The Use of Engineered Soils in Canada

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Abstract
The document will identify the three types of engineered soils currently used in Canada including cement modified soils, cement treated bases and full depth reclamation with cement. It will also identify the difference between cement modified material and cement stabilized material. The fine fraction improvement will also be discussed including: Cation exchange, Particle restructuring, Cementitous hydration and Pozzolanic reaction. The purpose of utilizing the three technologies will be presented, as well as, the type of material each process is best suited for and the amount of cement typically used in the procedure. The benefits of utilizing these technologies will also be discussed. The construction procedure will be presented along with quality control procedures followed. The final portion of the paper will identify some Canadian sites where the procedures have been used. Comments will also be provided on how well the various installations are performing.

1.0 Introduction

The first documented use of an Engineered Soil application in North America was in 1935 by South Carolina state DOT used cement modified soils to improve the roadbed for State Highway 41 near Johnsonville. Since that time, portland cement and blended cements have been used to stabilize soils and aggregates for pavement applications on thousands of kilometers of roadway all over the world. After almost 80 years of use, experience has demonstrated that different kinds of engineered soil-cement mixtures can be tailored to specific pavement applications. Engineered soils can be broken down into three main groups:

1) Cement Modified Soils (CMS) – Cement-modified soil is used to improve the engineering properties and construction characteristics of silt and clay soils by reducing the plasticity and enhancing the compaction and strength of the material. Typically the addition of 2 – 5% (by dry weight) of cement is used to modify the soil to provide an improved construction material and better working platform.

2) Cement Treated Soils (CTB) - Cement-treated base is a general term that applies to all hardened soil-cement that meets the minimum durability and strength requirements specified for a project. The CTB can be mixed-in-place, like CMS, using on-site soils or mixed in a central plant using selected aggregate. CTB uses more cement than CMS resulting in a strong, durable, frost resistant layer for the pavement structure. Typical cement contents range from 4 – 10% cement for the mixed in place procedure and 3 to 6 % for the plant mixed process. This results in a 7-day unconfined compressive strengths ranging from 2.1 – 5.5 MPa depending on the mix procedure and soil type.

3) Full Depth Reclamation of Asphalt with cement (FDR-C) – In this case, aggregate for the cement stabilized base is obtained by pulverizing and recycling an old asphalt surface and base material. This construction procedure is very similar to mixed-in-place CTB construction, except that there is an aggregate specification for the blend of the pulverized asphalt and old aggregate base material. FDR-C commonly uses 4 – 6% cement which results in unconfined compressive strengths ranging from 2.1 – 2.8 MPa in 7 days.

Figure 1 shows a typical pavement structure noting where the engineered soils are located and the other cement based products like conventional portland cement concrete pavement (PCCP) and roller compacted concrete (RCC). It is important to note that engineered soils are not concrete products. Figure 2 shows cores from a concrete and engineered soils project. Note that the concrete core is a homogeneous mixture with all the fine and course particles coated with a cementitious gel or paste and all voids are filled. The Engineered soil, however, does not have all the particles coated and voids filled. The soil agglomerations are bound by linkages created by the hydration process. The strength of engineered soils is much lower than concrete pavement too. Figure 3 shows the relationship between the cement content and water content for the various types of cement based paving materials. The engineered soils are highlighted in the diagram within the red dashed circle. Note the much lower cement content for the engineered soils products compared to conventional concrete and roller compacted concrete which are much higher strength material.

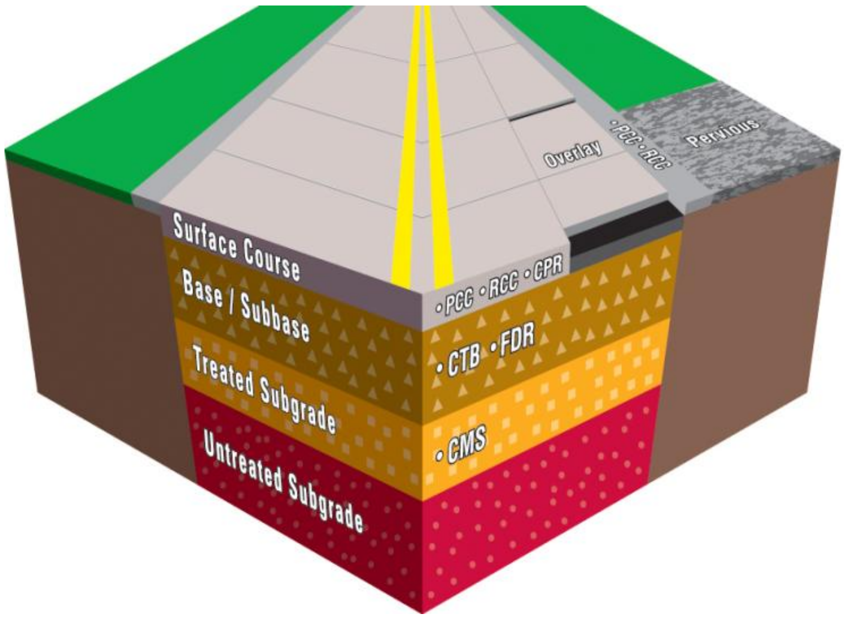
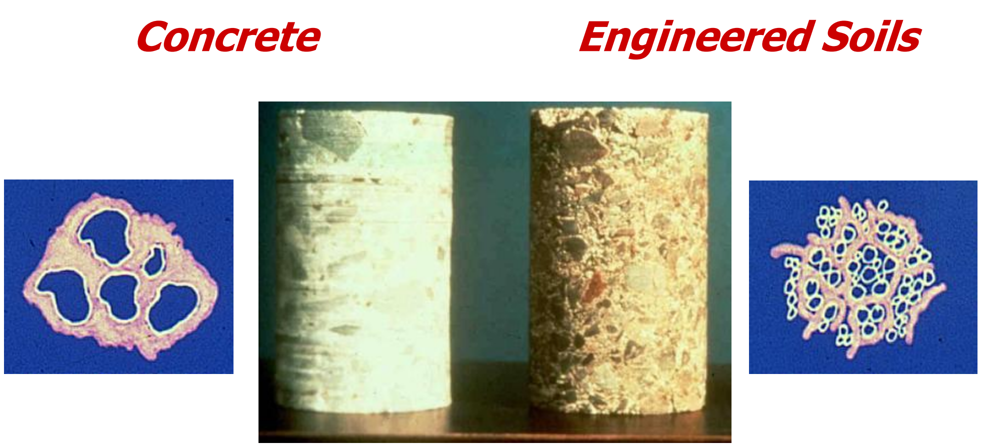


Figure 1: Cement-Based Materials in Pavements



Cementitious Gel or Paste

- *coats all particles*
- *fills voids*

Hydration Products

- all particles not coated
- voids not filled
- linkages bind soil agglomerations together

Figure 2: Comparison of Concrete Core to and Engineered Soils Core

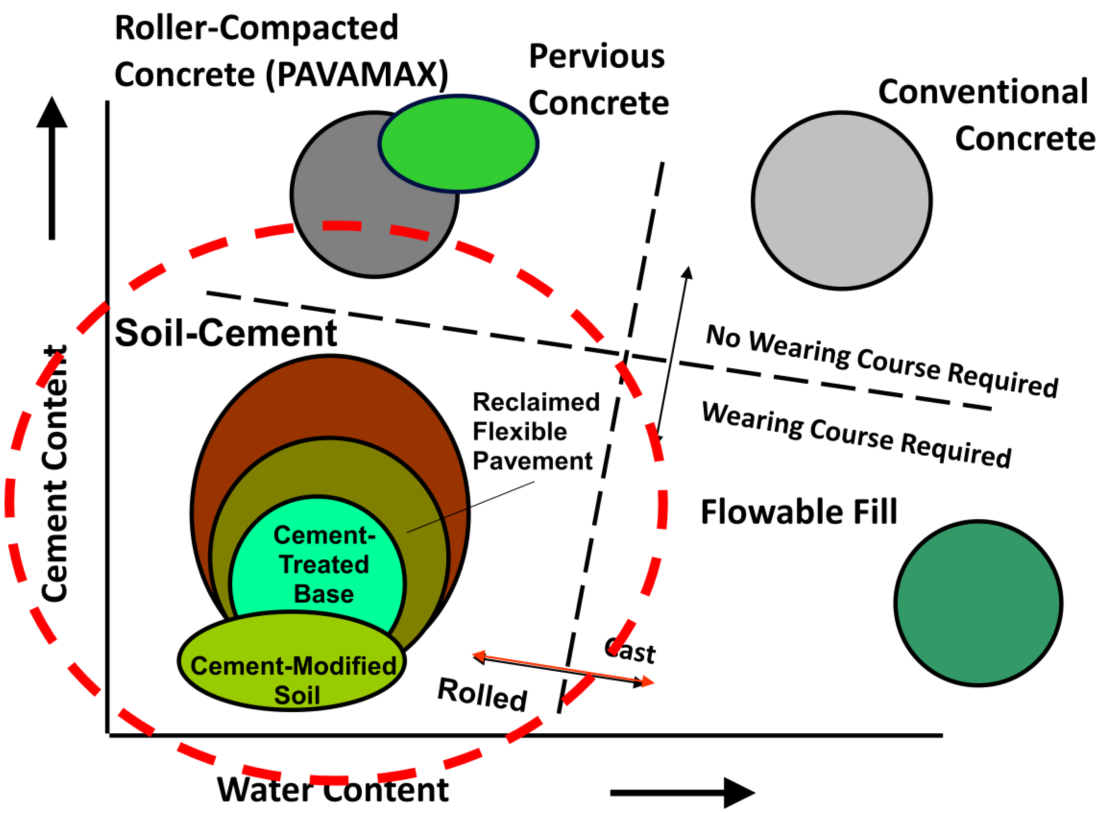


Figure 3: Comparison of Cement based Paving Materials by Cement Content and Water Content

2.0 Cement Modified Soils

A cement modified soil (CMS) is a material treated with a relatively small proportion of portland cement in order to change its undesirable properties so they are suitable for use in subgrade or foundation construction. Clays are usually candidates for modification. For example, many types of clay present undesirable engineering qualities such as high plasticity and significant shrink/swell properties that can be reasonably amended by modification. Cement modification uses chemical and mechanical means to improve such undesirable properties. The amount of cement added to the soil is less than that required to produce a hardened mass but is enough to improve the engineering properties of the soil. The mechanical and chemical changes produced are permanent as witnessed in long term performance studies of such materials.

By treating the soil with cement, the detrimental properties of clay can be improved through the following processes:

1) Cation exchange - Typical clays contain stacked silica and alumina layers. Figure 4 shows the surfaces of the clay particles have a negative surface charge. Due the bipolar nature of water and the system seeking neutrality water is naturally attracted to the clay particles. This is why clays tend to hold water due to this electrical attraction. When portland cement is added and Ca ions are in solution a cation exchange occurs where the Ca ions tend to replace the weaker dipolar water molecules and bond with the clay layer. This thinner layer of water between the clay particles results in a higher stability of the material.

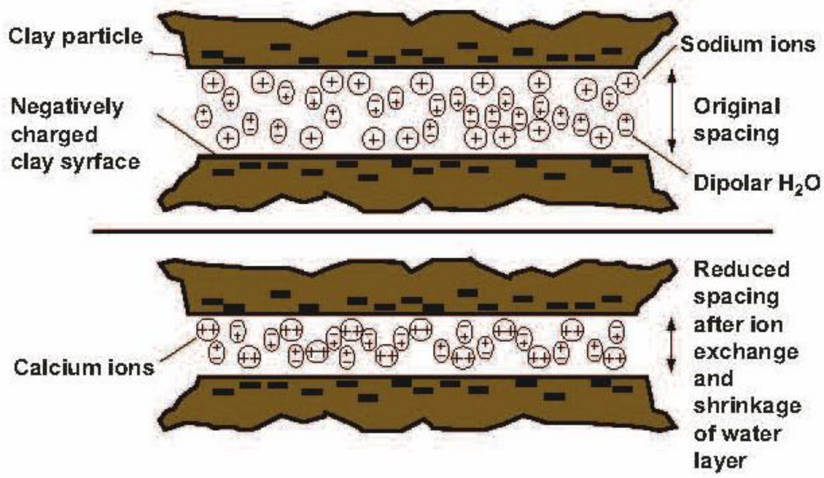


Figure 4: Cation Exchange - Ca ions tend to replace the weaker dipolar water molecules [Halsted 2008]

2) Particle restructuring - As the cation exchange progresses flocculation and agglomeration of the clay particles occur. Naturally clay particles such as the sheet silicate clays tend to align there platy structure parallel as seen on the top portion of Figure 5. Once Ca has exchanged and changed the charge regime, the clay particles tend to align edge to side in a much more stable configuration and bond on a larger scale to form agglomerated particles. The result is a material with a higher shear strength and improved texture. Both cation exchange and Flocculation / Agglomeration occur within hours of portland cement application.

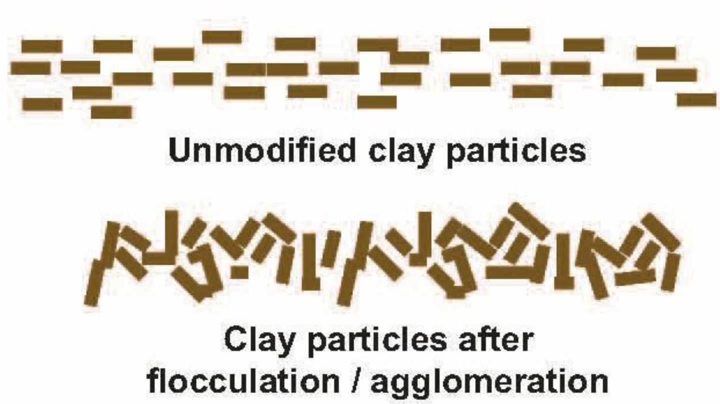


Figure 5: Particle restructuring - Flocculation and Agglomeration of the Clay Particles [Halsted 2008]

3) Cementitous hydration – This is a process that is unique to cement, and produces cement hydration products referred to in cement chemistry as calcium-silicate-hydrates (CSH) and calcium-aluminum-hydrates (CAH). CSH and CAH act as the “glue” that provides a bonded structure in a cement-modified soil by connecting flocculated clay particles through the formation

of clay-cement bonds as depicted in Figure 6. In general, cementitious bonding occurs within a day up to a month after mixing. This is where strength gain is noticed.

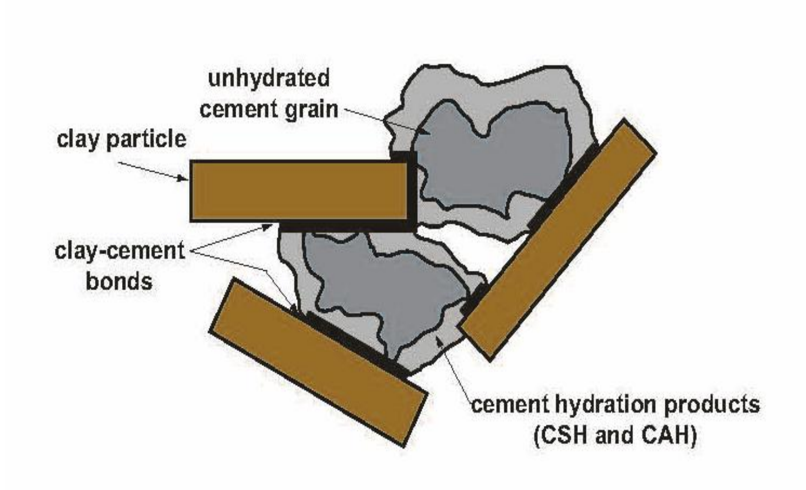


Figure 6: Cementitious Hydration – Creation of CSH and CAH [Halsted 2008]

4) Pozzolanic reaction - In addition to the primary CSH and CAH formation, hydrated portland cement also forms calcium hydroxide, or Ca(OH)2 or lime, which enters into a pozzolanic reaction. This secondary soil modification process takes the calcium ions supplied by the incorporation of portland cement and combines them with the silica and alumina dissolved from the clay structure due to the high pH or basic regime to form additional CSH and CAH. The pozzolanic reactions take place slowly, over months and years, and can further strengthen a modified soil as well as reduce its plasticity and improve its gradation. Figure 7 depicts the pozzolanic reaction with $Ca(OH)_2$ represented by blues spots. [Halsted 2008]

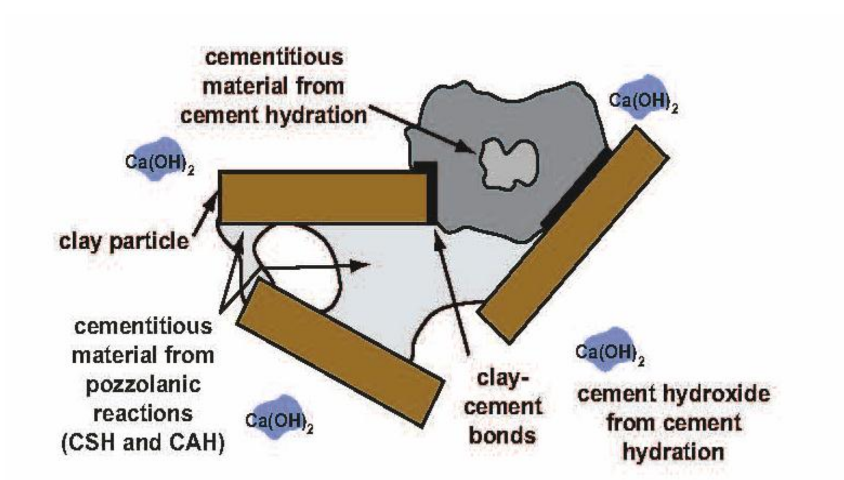


Figure 7: Cementitious Hydration – Creation of CSH and CAH [Halsted 2008]

Wind farm access roads in South West Ontario routinely use cement to stabilize the clay subgrades in the Region to improve their properties and provide a strong working platform. Therefore, the process should be considered for other types of roads. Cement modification can also be performed a wide range of soils to achieve stability or a solid working platform. The purpose of using cement modified soils is as follows:

1) Improve the properties of the subgrade soil:
    a) Reduce plasticity index
    b) Reduce volume change caused by moisture (improves shrink / swell characteristics)
    c) Improves the fine fraction constituents (mainly of clays)
    d) Improve wet strength
    e) Improve compactibility
    f) Increase in strength occurs though not usually quantified
    g) Permanent modification

2) Expedite construction by improving subgrade support in wet weather:
    a) Eliminate muddy construction sites due to drying effect
    b) Create an all-weather working platform

There are numerous benefits of using cement modified soils including the following:

1) Change in engineering properties - Small addition of cement to soils changes their engineering properties as discussed above.
2) Use in-place materials - Eliminates need for removal/replacement of inferior soils.
3) Low cost soil improvement – Small amount of cement allows the existing soils to be used as part of the pavement structure.
4) Improves pavement support – The stabilized soil has a higher and more consistent strength.
5) Forms weather-resistant work platform – The stabilized subgrade provides a consistent and stable working platform for construction equipment in all weather conditions.
6) Provides a permanent non-leaching modification – The cement stabilized subgrade provides a permanent non-leaching modification.

When constructing a cement modified soil it is important to have a detailed construction methodology plan to ensure an efficient job. Listed below are some of the key processes to consider:

1) Review Access Road Geometry – Ensure tender requirements for dimensions and profile are followed for the project including slope requirements for drainage, stabilization width requirements and correct any soft or unsuitable areas.

2) Ensure Consistent Supply of Cement – Select one supplier for the cement supply and ensure the required quantity is ordered for a specific date and time.

3) Soil Preparation - The in-situ soil to be treated should be brought to the approximate proposed final grade prior to stabilization activities. This minimizes the final grade work required after treatment and compaction, and reduces the risk of removing stabilized material to achieve the desired grade. If necessary, pre-wet dry soils to aid pulverization, or dry back wet soils by aeration with disc harrow or rotary mixer with its hood open.

4) Cement Application - The Portland cement used to stabilize the soil will be spread as a dry powder or slurry directly onto the surface of the soil at a controlled rate. The cement is distributed in dry form with mechanical spreader or in slurry form from distributor truck equipped with agitation system. The spread rate is defined as the mass of cement per unit cement in dry form with mechanical spreader or in slurry form from distributor truck equipped with agitation system surface area of the soil to be stabilized and is calculated as the volumetric mix design cement content multiplied by the dry density of the in-situ soil and the depth of soil to be stabilized. The cement content usually is in the range of 2 to 5 percent by dry weight.

5) Mixing **-** After application of the dry or slurry cement to the soil surface, the mixing process must be adequate to ensure thorough distribution of the binder throughout the design soil stabilization depth. Mixing should be performed by specialized pulverizing/mixing equipment utilizing a rotating drum with teeth to mix the soil and binder together. The equipment must be capable of processing to a minimum depth of 400 mm. The mixing equipment should be equipped with standard depth control and must maintain a consistent cutting depth and width. The machine shall also be equipped with a gauge to show the depth of the material being

processed. Mixing should be continued until the product is uniform in colour and is at the required moisture content throughout. The entire operation of cement spreading, water application and mixing shall result in a uniform pulverized mixture for the full design depth and width.

6) Moisture Content - During mixing sufficient water must be introduced to ensure compaction at the appropriate moisture content. This is achieved by directly spraying water into the drum of the mixing unit or by spraying water directly onto the surface of the treated soil. Scarification is required when the in-situ moisture content is more than 2% above the optimum moisture content. The soil should be dry under ambient conditions to within 2% of the optimum moisture content prior to stabilization.

7) Compaction and Final Grade - All compaction operations shall be completed with two (2) hours from the start of mixing. Where thick lifts (200-300 mm) of treatment have been undertaken, initial compaction with a padfoot (sheepsfoot) roller should be undertaken. It may be necessary to then grade the treated layer to ensure compliance with level and cross-fall requirements or to remove imprints from the padfoot compaction effort, followed by grading and the use of a steel wheel vibratory roller for final compaction. Where only thin lifts (<200mm) of treatment occur, a steel wheel vibratory roller is often only required to achieve the desired level of compaction. The processed material should be uniformly compacted to a minimum of 98% of the maximum dry density established during the mix design procedure. It is recommended to seal the surface with pneumatic-tire roller.

8) Curing Period - Finished portions of the stabilized base that are travelled on by equipment used in stabilizing an adjoining section should be protected in a manner as to prevent equipment from damaging completed work. After completion of final finishing, the surface should be cured by continuous moist-curing for a period of not less than 7 days or by application of a bituminous or other approved sealing membrane.

9) Traffic - Completed section of the stabilized base can be opened to low speed local traffic and to stabilization construction equipment provided that the curing material is not impaired and the stabilized base is sufficiently stable to withstand marring or permanent deformation. The section can be opened to other construction traffic 7 days after stabilization or later if possible.

Inspection and testing for the construction of the modified soils will be based on the requirements of the tender documents for the specific job. The engineer, with the assistance and cooperation of the contractor, should make such inspections and tests as deemed necessary to ensure the conformance of the work to the tender documents. These inspections and tests may include, but should not be limited to:

1) Obtaining test samples of the CMS material and its individual components at all stages of processing and after completion.
2) Observing the operation of all equipment used on the work. Only those materials, machines, and methods meeting the requirements of the tender documents should be used unless otherwise approved by the engineer.

All testing of processed material or its individual components, unless otherwise provided specifically in the tender documents, should be in accordance with the latest applicable ASTM or AASHTO specifications. [Halsted 2008]

The Portland cement Association has a very good document entitled “Guide to Cement Modified Soils” which gives greater details on the CMS process and has a suggested specification entitled, “Suggested Construction Specification for Cement – Modified Soil”.

3.0 Cement Treated Soils

Cement stabilization is a widely accepted practice in pavement construction. As defined in the introduction cement treated soils are utilized to provide strong, durable aggregate bases and subgrades for pavement structures. Many different types of material can be stabilized including soils (sand, silt, clay), gravel, crushed stone, slag, recycled HMA and recycled concrete. Some potential problem soils are organic soils, acid soils, sulfate soils and uniform sands. In general organic soils can be stabilized with cement and achieve the same strength and durability of ideal soils. In many cases a 1-2% increase of cement content will provide desired results. In most instances gradation of organic soils matters more than the type of organic. Unlike subgrade modification, stabilization it is usually designed for a target strength where the design durability requirements are met. In most cases the stabilized layer will contribute structurally to the pavement structure and the strength and durability are permanent creating an all-weather material.

Cement treated base (CTB) is an extremely dense, highly compacted mixture of aggregates, portland cement, and water, and is usually produced in a central batch plant mix setting as opposed to utilizing in-situ materials. Although the same ingredients make up CTB as conventional concrete there is a large difference in the strength of the two products. CTB mixed in a central patch plant or pug mill may obtain strengths as high as 5.5 MPa at 7 days based on a cement content of 3 to 6 percent by dry weight. If a mixed in-place procedure is used the 7-day strength is usually in the range of 2.1 to 2.8 MPa and requires a cement content in the range of 4 to 10 percent depending on the material being stabilized and strength requirement. By comparison, the design strength for concrete pavement is 32 MPa based on CSA A23.1 class C-2 exposure. If produced and placed properly, CTB is an extremely strong, durable, and economic product for use as both subbases and bases under city streets, rural roads, urban highways and airport runways, taxiways and aprons.

Another use for CTB is in drainage layer applications within a roadway structure commonly referred to as open graded drainage layer (OGDL). Cement Treated Permeable Base (CTPB), or OGDL, is used under Portland cement concrete pavements and asphaltic concrete pavements providing a highly permeable drainage layer under the surface pavement. Infiltration of water is one of the main causes of roadway failures. CTPB help collect and channel moisture away from a pavement structure thereby minimizing potential damage caused by water infiltration. The Ministry of Transportation of Ontario requires OGDL under all 400 series highway pavements.

The benefits of CTB can be placed into two broad categories - cost and performance benefits. Listed below are some of the key benefits:

1) Reduced thickness of pavement structure - Stabilization can provide competitive first cost when replacing traditional pavement materials such as aggregate base course. The stiffer nature of stabilized materials can allow thinner pavement sections leading to cost savings. The amount of granular material can be reduced for the structure due to the higher structural coefficient of a stabilized layer compared to unbound granular layers. There is also a possibility of reducing the thickness of the more expensive asphalt layer when taking into account the increased strength of the CTB compared to unbound granular bases.

2) Improved performance in rutting and fatigue cracking – As illustrated in Figure 8 the stiffer CTB material carries more of the load by spreading the load over a wider area, thereby, transferring less stress to the weaker subgrade material resulting in less potential for rutting. High vertical stress and resulting strain increase the likelihood of rutting in asphalt pavements. In addition, due to the stiffer nature of CTB the surface pavement does not flex or bend as much thus reducing the likelihood of fatigue failure occurring in the surface pavement. It must be noted that the performance of flexible pavements is highly dependent on each layer in the pavement structure. The use of a cement stabilized base or subgrade provides an extremely competent layer to the system.

3) Reduced moisture susceptibility - One of the major culprits in premature pavement failure is water infiltration into pavement layers, especially unbound base, subbase and subgrade layers. CTB

material has a reduced permeability compared to unbound aggregate layers; therefore, the bearing capacity of the stabilized layer will be maintained at higher level than an unbound granular base due to decreased moisture infiltration. A CTB will maintain a high level of strength and stiffness even when saturated. Figure 9 illustrates the reduced moisture susceptibility of CTB. Moisture can infiltrate unstabilized bases through high water tables or capillary action causing softening, lower strength, and reduced modulus. Cement stabilization reduces permeability, helps keep moisture out, and maintains a high level of strength and stiffness even when saturated. A cement stabilized base or subgrade would be an excellent choice for a pavement material in areas where high seasonal ground water levels are found. Its strength and durability will be maintained through seasonal changes including spring thaw conditions.

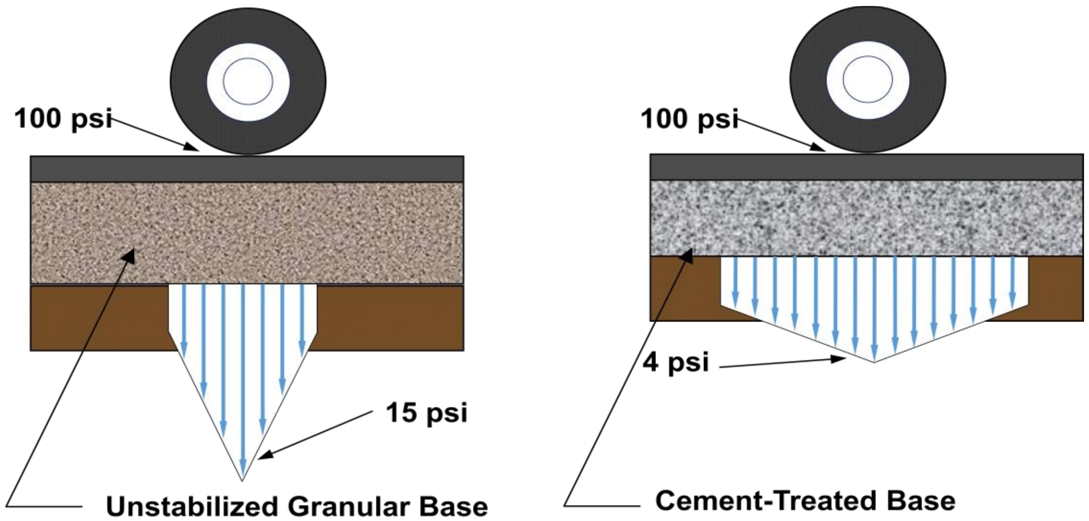


Figure 8: Improved Performance In Rutting and Fatigue Cracking [Halsted 2006]

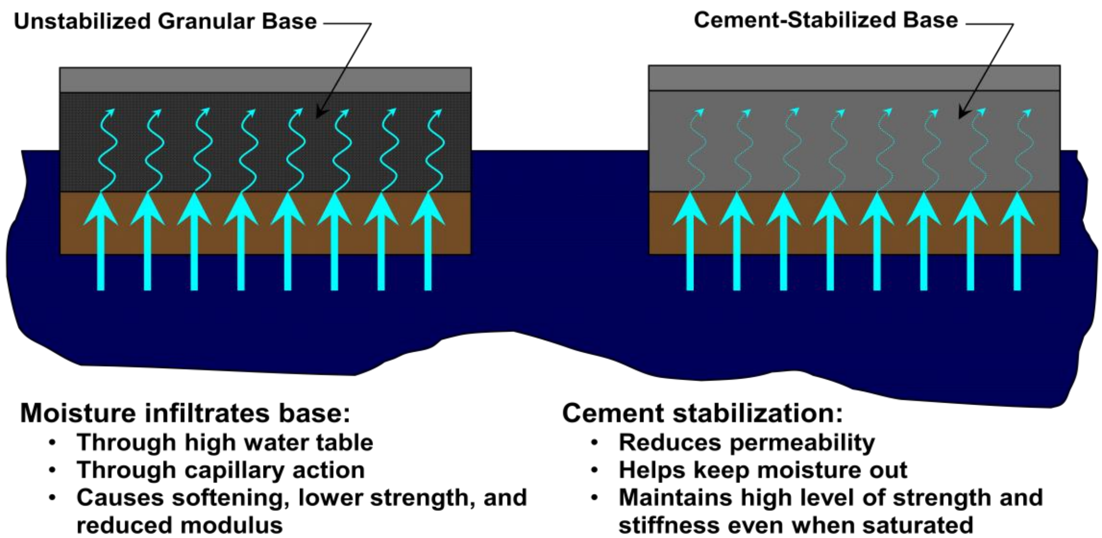


Figure 9: Reduced Moisture Susceptibility [Halsted 2006]

4) In-situ material stabilization- In-situ materials can also be stabilized which leads to cost savings and reduction in the use of virgin aggregate resources.

5) Speed of construction - The stabilization process is relatively quick which leads to on time construction schedules and savings.

6) Uniformity improvements – Uniformity improvements are obtained in the subgrade, base and subbase layers through CTB.

7) Decreased erosion potential – CTB provide a less erosive subbase material for rigid and flexible pavements.

8) Fuel savings and emissions reductions - Many of the benefits noted above can be recognized as energy savings by saving fuel costs associated with construction and maintenance. By saving fuel, emissions are reduced thereby providing a healthier environment for the travelling public.

When constructing a CTB the objective is to thoroughly mix the soil/aggregate material with the correct quantity of portland cement or blended cement and enough water to permit maximum compaction. The resulting CTB must be adequately cured to provide the necessary moisture needed for cement hydration to fully harden the CTB mixture. There are five fundamental control factors that need to be followed to provide quality CTB including the following:

1) Proper cement content
2) Adequate moisture content
3) Thorough mixing
4) Adequate compaction
5) Proper curing [Halsted 2006]

The construction steps vary depending on whether the job is a mixed-in-place process or a central batch plant process. Listed below are the basic steps for the construction process:

1) Preparation
    a) Checking and calibration of equipment
    b) Correcting any soft subgrade areas
    c) Shaping the area to proper crown and grade
1) Mixed-in-Place Processing
    a) Spreading portland cement and mix
    b) Applying water and mix
    c) Compacting
    d) Finishing
    e) Curing
2) Central Plant Processing
    a) Mixing soil/aggregate material, cement, and water in central plant
    b) Hauling and spreading
    c) Compacting
    d) Finishing
    e) Curing [Halsted 2006]

Like conventional concrete CTB will shrink naturally while curing. With properly designed pavements, and good construction procedures, the resulting cracks in the base will not significantly affect pavement performance. In some cases larger cracks in the CTB can result in stress concentrations, and the cracks may reflect from the base into the surface pavement. Usually proper construction procedures, crack minimization strategies, and crack sealing, if necessary, can eliminate requirements for significant maintenance due to reflective cracking. Newer techniques such as microcracking or using a stress absorbing interlayer have been very successful in reducing reflective cracking. A well designed and properly maintained CTB will normally outlast several asphalt overlays, providing decades of low maintenance service. [Halsted 2006]

Inspection and testing for the construction of the CTB will be based on the requirements of the tender documents for the specific job. The engineer, with the assistance and cooperation of the contractor, should make such inspections and tests as deemed necessary to ensure the conformance of the work to the tender documents. These inspections and tests may include, but should not be limited to:

1) Obtaining test samples of the CMS material and its individual components at all stages of processing and after completion.
2) Observing the operation of all equipment used on the work. Only those materials, machines, and methods meeting the requirements of the tender documents should be used unless otherwise approved by the engineer.

All testing of processed material or its individual components, unless otherwise provided specifically in the tender documents, should be in accordance with the latest applicable ASTM or AASHTO specifications. [Halsted 2006]

The Portland cement Association has a very good document entitled “Guide to Cement Treated Bases” which gives greater details on the CTB process and provides a specification entitled “Suggested Construction Specification for Cement – Treated Base”.

4.0 Full Depth Reclamation with Cement

There are numerous methods to maintain deteriorated asphalt pavement from as simple as a mill and fill process, to thin and thick overlays and even removal and replacement of the deteriorated asphalt. One option in the reconstruction tool box is to recycle the surface, base and subgrade by utilizing full depth reclamation with cement (FDR-C). This process pulverizes the existing bituminous surfacing and blends it with underlying base, subbase, and/or subgrade materials, which are then mixed with 4 to 6 percent by dry weight of portland cement to create a new stabilized base. A new riding surface is then placed, providing a new roadway structure using recycled materials from the failed pavement. Figure 10 shows the steps in the construction sequence including:

1) Pulverization of damaged asphalt to the required depth.
2) Addition of cement, mixing of cement into pulverized material, reshaping of the roadway to desired elevation and compacting the material to the desired density.
3) Curing for proper strength gain and microcracking to minimize the potential for reflective cracking into the surface pavement.
4) Placement of final riding surface course such as chip seal or asphalt.

The most appropriate time to utilize FDR-C process is under the following conditions:

1) The pavement is seriously damaged and cannot be rehabilitated with simple resurfacing.
2) The existing pavement shows distresses such as alligator cracking, deep depressions or soil stains on the surface indicating that the pavement problem likely exists in the base or subgrade.
3) The existing pavement distress requires full-depth patching over more than 15 to 20 percent of the surface area. Experience has shown that it is less expensive to use FRD-C when patching exceeds this amount. In addition, FDR-C provides the added benefit of having no patches in the final product.
4) The pavement structure is inadequate for the current or future traffic level.

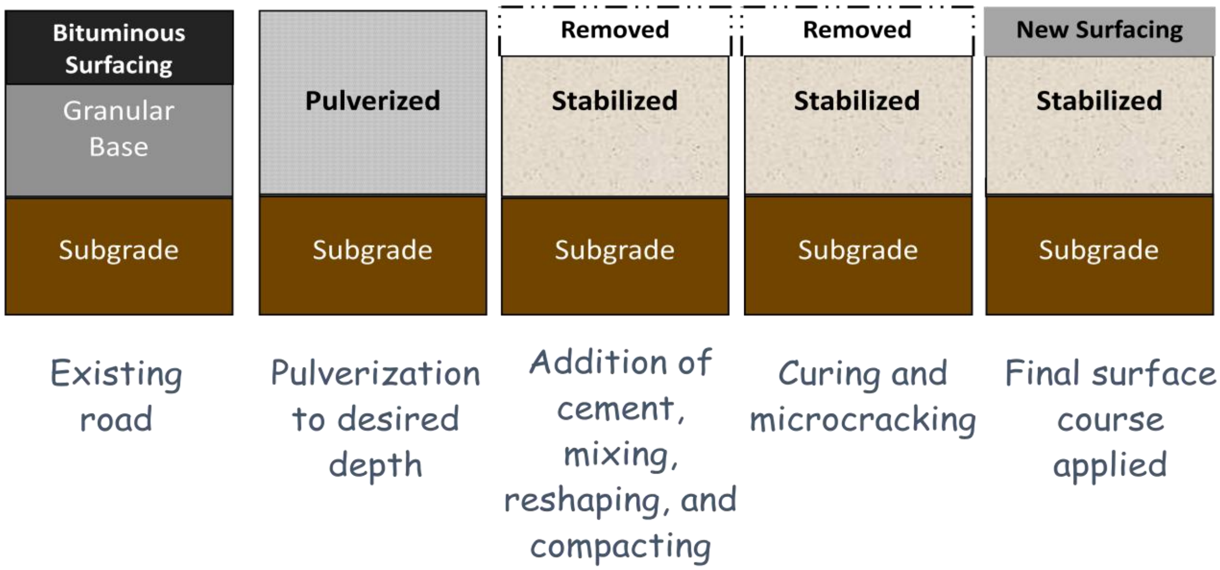


Figure 10: FDR-C Construction Process

Full depth reclamation with cement is the standard method of base stabilization for Strathcona County's rural road network in Alberta. This technique allows the County to recycle materials from existing road structure in the creation of a strong base prior to resurfacing and avoids reconstruction of the subgrade. The city of Edmonton has also used FDR-C on a few projects and has developed a specification on its use. The Nova Scotia Department of Transportation and Infrastructure has also tendered FDR-C jobs and has developed a detailed specification.

There are several advantages of utilizing FRD-C including the following points:

1) Better long term performance than original pavement structure.
2) Utilizes in-place material and conserves virgin aggregate sources.
3) Provides uniform and strong pavement layer.
4) Reduced energy transportation cost and reduction in CO_2 emissions by doing in-place recycling.
5) Reduced air pollution, traffic congestion, and damage of nearby roadways resulting from hauling new materials to the site, and disposal of old materials.
6) Conservation of land areas that would be used to dispose of the asphalt and base materials from the failed pavement.

The Portland Cement Association (PCA) has developed a very good document entitled, "Guide to Full Depth Reclamation (FDR) with Cement" which provides practical guidance on the following:

1) Pulverization
2) Grading, shaping and widening
3) Cement placement
4) Mixing
5) Compaction and final grading
6) Curing
7) Surfacing
8) Tips on traffic control
9) Reflective cracking

Field quality control is described in the PCA document entitled "Soil-Cement Inspectors Manual".

Some key construction points for FDR-C are as follows:

1) Modern equipment can pulverize to depths exceeding 450 mm (18 inches), however, it is not possible to properly compact deeper than 300 mm. PCA literature recommends windrowing and compacting in two or more lifts of equal thickness after treatment if the depth of pulverization exceeds 300 mm.
2) When grading the FRD-C material in place it is an ideal time to make improvements to the road crown, grade, drainage and superelevation since after stabilization the improvements will be permanent. It is also an excellent time to perform road widening. Stabilizing the entire roadway creates uniformity of the pavement base that greatly reduces maintenance compared to roads that are widened without being reclaimed.
3) Cement should be spread in a controlled manner preferably by spreader trucks that are designed for this operation. Placing the cement in an uncontrolled manner such as blowing under pressure should be avoided.
4) The most important time for dust control is when cement impacts the ground. Special enclosures can be used to minimize the amount of dust when cement is applied.
5) Obtaining the correct amount of moisture is very important in achieving target compaction.
6) Smooth-wheeled vibrating rollers, or tamping rollers can be used to provide initial compaction, with smooth-wheeled or pneumatic-tire rollers used to complete the operation.
7) Compaction density should be taken to ensure design densities are met. Compaction density is determined through ASTM D558. The test procedure uses the standard compaction effort similar to ASTM D698 (Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort [12,400 ft-lb/ft3 (600 kN-m/m3]) for soils.
8) Once the cement is mixed with water and the pulverized base material, the maximum time allowed for compaction is 2 hours.
9) The FDR material must be kept moist a minimum of 7 days following compaction. Proper curing can be achieved by continuous water spraying or application of an approved sealing compound or membrane. If the roadway is to have an asphalt surface, a bituminous prime coat can be applied at any time, as this will act as a curing compound.
10) The surfacing can be applied, as soon as, the FDR-C base is stable (does not rut or shove) under construction traffic. The time required for this can range from 4 to 48 hours. Light traffic can also travel on the FDR-C material in the same timeframe.
11) Up to seven (7) days may be required to make sure the base has gained sufficient strength to handle heavy truck traffic.
12) Proper construction procedure, crack minimization strategies, and maintenance sealing, if necessary, can eliminate requirements for significant maintenance due to reflective cracking. Newer techniques, such as, microcracking or using a stress absorbing inter-layer, have been very successful. A well designed and properly maintained FDR-C base will normally outlast several asphalt overlays, providing decades of low maintenance service. More information on control of reflective cracking in FDR-C can be found in the following PCA documents:
    a. Reflective Cracking in Cement-Stabilized Pavements, IS537
    b. Minimizing Cracking in Cement-Treated Materials for Improved Performance, RD123 [Luhr 2008]

Figure 11 and Figure 12 identify the primary and secondary testing required for FRD-C projects including:

1) Primary testing requirements
    a. Gradation
    b. Moisture
    c. Density

2) Secondary testing requirements
    a. Thickness
    b. Stiffness
    c. Stability [Luhr 2008]

Gradation

A common gradation requirement is for 100% to pass a 3-inch (50 mm), a minimum of 95% to pass a 2-inch (50 mm), and a minimum of 55% to pass a No. 4 (4.75 mm) sieve (ASTM C 136).

Moisture

A common moisture requirement is to be within 2% of the laboratory established optimum moisture content (ASTM D 558).

Density

A common density requirement is to be between 95% and 98% of the established laboratory standard Proctor density (ASTM D 558).

Figure 11: Primary Testing Requirements

Thickness

Requirements for base depths can vary from as little as 4 inches (100 mm) up to 1 foot (300 mm) depending on governing agency.

Stiffness

Measures in-place engineering values using structural layer stiffness, klbf/in (MN/m) and Young's Modulus of a material, kpsi (MPa).

Stability

Reclaimed base MUST be stable before next pavement course is constructed! Proof-rolling is the most commonly accepted practice.

Figure 12: Secondary Testing Requirements

5.0 Canadian Projects Using Engineered Soils

As noted in the previous section there are many examples of engineered soil usage in Canada. Cement modified soils are commonly used on construction sites to provide an all weather working platform and for access roads to wind farms. The City of Edmonton due to our high plastic lacustrine clay's cement modifies all their subgrade soils, on all new construction projects. Cement treated bases are commonly used under concrete pavements in airport facilities and OGDL are used under asphalt and concrete pavements on 400 series highways in Ontario. Full depth reclamation with cement has been used on jobs in Alberta, Ontario and Nova Scotia. Below are details on projects on the three different types of engineered soils:

1) Cement Modified Soil Project Example

   Pointe Aux Roches Wind Farm access road was constructed in September and October in 2010. The project consisted of CMS on 18km of subgrade stabilization for wind turbines. The subgrade was stabilized to a 300 mm depth using a 6% cement mixture followed by grading and placement of 100 mm of granular for the final surface. This provided a substantial savings form a typical access road construction process which would have been a 300 mm excavation followed by placement of 300 mm of crushed stone placed in the excavated area. These roads served as access to the wind turbines that received over 4,000 loads of concrete, rebar and component deliveries. Each road had anywhere from 1-4 turbines. The 27 turbines were spread out over a 40 km area in Stoney Point, ON. The access road performed very well during the construction process.

2) Cement Treated Base Project Example

   Amico Design Build chose to use a cement based open graded drainage layer for the Windsor Essex Parkway. Between 35,000 and 40,000 m^3 of modified Hydromedia will be placed in 2013 and 2014. The contractor chose cement based ODGL because it was cost effective, high level of service and quality, high rate of production by utilizing the pug mill mixing process, and it provides a uniform working platform which will not rut in hot weather. The Hydromedia has performed well to date after one winter.

3) Full Depth Reclamation with Cement Project Example

   No detailed information could be obtained on the FRD-C project in Canada. As noted in the FRD - C section Strathcona County's uses FDR-C as its standard method of stabilization of its rural road network. The City of Edmonton noted approximately 5% of the full depth reclamation jobs in their city are cement based with the other 95 % being foamed asphalt. All of the FDR-C projects using Foamed Asphalt as a stabilizer require the use of GU cement in the mix. The cement is there in part to help distribute the oil throughout the mix and give some early cohesion of the mix, allowing the hot mix asphalt to be placed sooner on the projects. The Nova Scotia Department of Transportation has also done several FDR-C jobs. The Northern US states also do a substantial amount of FDR-C. The document entitled, Full-Depth Reclamation with Portland Cement: A Study of Long-Term Performance, by Imran Syed identifies several FDR-C jobs in the US.

6.0 Conclusion

As noted in the body of the report, cement modified soils, cement treated bases and full depth reclamation with cement, also known as "Engineered Soils", have been used in many applications throughout Canada and have many structural and environmental benefits. Therefore, private owners and government agencies should consider engineered soils as potential solutions in their maintenance and construction tool box for gravel roads, asphalt and concrete pavement options. Table 1 below summarizes the three types of engineered soils and indentifies the following for each:

purpose of their use; materials best suited for; range of cement content; anticipated strength provided; and density requirements.

Table 1 Summary of Engineered Soils and Their Uses

	CEMENT MODIFIED SOILS (CMS)	**CEMENT TREATED SOILS (CTB) Mixed-In-Place**	**CEMENT MODIFIED SOILS (CTB) Mixed Plant**	**FULL DEPTH RECLAMATION (FDR)**
Purpose	Improves workability and construction of subgrade soils. Reduced PI and improves bearing strength.	Stiff foundation for pavement structure. Excellent construction platform.	Rigid base layer for asphalt or concrete pavements	Rigid base layer for asphalt or concrete pavements
Materials	Cohesive soils, silt/clay/sand mixtures	Natural soil mixtures, gravel/sand/silt/clay	Aggregates or aggregate/soil blends. Meets aggregate gradation limits.	Pulverized asphalt blended with old road base. Meets aggregate gradation limits.
Cement Content	2 to 5 percent (by dry weight)	4 to 10 percent (by dry weight)	3 to 6 percent (by dry weight)	4 to 6 percent (by dry weight)
Strength	none	2.1 to 2.8 MPa 7-day unconfined compressive strength	Up to 5.5 MPa 7-day unconfined compressive strength	2.1 to 2.8 MPa 7-day unconfined compressive strength
Density Requirements	Minimum 95 – 98% of maximum density	Minimum 95 – 98% of maximum density	Minimum 95 – 98% of maximum density	Minimum 95 – 98% of maximum density

Reference: Cement Based Solutions for Engineered Soils -Frequently Asked Questions, PW-ES-002, 2006.

7.0 References

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