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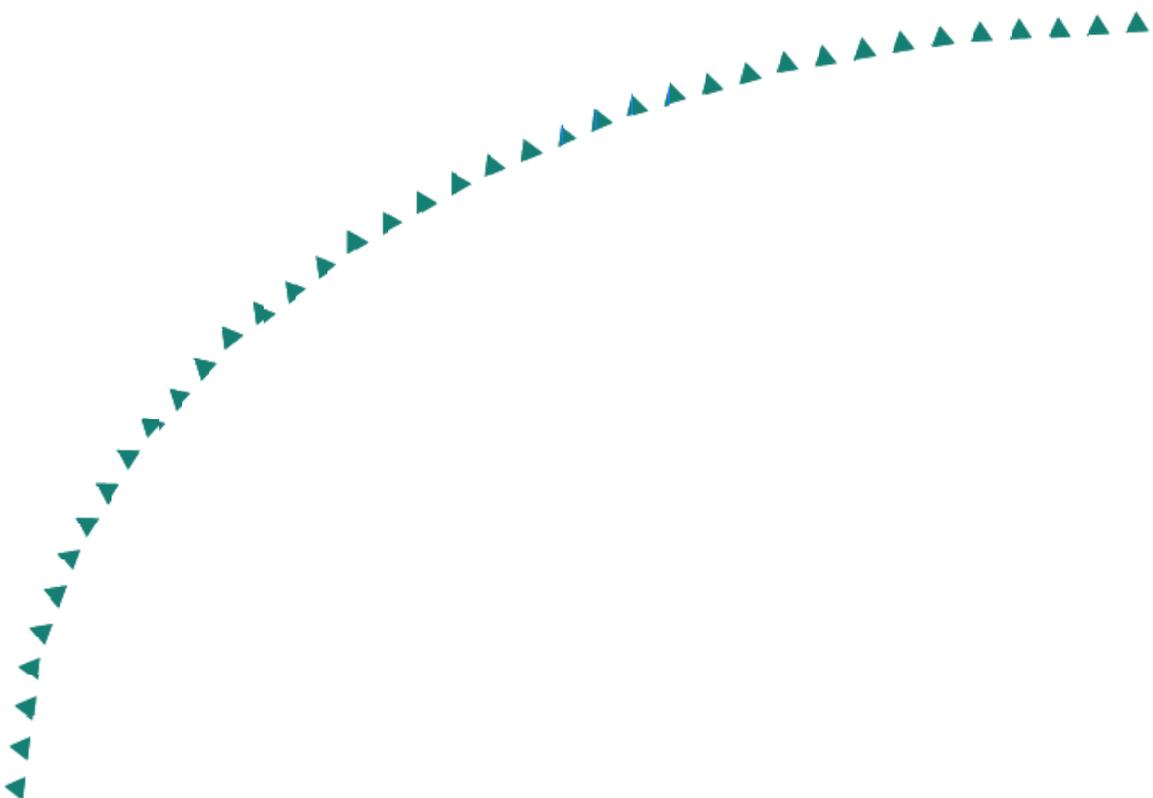
Final Report

Special Practices for Design and Construction of Subgrades in Poor, Wet, and/or Saturated Soil Conditions



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16. Abstract (Limit: 200 words) <p>Highway embankment construction progresses vertically in stages, beginning with the subgrade. For a variety of reasons, it is desirable to use naturally occurring soils for subgrade material. In some cases this is not possible due to poor soil conditions; in order to avoid realignment it is necessary to improve the subgrade material.</p> <p>A review of literature provides background for special construction methods to be used for subgrade soil enhancement. Additional information about modification, stabilization, reinforcement, and substitution methods and materials was gathered from a questionnaire directed to Minnesota state, county, and city highway engineers. Based on questionnaire response, a series of highway agency interviews were conducted to provide more detailed information about the enhancement methods.</p> <p>Enhancement selection recommendations and special practice methods for construction were developed from the agency interviews, questionnaire responses, and literature review.</p>			
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**SPECIAL PRACTICES FOR DESIGN AND
CONSTRUCTION OF SUBGRADES IN POOR, WET,
AND/OR SATURATED SOIL CONDITIONS**

FINAL REPORT

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The University staff of the project in particular thank the following groups and individuals who have participated in the information and expertise gathering to help develop the material presented.

1. The 40 county and 17 city staffs who replied to the questionnaires
2. The 18 agency staffs who met with the project staff to review and help develop the Best Practices for the procedures and discuss some successes and failures. They also helped find the 75 specific locations along with design information for these pavement sections.
3. David Beberg who worked with the project staff to provide in-site for establishing what procedures will provide the best solution for particular conditions and best practices based on his 40 years of experience with Mn/DOT.
4. The Technical Assistance Committee chaired by Lou Tasa who guided and prodded the staff to develop a report which will be useful to Minnesota local agencies. Other committee members were Jeff Blue, Ron Bray, Walter Leu, John Seikmeier, Joel Uhlring, Dave Van Deusen and Dan Warzala.

EXECUTIVE SUMMARY

The purpose of Minnesota Local Road Research Project 772 has been to review methods of subgrade enhancement not covered in the 2002 publication “*Best Practices for the Design and Construction of Low Volume Roads*”(1) The results of the study include:

1. Descriptions and definitions of traditional subgrade construction and enhancement choices.
2. Descriptions of subgrade enhancement procedures that have been used in Minnesota based on questionnaires (Appendices A and B), and agency visits (Appendix C).
3. Best practice summaries proposed for distribution to cities and counties for subgrade enhancement methods used in Minnesota
4. A database of existing enhancement installations as identified by Minnesota counties, cities and DOT (Appendix D).
5. a collection of digital photographs (Appendix E) showing subgrade enhancement construction in Minnesota, and
6. A flow chart with recommendations for particular subgrade enhancement situations for sand, silt, clay and peat soils.

Chapter 1, Introduction, reviews applicable design and construction methods presented in the low-volume roads best practices manual (1), drainage considerations, and Mn/DOT embankment specifications 2105, 2111, and 2123. Emphasis is placed on constructing embankments using established procedures that consider soil type (natural soils if possible), project conditions, and structural design and specifications. **Enhancement** is the improvement of existing embankment materials by the following methods:

1. surface drainage of runoff and subsurface drainage of infiltrated water
2. compaction (density control) using heavy equipment, and
3. moisture content adjustment through mechanical or chemical methods.

Other procedures have been used to improve subgrade materials performance. The type and amount of improvement categorize these procedures:

- moderate improvement of existing materials through **modification** with cementing or drying agents (lime, fly ash, bituminous)
- significant improvement of existing materials through **stabilization** with cementing or drying agents (Portland cement, lime, fly ash)
- **reinforcement** and **separation** using geosynthetics, and
- **substitution** with natural (granular, wood) or man-made materials (tires, foam).

Selection of an appropriate method is governed by the compatibility with in-service subgrade soil conditions, extent of improvement required, safety precautions or environmental concerns, and construction requirements. Field and lab tests are important when selecting a modifier or stabilizer type. When considering the use of geosynthetics it is important to consider the type of geosynthetic, the intended function (reinforcement, separation, and filtration), factors affecting life span, in situ conditions, and installation.

Substitution is a method that directly enhances the subgrade by removing unstable or unsuitable soil and replacing or covering it with other suitable material. The use of lightweight fill materials such as wood chips, shredded tires, or foam may be appropriate when the in situ soils cannot tolerate “normal” weight fill material such as select granular or breaker run material.

When alternative materials are used it is important to follow pollution control guidelines. Tires and fly ash should be used above the water table to minimize the potential for leaching metals into the environment.

Chapter 2, Subgrade Enhancement Procedures Used in Minnesota, includes information on the development of the **questionnaire** (Appendices A and B), **agency interviews** (Appendix C), and subgrade enhancement installation **database** (Appendix D).

The questionnaire was used to request information on the use of various materials, number of projects constructed, how the agency viewed the performance, and if the projects can be located. Replies were received from 40 counties and 17 cities.

Following the questionnaire, a series of agency visits were conducted to obtain more information on specifications and procedures used for construction with specific materials, document the performance of installations in that agency, and determine the location of projects using the procedures for inclusion in a statewide database.

The information obtained during the agency visits has been used to develop the Best Practices Summaries presented in Chapter 3. The project staff was able to identify 75 installations. The information in the database should be maintained and reviewed periodically so that documented performance can be used to include these methods of subgrade enhancement in future design procedures. Documentation of performance will help determine what procedures are really cost effective.

Chapter 3, Best Practice Summaries for Special Subgrade Enhancement Procedures in Minnesota, includes brief summaries of subgrade construction procedures that have been used in Minnesota. The procedures include those for natural soils, drying with lime, stabilization with fly ash, separation with geofabrics, reinforcement with geogrids, and substitution with; select granular, breaker run limestone, wood chips, and shredded tires.

Each summary includes:

- Purpose for which procedure is used
- Conditions appropriate for the procedure
- Material(s) including specification references
- Design quantities
- Best construction weather and transportation
- Construction control procedures
- Precautions
- Value (comparison of cost and expected life)
- Contacts (those who would provide more information)

Chapter 4, Recommendations, are based on the review of literature, responses to questionnaires sent to cities and counties, and discussions and review of specific projects with city, county, and Mn/DOT engineers and suppliers. Recommendations for when and how to use the procedures are presented in Tables 4.1A – 4.1D. The tables are divided by soil type defined using categories from the MnPAVE (63) design soil parameters.

- A. Granular
- B. Semi Plastic
- C. Plastic
- D. Peat and/or Swamp

The moisture conditions estimated for the grade are estimated using:

- 1. height of the final grade above the water table and
- 2. drainage provided for the pavement section.

The flow charts present five subgrade enhancement alternatives based upon in situ soils, location of water table relative to the grade, drainage characteristics of in situ soils, and moisture conditions.

- 1. Modification/Stabilization with Lime
- 2. Stabilization with Fly Ash
- 3. Separation with Geofabrics
- 4. Reinforcement with Geogrids
- 5. Substitution
 - a. Select Granular
 - b. Breaker Run Limestone
 - c. Bituminous Recycled Material
 - d. Wood Chips
 - e. Shredded Tires
 - f. Foam

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CHAPTER 1: INTRODUCTION

1.1 Background

The subgrade or embankment soil on which a pavement is built is the most important part of the pavement structure because:

- It is the layer on which the remainder of the structure is supported and helps resist the destructive effects of traffic and weather.
- It acts as a construction platform for building subsequent pavement layers.
- The entire pavement section would have to be removed and replaced to correct embankment performance problems created by lack of strength or uniformity.

It is imperative that the embankment be built as strong, durable, uniform and economical as possible. The most economical embankment is one that will perform well for many decades.

Chapter 4 of the Best Practices Manual (1) presents methods to help achieve adequate stiffness, strength, and uniformity for a given embankment soil. The procedure starts with a good soil survey at the location so that proper design and construction procedures can be included for the project. Methods for conducting soils surveys are presented in the Mn/DOT Geotechnical and Pavement Manual (2). Section 4.2 presents the procedure to conduct a good soil survey at a given location.

The design factors used to evaluate the soil on a project for the three Minnesota procedures are also presented in Chapter 4 of the Best Practices Manual (1) and the Mn/DOT Geotechnical and Pavement Design Manual (2). The Falling Weight Deflectometer (FWD) and Dynamic Cone Penetrometer (DCP) are used to determine the in-place stiffness or strength of the soils, subbase, and base materials. The advantage of using field measurements is that variability can be determined. Variability is an input for the MnPAVE (65) design procedure.

1.2 Project Summary

The purpose of Minnesota Local Road Research Project 772 has been to review methods of subgrade enhancement and form a report that includes:

1. Chapter 1: Introduction, descriptions and definitions of traditional subgrade construction and enhancement choices based on literature review.
2. Chapter 2: descriptions of subgrade enhancement procedures that have been used in Minnesota based on questionnaires (Appendices A and B), agency visits (Appendix C), and literature review.
3. Chapter 3: best practice summaries that have been proposed for distribution to cities and counties for subgrade enhancement methods used in Minnesota.
4. A database of existing enhancement installations as identified by Minnesota highway agencies (Appendix D).
5. A collection of digital photographs (Appendix E) showing subgrade enhancement construction in Minnesota, and

6. Tables 4.1A-D, flow charts that summarize recommendations for particular subgrade enhancement situations.

Chapter 1: Introduction, includes the literature review of subgrade construction and enhancement methods:

1. review of the applicable design and construction methods presented in the low-volume roads best practices manual (1)
2. drainage considerations
3. Mn/DOT embankment specifications 2105, 2111, and 2123.

In Chapter 1 emphasis is placed on constructing embankments using established procedures that consider soil type (natural soils if possible), project conditions, and structural design and specifications. **Enhancement** is the improvement of existing embankment materials by the following methods:

4. surface drainage of runoff and subsurface drainage of infiltrated water
5. compaction (density control) using heavy equipment, and
6. moisture content adjustment through mechanical or chemical methods.

Other procedures have been used to improve subgrade materials performance. The type and amount of improvement categorize these procedures:

1. moderate improvement of existing materials through **modification** with cementing or drying agents (lime, fly ash, bituminous)
2. significant improvement of existing materials through **stabilization** with cementing or drying agents (Portland cement, lime, fly ash)
3. **reinforcement** and **separation** using geosynthetics, and
4. **substitution** with natural (granular, wood) or man-made materials (tires, foam).

Selection of an appropriate method is governed by the compatibility with in-service subgrade soil conditions, extent of improvement required, safety precautions or environmental concerns, and construction requirements. Field and lab tests are important when selecting a modifier or stabilizer type. Field tests; such as test rolling, deflection testing, and the dynamic cone penetrometer, will show the types and properties of the subgrade and borrow materials. When considering an additive; like lime, fly ash, cement or asphalt, lab tests like the Atterberg limits and AASHTO T-99 can be used with trial mixes to determine engineering properties and optimum proportions for the modified or stabilized materials (5 and 9).

When considering the use of geosynthetics it is important to consider the type of geosynthetic, the intended function (reinforcement, separation, and filtration), factors affecting life span, in situ conditions, and installation. Geogrid/geotextile composites can often provide better results than the components individually (33, 36, and 37).

Substitution is a method that directly enhances the subgrade by removing unstable or unsuitable soil and replacing or covering it with other suitable material. The use of lightweight fill materials such as wood chips, shredded tires, or foam may be appropriate when the in situ soils cannot tolerate “normal” weight fill material such as select granular or breaker run material.

When alternative materials are used it is important to follow pollution control guidelines. Tires and fly ash should be used above the water table to minimize the potential for leaching metals into the environment.

Chapter 2: Subgrade Enhancement Procedures Used in Minnesota, includes information on the development of the **questionnaire** (Appendices A and B), **agency interviews** (Appendix C), and subgrade enhancement installation **database** (Appendix D).

The questionnaire was used to request information on the use of various materials, number of projects constructed, how the agency viewed the performance, and if the projects can be located.

Replies were received from 40 counties and 17 cities. The replies have shown that cities and counties in Minnesota use many procedures and that with proper application there will be good performance of pavement sections.

Contacts were made with agencies representing the applications listed in Table 2.1. The purpose of the visits was to obtain more information on specifications and procedures used for construction with the given materials, document the performance of installations in that agency, and determine the location of projects using the procedures for inclusion in a statewide database.

The information obtained during the agency visits has been used to develop the Best Practices Summaries presented in Chapter 3.

A database in the form of a spreadsheet has been setup to document the location, design and evaluation of projects built using the procedures. The project staff was able to identify 75 installations. The information in the database should be maintained and reviewed periodically so that documented performance can be used to include these methods of subgrade enhancement in future design procedures. Documentation of performance will help determine what procedures are really cost effective.

Chapter 3: Best Practice Summaries for Special Subgrade Enhancement Procedures in Minnesota, includes brief summaries of subgrade construction procedures that have been used in Minnesota. The procedures include those for natural soils, drying with lime, stabilization with fly ash, separation with geofabrics, reinforcement with geogrids, and substitution with; select granular, breaker run limestone, wood chips, and shredded tires.

Each summary includes:

- Purpose for which procedure is used
- Conditions appropriate for the procedure
- Material(s) including specification references
- Design quantities
- Best construction weather and transportation
- Construction control procedures

- Precautions
- Value (comparison of cost and expected life)
- Contacts (those who would provide more information)

Appendix A includes a copy of the Agency Questionnaire.

Appendix B includes a summary of the 57 agency responses (40 county, 17 city) to the questionnaires.

Appendix C lists the 16 agency interviews conducted in the summer, 2002 and includes a description of the interview process:

- specifics of construction methods
- success with various subgrade enhancement techniques
- tours of completed and in-progress projects
- ride and photo documentation.

Appendix D is the fall, 2002 version of the Minnesota Subgrade Enhancement Installation Areas database. Installation types included are:

- Modification
- Stabilization
- Separation
- Reinforcement, and
- Substitution.

Appendix E is a compilation of digital photos contributed by the project staff and interviewed agencies.

1.3 Traditional Subgrade Enhancement Choices

1.3.1 Drainage

Good drainage for a pavement section and most importantly the embankment soil must be provided. Specific design considerations to achieve adequate drainage are given in the Mn/DOT Geotechnical and Pavement Manual (2). An important design factor is to try to keep the final grade at least 5 ft (1.7 m) above the water table. If this is not possible a height of 3 ft (1 m) above the water table could be used with special procedures and care.

Drains can also be used in the pavement section. However, for them to work properly it is necessary to construct a drainable base and/or subbase. Proper drainage will help maintain the strength of the pavement section and minimize frost heave and thaw weakening.

1.3.2 Subgrade (Embankment) Soil Construction

To achieve the design values estimated for the actual embankment soils in the field, proper construction practices must be followed. These start with specifications that help

define good construction. In Chapter 4 of Reference 1 the specifications that pertain to embankment soil construction, general construction design considerations, and some field checklists are presented. Constructing uniform embankment layers is the goal for all projects. The engineer should use mixing, tapering, watering, compacting, and all standard best practice procedures prior to special, non-standard, treatments.

1.3.2.1 Specifications

Mn/DOT has three specifications that pertain to the construction of embankments. These are Specification 2105, 2111, and 2123. Specification 2105 “Excavation and Embankment” includes two types of density control which are “Specified” (sand cone) and “Quality” (visual) compaction. Both methods state that compaction must be accomplished to the satisfaction of the engineer. For “Quality” compaction an experienced engineer or inspector must be on the project to judge if adequate compaction is achieved. For “Specified” compaction the judgment of the engineer is aided by the determination of a measured density. The density must be measured using the representative moisture-density test for the soil being constructed. The **Specified Density Method** is recommended by Mn/DOT.

Specification 2111 presents the test rolling method for subgrade acceptance. Test rolling is a supplement to Specification 2105. Test rolling evaluates uniformity and consistency of subgrade support relative to rutting. Test rolling will detect weak/unstable areas due to inadequate compaction or high moisture content. Failed areas will require corrective measures that could include removing the unstable/unsuitable materials, reducing moisture content, and recompaction of the soils.

Test rolling is not recommended for the following situations:

- Areas having less than 30 in. (0.75 m) subcut backfill in depth. These areas would probably not pass the requirements in Specification 2111.
- Areas having shallow underground utilities or structures.
- Areas having closely spaced bridges.
- Areas where geosynthetics are placed within the upper 5 ft (1.7 m) of the subgrade.

An experienced inspector can determine where soft spots occur in the constructed subgrade and make sure corrective measures are taken. The test roller method of compaction control is recommended along with Specification 2105 because almost total coverage of the embankment grade construction is possible.

Specification 2123 lists the equipment and characteristics of the equipment required to carry out Specifications 2105 and 2111.

1.3.2.2 General Design Considerations

Based on the soil type, project conditions, structural design and specifications, certain procedures need to be established and followed to achieve good embankment construction. The goal is to provide a strong and uniform embankment for the pavement structure. Many of the procedures presented depend on the type of soil encountered on the project. As the project is started variations in the soils may be encountered and

therefore the field engineer and inspector must be aware of the effect of these changes. The following recommendations are presented in Chapter 4 of Reference 1.

- Excavation and Embankment Construction: Ideally, the finished grade should be kept at least 5 ft (1.7 m) above the water table in order to reduce capillary moisture and should be at least equal to the depth of frost penetration in order to minimize frost heave. In rare instances the height of grade above the water table can be reduced to 3 ft (1 m).
- The existing soils and their preparation including subgrade correction: embankment placement, and protection of the completed embankment need to be considered.
- Soils Evaluation: Soils must be evaluated based on whether they are suitable or unsuitable, excavated soils, salvaged materials, or borrow.
- Soils Preparation: Proper preparation of the soils for good uniformity involves reworking, blending, mixing, and enhancing the existing materials. The mixing of existing soils will help eliminate pockets of high moisture and unstable soils. Subcutting, and/or mixing and proper compaction will help provide a uniform subgrade. Proper compaction can be verified with specified densities and test rolling. Lime or other treatments for moisture control may be considered.
- Subgrade Correction: Subcuts should be made to ensure uniformity of material and stability in the upper portion of the embankment. Subcuts are used to reduce or eliminate differential or pocketed high-moisture conditions, unstable materials, frost heave potential, and non-uniform subgrade conditions. Typical subcut depths range from 2 to 4 ft (0.6 to 1.2 m) with a 1 ft (0.3 m) minimum. Subcuts must be used especially where there are silty type soils, which are particularly frost susceptible. In areas of the embankment that may generate frost heaves the subcut depth must extend below the frost line. The subcut should be backfilled with select granular material. If it is not practical to use select granular, then the existing soil should be uniformly mixed to a moisture content appropriate for good compaction. Drains may be needed in the bottom of the subcut to assure that water does not collect in the subcut. For high water tables provisions must be made for drainage so that construction equipment can operate.
- Placement of Embankment and Backfill Materials: As embankment materials are placed, the same soil should be used throughout each layer to prevent non-uniform moisture and drainage conditions.
- Compaction: Compaction must be performed in accordance with Mn/DOT Specification 2105 supplemented with 2111 using the equipment specified in Specification 2123.
- Areas such as road widenings, culverts, where cut transitions to fill, and bridges warrant special consideration: Use flat (20 horizontal to 1 vertical) tapers when matching dissimilar soils or installing non-frost susceptible soils (63).

1.3.2.3 Construction Notes and Procedures

The Mn/DOT Office of Construction, Technical Certification Section has published an “Inspector’s Job Guide for Construction”. This Guide gives the inspector a checklist that will help get a project started and documents the parameters and procedures that need to be considered based on the specifications. One item in particular that will help keep a

project under control is for the inspector to keep a good daily diary. This will help all people involved with the project feel confident that work is progressing at an appropriate rate and that the inspection work is being accomplished.

1.3.3 Subgrade Enhancement

Many different procedures have been used to enhance the performance of a subgrade. The methods that have been used with varying degrees of success are the following:

- remove and replace,
- improvement of existing materials using density and moisture control,
- modification of existing materials,
- stabilization, and
- reinforcement using geosynthetics.

Mn/DOT and cities and counties have tried some of the procedures. Minnesota Local Road Research Project 772 is a study of the use of various methods of modification, stabilization and reinforcement in Minnesota and surrounding states

1.3.3.1 Subgrade Soil Enhancement Procedures for Natural Soils

The following procedures are should be used primarily to enhance standard layered construction techniques. Enhancement of existing subgrade embankment materials is often done the by one of the following methods:

- drainage,
- compaction, and
- moisture content adjustment

Drainage commonly refers to the removal of surface and/or subsurface water. **Surface drainage** is the removal of watershed runoff and is accomplished through using storm sewers, ditches, culverts, or bridges.

Subsurface drainage is the removal of infiltrated water in the pavement and is accomplished through the use of impermeable barriers, pipes, drains, and geosynthetics (3).

Compaction is the most common method of enhancement. Compaction refers to increasing the soil density by mechanical means, such as the use of heavy equipment (4). Higher soil density for the same moisture content will result in a stiffer and/or stronger subgrade soil.

Moisture content adjustment refers to either the removal of moisture by mechanical or chemical methods (5).

1.3.3.2 Drainage

The Mn/DOT Geotechnical and Pavement Manual (2) notes that the performance of a base (or subgrade) will be proportional to its degree of saturation. Drainage systems may be utilized to prevent decreased strength from frost heave from volume changes below

the surface and lower inter-particle friction resulting from increased pore water pressure (2).

Two common types of drainage systems are longitudinal edge drains and permeable base layers. Longitudinal drains can be built-in or retrofitted. Filter materials and pipes are used to enhance the effectiveness of longitudinal drains. Permeable base layers utilize gradations having a large top size and few fines (2). The quality of subsurface drainage is dependent on soil permeability, location of seepage within the system, the type of filter material, and the type or size of the underdrain pipe (3).

1.3.3.2.1 Design Factors For Drainage

There are three drainage options for reconstruction projects:

- Design a permeable base with edge drains.
- Daylight the base.
- Use longitudinal edge drains only.

Note that daylighted bases are prone to clogging and are not recommended and the effectiveness of longitudinal edge drains is limited if the base is not permeable (2).

Permeable bases may be treated with asphalt (2-5% by weight) or Portland cements (2-3 bags/cubic yard) for strength in construction. A separator layer should be installed a minimum depth of 4 in. (102 mm) below the permeable base to prevent the migration of fine aggregate particles. Aggregate should have a dense gradation meeting the following uniformity requirements:

- $\frac{D_{15}}{D_{85}}$ of $\frac{\text{filter}}{\text{subgrade}}$ and $\frac{\text{base}}{\text{filter}} \leq 5$
- $\frac{D_{50}}{D_{50}}$ of $\frac{\text{filter}}{\text{subgrade}}$ and $\frac{\text{base}}{\text{filter}} \leq 25$
- $20 \leq \frac{D_{60}}{D_{10}} \leq 40$

Where:

D15 = Maximum particle size at which 15 percent of the aggregate is finer.

D50 = Maximum particle size at which 50 percent of the aggregate is finer.

D85 = Maximum particle size at which 85 percent of the aggregate is finer.

These specifications will minimize the infiltration of one layer into a neighboring upper or lower layer.

1.3.3.2.2 Subsurface Hydrology

Drainage systems typically remove water from infiltration and groundwater sources. Darcy's Law characterizes water movement for saturated conditions. In order to calculate the quantity of water in the pavement system the designer must estimate the permeability coefficient and the hydraulic head in the system. Permeability may be measured with field methods, lab permeability tests or estimates from a soil grading

analysis. Hydraulic head data may be collected from observing the location of wet stratum when collecting soil borings (3).

A drainage system should maintain adequate capacity since it may be used to drawdown the water table, intercept lateral seepage above an impervious pavement layer, drain infiltrating surface water, prevent capillary rise or collect discharge from other drainage systems. It is important to use an analysis for determining the design requirements. The analysis must include:

- location of seepage areas,
- maximum rate of flow into the pavement structure,
- type of filter material for drains,
- type of drain rock for below-pavement use (single sized material), and
- data on the local climate including expected frost heave (3).

1.3.3.2.3 Drainage Analysis

There are two commonly used analysis methods. (i.) Time-to-Drain and (ii.) Inflow-Outflow estimates.

i. Time-To-Drain

A **Time-to-Drain** analysis considers the damage that is likely to occur at an 85 percent saturation level but does not consider rainfall. Since dense soil gradations will generally not have enough permeability to comply with the FHWA recommendation of 50 percent drainage in 1 to 2 hours (for interstates and freeways) they must often be improved. The choices for improvement are:

- increase permeability,
- increase the cross slope, and
- decrease the length of the flow path (2).

ii. Inflow-Outflow

Inflow-Outflow analysis uses a calculated Q_{IN} (a representative value is approximately 2.4 ft³/day/ft (0.23 m³/day/m) to design drainage that removes infiltrated water under fully saturated conditions and limits the time of saturation to a short duration after rain stops. This method usually requires a base permeability that is higher than the Time-to-Drain method (i).

1.3.3.2.4 Drainage During Construction

Some common approaches to drainage enhancement during construction are to:

- Make wet cuts in stratified material and install toe drains and cross-drains.
- When the ground water table is high, place deep trenches on the sides of the road, raise the grade of the road, or use a full depth asphalt pavement (3). (Mn/DOT does not recommend full depth pavement designs.)

Beware of frost heave due to ice lenses. Frost heave damages the pavement and the drainage structure. To prevent frost heave, remove material to $\frac{3}{4}$ depth of frost penetration or mix the soil to prevent differential heaving (3).

1.3.3.2.5 Drainage Effectiveness

Permeable Asphalt Stabilized Base (PASB) - the material is coated with asphalt but the voids between grains are not filled. The coefficient of permeability is approximately 1,000 ft/day (300 m/day) (5, 6).

CLASS 5 Dense Graded Base – (Mn/DOT) material has a coefficient of permeability of 0.4 ft/day (120 mm/day) (6). At 0.4 ft/day (120 mm/day) and a flow gradient of 1.0, dense Class 5 material drains well when above granular subbase material but does not drain when placed over plastic soils and there is a low flow gradient (Cochran).

Pavement drainage systems were evaluated in a 1995 Mn/DOT report (6). The report evaluated pavement drainage systems under Jointed Plain Concrete Pavement (JPCP) and focused on four types of drainage systems having longitudinal edge drains. Drainage flow, percent rainfall drained, time to drain, base and subgrade moisture content and joint durability was evaluated. The systems included a Mn/DOT standard dense graded base, two dense graded bases with transverse drains under the transverse joints (geo-composite fins and drainage pipe) and a Permeable Asphalt Stabilized Base.

Cost differentials were provided for each type of drainage design in terms of savings over the PASB design.

The study concluded that all of the designs were functional but the PASB drained the most water within 2 hours of the end of rainfall. PASB provided the driest pavement foundation and the least early distress. Sealing joints temporarily reduced all inflow but within 2 weeks the inflow resumed, regardless of the apparent excellent condition of the joint seals (6).

1.3.3.3 Soil Compaction

Higher strength, stiffness, and lower permeability will generally result from higher compaction.

Compaction is the densification of soil by mechanical manipulation. The effectiveness of the compaction process is dependent on the soil type, moisture content and method of compaction (7). Densification is achieved in 4 to 12- in. (102 to 305-mm) lifts as heavy equipment reduces voids in the soil mass. Density is measured in terms of the dry unit weight of the soil. The amount of compaction varies depending on the proposed use of the soil. Compaction is usually accomplished in 6 to 10 equipment passes. The use of more passes is usually uneconomical (9).

1.3.3.3.1 Materials and Equipment

Table 1.1. Methods for incorporating water prior to compaction (Highway Res. Bd. Bull. 58, 1952 Compaction of Embankments, Subgrades, and Bases)

Generalized correlation of soil classification and equipment	
Type of Soil	Equipment and Methods
Heavy clays	Difficult to work and incorporate water. Best results usually obtained by sprinkling followed by mixing on grade. Break clods and cut in water with disc harrows then use heavy-duty cultivators and rotary speed mixers. Loose lift thickness in excess of 6 in. is difficult to work. Take time to distribute moisture uniformly. Sheepsfoot and pneumatic-tires rollers work well for cohesive soils.
Medium clayey soils	Can be worked in pit or on grade. Sprinkle then use cultivators and rotary speed mixers. Use sheepsfoot and pneumatic-tire roller.
Friable silty and sandy soils	Sprinkle and mix. Mixing can be done with cultivators and rotary speed mixers to depths of 8 to 10 in. Silty soils may also be compacted efficiently with sheepsfoot and pneumatic wheeled rollers; smooth-wheeled rollers may be used.
Granular soils	Use vibratory rollers.

Mn/DOT specifies minimum equipment and construction standards. Chapter 5.4.1.2.1.4. of the Mn/DOT report, “Best Practices for the Design and Construction of Low Volume Roads”(1) summarizes that compaction may be controlled with one of three methods:

- Specified Density, (Compact to 100% AASHTO T-99 maximum density). Mn/DOT specification 2105 for soils and Mn/DOT specification 2211 for bases and subbases.
- Quality (Ordinary Compaction using steel-wheeled or pneumatic-tired rollers), and the
- Penetration Index Method (The Dynamic Cone Penetrometer gives a direct measure of soil strength and uniformity. Uniformity is especially important in Minnesota because of the effect of frost heave.) At this time the Penetration Index Method is only used for granular bases and subbases.

1.3.3.3.2 Moisture Content Adjustment

Laboratory tests using standard methods, such as the AASHTO T 99-90 standard moisture-density test, are used for setting limits on construction conditions. Moisture-density tests are used when constructing with specified density methods (Mn/DOT Specifications 2105 and 2211).

Section 5-2.01.04 3 of the Mn/DOT Geotechnical and Pavement Manual (2) states that compaction moisture control must comply with Mn/DOT Spec. 2105.3F. Embankment moisture content should be:

- less than 115% of optimum when 95% maximum density is specified
- 65% - 102% of optimum when 100% maximum density is specified.

There are special moisture restrictions for problem soils. Restrictions for expansive soils state the moisture content should be:

- 90 – 115% of optimum for material below the top 3 ft (1 m) of fill and
- 90 – 102% within the top 3 ft (1 m)

Restrictions for red drift soils state the compaction moisture content should be 65 – 95% of optimum. (2).

1.3.3.4 Soil Modification

Subgrade modification is the improvement of subgrade materials workability, stiffness or plasticity resulting from the use of additives such as cementing or waterproofing agents. The extent of improvement required from modification is greater than ordinary mechanical methods alone but less than that required for full subgrade stabilization.

1.3.3.4.1 Modification Using Cementing Agents

There are various materials used as cementing agents for modification of soils. When selecting a modifier type it is important to use field tests to show types and properties of the subgrade and borrow materials. It is also important to use lab tests to learn the engineering properties of mechanically modified and chemically modified soils and borrow material (9). The use of trial mixes is recommended with cement, lime and fly ash modifying agents (2).

The discussion of materials for modification will be limited to **lime, fly ash, lime-fly ash, and bituminous**.

1.3.3.4.1.1 Lime

Lime reacts with medium, moderately fine, and fine soils to produce decreased elasticity, increased workability, decreased swell, and increased strength. Lime may be effective for soils with clay content as low as 7% (9). Lime also works well when stabilizing (modifying) granular materials and lean clays. Cation exchange and flocculation-agglomeration changes the texture of clay soils (called lime modification). This flocculation process causes a short-term increase in strength. In addition, pozzolanic reactions occur when lime, water, soil and silica react to form various cementing compounds. This process causes a long term strength gain that may be as high as 100 psi (690 kPa) at 28 days, 625 psi (4.3 MPa) at 56 days, and 1580 psi (10.9 MPa) at 75 days (cured at 120 F (49 C) with 5% lime). Soil properties including optimum pH (about 12.4, where the solubility of silica and alumina increase) influence the lime reactivity of a soil (10).

Lime is used to treat fine-grained soils that have a plasticity index > 10 and a clay content > 10%. Mn/DOT cautions that the use of lime may increase frost susceptibility, pavement roughness and cracking (2).

1.3.3.4.1.2 Fly Ash

Fly ash can act as a pozzolan or as filler to decrease voids in fine-grained soils. Most clays are pozzolanic in nature so silty soils are generally better suited to **lime-fly ash** or **cement-fly ash** treatment. A wide variety of gradations including sand, gravel, crushed

stone and slag materials have been used with lime-fly ash. Coarser gradations have greater resistance to frost (9).

Fly Ash is produced during the combustion of coal and consists of the inorganic matter present in the coal that has been fused during coal combustion and solidified while suspended in the exhaust gases by electrostatic precipitators. Some **Fly Ash** materials from sub-bituminous coals have over 20% CaO which makes them self-cementing. Bituminous coals (from the eastern US) have little calcium and therefore are not as self-cementing.

ASTM D-5239 defines the cementing properties of fly ash using three categories:

- Very Self-Cementing Fly Ash (20-30% CaO) – Compressive strengths greater than 500 psi (3.45 MPa) at seven days using Test Method C 109.
- Moderately Self-Cementing Fly Ash – Compressive strengths greater than or equal to 100 psi (0.70 MPa) but less than or equal to 500 psi (3.45 MPa) at seven days.
- Non Self-Cementing Fly Ash – compressive strengths less than 100 psi (0.70 MPa) at seven days.

Lime or some other source of CaO must be added to Non Self Cementing Fly Ash to produce a stabilizing material.

Coal from the same source can produce different types of fly ash if burned and solidified under different conditions. Ash crystallinity and sulfate content can be affected. Fly ash with sulfate contents up to 7% do not usually cause problems; however, fly ash materials with sulfate contents greater than 10% should be avoided because they can cause expansive reactions when mixed with soil.

Fly ash from a given power plant will usually be consistent because:

- Coal will be from a single source.
- Burning equipment and methods will be the same.

The primary factors that influence the mineralogy of a self-cementing coal fly ash are:

- Chemical composition of the coal.
- Coal combustion process including coal pulverization, combustion, flue gas cleanup and fly ash collection operations.
- Additives used include oil additives for flame stabilization, combustion, combustion side corrosion control additives and chemicals injected to facilitate SO₂ or fly ash removal.
- The mineralogy and degree of crystallinity of the ash is dictated by the boiler design and operation, as this controls the rate at which the fused mineral matter is cooled.

Quality control and assurance of fly ash from a given source is generally limited to the elemental analysis provided by ASTM C 311 (56). This analysis provides the values used for determining compliance of the ash with ASTM C-618 (57). **The elemental**

analysis alone will not provide the basis to assess the self-cementing characteristics of the material. This can only be evaluated using the strength tests referenced in ASTM D-5239 (55).

Fly ash has the potential to leach toxic substances into the environment. Fly ash design should only be done after considering the most up-to-date recommendations of pollution control agencies. See Section 3.3.2 for a presentation of environmental considerations.

1.3.3.4.1.3 Lime-Fly Ash

There is currently no Mn/DOT specification for **lime-fly ash** modification. This treatment is used for silty soils. The lime content is usually 2 – 8% with an ash content of 8 – 36% (2). There is a pozzolanic reaction that produces a cementing compound when lime (calcium) and fly ash (silicas, aluminas) are combined with water. Not all fly ash is the same since it is a waste product of coal combustion. There are three types (lignite, bituminous, sub-bituminous). Lignite and sub-bituminous ash have better pozzolanic properties (11).

1.3.3.4.1.4 Design Factors For Cementing Agents

Mix design is done to improve various engineering properties such as Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI), swell characteristics, cured strength, and uncured strength. The process involves analysis of the soil at various lime percentages. CBR or R-value methods are used to evaluate the mixes. Cementing agent content is usually specified as a percentage of dry soil weight. Samples are prepared dry and then blended with water.

Design criteria depend on the engineering objectives. Some common criteria are:

- no further decrease in PI with increased cementing agent percentage
- acceptable PI reduction for a particular modification objective
- acceptable reduction of swell potential, and
- sufficient CBR or R-value increase for the proposed use (10).

Table 1.2 is a list of typical climatic limitations and precautions to consider when using lime or fly ash.

Table 1.2. Limitations and Safety Precautions for Lime and Fly Ash Modification (9)

Modification Type	Climatic Limitations	Construction Safety Precautions
Lime Lime Fly Ash	<ul style="list-style-type: none"> • Do not use on frozen soils. • Air temperatures 5C (40F) and rising. • 1 month before first hard freeze. • 2 weeks of warm weather desirable prior to fall and winter temperatures. 	<ul style="list-style-type: none"> • Quicklime: Do not contact skin. • Hydrated Lime: Do not contact moist skin for prolonged period. • Use safety glasses and protective clothing at all times. • Do not use during windy conditions.

1.3.3.4.1.5 Application to AASHTO Design

There are limitations when using the equation: $SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$ because of the variability of layer coefficients a_2 and a_3 . The level of treatment and type of soil to be modified requires careful selection of coefficients. In addition, the procedure is limited to highway loading. Fixed values for structural coefficients are not warranted since engineering properties of the mix, subgrade support and structural makeup of the pavement all influence performance.

Mechanistic-empirical design methods such as MnPAVE require the determination of the resilient modulus and Poisson's ratio. Standard lab tests and field tests such as the DCP and FWD should be used (9).

Table 1.3. Approximate strength values resulting from fly-ash modification (14% by weight) as observed by Mn/DOT (24)

Soil Type	Pre-Ash Modification		Post-Ash Modification (one month after modification)	
	FWD Subgrade Modulus psi (MPa)	Design Modulus psi (MPa)	Soil-ash over soil Design Modulus psi (MPa)	Soil-ash Design Modulus psi (MPa)
Silty-clay-loam	4,500 (31)	3,700 (25.2)	6,200 (42.8)	13,600 (93.2)

Proportions for AASHTO design may be found from testing various combinations of subgrade soil and modifying agent.

For more information on fly ash design, construction, and environmental concerns see Section 1.3.3.5.2.8.

1.3.3.4.1.6 Construction

No procedures are currently recommended or available to evaluate the effect of lime modification on the thickness requirements using the current Mn/DOT procedures.

Construction of a lime or fly ash modified subgrade is usually done by end-dumping the ash on the subgrade, spreading, and mixing. Mn/DOT notes that fly ash is a very fine material and controlling dust during the dumping and spreading process would enhance the construction process. Moisture content should be monitored before and after application of fly ash and at the rotary mixer (24).

All compaction should be completed within two hours using pad-foot vibratory compaction, pneumatic-tire compaction, or smooth-drum compaction (24).

There are three common methods of lime construction:

- in place mixing
- plant mixing, and
- pressure injection.

For the in place method lime is added in 1 or 2 increments and stabilization is possible. The pressure injection method can go to depths of 2.1 to 3 meters (7 to 10 feet) to control swelling of unstable soils.

The **Construction Steps for Lime Treatment:**

- Prepare the soil. (Must be careful of the fluff action that is possible when using lime).
- Apply the lime. Dry hydrated lime and dry quicklime may be applied by bulk application methods or by the single bag method. **Quicklime must be applied with greater emphasis on safety.** Lime may also be applied by the slurry method.
- Compact the soil. Most projects require 95% of AASHTO T-99 for subbases and usually 98% for base courses. The compactive effort may be applied with a sheepsfoot roller followed by a multiple wheeled pneumatic roller. (A flat wheel may be used for finishing). Note that single lift compaction may be done with a vibratory roller or pneumatic roller followed by a light pneumatic or steel roller to finish.
- Cure the mix. Temperatures should be above 40 – 50 F (5 – 10 C). Moisture content should be kept close to optimum to aid compaction and curing. Curing may be done with moist cure or asphalt-membrane cure techniques (10).

1.3.3.4.1.7 Performance

Mn/DOT has found that fly ash is useful for temporarily strengthening soil at construction sites and also shows promise as a long-term reinforcement material. Toxicity and regulatory issues are under investigation (24).

1.3.3.4.2 Modification with Bituminous Materials

Asphalt is a product of the petroleum industry. Asphalt is available in standard binder form with properties varying according to performance grade (PG). Asphalt is also available in emulsified form where droplets are held in suspension Anionic, Cationic, or other types of asphalt emulsions available for specific applications.

Asphalt can be used with soils that meet the requirements of:

- maximum percent passing the 0.075 mm (No. 200) sieve is less than 25 %,
- PI is less than 6,
- sand equivalent is less than 30 and,
- $(PI \times \text{percent passing the 0.075 mm (No. 200) sieve})$ is less than 72.

In general asphalt modification techniques may be used with A-1-a, A-1-b, A-2-4, A-2-6, A-3, A-4, and low-PI A-6 soils (9).

1.3.3.4.2.1 Design Factors

Key points:

Determine the desired depth of modified subgrade (upper 4 in. (100 mm), etc.) or the total amount of bituminous treatment (plant mix aggregate asphalt, plant mix sand emulsion base or emulsion treated subgrade) (13).

Table 1.4. Limitations and Safety Precautions for Asphalt Treatment (9)

Modification Type	Climatic Limitations	Construction Safety Precautions
Asphalt	<ul style="list-style-type: none"> • Air temp above 50F (10C) when using emulsions. • Air temperatures 40F (5C) and rising when placing thin lifts 1 in. (25.5 mm) of hot mixed asphalt concrete. • Hot – dry weather is preferred 	<ul style="list-style-type: none"> • Some cutbacks have flash and fire points below 100F (40C). • Hot mix asphalt cement temperatures may be as high as 350F (175C).

1.3.3.4.2.2 Construction

See the Mn/DOT Standard Specifications for Construction 2207 for asphalt base stabilization.

According to The Asphalt Handbook (14), asphalt may be applied by four methods, blade mixing, rotary mixing, travel plant mixing and stationary mixing facilities.

Blade Mixing uses multiple drag blades to blend the asphalt and aggregate together. Spread the material out with a grader so the moisture content is 3% or less and asphalt is applied from a distributor in 2 to 3 passes. The asphalt is partially mixed in after each pass.

Rotary Mixing uses a machine to cut through the grade to a specified depth and then applies asphalt. This method is also commonly used for cold recycle construction.

Travel Plant Mixing uses a self-propelled pugmill that can use recycled, virgin or a blend of materials.

Stationary Mixing Facilities have some advantages: weather is less of a factor, aggregates may be heated (dried) prior to mixing, and there is good control over proportions (this may be more important for pavement layers than subgrade).

Aeration, spreading and compaction:

In the case of sands and sandy soils (base material) volatile components should be reduced by at least 2/3. The material can be placed to one side in windrows. Blade spreading is done in several layers. Note that emulsified asphalt should not be placed if the temperature is less than 50F (10C).

Rolling:

If rolling is done prematurely the evaporation process is retarded, thereby increasing the time needed to attain density and cohesion. Roller selection may include:

- Open grade: steel wheel initially followed by vibratory roller
- Dense grade: steel wheel or pneumatic followed by vibratory roller

If there is any sign of rutting during compaction the rolling should stop. Wait until the moisture content is reduced to resume rolling (14).

Techniques previously used in Minnesota:

- Compact subgrade to 100% maximum AASHTO T-99 density and apply 2 gallons per square yard dilute emulsion. (30% SS-1 and 70% water) and mix full depth of treatment with rotary mixers.
- Compact with pneumatic tired rollers and apply a dilute application of emulsion (0.7 gallon per square yard) to prevent raveling.
- Construct the base.
- Cure (13).

1.3.3.4.2.3 Performance

In the past, data had shown the outer wheel path was weaker than the inner wheel path. Tests on the stabilized subgrade (plate bearing) show progressively higher values up to 49 days but only equal to non-emulsified sand.

The lower base cures at 24 to 43 days. A 1- in. (25-mm) crust forms with softer material below. The conditions have shown that curing time is needed for a sand-asphalt-stabilized base. Benkelman beam data showed that the 6- in. (150-mm) stabilized base needed at least 2 weeks for satisfactory curing (13).

1.3.3.4.3 Modification with Chlorides

Calcium chloride and sodium chloride material have been used for modification of embankment soils in Minnesota and elsewhere. Illinois has permitted sodium chloride treatment when modifying the shoulders and bases of secondary roads. However, Illinois excludes the use of calcium chloride as a stabilizing agent because of performance-cost shortcomings (15).

1.3.3.4.3.1 Minnesota Test Sections

Minnesota agencies have arrived at conclusions similar to Illinois. A 1960 Minnesota study (Nobles County) compared the effectiveness of sodium chloride, calcium chloride and cutback asphalt. It was found that chlorides tend to rapidly migrate out of the roadway structure. After a five-year period the embankment chloride levels were approximately zero. Use of chlorides neither increased construction efficiency nor improved performance in test sections (16). The treatment rate for NaCl was 2.4 lb per square yard (1.3 kg per square meter) (0.8% by weight MHD specification 3910 rock salt). Treatment rate for CaCl₂ was 1.3 lb per square yard (0.7 kg per square meter) (0.42% by weight). Surface construction was bituminous.

1.3.3.5 Soil Stabilization

Subgrade stabilization is subgrade improvement through the use of Portland cement, lime-fly ash or other additives.

Portland cement may be used to stabilize sandy soils and lean clays. Cement stabilization guidelines given by the FHWA (8, 22). AASHTO says soil classes A-4 to A-7 are suitable for lime and fly ash stabilization (9).

Fly ash has been used most recently for subgrade stabilization in Minnesota.

Table 1.5. Approximate Elastic Parameter (Resilient Modulus) Values for Stabilized Pavement Materials (9)

Material	Resilient Modulus MPa (ksi)	Poissons's Ratio
Cement treated base	Uncracked: up to 13,800 (2,000) Cracked: Down to values of untreated granular base	0.30
Lime – Fly Ash (R-1)	10,400 – 17,300 (1,500 – 2,500)	Low stress level: 0.08 High stress level: 0.30
Lime treated base	Uncracked; up to 3,450 (500)	0.15
Soil lime mixtures for compressive strength range [psi (MPa)]		
100 – 200 (0.69 – 1.38)	170 – 690 (25 – 100)	0.15
200 – 400 (1.38 – 2.76)	690 – 2,070 (100 – 300)	0.15
> 400 (> 2.76)	2,070 + (300 +)	0.15

1.3.3.5.1 Stabilization with Portland Cement

Soils Suitable for Cement Stabilization:

Cements are most economical with sands, sandy and silty soils, and clayey soils of low to medium plasticity (PI < 30 %) since it is difficult to mix into a soils having a PI > 30 %. If the pH of a 10:1 soil cement mix after 15 minutes is at least 12.1 it is unlikely that organic substances will interfere with strength development (22).

Portland cement has not been used in Minnesota over the past 20 years because of poor performance, including cracking.

1.3.3.5.1.1 Mixture Design

High strength stabilization is based on properties such as the resilient modulus and Poisson's ratio (17). Linear elasticity is assumed within certain ranges of repeated loading. The soil-cement modulus in compression is a function of the deviator stress, confining pressure, unconfined compressive strength, and cement content (22).

An approximate cement content may be selected from the following table. For many stabilization applications satisfactory stabilization is achieved using lower cement contents.

Table 1.6. Cement Stabilization Requirements for Various Soils (22)

AASHTO Soil Classification	Unified Soil Classification	Usual Range in cement requirement		Estimated cement content and that used in moisture-density test [% by weight]	Cement contents for wet-dry and freeze-thaw tests [% by weight]
		[% by volume]	[% by weight]		
A-1-a	GW, GP, GM, SW, SP, SM	5 – 7	3 – 5	5	3 – 5 – 7
A-1-b	GM, GP, SM, SP	7 – 9	5 – 8	6	4 – 6 – 8
A-2	GM, GC, SM, SC	8 – 12	5 – 9	7	5 – 7 – 9
A-3	SP	8 – 12	7 – 11	9	7 – 9 – 11
A-4	CL, ML	8 – 12	7 – 12	10	8 – 10 – 12
A-5	ML, MH, CH	8 – 12	8 – 13	10	8 – 10 – 12
A-6	CL, CH	10 – 14	9 – 15	12	10 – 12 – 14
A-7	OH, MH, CH	10 – 14	10 – 16	13	11 – 13 – 15

Perform Detailed Testing:

- i. Determine pH of mixture after 15 minutes.
 - If pH < 12.1 do not use cement.
- ii. Determine amount of sulfates present.
 - If > 90% sulfate and fine grained soil do not use cement.
 - If > 90% sulfate and coarse grained soil use sulfate resistant cement.
 - If < 90% sulfate determine cement content.
- iii. If soil contains less than 50% silt and less than 20% clay use PCA short cut test procedures for sandy soils. All other soils use tables to select trial cement contents.
- iv. Perform freeze-thaw and wet-dry tests.

1.3.3.5.1.2 Mixture Characteristics and Criteria

Table 1.7. Criteria for Soil-Cement as Indicated by Wet-Dry and Freeze-Thaw Durability Tests (22)

AASHTO Soil Group	Unified Soil Group	Max. Allowable Weight Loss - %
A-1-a	GW, GP, GM, SW, SP, SM	14
A-1-b	GM, GP, SM, SP	14*
A-2	GM, GC, SM, SC	14
A-3	SP	14
A-4	CL, ML	10
A-5	ML, MH, CH	10
A-6	CL, CH	7
A-7	OH, MH, CH	7

*10% is maximum allowable weight loss for A-2-6 and A-2-7 soils

Additional Criteria:

- Maximum volume changes during durability test should be less than 2 percent of the initial volume.

- Water content during the test should be less than the quantity required for sample saturation at the time of molding.
- Compressive strength increases with age of specimen.

Mixture Characteristics:

Some common values for properties of cement stabilized soil are listed in Table 1.8, including density, strength properties, CBR, moduli, and assorted others.

Table 1.8. Summary of some properties of cement stabilized soil (22)

UC = unconfined compressive strength, C = cement content, % by weight			
Property	Granular Soils	Fine grained soils	Notes
Density			May be higher or lower than untreated soil. Delay between mixing and compaction causes density reduction.
Unconfined Compressive Strength	<ul style="list-style-type: none"> • UC = (90 to 150) C • UC = (0.5 to 1.0) C • K = 70 C [psi] • K = 0.5 C [MN/m²] 	<ul style="list-style-type: none"> • UC = (40 to 80) C • UC = (0.3 to 0.6) C • K = 10 C [psi] • K = 0.07 C [MN/m²] 	<ul style="list-style-type: none"> • UC in psi • UC in MN/m²
Cohesion	To a few hundred psi $c = 7.0 + 0.225(UC)$ psi To a few MN/m ² $c = 0.05 + 0.225(UC)$ MN/m ²		Depends on C, d
Friction Angle		30 – 40 degrees	May decrease at high confining pressures

The use of trial mixes is recommended with stabilizing agents such as cement, lime and fly ash (2).

1.3.3.5.1.3 Construction of Portland Cement Stabilized Soils

Construction (17)

- For best results place the cement in a single layer (since bonding between layers is an issue).
- Illinois DOT recommends saw and seal in cement and fly ash construction.

Certain safety precautions should be observed when constructing with cement products and are listed in Table 1.9.

Table 1.9. Limitations and Safety Precautions for Cement and Fly Ash Stabilization (9)

Stabilization Type	Climatic Limitations	Construction Safety Precautions
Cement Cement – fly ash	<ul style="list-style-type: none"> • Do not use on frozen soils. • Air temperatures 40F (5C) and rising. • 1 week before first hard freeze. • Do not use in heat to prevent shrinkage cracks. 	<ul style="list-style-type: none"> • Hydrated Lime: Do not contact moist skin for prolonged period. • Use safety glasses and protective clothing at all times.

1.3.3.5.2 Stabilization with Fly Ash

Fly ash has been used for many of the same soil stabilization applications as lime and Portland cement. These include:

- Drying Agent – the reduction of soil moisture content to facilitate mechanical compaction.
- Reduction of Shrink-Swell properties of clay soils.
- Stabilization to increase Strength – CBR values have been shown to increase from 2-3 up to 25-30 for a clay stabilized soil allowing a corresponding decrease in pavement thickness requirements.

Conditions: A clay-type soil especially if above optimum moisture conditions in the field and/or existing pavements in poor condition.

1.3.3.5.2.1 Laboratory Mixture Design

Since most stabilization applications with fly ash rely on the ash as the stabilizing agent, the test and design procedures must address the rapid rate of hydration when the ash is exposed to water. Ash hydration alters the soil compaction characteristics because soil particles become bonded together in a loose state. A portion of the compactive energy is lost in disrupting these bonds. Maximum density achieved therefore decreases as the hydration reaction progresses after blending of the soil, fly ash, and water.

Self-cementing fly ash hydrates more rapidly than Portland cement; therefore, a 2-hour delay in compaction can result in a decrease in maximum density of up to 10 pcf (1.6 kN/m³) or more. Usually a 2-hour delay time can be achieved even with rudimentary equipment. When pulvamixers are used with experienced personnel a 1-hour compaction time can be readily achieved.

The allowable range in moisture content must be specified and be monitored during construction to ensure that moisture contents of the stabilized section are near the optimum for maximum strength. If the actual compaction in the field will be completed within the specified 2-hour delay period, actual strengths achieved in the field would be between the laboratory test results with 0 and 2 hour compaction delay.

No standard methods have been adopted for the design of materials stabilized with fly ash. Depending upon the application either standard or modified Proctor compactive energy may be used (ASTM C-593 and ASTM D-1633). For most county road

application, standard Proctor compaction should be adequate.

For cohesive soils, the moisture content should be up to 10 percent below optimum moisture content for maximum density. Test specimens should be cured for 7 days at 100F (38C) in accordance with ASTM C-593 after which compressive strength should be determined. The optimum moisture content for maximum strength has been shown to be consistent for cure periods of 7, 28, and 56 days. Therefore, optimum moisture content can be determined using 7-day strengths.

The reduction of PI for clay soils will be less for fly ash compared to lime.

1.3.3.5.2.2 Construction Procedures and Concerns

The laboratory mix design is usually conducted to establish the optimum ash and moisture contents. Maximum dry density and strength gain for design and construction testing are determined. A general construction specification is presented in Chapter 3.

The following goals must be achieved to result in a good project:

- Uniform distribution of the fly ash
- Proper pulverization and thorough mixing of the fly ash with the material to be stabilized
- Control of moisture content for maximum density and strength
- Final compaction within the prescribed time frame (usually 2 hours)

Typical design specifications call for fly ash contents of 1 to 2 percent greater than optimum determined in the laboratory. The best way to obtain a uniform application is by careful blading of the fly ash over the exposed grade from uniform windrows deposited by the transports. The quantity of ash is calculated knowing the depth, width, length and design percent of fly ash. Uniform distribution can be accomplished using metered gates on the transport or direct metering of the ash into the mixing drum of a mobile mixer.

Construction discs can effectively blend the ash with cohesive soils. The depth the disc is cutting must be closely monitored. Where higher degrees of stabilization are required the use of a self-propelled mixer (pulvaximixer) is required to ensure adequate pulverization and uniform distribution of moisture and fly ash. One or two passes of a mixer can be used to obtain good mixing.

1.3.3.5.2.3 Field Moisture Content

Control of moisture content is both critical and difficult. Strengths of the stabilized materials decrease significantly as the moisture increases above the optimum moisture for maximum strength. Strength also decreases on the dry side of optimum moisture and increased compactive effort is required.

Maintaining moisture contents within a range of 0 to 4 percent above optimum moisture content for maximum compressive strength is typically recommended and is readily

achieved with proper equipment.

Significant quantities of water may be required to bring the moisture to the design level. The following aspects of moisture control must be considered.

If water is added after the fly ash is blended, the final strength of the stabilized material will be reduced due to hydration of the ash before compaction is completed.

- Adding sufficient water to the pulverized material prior to distribution of the ash may make the untreated material unstable, hampering distribution and operation of construction equipment.
- Applying water directly onto the fly ash distributed on the surface is not advisable since this increases the rate of hydration.
- Water can be added after the fly ash has been incorporated; however, additional passes with the mixing equipment will be required to achieve uniform mixing.
- Introducing water directly into the drum of a rotary mixer is the most effective procedure controlling moisture content, ensuring that it falls within the desired range and provides the most uniform mixing without additional delay in compaction.

Moisture contents can be monitored using a nuclear density gauge. The nuclear gauge may not give an accurate moisture measurement; however, it can give a good indication of uniformity.

1.3.3.5.2.4 Compaction

Compaction of the mixture must be accomplished as soon as possible following the final pass of the mixing equipment. When using paving-train type operations initial compaction can easily be achieved within 15 minutes of the final pass of the mixing equipment.

Initial compaction is most often accomplished using a vibratory padfoot or a self-propelled padfoot roller operated immediately behind the mixing equipment. The padfoot provides good compaction from the bottom of the stabilized layer and imparts a kneading action that can give some additional mixing.

After initial compaction the materials should be shaped to final grade by blading. Final compaction is done using a self-propelled, pneumatic-tired roller. Shaping should not be delayed.

1.3.3.5.2.5 Curing/Temperature

The surface of the stabilized lift should be maintained in a moist condition to help hydration of the fly ash. Curing can be accomplished through periodic application of water on the surface until the next lift or a wearing surface is constructed over the stabilized material.

Temperature Effects

Stabilization with fly ash can be performed satisfactorily down to temperatures of 50F

(10C). Construction can be accomplished at cooler temperatures with modified procedures. At cooler temperatures two passes of a pulvamixer may be required to reduce the maximum size of the material to less than 1 in. (25 mm). Cooler temperatures may be beneficial apparently because the cooler temperature retards hydration. However, cooler temperatures also result in decreased density for the same compactive effort. With additional compactive effort, and in-place densities are adequate, the strength of the compacted section can be near design strength when constructed below 40F (4.5C).

Cooler temperatures have greater impact on soil pulverization and compaction than on ash hydration. Soil temperatures below 50F (10C) help retard ash hydration, which increases long-term strength of the stabilized material. Multiple passes of the pulvamixer may be required to achieve pulverization and mixing with the ash. Additional compactive effort may also be required to obtain specified density.

Effective stabilization of clay soils as long as soil temperature is above 32F (0C) and construction procedures are modified to attain proper mixing and compaction of the stabilized materials.

1.2.3.3.4 Pavement Thickness Design Considerations

The following guidelines for thickness design are presented in Reference 56. When considering the effect of a fly ash stabilized layer on the pavement section the structural properties of the material must be evaluated. The stiffness of the stabilized layer is dependent on the factors discussed in the mixture design and construction sections. These include: fly ash source, fly ash content, retarder type and dosage, material gradation, fines content, plasticity index, moisture content and compaction delay time.

Laboratory evaluation of individual mixes is necessary because of the many variables. It will be necessary to establish a minimum strength required and then conduct the laboratory design to produce the desired strength.

The variables to specify are:

- Compaction delay, usually 1-2 hours
- Moisture – Density relationship for the design fly ash content
- Quantity of retarder

The strength tests should be conducted on specimens cured for a minimum of seven (7) days to assess the full benefits provided by the fly ash. If final compaction can be achieved in less than the specified delay time, the stabilized soil will have a higher strength and density than the laboratory mixtures.

The following table lists the coefficients assigned to materials with various fine aggregate contents and laboratory unconfined compressive strengths.

Table 1.10. Structural Coefficients for Fly Ash Stabilized Materials for Various Unconfined Compressive Strengths

Fines Content (% - No. 200)	7-day Unconfined Strength, psi (MPa)	Range of Structural Coefficients (a_2) **
> 50%	100-300 (0.69 – 2.1)	0.08 – 0.14
25 to 50%	150-500 (1.0 – 3.4)	0.11 – 0.17
10 to 25%	150-800 (1.0 – 5.5)	0.15 – 0.25
< 10%	150-1000+ (1.0 – 6.9)	0.18 - 0.28

** For definition of structural coefficient see Chapter III of the AASHTO Design Guide (62).

The structural coefficients are quite variable for a given compressive strength. Materials with good gradation characteristics will yield higher strengths. The use of a retarder is generally required to achieve a 7-day compressive strength higher than 500 psi (3.45 MPa). With a good laboratory design and careful field control the design factors listed should be conservative.

The structural coefficients listed are for the Structural Number used for defining pavement thicknesses in the AASHTO Design Guide (9). A coefficient of 0.14 represents a good well-graded granular base, which would have a granular equivalent factor of 1.0. Therefore, to convert the factors in the table to GE factors divide by 0.14.

1.3.3.5.2.6 Concerns

1.3.3.5.2.7 High Sulfate Ashes

There are two common high-sulfate content ashes: fluidized bed combustion (**FBC**) and flue gas desulfurization (**FGD**) ash. These materials can exhibit self-cementing properties similar to subbituminous coal ashes. **These materials may cause serious expansion characteristics when hydrated.** Therefore, the following should be considered when evaluating the sulfate content of an ash.

- Ash in the soil or groundwater can influence swell potential and be considered in addition to the amount of sulfate in the ash

The relative damage/deterioration of a high-sulfate ash-stabilized material can be categorized based on combined clay and colloid content as follows:

Relative Damage	Clay and Colloids Content
Minor	5-10%
Moderate	10-30%
Major/Severe	Greater than 30%

The availability of free moisture in the stabilized material is critical to long term performance. With saturated or near-saturated conditions, sulfate, silica and alumina ions

within the fluid are mobile and free to react.

1.3.3.5.2.8 Environmental Concerns

The primary environmental concern when using self-cementing ashes is the migration of metals. Data from four roadbases and one embankment suggested that very localized migration of ash derived metals had occurred into the underlying soils. Depth of migration was less than 2 ft (0.7 m) below the stabilized section on two study projects (62).

Most applications of fly ash stabilized soils or bases would be designed such that the material would be above the water table and water flow through the material would be minimal. This is necessary to maintain the structural integrity of the stabilized and layers of the pavement section. If there is a groundwater associated problem the stabilized section is encapsulated in a geofabric.

To evaluate the potential of leaching particular materials the specific metals in a given ash should be determined. The source of coal for a given generating plant is usually the same because the burning system is setup for that coal source.

An EPRI Demonstration Project was conducted in Kansas to assess the migration of metals from the stabilized section in to the underlying subgrade. Of the 23 metals evaluated, only none were present in a higher concentration in the fly ash than in the soil below the section to be fly ash-stabilized. Barium was the only metal that was present in significantly higher concentrations than in the soil.

The Toxicity Characteristic Leaching Procedure (TCLP) has been used by a number of agencies to determine what and how much of various metals are leached from various situations and environments. Studies at specific locations showed that the metals leached from the ash were a small percentage of the total metals present in the existing soils. Overall, it was found that the hydration and solidification of the ash in addition to the natural soil attenuation characteristics caused a reduction in leachable barium.

Fugitive Dust can be a problem just as for any other construction process. Maximum dust is generated at the time the ash is discharged from the tankers or end dump trailers onto the pavement subgrade. Construction activity will generally minimize fugitive dust. When a rotary mixer is used, water is added in the mixer, which minimizes fugitive dust. This is the procedure that also is most effective in constructing a good stabilized soil subgrade (62).

1.3.3.5.2.9 Louisiana Lime-Fly Ash Study

Studies show that lime-fly ash is an excellent method of improvement because of crack resistance (12). Louisiana constructed lime-fly ash (class C) test sections on two state highway reconstruction projects. Four lime-fly ash test road bases were proportioned using 2% lime plus 4% fly ash and 3% lime plus 6% fly ash on each project. The

construction was done on an old cement treated base. No new soil was used in the base. The project was located on rural, low volume state highways.

Comparisons of laboratory samples and field samples were made. Crack maps and Dynaflect measurements were done for 5 years following completion of construction. Rutting was measured at 5 years. Lime-fly ash sections showed less cracking than soil-cement.

- Pulverize old base (60% of material passes No. 4 (4.75-mm) sieve).
- Form typical sections
- Mix in lime and let cure three days
- Mix in fly ash
- Compaction to 95% of required density within 6 hours of adding fly ash.
- Grading. (AASHTO T-99 standard)
- Asphaltic membrane applied to prevent rapid drying during the following three-day cure period.

Results:

Visible rutting never occurred. Measurements were taken from the outer wheel path at year 5. Crack Maps showed that soil-cement sections on both projects had more cracking than the lime-fly ash sections. The difference between 2 and 3 percent lime was not significant.

Table 1.11. Total transverse and longitudinal cracks at 6 years (12)

2% lime	3% lime	Soil-cement
157 ft (48 m)	244 ft (75 m)	1200 ft (366 m)

Field and lab comparisons showed that soil-cement had the highest strengths (greater than 500 psi (3.45 MPa) at 28 days). Lime-fly ash (LFA) strengths were lower than soil-cement at about 150 psi (1.04 MPa) at 56 days. Dynaflect testing showed that over the course of 5 years the structural number decreased and stabilized.

Louisiana Cost Comparisons:

The cost figures have not been corrected for present value.

- Cost per linear foot
 - Soil-cement \$5.53
 - Lime \$2.12
 - Fly Ash \$1.42
- Cost per square yard at 8.5 in. (216 mm) thickness
 - Soil-cement \$2.20
- Cost per square yard at 10 in. (254 mm) thickness
 - Lime-Fly Ash \$2.50
- Other cost factors:

step placement of LFA
72-hour cure period

Louisiana recommends that the designer consider LFA as an alternative when LFA is more cost effective than cement or there is a need to reduce surface cracking.

1.3.3.6 Geosynthetics

Geosynthetics are a class of textile materials that are extruded petroleum polymer-based thin pliable sheets of varying permeability (Table 1.11). There are many different varieties, such as **geotextiles**, **geogrids**, **geonets**, **geocells**, and **geomembranes**. One difference is the size of the aperture, with geogrids having the largest aperture. Most varieties of geosynthetics used for pavement applications in Minnesota are of Mn/DOT Type V and VI (Spec 3733.1) classification.

Table 1.12. Mn/DOT Geosynthetic Classification (Spec 3733.1)

Class	Description
Type I	For use in wrapping subsurface drain pipe or for other specified drainage applications.
Type II	For use in wrapping joints of concrete pipe culvert and as a cover over drain field aggregate.
Type III	For use under Classes I and II random riprap, gabions, andrevet mattresses.
Type IV	For use under class III and IV random riprap, hand-placed riprap, and quarry-run riprap.
Type V	For use in separating materials (stabilization).
Type VI	For use in earth reinforcement and Class V random riprap.

Geosynthetics are used in many areas of ground construction. Common highway applications include separation, reinforcement, drainage and filtration. The usefulness and effectiveness are directly dependent on the application, the type of geosynthetic, and the design in which the geosynthetic is incorporated.

Interpretation of the benefits associated with geosynthetics can be difficult. Some of the most common benefits are cost savings, longer life, and improved performance. Obtaining quantifiable improvement using geosynthetics requires careful design along with correct and careful installation procedures.

Proper design procedure requires more information than what is presented in this report. The purpose of this overview is to provide an introduction to geosynthetic applications and construction procedures. This information can be used to facilitate the decision whether geosynthetics are appropriate for specific pavement design applications.

1.3.3.6.1 Geotextiles

Geotextiles are permeable textile-like materials most commonly composed of a polymer like polypropylene and polyester (25). The two most common geotextile varieties are woven and non-woven. The woven varieties are made from both monofilament and multifilament fibers. The non-woven (multifilament) varieties are bonded together after extrusion by one of three processes: melt-bonding, needle-punching, or resin-bonding.

Applications

Geotextiles are used in three major categories of pavement system improvement:

- Separation
- Reinforcement
- Filtration

The most common pavement application for geotextiles is **separation** of dissimilar materials (26). Separation between an underlying fine-grained soil and an aggregate base or granular subbase to prevent contamination of the base material has been used for many applications. Separation is mostly needed for grades that will be saturated or close to saturation.

Reinforcement of weak soils is another application for geotextiles. Reinforcement applications require tensioning of the geotextile and achieving sufficient tension throughout the entire fabric is difficult. Tension may also be developed after construction is complete if larger strains and deflections are tolerable. Current research suggests that the use of geotextile-geogrid composites is more effective than geotextiles for reinforcement applications.

Filtration within drainage systems is also a major application of geotextiles (25). The small aperture size will keep large particles from entering the drainage layer or pipe, while allowing some of the small suspended particles to pass without clogging the filter.

Geotextiles are also used as a protective outer layer of geocomposites (see Section 4.1).

Some common types of geosynthetics are shown in Figure 1.1. Geosynthetic materials used for separation in Minnesota are referred to in the Standard Specification 3733.2 as Type V and are similar to panel (b) in Figure 1.1.

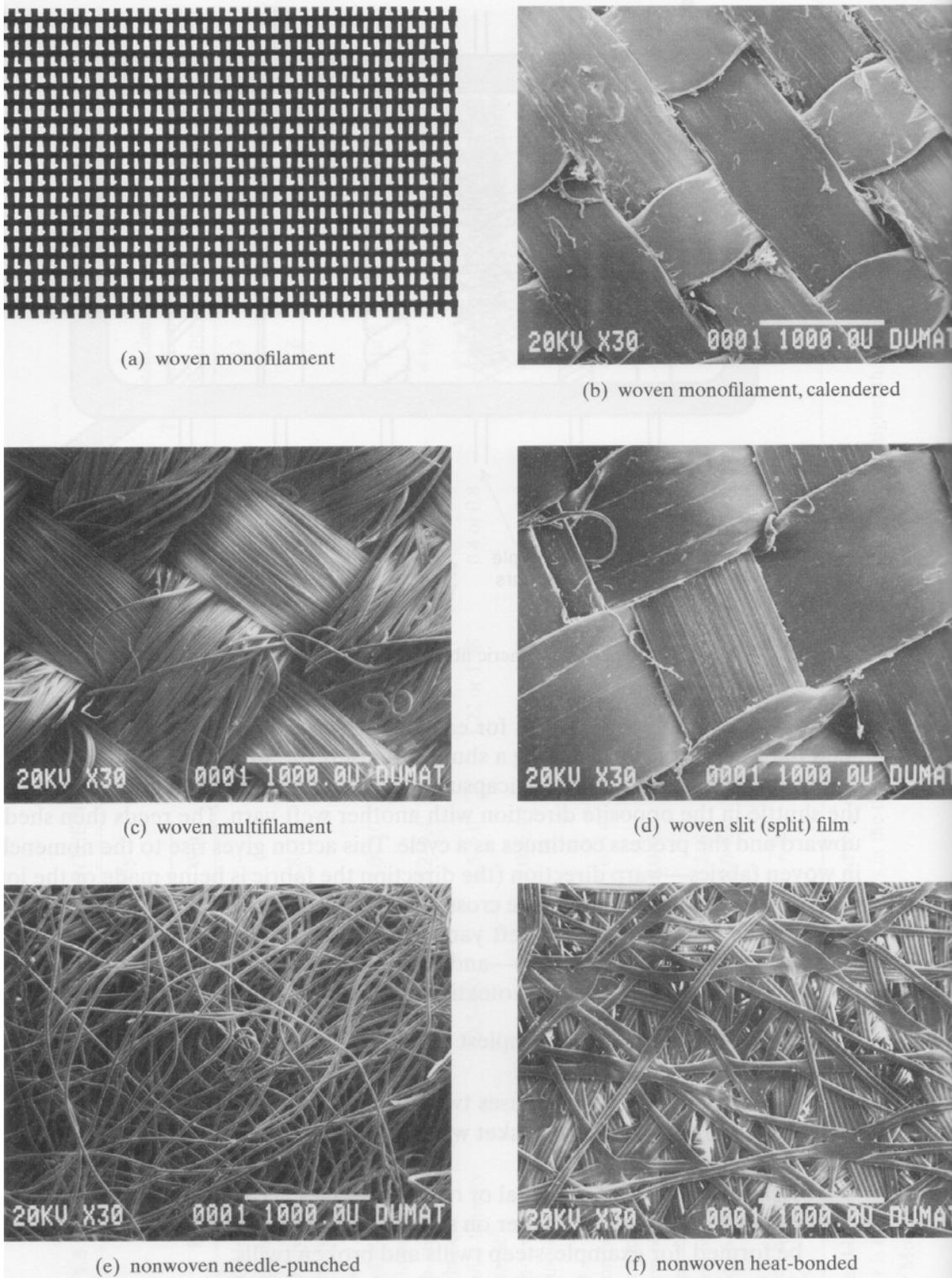


Figure 1.1. Common Geosynthetics (25)

1.3.3.6.2 Geogrids

Geogrids, a stiff structure, differ from geotextiles in that they have large apertures, typically 0.4 – 4 in. (10-100 mm) between ribs (25). The primary use of geogrids is soil reinforcement. Some geogrids begin as a geomembrane with holes punched through it. The geogrids may be run through rollers with different rotational speeds or placed in a stretcher to elongate the polymers. Both uniaxial and biaxial elongation versions are commercially available (Figure 1.2a, 1.2b, 1.2d). The benefit of polymer elongation is that the polymer goes into a post-yield state, which increases the material strength, modulus, and resistance to creep (25). Elongation should be in the direction of the major principal stress. If the direction of the primary stress is unknown, it is recommended to use a biaxial grid. Many variations of geogrids are commercially available (Figure 1.2a-1.2d). Choice of an appropriate type is a function of the application and manufacturers' specifications.

Applications

Geogrids are commonly used to improve the modulus of a granular base, by providing lateral confinement and reducing “walk out” of the base material. Haas (27) showed that the use of geogrids could significantly reduce deformation and improve the durability and lifespan of paved roads. The greater resistance to failure is due primarily to an increase in stiffness and the load spreading ability of geogrids. The increase in stiffness suggests that a decrease in the thickness of base material or HMA is possible for some situations (28, 29, 30, and 31). A more common approach is to consider that the increased stiffness of the standard base and HMA thickness translates into a longer lifespan. It has been shown that the placement of geogrids at mid-depth of a base course dissipates the magnitude of the stress transferred through the geogrid (28). Tension will need to be developed in order to realize the full capacity of the system. This can be accomplished in two ways.

- Pre-tensioning and anchoring
- Developing tension by overburden after installation

1.3.3.6.3 Geonets

Geonets are primarily used for drainage applications and are similar to geogrids except that the aperture is usually about 0.5 x 0.3 in. (12 x 8 mm) (24). They are manufactured from polyethylene. The ribs are manufactured at angles of 70° and 110°. This diamond shaped pattern changes the amount of vertical loading that the geonet can support. Thickness is the most influential factor on the drainage performance of a geonet, and should be determined using ASTM D1777. A thicker net will allow better drainage. Greater thickness can be achieved by adding a foaming agent during manufacture, which increases the thickness up to 0.2 – 0.3 in. (5 to 7 mm) and sometimes up to 0.5 in. (13 mm). The hydraulic properties of a geonet should be determined using ASTM D4716 (Constant head hydraulic transmissivity).

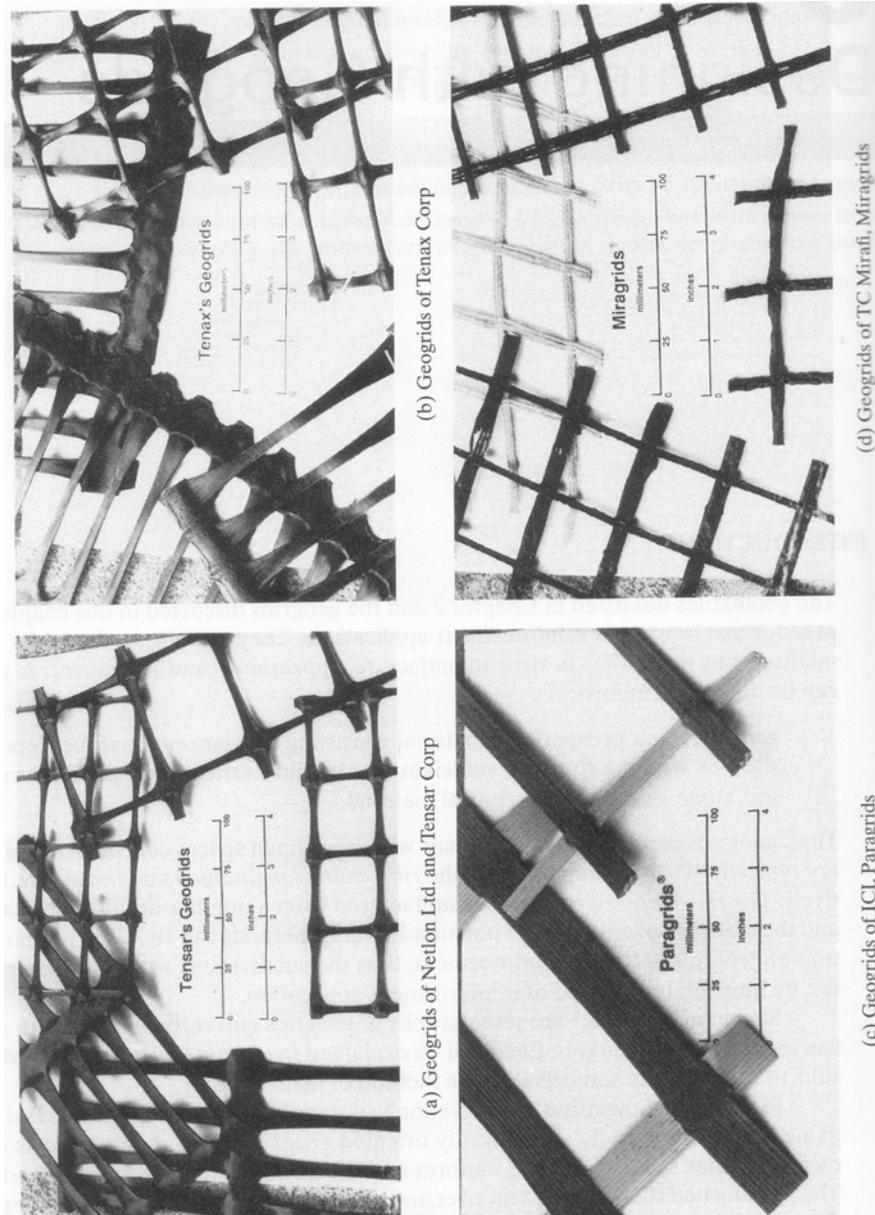


Figure 1.2. Examples of Types of Geogrids (25)

Geonets are usually separated from the in situ soil, both below and above, by another geosynthetic, such as a geotextile in pavement applications.

The long-term conditions surrounding the geonet also need to be assessed in order to design a system that will not degrade over time. Soil may block the openings of the geonet. Temperature can also be destructive to these systems, because the polymers will creep faster at high temperatures. The design must account for the maximum temperature expected. Subsurface chemicals being transported, which can damage the geonet, must be determined. Composition of the water therefore, is important. The amount of a dissolved chemical that the geonet and separation layers will be exposed to is much greater than in

most reinforcing situations, due to the increase flow rate of geonet systems. A high flow-rate factor of safety must be used in order to ensure a long performance life.

Applications

These materials are almost exclusively used for drainage applications. They are separated from the in situ soil by another geosynthetic placed on both sides of the geonet. This separation allows for lateral drainage in embankment applications, or vertical drainage in retaining walls.

1.3.3.6.4 Geomembranes

Geomembranes are relatively impermeable barriers used for complete separation (25). The term impermeable layer is used because the permeability of water vapor for the material is between 1.9×10^{-17} and 1.9×10^{-20} ft/day (5×10^{-11} and 5×10^{-14} cm/s). This type of geosynthetic consists of two major categories:

- Modified
- Waterproof

Modified geomembranes are impregnated with bitumen, or elastomeric materials in the field.

The second geomembrane type is manufactured to be waterproof. For this class of geosynthetics, tensile strength, tear resistance, puncture resistance, and seam behavior are more important than in other geosynthetic applications because failure or deterioration of any type that allows increased permeability will compromise the entire system. Resistance to chemicals must also be considered, as it may reduce the effective life of the material. To reduce the possibility of failure, other types of geosynthetics are often used to add a protective barrier on both sides of the geomembrane (32).

Applications

Geomembranes are used in transportation applications to stop intrusion of water into expansive soils, (25, and 32). This application has two variations, horizontal and vertical depending on the direction of fluid flow. Determining if one or both are necessary depends on groundwater flow and surface infiltration. Horizontally-installed geomembranes vary in width depending on the application. Vertically-installed geomembranes typically are placed to a depth of 5 to 8 ft (1.5 to 2.5 m), such as for cut off wall applications. They must be wide enough to prevent water from vertically infiltrating and to isolate the overlying material. In frost sensitive soils, geomembranes will allow for the control of moisture content, reducing the effects of differential frost heave. Geomembranes are also used for containment of runoff and contaminated fluids as well as for waterproofing foundations, walls, and bridge abutments.

1.3.3.6.5 Geocells

Geocells are another type of geosynthetic sometimes installed as a geocomposite (defined in Section 1.3.3.6.6). Geocells are composed of polymer strips that are arranged to form vertical boxes, which are then filled with sand. This soil-containment system is able to

distribute large vertical forces and compensate for weak soils. The geocell is sometimes installed with a protective geotextile above and below.

Applications

Geocells are typically used for reinforcement or containment, installed in or below the base course.

1.3.3.6.6 Geocomposites

Geocomposites are a combination of two or more types of geosynthetics (25). A geonet or geogrid with another geosynthetic on either side is a common example of a geocomposite. A geomembrane reinforced with geotextiles is also an example of a geocomposite. Geocomposites are often used to enhance the performance of the primary synthetic chosen.

Strip or wick drains are composites that use a large aperture geogrid or geonet middle layer and fine aperture geotextile as a filter sandwiching the middle layer. There are many different arrangements that can be made for various purposes. The properties of each system are dependent on the components chosen and their interactions.

Applications

A composite is intended to create a synergistic effect where the performance of the entire system is greater than its individual components. The primary factors in composite selection are cost and the results achieved. The construction of a temporary access road over wetland soils was facilitated by the use of a geofabric-geogrid combination (34). The purpose of this design was to minimize the impact on local vegetation. The use of geosynthetics allowed for minimal disturbance to the subgrade. The use of geofabrics for separation and geogrids to increase the friction between dissimilar layers has been effective in many situations such as subgrade reinforcement and pavement overlays.

1.3.3.6.7 Design Factors

1.3.3.6.7.1 Separation

Geosynthetics can be used as a separating layer. Soil separation is a primary concern for pavement sections with wet or saturated fine-grained plastic soils. The small grain size of some soils allows the subgrade soil to infiltrate the granular base, or the granular base to migrate into the subgrade. This mixing of subgrade and base course material will result in contamination of the base and a decrease in stiffness and strength of the pavement system, allowing excess deformation of the HMA surface. Installing a separation layer will help retain the design stiffness, which will help increase the pavement life.

Installation of a geosynthetic (geotextile) has been proven to be a successful method to limit soil intrusion into a coarse aggregate (26, 35). Selection of a suitable separation layer is dependent on the grain size of the soil. The aperture of the geosynthetic should be smaller than the smallest grains. If there is material smaller than the aperture, migration will occur. The migration of the fines is facilitated by water and the pumping effect caused by repeated loading.

1.3.3.6.7.2 Reinforcement

Geosynthetics have many reinforcement applications. Installation of load distributing geosynthetics can have a significant effect on the strength parameters of the embankment system. Because soils fail in shear, a high tensile strength material compliments the low shear strength of soils, and is able to dissipate the shear stress, resulting in an increased load carrying ability of the subgrade (32). It is common not to decrease the thickness of the base but rather to provide more stability and stiffness, thereby increasing pavement life (36, 37).

Geogrids are able to distribute wheel loads when placed within or below the base course layer. This is due to the friction developed between the geogrid and the granular material. This friction is much greater than between geotextiles and granular material. The tension necessary to increase structural support is not immediately developed; the amount of time necessary for the tensile stress to develop is a function of the properties of the soils, geosynthetic, and loading. In a project carried out by the Wyoming Department of Transportation, a control section and a geogrid-reinforced section were found to have similar stiffness (resilient modulus) after three years. The geogrid was placed in the middle of the granular base layer with a decreased thickness. The significance of this study is the decrease of the base thickness from 17 in. (430 mm) to 11 in. (280 mm), without a decrease in stiffness (28).

1.3.3.6.7.3 Drainage and Filtration

Design of a geosynthetic drainage system must consider three major components.

- Maximum flow rate necessary to drain area
- Percent and size of fine-grained material
- Type of drain system to be implemented

Drainage and filtration can be difficult tasks, because water must continually pass through the geosynthetic while retaining the soil. Designing a system to facilitate this process depends on the percent and size of fines in the soil, as well as the flow rate of the water that needs to be removed.

The maximum aperture of the geosynthetic must be smaller than the larger particles in the soil, retaining a majority of the soil. The smaller particles will block the openings reducing the flow, and limiting the influx of additional soil, essentially self-filtering.

A list of common transmissivities is given in Table 1.12. Use of transmissivity values to design drainage systems will help ensure adequate flow with proper soil retention. These properties are defined as the following:

Design criteria (32)

1. Retention

- $AOS \leq B * D_{85}$ AOS = Apparent opening size
- $C_u \leq 2$ or ≥ 8 B = 1
- $2 \leq C_u \leq 4$ B = $0.5 * C_u$
- $4 < C_u < 8$ B = $8 / C_u$

- $C_u = \text{Coefficient of Uniformity} = \frac{D_{60}}{D_{10}}$
 - Where; D_{85} , D_{60} , D_{10} = soil particle size with 85%, 60%, and 10% smaller (mm).
2. Permeability
 - $k_{\text{geotextile}} > (1 \text{ to } 10) * k_{\text{soil}}$ – depending on flow requirements
 3. Clogging resistance
 - radient ratio test (ASTM D5101)

Other empirical methods may be implemented for less critical situations.

The use of these criteria will aid in the proper design of geosynthetic drainage systems. Geotextile filters will allow for the use of lower quality aggregate, and may eliminate or decrease the need for collector pipes. Separation of the drainage material by a geosynthetic will also decrease the possibility of contamination of the aggregate during construction (32).

Table 1.13. Typical Values of Transmissivity (In-Plane drainage Capability) of Geotextiles* (25)

Type of Geotextile	Transmissivity m ² /s	Permeability Coefficient m/s
Nonwoven, heat-bonded	3.0×10^{-9}	6×10^{-6}
Woven, slit-film	1.2×10^{-8}	2×10^{-5}
Woven, monofilament	3.0×10^{-8}	4×10^{-5}
Nonwoven, needle-punched	2.0×10^{-6}	4×10^{-4}
* Values taken at applied normal stress of 40 kPa		

Geocomposites are also used for drainage applications. The combinations of geosynthetics used are designed specifically for the drainage purposes. In these situations the drain is a geosynthetic, not an aggregate, and geotextiles are still used as filters. Performance, flow, and soil retention without clogging are the primary considerations that need to be considered when using geocomposites or other systems in drainage design.

1.3.3.6.7.4 Effective Life Span

The effective life of a geosynthetic is a function of many factors. Solar radiation, heat, ozone, and acid rain all begin to degrade the polymer before the geosynthetic is in service. Ultraviolet radiation, specifically UV-B, will cause severe polymer damage. Heat from solar radiation may cause some damage to the geosynthetic, and placing the geosynthetic in close proximity to hot materials such as asphalt or joint compound may compromise strength and longevity of the geosynthetic. Excess temperature should be avoided because polypropylene melts at 330 F (165 C) and polyester melts at 480 F (250 C). On the opposite side of the spectrum, low temperatures can cause the materials to become brittle and decrease workability.

Appropriate procedures must be implemented in order to insure that damage is minimized during construction. The stresses endured during construction may be significantly greater than those expected during service. This is due to the limited amount of material available to distribute the stresses above the geosynthetic during construction. Construction equipment may cause failure during construction, because the it is often heavier than the calculated loads developed by the traffic after construction.

After installation is complete, other degradation processes take over. Acidity or alkalinity of groundwater may cause a decrease in strength. The groundwater composition and pH should be tested and used during design to select a geosynthetic that will minimize the effect of the groundwater. Physical damage can still occur, though not likely from human interaction. Plant roots as well as insects and burrowing rodents may create holes that will decrease the strength and effectiveness of the geosynthetic (40). Chemical degradation is likely the primary concern after installation.

1.3.3.6.7.5 Effective Longevity

The effective longevity will vary depending on the in situ conditions and the intended applications. Properties of installed geosynthetics have been shown to be stable for over 20 years (41). Geosynthetics used for filtration and drainage have been shown to assist in the development of an internal soil filter based on a bridging network (42).

Creep Degradation

The value for the strength reduction factor is based on the inverse percentage of the quasi-static strength at which no creep occurs. The reduction factor will be a product of the polymer, manufacturing process, and type of geosynthetic. ASTM D5262 is the procedure used to measure the rate of creep under tensile load.

Installation Damage

Damage of geosynthetics during installation and compaction can be a major component of the decrease in tensile strength over the life of the material (43). The average diameter of the granular backfill material will significantly influence the amount of damage. The amount of installation damage may be assessed using ASTM D5818.

Chemical and Biological Deterioration

Chemical and biologic degradation are environmentally dependant factors (25, 32). Chemical degradation is directly related to the composition and pH of the soil and groundwater. These parameters can be determined by analyzing the conditions near the construction site. Biologic degradation is more difficult to estimate because it is not a true deterioration of the material. It however, increases deterioration of material properties such as permeability and local tear resistance. Two types of biologic deterioration are commonly encountered:

- clogging of the apertures by bacteria or other small organisms,
- holes created by rodents

Polymeric Aging

Polymeric aging is the gradual process that brings the polymer into a state of equilibrium. The equilibrium state can be maintained unless a degradation process occurs.

Degradation may be associated with exposure to many different compounds. The two simplest are;

- oxidative degradation and
- degradation caused by exposure to a strong acid or base.

The extent of the degradation effect is dependant on concentration and the amount of time in contact. Studies by Elias have shown that polyester geosynthetics degrade in the presence of strong acid and alkaline solutions (44).

1.3.3.6.7.6 Summary

The effectiveness of a system using geosynthetics is different for every situation (28, 29, and 30). It has been shown that geosynthetics distribute shear stress over a greater area when it is in tension (46). The result will be different for each application depending on type of geosynthetic used, soil and granular material both above and below the geosynthetic, as well as the load and distance from the load. These parameters cannot be simulated easily in the laboratory and a conservative design approach must be taken until the effects of geosynthetic are better understood in field applications. FHWA (32), AASHTO, and ASTM have recommended design parameters for specified geosynthetic applications.

The effectiveness of geosynthetics will be greater for poor quality in situ conditions (39).

Geosynthetics can be used between different materials to provide separation or within a granular layer to provide reinforcement and confinement. Initial tension also increases the amount of initial support. However, some geosynthetic materials are susceptible to creep therefore reducing the externally applied tension.

Geosynthetics used to reinforce extremely weak soils provide a greater amount of support than a geosynthetic used to reinforce moderate soils. Geocomposites are often able to provide better results than a single material. Geogrid/geotextile composites have been shown to provide better results than the components individually (33, 36, and 37).

1.3.3.6.7.7 Construction

1.3.3.6.7.7.1 Selection and Installation

Success with geosynthetics begins with choosing the right material for a given application. Knowledge of the conditions the geosynthetic will be exposed to, along with the desired properties of the geosynthetic, will lead to a successful project. Considering the properties (Table 1.13) provided by multiple products used as a composite is likely to more completely fulfill the desired aspects of the project.

The construction area must be cleared of debris that may cause damage to the geosynthetic. As the geosynthetic is laid in place, care should be taken to check orientation and also prevent overexposure to sunlight. After the material is put in place seams may need to be secured. Keeping the geosynthetic in place during construction may be difficult; as some materials may curl or slip as the aggregate is placed.

Table 1.13. Geosynthetic Property Testing Methods

Property	Test Method
Apparent Opening Size	ASTM D4751
Water Permittivity	ASTM D4491
Tensile Strength	ASTM D4595
Geosynthetic Durability	ASTM D5819
Secant Modulus at 5% strain	ASTM D4595
Seam Breaking Strength	ASTM D4884
Puncture Resistance	ASTM D4833
Tear Strength	ASTM D4533
Ultraviolet Radiation Stability	ASTM D4355
Burst Strength	ASTM D5617
Hydraulic Conductivity Ratio	ASTM D5567
Biological Clogging	ASTM D1987
Temperature Stability	ASTM D4594
Clogging Potential	ASTM D5101
Coefficient of Friction	ASTM D5321
Chemical Resistance	ASTM D5322
Installation Damage	ASTM D5818
Creep Resistance	ASTM D5262
Multi-Axial Tension	ASTM D5617
Geogrid Chem. Resistance	ASTM D6213
Geotextile Chem. Resistance	ASTM D6389

After the geosynthetic is installed, the granular base course should be put in place such that material is not dumped directly on the geosynthetic, and a minimum of 6 in. (150 mm) is in place before any equipment is driven over the geosynthetic. A complete construction sequence for soft and firm subgrade conditions is given as modified from Holtz 1998 (32).

1.3.3.6.7.2 Subgrade Preparation for soft foundations

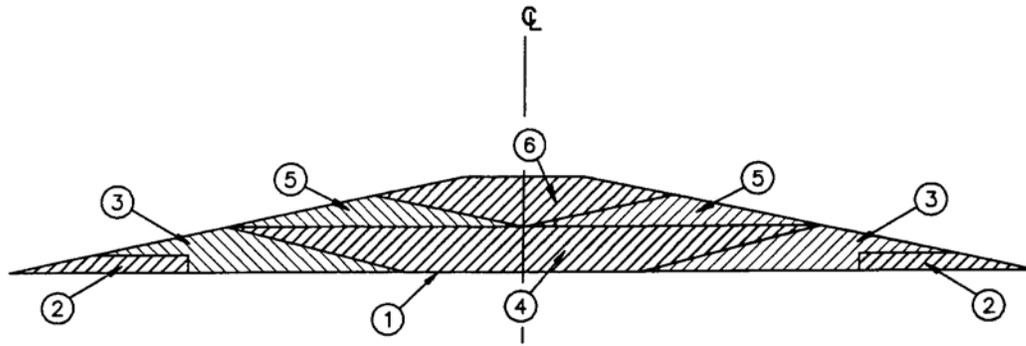
- Cut tree stumps flush with the ground surface.
- Do not remove or disturb root mat.
- Leave vegetative cover, such as grass and reeds, in place.
- For undulating sites or areas where there are many stumps and fallen trees, construct a working table before placement of the embankment reinforcement. In this case, a lower strength sacrificial geosynthetic can be used to construct and the support the working table.

1.3.3.6.7.3 Geosynthetic Placement Procedures

- Orient the geosynthetic correctly with the machine. This depends on the type of geosynthetic and the intended design objectives. In general for uniaxial geosynthetics:
- no seams should be parallel to the embankment alignment.
- these widths should be factory-sewn to provide the largest width compatible with shipping and field handling.
- Unroll the geosynthetic as smooth as possible transverse to the alignment. **Do not drag it.**
- Geotextiles should be sewn as required with all seams up and every stitch inspected. Clamps, cables, pipes, etc. should positively join Geogrids. The following criteria should be used to evaluate sewing;
- The seams should be sewn J-seam style (a Prayer-seam is also permissible).
- One row of sewing is required when using two spools of thread to give a 401-stitch.
- If the stitching is “untested” two rows are needed not more than 0.5 in. apart.
- Need 4 –7 stitches per inch.
- The geosynthetic should be manually pulled taut to remove wrinkles. Weights (sand bags, tires, etc.) or pins may be required to prevent lifting by wind.
- Before covering, the engineer should examine the geosynthetic for damage that should be repaired by one of the following methods:
- Replace large defects by cutting along the panel seam and sewing in a new panel.
- Cut out smaller defects and sew a new panel into that section.
- Overlap defects less than 6 in. (150 mm) a minimum of 3 ft (1 m) in all directions from the defective area.

1.3.3.6.7.4 Fill Placement, Spread and Compaction

1. *Construction sequence for extremely soft foundations (when a mud wave forms) is shown in Figure 1.3.*
 - a. End-dump fill along edges of geosynthetics to form toe berms or access roads as shown (Fig. 1.3).
 - Use trucks and equipment compatible with constructability design assumptions (Table 1.16).
 - End-dump on the previously placed fills; do not dump directly on the geosynthetic.
 - Limit height of dumped piles, e.g., to less than 3 ft (1m) above the geosynthetic layer, to avoid local bearing failure. Spread piles immediately to avoid local depressions.
 - Use lightweight bulldozers and/or front-end loaders to spread the fill.
 - Toe berms should extend one to two panel widths ahead of the remainder of the embankment fill placement.



SEQUENCE OF CONSTRUCTION

1. LAY GEOSYNTHETIC IN CONTINUOUS TRAVERSE STRIPS, SEW STRIPS TOGETHER
2. END DUMP ACCESS ROADS
3. CONSTRUCT OUTSIDE SECTIONS TO ANCHOR GEOSYNTHETIC
4. CONSTRUCT INTERIOR SECTIONS TO "SET" GEOSYNTHETIC
5. CONSTRUCT INTERIOR SECTIONS TO TENSION GEOSYNTHETIC
6. CONSTRUCT FINAL CENTER SECTION

Figure 1.3. Sequence of Construction (32)

- b. After constructing the toe berms, spread fill in the area between the toe berms.
 - Placement should be parallel to the alignment and symmetrical from the toe berm inward toward the center to maintain a U-shaped leading edge (concave outward) to contain the mud wave (Figure 1.4).

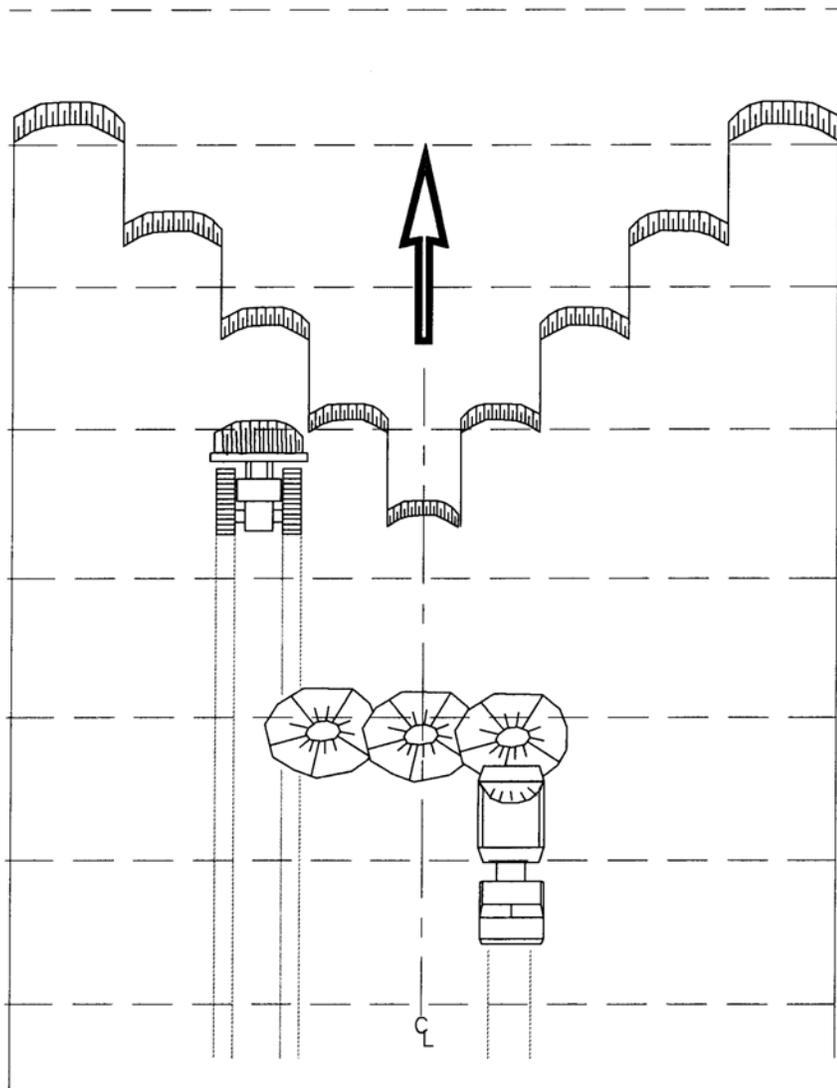


Figure 1.4. Fill placement sequence on soft foundation (32)

- c. Traffic on the first lift should be parallel to the embankment alignment; no turning of construction equipment should be allowed.
 - Construction vehicles should be limited in size and weight to limit initial lift rutting to 3 in. (75 mm). If rut depth exceeds 3 in., decrease the construction vehicle size and/or weight.
- d. The first lift should be compacted only by tracking in place with bulldozers and end-loaders.
- e. Once the embankment is at least 2 ft (600 mm) above the original ground, subsequent lifts can be compacted with a smooth drum vibratory roller or other suitable compactor. If local liquefied soil conditions occur, any vibration should be turned off and the weight of the drum alone should be

used for compaction. Other types of compaction equipment also can be used for nongranular fill.

2. After placement, the geosynthetic should be covered within 48 hours.

For less severe conditions (i.e., when no mudwave forms):

- a. Place the geosynthetic with no wrinkles or folds; if necessary, manually pull it taut prior to fill placement.
- b. Place fill symmetrically from the center outward in an inverted U (convex outward) construction process, as shown in Figure 1.5. Use fill placement to maintain tension in the geosynthetic.
- c. Minimize pile heights to avoid localized depressions.
- d. Limit construction vehicle size and weight so initial lift rutting is no greater than 3 in. (75mm).
- e. Smooth-drum or rubber-tired rollers may be considered for compaction of the first lift; however, do not over compact. If weaving or localized quick conditions are observed, the first lift should be compacted by tracking with construction equipment.

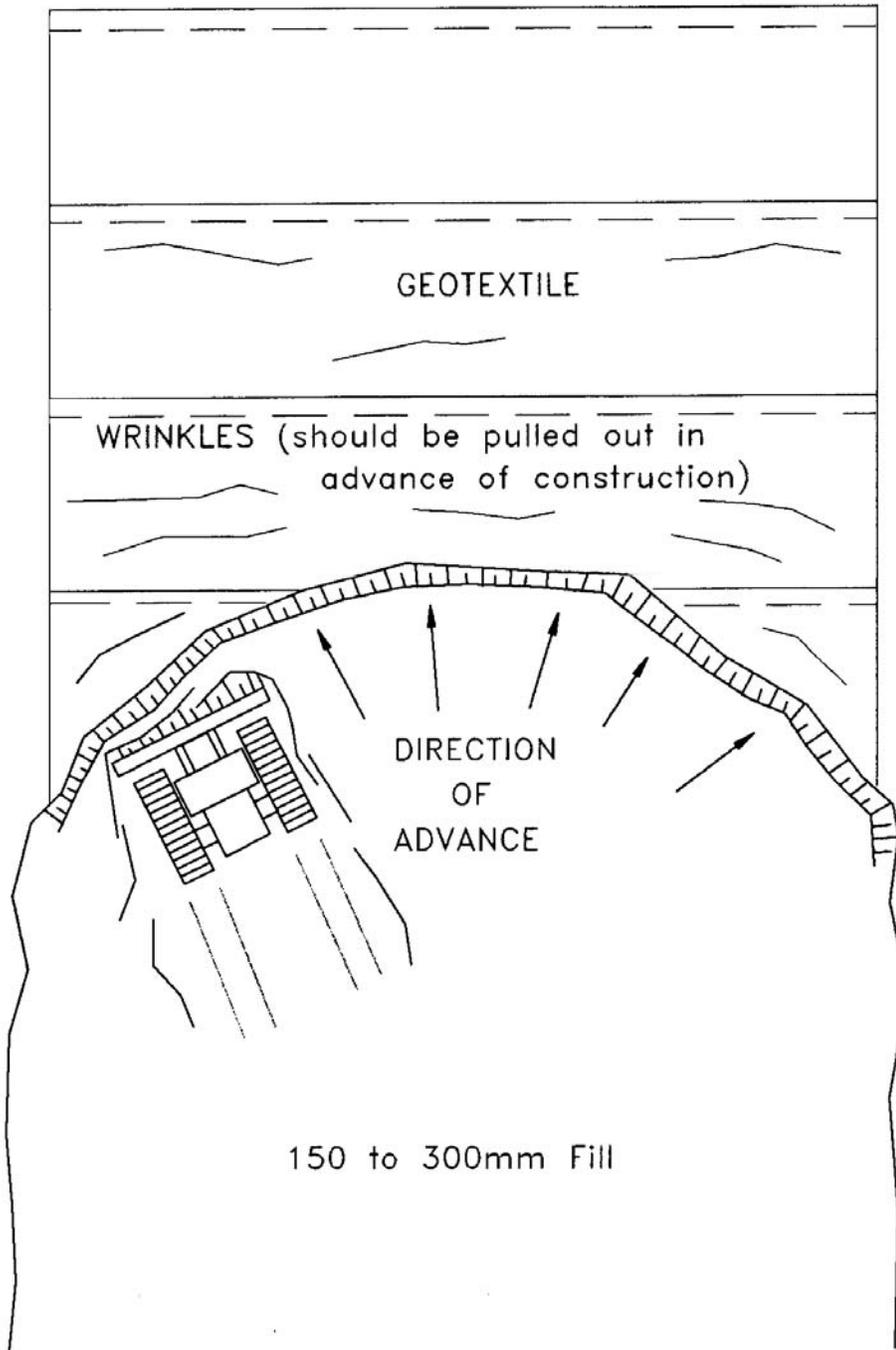


Figure 1.5. Fill placement on foundation with no mudwave (32)

1.3.3.7 Substitution

Substitution is a method that directly enhances the subgrade by removing unstable or unsuitable soil and replacing or covering it with other suitable material.

If the use of in situ soil or available borrow is not practical from an engineering or financial standpoint then substitution with lightweight fill materials (Table 1.14) may be a solution.

Table 1.14. Characteristics of Common Lightweight Fill Materials (52)

Material	Expected Compacted Density lbs/ft ³ (kg/m ³)	Comments
Wood Products (Chips)	24 – 36 (380 – 575)	Readily available, renewable. Easily placed with standard construction equipment. Should remain saturated at all times. Sawdust form is a relatively inexpensive byproduct of lumber industry. Formal design parameters do not exist. Design based on field experiments.
Shredded Tires	20 – 45 (320 – 720)	Readily available. Considered a by-product, relatively inexpensive. Easily placed by standard construction equipment. Design parameters are based on field experiments. Use restricted to above the water table by MPCA regulations.

1.3.3.7.1 Select Granular

Mn/DOT specification 3149.2 identifies Select Granular borrow is either pit-run or crushed material having $\frac{\text{Mass passing No. 200 (0.075 mm)}}{\text{Mass passing 1in. (25 mm)}} \leq 0.12$. Construction with

Select Granular material should be governed by the standard practices given in Mn/DOT 2105 and 2112.

1.3.3.7.2 Breaker Run Limestone

Breaker Run Limestone is a material that is well graded from fine aggregate up to an approximate maximum particle size of 6 in. (150 mm). Breaker Run Limestone, along with geofabric and Class 5 material, has been used in Minnesota as a replacement for wet plastic soils. The construction procedure is described in greater detail in Section 3.5.2.

1.3.3.7.3 Wood Chips

Construction specifications and design guidelines for wood products are not available. It has been found that wood will not biodegrade under anaerobic conditions so care must be taken to place wood material below the water table (52). It is also desirable to place a cap of plastic soil to prevent biodegradation of the wood chip material.

Mn/DOT conducted a 1976 study that included log and wood chip construction. The methods were described as corduroy and wood chip and were used to widen sections of road over a swamp (52).

- Corduroy – Place tied logs perpendicular to the road. The corduroy creates a working platform for further construction.
- Wood chip working platform – Create a working platform using a layer of wood chips. Place a 2-ft (600-mm) thickness then cover with a minimum of 6 in. (150 mm) of clay to reduce exposure to air.
- Wood chip embankment – Use of wood chips to reduce weight on soft subgrade materials, especially for sites requiring large amounts of fill material. Cover with a 2-ft (600-mm) thickness of clay to reduce exposure to air.
- Keyed widening - Peat, muck or poor quality soils are dug out.

Observations and conclusions from the study:

- Wood will not displace in front of machinery but running water may easily displace wood chips.
- Disturbance of the existing vegetation mat (drainage ditches) can cause longitudinal cracking in adjacent lanes. Locate the ditches far enough away from the road so as to prevent transverse movement.
- The construction costs of floated widenings are much less than the keying method. Floating widenings are also much quicker to construct than keyed widenings.

Methods of controlling bio-degradation in embankments containing wood products (52):

- Construct in a manner that ensures the wood stays below the water table.
- Seal wood with chemicals (may be an environmental issue). Emulsified asphalt may be an option. Chemical treatment may be expensive and difficult to apply.
- Use a geotextile or a plastic soil fill to restrict/reduce the exposure to air and retard degradation.

Wood and wood chips may be used in construction without the need of special equipment.

See also “Wood Chips as a Lightweight Fill”(53).

1.3.3.7.4 Shredded Tires

Table 1.15. Advantages, Disadvantages and Practical Areas of Use of Common Lightweight Fill Materials – WASTE TIRES (52)

Material	Advantages	Disadvantages	Practical Areas of Use
Waste Tires	Inexpensive. Easily placed. Non-biodegradable.	Must be kept above water table. May leach toxins. Minimal design parameter available.	Bogs/wetlands when water table is not near the surface.

Mn/DOT has sponsored some research on the use of shredded tires. See also Development of Design Guidelines for Use of Shredded Tires as a Lightweight fill in Road Subgrade and Retaining Walls (54).

Waste tires are an inexpensive source of lightweight fill but the MPCA has found they may also be a source of potential environmental problems when used in construction projects.

MPCA Guidelines (52)

Soil pH is important because acidic conditions (northeast MN) may cause leaching of toxic metals and alkaline conditions (southwest MN) may cause leaching of Polynuclear Aromatic Hydrocarbons (PAHs). MPCA notes that drinking water Recommended Allowable Limits (RALs) may be exceeded under “worst-case” conditions for arsenic, barium, cadmium, chromium, lead, selenium, and carcinogenic and non-carcinogenic PAHs. “Worst-case” case conditions for metals appear to occur at low pH (acid) conditions. “Worst-case” conditions for organics appear to occur at high pH (basic) conditions.

Prevent leaching contamination by placing tire materials only in the unsaturated zone (above the water table) of the roadway subgrade. Place alternative materials, such as wood chips or soil, below the water table.

Methods and Equipment

In 1986 the Hedbom Forest Road in Floodwood, MN was constructed using a variety of waste tire material below the base. Sizes from whole to shredded tires were used. As of 1989 all of the sections were performing well.

Road Repair and Construction

Tire shreds cannot be used below the water table. Design slopes to reduce water infiltration and drain surface water away from shredded tires.

General Construction (Applies to all construction projects)

The most common method is encapsulation within geotextile materials.

- Use geofabric material above and below the shredded tires. The fabric will prevent movement of soil into the tire shreds, and will hold them in place.
- Tire shreds must be covered by a low-permeability surface (soil) to reduce seepage of surface water.
- Lift thickness of shredded tires may be up to 3 ft (1 m).

Interim Design Guidelines (52)

This interim report was generated from data from a private access road constructed with shredded tire thickness of 3 to 6 ft (1 to 2 m):

- The rate and effectiveness of compaction are similar to sawdust fills.
- Approximately 99 percent of maximum compaction can be achieved with about 24 passes of a D7 caterpillar.

- The maximum bulk unit weight of tire shreds with an average particle area of 1 sq ft (0.3 sq m) is approximately 20 to 23 pcf (320 to 370 kg/cu m).

1.3.3.7.5 Substitution With Foam

Foam is useful as a lightweight fill material when use of in situ soil or available borrow is impractical from an engineering or financial standpoint. Foam provides a very low density as indicated in Tables 1.16 and 1.17.

Table 1.16. Characteristics of Common Lightweight Fill Materials (52)

Material	Expected Compacted Density pcf (kg/m ³)	Comments
Expanded Polystyrene Foam (EPS or Geofom)	3 (48)	With respect to other materials has the lowest available density for the strength it supplies. Easily placed, no need for additional equipment. Little effect from environmental conditions such as submersion. Requires the least amount of soil replacement for given load reduction. High unit cost.

Table 1.17. Expanded Polystyrene Foam (EPS) (52)

Material	Advantages	Disadvantages	Practical Areas of Use
Expanded Polystyrene	Lightest fill available. Does not exert lateral forces. Easily placed with minimal equipment.	High cost. Not readily available. Insulates subgrade, which may lead to surface icing.	Near bridges and other structures requiring minimal lateral forces.

1.3.3.7.5.1 Design Factors

The foam products discussed in this report are of the type “Expanded Polystyrene” (EPS), also referred to as “geofom”. Historically the use of this product has been less common in the United States than in other countries, such as Norway.

EPS can be manufactured to various densities and strengths. Therefore cost is dependent on the strength specifications and the amount needed. The benefits of using EPS are realized in the analysis of load reduction and excavation costs compared to those of standard fill materials. In some cases the use of protective concrete slabs or fabrics will add additional cost (52).

Previous studies have found that the compressive strength of the expanded polystyrene remains constant in use. Although some compressive strengths have shown increases; this is thought to occur because of an increase in the moisture content over time.

Expanded polystyrene:

- has been shown to be moisture resistant when submerged after nine years,
- dissolves when exposed to petroleum products,
- is flammable and care must be taken with any high temperature work near EPS, and
- is available in a more expensive, self-extinguishing version (52).

1.3.3.7.5.2 Construction

No special equipment is required for placing EPS. In most cases slabs of EPS may be placed by hand. If needed, makeshift handles can be created by inserting screwdrivers into a slab of EPS to help maintain stability in windy conditions

1.3.3.7.5.3 Precautions

It is recommended that in-service deflections should be offset either by either a 4-in. (100-mm) slab of concrete or increasing the bituminous surface by 12 to 16 in. (300 to 400 mm).

EPS foam can degrade when exposed to petroleum based chemicals so some design situations may require protection. Protect EPS with either a concrete covering or a petroleum resistant geotextile.

EPS can insulate pavement surfaces from radiant heat in the embankment. This is of concern during winter when ice buildup can cause hazardous driving conditions (52).

CHAPTER 2: SUBGRADE ENHANCEMENT PROCEDURES USED IN MINNESOTA

2.1 General

A review of a number of procedures available for pavement subgrade construction and enhancement is presented in Chapter 1. Most roadways are built with the soil naturally occurring along the alignment. The procedures recommended to construct subgrades in cold climates are presented in the Mn/DOT Geotechnical Manual (2) and the Best Practices Manual for Design and Construction of Low Volume Roads in Minnesota (1). The principles of constructing a uniform subgrade include:

1. Providing good drainage
2. Mixing soils
3. Good compaction
4. Appropriate moisture content

Applying these principles will result in a good subgrade and good pavement performance.

When poor soil or moisture conditions occur it may be necessary to enhance the subgrade during and after construction to provide a strong and uniform material. The following methods have been reviewed in Chapter 1.

1. Soil Modification; lime, fly ash, cement, and bituminous materials
2. Soil Stabilization; cement, fly ash, lime-fly ash
3. Use of Geosynthetics
 - a. Separation using geofabrics
 - b. Reinforcement using geogrids
4. Substitution with Select Granular, Wood Chips, Shredded Tires, Foam

Mn/DOT and Minnesota counties and cities have used a number of these procedures. One task for this project has been to determine which procedures have and have not been used successfully and establish why or why not they have been successful. Using these procedures, the Best Practice Guidelines for design and construction, and the references presented above, 2-3 page reviews of the best practices were developed.

Information for the procedures used in Minnesota was obtained and documented by:

1. Sending questionnaires to Minnesota cities and counties to determine the extent that the methods were being used and how successful they were.
2. Visiting a number of cities and counties to establish more specific procedures and suggestions on how best to design and construct subgrades using the guidelines.
3. Developing a spreadsheet database showing the location of installations along with pavement design and traffic conditions. It is recommended that the condition of these roadways is reviewed periodically to document the performance of the various methods of subgrade enhancement.

2.2 Questionnaire

2.2.1 Development

The questionnaire presented in Appendix A requested information on the use of various materials for Modification, Stabilization, Reinforcement and Substitution. The experience with procedures was requested using the number of projects constructed, how well the projects performed and if the projects can be located.

Appendix A includes the introductory material explaining the research and purpose of the questionnaire.

2.2.2 Reply Summaries

Replies were received from 40 counties and 17 cities. The replies are tabulated in Appendix B. The following general comments summarize the replies:

1. Modification has been accomplished using lime, fly ash, Class 7 aggregate, reclaimed bituminous and Base 1. Satisfactory performance has been obtained with each except for, bituminous, Base 1, and one lime modified project.
2. Stabilization has been accomplished with lime, fly ash, breaker run limestone, bituminous millings and bituminous materials. All of the projects reported were performing well. (note: the use of breaker run limestone has subsequently defined as substitution).
3. The use of geosynthetics has been subdivided into:
 - a. Separation applications using geofabrics – 24 counties and 9 cities have used geofabrics for separation with about 60% satisfactory performance. Geofabrics have been used to protect breaker run limestone, wood chips and shredded tires from contamination.
 - b. Reinforcement applications using geogrids – Ten counties and one city have used geogrids with about 50% satisfactory performance.
4. Substitution/Replacement has been accomplished with:
 - a. Foam – Three counties and one city with at best mixed results
 - b. Fly ash – One county has used fly ash substitution with mixed results
 - c. Shredded tires – Five counties and one city have used shredded tires, four of which experienced satisfactory results.
 - d. Wood Chips – Four counties and two cities have used wood chips with mixed results.
 - e. Cinders – One county has used cinders satisfactorily.
 - f. Select Granular materials have also been used as a portion of fills and subcuts for construction with in-place soils. The procedures for selection of materials and construction specifications and procedures are presented in Chapter 4 of Reference 1. 15 –20 projects have been reported with satisfactory performance.

The replies to the questionnaires have shown that many procedures are being used by cities and counties in Minnesota and that with proper application they can result in good performance of pavement sections.

2.3 Visits to Individual Agencies

2.3.1 Summary of Applications

Table 2.1 is a list of the agencies using the procedures and materials indicated. The table shows that a wide variety of procedures are used to enhance subgrade construction in Minnesota.

2.3.2 Agencies visited and procedures used

Contacts were made with agencies representing the applications listed in Table 2.1. The time and budget constraints of the project allowed 18 agency visits (shown in bold) during the summer, 2002. The purpose of the visits was to:

1. Obtain more information on the specifications and procedures used for construction with the given materials.
2. Document the performance of installations in that agency
3. Determine location of projects using the procedures to include in a statewide database.

During the visits the best practices for the particular procedures were reviewed. The following questions were discussed to help develop a list of best practices:

1. For what conditions is this procedure appropriate?
2. How should the materials be picked and specified?
3. What in-place soil type and moisture conditions are appropriate?
4. Is protection of the materials needed?
5. Are there environmental concerns?
6. Are there safety concerns?
7. What are some construction best practices?
8. What is the expected life compared to cost?
9. Who are people for others to contact for additional information?

The information obtained during the agency visits has been used to develop the Best Practices Summaries presented in Chapter 3.

Table 2.1. Summary of Subgrade Enhancement Procedures Reported by Minnesota Counties and Cities

Procedure	Material	Agency
Modification	Lime	Aitkin, Ramsey , Ottertail
	Fly Ash	Blue Earth
	Bituminous	Brown, Ramsey , Wabasha
Stabilization	Fly Ash	Blue Earth, Rock, Scott, Waseca
	Lime	Ottertail, East Grand Forks
	Bituminous	Brown, Crow Wing
	Breaker Run Limestone	Dodge , Goodhue
Geosynthetic	Geofabric	Aitkin, Anoka, Blue Earth, Carlton , Clay, Clearwater , Crow Wing, Dakota, Faribault, Goodhue, Isanti, Lake of the Woods, Mille Lacs , Nicollet, Nobles, Ottertail, Ramsey, Scott , Steele, Washington, Wright, Albert Lea, Crookston , Fairmont, Grand Rapids, Hibbing, Maple Grove, North Branch, Rochester and St. Paul.
	Geogrid	Albert Lea, Fillmore, Hubbard, Lake of the Woods, Ramsey, St. Louis , Sibley, Traverse,
Substitution	Select Granular	Chanhassen, Carlton , Crow Wing, Goodhue, Dodge , Traverse, Steele
	Wood Chips	Clearwater, Mille Lacs, Ramsey, Waseca , Grand Rapids, Maple Grove
	Geofoam	Anoka, Clearwater, Ramsey , St. Paul
	Shredded Tires	Carlton, Mille Lacs, Ramsey , Grand Rapids
	Cinders	Dakota

Note: Agencies shown in **bold** were visited

2.4 Database developed with location of projects

A database in the form of a spreadsheet has been setup to document the location, design and evaluation of projects which have been built using the procedures discussed above. As the designs are compared to the performance over a period of time the information from the database can be used to evaluate the cost effectiveness of the embankment enhancement procedures.

2.4.1 Variables

The variables needed to evaluate the performance are included in the database.

1. The agency, Roadway I.D. and limits make it possible to locate the project.
2. The year built will determine the life of the project relative to the procedure and cost
3. The traffic in terms of AADT, HCADT and/or ESALs will identify the loading to which the pavement section is subjected.

4. The soil type in terms of Soil Class, R-Value and/or Resilient modulus will help relate the performance to the Soil Factor, R-Value or MnPAVE (64) Design procedures.
5. The field moisture conditions will help determine what field conditions are being “improved”.
6. The type and thickness of each of the pavement layers need to be documented so that the pavement section can be defined.
7. The date and condition should be used over a period of time to define the performance of the pavement section.
8. The cost of the procedures and pavement section should also be documented to help establish cost/benefits.

2.4.2 Database Setup (Appendix C, Appendix D)

During the visits the agencies were asked to identify as many installations as possible. The project staff received plans from many of the agencies and was able to identify 75 installations. As of the fall 2002, there were:

- 4 Modification installations
- 4 Fly ash stabilization test sections in Waseca County
- 33 Separation with geofabric installations
- 20 Reinforcement of the subgrade with geogrid
- 14 Substitution installations, 1 Breaker Run Limestone
 - 6 Wood chips
 - 7 Shredded tires

The information provided in the database should be maintained and reviewed periodically so that documented performance can be used to include these methods of subgrade enhancement in future design procedures. Documentation of performance will help determine what procedures are really cost effective.

CHAPTER 3: BEST PRACTICE SUMMARIES FOR SPECIAL SUBGRADE ENHANCEMENT PROCEDURES IN MINNESOTA

3.1 Introduction

Methods for subgrade enhancement have been presented in Chapter 1. A summary of procedures presented in the Best Practices Manual (1) is included for the construction of subgrades with the natural soils. Chapter 2 presents methods which have been used in Minnesota. The procedures that have been used successfully in Minnesota are influenced by the freeze-thaw environment and local soil conditions. The cold weather environment requires that all soils and methods of enhancement result in a well-drained, well-compacted and uniform construction.

The Best Practice Summaries presented are the result of the questionnaire responses and visits to Minnesota cities and counties during 2002.

Each summary includes:

- Purpose for which procedure is used
- Conditions appropriate for the procedure
- Material(s) including specification references
- Design quantities
- Best construction weather and transportation procedures
- Construction control procedures
- Precautions
- Value (comparison of cost and expected life)
- Contacts (those who would provide more information)

The following summaries are included with this report:

1. Natural Soils
2. Modification
 - a. Lime
 - b. Base 1
3. Stabilization
 - a. Lime
 - b. Fly Ash
4. Separation with geofabrics
5. Reinforcement with geogrids
6. Substitution
 - a. Select Granular
 - b. Breaker Run Limestone
 - c. Wood Chips
 - d. Shredded Tires

3.2 Natural Soils

The subgrade or embankment soil on which a pavement is built is the most important part of the pavement structure because:

- It is the layer on which the remainder of the structure is supported and helps resist the destructive effects of traffic and weather.
- It acts as a construction platform for building subsequent pavement layers.
- The entire pavement section would have to be removed and replaced to correct embankment performance problems created by lack of strength or uniformity.

It is imperative that the embankment be built as strong, durable, uniform, and economical as possible. The most economical embankment is one that will perform well for many decades.

Chapter 4 of the Best Practices Manual (1) presents methods to help achieve adequate stiffness, strength and uniformity for a given embankment soil. The procedure starts with a good soil survey at the location so that proper design and construction procedures can be included for the project. Methods for conducting soils surveys are presented in the Mn/DOT Geotechnical and Pavement Manual (2). Section 4.2 presents the procedure to conduct a good soil survey along a given grade.

3.2.1 Specifications

Mn/DOT has three specifications (2105, 2111, and 2123) that pertain to the construction of embankments. Specification 2105 “Excavation and Embankment” includes two types of density control [“Specified” (sand cone) and “Quality” (visual) compaction]. Both methods state that compaction must be accomplished to the satisfaction of the engineer. For “Quality” compaction an experienced engineer or inspector must be on the project to judge if adequate compaction is achieved. For “Specified” compaction the judgment of the engineer is aided by the determination of a measured density. The density must be measured using the representative moisture-density test for the soil being constructed. The **Specified Density Method** is recommended by Mn/DOT.

Specification 2111 presents the test rolling method for subgrade acceptance. Test rolling is a supplement to Specification 2105. Test rolling evaluates uniformity and consistency of subgrade support relative to rutting. Test rolling will detect weak/unstable areas due to inadequate compaction or high moisture content. Failed areas will require corrective measures which could include removing the unstable/unsuitable materials, reducing moisture content and recompaction of the soils.

Test rolling is not recommended for the following situations:

- Areas having less than 30 in. (0.75 m) subcut backfill in depth. These areas would probably not pass 2111 requirements.
- Areas having shallow underground utilities or structures.
- Areas having closely spaced bridges.
- Areas where geosynthetics are placed within the upper 5 ft (1.7 m) of the subgrade.

An experienced inspector can determine where soft spots occur in the constructed subgrade and make sure measures are taken to correct these. The test roller method of compaction control is recommended along with Specification 2105 because almost total coverage of the embankment grade construction is possible.

Specification 2123 lists the equipment and characteristics of the equipment required to carry out Specifications 2105 and 2111.

3.2.2 General Design Considerations

Based on the soil type, project conditions, structural design and specifications, certain procedures need to be established and followed to achieve good embankment construction. The goal is to provide a strong and uniform embankment for the pavement structure. Many of the procedures presented depend on the type of soil encountered on the project. As the project is started variations in the soils may be encountered and therefore the field engineer and inspector must be aware of the effect of these changes. The following recommendations are presented in Chapter 4 of reference 1.

- Excavation and Embankment Construction
 1. Ideally, the finished grade should be kept at least 5 ft (1.7 m) above the water table in order to reduce capillary moisture and should be at least equal to the depth of frost penetration in order to minimize frost heave (Figure 3.1). A minimum height of 3 ft (1 m) should be maintained.
 2. The existing soils and their preparation; including subgrade correction, embankment placement, and protection of the completed embankment need to be considered.
- Soils Evaluation: Soils must be evaluated based on whether they are suitable or unsuitable, excavated soils, salvaged materials, or borrow.
- Soils Preparation: Proper preparation of the soils for good uniformity involves **reworking, blending, mixing, and enhancing** the existing materials. The mixing of existing soils will help eliminate pockets of high moisture and unstable soils. Subcutting, and/or mixing and proper compaction will help provide a uniform subgrade. Proper compaction can be verified with specified densities and test rolling. Lime or other treatments for moisture control may be considered.
- Subgrade Correction: Subcuts must be made to ensure uniformity of material and stability in the upper portion of the embankment. Subcuts are used to reduce or eliminate differential or pocketed high-moisture conditions, unstable materials, frost heave potential, and non-uniform subgrade conditions. Typical subcut depths range from 2 to 4 ft (0.6 to 1.2 m) with a 1 ft (0.3 m) minimum. **Subcuts must be used especially where there are silty type soils, which are particularly frost susceptible. In areas of the embankment that may generate frost heaves the subcut depth must extend below the frost line. The subcut should be backfilled with select granular material. If it is not practical to use select granular, then the existing soil should be mixed uniformly to a moisture content appropriate for good compaction. Drains may be needed in the bottom of the subcut to assure that water does not collect in the subcut.**

- Placement of embankment and backfill materials: As embankment materials are placed, the same soil should be used throughout each layer to prevent non-uniform moisture and drainage conditions.
- Compaction: Compaction must be performed in accordance with Mn/DOT Specification 2105 supplemented with 2111 using the equipment specified in Specification 2123.

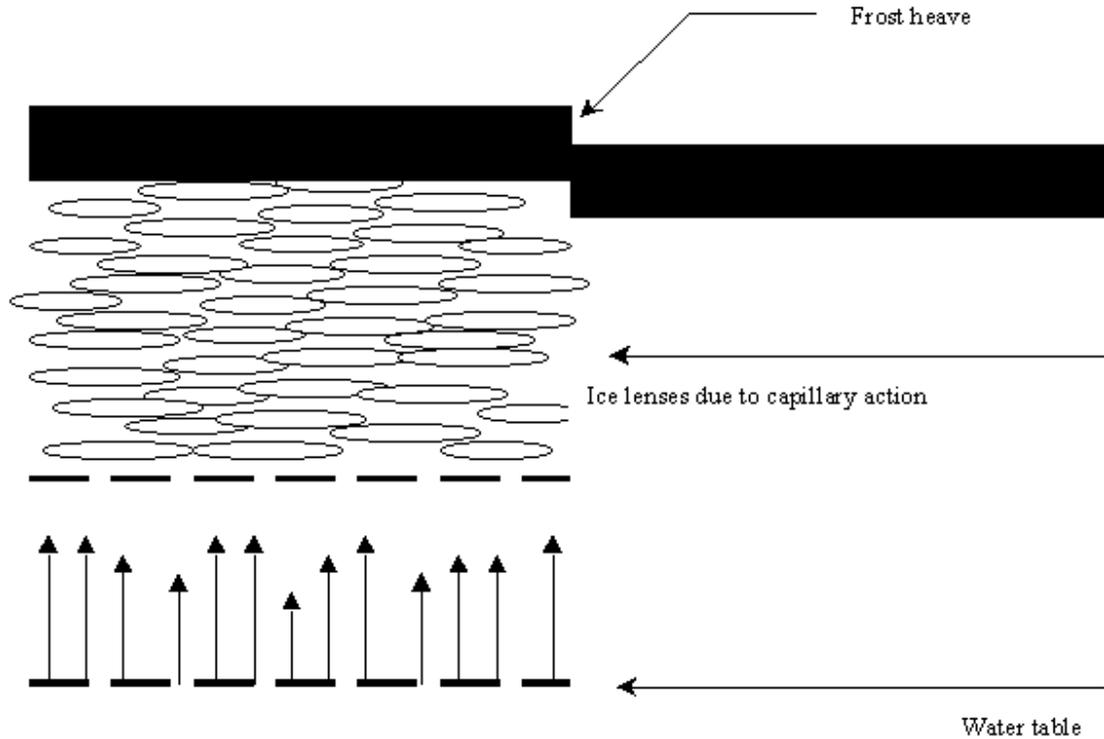


Figure 3.1. Frost heave resulting from ice lenses (4).

3.2.3 Construction Notes and Procedures

The Mn/DOT Office of Construction, Technical Certification Section has published an “Inspector’s Job Guide for Construction”. This Guide gives the inspector a checklist that will help get a project started and document the parameters and procedures that need to be considered based on the specifications. One item in particular that will help keep a project under control is for the inspector to keep a good daily diary. This will help all people involved with the project feel confident that work is progressing at an appropriate rate and that the inspection work is being accomplished.

3.2.4 Contacts

The Mn/DOT Maplewood laboratory or District Materials Engineer are good contacts for questions on the design and construction of natural soil subgrades.

3.3 Drying/Modification/Stabilization

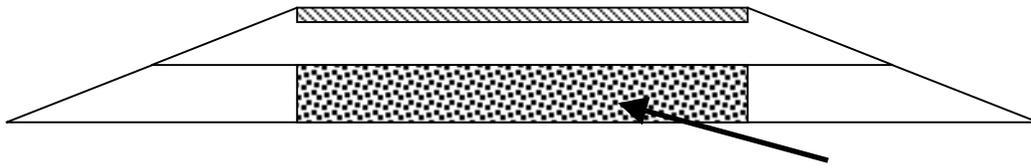


Figure 3.2. Drying/Modification of existing subgrade soils.

3.3.1 Drying/Modification with Lime

Purpose – Lime is used to help dry and modify very wet soil which has more than 10% clay particles and has a plasticity index greater than 10.

Conditions – Very wet soil and construction conditions; the alternative which is to haul away the clay or try to dry it by evaporation, disking or some other means is usually time consuming, unless there is dry hot weather. Lime is also used to stabilize and strengthen the subgrade making it part of the pavement design. However, using a lower percent of lime has been found to expedite construction in rainy weather. It has helped dry the soil and provide a good working platform. Mn/DOT recommends using lime only after October 1 to expedite construction.

Materials – **Hydrated Lime** only is recommended for safety reasons. Both quicklime and hydrated lime have a high affinity for water producing a blotting action on fine-grained soils. However, quicklime when mixed with water creates a great amount of heat resulting in dangerous conditions for workers.

- **Specifications** – Mn/DOT 3106. Mn/DOT Grading and Base Manual 5-692.521.

Design Quantities

- **Depth** – The lime is usually mixed to a depth of 1 ft (0.3 m).
- **Quantity (percent)** – usually use ½ to 1 percent lime and **never** more than two percent. Higher percentages are used for stabilization and result in a stabilized soil. About 5 lb per square yard (2.3 kg per square meter) is recommended for drying.
- **Compaction Control** – a sheepsfoot roller is used after mixing and drying by discing.

Construction

- **Weather**
Best – Sunny and dry
Worst – Cool, misty, and overcast
Never – Construct when below freezing
- **Transportation/Storage**
Tanker trucks or bags. Bags must be kept dry before use.

- **Measurement of Quantities**
About 5 lb per sq yard (2.7 kg per sq m) = one percent lime to a depth of 1 ft (0.3 m).
- **Methods of Mixing**
Best – A distribution truck blowing lime on the surface of the wet soil under a drag-along tarp to prevent blowing of the lime.
Okay – Place bags along the roadway, open by hand and spread with shovel along the grade.
NO GOOD – not using a tarp along with a distribution truck especially on a day with any wind.
- **Construction Control**
Materials – Only good for wet soils with 10 percent or more clay particles.
Proportions (Uniformity) – Soil and lime must be thoroughly mixed before compaction to provide a uniform subgrade; otherwise differential heave will occur during frost periods.
Compaction – The maximum density and optimum moisture content of a soil can change significantly when even 1-2 percent lime is added. Appropriate moisture-density curves of the lime-treated soil must be maintained.
- **Precautions**
Wind – Avoid placing lime on a windy day. Lime is very fine and will blow into adjacent areas easily.
Heat – Water and quicklime mixtures create heat. Also, hydrated lime can be caustic. Extreme **Safety Precautions** should be used. Workmen who handle, spread and mix the lime should wear tight fitting goggles, gauntlet gloves, long sleeves and pants tucked into boots. Wash off lime dust from the skin as soon as practical and in the case of exposure to the eyes flush out with clean water and see a doctor. Humid weather conditions can cause especially serious problems.
Non-Uniformity – A lack of uniformity in application rate and mixing will result in a permanently rough road.

Value

- **Cost**- At 3-5 cents per pound the lime material cost is generally 5-6 cents per square foot. This is a relatively small expense to make a subgrade more workable especially late in the construction season.
- **Criteria** – Mn/DOT allows the use of lime only after October 1 with the Engineer's permission and at the contractor's expense.
- **Expected Life** – The lime will generally leach out of the soil after 1-3 years.

3.3.2 Stabilization Using Fly Ash

Purpose: Fly ash has been used for a variety of stabilization and recycling applications. These include:

- Drying action to facilitate soil compaction
- Treatment of expansive clay soils to reduce shrink-swell potential

- Stabilization of subgrade soils to improve subgrade support capacity to allow reduction in pavement thickness and recycling of existing pavements to produce a base section having support capacity greater than the original material.

Conditions:

- A clay-type soil especially if above optimum moisture conditions in the field.
- An existing pavement in poor condition.

Materials: Fly Ash is produced during the combustion of coal and consists of the inorganic matter present in the coal that has been fused during coal combustion and solidified while suspended in the exhaust gases by electrostatic precipitators. Some **Fly Ash** materials from sub-bituminous coals have over 20% CaO which makes them **self cementing**. Bituminous coals (from eastern USA) have little calcium and therefore are not as self-cementing.

ASTM D-5239 defines the cementing properties of fly ash using three categories:

- Very Self-Cementing Fly Ash (20-30% CaO) – Compressive strengths greater than 500 psi (3.45 MPa) at seven days using ASTM Test Method C 109
- Moderately Self-Cementing Fly Ash – Compressive strengths greater than or equal to 100 psi (0.70 MPa) but less than or equal to 500 psi (3.45 MPa) at seven days.
- Non Self-Cementing Fly Ash – Compressive strengths less than 100 psi (0.70 MPa) at seven days.

Lime or some other source of CaO must be added to Non Self Cementing Fly Ash to produce a stabilizing material.

Coal from the same source can produce different types of fly ash if burned and solidified under different conditions. Ash crystallinity and sulfate content can be affected. Fly ash with sulfate contents up to 7% do not usually cause problems; however, fly ash materials with sulfate contents greater than 10% should be avoided because they can cause expansive reactions when mixed with soil.

Fly ash from a given power plant will usually be consistent because:

- Coal will be from a single source
- Burning equipment and methods will be the same

Quality control and assurance for fly ash from a given source is generally limited to the elemental analysis provided by ASTM C-311 (56). This analysis provides the values used for determining compliance of the ash with ASTM C-618 (57). The elemental analysis alone will not provide the basis to assess the self-cementing characteristics of the material. This can only be evaluated using the strength tests referenced in ASTM D-5239 (55).

Specific fly ash materials should be evaluated based on the physical properties of the ash-stabilized materials, which cannot be predicted based on the chemical composition of the ash.

STABILIZATION APPLICATIONS

Fly ash has been used for many of the same soil stabilization applications as lime and Portland cement. These include:

- Drying Agent – the reduction of soil moisture content to facilitate mechanical compaction.
- Reduction of Shrink-Swell properties of clay soils
- Stabilization to increase Strength – CBR values have been shown to increase from 2-3 up to 25-30 for a clay stabilized soil allowing a corresponding decrease in pavement thickness requirements.

LABORATORY MIXTURE DESIGN

A laboratory mix design is usually conducted to establish the optimum ash and moisture contents. Maximum dry density and strength gain for design and construction testing are determined.

Since most stabilization applications with fly ash rely on the ash as the stabilizing agent, the test and design procedures must address the rapid rate of hydration when the ash is exposed to water. Ash hydration alters the soil compaction characteristics because soil particles become bonded together in a loose state. A portion of the compactive energy is lost as these bonds are broken. Maximum density achieved therefore decreases as the hydration reaction progresses after blending of the soil, fly ash and water.

Self-cementing fly ash hydrates more rapidly than Portland cement; therefore, a 2-hour delay in compaction can result in a decrease in maximum density of up to 10 pcf (1.6kN/m³) or more. Usually a maximum 2-hour delay time can be achieved even with rudimentary equipment. When pulvaxmixers are used with experienced personnel a 1-hour compaction time can be readily achieved.

The allowable range in moisture contents must be specified and be monitored during construction to ensure that moisture contents of the stabilized section are near optimum.

No standard methods have been adopted for the design of materials stabilized with fly ash. Consult ASTM C-593 and ASTM D-1633. Depending upon the pavement section either standard or modified Proctor compactive energy may be used. For most county road applications, standard Proctor compaction should be adequate.

Test specimens should be cured for 7 days at 100F (38C) in accordance with C-593 after which the compressive strength should be determined. The optimum moisture content for maximum strength has been shown to be consistent for cure periods of 7, 28, and 56 days. Therefore, optimum moisture content can be determined using 7-day strengths.

The reduction of P.I. for clay soils will be less for fly ash compared to lime.

Compaction Characteristics of Clay Soils with Fly Ash

Compaction and moisture control specifications for untreated clay soils typically require moisture contents on the wet side of optimum moisture content to limit the swell potential of the compacted soil. Unlike untreated soils, compaction of fly ash stabilized soils at the lower moisture contents does not increase swell potential because the lower moisture content results in higher strength.

Generally, the optimum moisture content for maximum strength occurs below the optimum moisture content for maximum density. Also, the maximum density and strength achieved decreases with increased compaction. For practical design purposes, tests run with a 2-hour compaction delay are used to determine a conservative estimate of strength properties. In the field a maximum delay time of 2 hours should/can be achieved.

Construction Considerations

A general construction specification is attached as Table 4.1A – D.

The following goals must be achieved to result in a good fly ash stabilization project:

- Uniform distribution of the fly ash
- Proper pulverization and thorough mixing of the fly ash with the material to be stabilized
- Control of moisture content for maximum density and strength
- Final compaction within the prescribed time frame (usually 2 hours).

Typical design specifications call for fly ash contents of 1 to 2 percent greater than optimum contents determined in the laboratory. Pneumatic tankers or bottom dump trailers are used to transport fly ash to the project. Careful blading of the fly ash over the exposed grade from uniform windrows deposited by the transports is the best way to obtain uniformity of application. The quantity of ash can be calculated knowing the depth, width, length and design percent of fly ash. Uniform distribution can be accomplished using metered gates on the transport or direct metering of the ash into the mixing drum of a mobile mixer.

Construction discs can effectively blend the ash with cohesive soils. The depth the disc is cutting must be closely monitored. Where higher degrees of stabilization are required the use of a self-propelled mixer (pulvaxer) is required to ensure adequate pulverization and uniform distribution of moisture and fly ash. One or two passes of a mixer can be used to obtain good mixing.

Field Moisture Control

Control of moisture content is both critical and difficult. Strengths of the stabilized materials decrease significantly as the moisture increases above the optimum moisture for maximum strength. Strengths also decrease on the dry side of optimum moisture and increased compactive effort is required.

Maintaining moisture contents within a range of 0 to 4 percent above optimum moisture content for maximum compressive strength is typically recommended and is readily achieved with proper equipment.

Significant quantities of water may be required to bring the moisture to the design level. The following aspects of moisture control must be considered.

- If water is added after the fly ash is blended the final strength of the stabilized material will be reduced due to hydration of the ash before compaction is completed.
- Adding sufficient water to the pulverized material prior to distribution of the ash may make the untreated material unstable, hampering distribution and operation of construction equipment.
- Applying water directly onto the fly ash distributed on the surface is **not** advisable since this increases the rate of hydration.
- Water can be added after the fly ash has been incorporated; however, additional passes with the mixing equipment will be required to achieve uniform mixing.
- **Introducing water directly into the drum of a rotary mixer is the most effective procedure in controlling moisture content so it falls within the desired range and providing the most uniform mixing without additional delays in compaction.**

Moisture contents can be monitored using a nuclear density gauge. The nuclear gauge may not give an accurate moisture measurement; however, it can give a good indication of uniformity.

Field Compaction

Compaction of the mixture must be accomplished as soon as possible following the final pass of the mixing equipment. When using a paving train type operation initial compaction can easily be achieved within 15 minutes of the final pass of the mixing equipment.

Initial compaction is most often accomplished using a vibratory padfoot or a self-propelled padfoot roller operated immediately behind the mixing equipment. The padfoot provides good compaction from the bottom of the stabilized layer and imparts a kneading action which can give some additional mixing.

After initial compaction the materials should be shaped to final grade by blading and final compaction done using a self-propelled, pneumatic-tired roller. **Shaping should not be delayed.**

Curing

The surface of the stabilized lift should be maintained in a moist condition to help hydration of the fly ash. Curing can be accomplished through periodic application of water on the surface until the next lift or a wearing surface is constructed over the stabilized material.

Temperature Effects

Stabilization with fly ash can be performed satisfactorily down to temperatures of 50F (10C). Construction can be accomplished at cooler temperatures with modified procedures. At cooler temperatures two passes of a pulv mixer may be required to reduce the maximum size of the material to less than 1 in. (25 mm). Cooler temperatures may be beneficial because the cooler temperature retards hydration. However, cooler temperatures also result in decreased density for the same compactive effort. With additional compactive effort, and in-place densities are adequate, the strength of the compacted section can be near design strength when constructed below 40F (4.5C).

Effective stabilization of clay soils can be accomplished as long as soil temperature is above 32F (0C) and construction procedures are modified to attain proper mixing and compaction of the stabilized materials.

High-Sulfate Ashes

There are two common high-sulfate content ashes: fluidized bed combustion (FBC) and flue gas desulfurization (FGD) ash. These materials can exhibit self-cementing properties similar to subbituminous coal ashes. These materials may cause serious expansion characteristics when hydrated. Therefore, the following should be considered when evaluating the sulfate content of an ash.

- Ash having a SO₂ content of 5 to 10 percent should be considered potentially expansive until laboratory testing indicates otherwise
- Ash having a SO₂ content greater than 10 percent should not be used for stabilization applications.
- Soluble sulfates in the soil or groundwater can influence swell potential and be considered in addition to the amount of sulfate in the ash.
- The relative damage/deterioration of a high-sulfate ash-stabilized material can be categorized based on combined clay and colloid content as follows:

Relative Damage	Clay and Colloids Content
Minor	5-10%
Moderate	10-30%
Major/Severe	Greater than 30%

- The availability of free moisture in the stabilized material is critical to long term performance. With saturated or near-saturated conditions, sulfate, silica and alumina ions within the fluid are mobile and free to react.

Environmental Considerations

The primary environmental concern when using self-cementing ashes is the migration of metals. Data from four roadbases and one embankment suggested that very localized migration of ash derived metals had occurred into the underlying soils. Depth of migration was less than 2 ft (0.7 m) below the stabilized section on two study projects.

Most applications of fly ash stabilized soils or bases would be designed such that the material would be above the water table and water flow through the material would be minimal. This is necessary to maintain the structural integrity of the stabilized and layers of the pavement section. If there is a groundwater-associated problem, the stabilized section should be encapsulated in a geofabric.

To evaluate the potential of leaching particular materials the specific metals in a given ash should be determined. The source of coal for a given generating plant is usually the same.

An EPRI Demonstration Project was conducted in Kansas to assess the migration of metals from the stabilized section into the underlying subgrade. Of the 23 metals evaluated, only nine were present in a higher concentration in the fly ash than in the soil below the section to be fly ash-stabilized. Barium was the only metal that was present in significantly higher concentrations than in the soil.

The Toxicity Characteristic Leaching Procedure (TCLP) has been used by a number of agencies to determine what and how much of various metals are leached from various situations and environments. Studies at specific locations showed that the metals leached from the ash were a small percentage of the total metals present in the existing soils. Overall it was found that the hydration and solidification of the ash, in addition to the natural soil attenuation characteristics, caused a reduction in leachable barium.

Fugitive Dust can be a problem just as for any other construction process. Maximum dust is generated at the time the ash is discharged from the tankers or end dump trailers onto the pavement subgrade. Construction activity will generally minimize fugitive dust. When a rotary mixer is used water is added in the mixer, which minimizes fugitive dust. This is the most effective procedure for constructing a good stabilized soil subgrade.

Weather

a. Best

- Damp or dry
- Little or no wind
- Temperature above 40F (4.5 C).

b. Worst

- Saturated
- Windy
- Temperature below 32F (0C).

Transportation/Storage

The fly ash is delivered to the project either by:

- Tarped dump trucks or
- Tanker trucks with pressurized pumping systems

Measurement of Quantities

- Fly ash metered from the truck and trucks counted.
- Moisture added to grade as needed.
- Disking may be used to decrease moisture content

Method(s) of Mixing

- a. Trucks dump fly ash in uniform windrow (if no wind);
- b. Spread laterally across the embankment with a bulldozer
- c. Mix with a recycler (BOMAG) traveling at 20-30 ft/min (6 – 10 m/min) or disked to design or lift depth.
- d. If water needed, the truck is pulled through the grade with a bulldozer.
- e. Shape the grade with a bulldozer

Compaction Procedures

- a. Initial compaction – pad foot roller or sheepsfoot roller
- b. Final compaction – steel wheeled roller to provide smooth surface and help shed water
- c. Compaction control – Mn/DOT Specification 2105 allows for specified density based on a moisture-density test with the given percent fly ash **or** quality compaction with proofrolling.
- d. **Compaction must be accomplished within two (2) hours because working of the mixture after that may break up the products of hydration which stabilize the soil.**

Curing of Soil-Fly Ash mixture: When self cementing fly ash is mixed with water, hydration of the material creates the gel which binds (stabilizes) the soil resulting in the stronger more uniform lower permeability material. The hydration requires water. Therefore, the surface of the grade should be kept damp.

Construction Rate: about 1 to 1.2 km (0.75 to 1 mile) of stabilized grade can be constructed in one day.

PRECAUTIONS:

1. **Wind:** watch out for windy conditions if fly ash laid out on the grade.
2. **Mixing:** mix in fly ash as soon as possible
3. **Protection:** Workers should wear protective equipment to avoid burning skin, eyes, nose and mouth.

VALUE:

1. **Cost:**

- 2. Life:** With proper mix design and construction it is expected the grade would last at least 50 years.

Contacts

Mr. Jeff Blue, Waseca County Engineer
Waseca City Engineer
Mineral Solutions

3.4 Geosynthetics

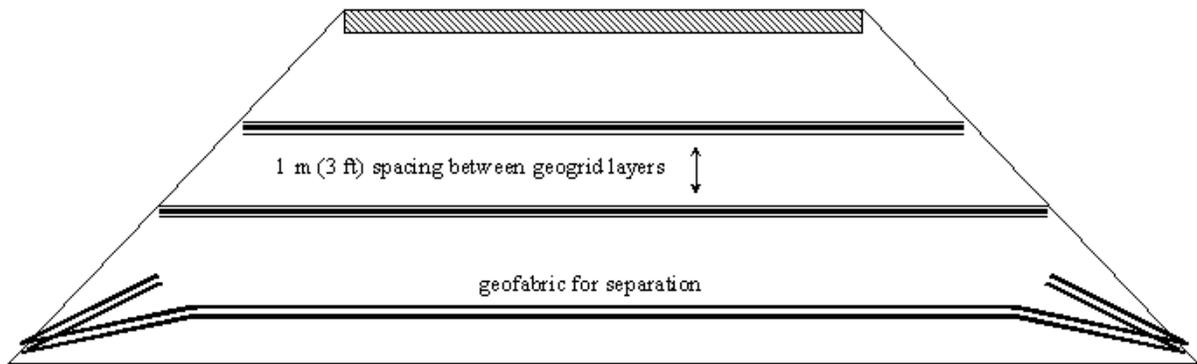


Figure 3.3. Potential locations for geotextiles within embankment

3.4.1 Separation – geofabrics

Purpose: Separate wet silt or clay soils from granular subbase or base materials

Conditions: Areas with high moisture content fine-grained soils near the water table and/or where pumping action may cause infiltration of the soil into the upper layers.

Materials:

- Mn/DOT Type V defined in Specification 3733; this is usually a slit film geofabric with a minimum grab tensile strength of 200 psi (1.40 MPa).
- Mn/DOT Type VI with a minimum bi-directional strength of 300 psi (2.10 MPa) is recommended for weaker, wetter conditions; Type VI is usually a woven fabric.
- Water Conductivity – minimum of 10 gallons/sq-ft/minute (400 liters/sq m/minute)
- Manufacturer certification of geofabric must be received from contractor.

Design Considerations:

- Geotextiles used under granular materials over soft wet clays can provide separation and eliminate contamination of the granular material however,
- A geotextile needs to be placed within 12 in. (0.3 m) of the surface to mobilize tension under wheel loads at the surface.

The key to getting a good bid price on placement of a geotextile is to allow placement in such a way as to not significantly delay the contractor’s normal operations

- **Quantities**
Geofabrics come in standard widths, typically, 12, 15, and 18 ft (4, 5 and 6 m). By specifying an overall width that fits some combination of these widths and allowing about 0.5 ft (0.2 m) for sewing material waste will be minimized.
- **Recommended Width**
The recommended width of geofabric is the width of the driving surface plus about 2 ft (0.7 m) on each side.
 - Gravel Surface, a 24 ft (8 m) width would require fabric at least 28 ft (9.1 m) wide. Two 15 ft (5 m) rolls sewn together in the factory sewn together

would produce a width a little over 29 ft (9.2 m) wide. On gravel surface roads, the width should be as close as possible to the shoulder to shoulder width.

- Bituminous Surface, with an 24 ft (8 m) and 4 ft (1.3 m) shoulders a fabric width would be 32 ft (10.9 m). A combination of a 18 ft (6 m) and 1 ft (5 m) or three 12 ft (4 m) rolls would be appropriate. If the width is too great pre-sewing is not practical and field sewing is required.

- **Recommended Length**

By specifying bi-directional grab strength, the fabric can be placed in the long direction typically in lengths of 200 to 300 ft (60 to 100 m). This will minimize delay.

- **Area**

The area of geofabric to be used for design and bidding should be the area of the embankment covered. Overlap and the amount of fabric allowed for proper sewing should not be used for calculating area of coverage.

- **Stitching/Overlap**

The geofabric should be laid out parallel to the centerline if field stitching if required, use a 3-ft (1-m) overlap. Use a J-stitch with a double stitch, not more than ½ in. (12 mm) apart.

If prayer stitches are used then two lines of sewing should be used. A 401 stitch is best. All seams should be sewn “face up” for inspection.

Construction:

- **Weather**

Best: No wind, dry, warm

Okay, Slight wind, some precipitation, cool

Worst: Windy, wet, cold

- **Placement Proper placement is critical**

Subgrade must be stable:

1. For normal hauling operations geofabric will not substitute for poor subgrade preparation

Geofabric Placement

1. Roll out and stretch out over subgrade
2. Provide some anchor on edges (small shovels of soil)
3. Minimize wrinkles (Fabric should be “Stretched” across subgrade)
4. Transverse Continuity (joints): near end of roll
 - a. Place next roll like shingles with 6-ft (2 m) overlap or
 - b. Sew the connection; (double or triple stitch)

Placement of Granular Material over Geofabric

1. Trucks (belly dumps) can travel directly on geofabric if extremely careful. While on fabric a constant speed of 5-7 mph (8 – 11 kph) is recommended

through dumping. Shifting is not allowed while on the geofabric. **No turns, braking or spinning tires.**

2. Place material down center in a windrow
3. Spread material forward and to the sides (stretch fabric to remove wrinkles in this way).
4. Cover middle portion of the fabric first with a 3 to 4-in. (75 to 100-mm) layer of granular material. This may require one or two truck dumps side by side between 70 and 100 ft (20 and 30 m) long to get the proper sized windrow. A shorter distance may result in a windrow too high and cause the trailer to ride up on the windrow and spin the wheels.

At the end of a workday the contractor should place an additional 3 to 4-in. (75 to 100-mm) layer of granular over the fabric and complete the spreading operations over the entire fabric width.

Typically, one mile of roadway can be placed in this way in one working day.

Value

a. Cost:

- \$0.75 to \$1.25 per yd² (\$0.90 to \$1.50 per m²) for Type V
- \$1.00 to \$2.00 per yd² (\$1.20 to \$2.40 per m²) for Type VI

For a width of 30 ft (10 m) this equivalent to

- \$13,200 to \$22,000 per mile (\$7,920 to \$13,200 per km) for Type V
- \$17,600 to \$35,200 per mile (\$10,560 to \$21,120 per km) for Type VI

b. Expected Life: 50 years with proper design and installation

c. Comments: Proper materials and construction procedures are necessary to obtain good performance.

Contacts

1. James Mehle, City of Albert Lea
2. Alan Forsberg, Blue Earth County
3. Stephen Gale, Gale-Tec Engineering, Inc.
4. David Olsonowski, Hubbard County
5. Richard Sanders, Polk County
6. Joel Uhlring, St. Louis County
7. Daniel Jobe, Scott County
8. Virgil Hawkins, Wright County

3.4.2 Reinforcement – geogrids

Purpose: Geogrids have been used to reinforce and stabilize a fill in a swamp area where the fill itself does not have the strength to stand up.

Conditions: Over a swamp where geofabrics are used to stabilize poor soils especially by limiting shear strain and increasing shear strength at the location of a failure plane. Reinforcement may be needed particularly for relatively high fills over poor soils.

Material(s)

Specifications:

Best: Biaxial Grid – polypropylene geogrid (BX 1200) or approved equal with the following properties:

1. Tensile Strength @ 5% strain (MD/XD) > 810/1360 lb/ft
2. Junction Strength (MD/XD) > 1180/1778 lb/ft
3. Flexural Stiffness > 750,000 mg-cm
4. Torsional Stiffness > 6.5 kg-cm/deg

Uniaxial Geogrid – The Uniaxial Geogrid shall be a uniaxial polypropylene geogrid (UX 1600) or approved equal with the following properties:

1. Initial Modulus in use (MD) > 144,620 lb/ft
2. Long-term Allowable Load (MD) > 3,771 lb/ft
3. Junction Strength > 8,865 lb/ft
4. Flexural Stiffness > 6,000,000 mg-cm

Not Appropriate: Some materials are not as stiff and are more brittle.

A sample of the geogrid should be supplied, along with its test results for the design requirements to the Agency, for approval, prior to placement on the job **or** manufacturer certification of geogrid must be received from contractor

Special Considerations:

- Wider rolls are better because the material is easier to place.
- Tension in the geogrid is not developed immediately; therefore, some type of anchorage (pins) will provide necessary reinforcement
- Ductility will be needed as strains may get higher.

Construction

- a. Weather: Best: Any time not frozen
Worst: Freezing
- b. Transportation/Storage: Must keep geogrid covered as indicated in Mn/DOT specifications.
- c. A sample of the geogrid shall be supplied, along with its test results for the design requirements to the Agency, for approval, prior to placement on the job.

- d. Measurement of Quantities: The quantity of geogrid shall be measured in place by the yd^2 (m^2) actually covered. No allowance shall be made for laps and seams.
- e. The geogrid shall be installed per the manufacturer's recommendation with the approval of the Engineer.

Criteria for connecting geogrids:

- Biaxial geogrid shall be shingled or overlapped in the direction of fill placement, a minimum of 2 ft (0.7 m) and tie as per manufacturer's recommendations. Because the geogrid has a tendency to bulge, it may be essential to cut and retie the fasteners.
- Adjacent rolls of Biaxial geogrid shall be overlapped one 1 ft (0.3 m) to obtain the road covering width shown in the plans.
- Uniaxial geogrid shall be cut to length and rolled perpendicular to the roadway. No overlap of the Uniaxial geogrid is necessary.
- Polk County recommends not anchoring due to the wave, but rather having construction personnel monitor and maintain the overlap. This method of eliminating bulging is less labor intensive than using fasteners.

f. Construction Procedures:

i. Best Practices

- Use geogrid under or at the midpoint of base to reduce cracking. A depth of 17 or 18 in. (0.43 or 0.46 m) will give the maximum strength.
- For fill on top of geogrid dump granular base in the middle and work toward the edges.
- End dump and push with a bulldozer.
- Alternate method of installation is to dump directly on the geogrid then continuing on the grid empty with no turning or shifting at a constant speed of 5 – 7 mph (8 – 11 kph).

ii. Precautions

- Keep a constant speed of 5 – 7 mph (8 – 11 kph) when spreading. This helps prevent shoving.
- No turning movements and no braking

Value

- a. Typical Cost:: Geogrid – UX, \$9.00/sq yd (\$9.00/sq m)
 - BS, \$3.65/sq yd (\$3.45/sq m)
 - Typically, \$30,000 / mile (\$18,000/km) for a good road

The contract price shall include full compensation for furnishing all labor, equipment, materials, tools and incidentals necessary to place the geogrid as shown on the plans.

- b. Expected Life: with good design and construction practices should last 50 years+.
- c. Comments – Geogrids have retarded longitudinal cracking by dissipating the wheel loads when grid placed between the subgrade and the base course or within the base course layer. Friction and interlock occur between the geogrid and the granular material.

Contacts

- 1. Dan Suave, Clearwater County
- 2. Rich Sanders, Polk County
- 3. Joel Uring, St. Louis County
- 4. Graig Gilbertson, NW District, Mn/DOT
- 5. James Mehle, City of Albert Lea

3.5 Substitution

3.5.1 Select Granular

Purpose: Select Granular has been used as a substitute subgrade material for regions having poor soils.

Conditions: Areas with high moisture content fine-grained soils near the water table.

Materials: Mn/DOT specification 3149.2 identifies Select Granular borrow is either pit-run or crushed material graded from coarse to fine, having

$$\frac{\text{Mass passing No. 200 (0.075 mm)}}{\text{Mass passing 1in. (25 mm)}} \leq 0.12.$$

“The material shall not contain oversize salvaged bituminous particles or stone, rock or concrete fragments in excess of the quantity or size permissible for placement as specified. This is a very open gradation specification. The material should not be very frost or moisture susceptible. To minimize frost and moisture susceptibility there should be less than seven percent passing the No. 200 (0.075 mm) sieve (1).”

Design Considerations: Reported practice is to subcut and then fill with 2 ft (0.6 m) of select granular followed by 1 ft (0.3 m) of Mn/DOT Class 5 material. Depending on the existing soil it may be desirable to use a geofabric separation layer between soft, wet soils and the granular material.

Construction: Construction with Select Granular material should be governed by the standard practices given in Mn/DOT 2105 and 2112.

Value:

Contacts: City of Chanhassen, Mn/DOT District Materials Engineer



Figure 3.4. 6-in. (300-mm) Breaker Run Limestone.

3.5.2 Breaker Run Limestone

Purpose: Breaker run limestone, shown in Figure 3.4, has been used in Minnesota as a substitute for undesirable subgrade materials, particularly where fine grained, wet soils occur. Satisfactory compaction is achieved using the Quality Compaction Method given by 2211.3C2 in the *Minnesota Standard Specifications for Construction*. After compaction and grading the embankment is ready for placement of granular base materials (Class 5 or 6 recommended) and bituminous surfacing.

Material: The term breaker run limestone shall refer to a limestone/dolostone material that has been run through a crusher one time and then screened for maximum size. The material has a maximum particle size of 6 in. (150 mm) and is well graded from the top size down to the number No. 200 (0.075-mm) sieve. Item S-4.1 from the specifications for S.A.P. 20-625-01 states that 100% breaker run limestone material shall be graded from coarse to fine and pass the 6-in. (150-mm) sieve. Column (A) of Table 3.1 shows the result of a sieve analysis performed on a breaker run sample collected from a construction site. Column (B) contains the same information but with some interpolated values. Column (C) is the gradation band for MnDOT Class 5 aggregate containing more than 60 percent crushed quarry rock.

Table 3.1. Breaker-Run Limestone and MnDOT Class 5 Gradations

Sieve	Breaker Run		MnDOT Class 5 (+ 60% crushed)
	A	B	C
6 in. (150 mm)	100	100	-
3 in. (75 mm)	-	90	-
2 in. (50 mm)	-	82	-
1.5 in. (39 mm)	80	80	-
1.0 in. (25 mm)	72	72	100
3/4 in. (19 mm)	67	67	90 – 100
3/8 in. (9.5 mm)	56	56	50 – 90
No. 4 (4.76 mm)	43	43	35 – 70
No. 10 (2 mm)	-	22	20 – 55
No. 30 (0.6 mm)	10	10	-
No. 40 (0.425 mm)	-	8	10 – 35
No. 200 (0.075 mm)	0.3	0.3	3 – 10

Breaker run material may contain some magnesium. Materials normally used for this type of backfill will not meet the insoluble residue requirements given in Minnesota specification 3138.2A3.

Construction: Sunny and dry weather conditions are best when constructing with breaker run limestone. The worst weather conditions would be overcast/misty or frozen.

Recommended practice is to end dump the breaker run material then spread it with a bulldozer. Compacted lift thickness should not exceed 9 in. (0.25 m). The lift moisture content should be adjusted to 4 to 5 percent then followed by compaction. Compaction is carried out using a vibratory steel-wheeled roller.

In cases where the design includes geofabric there is a danger of the coarse breaker run material causing tears or otherwise damaging the geofabric. To prevent this damage a 6-in. (0.2-m) separation layer of granular material (Class 5 recommended) should be included. In keeping with good construction practice the geofabric should be sewn or overlapped. Sewing shall be J-seam or prayer-seam according to Minnesota specification 3733.2B(D). An overlap of 1 to 3 ft (0.3 to 1 m) is adequate. A granular separation material should be initially spread along the centerline. This keeps the geofabric taut and wrinkle free.

Figures 3.5, 3.6, and 3.7 illustrate breaker run limestone construction with geofabric.

Current (2002) Costs: Breaker run limestone has been priced at \$8.39 per ton from the Mantorville quarry. This bid was contingent upon the purchase of 14,000 yd³ (10,700 m³).

Contacts: For more information on breaker run limestone contact Guy Kohlhofer, Dodge County Engineer at guy.kohlhofer@co.dodge.mn.us.



Figure 3.5. Overlapping layers of Type V nonwoven geofabric separate granular material from wet, fine soil. 6 in. (130 mm) of Class 5 granular material protects the geofabric from the breaker run material.



Figure 3.6. A bulldozer spreads Class 5 material down the center while a steel wheeled roller compacts nearby.



Figure 3.7. Steel wheeled roller applies compactive effort to a 9- in. (230-mm) lift of Breaker Run Limestone.

3.5.3 Wood Chips

Purpose: Wood Chips have been used in Minnesota as a lightweight substitute for undesirable subgrade materials. Wood chips have a unit weight of approximately 30 pcf (480 kg/m³) and are particularly suited to swamp-like conditions where the water table is close to the surface. Wood chip construction can be combined with the use of other lightweight fills and the use of geotextiles.

Material Description: The term wood chips shall refer to byproduct materials having a relatively uniform size and obtainable by volume (m³ or yd³ placed) from various wood industry sources. The term shall not refer to bark, leaves, twigs or stumps.

- A. Wood chips having a uniform gradation and an average size of approximately 3 in. (75 mm) may be available in some locations. Chips having a maximum size of 2-3 in. (50 – 75 mm) and semi-cubic shape can be produced from a pallet recycler.
- B. Lumber mill sawdust (Figure 3.8) is a material having a maximum size of approximately 2 in. (50 mm). The shape of lumber mill sawdust varies from flat and elongated particles to semi-cubic shapes. Wood chips of other sizes may be available locally from a variety of sources such as municipalities but they may have greater variation than that from wood industry sources.



Figure 3.8. Lumber-Mill Sawdust

Construction: Wood chip construction is best when done under warm, dry conditions. The most unfavorable construction conditions would be frozen or moist (wet).

- Standard use: In Minnesota the most common method of preventing decay is to keep the wood chip layer below the water table elevation. For some conditions it may be reasonable to partially or fully encapsulate the wood chips with geofabric and soil.
- Alternate use: Use above the water table elevation is possible if the entire layer of wood chips is protected from moisture. Service conditions should be high and dry. The wood chip material should be dry when installed.

The wood layer should be encapsulated in geofabric to prevent loss of material.

The geofabric may be Type V or VI, woven or nonwoven material. Whenever possible the geofabric should be placed on compacted soil. In keeping with good construction practice the geofabric should be sewn or overlapped. Sewing shall be J-seam or prayer-seam according to Minnesota specification 3733.2B(D). An overlap of 1 to 3 ft (0.3 to 1.0 m) is usually adequate but depends on in-situ moisture conditions.

Wood chip construction does not require special equipment. End dump the wood chips and place them in 1 to 2 ft (0.3 – 0.6 m) lifts using bulldozers (Figure 3.9). The chips should next be covered with a minimum of 6 in. (150mm) of plastic soil to reduce exposure to air. Proceed with compaction after placement of plastic soil.



Figure 3.9. Bulldozer spreading Lumber-Mill Sawdust

Precautions:

- Poorly graded chips or non-uniform chips (sticks with organic debris) will not compact adequately.
- Moving water may easily displace wood chips.
- Beware of transverse movement that may cause longitudinal cracking.
- Fungi are the most common wood destroyers and causes significant strength loss for small weight loss. Fungi need air and moisture to be effective. Applications using continuous total submersion in fresh water will prevent fungal destruction.
- Help ensure the uniformity of wood material by obtaining wood from a single source per fill project.

Settlements of approximately 2 ft (0.6 m) (for 20-ft (6-m) excavations) have been observed over a 10-year period in swamp excavation projects that utilize sawdust as a fill material. However, there have been excellent results when using wood chips for fill and

floated widening projects in swampy areas. When using wood chips in this manner the 20-year settlement is limited to that associated with initial construction.

See also *Wood Chips as a Lightweight Fill*, Mn/DOT, 1996 (53).



Figure 3.10. Wood Chips above Geofabric

Value: Wood chips have traditionally been very inexpensive however the paper industry has recently emphasized use of these types of byproducts.

Table 3.2. Typical costs of Wood Chips

Material type	Cost
Coarser than sawdust	\$7.62 /yd ³ (\$10/m ³)
Recycled chips	\$5 – 6 /yd ³ (\$6.50/m ³)

Contacts:

Minnesota counties using Wood Chip construction

Dan Sauve, Clearwater County Engineer, dan.sauve@co.clearwater.mn.us

Richard Larson, Mille Lacs County Engineer , dick.larson@co.millelacs.mn.us

Robert Paine. Ramsey County Engineer, robert.paine@co.ramsey.mn.us

Jeff Blue, Waseca County Engineer, jeff.blue@co.waseca.mn.us

3.5.4 Shredded Tires

Purpose: Shredded tires have been used as a lightweight fill and drainage layer(s). They can replace common borrow and use discarded tires which would otherwise need to be wasted in landfills.

1. **Tire shreds** have a compacted dry density of one-third to one-half of the compacted dry density of typical soil. They are therefore attractive lightweight fill for construction on weak, compressible soils where slope stability or excessive settlement is a concern.

2. The **thermal conductivity** of tire shreds is about eight times greater than typical granular materials and therefore they can be used as an insulating layer 6 in. (150 mm) to 18 in. (450 mm) thick.

3. The high **hydraulic conductivity** of tire shreds, which is generally greater than 0.4 in./sec (1 cm/sec), makes them suitable for many drainage applications.

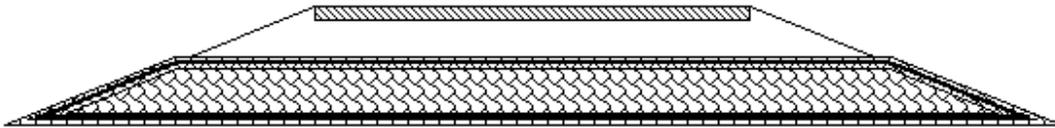


Figure 3.11. Tire shreds encapsulated in geofabric

Conditions: An area which has a poor wet soil and will settle significantly under normal aggregate or soil fills.

Material(s): ASTM 6270 defines the following materials and quantities related to scrap tires:

Definitions:

a. **Shredded tire:** a size reduced scrap tire where reduction is accomplished with a “shredder”

b. **Tire chips:** pieces of scrap shredded tire that have a basic geometric shape and are generally between 0.5 in. (12 mm) and 2 in. (50 mm) in size and have most of the wire removed (also called chipped tires).

c. **Tire shreds:** pieces of scrap tire that have a basic geometric shape and are generally between 2 in. (50 mm) and 12 in. (305 mm) in size.

d. **Whole tire:** scrap tire that has been removed from the rim, but has not been processed.



Figure 3.12. Tire Shreds.

Design Quantities for use of tire shreds:

a. Gradation: The materials should be chunky Tire Shreds with a minimum size of 6 in. (150 mm) and maximum size of 12 in (300 mm). They should not include any ½ tires.

b. Depth: The Tire Shreds should be placed initially about 15 ft (5 m) loose and then compacted to 10 ft (3+ m).

c. Thickness Design Elements: The soil on which the fill is to be placed should be smoothed and covered with a Type V non-woven geofabric to prevent infiltration of soil into the tire shreds. A 2-ft (0.7-m) layer of soil or granular material is placed over the Tire Shreds and used as a separation layer during compaction.

The shredded tire layer should be wrapped completely in a layer of woven or unwoven geofabric.

d. Compaction: Compaction is accomplished similar to quality compaction procedures, i.e. until no further consolidation of the embankment is observed. This can be accomplished with four or five passes of a bulldozer operating on top of the soil or granular layer. The inspector can usually tell when the system is solid/compacted.

Construction:

a. Weather: Weather is not a big factor. The only problems would be if the grade was frozen or 100 percent saturated.

b. Transportation can be accomplished with live-bottom truck, dump truck, or any other over-the-road vehicle. In Carlton County a system was set up whereby the supplier advertised that transportation would be available to remove used tires from the

county. When shredded tires were brought to the job site the same trucks picked up scrap tires for transport back to the tire-shredding site.

c. Shredded tires were moved around and from the storage area adjacent to the project using a “**thumb probe**” device pictured in Figure 3.13 attached to a front-end loader. This device expedited the transfer of shredded tires around and to the project site. The quantity of shredded tires was measured in truckloads.

d. If more than a compacted 10-ft (3-m) lift of tires is specified then a minimum of 2-ft (0.6-m) of clay separation is necessary.

e. Construction Control

i. Materials-uniformity can be attained by having a constant gradation

ii. Procedures-use the probe device to place the shredded tires in a consistent horizontal orientation.

iii. Measurements-thickness of the layers should be monitored using survey levels

f. Best Practices

i. Use the “**Thumb Probe**” to move the tires into a uniform horizontal configuration.

ii. Totally wrap shredded tires in a Type V fabric.



Figure 3.13. Placing tire shreds. Loader uses a thumb-like attachment to enable grasping.



Figure 3.14. Loader distributing and compacting tire shreds.

g. Precautions

i. Tires can burn and therefore the shredded tire storage area and fill should be protected from accidental causes of fire or arson until properly covered.

ii. The fill needs to be designed to minimize the possibility of an internal heating reaction (fire). Heating and eventually fire can be caused by oxidation of the steel belts or rubber.

iii. Minimize free access to **air and water**

iv. Use relatively large size shreds to minimize surface area.

v. **Type I and Type II** fills with tire shreds should be free of all contaminants such as oil, grease, and gasoline that could be a fire hazard.

vi. **For a Class I fill (less than 3 ft (1 m) deep)** a maximum of 50% should pass the 1.5 in. (38 mm) sieve and 5% pass the No. 4 (4.75 mm) sieve.

No special design considerations to minimize heating would then be needed for Class I fills.

vii. **For Class II fills (1-3 m (3 to 9 ft) deep)** a maximum of 25% should pass the 1.5 in. (38 mm) sieve and 1% pass the No. 4 (4.75

mm) sieve. There should also be less than 1% metal fragments exposed.

viii. **Class II fills** should be constructed to minimize infiltration of water and air into the system. There also should be no direct contact between topsoil and the shreds.

ix. The top and sides of the fill should be covered with a 1.5-ft (0.5-m) thick layer of compacted soil with more than 30% fines.

x. The grade should be built so that water will drain away from the shreds.

xi. The pavement and soil should be extended to the shoulder so that water will drain to the ditch.

xii. The thickness of the drainage layer where it is daylighted should be minimized.

xiii. The granular base should be separated from the tire shreds with a non-woven geofabric.

xiv. The shredded tire fill will be softer (less stiff) than most other fill materials. The overlying pavement must be designed for the design traffic considering this condition.

Value:

- a. Cost
- b. Expected Life** – 50 years
- c. Comments**

Contacts:

- a. Carlton County
 - Wayne Olson
 - Randy McCusky
- b. Mn/DOT
 - Blake Nelson
 - John Seikmeier
- c. First State Tire Co.
 - Steve O'Brien

CHAPTER 4: RECOMMENDATIONS

4.1 Recommendations

Procedures to use for special subgrade conditions in Minnesota have been presented in this report. Most projects can be designed with the grade at least 5 ft (1.7 m) above the water table with adequate drainage provided to result in a good uniform well compacted subgrade. However, if the grade must be built closer to the water table and if peat or other undesirable materials exist in the grade then special procedures such as those presented here can be used.

The subgrade soil design and construction procedures presented in this report are based on the review of literature, responses to questionnaires sent to cities and counties, and discussions and review of specific projects with city, county, and Mn/DOT engineers and suppliers. Recommendations for when and how to use the procedures are presented in Tables 4.1A – 4.1D. The tables are divided by soil type:

- A. Granular
- B. Semi Plastic
- C. Plastic

The soil types are defined using categories from the MnPAVE (64) design soil parameters.

The moisture conditions estimated for the grade are estimated using:

1. height of the final grade above the water table and
2. drainage provided for the pavement section.

The height of the final grade above the water table is sometimes limited by the presence of peat or some other compressible material in the grade. Table 4.1D applies to layers of peat or other unstable materials occurring in the grade.

Mn/DOT recommends that the grade be designed at least 5 ft (1.7 m). If a peat or other compressible layer exists along the alignment regular aggregate may be too heavy, causing the material to displace. One remedy would be to replace (substitute) a portion of all of the compressible material.

Table 4.1D included the recommended procedures of various thicknesses of peat, drainage, and moisture content.

The moisture conditions of the subgrade soil are estimated using:

- the height of the grade above the water table and
- drainage designed into the pavement section.

The height above grade is measured from the centerline. It is assumed the side slope is sufficient for runoff. It is also assumed that the surface is sealed enough to promote runoff.

Tables 4.1A – D: Summary of Subgrade Soil Enhancement Procedures

The following charts present subgrade enhancement alternatives based upon in situ soils, location of water table relative to the grade, drainage characteristics of in situ soils, and moisture conditions.

1. Modification/Stabilization with Lime
2. Stabilization with Fly Ash
3. Separation with Geofabrics
4. Reinforcement with Geogrids
5. Substitution
 - a. Select Granular
 - b. Breaker Run Limestone
 - c. Bituminous Recycled Material
 - d. Wood Chips
 - e. Shredded Tires
 - f. Foam

Table 4.1A. Subgrade Soil Enhancement Flow Chart

Soil Type	Grade above Water Table	Drainage*	Moisture** Conditions	Special Subgrade Soil Enhancement
Granular, gravel, sand, loamy sand	>6 feet (2 meters)	Good	Dry/damp	None
		Fair	Dry/damp	None
		Poor	Wet	None
	3 – 6 feet (1 – 2 meters)	Good	Dry/damp	None
		Fair	Wet	None
		Poor	Wet	None
	1 – 3 feet (0.3 – 1 meter)	Good	Dry/damp	None
		Fair	Wet	None
		Poor	Saturated	3

* Good – longitudinal and transverse drainage with free draining base daylighted.
 Fair – longitudinal and transverse drainage **without** free draining base or not daylighted.
 Poor – drainage not provided and no free draining base.

** Dry/damp – maximum strength attainable
 Wet – reduced strength
 Saturated – reduced strength and pumping can occur

Table 4.1B. Subgrade Soil Enhancement Flow Chart

Soil Type	Grade above Water Table	Drainage*	Moisture** Conditions	Special Subgrade Soil Enhancement
Semi Plastic, pl SL, L, SiL, SCL, CL, SiCL	>6 feet (2 meters)	Good	Dry/damp	None
		Fair	Dry/damp	3
		Poor	Wet	1,2,3
	3 – 6 feet (1 – 2 meters)	Good	Dry/damp	None
		Fair	Wet	1,2,3
		Poor	Wet	1,2,3
	1 – 3 feet (0.3 – 1 meter)	Good	Dry/damp	None
		Fair	Wet	1,2,3
		Poor	Saturated	1,2,3,4,5

- * Good – longitudinal and transverse drainage with free draining base daylighted.
 Fair – longitudinal and transverse drainage **without** free draining base or not daylighted.
 Poor – drainage not provided and no free draining base.

- ** Dry/damp – maximum strength attainable
 Wet – reduced strength
 Saturated – reduced strength and pumping can occur

Table 4.1C. Subgrade Soil Enhancement Flow Chart

Soil Type	Grade above Water Table	Drainage*	Moisture** Conditions	Special Subgrade Soil Enhancement
Plastic, SC, SiC, Clay, Peat	>6 feet (2 meters)	Good	Dry/damp	None
		Fair	Dry/damp	None
		Poor	Wet	1,2,3
	3 – 6 feet (1 – 2 meters)	Good	Dry/damp	None
		Fair	Wet	1,2,3
		Poor	Wet	1,2,3
	1 – 3 feet (0.3 – 1 meter)	Good	Dry/damp	1,2,3
		Fair	Wet	1,2,3
		Poor	Saturated	1,2,3,4

- * Good – longitudinal and transverse drainage with free draining base daylighted.
Fair – longitudinal and transverse drainage **without** free draining base or not daylighted.
Poor – drainage not provided and no free draining base.
- ** Dry/damp – maximum strength attainable
Wet – reduced strength
Saturated – reduced strength and pumping can occur

Table 4.1D. Subgrade Soil Enhancement Flow Chart PEAT AND/OR SWAMP AREAS

Thickness of Peat	Drainage*	Moisture** Conditions	Special Subgrade Soil Enhancement
< 6 feet (2 meters)	Good	Dry/damp	6a, 6b, 3
	Fair	Dry/damp	6a, 6b, 3
	Poor	Wet	6a, 3
6 – 12 feet (2 – 4 meters)	Good	Dry/damp	6a
	Fair	Wet	6a, 6b, 6e
	Poor	Wet	6a, 6b, 6e, 3, 4
> 12 feet *** (4 meters)	Good	Dry/damp	6a, 6b, 6e, 6f
	Fair	Wet	6a, 6b, 6e, 6f, 3, 4
	Poor	Saturated	6a, 6b, 6e, 6f, 3, 4

* Good – longitudinal and transverse drainage with free draining base daylighted.
 Fair – longitudinal and transverse drainage **without** free draining base or not daylighted.
 Poor – drainage not provided and no free draining base.

** Dry/damp – maximum strength attainable
 Wet – reduced strength
 Saturated – reduced strength and pumping can occur

*** Peat quality varies with the amount of natural fibers present and the level of decomposition. When depth > 12 ft (4 m) consult a geotechnical engineer.

Note: If the grade is being constructed at 3 ft (1 m) above the water table or less, special precautions must be made so that the construction equipment does not sink into the grade.

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APPENDIX A
AGENCY QUESTIONNAIRES

Questionnaires were sent to the following Minnesota cities and counties at the end of 2001 to determine the previous level of involvement with subgrade improvement.

Counties:

Aitkin	Cass	Douglas	Itasca
Anoka	Chippewa	Faribault	Jackson
Becker	Chisago	Fillmore	Kanabec
Beltrami	Clay	Freeborn	Kandiyohi
Benton	Clearwater	Goodhue	Kittson
Big Stone	Cook	Grant	Koochiching
Blue Earth	Cottonwood	Hennepin	Lac Qui Parle
Brown	Crow Wing	Houston	Lake
Carlton	Dakota	Hubbard	Lake of the Woods
Carver	Dodge	Isanti	Le Sueur
Lincoln	Murray	Pope	Sherburne
Lyon	Nicollet	Ramsey	Sibley
Mahnomen	Nobles	Red Lake	Stearns
Marshall	Norman	Redwood	Steele
Martin	Olmsted	Renville	Stevens
McLeod	Otter Tail	Rice	Swift
Meeker	Pennington	Rock	Todd
Mille Lacs	Pine	Roseau	Traverse
Morrison	Pipestone	St. Louis	Wabasha
Mower	Polk	Scott	Wadena
Waseca			
Washington			
Watowan			
Wilken			
Winona			
Wright			
Yellow Medicine			

Cities:

Albert Lea	Fairmont	Maple Grove	St. Paul
Chanhassen	Farmington	North Branch	Thief River Falls
Crookston	Grand Rapids	Pipestone	
Eagan	Hibbing	Plymouth	
East Grand Forks	Inver Grove Heights	Rochester	

The following is a copy of the questionnaire sent to Minnesota agencies at the end of 2001:

**Best Practices for Design and Construction of
Pavement Subgrades and Embankments in Minnesota**

Questionnaire on Existing Projects and Practices

City/County _____

Respondent _____

Phone _____

FAX _____

e-mail _____

1. Has your city/county used any materials either experimentally or routinely for **Modification** of embankment soils?

Yes No

- a. What type of material was used for **Modification**?

Cement Lime Fly ash Bituminous/asphalt

Other Describe _____

- b. How many projects were constructed? _____

c. Was the performance satisfactory? Yes No Mixed

d. Can the project(s) be located now? Yes No

2. Has your city/county used any materials either experimentally or routinely for **Stabilization** of embankment soils?

Yes No

- a. What type of material was used for **Stabilization**?

Cement Lime Fly ash Bituminous/asphalt

Other Describe _____

- b. How many projects were constructed? _____

c. Was the performance satisfactory? Yes No Mixed

d. Can the project(s) be located now? Yes No

3. Has your city/county used any materials either experimentally or routinely for **Reinforcement** of embankment soils?

Yes No

- a. What type of material was used for **Reinforcement**?

Geofabric Geogrid Other _____

- b. How many projects were constructed? _____

c. Was the performance satisfactory? Yes No Mixed

d. Can the project(s) be located now? Yes No

4. Has your city/county used any materials either experimentally or routinely for **Substitution** or **Replacement** of embankment soils?

Yes No

a. What type of material was used for **Substitution**?

Shredded Tires Wood Chips Foam Other _____

b. How many projects were constructed? _____

c. Was the performance satisfactory? Yes No Mixed

d. Can the project(s) be located now? Yes No

5. Are there any other types of construction which you feel would fit into the scope of this project?

THANK YOU FOR YOUR HELP!

APPENDIX B

AGENCY RESPONSES TO QUESTIONNAIRES

Question 1, Modification:

County Response

Yes, 6
No, 34

material	# projects	performance	known location
lime	2	satisfactory	Y
fly ash	1	satisfactory	Y
reclaimed Bituminous. 7C used as Agg. Base.	2	satisfactory	Y
base 1 from Team	3, 4	unsatisfactory	Y
lime(to dry subgrade), bituminous/asphalt(to bridge bad grade)	1 lime, several bit.	mixed	Y
Bituminous...Not sure? We used broken up bit. Roadway used in embankment areas as fill.	2	satisfactory	Y

City Response

Yes, 0
No, 17

Question 2, Stabilization

County Response

Yes, 7

No, 33

material	# projects	performance	known location
Bituminous millings: maint - frost boils		satisfactory	?
Bituminous. Full depth asphalt pavement design more than embankment stabilization.	1	satisfactory	Y Now 30-years old.
Breaker Run Limestone (6" minus)	4	satisfactory	Y
limestone breaker run	limited use	satisfactory	N
lime	1	satisfactory	Y
fly ash	1	satisfactory	Y SAP 67-602-004 one mile
fly ash	1	satisfactory	Y

City Response

Yes, 1

No, 16

material	# projects	performance	known location
lime	1	satisfactory	Y

Question 3, Reinforcement

County Response

Yes, 27

No, 11

material	# projects	performance	known location
geofabric	many	satisfactory	Y somewhat
geofabric	3	mixed	Y
geofabric, geogrid	3	satisfactory	Y
geofabric	6	satisfactory	Y
geofabric: Bottom of subcuts between layers of bit. Surfacing	5	mixed (overlay), satisfactory (subcut)	Y
geofabric	3	mixed	Y
geofabric	1	satisfactory	Y
geofabric, geogrid	6 to 10	satisfactory	Y
geofabric, geogrid	-	Mixed, Depends on how Performance is defined.	Y CSAH 2, CSAH 11, CSAH 26, CSAH 29, CR 168, CSAH 8
geogrid	1	satisfactory	Y
geofabric combined w/a layer of breaker run rock	3	satisfactory	Y
geofabric	2	satisfactory (1 project is holding up fine (type U) other project was just constructed in 2001 (type UI)	Y
geogrid	1	mixed	Y
geofabric	1	mixed	Y
geofabric	6	mixed	Y
geofabric, geogrid		satisfactory	Y
geofabric	used in soft spots	satisfactory	N
geofabric, geogrid	5	satisfactory	Y
geofabric	many	satisfactory	Y & N
geofabric	2	satisfactory	Y
geofabric	1	mixed	Y
geofabric, geogrid	1	satisfactory	Y
geofabric, geogrid	20 plus	mixed	Y
geofabric	5	satisfactory	Y

Reinforcement , County Response continued.

material	# projects	performance	known location
geofabric	1	satisfactory	Y
geofabric	2	mixed	Y
geofabric, geogrid	many	mixed	Y

City Response

Yes, 12

No, 15

material	# projects	performance	known location
geofabric, geogrid	1 each	mixed	Y
geofabric	15 - 20	satisfactory	Y
geofabric	10	satisfactory	Y
geofabric	1	satisfactory	Y
geofabric	6	satisfactory	Y
geofabric	4	mixed	Y
geofabric	numerous	satisfactory	N
geofabric	1	satisfactory	Y
geofabric	6 per season	satisfactory	Y
geofabric	20 - 25	mixed	Y
geofabric	4	satisfactory	Y
	minor patching only	satisfactory	Y

Question 4, Substitution

County Response

Yes, 10

No, 28

material	# projects	performance	known location
foam, fly ash	2	too soon to tell	Y
shredded tires	1	satisfactory	Y
shredded tires	4	satisfactory	Y
wood chips	2, 3	mixed	Y
cinders? Light-weight fill	1	satisfactory	Y
shredded tires, wood chips	3	mixed	Y
shredded tires, wood chips, foam	3	mixed	Y
shredded tires, developing foam	1	satisfactory	Y
soil	1	mixed	Y
Wood chips	1	satisfactory	Y

City Response

Yes, 5

No, 12

material	# projects	performance	known location
Select Granular	15 - 20	satisfactory	Y
shredded tires, wood chips	1	satisfactory	Y
foam	1	unsatisfactory	Y
wood chips	1	mixed	Y
foam, lightweight aggregate	1	satisfactory	Y

Question 5, Are there any other types of construction which you feel would fit into the scope of this project?

Combined County and City Response

- Routinely use granular soil as replacement for poor soils.
- Subcutting routinely employed and is critical, in my opinion, for good performance of embankments and grading in general.
- Lincoln County only used geofabric to stabilize soft spot on grading projects for base and bituminous.
- Just that we need more money to rebuild and maintain the road and bridge system. I don't think you can fix that.
- Widened a river bottom road grade using oversize shot rock.
- We currently construct using shredded tires, geofabric, geogrid, geocell.
- Our typical section on re-grading or building new alignments almost always includes a 2" layer of clean granular borrow (nonfrost susceptible) soil immediately below the pavement section. Geogrid is incorporated into this layer and/or fabric below the layer when poor and/or weak subgrade conditions are encountered.
- We experimented adding fly ash to an area of aggregate base C15 and thus reducing the bit section, however, after a few years we overlaid this section.
- All embankment from shoulder PI to shoulder PI, 3' deep, is constructed by specified density, 100% compaction.
- We are looking into repairing "frost boils" w/FEMA funds in summer of 2002 - removing 2' of road section replacing w/geogrid 6" drain rock - 12" subbase and 6" road material. Suggestions are welcomed.
- Given the city of Chanhasen's clay soil conditions and high moisture content, the typical street section is 24 inches Select Granular, 12 inches class 5, 2 inches Bit-base, 1.5 inches Bit wear. We have had to construct street sections with geofabric and 36 inches sand, 12 inches class 5.
- We routinely use geotextile to separate the soft clay subgrades from the aggregate base to prevent pumping and contamination during construction. The biggest wheel loads come of these residential streets ever experience is the belly-dump hauling the aggregate base.
- Geofabric was 1 time use in short stretch of roadway.
- Typical subgrade excavation where unsuitable material is removed and replaced with granular borrow. A very typical process not included in your definition of substitution or replacement.

The preferred method is to remove and replace unstable material with granular borrow.

APPENDIX C

AGENCY INTERVIEWS CONDUCTED DURING SUMMER, 2002

Agency interviews included a combination of:

- Interview of engineering department regarding questionnaire results.
- Gathering specifics of construction methods and success with various subgrade enhancement techniques.
- Tours of completed and in-progress projects.
 - Ride and photo documentation.

Agencies interviewed were:

1. Ramsey County
2. Mn/DOT NW District (Bemidji)
3. Clearwater County
4. Polk County
5. City of Crookston
6. Lake of the Woods County
7. Hubbard County
8. Mille Lacs County
9. Dodge County
10. City of Albert Lea
11. Carlton County
12. St. Louis County
13. Scott County
14. Wright County
15. Waseca County
16. Blue Earth County

APPENDIX D

**MINNESOTA SUBGRADE ENHANCEMENT INSTALLATION
LOCATIONS**

Modification and Stabilization Installations

SUBGRADE ENHANCEMENT INSTALLATIONS - I (MODIFICATION / DRYING)																			
Agency	Roadway	Limits	Year Bit	Traffic			Existing Soil Conditions			Field Moisture Conditions	Enhancement	Subbase		Base		Surface		EVALUATION	
				AAADT	HCAADT	ESAL's	Class	R-Value	M _r			Type	Thick.	Type	Thick.	Type	Thick.	Date	Condition(s)
Cleanwater City																			
Lake of the Woods City	CSAH 19	(A) Baudette: TH 11 W to TH 72 S to CSAH 19 from TH 72 to 3 mi. E (CR 89)	2000?											aggregate	1-ft.	BASE I on CI 5	8-in.		
Lake of the Woods City	CSAH 19	(B) Baudette: TH 11 W to CR 88 Project on CR 89 S 2.5-mi. to CSAH 19.	2000?										aggregate	1-ft.	CI 5	12-in.			
Lake of the Woods City	North Angle Road	5 mile project.														CI 5	12-in.		

SUBGRADE ENHANCEMENT INSTALLATIONS - II (STABILIZATION)																			
Agency	Roadway	Limits	Year Bit	Traffic			Existing Soil Conditions			Field Moisture Conditions	Enhancement	Subbase		Base		Surface		EVALUATION	
				AAADT	HCAADT	ESAL's	Class	R-Value	M _r			Type	Thick.	Type	Thick.	Type	Thick.	Date	Condition(s)
Waseca City	CSAH 8	(A) New Richard: MN 13 N to 8 E, Project st1 + 739 to 2 + 550 begins CL with S (sta 0+925)	2000	750			Silty-Clay-Loam	10 - 15 (25 post-ash)	4500 psi	wet	14% Fly ash (Sherco and Riverside #6)	Ash modified silty-clay-loam	8-in.	CI 5	4-in.	HMA	7-in.		
Waseca City	CSAH 8	(B) New Richard: MN 13 N to 8 E, Project st2 + 550 to 3 + 350 begins CL with S (sta 0+925)	2000	750			Silty-Clay-Loam	10 - 15 (25 post-ash)	4500 psi	wet	14% Fly ash (100% Sherco)	Ash modified silty-clay-loam	8-in.	CI 5	4-in.	HMA	7-in.		
Waseca City	CSAH 8	(C) New Richard: MN 13 N to 8 E, Project st4 + 154 to 4 + 950 begins CL with S (sta 0+925)	2000	750			Silty-Clay-Loam	10 - 15 (25 post-ash)	4500 psi	wet	14% Fly ash (Sherco and Riverside #6)	Ash modified silty-clay-loam	8-in.	CI 5	4-in.	HMA	7-in.		
Waseca City	CSAH 8	(D) New Richard: MN 13 N to 8 E, Project st5 + 950 to 5 + 750 begins CL with S (sta 0+925)	2000	750			Silty-Clay-Loam	10 - 15 (25 post-ash)	4500 psi	wet	14% Fly ash (Class C)	Ash modified silty-clay-loam	8-in.	CI 5	4-in.	HMA	7-in.		

Separation Installations

SUBGRADE ENHANCEMENT INSTALLATIONS - III A (SEPARATION)																		
Agency	Roadway	Limits	Year Bld	Traffic			Existing Soil Conditions		Field Moisture Conditions	Enhancement	Subbase		Base		Surface		EVALUATION	
				AAADT	HCAADT	ESAL's	Class	R.Value			Mt.	Type	Thick.	Type	Thick.	Type	Thick.	Date	Condition(s)
Blue Earth Cnty	CSAH 20	Lake Crystal, N of T-684, N of T-680 th 2100-ft N of TH60	2001	947	93	...	organic soils (GALE-TEC report 8/23/01)	10	...	Class VI multifilament polyester fabric, Geolon® PET 300/60 from Amsterdam	select granular above 1 or 2 geofabric layers	5-ft.	CL 5	10-in.	HMA wear HMA binder HMA base	2-in. 2-in. 2-in.	...	Successful engineered fill with two layers of high strength geotextile and surcharge over deep peat deposits. Laid transversely. Sharp settlement failure over deep peat deposits with medium high fill needed to meet vertical curve standards. Failure may be due to fabric failure or rate of fill.
Blue Earth Cnty	County 188	NE part of county, N of T-684, N of Gillfillin Lake and 26' single vertical curve	...	...	...	...	...	...	Type V fabric	fill	15-ft.	...	Asphalt	...	...	...	Successful engineered fill with two layers of high strength geotextile. Geotextile reinforced road fill and prevented differential settlement between peat deposit on south side and clay deposit on north side of centerline.
Blue Earth Cnty	CSAH 90	W of Mankato: US 189W to CSAH 90E, Project before T-493	...	...	...	...	Peat (south) Clay (north)	...	Type V fabric and edge drains	fill	20-ft.	class 5	Asphalt	...	...	...	Successful engineered fill with high strength geotextile and surcharge over deep peat deposits.
Blue Earth Cnty	CSAH 3	E of Mankato: US 14E to MN 22N to CSAH 3E, Project near T-351 and before RR track.	1997	...	...	...	Peat	...	Type V fabric one year before.	fill	6 - 7-ft.	...	...	...	...	...	Opened up Oct. 1. Class V rolled down plus gravel fall/winter/spring. Successful use of geotextile for emergency local access when grading was interrupted for the season by early "Halloween Blizzard" snow storm.
Blue Earth Cnty	County 186	E of Mankato: US 14E to County 186N, Project N of CSAH 3 intersection approx. 0.5 mile.	1990	...	...	...	...	...	Type V fabric and gravel	...	...	...	...	...	...	...	...
Crookston City		clay	...	Type V or Type VI fabric	clay type soils		Cl 5	17-in.	HMA	4-in.

SUBGRADE ENHANCEMENT INSTALLATIONS - III A (SEPARATION)

Agency	Roadway	Limits	Year Bilt	Traffic			Existing Soil Conditions			Field Moisture Conditions	Enhancement	Subbase		Base		Surface		EVALUATION	
				AADT	HCAADT	ESAL's	Class	R.Y. Value	M			Type	Thick.	Type	Thick.	Type	Thick.	Date	Condition(s)
Dodge Cnty	County 25	"soft soil"	Type V fabric. Nonwoven	Breaker run Limestone over CL5 over fabric	CL5	10 - 12-in.	HMA 2350 wear HMA 2350 nonwear	2-in. 2.5-in.		
Lake of the Woods Cnty	CSAH 3	CSAH 3 from CSAH 166 + W of Baudette	1990-93	...	...	...	soil factor 130	...	Type V fabric (sewn)	...	CL5	8-in.	HMA 2331	3-in.	...	...	
Lake of the Woods Cnty	CSAH 39	CSAH 39 from TH 11 to TH 172. near Baudette??	1997	...	...	...	soil factor 130	...	Type VI fabric. Woven (overlap, not sewn)	...	CL5	8-in.	HMA 2331	4-in.	...	...	
Lake of the Woods Cnty	CSAH 35	CSAH 35 from CSAH 1. 2 miles. Project Sta 0 +00 to 85 +00 SAP 39-635-08	1995-96	...	...	...	soil factor 130	...	Type V fabric (sewn)	...	CL5	8-in.	HMA 2331	4.25-in.	...	...	
Lake of the Woods Cnty	CSAH 1	CSAH 1 to TH 72. 3.98 miles. Project Sta 0 +00 to 210 +00. SAP 39-601-18 & 20	1994-95	...	...	...	soil factor 130	...	Type V fabric (sewn)	Select Granular	CL5	6-in.	HMA 2332	4-in.	...	...	
Mn/DOT NW District Graig Gilbertson; graig.gilbertson@dot.state.mn.us	T.H. 72	RP42.45 to RP42.70	1997 ??	...	...	...	...	...	Biaxial Geogrid	Select Granular	CL5	150 mm	HMA type 31 base	40 mm base	7.30.02	South of the sections the CL has longitudinal crack. T.C. 250 - 300-ft. intervals. NOTE: That from RP45 - RP46 T.C.
Mn/DOT NW District Graig Gilbertson; graig.gilbertson@dot.state.mn.us	T.H. 72	RP42.40 to RP 42.95	1997 ??	...	...	...	...	...	Type VI fabric	Select Granular	CL5	150 mm	HMA type 31 base	40 mm base	7.30.02	Essentially no longitudinal crack. T.C. at 300-ft. intervals.
Mn/DOT NW District Graig Gilbertson; graig.gilbertson@dot.state.mn.us	T.H. 72	RP42.95 to RP43.20	1997 ??	...	...	...	...	...	Geocell (filled with granular)	Select Granular	CL5	150 mm	HMA type 31 base	40 mm base	7.30.02	A few T.C. at 200-ft. intervals.
Mn/DOT NW District Graig Gilbertson; graig.gilbertson@dot.state.mn.us	T.H. 72	RP43.45	1997 ??	...	...	...	...	...	Type V fabric	na	CL5	465 mm	HMA type 31 base	40 mm base	7.30.02	Very little longitudinal cracking. T.C. at 200-ft. intervals.
Mn/DOT NW District Graig Gilbertson; graig.gilbertson@dot.state.mn.us	T.H. 11	S.P. 3901-37 W of Baudette? W of School?	1996	...	...	...	...	...	Biaxial Geogrid above 50 mm C16 base and previous in-place (old bituminous and base approx 600 mm)	C16	CL6	100 mm	HMA type 41 wear leveling type 31 base	50 mm each	...	...	

SUBGRADE ENHANCEMENT INSTALLATIONS - III A (SEPARATION)																	
Agency	Roadway	Limits	Year Bt	Traffic		Existing Soil Conditions		Field Moisture Conditions	Enhancement	Subbase		Base		Surface		EVALUATION	
				AADT	HCAADT	ESAL's	Class			R-Value	Mt.	Type	Thick.	Type	Thick.	Type	Thick.	Date	Condition(s)
Polk Cnty	County 59	6.5 miles (1)	1997	---	---	---	---	swamp	Tensor BX100 below base	---	aggregate	6-in.	HMA P658-28	3-in.	7.29.02	8-9 ton rating	
Polk Cnty	County 59	(2)	1997	---	---	---	---	swamp	Type V fabric below base	---	CL-5, 6-12% pass # 200	6-in.	HMA P658-28	3-in.	7.29.02	10 cracks. 3 curves. Cracks occur at curves. 15 transverse cracks.	
Polk Cnty	County 59	(3)	1997	---	---	---	---	swamp	?	---	aggregate	6-in.	HMA P658-28	4-in. (3 plus 1 in. 02)	7.29.02	8 ton rating. Push and shove.	
Scott Cnty	County 64	New Prague: MN 13/19 E to 13 N to County 64 (240th St) E. Project from 1/4 corner of sec. 9, T112N, R22W to 230th St. E (bridge 97555 approx). 5.5 miles NE of city of New Prague.	1993	---	5.90%	---	12	wet soil (swamp)	Type VI woven below double layer of geogrid all placed below 1-ft. select material and below triple banner culvert.	select material	0/5	6-in.	HMA type 41 wear binder type 31 base	2-in. each		Some settlement reported.	
Scott Cnty	CSAH 2 (old County 54)	New Prague: MN 19 E to CSAH 11 N to CSAH 2. Enhancement from County 2 (1 mile W) to Naylor Ave. (0.5 mile E).	1985	---	less than 150	---	soil factor 100	---	geotextile construction fabric overlapped	granular borrow	0/5	9-in.	HMA surface spec 2341 binder spec 2331	1.5-in. each	---	---	
Scott Cnty	CSAH 2	New Prague: MN 19 E to MN 13 N to CSAH 2. Project approx 0.25 mile E of 13 ending at Freeborn Ave.	1985	---	---	---	---	---	geotextile construction fabric sewn	---	---	---	---	---	---	---	
Scott Cnty	CSAH 78	Shakopee: US 169 W to 78 E. Project fabric portion from intersection county 79 to a point E approx 2,000 ft.	1993	---	5.90%	---	25	---	Type V fabric. Sewn.	granular	0/5	6-in.	HMA type 41 wear binder type 31 base	2-in. each	---	---	
Scott Cnty	County 87	Prior Lake: CSAH 21 SE to County 87. Project from CSAH 21 to County 88.	1998	---	5.90%	---	20	swamp	Type V fabric. Woven	granular borrow	0/5	5-in.	HMA spec 2331 type 41 wear type 31 base	1.5-in. wear 2.5-in. base	---	---	
Scott Cnty	County 62	SE St to Elkton/New Market. CSAH 2 W to CSAH 91 N 2 miles to County 62 W. Project from CSAH 91 to County 87.	2002	---	5.90%	---	14	---	Type VI fabric. Woven	select material	0/5	8-in.	HMA spec 2331 type 41 wear type 31 base	1.5-in. wear 2.5-in. base		clay fill (10-15 ft)	

SUBGRADE ENHANCEMENT INSTALLATIONS - III A (SEPARATION)																		
Agency	Roadway	Limits	Year Bit	Traffic			Existing Soil Conditions		Field Moisture Conditions	Enhancement	Subbase		Base		Surface		EVALUATION	
				AAADT	HCAAADT	ESAL's	Class	R-Value			Mt.	Type	Thick.	Type	Thick.	Type	Thick.	Date	Conditions(s)
Wright Crty	CSAH 111	Monticello, CSAH 35W to CSAH 111N. Project runs N 0.5 mile from 127th St.	1980	...	...	...	...	...	500 M????	Fill	2-ft.	...	...	...	...	...	...	some seams burst (not strong enough)
Wright Crty	CSAH 14	Delano: US 12W to CSAH 14. North approx. 1.4 miles to the Crow River.	1999-2000	...	...	peat, 40 ft on North approach	...	...	Type V fabric	...	...	...	...	...	...	na	na	still settling (2002)
Wright Crty	CSAH 34	Hanover: Project from junction with CSAH 19 to approx. 0.5 miles west.	1992, overlay 99	...	...	...	...	...	...	...	...	...	...	...	...	na	na	overlay in 99 but starting to settle again
Wright Crty	CSAH 20	Hanover: From Jct. CSAH's 19 and 20 0.5 to 1 mile. Begin project at S bank of lake.	1995, paved 97	...	...	...	...	...	Type VI fabric. Was also sucharged.	...	...	...	...	...	...	...	...	...
Wright Crty	CSAH 9	Buffalo: CSAH 35W to CSAH 9W. Project approx. 0.3 miles NW of Dempsey CSAH 109.	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Wright Crty	CSAH 5	Annandale: 0.5 mile length along west shore of Pleasant Lake.	1985	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Wright Crty	Hwy 1805	Possible. Monticello: CSAH 18 (Jason Avenue) SE from CSAH 75. Projec. approx 0.25 mile E of School Blvd intersection. Length approx .25 mile.	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Wright Crty	Hwy 1807	Monticello: CSAH 18 (Jason Avenue) SE from CSAH 75. Projec. approx 2.5 mile E of School Blvd intersection. Length approx .25 mile.	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Wright Crty	County 124 (or CSAH 9)	Buffalo: CSAH 35W to Twin Lakes (approx. 2 miles from CSAH 12)??	...	...	...	...	...	...	Grid between lakes.	...	...	...	...	...	...	na	na	failure

Reinforcement Installations

SUBGRADE ENHANCEMENT INSTALLATIONS - III B (REINFORCEMENT, GEORGRIDS)																
Agency	Roadway	Limits	Year Bt	Traffic		Existing Soil Conditions		Field Moisture Conditions	Enhancement	Subbase		Base		EVALUATION Condition(s)		
				AAOT	HCA/ADT	ESAL's	Class			R-Value	M	Type	Thick.		Type	Thick.	Date
Albert Lea City	Plaza Street	S. of Holiday Ave. to 140th and sewer. 140 ft. long.	2000	...	...	...	silty	...	Geogrid	...	CL5 above CL3	Approx. 6 and 10-in.	HMA 2340 mix	4-in.	8.19.02	Small short crack.
Albert Lea City	Mangatha Ave.	8th to S. of 10th Street.	1997	910	...	...	peat	...	Type V fabric with edge drains.	2 - 3-ft. gravel borrow	CL5 above CL3	Approx. 6 and 10-in.	HMA 2340 mix	4-in.	8.19.02	Unrepaired for 2.5 blocks.
Cleanwater City	...	SAP 15-637-02	2001	...	...	...	...	swamp	EX 1200 or UX 1600 geogrid	6-in. granular fill	CL5	initially plus 6-in. blacktop	HMA	3.5-in.		
Chancellor City	...	...	2001	...	...	...	...	swamp	Muck excavation	granular fill	CL5	initially plus 6-in. blacktop	HMA	3.5-in.		
Hubbard City	CSAH 3	Lake George, US N of Jct County 95 CSAH 3N. 2 sections of approx. 1 mile.	1996	...	...	...	on existing subgrade	swamp within 6 - 7-in.	Tensar geogrid	old CI5 base	CL5	6-in.	HMA	3-in.	7.31.02	Southern mile, 1 tensile crack at culvert. 4 Tensile cracks/mile.
Hubbard City	CSAH 3	Lake George, US N of Jct County 95 CSAH 3N. 2 sections of approx. 1 mile.	1996	...	...	...	on existing subgrade	swamp within 6 - 7-in.	Tensar geogrid	old CI5 base	CL5	6-in.	HMA	3-in.	7.31.02	Northern mile, 3 - 4 tensile cracks.
Hubbard City	CSAH 6	Hubbard, CSAH 6 S of 0+00 Sta 0+479 assumed to be at junction with CSAH 47.	2000	872 present, 1396 projected for 2020	Projected less than 150	...	...	...	saw and seal without aggregate enhancement	Aggregate base spec. 3138, CI5 Mod (includes reclaimed material)	Bituminous Base Spec 2331	50-mm.	Bituminous Base Spec 2331	40-mm.	7.31.02	No cracks. Well sealed.
Hubbard City	CSAH 6	Hubbard, CSAH 6 S of 0+00 Sta 0+675 assumed to be at junction with CSAH 47.	2000	872 present, 1396 projected for 2020	Projected less than 150	...	...	...	Fiber mat 9.5 m wide	Aggregate base spec. 3138, CI5 Mod (includes reclaimed material)	Bituminous Base Spec 2331	50-mm.	Bituminous Base Spec 2331	40-mm.	7.31.02	No cracks.
Hubbard City	CSAH 6	Hubbard, CSAH 6 S of 0+00 Sta 0+325 assumed to be at junction with CSAH 47.	2000	872 present, 1396 projected for 2020	Projected less than 150	...	...	...	Geogrid	Aggregate base spec. 3138, CI5 Mod (includes reclaimed material)	Bituminous Base Spec 2331	50-mm.	Bituminous Base Spec 2331	40-mm.	7.31.02	No cracks.
Hubbard City	CSAH 6	Hubbard, CSAH 6 S of 0+00 Sta 0+362 assumed to be at junction with CSAH 47.	2000	872 present, 1396 projected for 2020	Projected less than 150	...	...	...	Geogrid on reclaimed bituminous	Aggregate base spec. 3138, CI5 Mod (includes reclaimed material)	Bituminous Base Spec 2331	50-mm.	Bituminous Base Spec 2331	40-mm.	7.31.02	No cracks. Some rutting.
McBride, NY District 6; Gilbertson, NY District 6	T.H. 71	S. P. 2065-28 Mile Post 271.95	...	...	...	...	...	swamp	Geogrid for culvert reinforcement	Select Gray borrow	CL5	250 mm	HMA MV 3 nonwear	40 mm wear 80 mm nonwear	...	...
McBride, NY District 6; Gilbertson, NY District 6	T.H. 200	S. P. 1504-09 114+153 to 114+173 to 114+520	...	...	...	...	...	swamp	Blank Geogrid at 150 mm spacing of agg. Base CI5	Select Gray borrow	CL5	300 mm	HMA type 41 base	50 mm wear 150 mm base	...	...

SUBGRADE ENHANCEMENT INSTALLATIONS - III B (REINFORCEMENT, GEORIDS)

Agency	Roadway	Limits	Year Blt	Traffic			Existing Soil Conditions			Field Moisture Conditions	Enhancement	Subbase		Base		Surface		EVALUATION		
				AAADT	HCAADT	ESAL's	Class	R.Value	M _r			Type	Thick.	Type	Thick.	Type	Thick.	Date	Condition(s)	
Polk Cnty	County 5B	4.5 miles	1997	---	---	---	---	---	---	swamp	Tensor BX1100	granular	6-in.	HMA PG58-28	3-in.	7.29.02	11 transverse cracks.			
St. Louis Cnty	CSAH 48	(A) LaVaque Rd. Proctor, S of County 5B, Started St. Louis River Rd to 6th. End of job 5th.	2000	220	---	---	Silty sand w/gravel glacial till	---	---	Hillside with soil lenses weeping water	Type V fabric, Amoco 4553 5oz., nonwoven 230-lb. tensile	C15 over select granular	200 mm 600 mm	2550 HMA	40 mm 40 mm 100 mm	8.20.02	No cracks. Some saw and seal.			
St. Louis Cnty	CSAH 48	(B) LaVaque Rd. N. of CSAH 9(Martin Rd.) to CSAH 35(GSchultz Rd.)	1997/98	3050	---	---	12 ft. to 20 ft. of peat	---	---	Swamp, muck, seasonal and periodic flooding	Tensor BX1200 geogrid, Type V fabric, 75-oz. separation layer maintained between geotextiles.	muck	---	Type 41wear Type 31binder Type 31base	40-mm 40-mm 100-mm	6.27.02	No transverse cracks. One longitudinal crack where close to lake			
St. Louis Cnty	County 688	(C) Proctor, Birk Rd 241, St. Louis; River Rd over RR.	1997	2250	---	---	20 ft. of peat	---	---	Swamp	Type VI fabric, woven, wide width, Tensile str of 200lb/in@5% elongation	granular borrow	Fabric placed 10- ft. down.	C15 over select granular	200 mm 600 mm	Type 41wear Type 31binder Type 31base	40-mm 40-mm 100-mm	8.20.02	Distressed, Distressed cracks, some uneven settlement in roadway.	
St. Louis Cnty	CSAH 31	(D) Brookston; US 2W from Duluth to CSAH 31S (Twin Lakes Rd.) Project is approx. 2.5 miles S. of US 2.	1994	300	---	---	Peat	---	---	wet to dry, high ground to swamp	Tensor BX1200 geogrid. Initially 12- ft. of fill above the grid where grade rises out of the swamp. Failure required repairing with layers of grid.	Grid layers	Grid every 3-ft. (vertical)	C15 over select granular	200 mm 600 mm	HMA	40-mm 40-mm 100-mm	8.20.02	No cracks.	
St. Louis Cnty	CSAH 47	(E) Meads Lake US 53 N from Duluth to CSAH 47 Project located approx. 1.5 miles S. of unpaved CSAH 47.	pre 1996	430	---	---	Peat	---	---	wet to dry, high ground to swamp	Tensor BX1200 geogrid. Initially 10- ft. of fill above the grid where grade rises out of the swamp. Failure required repairing with surcharge fill.	1 layer grid	3 - 4-ft.	C15 over select granular	200-mm 600-mm	HMA	40-mm 40-mm 100-mm	8.20.02	No cracks. West side dropped 6-ft. - 2 - 3-ft. dip.	
St. Louis Cnty	CSAH 5	(F) Tonola, MN 73N from Florewood to CSAH 133E. Project from CSAH 133 to approx. 3.5 miles north.	2001	360	---	---	silt	---	---	Moist to wet silt and clayey silt	Type VI fabric, Amoco 4512 12-oz. Nonwoven.	fill above grid	3 - 4-ft. down from top of pavement.	C15 over select granular	200-mm 900-mm	HMA 2350 mix	40-mm 40-mm 100-mm	8.20.02	A few tensile cracks	
St. Louis Cnty	CSAH 5	(G) Length = 200- ft. Tonola Approx. 1 mile S. on CSAH 5		360	---	---	silt	---	---	---	Tensor BX1100 and BX1200, drainage at bottom. (slide repair)	5.2-ft. lifts of fill and grid	12-ft.	---	---	aggregate surface	---	---	---	BX1200 used for bottom 3 lifts.

Substitution Installations

SUBGRADE ENHANCEMENT INSTALLATIONS IV-A. SUBSTITUTION (SELECT GRANULAR or BREAKER RUN LS)																
Agency	Roadway	Limits	Year Bt	Traffic			Existing Soil		Field Moisture Conditions	Enhancement	Subbase		EVALUATION			
				HCAADT	ESAL's	Class	R-Value	Mt.			Type	Thick.		Date	Condition(s)	
Dodge Cnty	County 25	---	2002	---	---	---	---	---	moist to wet	Breaker Run Limestone over Type V nonwoven fabric	Breaker run Limestone BLS 6-in. CL5	CL5 modified to be 100% crushed	HMA 2350 wear HMA 2350 nonwear	2-in. 2.5-in.	---	---

SUBGRADE ENHANCEMENT INSTALLATIONS - IV B (SUBSTITUTION)																
Agency	Roadway	Limits	Year Bt	Traffic			Existing Soil Conditions		Field Moisture Conditions	Enhancement	Subbase		Surface		EVALUATION	
				HCAADT	ESAL's	Class	R-Value	Mt.			Type	Thick.	Type	Thick.		Date	Condition(s)
Cleanwater Cty	CSAH 40	Shedlin, US 2 E to CSAH 2 S 13 mi to CSAH 40 E	1983	---	---	peat	---	swamp	geofabric+wood chips	---	CL5	7-in.	HMA Overlay 1999	3.5-in. 3-in.	7.29.02	2 ft. settlement in 15 yrs
Cleanwater Cty	CSAH 30	Bagley, US 2 E to CSAH 30 S.	2002	---	---	peat	---	swamp	muck excavation	future	CL5 CL5	6-in. 6-in.	HMA	3.5-in	---	Removed peat and backfilled with granular material. Type 1100 geogrid under class 5.
Cleanwater Cty	CSAH 28	S. Bagley	1985. Redone in 2001	---	---	---	---	swamp	Originally geofabric and wood chips. Rebuilt with geogrid and grader fill to grade.	---	CL5	6-in.	HMA	3.5-in.	---	Left fabric & wood chips but placed geogrid above subgrade to help differential settling. 2 ft. settlement in 15 years.
Millie Lacs Cnty	County 25	---	---	---	---	---	---	High and dry at placement of sawdust.	Sawdust, enclosed in plastic to enable later addition of CO ₂	soil fill above sawdust	---	---	---	---	---	---
Mn/DOT NW District Graig Gilbertson; graig.gilbertson@dot.state.mn.us	T.H. 1	STA 205+00 to 207+00, 209+00 to 213+00m S. P. 3602-24 Northome BIKE PATH	---	---	---	---	---	---	geofabric (type Y) above wood chips	granular material above chips	15-in. gran 6-in. chips	CL5	HMA MV 3 wear	3-in. (2 lifts)	---	---
Waseca City	CSAH 2	Waseca: US 14 W to CSAH 2 W. Project runs to approx. 4 mi west of intersection	approx 2000	---	---	peat	---	dry, bottom of vertical curve but chips above water	geofabric+wood chips	chips	10 - 13-ft.	CL5	PCC	8-in.	---	---

SUBGRADE ENHANCEMENT INSTALLATIONS - IV C (SUBSTITUTION) SHREDDED TIRES																		
Agency	Roadway	Limits	Year Bld	Traffic			Existing Soil Conditions		Field Moisture Conditions	Enhancement	Subbase		Base		Surface		EVALUATION	
				AADT	HCAADT	ESAL's	Class	R-Value			M _t	Type	Thick.	Type	Thick.	Type	Thick.	Date	Condition(s)
Carlton Cnty	CSAH 13	E of Moose Lake on County 137E to CSAH 13E. Project begins at intersection	2001-02	50(1998)	---	CL - ML	---	moist, low lying	Shredded Tires capped with Type V geofabric to correct vertical alignment 7 - 18-ft.	Tire shreds	Max. 10-ft. thickness. 2-ft. fill between tire lifts.	granular fill.	2-ft	Class 5 aggregate	6-in.	7.27.02	under construction	
Carlton Cnty	CSAH 12	Kettle River. CSAH 12E approx. 2 miles.	2001	410 (1998)	---	SM - ML	---	moist, low lying	Shredded Tires capped with geofabric, subgrade drainage	Tire shreds	3-ft.	granular fill.	1.5-ft pit run and 6-in. CI 5	HMA after 3+ months	3.5-in.	7.27.02	Uncracked	
Carlton Cnty	Barnum Township	Barnum. CSAH 13S 1.5 miles. Aggregate Surface East 0.25 mile to Agg Surf NE. Approx. 0.5 mile to Agg Surf W.	1999-2000	---	---	CL - ML	---	---	Shredded Tires capped with geofabric	Tire shreds	2-ft. to 12-ft.	granular fill.	1.5-ft.	CI 5	4-in.	---	---	
Carlton Cnty	CSAH 11	CSAH 11 N of CSAH 10. 800-ft. grade correction having 500-ft. subgrade correction.	1996	60 (1998)	---	CL - ML	---	---	Shredded Tires capped with geofabric	Tire shreds	14-ft. max depth	granular fill.	18-in.	CI 5	6-in.	---	---	
Mille Lacs Cnty	US 65	---	---	---	---	---	---	moist, low lying	Shredded Tires capped with geofabric	2-ft. of dirt fill over tires	---	---	---	Asphalt	---	---	---	
Mille Lacs Cnty	CSAH 11	---	---	---	---	---	---	moist, low lying	Shredded Tires capped with geofabric	2-ft. of dirt fill over tires	---	---	---	Asphalt	---	---	---	
Mille Lacs Cnty	CSAH 4	---	---	---	---	---	---	moist, low lying	Shredded Tires capped with geofabric	2-ft. of dirt fill over tires	---	---	---	Asphalt	---	---	---	
Mn/DOT NW District Graig Gilbertson; graig.gilbertson@dot.state.mn.us	T. H. 2	EBL = STA 1329+0.10 to 1335+00	---	---	---	---	---	swamp	Tires and Type V geotextile used below shoulder portions of embankment. Fabric on outside and top face of fill.	---	select granular borppw	12-in. min.	HMA type 41 wear type 41 binder type 31 base	1.5-in. wear 2.5-in. binder 7-in. base	---	---	---	

APPENDIX E

PHOTOS

Photographs of subgrade enhancement construction practices are available in digital format. The photographs include projects with varying degrees of success or failure. Topics included are:

- Breaker Run
- Foam
- Geofabric
- Geogrid
- Shredded Tires
- Wood Chips