. The axle load influences the amount of damage inflicted to the road structure by a vehicle.

**Base course:** The structural layer placed on top of the subgrade with the role of distributing vehicle loads and transmitting to the subgrade. In this guide, the base course is the only structural layer.

**Bearing capacity:** The ability of a soil to support loads. A higher bearing capacity signifies a higher strength of the soil. Soils in road applications must be able to support vehicle loads over the intended use of the road.

**Biaxial geogrid:** Geogrid with rectangular grid openings.

**California Bearing Ratio (CBR):** Common measure of bearing capacity or soil strength for road applications. The CBR value is affected by many factors including material type, moisture content, and degree of compaction. The CBR can be determined through standardized lab testing or in-field test procedures.

**Cellular confinement:** Confinement mechanism of geocells. Fill material is fully laterally confined.

**Clay:** Fine grained soil with low permeability. Weak subgrade and road building material. Requires more involved on-site identification procedure or laboratory testing to distinguish from a silt soil.

**Coarse-grained soil:** As defined by the USCS classification system, soil with 50% or more particles larger than 0.075 mm, which is the smallest size visible to the naked eye. This includes sands and gravels.

**Compaction:** The process by which voids or air space are removed from a soil or granular material. This increases the density and strength of the material. Compaction improves the quality of a road building material and leads to a lower required thickness. All design charts provide the required base course thickness after it has been compacted. Without compaction, the base course will not develop the required strength for the design.

**Confinement:** The strength of a soil can be increased through confinement by a geosynthetic.

**Critical section:** A road segment with very weak subgrade soil which necessitates above average interventions such as geosynthetic reinforcement.

**Crown:** A best practice in road design where the road is highest at its centerline with each side gradually sloping down to allow for good drainage and prevent water from puddling on the surface.
Design life: This guide defines the design life as the period of time needed to reach an expected traffic impact equivalent to 100,000 ESALs or less. The daily traffic level and impact per vehicle will determine the length of this period.

Dilatancy test: Field identification procedure for fine grained soils. A moist soil’s reaction to shaking after removing particles larger than 5 mm. A handful is vigorously shaken in one’s palm. The reaction is measured by how quickly water appears on the surface of the soil sample and how quickly it disappears when squeezed. Very fine sands and inorganic silts have the quickest reactions.

Drainage: Water or moisture content is removed over time from the road structure. This can be accelerated by avoiding low permeability clays and silts and using good quality aggregate with good particle distribution and good permeability.

Dry strength test: Field identification procedure for fine grained soils. A soil’s resistance to crumbling and breaking when dry after removing particles larger than 5 mm. The higher a soil’s plasticity, the higher its dry strength.

Equivalent Single Axle Load (ESAL): The ESAL concept is used to compare vehicle impact from all types of truck axle and tire configurations. This is done by converting different configurations into equivalent number of passes of the standard axle. The standard axle is defined as an 80 kN (18,000 lbs) dual wheel single axle. It has a value of 1 ESAL. A higher impact configuration will have an ESAL value greater than 1, meaning it is equivalent to more than 1 pass of the standard axle. This is the case for heavy hauling trucks. The total ESAL value of a truck is the sum of all ESAL values from each of its axles.

Fill material: Generally defined as any material deposited to fill a depression or hole and raise the ground surface. In this guide, fill material refers primarily to the aggregate material used to fill the three-dimensional cells of a geocell.

Fine grained soil: As defined by the USCS classification system, fine grained soils have 50% or more particles smaller than 0.075 mm which is, the smallest size visible to the naked eye. These soils include silts, clays and organic materials such as peat.

Fines: Fines are particles smaller than 0.075 mm. They are not visible to the naked eye.

Geocells: Three-dimensional honeycomb shaped geosynthetics that provide a high level of reinforcement through cellular confinement of fill material.

Geological source: The geological source of a road building material can have a great influence on its quality and durability. An aggregate’s resistance to weathering and abrasion will depend on what type of rock it originates from. An aggregate can be considered well graded but be of a poor geological source and therefore be of low quality for road building.
**Gradation:** Refers to a soil’s distribution in particle sizes. Well graded soil has a low number of fine particles and well distributed coarse grained particles. Good gradation is an indicator of material quality but not the only measure.

**Gravel loss:** Resurfacing results in a certain amount of gravel loss upon each grader passage when maintenance is performed. This is why an adequate wearing course should be provided in addition to the structural base course.

**Gravel:** Coarse grained material with 50% of particles larger than 5 mm and up to 75 mm, as defined by the USCS classification system.

**Groundwater:** Water present beneath the earth’s surface that infiltrates a soil from below through its voids. The effects of groundwater on a road will depend on the depth of the water table.

**Hydrophilic:** A property of wicking geotextiles that attracts moisture and removes it from the surrounding soil.

**Hygroscopic:** A property of a wicking geotextile that attracts moisture.

**Interlocking:** The primary reinforcement mechanism of geogrids where aggregate particles interlock with one another inside the grid openings.

**Maintenance:** For the purposes of this guide, maintenance is defined as grading and levelling the road surface to eliminate rutting and to restore proper road geometry. Maintenance can be performed when needed or at regular intervals based on the expected traffic impact.

**Manufactured aggregate:** High-quality imported crushed material. Each province has its own set of standard specifications for these high-quality road building materials.

**Moisture content:** The water contained inside the pore spaces and voids of a soil. A high moisture content will greatly reduce the strength of a soil.

**Non-woven geotextile:** Non-woven geotextiles are composed of synthetic materials bonded together chemically, thermally, or using needle punching among other methods. They are typically used as a separation layer.

**Optimum Moisture content:** Moisture content level that leads to optimal density during compaction.

**Organic soil:** Soil that contains organic matter with very low strength. Silts and clays can have organic content. Peat soil is mostly composed of organic material and extremely weak.

**Particle shape:** The degree of angularity or smoothness of particles. Higher angularity increase friction and interlocking between particles and increases soil strength. Smooth particle soils have less interparticle friction and therefore lower strength. The effect of particle shape is most evident in gravel.

**Peat:** Mostly composed of organic material identifiable by its distinct odour and colour.

**Perforations:** Geocells can be perforated with small holes to allow for drainage.
**Permeability:** The ability for water to flow through a material. High permeability allows for good drainage while low permeability materials retain water. The higher the fines content in a soil, the lower the permeability.

**Pit-run:** Term used to describe non-manufactured naturally occurring road building aggregate found on site or within a reasonable distance.

**Plasticity:** The degree to which a soil can be deformed without reaching failure.

**Reinforcement:** Process by which the strength or load carrying capacity of a road structure is increased either mechanically or chemically. This guide is only concerned with mechanical reinforcement in the form of geosynthetics.

**Sand:** Coarse grained soil defined by 50% or more particles being smaller than 5 mm, as defined by the USCS classification system.

**Saturated soil:** When pore spaces of a soil are completely filled with water. The soil is at its weakest in this state. Low permeability fine grained soils do not drain well and stay saturated for longer periods of time.

**Separation:** When a barrier is provided at the interface between two layers of a road to prevent the weaker layer below from mixing with the stronger layer above and degrading its structural integrity. This is the primary function of non-woven geotextiles.

**Side ditch:** Side ditching is used to collected and carry water away from the road structure.

**Side slopes:** Downward sloping of the sides of the road alignment to facilitate drainage and send water to the side ditches.

**Silt:** Fine grained soil with low permeability. Weak subgrade and road building material. Requires more involved on-site identification procedures or laboratory testing to distinguish from a clay soil.

**Soil:** Relatively loose agglomerate of mineral and organic material and sediment found above the bedrock. The primary soil groups are clays, silts, sands, and gravels.

**Subgrade:** The in-situ soil or fill material layer upon which the road structure is built. The weakest subgrade are silts, clays, and organic soils.

**Surface rutting:** The channelized tire track depressions created in the road surface by traffic circulation. Rutting increases over time to the point where maintenance is required to restore the road surface.

**Toughness test:** Field identification procedure for fine grained soils. A small sample of soil is molded into the consistency of putty and rolled out by hand in a thin layer of about 3 mm thickness on a smooth surface. Water may need to be added in order to obtain the correct consistency. The thread is refolded and rerolled several times until it crumbles which signifies
that it has reached its plastic limit. The test measures the soil’s consistency or toughness when it has reached this point.

**Traffic impact:** The traffic impact is a combination of the level of traffic and the impact per vehicle pass. It can be quantified using the equivalent single axle load (ESAL) concept.

**Triaxial geogrid:** Geogrid with triangular grid openings.

**Unified Soil Classification System (USCS):** Common system used to classify soils which primarily distinguishes soils based on particle size distribution, plasticity, and presence of organic material. There are four major divisions: coarse grained, fine grained, organic soils, and peat.

**Wearing course:** The running surface or wearing course is a recommended fixed layer of coarse-grained aggregate with a higher degree of fines in order to provide a smooth rolling surface for driver comfort and to account for gravel loss.

**Wicking geotextile:** A type of high-strength woven geotextile that has hydrophilic and hygroscopic yarn which facilitates the removal of moisture from the surrounding soil in addition to reinforcement and separation.

**Woven geotextile:** Woven geotextiles are composed of narrow strips of synthetic material that are woven together. They can provide reinforcement and separation.
REFERENCES


APPENDIX A: GEOSYNTHETIC SELECTION

Tables 10, 11, and 12 summarize relevant specification criteria for each reinforcement option provided in the design charts. There are three types of reinforcement geotextile options: woven, high-strength woven, and high-strength wicking (Tencate Geosynthetics Americas, 2015a, 2015b, 2015c). Although available in a wide range of thicknesses, no specifications are provided for non-woven geotextiles since they are all treated as the same for the purposes of this guide. There are three types of geogrids: biaxial, high-strength biaxial, and triaxial (Tensar International Corporation, 2013, 2014). There are two types of geocells: thin with large cells and thick with small cells (PRS Geo-Technologies, n.d.). The specifications listed in these tables are guidelines to help choose among available geosynthetic products. Although they are based on specific manufacturer specification sheets, the values can be used to select any relevant product from other manufactures provided they meet the listed property requirements. More information may be required and can be obtained by contacting a manufacturer or distributor.

Table 10. Geotextile specifications

<table>
<thead>
<tr>
<th>Property</th>
<th>Test method</th>
<th>Units</th>
<th>Woven</th>
<th>High-strength woven</th>
<th>High-strength wicking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength at 2% strain (CD)</td>
<td>ASTM D4595</td>
<td>kN/m (lb/ft)</td>
<td>Less than 14.9 (1020)</td>
<td>14.9 (1020) or more</td>
<td>15.8 (1080) or more</td>
</tr>
<tr>
<td>Tensile strength at 2% strain (MD)</td>
<td>ASTM D4595</td>
<td>kN/m (lb/ft)</td>
<td>Less than 8.8 (600)</td>
<td>8.8 (600) or more</td>
<td>-</td>
</tr>
<tr>
<td>Tensile strength at 5% (CD)</td>
<td>ASTM D4595</td>
<td>kN/m (lb/ft)</td>
<td>Less than 32.9 (2256)</td>
<td>32.9 (2256) or more</td>
<td>-</td>
</tr>
<tr>
<td>Tensile strength at 5% strain (MD)</td>
<td>ASTM D4595</td>
<td>kN/m (lb/ft)</td>
<td>Less than 1800 (26.3)</td>
<td>1800 (26.3) or more</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: Values presented in table are minimum average roll values.
### Table 11. Geogrid specifications

<table>
<thead>
<tr>
<th>Property</th>
<th>Test method</th>
<th>Units</th>
<th>Biaxial</th>
<th>High-strength biaxial</th>
<th>Triaxial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aperture shape</td>
<td></td>
<td></td>
<td>Rectangular</td>
<td>Rectangular</td>
<td>Triangular</td>
</tr>
<tr>
<td>Tensile strength at 2% strain (MD)</td>
<td>ASTM D6637–10 method A</td>
<td>kN/m (lb/ft)</td>
<td>Less than 6 (410)</td>
<td>6 (410) or more</td>
<td>-</td>
</tr>
<tr>
<td>Tensile strength at 5% strain (MD)</td>
<td>ASTM D6637–10 method A</td>
<td>kN/m (lb/ft)</td>
<td>Less than 11.8 (810)</td>
<td>11.8 (810) or more</td>
<td>-</td>
</tr>
<tr>
<td>Ultimate tensile strength</td>
<td>ASTM D663 –10 method A</td>
<td>kN/m (lb/ft)</td>
<td>Less than 19.2 (1310)</td>
<td>19.2 (1310) or more</td>
<td>-</td>
</tr>
<tr>
<td>Radial stiffness at 0.5% strain</td>
<td>ASTM D6637-10</td>
<td>kN/m (lb/ft)</td>
<td>-</td>
<td>-</td>
<td>300 (20,580) or more</td>
</tr>
<tr>
<td>Aperture stability modulus</td>
<td>ASTM D7864-15</td>
<td>mN/deg</td>
<td>Less than 0.65</td>
<td>0.65 or more</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: Values presented in table are minimum average roll values.

### Table 12. Geocell geometry specifications

<table>
<thead>
<tr>
<th>Property</th>
<th>Units</th>
<th>Thin with large cells</th>
<th>Thick with small cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell height</td>
<td>mm</td>
<td>Less than 150</td>
<td>150 or more</td>
</tr>
<tr>
<td>Cell dimensions (optimal opening)</td>
<td>mm²</td>
<td>Larger than 260 x 224 mm</td>
<td>260 x 224 mm or smaller</td>
</tr>
</tbody>
</table>
APPENDIX B: BENEFITS OF COMPACTION

The chart in Figure 21 is provided solely for demonstration purposes. It shows the difference in required thickness when foregoing compaction. Compacted and uncompacted unreinforced designs are provided for both low-quality and high-quality base course materials. An uncompacted base material will always require more thickness in order to achieve the same load support as the same base material in a compacted state. The benefit of compaction can be seen in the fact that a compacted low-quality material requires less gravel thickness than an uncompacted high-quality material. Compaction is therefore always recommended. Uncompacted thicknesses were estimated using a chart in Barksdale (1991) to determine equivalent uncompacted strength and then imputed to Giroud and Han (Giroud and Han, 2004a, 2004b).

Figure 21. Benefits of compaction.
APPENDIX C: DESIGN ILLUSTRATIVE EXAMPLE

A design example is shown below to help understand how to use the guide.

1. The subgrade soil is identified as being a low plasticity clay or CL according to the USCS classification using Tables 2, 3 and 4.

2. Table 5 is used assuming worst case conditions and a CBR = 0.5 is obtained. Lab testing is also performed and the CBR of the soil is determined as CBR = 1. Since lab testing is more reliable, the design subgrade CBR is taken as CBR = 1.

3. The subgrade CBR is below 1.5, which means it falls under the critical subgrade strength design range. In this range, geotextile and geocell options are provided.

4. The base course material options are now considered. Using Tables 2, 7, and 8, the pit-run available near the worksite is identified as being a silty gravel or GM.

5. Using table 5, its CBR value is estimated to be equal to 40 assuming fair conditions. This material meets many of the high-quality conditions listed in table 7. However, given its estimated CBR value, it will be considered as a low-quality base course for the use of the design charts.

6. The road is expected to see 80,000 ESALs over its intended period of use. This fits within the maximum traffic input of 100,000 ESALs.

7. Given the above input data, a high-strength woven geotextile is chosen. Figure 13 is used to determine the required base course thickness. Figure 22 demonstrates the use of the design chart.

The required unreinforced compacted thickness for these inputs is 780 mm (31 inches).

The required compacted reinforced thickness of 410 mm (16 inches).

This results in gravel savings of 370 mm or 47%.

As per requirements, a wearing course of 100 mm (4 inches) should be used. Therefore,

Total compacted thickness required = reinforced base course thickness + wearing course thickness = 410 + 100 = 510 mm.
Figure 22. Illustrative design example.
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