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Stabilization Selection Guide for Aggregate- and Native-Surfaced Low Volume Roads

Cover photo: Alan Anderson, Black Hills National Forest

Stabilization Selection Guide for Aggregate- and Native-Surfaced Low-Volume Roads

Maureen A. Kestler, Civil Engineer, Forest Service,
San Dimas Technology & Development Center

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CHAPTER ONE

Overview

INTRODUCTION

Soil stabilizers can be used to treat the upper several inches of soil or aggregate surfaces of low-volume roads (LVRs) when the strength or other properties of the in-place soil do not meet the desired or required levels for anticipated traffic. Soil can be either modified or stabilized by many methods, including chemical, mechanical, thermal, and electrical (Danyluk 1986; Martel et al. unpublished). Modification is generally short term and includes benefits such as improvement in workability (expediting construction and saving time and money). Stabilization generally results in a longer term strength gain.

- Chemical stabilization is achieved by mixing chemicals, such as cement, lime, fly ash, bitumen, or combinations of these materials, with soil to form a stronger composite material. Selection of the type and percentage of additive is a function of the soil classification and the degree of improvement desired. Chemicals and/or emulsions can be used as:
  - Compaction aids to soils.
  - Binders and water repellents.
  - A means of modifying the behavior of clay to form a stronger composite material.

  Chemical stabilization can aid in:
  - Dust control.
  - Water-erosion control.
  - Fixation and leaching control of both waste and recycled materials (Das 2000).
- Mechanical modification/stabilization involves mixing (two or more soils to obtain a material of desired specification), draining, and/or compacting soil. Alternately, fibrous or other nonbiodegradable reinforcing materials, such as geosynthetics/geocomposites/fibers, can be mixed in or physically placed with the geomaterial to improve strength.
- Thermal stabilization involves heating or freezing soil.
  - Heating the soil to 600 °C can irreversibly dehydrate or fuse soil particles.
  - Freezing can strengthen the soil by solidifying water content.
- Electrical stabilization involves applying a direct electrical current to the soil. This causes water to migrate out of the soil to an electrode.

This guide focuses on chemical and mechanical methods. Definitions used in conjunction with stabilization are provided in appendix A.

PURPOSE

The purpose of this guide is to facilitate the selection of modification/stabilization agents and techniques for aggregate-surfaced and native/unsurfaced LVRs. The objective is to provide low-cost alternatives that reduce aggregate wear and loss, reduce road-surface maintenance (i.e., blading out ruts), and reduce the time period between major rehabilitation (i.e., between adding new aggregate or the total reconditioning of the road pavement).

This guide provides information on available stabilizing agents, appropriate conditions for use, selection procedures, quantity determination, and contact information for manufacturers/suppliers. Emphasis is on the modification/stabilization of existing in-place road surface materials, but many of the methods can be used in the construction of new roads. Construction procedures for application are also presented.

The intended audience includes road managers, engineers, and technicians involved in road maintenance, construction, and reconstruction. Those involved in trail maintenance and construction also may find the guide beneficial, as stabilizers used on trails, particularly accessible trails, help provide a smooth, durable surface. Information on the use of synthetics for trails can be found in the Forest Service, U.S. Department of Agriculture, publication “Geosynthetics for Trails in Wet Areas” by Groenier (2008). Information on accessible trails is provided in another Forest Service publication, “Soil Stabilizers on Universally Accessible Trails” (Bergmann 2000).

SCOPE OF GUIDE

This guide focuses primarily on chemical and mechanical methods. It serves as an updated sequel to two reports prepared in the 1990s, “Non-Standard Stabilizers” (Scholen 1992) and “Stabilization with Standard and Nonstandard Stabilizers” (Bolander 1995), and incorporates applicable tables from the “Surfacing Selection Guide” recently developed by the U.S. Department of Transportation, Federal Highway Administration (FHWA), Central Lands Federal Highway Division (FHWA 2005), and tables from the Transportation Research Board (TRB) (Petry and Sobhan 2005). The guide also incorporates procedures from the U.S. Army Corps of Engineers (USACE), and reflects discussions with engineers and contractors, manufacturers and suppliers, and individuals from other agencies with stabilization expertise.

Traditional and Nontraditional Modification/Stabilizer Agents

Traditional Chemical Stabilizers

Traditional chemical techniques include:

- Cement (generally used as a base-course treatment and not as a surface treatment, but included because it is one of the standard "traditional" stabilizers).
- Lime.
- Fly ash.
- Bituminous materials.
- Combinations of the above.

Two procedures for selecting types and quantities of these products are provided.

Nontraditional Stabilizers

Nontraditional stabilizers are typically grouped into seven categories:

- Chlorides (chlorides, salts, calcium chloride, magnesium chloride, sodium chloride).
- Clay additives (clay additives, clay, filler, bentonite, montmorillonite).
- Electrolyte emulsions (electrolyte stabilizers, ionic stabilizers, electrochemical stabilizers, acids).
- Enzymatic emulsions (enzymatic emulsions, enzymes).
- Lignosulfonates (lignosulfonates, lignin, lignin sulfate, lignin sulfides).
- Synthetic-polymer emulsions (synthetic-polymer emulsions, polyvinyl acetate, vinyl acrylic).
- Tree-resin emulsions (tree-resin emulsions, tall-oil emulsions, pine-tar emulsions).

Although the guide does not provide a comparable step-by-step procedure for selecting nontraditional stabilizers, general information tables are provided to help select a nontraditional stabilizer.

Mechanical Stabilizers

The guide also includes information on mechanical modification/stabilizing methods. These range from more conventional compaction and geosynthetics to less conventional woodchips and mats.

CHAPTER ONE

Other Categories

Many categories are included under the topic of stabilization. However, because of the broadness of the following three categories, the reader will be referred to other specialty guides and design programs for guidance and further details.

Dust Palliatives

This guide includes chemicals that serve as both dust suppressants and stabilizers, but does not discuss chemicals that are used exclusively for dust control. Although dust control is a side benefit of many of the stabilization techniques described, if one's primary objective is to control dust, the reader is referred to "Dust Palliative Selection and Application Guide" (Bolander and Yamada 1999), "Chemical Additives for Dust Control, What We Have Used and What We Have Learned" (Bolander 1997), and "Best Practices for Dust Control on Aggregate Roads" (Johnson and Olson 2009). Additional information is available on the USACE Web site, https://transportation.wes.army.mil/triservice/fileslist.aspx?GroupId=2 (U.S. Army Corps of Engineers), which provides a comprehensive list of manuals, videos, reports, photos, and PowerPoint presentations on various aspects of dust control including:

- Chemical Dust Abatement for Desert Roads.
- Chemical Dust Abatement for Roads in Temperate Climate.
- Dust Abatement Equipment.

Additional publications on dust palliatives are available from the 2008 Road Dust Management Practices and Future Needs Conference in San Antonio, Texas, November 2008, http://www.meetingsnorthwest.com/DustConference.htm

Stabilizers for Paved Roads

Although stabilization can be used to improve foundation layers supporting a paved road—thereby reducing the required structural thickness—the design of a stabilized subgrade or base layers in conjunction with a paved surface is beyond the scope of this report. Numerous publications and pavement-design programs provide guidance on selection and design of stabilized layers for paved roads (Department of the Army 1994; FHWA 2005).

For bituminous surface treatments, there is a vast list of publications and guides by Local Technical Assistance Programs (LTAPs) or Technology Transfer (T^2) Centers, State Departments of Transportation, such as the "Minnesota Sealcoat Handbook" (Wood 2006), and the military. Additional publications include those by FHWA (2005), Yamada (1999), Bolander et al. (1999), and Niezgoda et al. (2000).

Deep Mixing and Grouting

Chemical stabilization also includes deep mixing and grouting. They are not covered in this guide; the reader is referred to outside references. (ASCE 2004; Bushman et al. 2004; Karol 2003; Warner 2004).

GENERAL INFORMATION AND BACKGROUND

Much published literature on stabilization techniques for unpaved road surfacing is currently available. However, most publications are on specific methods—such as lime stabilization—or specific aspects of geosynthetics. Some general guides do exist, but even they are generally limited to selecting and designing for a traditional chemical treatment, or designing for a geosynthetic installation. One must generally have a slight idea of what type of stabilization task he or she wishes to pursue, then select and design from that starting point.

A large-scale project to develop a decision tool for selecting the most cost-effective solution for a given site (road) and operating conditions (type of traffic, intensity, season of use, etc.) is ongoing at the time this guide is being written. The Web site http://carrlo.fsg.ulaval.ca/ is currently in French, but numerous publications in English are scheduled over the 5-year duration of the program and will be referenced on the Web site. A summary of the evaluation program (Legere 2007) follows:

> "Various studies have been conducted to understand the general behavior and improve the performance of unpaved roads. However, most of the research conducted is only applicable in specific working conditions. After consultation with many unpaved road managers, designers, and several key players in this area, a consensus was made on the need to develop a guide of adapted and economic solutions for the construction, rehabilitation and management techniques for unpaved roads. This will take into consideration all of the characteristics of a given project in order to keep unpaved road surfaces performing, safe and smooth. It is in that perspective that Université Laval in Quebec city, Canada, with financial support from the Natural Sciences and Engineering Research Council of Canada, as well as a group of several partners from different interests such as FPInnovations – FERIC division, Ciment Saint-Laurent, Bitume-Québec, Junex, Les Entreprises Bourget, the Ministère des transports du Québec, and the Société de développement de la Baie-James, has undertaken in 2005 a major research project to

> fulfill the needs in this field. The research project is identified as the CARRLo project, which stands for Chemins d'Accès aux Ressources et Routes Locales. To date, most testing has been conducted in the laboratory, but field tests are next scheduled, much of which includes test equipment as shown in figure 1.1."

Those seeking guidance for selecting stabilizers for surfacing unpaved roads are encouraged to seek publications from this effort as the program progresses, as well as other references cited throughout this guide.

Figure 1.1—CARRLo test program simulator (Glen Legere).

HOW TO USE THIS GUIDE

After a general introduction to stabilization in chapter 1, chapter 2 provides a discussion on traditional and nontraditional stabilizers. Corresponding appendixes show the procedure for selection and determination of traditional stabilizers, and include tables with general information on nontraditional chemical additives. The tables provide specific products, suppliers, and contact information.

Chapter 3 and corresponding appendixes cover mechanical stabilization. Several techniques are discussed, and design procedures, information tables, and decision tables are provided.

Chapter 4 and the corresponding appendixes discuss construction hints. Construction topics, such as materials, equipment, placement processes, and weather restrictions, are included.

CHAPTER TWO
Chemical Stabilization

SELECTING A TRADITIONAL CHEMICAL ADDITIVE

Consider these factors when selecting a chemical stabilizer:

- Type of soil to be stabilized.
- Purpose of the stabilized layer.
- Type of soil improvement desired (modification or stabilization/improvement of strength characteristics).
- Required strength and durability of the stabilized layer.
- Cost.
- Environmental conditions.

Traditional chemical stabilizers include:

- Cement.
- Lime.
- Fly ash.
- Bituminous materials.
- Combinations of the above.

Selection Process

Two procedures for selecting a traditional stabilizer are provided by table 2.1.

Both methods require soil testing. The first method requires a gradation and Atterberg limit test; the second method requires some additional testing as noted in the procedure. General information on each stabilizer follows table 2.1.

Follow the USACE procedure to optimize the type and quantity of stabilizer required to achieve the desired characteristic and to minimize cost. The reason to do this is because there is generally more than one stabilizer applicable for any one soil type. However, based on features, such as soil granularity, plasticity, or texture, some stabilizers are more applicable to certain soils than others (Army 1994). The USACE procedure enables optimal selection of the right stabilizer for the particular soil, and optimizes the cost by determining the minimal quantity of stabilizer required to achieve the desired strength. The USACE procedure also provides quantities for modification. The simplified procedure is significantly easier; it just requires looking at tables for the known gradations and Atterberg limits. However, the quantities for modification will still require looking at tables for the USACE procedure.

Table 2.1—Two procedures for selecting a traditional chemical stabilizing agent.

1. Simplified Procedure or	2. Simplified USACE Procedure
Step 1—Determine the type of material present (classify soil and/or aggregate). Conduct a grain size distribution and Atterberg limits tests (select either the ASTM or the AASHTO test from appendix table D.1).	**Step 1—**Determine the type of material present (classify soil and/or aggregate). Conduct a grain size distribution and Atterberg limits tests (select either the ASTM or the AASHTO test from appendix table D.1). Further testing may be required as directed by the table.
Step 2—Determine the objective (stabilization or modification). If modification, it is recommended to use method 2, or at least look at the USACE tables of method 2.	**Step 2—**Determine the objective (stabilization or modification). If modification is required, continue with this procedure as modification quantities are provided.
Step 3—Select a stabilizing agent: Several candidate stabilizers can be selected using various combinations of appendix figure B.1 and appendix tables B.1 through B.4. The candidate stabilizers can be narrowed down to one by using multiple tables, including information pertaining to each stabilizer in table B.4. Or one could use figure C.1 with table C.1.	**Step 3—**Select a stabilizing agent: appendix figure C.1 (a soil-gradation triangle) and appendix table C.1 are used, in combination, to determine candidate stabilizers. Accompanying instructions are provided immediately above figure C.1. Added general information on each traditional stabilizer follows this table.
Step 4—Determine the amount required using recommendations in appendix table B.3 or B.4 and by checking with local suppliers or manufacturers.	**Step 4—**Determine the amount using the procedure in appendix tables C.2 (a-f). These are separate tables that provide instructions for each chemical stabilizer.
Step 5—Select one or two alternatives for further evaluation.	**Step 5—**Select one or two alternatives for further evaluation (using the simplified or USACE method).
Step 6—Determine the expected costs of the various alternatives and determine if cost effective; appendix table B.4 may provide a rough idea, however, calling local suppliers and using local labor estimates is recommended for final selection.	**Step 6—**Determine the expected costs of the various alternatives and determine if cost effective; appendix table B.4 may provide a rough idea, however, calling local suppliers and using local labor estimates is recommended.

Traditional Chemical Stabilizing Agents

Portland Cement (Note: Do not use a cement-stabilized material for surfacing)

Adding cement to soil increases soil strength, decreases compressibility, reduces swell potential, and increases durability. It is similar to lime, but has pozzolanic materials that cause rapid hardening, resulting in a solid, bound, impermeable layer. Cement-stabilized soils are typically ***used as a stabilized subgrade or road base (figure 2.1), but not as surfacing*** (except possibly for low-speed roads and parking lots) primarily because the material becomes brittle and cracks under traffic loading. Shrinkage cracks in the surface can be avoided if unconfined strengths are kept below 700 pounds per square inch. Curing of a soil-cement mixture is essential (the surface must be kept wet for the first 7 days of curing), at a minimum, by either periodically applying water or by sealing the surface with a fog seal or similar seal.

Fine-grained soils can be stabilized with cement, and sandy soils are readily stabilized with cement; but the major application of soil cement is in bases and subbases of secondary roads. ***Cement should not be used for soils with high organic content or soils that contain sulfates. Extreme caution must be exercised if used in areas subject to seasonal freezing.***

Soils can be stabilized by several types of cement: Type I (normal), Type Ia (air entraining), Type II (greater sulfate resistance for a similar price to Types I and Ia), and Type III (high early strength, with a finer particle size and different chemical composition). Types I or II are more typically used for stabilizing, with Type II perhaps being used the most. Chemical- and physical-property specifications for Portland cement are available in ASTM C 150.

Information on testing and determining quantities using the USACE method is available in appendix table C.2a. Additional details on construction, safety, environmental concerns, cost, etc. are provided in respective sections of appendix table B.4 (FHWA 2005).

Section 6.3 of the FHWA Web site http://www.cflhd.gov/techDevelopment/completed_projects/pavement/context-roadway-surfacing/#supplement (FHWA 1995), provides additional photos.

2.1a—Cement application.

2.1b—Water truck (Charles Miller, Porter, Maine).

Figure 2.1c—Compacting (Charles Miller, Porter, Maine).

Figure 2.1—Cement, a traditional stabilizing agent. Generally, cement is used for the base and not the surface.

Lime (Lime stabilized soil is rarely used as a surfacing material)

Adding lime to soil generally decreases soil density, decreases plasticity, improves workability, and reduces volume-change characteristics. It may or may not improve strength characteristics. Strength characteristics depend on the soil type. It is used primarily to treat fine-grained soils.

Common forms of lime include hydrated high-calcium lime, monohydrated dolomitic lime, calcitic quicklime, and dolomitic quicklime. The design criteria presented here are for hydrated quicklime, the most commonly used form of lime. Design quicklime quantities would be 75 percent of design hydrated lime quantities.

In contrast to Portland cement, lime cementation takes place slowly. ***Like cement, a surface coat of a different material is typically applied because of the poor resistance to abrasive action of continued traffic.*** However, if there is no surfacing, periodic blading does remove deformations without adversely affecting the lime-soil reaction.

Information on testing and determining quantities using the USACE method is available in appendix table C.2b. Additional details on construction, safety, environmental concerns, cost, etc. are provided in respective sections of appendix table B.4 (FHWA 2005).

Photos showing lime being used as a stabilizing agent are available in section 6.2 of the FHWA Web site http://www.cflhd.gov/techDevelopment/completed_projects/pavement/context-roadway-surfacing/#supplement (FHWA 1995).

Lime Fly Ash and Lime-Cement Fly Ash (Note: Do not use a cement-stabilized material for surfacing)

Coarse-grained soils with little to no fines can be stabilized using lime fly ash or lime-cement fly ash. Like cement, fly ash is typically used to stabilize the subbase or subgrade, and should not be used for surfacing materials. Fly ash (or coal ash) is a mineral residue from the combustion of pulverized coal, and is transported from the boilers by flue gases. When fly ash is mixed with lime and water, a cemented mass capable of withstanding high compressive stresses is formed.

Fly ash requires good mixing, compaction immediately after mixing, and proper water for curing.

Information on testing and determining quantities using the USACE method is available in appendix table C.2c.

A photo showing fly ash being used as a stabilizing agent is available in section 6.1 of the FHWA Web site http://www.cflhd.gov/techDevelopment/completed_projects/pavement/context-roadway-surfacing/#supplement (FHWA 1995).

Bitumen/Asphalt

Stabilization using asphalt differs significantly from stabilization using lime or cement. The primary mechanisms for cohesive and noncohesive materials are (1) waterproofing and (2) waterproofing and adhesion, respectively. Fine-grained materials are coated with asphalt, thereby slowing down the penetration of water, which would otherwise lead to reduced strength. Coarse-grained materials are similarly coated/waterproofed, but the particles also adhere to the asphalt, and the asphalt acts as a binder.

In contrast to lime and cement, freeze-thaw and wet-dry durability tests are not applicable for asphalt-stabilized mixtures.

Types of bituminous-stabilized soils include sand bitumen, gravel or crushed-aggregate bitumen, and bitumen lime (lime is added to the soil-bitumen mix when the soil's plasticity index is higher than 10).

Information on testing and determining quantities using the USACE method is available in appendix table C.2d.

Photos showing bituminous surface treatments are available in chapter 1 of the FHWA Web site http://www.cflhd.gov/techDevelopment/completed_projects/pavement/context-roadway-surfacing/#supplement (FHWA 1995).

Lime-Cement and Lime-Bitumen

Stabilizers can be used in combination to enable one stabilizer to compensate for the lack of effectiveness of another in treating a particular characteristic of a soil. For instance, Portland cement or asphalt cannot be mixed with plastic clays. However, adding lime makes the soil friable, in turn enabling the cement or asphalt to be mixed readily.

Information on testing and determining quantities using the USACE method is available in appendix table C.2e.

SELECTING A NONTRADITIONAL ADDITIVE

Introduction

The market is becoming increasingly populated by alternative nontraditional stabilization products, such as concentrated liquid stabilizers and waste byproducts. This is because of the potentially lengthy cure times and the large quantities of additive required for the desired strength gain for most traditional chemical stabilizing agents, as well as adverse chemical reactions for a few traditional chemical stabilizing agents (in sulfate-bearing soils for cement, lime, and fly ash).

Nontraditional stabilizers are typically grouped into seven categories:

- Chlorides (chlorides, salts, calcium chloride, magnesium chloride, sodium chloride).
- Clay additives (clay additives, clay, filler, bentonite, montmorillonite).
- Electrolyte emulsions (electrolyte stabilizers, ionic stabilizers, electrochemical stabilizers, acids).
- Enzymatic emulsions (enzymatic emulsions, enzymes).
- Lignosulfonates (lignosulfonates, lignin, lignin sulfate, lignin sulfides).
- Synthetic-polymer emulsions (synthetic-polymer emulsions, polyvinyl acetate, vinyl acrylic).
- Tree-resin emulsions (tree-resin emulsions, tall-oil emulsions, pine-tar emulsions).

Appendix table G.1 (FHWA 2005) provides a comprehensive overview of nontraditional additives. However many of these products are advertised as (1) requiring lower additive quantities and reduced cure times, and (2) yielding higher material strengths and superior durability. It should be noted that limited independent research has been completed to distinguish between products that deliver such enhanced performance and those that do not, or only partially do (Tingle and Santoni 2003). Comparisons and subsequent selection of products can therefore be subjective and sometimes complicated.

1. By nature, some stabilizing products perform well in certain soil types or environments, but perform poorly in others.
2. Because most of the recently introduced products are proprietary, mechanisms of stabilization are generally unknown.
3. Marketing strategies yield frequent discontinuity in brand names; this in turn, results in a lack of product history and user familiarity.

Some stabilizers are literally resting on the laurels of the manufacturer's claims. Procedures for the evaluation of a product are generally developed by individual agencies using the selected test standards in appendix F. Occasionally a summary of known evaluations by other agencies will be provided by the product manufacturer, as will recommendations for conducting in-house product evaluations, if desired.

Evaluation and selection of a nontraditional stabilizer

If a nontraditional stabilizer is going to be used, one should consult appendix table G.1 (FHWA 2005) for suggested soil types, environments, etc. Some preliminary tests should be conducted to determine if the candidate stabilizer will work for the specific soil type. Table 2.2 lists tables taken from the TRB's circular "Evaluation of Chemical Stabilizers, State of the Practice Report" (Petry and Sobhan 2005), which in turn lists applicable test protocols from which to choose for conducting evaluations.

Table 2.2—Tables that list standardized tests from which one can choose for conducting an evaluation.

Appendix table	To test:
Table D-1	Untreated soil
Table F-1	Stabilizer
Table F-2	Treated soil

All tests certainly need not be conducted, just those on a limited number of desired properties to be altered (e.g., gradation, Atterberg limits, unconfined compression for strength). Based on the test results, an appropriate chemical stabilizer, which will improve this property, can be determined.

When considering a stabilizing agent, it might be beneficial to consult with someone who has used that product under as similar conditions as possible/practical (environment, soil type, anticipated traffic level, etc.). If time allows, try to conduct full-scale test sections in the field to enable a full-scale evaluation of performance in the project environment. Ideally, these tests should be done a year in advance to observe the performance over the passage of time and seasons. Low application rates will provide modification and higher amounts will provide stabilization. It may be necessary to provide higher application rates than recommended by the manufacturer to make the product work.

One major difference that should be noted before selecting a nontraditional stabilizing agent—or for that matter prior to choosing any stabilizing agent—is its ability to reactivate. Some products set up and cannot be reactivated with normal ripping and reshaping with routine maintenance equipment. Examples include traditional stabilizing agents, such as Portland cement, lime, and asphalt/emulsions, as well as some nontraditional stabilizing agents such as nontraditional enzymatic emulsions including EMC SQUARED (EMC^2). In contrast, nontraditional chlorides or clays (such as bentonite) allow reactivation.

If reactivation is desired, an agent such as calcium chloride or magnesium chloride is recommended. The Forest Service has conducted fairly comprehensive studies on the chlorides but in specific locations; the reader is referred to Monlux and Mitchell (2006, 2007). Figure 2.2 shows the use of chlorides for this Forest Service evaluation.

Conversely, if a permanent solid-wear surface (that cannot be recrowned if improperly crowned when the stabilizing agent was placed) is desired, an enzymatic emulsion should be evaluated and considered. The Ozark-St. Francis National Forest has used EMC^2 and Roadbond En1 extensively with much success. To the observer, a road stabilized with these products looks no different than an unstabilized gravel road (figure 2.3).

An additional publication on nontraditional additives is available by Bolander (1999).

Figure 2.2a—Dry chloride application.

Figure 2.2b—Mixing dry chloride.

Figure 2.2c—Liquid chloride application.

Figure 2.2d—Blade mixing dry chloride.

Figure 2.2—Calcium and magnesium chloride, Forest Service project (Steve Monlux and Mike Mitchell).

Figure 2.3a—Spreading and compacting.

Figure 2.3b—Finished surface.

Figure 2.3c—Close-up of finished surface.

Figure 2.3—EMC squared, an enzymatic emulsion, Black Hills National Forest (Alan Anderson, R2).

A variety of additional photos of nontraditional stabilizing agents is available in chapter 5 of the FHWA Web site http://www.cflhd.gov/techDevelopment/completed_projects/pavement/context-roadway-surfacing/#supplement (FHWA 1995). Sections (of that Web site) with photos of specific categories include:

FHWA section 5.1 – Chlorides.

FHWA section 5.2 – Clay Additives.

FHWA section 5.3 – Electrolyte Emulsions.

FHWA section 5.4 – Enzymatic Emulsions.

FHWA section 5.5 – Lignosulfates.

FHWA section 5.6 – Organic-Petroleum Emulsions.

FHWA section 5.7 – Synthetic-Polymer Emulsions.

FHWA section 5.8 – Tree-Resin Emulsions.

CHAPTER THREE

Mechanical Stabilization

INTRODUCTION

Mechanical stabilization covers everything from compacting and blending soils, to incorporating any of a vast assortment of conventional geosynthetics, to using (installing, placing, incorporating, blending) less conventional materials, such as woodchips, sawdust, and woodmats, to aid in meeting the required strength. This section references tables that provide information on conventional and less conventional mechanical-stabilization techniques.

SELECTING A MECHANICAL-STABILIZING TECHNIQUE

Compaction and geosynthetics are the most widely used and accepted mechanical-stabilizing techniques. Appendix table H.1 provides a comprehensive listing of issues and concerns, such as serviceability, safety, environment, and cost for three selected mechanical-stabilization categories: cellular confinement, fiber reinforcement, and geotextile/geogrid reinforcement (FHWA 1995). The chapter also briefly discusses several less conventional and far less used techniques. Appendix table H.2 is a decision matrix resulting from a military test in which many of these less conventional expedient stabilization techniques were evaluated (Kestler et al. 1999). Although military and forest roads may differ in purpose, some of these stabilizing surfaces could be used within the Forest Service for temporary roads over soft ground and localized sections requiring stabilization. The emphasis here is on localized sections; the surfaces are generally not recommended as a stabilization technique for a road of any length. The table provides rankings on factors such as traction, equipment required for construction, life expectancy, ease of walking/foot traffic, etc. Ashmawy et al. (2006) provide a comprehensive assessment of various recycled materials that can be used to stabilize marginal soils in Florida. Such materials include scrap tires and slag because of their relatively low cost and desirable engineering properties. These less conventional techniques may provide viable alternatives to more costly standard stabilization techniques, but require sound engineering judgment and good management practices.

Compaction

Compaction is the most basic of the mechanical-stabilization techniques. Proper compaction is essential. It increases density thus lowering the potential of increased moisture content, even in case of saturation. Both increased density and decreased moisture content potentially increase strength.

Geosynthetics

The term geosynthetics is defined as a set of materials used to improve the performance of grounds or foundations in geotechnical engineering. Thus incorporating any of an extensive variety of geosynthetics can stabilize a soil (figure 3.1). Excluding compacting, using a geosynthetic is probably the most widely accepted mechanical-stabilization technique.

Figure 3.1a—Geogrids (GSI 2003).

Figure 3.1b—Geonets (GSI 2003).

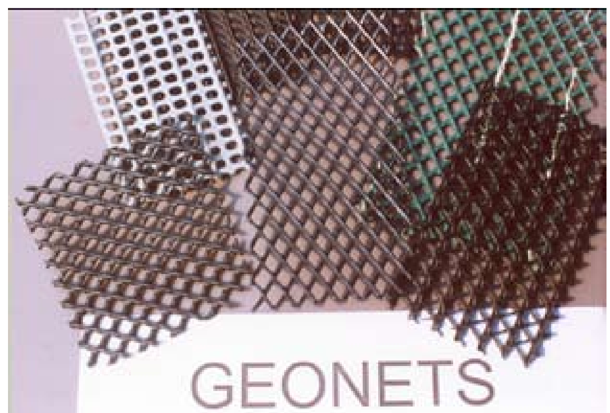

Figure 3.1c—Geomembranes (GSI 2003).

Figure 3.1—Geosynthetics.

Figure 3.1d—Geocomposites (GSI 2003).

Figure 3.1e—Polymeric Geogrid used on a slip-repair project on a paved road in the developed recreation area, Wayne NF (Cindy Henderson).

Figure 3.1f—Geosynthetic used immediately beneath asphalt.

Figure 3.1g—Geosynthetic installation at York Pond Road, White Mountain NF.

Figure 3.1—Geosynthetics (continued).

Figure 3.1h—Geosynthetic used for separation, White Mountain NF.

Figure 3.1i—Before Geoblock: Cycle trail hardening project, Francis Marion NF (Scott Groenier).

Figure 3.1j—After Geoblock: Cycle trail hardening project, Francis Marion NF (Scott Groenier).

Figure 3.1—Geosynthetics (continued).

Figure 3.1k—Caribou Lake Trail using Solgrid, intended for minimal visual impact, Alaska, (Kevin Meyer, National Park Service).

Figure 3.1l—Solgrid, Caribou Lake Trail 2-years later, Alaska, (Kevin Meyer, National Park Service).

Figure 3.1—Geosynthetics (continued).

Additional photos of geotextiles/geogrid and cellular confinement are available in sections 4.3 and 4.1, respectively, of the FHWA Web site: http://www.cflhd.gov/techDevelopment/completed_projects/pavement/context-roadway-surfacing/#supplement (FHWA 1995).

CHAPTER THREE
BACKGROUND AND DESIGN THEORY

Geosynthetics have been used in LVRs for years to reduce the amount of aggregate required or to extend the service life of the road. However, successful implementation depends upon the design method, specifications, and construction. A comparison of three primary empirical design methods, provided by Tingle and Jersey (2007), is summarized briefly below:

(1) The first design procedure for geotextile-reinforced unpaved roads was provided by Barenberg (1975). This was based on limit equilibrium bearing capacity (aggregate base thickness is selected such that the vertical stress on the subgrade is less than the theoretical limit for subgrade shear failure). This was modified by Steward et al. (1977), and adopted by the Forest Service and the USACE. More recently, the method was further modified by Tingle and Webster (2003) to include geogrid design, and is described in Engineering Technical Letter 1110-1-189 (U.S. Army 2003).

(2) An alternative design procedure was based on the tensioned membrane effect changing the failure mode from localized shear for an unreinforced system to generalized shear for the geotextile-reinforced system. The classic popular design theory by Giroud and Noiray (1981) combined this concept with the limit equilibrium bearing capacity theory.

(3) More recently, the Giroud and Noiray design theory was further modified by Giroud and Han (2004) to include stress distribution, base-course strength properties, geosynthetic-base interlock, and geosynthetic in-plane stiffness.

Each of these methods may be advantageous for various scenarios. Tingle and Jersey conducted a cost–benefit analysis of the three methods for selected subgrade California Bearing Ratios (CBR). Table 3.1 shows a comparison of results.

Table 3-1. Cost benefit analysis of materials (Tingle and Jersey 2007).

	Design Thickness (in.)	Aggregate Reduction (in.)	Geosynthetic Costs ($/mi)[a]	Aggregate Savings ($/mi)[b]	Materials Savings ($/mi)[c]
1 CBR subgrade strength					
ETL 1110-1-189					
Unreinforced	15	0	—	—	—
Geotextile	9	6	26,400	81,312	54,912
Geogrid	8	7	316,800	94,864	-221,936
Giroud and Noiray					
Unreinforced	15.5	0	—	—	—
Geosynthetic	9.5	6	26,400	81,312	54,912
Giroud and Han					
Unreinforced	24	0	—	—	—
Geotextile	17.5	6.5	26,400	88,088	61,688
Geogrid	10.5	13.5	316,800	182,952	-133,848
3 CBR subgrade strength					
ETL 1110-1-189					
Unreinforced	8	0	—	—	—
Geotextile	6	2	26,400	333	-26,067
Geogrid	6	2	316,800	333	-316,467
Giroud and Noiray					
Unreinforced	8	0	—	—	—
Geosynthetic	5.5	2.5	84,480	417	-84,063
Giroud and Han					
Unreinforced	15.5	0	—	—	—
Geotextile	9	6.5	26,400	1,083	-25,317
Geogrid	4	11.5	316,800	1,917	-314,883

[a]Assumed aggregate cost of $22/ton.
[b]Assumed geotextile cost of $0.25/ft^2, assumed geogrid cost of $3/ft^2.
[c]Savings purely in terms of material costs.

Over the years, significant additional contributions to geosynthetic uses beyond just LVRs, such as for slope stability and retaining walls, have been made by Forest Service representatives, particularly those in region 6.

CHAPTER THREE

General

Comprehensive overviews of all aspects of geosynthetics are provided by "Geosynthetic Design and Construction Guidelines Participant Notebook, National Highway Institute (NHI) Course No. 13213" (Revised April 1998) FHWA-HI-95-038 (Holtz et al. 1998), and the "Handbook of Geosynthetics." The former is available at http://www.fhwa.dot.gov/pavement/pub_details.cfm?id=1 . The latter can be downloaded from the Geosynthetics Materials Association Web site, http://www.gmanow.com, which provides added information on geosynthetics and related activities as well.

The Minnesota Local Roads Research Board provides a Web site detailing a geosynthetic design process for roads and highways, including the design guidelines for temporary and unpaved roads referenced above, developed by Steward et al. (1977) for the Forest Service. http://www.lrrb.org/Geosynthetics_Design_CD/start.asp, more specifically: http://www.lrrb.org/Geosynthetics_Design_CD/InternetExplorer/HTMLsections/chapter5FHWA/5-6.html

Appendix I provides guidelines for temporary and unpaved roads taken from these sites and Steward et al. (1977).

The geosynthetics field in itself is so broad, the reader is referred to appropriate publications for additional details on any particular geosynthetic. An extensive list of geosynthetic consultants, distributors, installers, manufacturers, organizations, test laboratories, and regulatory agencies is available at http://www.geosynthetic-institute.org/links.htm. Further information on geosynthetics is provided in Steward et al. (1977) and information on trails in Monlux and Vachowski (2000) (revised by Groenier 2008).

Reinforcing Fibers

Inclusion of randomly distributed, discrete synthetic fibers, which are used for fiber-reinforced concrete and slopes, significantly increases load-bearing capacity of soft soils, particularly sandy soils (Santoni et al. 2001; Santoni and Webster 2001; Tingle et al. 1999). The sand-fiber mix essentially forms a reinforced soil mesh. Fibers are most frequently polypropylene, and are generally available as monofillament difibrillated. They are approximately 1/2 to 2 inches in length. Further details are provided in appendix table H.1. Alternately, a less efficient but lower cost version made of materials such as straw flax, has been used in Canada (Bradley and Burns 2002). A separate wear surface is required. (Appendix table H.1 advises against using reinforced soil as a high-speed surface course, but the table was taken from the surfacing guide and was evaluated as a surfacing material.)

Figure 3.2a—
Reinforcing fibers. (Tammy Stewart, geosyntheticsolution.com)

Figure 3.2b—
Recycled Nycon-G-Plus green fibers. (Paul Bracegirdle, Pure Earth, Inc.).

Figure 3.2c—Reinforcing fibers. (Tammy Stewart, geosyntheticsolution.com)

Figure 3.2—Discrete reinforcing fibers.

Additional photos of fiber reinforcement are available in chapter 4, section 4.2, of the FHWA Web site http://www.cflhd.gov/techDevelopment/completed_projects/pavement/context-roadway-surfacing/#supplement (FHWA 1995).

CHAPTER THREE

Woodchips and Chunkwood

Stabilization of sections of wet soils or sugar sands can be accomplished by mixing in woodchips or chunkwood (Arola et al. 1991). Chunkwood is preferred over woodchips because the chunks are well graded and chunk-interlock can be obtained. Chunkwood is difficult to find unless one is near an old Forest Service prototype woodchunker, or a newer commercial one. So realistically, woodchips are recommended. Because wood is biodegradable, this is not a permanent fix, but it will stabilize for many years.

Figure 3.3a—Chunkwood. (Sally Shoop, CRREL)

Figure 3.3b—Forest Service woodchunker. (Dick Karsky, Missoula Technology & Development Center)

Figure 3.3—Chunkwood.

Mats

Mats, made from a variety of materials, can be placed atop soft soil and provide a stabilized surface. Interlocking wood mats can be constructed in the field, or purchased commercially. The same applies for tire mats. Both work well for localized soft spots. Figure 3.4a depicts small prefabricated wood pallets that were constructed onsite by the Forest Service and the Wisconsin National Guard. Commercially available tire mats and “dura-mats” are shown in figures 3.4b through 3.4d. Unless the mats are small, as shown in figure 3.4a, heavy equipment is required for placement;

nevertheless, placement is typically quick and easy for that equipment.

Figure 3.4a—Wood mats being constructed by Forest Service and Wisconsin National Guard (Kestler et al. 1999).

Figure 3.4b—Tire mats (Sally Shoop, CRREL).

Figure 3.4c—Dura-Base mats, temporary access road for electrical contractor, tidal flats Girdwood, Alaska, (Dennis Swarthout, Compos-itech).

Figure 3.4d—Dura-Base road construction, Alaska. (Dennis Swarthout, Carol Huber).

Figure 3.4—Mats.

Fascine/Pipe Bundles

A fascine is a series of polyvinyl chloride pipes linked together with steel cable (Mason 1990)(figure 3.5). A fascine can be used on soft soils, or to fill in low-lying areas while still maintaining drainage though the pipes. Steel grating or fencing atop the fascine can provide an efficient travel surface. The fascine can be pulled out easily when the temporary road is no longer needed.

Figure 3.5—Fascine (Mason and Moll 1995).

Slash and Logs/Corduroy

One of the simplest, most natural, and (excluding labor) economical methods of stabilization is to incorporate slash and tree limbs into a debris mat. This method is often used on peat (Phukan 1982), and was formerly used as a lightweight fill/base with a soil-wear surface for timber-access roads in the Tongass National Forest (Brunette 1993). Slash can be placed at angles to the direction of travel, or ruts can be filled with logs, and covered with angled smaller branches. Slash can be used in combination with other stabilization methods when large quantities of fill material are not available within a reasonable haul distance. Typically wood/corduroy is used in combination with a geosynthetic as shown in figure 3.6.

Figure 3.6—Corduroy atop geosynthetic, Australia (Gordon Keller).

CHAPTER FOUR
Construction Hints

Construction hints for traditional chemical-stabilization techniques, nontraditional chemical-stabilization techniques, and selected mechanical-stabilization techniques are provided in appendix tables B.4, G.1, and H.1, respectively (FHWA 2005). For each stabilization material, there is a corresponding construction section that addresses:

- ❑ Availability of experienced personnel.
- ❑ Materials.
- ❑ Equipment.
- ❑ Manufacturing/mixing process.
- ❑ Placement process.
- ❑ Weather restrictions.
- ❑ Construction rate.
- ❑ Lane closure requirements.
- ❑ Other comments.

Figures in chapters 2 and 4, as well as several figures in chapter 3 show typical construction activities for traditional and nontraditional stabilizing techniques.

Figure 4.1a—Chemicals were placed on a test section, spread on the surface, tilled into the soil, compacted, and allowed to cure. Sections were trafficked after 48 hours of curing, and performance measured. (Sally Shoop, CRREL).

4.1—Construction.

Figure 4.1b—Cement application, region 6 (Dave Katagiri).

Figure 4.1c—Cement application, region 6 (Dave Katagiri).

Figure 4.1d—Grading cement-treated base, region 6 (Dave Katagiri).

4.1—Construction (continued).

Figure 4.1e—Rolling cement-treated base, region 6 (Dave Katagiri).

Figure 4.1—Construction (continued).

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APPENDIX A

Definitions

APPENDIX A—DEFINITIONS (ARMY 1994)

Bitumen—Asphalt or coal tar. Bituminous emulsions and cutback bitumens are used for stabilization.

Cement—Term short for Portland cement. A manufactured material that reacts chemically and hardens in the presence of water.

Chemical stabilization/additive stabilization—Adding appropriate percentages of cement, lime, fly ash, bitumen, other chemicals, or combinations to the soil to change soil properties. Smaller amounts are required to "modify" (change properties such as gradation, workability, or plasticity); larger amounts are required to improve strength or durability.

Fly Ash—Fine solid particle of noncombustible ash that is carried away in the draft during combustion of fuel (usually coal). There are two types;

- Class C—contains high amounts of lime, is pozzolanic, and is self-reactive in the presence of water.
- Class F—contains a low amount of lime and needs additional time to form a pozzolanic reaction.

Mechanical stabilization—Mixing two or more soils to obtain desired gradation, or placing a nonchemical, nongranular material in or on soil to provide added strength (e.g., geocomposites, geofibers, etc.)

Modification—Stabilization process that results in improvements of properties, but not targeted at increasing strength or durability.

Stabilization—Process of blending and mixing materials with a soil to improve selected soil properties. This may include mixing soils to obtain desired gradation or mixing in a chemical additive to alter soil gradation, plasticity, or serve as a binder.

APPENDIX B

Traditional Chemical Stabilizers

APPENDIX B - TRADITIONAL CHEMICAL STABILIZERS: SIMPLIFIED METHOD OF SELECTING AND DETERMINING QUANTITIES

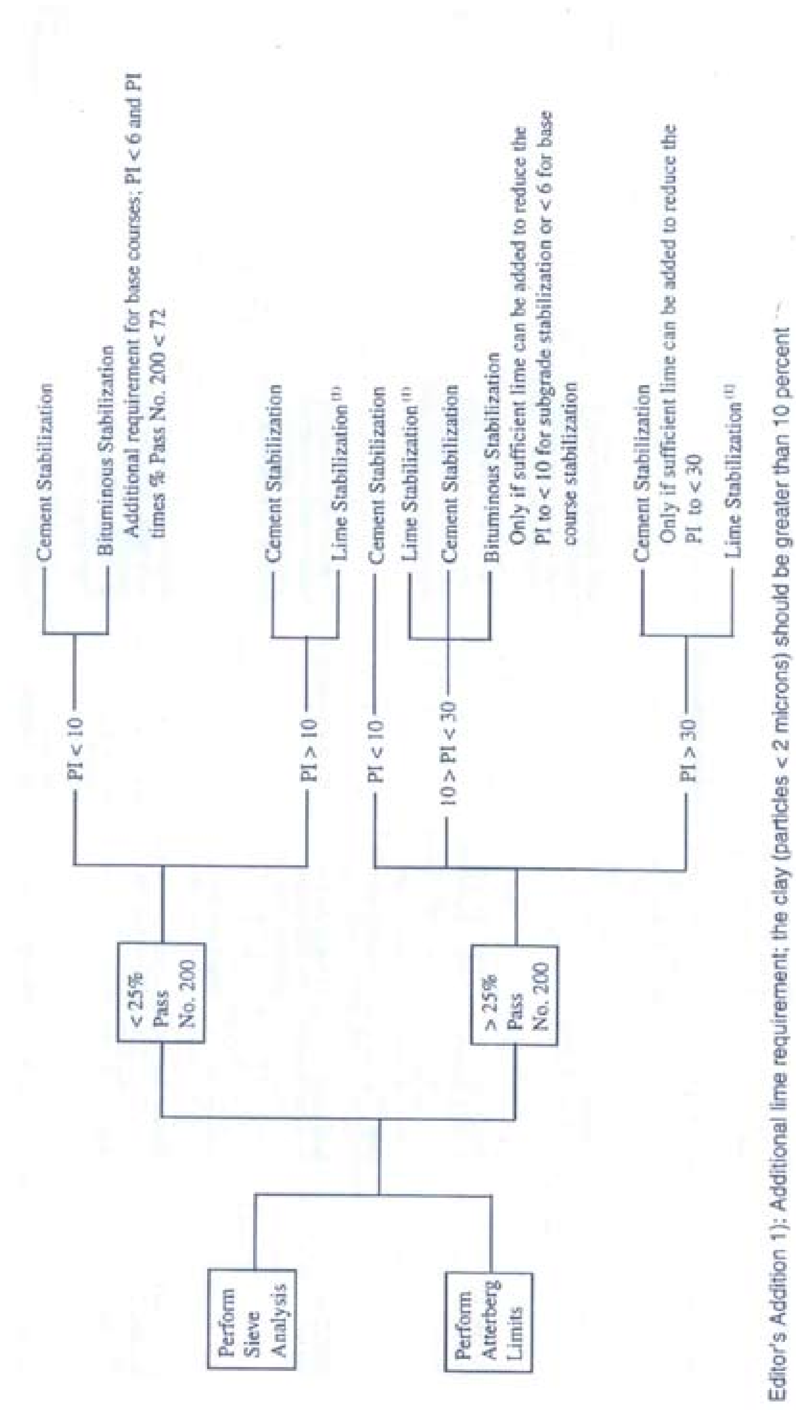


Figure B.1—Selection of stabilizer flowchart (Bolander 1995) Source Soil Stabilization.

APPENDIX B

Table B.1—Aid in selecting a commercial stabilization unit

USCS Soil Classification	Stabilization Agent Recommended	Restriction on LL, PL, PI of soil	Restrictions on % Pass No. 200	Remarks
SW or SP	Bituminous Portland Cement	— —	— —	—
SW-SM, SP-SM, SM-SC, or SP-SC	Bituminous Portland Cement Lime	PI not to exceed 10 PI not to exceed 30 PI not less than 12	— — —	—
SM, SC, or SM-SC	Bituminous Portland Cement Lime	PI not to exceed 10 PI not to exceed ((50-P200)/4 + 20) PI not less than 12	Not to exceed 30%	—
GM or GP	Bituminous Portland Cement	— —	— —	Well-graded material only Material should contain at least 45% by weight of material passing No. 4 sieve
GW-GM, GP-GM, GM-GC, or GP-GC	Bituminous Portland Cement	PI not to exceed 10 PI not to exceed 30	— —	Well-graded material only Material should contain at least 45% by weight of material passing No. 4 sieve
	Lime	PI not less than 12	—	
GM-GC, or GM-GC	Bituminous Portland Cement	PI not to exceed 10 PI not to exceed ((50-P200)/4 + 20)	Not to exceed 30%	Well-graded material only Material should contain at least 45% by weight of material passing No. 4 sieve
	Lime	PI not less than 12		
CH, CL, MH, ML, OH, OL, or ML-CL	Portland Cement Lime	LL less than 40 and PI less than 20 —	— —	Organic and strongly acid soils falling within this area are not susceptible of stabilization by ordinary means

Definitions: LL = liquid limit, PL = plastic limit, PI = plasticity index, P200 = % passing No. 200 sieve, USCS = Unified Soil Classification System

Source: "Soil Stabilization in Pavement Structures, A Users Manual – Volume 2, Mixture Design Considerations," page 13.

Table B.2—Soil types and stabilization methods that appear best suited for specific applications (Bolander 1995)

Table 6.—Soil types and stabilization methods which appear best suited for specific applications

Purpose	Soil Type	Recommended Stabilization Methods
1. Subgrade Stabilization		
A. Improved load-carrying and stress-distributing characteristics	coarse granular	SA, SC, MB, C
	fine granular	SA, SC, MB, C
	clays of low PI	C, SC, CMS, LMS, SL
	clays of high PI	SL, LMS
B. Reduce frost susceptibility	fine granular	CMS, SA, SC, LF
	clays of low PI	CMS, SC, SL, CW, LMS
C. Waterproofing and improved runoff	clays of low PI	CMS, SA, CW, LMS, SL
D. Control of shrinkage and swell	clays of low PI	CMS, SC, CW, C, LMS, SL
	clays of high PI	SL
E. Reduce resiliency	clays of high PI	SL, LMS
	elastic silts and clays	SC, CMS
2. Base course stabilization		
A. Improvement of substandard materials	fine granular	SC, SA, LF, MB
	clays of low PI	SC, SL
B. Improved load-carrying and stress-distributing characteristics	coarse granular	SA, SC, MB, LF
	fine granular	SC, SA, LF, MB
C. Reduction of pumping	fine granular	SC, SA, LF, MB, membranes
3. Shoulders (unsurfaced)		
A. Improved load-carrying ability	all soils	See section 1A above; also MB
B. Improved durability	all soils	See section 1A above
C. Waterproofing and improved runoff	plastic soils	CMS, SL, CW, LMS
D. Control of shrinkage and swell	plastic soils	See section 1E above
4. Dust palliative	fine granular	CMS, CL, SA, oil, or bituminous surface spray
	plastic soils	CL, CMS, SL, LMS
5. Ditch lining	fine granular	PSC, CS, SA
	plastic soils	PCS, CS
6. Patching and reconstruction	granular soils	SC, SA, LF, MB

KEY

C	Compaction	CW	Chemical Waterproofers	PSC	Plastic Soil Cement
CMS	Cement Modified Soil	LF	Lime Flyash	SA	Soil Asphalt
CL	Chlorides	LMS	Lime Modified Soil	SC	Soil Cement
CS	Chemical Solidifiers	MB	Mechanical Blending	SL	Soil Lime

Source: *Soil Stabilization in Pavement Structures, A Users' Manual–Volume 2 Mixture Design Consideration*, p. 12

APPENDIX B

Table B.3—Summary of recommended stabilization procedure and recommended amount of admixture (Bolander 1995)

Method	Addition Weight, %	Soil Type: Coarse Granular	Soil Type: Fine Granular	Soil Type: Low Plastic Clay	Soil Type: High Plastic Clay	Special Advantage	Climatic Limitations	Construction Safety Precautions
Cement	3–5	A				strength increases in short time	no frozen soils, air temp 40 °F and rising, need 1 week before freeze	cement; no contact with wet skin for very long; safety glasses and protective clothing worn
	5–9		A					
	9–12			A				
	10–16				B			
Lime	–	N/A	N/A			rapid clay plasticity decrease	no frozen soils, air temp 40 °F and rising, need 4 weeks before freeze	quicklime; no contact with wet skin at all; safety glasses and protective clothing worn
	2–6			A				
	2–8				A			
Lime & fly ash	3–5% lime 10–20% fly ash	A	A			same as lime	same as lime	same as lime
	5–9% lime 10–25% fly ash			B				
	–				N/A			
Asphalt	3–6	A	A			–	hot, dry weather preferred for all asphalt stabilization	hot mix asphalt may be as high as 350 °F, some cutbacks have flash points below 100 °F
	5–9			B				
	–				N/A			

Sources: "Soil Stabilization in Pavement Structures, A Users Manual—Volume 2, Mixture Design Considerations," page 26 and Evaluation of Alternate Systems for Surfacing Forest Roads—Final Report, page 47.

Table B.4—Traditional chemical stabilizers (from FHWA surfacing context sensitive roadway surfacing selection guide 2005)

FLY ASH

GENERAL INFORMATION

Generic Name(s): Fly Ash, Coal Ash, Bottom Ash

Trade Names: N/A

Product Description: Fly ash is a residue of coal combustion that occurs at power generation plants throughout the United States. Fly ash can be used to lower the water content of soils, reduce shrink-swell potential, increase workability, and increase soil strength and stiffness. Two types of fly ash can be used to stabilize soils: Class C and Class F. Both classes of fly ash contain pozzolans, but Class C fly ash is rich in calcium that allows it to be self-cementing. Class F fly ash requires an activation agent (e.g., lime or cement) for a pozzolanic reaction to occur and create cementitious bonds within the soil.

Product Suppliers: Representative list of producers can be obtained from: American Coal Ash Association, 15200 East Girard Avenue, Suite 3050, Aurora, CO 80014, (720) 870-7897, www.acaa-usa.org.

APPLICATION

Typical Use: Soil stabilizer.

Traffic Range: Fly ash-stabilized soils/aggregates are not used as a surfacing material. Fly ash-stabilized subgrade and subbase materials can be used for very low to high traffic volume applications.

Restrictions:

- **Traffic:** None.
- **Climate:** None.
- **Weather:** None.
- **Terrain:** None.
- **Soil type:** Fly ash can be used to modify/stabilize a variety of materials, including clays, silts, sands, and gravel.
- **Other:** For fly ashes with greater than 10-percent sulfates, high initial strengths have been observed for fly ash-stabilized materials, but the durability of the stabilized material may be reduced.

Other Comments: Fly ash stabilization is often used as a construction expedient when wet soil conditions are present and weather conditions or time constraints prevent the contractor from processing the soil to dry it out. The fly ash lowers the water content and plasticity of the soil and improves workability; this allows for construction of an adequate working platform for construction operations. Fly ash also is used to reduce the shrink/swell potential of clay soils.

Table B.4—Traditional chemical stabilizers (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

DESIGN

SLC: 0.10 to 0.20. Value will vary with soil type and fly ash mixing percentage. Laboratory mixing should be performed to determine the strength of the stabilized material. Using laboratory strength testing results, an estimate of the SLC can be made using correlations, local practice, or engineering judgment.

Other Design Values: Fly ash stabilization of clay soils can increase CBR values from 2 to 3 (untreated) to 25 to 35 (treated). Unconfined compressive strengths for fly ash-stabilized clay soils can vary from 700 to 3,500 kPa (100 to 510 psi), depending on fly ash source and application rate and the material being stabilized.

Base/Subbase Requirements: The use of fly ash-stabilized subgrade can reduce the design thickness for base and/or subbase layers.

Other Comments: The base thickness and appropriate road surfacing should be selected based on anticipated traffic volumes.

CONSTRUCTION

Availability of Experienced Personnel: Fly ash stabilization is relatively straightforward and qualified contractors are, in general, widely available.

Materials: Fly ash and water are required for fly ash stabilization. Fly ash is a residue of coal combustion that occurs at power generation plants throughout the United States. Two types of fly ash can be used to stabilize soils: Class C and Class F. Class C fly ash is produced from burning lignite and subbituminous coal mostly found in the western United States. Class F fly ash is produced from burning anthracite or bituminous coal mostly found in the eastern, southern, and midwestern United States.

Equipment: Equipment required for fly ash stabilization includes: mechanical spreader, tanker or water truck with spray bar, rotary mixer or disc, grading equipment (i.e., bulldozer or motorgrader), and light sheepsfoot or pneumatic roller. Equipment is widely available in most areas, but availability may be limited in remote areas.

Manufacturing/Mixing Process: Subgrade and base materials are usually treated with fly ash using in-place mixing.

Placement Process: The fly ash is uniformly applied to the existing surface and water is sprayed on the surface. A rotary mixer or disc is then used to mix the fly ash, soil, and water together. If water can be added by the rotary mixer during processing, this approach is recommended. Maximum strengths are obtained when the moisture content is 0 to 7 percent below the optimum water content, depending on the material being treated. Subgrade soils are usually treated to a depth of 200 mm (8 in). For deeper mixing and stabilization, the material should be mixed and compacted in 200 mm (8 in) lifts. Once mixed, the loose surface is graded and compacted. Delays in compaction can result in lower maximum strengths for the stabilized material. Therefore, construction specifications often require that mixing, grading, and compacting must be finished within 2 hours of fly ash spreading.

Table B.4—Traditional chemical stabilizers (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

Weather Restrictions: Avoid construction during heavy rain or snow events and when the soil is frozen. Fly ash stabilization should only be performed when air temperatures are greater 10 ºC (50 ºF).

Construction Rate: Fly ash application rates are in the range of 2,950 to 4,200 m^2/day (3,500 to 5,000 yd^2/day).

Lane Closure Requirements: The roadway lane should be closed during construction. If possible, it is recommended that the lane remain closed until a wearing surface can be applied; however, the treated material can be opened to temporary traffic after 1 day.

Other Comments: The required application rate will vary based on the characteristics of the fly ash and the material to be treated and the degree of modification/stabilization desired. Application rates can be in the range of 10 to 20 percent. Laboratory testing is recommended to determine/verify the appropriate application rate.

SERVICEABILITY

Reliability and Performance History: Fly ash stabilization has been used for soil stabilization for roads for more than 50 years. Research, design and construction information, and project experience are available.

Life Expectancy: Life expectancy varies depending on traffic, degree of stabilization, total road structure, and weather conditions. Fly ash-stabilized materials should not be used as a permanent surfacing material. Typical life expectancy for fly ash-stabilized subgrade or base materials, assuming that the roadway has a proper structural design, is more than 20 years and will generally last for the lifetime of the roadway.

Ride Quality: N/A; not a surfacing.

Main Distress/Failure Modes: The road surfacing distress mode should not be directly impacted by the use of fly ash stabilization. Where a stabilized subbase layer is used, any differential movement of the underlying subgrade, due to expansive soils or frost action, could in turn crack the stabilized subbase and lead to cracking of the road surfacing.

Preservation Needs: N/A; not a surfacing.

SAFETY

Hazards: None.

Skid Resistance: N/A; not a surfacing.

Road Striping Possible?: N/A; not a surfacing.

Other Comments: None.

Table B.4—Traditional chemical stabilizers (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Fly ash is a residue of coal combustion that occurs at power generation plants throughout the United States.

Delivery and Haul Requirements: Fly ash must be transported to the site from the distributor. Haul distances may be significant for remote sites.

Potential Short-Term Construction Impacts: Construction process can damage vegetation adjacent to the road.

Potential Long-Term Environmental Impacts:

Leachate: Fly ash stabilization can lower the permeability of the treated soil, but the treated material is still susceptible to leaching. Fly ash composition varies depending on the source of coal and the type of power plant that generated the fly ash. Most fly ashes contain heavy metals, as well as other compounds, that could potentially impact the environment. A water leach test should be performed on the soil-fly ash mixture to determine if the leachate meets regulatory standards for use.

Surface runoff: Since it is not used as a surfacing, fly ash does not impact surface runoff.

Erosion: Fly ash-stabilized materials are a bound material and not very susceptible to erosion, especially considering that the stabilized material is not used as a surfacing material.

Water quality: Fly ash-stabilized materials have the potential to leach out heavy metals and other compounds that may affect ground water and nearby surface waters. Laboratory testing and transport modeling may be required to determine potential water quality impacts if water sources are located near the stabilized area.

Aquatic species: Fly ash-stabilized materials have the potential to leach out heavy metals and other compounds that may affect aquatic species. Laboratory testing and transport modeling may be required to determine potential aquatic species impacts if water sources are located near the stabilized area.

Plant quality: None.

Air quality: None.

Other: None.

Ability to Recycle/Reuse: The treated soil/aggregate can be reused as a construction material.

Other Environmental Considerations: N/A

Table B.4—Traditional chemical stabilizers (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

AESTHETICS

Appearance: Fly ash stabilization does not significantly alter the appearance of a soil/aggregate material. The appearance will be of a soil/aggregate surface with the overall color determined by the material type and source. However, the fly ash-stabilized material is typically covered with a wearing surface.

Appearance Degradation Over Time: Fly ash-stabilized materials do not experience appearance degradation over time.

COST

Supply Price: N/A

Supply + Install Price: \$2.50 to \$4.50/m^2 (\$2.10 to \$3.80/yd^2)

EXAMPLE PROJECTS

Ozark National Forest, AR.

Newark International Airport, Newark, NJ.

SELECT RESOURCES

Acosta, H.A.; Edil, T.B.; Benson, C.H. 2003. “Soil Stabilization and Drying Using Fly Ash,” Geo Engineering Report No. 03-03, University of Wisconsin-Madison, 137 p.

Ferguson, Glen. 1993. “Use of Self-Cementing Fly Ashes as a Soil Stabilization Agent,” Fly Ash for Soil Improvement, American Society of Civil Engineers, pp. 1-14.

Table B.4—Traditional chemical stabilizers (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

LIME

GENERAL INFORMATION

Generic Name(s): Lime, Quicklime, Hydrated Lime

Trade Names: N/A

Product Description: Lime can be obtained in the form of quicklime or hydrated lime. Quicklime is manufactured by calcination of limestone at high temperatures, which chemically transforms calcium carbonate into calcium oxide. Hydrated lime is created when quicklime chemically reacts with water. Lime can be used to stabilize clay soils and submarginal base materials (i.e., clay-gravel, caliche, etc.). When added to clay soils, lime reacts with water in the soil and reduces the soil's water content. The lime also causes ion exchange within the clay, resulting in flocculation of the clay particles. This reaction changes the soil structure and reduces the plasticity of the soil. These changes will increase soil workability and can increase the soil strength and stiffness. In the long term, calcium hydroxide in the water reacts with the silicates and aluminates (pozzolans) in the clay to form cementitious bonds that further increase the soil strength.

Product Suppliers: Representative list of manufacturers, suppliers, and contractors can be obtained from: National Lime Association, 200 North Glebe Road, Suite 800, Arlington, VA 22203, (703) 243-5463, www.lime.org.

APPLICATION

Typical Use: Soil stabilizer.

Traffic Range: Lime-stabilized subgrade and subbase materials can be used for very low to high traffic volume applications.

Restrictions:

Traffic: None.

Climate: None.

Weather: None.

Terrain: None.

Soil type: Lime works best for clayey soils, especially those with moderate to high plasticity (plasticity index greater than 15). Lime does not work well with silts and granular materials because the pozzolanic reaction does not occur due to a lack of sufficient aluminates and silicates in these materials. For lime to effectively stabilize silts or granular materials, pozzolanic admixtures (i.e., fly ash) should be used in addition to lime.

Other: For soils with high sulfate contents (greater than 0.3 percent), lime stabilization is generally not recommended.

Table B.4—Traditional chemical stabilizers (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

Other Comments: Lime stabilization is often used as a construction expedient when wet soil conditions are present and weather conditions or time constraints prevent the contractor from processing the soil to dry it out. The lime lowers the water content and plasticity of the soil and improves workability; this allows for construction of an adequate working platform for construction operations. Lime is also used to reduce the shrink/swell potential of clay soils.

Lime-stabilized soils/aggregates are rarely used as a surfacing material, except for possible use as temporary construction or haul roads. Unprotected lime-stabilized materials have poor resistance to the abrasive action of continued traffic. Therefore, lime-stabilized materials should be covered with some type of wearing surface.

DESIGN

SLC: 0.08 to 0.14. Value will vary with soil type and lime mixing percentage. Laboratory mixing should be performed to determine the strength of the stabilized material. Using laboratory strength testing results, an estimate of the SLC can be made using correlations, local practice, or engineering judgment.

Other Design Values: For clayey soils treated with lime, unconfined compressive strengths of greater than 690 kPa (100 psi) are common and can be 2,750 kPa (400 psi) or greater, depending on the soil.

Base/Subbase Requirements: Roadway should be designed with adequate base and/or subbase support.

Other Comments: The road surface should be graded to promote surface drainage and prevent ponding on the road surface that can promote softening of the treated materials. The base thickness and appropriate road surfacing should be selected based on anticipated traffic volumes.

CONSTRUCTION

Availability of Experienced Personnel: Lime stabilization is commonly used for soil modification and stabilization and experienced contractors are, in general, widely available.

Materials: Quicklime or hydrated lime and water are required for lime stabilization. Quicklime is highly reactive with water and releases large quantities of heat during the chemical reaction. A detailed safety program is needed when constructing with quicklime. Although quicklime is more effective (25 percent more reactive), hydrated lime is commonly used because it is safer to work with.

Equipment: Equipment required for lime stabilization includes: mechanical spreader, tanker or water truck with spray bar, rotary mixer, grading equipment (i.e., bulldozer or motorgrader), and light sheepsfoot or pneumatic roller. Equipment is widely available in most areas, but availability may be limited in remote areas.

Manufacturing/Mixing Process: Lime can be mixed with base materials at the aggregate plant; however, subgrade and base materials are usually treated with lime using in-place mixing.

Table B.4—Traditional chemical stabilizers (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

Placement Process: The lime is uniformly applied to the existing surface and water is sprayed on the surface. A rotary mixer is then used to mix the lime, soil, and water together. If water can be added by the rotary mixer during processing, this approach is recommended. Enough water should be added to raise the soil moisture content to 3 percent above optimum moisture content, to allow for hydration of the lime. Subgrade soils are usually treated to a depth of 200 mm (8 in). For deeper mixing and stabilization, the material should be mixed and compacted in 200 mm (8 in) lifts. Once mixed, the loose surface is graded and compacted. For lime stabilization, the lime treated soil must be given time for the chemical reactions to change the material, or for the soil to “mellow;” the mellowing period is typically 1 to 7 days. After the mellowing period is over, the soil should be remixed, graded, and compacted. For drying or soil modification, mellowing is not usually required.

Weather Restrictions: Avoid construction during heavy rain or snow events and when the soil is frozen. Warm temperatures are required for the chemical reactions to occur between the lime and soil; therefore, the air temperature should be above 4 ºC (40 ºF) for soil stabilization applications.

Construction Rate: Lime application rates are in the range of 2,950 to 4,200 m^2/day (3,500 to 5,000 yd^2/day).

Lane Closure Requirements: The roadway lane should be closed during construction. If possible, it is recommended that the lane remain closed until a wearing surface can be applied; otherwise, the treated material can be opened to traffic after 1 day for temporary use.

Other Comments: The required application rate will vary based on the characteristics of the material to be treated and the degree of modification/stabilization desired. For soil modification purposes, lime application rates are normally 2 to 3 percent (by weight). Larger quantities of lime are required for pozzolanic reactions, and thus strength gain, to occur. For soil stabilization, lime application rates are normally 5 to 6 percent (by weight). Laboratory testing is recommended to determine/verify the appropriate application rate.

SERVICEABILITY

Reliability and Performance History: Lime is a commonly used product for soil/aggregate modification and stabilization and has been used for well over 40 years. Significant research, design and construction information, and project experience are available.

Life Expectancy: Life expectancy varies depending on traffic, degree of stabilization, and weather conditions. Lime-stabilized materials can be used as a temporary road surfacing, but should not be used as a permanent surfacing material. For soils treated with a low percentage of lime and not adequately protected from moisture, some studies claim that the lime can leach out of the treated soil and the soil will regain the properties of the untreated material. This leaching process has been observed in projects after 5 to 12 years or more. For higher application rates associated with soil stabilization, the lime is bound to the soil particles through the pozzolanic reactions that occur and is not susceptible to leaching. As a result, typical life expectancy for lime stabilized subgrade or base materials, assuming that the roadway has a proper structural design, is more than 20 years and can be greater than 45 years for some projects.

Table B.4—Traditional chemical stabilizers (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

Ride Quality: Lime-treated materials can provide fair-to-good ride quality, depending on the material characteristics, when used as a temporary road surfacing.

Main Distress/Failure Modes: Cracking of the stabilized layer due to differential movement of the underlying subgrade.

Preservation Needs: None.

SAFETY

Hazards: Quicklime is highly reactive with water and releases large quantities of heat during the chemical reaction. A detailed safety program is needed when constructing with quicklime.

Skid Resistance: Lime-stabilized materials can provide marginal to adequate skid resistance when used as a temporary road surfacing.

Road Striping Possible?: N/A; not a surfacing.

Other Comments: None.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Lime and water are required for lime stabilization. Lime is manufactured from limestone through a very energy intensive process. In addition to significant energy consumption during the manufacturing process, lime manufacturing produces large amounts of carbon dioxide (CO_2).

Delivery and Haul Requirements: Lime must be transported to the site from the distributor. Haul distances may be significant for remote sites.

Potential Short-Term Construction Impacts: The construction process and equipment can damage vegetation adjacent to the road. If the lime-stabilized material is not protected from surface runoff, some lime could be washed into the surrounding environment and have an environmental impact by raising the pH of the water (lime treated soils have a pH of around 10). However, lime has a relatively low solubility in water, so the amount of lime product carried by the surface runoff should be small. Best Management Practices (BMPs) should be employed during construction to prevent the surrounding environment and water bodies from being exposed to large quantities of lime.

Potential Long-Term Environmental Impacts:

Leachate: For soils treated with a low percentage of lime and not adequately protected from moisture, the lime can leach out of the treated soil. The amount of movement due to leaching for calcium oxide particles is on the order of 125 mm (5 in). Therefore, leaching of lime from the stabilized material should not adversely affect the surrounding environment.

Surface runoff: Lime-stabilized soils generally have relatively low permeability and, thus promote surface runoff. However, surface runoff water quality is not generally impacted by lime stabilization. In parking areas, oil and other vehicle fluids can be collected by surface runoff, affecting the water quality.

Table B.4—Traditional chemical stabilizers (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

Erosion: Lime-stabilized materials are a bound material and not very susceptible to erosion. At lower application rates, lime-modified soil may still be subject to erosion when exposed to fast-moving waters; however, the lime-modified soil will usually be protected by a surfacing layer that will protect it from erosion.

Water quality: None.

Aquatic species: None.

Plant quality: None.

Air quality: None.

Other: None.

Ability to Recycle/Reuse: The treated soil/aggregate can be reused as a construction material.

Other Environmental Considerations: None.

AESTHETICS

Appearance: Lime stabilization does not significantly alter the appearance of a soil/aggregate material. The appearance will be of a soil/aggregate surface with the overall color determined by the material type and source. However, the lime-stabilized material is typically covered with a wearing surface.

Appearance Degradation Over Time: Lime-stabilized materials do not experience appearance degradation over time.

COST

Supply Price: N/A

Supply+Install Price: \$1.60 to \$2.40/m^2 (\$1.30 to \$2.00/yd^2) for 200 mm (8 in) mixing depth.

EXAMPLE PROJECTS

Natchez Trace Parkway, Madison, MS.

Bald Knob National Wildlife Refuge, White County, AR.

SELECT RESOURCES

Little, Dallas. 1987. Fundamentals of the Stabilization of Soils with Lime, Bulletin No. No. 332, National Lime Association, Arlington, VA, 21 p.

Little, Dallas. 1999. Evaluation of Structural Properties of Lime Stabilized Soils and Aggregates, Volume 1: Summary of Findings, National Lime Association, 97 p.

National Lime Association. 2004. Lime-Treated Soil Construction Manual: Lime Stabilization & Lime Modification, Bulletin 326, National Lime Association, Arlington, VA, 41 p.

Table B.4—Traditional chemical stabilizers (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

PORTLAND CEMENT

GENERAL INFORMATION

Generic Name(s): Portland Cement, Cement, Cement-Modified Soil (CMS), Cement-Treated Base (CTB), Soil-Cement

Trade Names: N/A

Product Description: Portland cement can be used to stabilize any soil except highly organic soils. Portland cement increases soil strength, decreases compressibility, reduces swell potential, and increases durability. Cement stabilization creates a hard, bound, impermeable layer. Cement-stabilized materials are rarely used as a surfacing material because they can become brittle and crack under traffic loads; cement-treated soils are most frequently used as a stabilized subgrade or road base.

Product Suppliers: Representative list of manufacturers, suppliers, and contractors can be obtained from: Portland Cement Association, 5420 Old Orchard Road, Skokie, IL, 60077-1083, (847) 966-6200, www.cement.org.

APPLICATION

Typical Use: Soil stabilizer.

Traffic Range: Cement-stabilized materials are rarely used as a surfacing material. Cement-stabilized subgrade and base materials can be used in roads for very low to high traffic volume applications.

Restrictions:

Traffic: None.

Climate: Cement-stabilized bases should not be used in areas subject to seasonal frost heave.

Weather: None.

Terrain: None.

Soil type: Cement stabilization should not be used for soils with high organic content or containing sulfates.

Other: None.

Other Comments: Portland cement can be used for soil modification (e.g., decrease plasticity of marginal aggregate to make it acceptable for use as a base material) or soil stabilization (e.g., increase strength of existing soft subgrade material). Portland cement binds the surface particles and reduces dust generation when used as a temporary road surfacing.

Table B.4—Traditional chemical stabilizers (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

DESIGN
SLC: 0.12 to 0.25 (increases with increasing compressive strength).
Other Design Values: For fine-grained soils, unconfined compressive strengths of 860 to 3,450 kPa (125 to 500 psi) are common. CBR values for weak soils (CBR of 2) can be increased to a CBR of 40.
Base/Subbase Requirements: Roadway should be designed with adequate base and/or subbase support. For cement-stabilized subgrades, a subbase layer is usually not required and a bound base should be used. Where cement is used to provide a treated base, the surfacing can consist of a range of materials including PCCP and HACP.
Other Comments: The road surface should be sloped to promote surface runoff and prevent ponding on the road surface that can lead to softening of the treated materials. The base thickness and appropriate road surfacing should be selected based on anticipated traffic volumes.
CONSTRUCTION
Availability of Experienced Personnel: Portland cement stabilization is a commonly used soil stabilizer and experienced contractors are, in general, widely available.
Materials: Portland cement and water are required for cement stabilization.
Equipment: Equipment required for Portland cement stabilization includes: tanker or water truck with spray bar, pulverizer, grading equipment (i.e., bulldozer or motorgrader), and roller. Equipment is widely available in most areas, but availability may be limited in remote areas.
Manufacturing/Mixing Process: Portland cement is typically mixed with base materials at the aggregate plant; stabilization of subgrade soils with cement is normally achieved by in-place mixing.
Placement Process: For new construction projects where aggregate must be hauled to the site, the cement can be mixed with the aggregate in a pugmill before transporting to site. This method provides the most uniform mixing. Alternatively, if the soil/aggregate is in place, the cement is uniformly applied to the existing surface and then mixed into the surface using a rotary mixer. Subgrade soils are usually treated to a depth of 150 mm (6 in). For deeper mixing and stabilization, the material should be mixed and compacted in 150 mm (6 in) lifts. Once mixed, the loose surface is sprayed with water using a water truck and then graded and compacted. The compacted surface should be sprayed with water again to ensure that enough water is provided for cement hydration.
Weather Restrictions: Avoid construction during heavy rain or snow events and when the subgrade is frozen.
Construction Rate: Portland cement application rates are on the order of 2,950 to 4,200 m^2/day (3,500 to 5,000 yd^2/day).
Lane Closure Requirements: The roadway lane should be closed during construction, but can be opened to light traffic once construction is complete.

Table B.4—Traditional chemical stabilizers (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

Other Comments: The required application rate will vary based on the characteristics of the material to be treated and the degree of stabilization desired; typical application rates are 3 to 5 percent by weight. Laboratory testing is recommended to determine/verify the appropriate application rate.

SERVICEABILITY

Reliability and Performance History: Portland cement is a commonly used product for soil/aggregate modification and stabilization and has been used for well over 50 years. Significant research, design and construction information, and documented project experience are available.

Life Expectancy: Life expectancy varies depending on traffic, weather conditions, and surfacing type. Cement stabilized materials can be used as a temporary road surfacing, but should not be used as a permanent surfacing material because they can become brittle and crack under traffic loads. Typical life expectancy for cement stabilized subgrade or base materials, assuming that the roadway has a proper structural design, is more than 20 years and can be greater than 45 years for some projects.

Ride Quality: Portland cement-treated materials can provide fair to good ride quality, depending on the material characteristics, when used as a temporary road surfacing.

Main Distress/Failure Modes: Cracking (due to nonuniform subgrade support and frost action, when used as a road base layer)

Preservation Needs: None.

SAFETY

Hazards: None.

Skid Resistance: Cement-stabilized materials can provide adequate skid resistance when used as a temporary road surfacing.

Road Striping Possible?: N/A; not a surfacing.

Other Comments: None.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Portland cement and water are required for cement stabilization. Portland cement is manufactured from limestone through a very energy intensive process. In addition to significant energy consumption during the manufacturing process, Portland cement manufacturing produces large amounts of carbon dioxide (CO_2); various reports claim that cement manufacturing is responsible for 2 to 7 percent of CO_2 produced by humans.

Delivery and Haul Requirements: Portland cement must be transported to the site from the distributor. Haul distances may be significant for remote sites.

Potential Short-Term Construction Impacts: Construction process can damage vegetation adjacent to the road, but offsite impacts can be mitigated by careful handling.

Table B.4—Traditional chemical stabilizers (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface runoff: None.

Erosion: None.

Water quality: None.

Aquatic species: None.

Plant quality: None.

Air quality: None.

Other: None.

Ability to Recycle/Reuse: The treated soil/aggregate can be crushed/pulverized and reused a general construction fill material.

Other Environmental Considerations: None.

AESTHETICS

Appearance: Cement stabilization does not significantly alter the appearance of a soil/aggregate material. The appearance will be of a soil/aggregate surface with the overall color determined by the material type and source. However, the cement-stabilized subgrade and base layers are typically not visible once the roadway is constructed.

Appearance Degradation Over Time: N/A

COST

Supply Price: N/A

Supply + Install Price: \$3.30 to \$4.10/m^2 (\$2.80 to \$3.40/yd^2) for 150 mm (6 in) mixing depth.

EXAMPLE PROJECTS

Joshua Tree National Park, CA.

SELECT RESOURCES

Portland Cement Association (2003). Soil-Cement Information: Properties and Uses of Cement-Modified Soils, IS 411.02, Portland Cement Association, 12 pp.

APPENDIX C—TRADITIONAL CHEMICAL STABILIZERS: USACE METHOD OF SELECTING AND DETERMINING QUANTITIES

Figure C.1 (a soil gradation triangle) and table C.1 are used, in combination, to determine candidate stabilizers. The triangle in figure C.1 is divided into areas of soils with similar grain size. Enter the figure with percent passing the #200 sieve and total percent material between the #4 and #200 sieves (i.e., percent passing the #4 but retained on the #200 sieve), then proceed to table C.1, which provides candidate stabilizers corresponding to each area in the triangle as well as restrictions based on grains size and/or plasticity index (PI). The area from figure C.1 is in the first column, the soil classification (which provides a check) is in the second column, candidate stabilizers are in the third column, and restrictions on use are in the remaining columns.

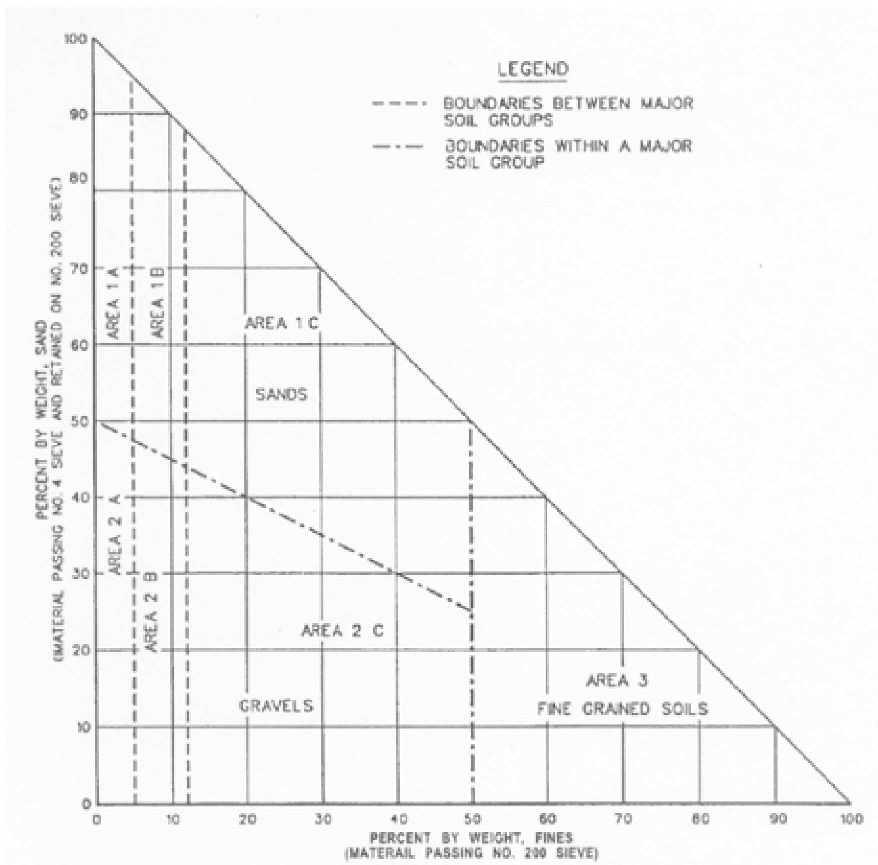


Figure C.1—Gradation triangle for aid in selecting a commercial stabilizing agent (from Army 1994).

APPENDIX C

Table C.1—Guide for selecting stabilizing additive (slight variation of table B-1) (from Army 1994)

Area	Soil Class.[a]	Type of Stabilizing Additive Recommended	Restriction on LL and PI of Soil	Restriction on Percent Passing No. 200 Sieve[a]	Remarks
1A	SW or SP	(1) Bituminous			
		(2) Portland cement			
		(3) Lime-cement-fly ash	PI not to exceed 25		
1B	SW-SM or SP-SM or SW-SC or SP-SC	(1) Bituminous	PI not to exceed 10		
		(2) Portland cement	PI not to exceed 30		
		(3) Lime	PI not to exceed 12		
		(4) Lime-cement-fly ash	PI not to exceed 25		
1C	SM or SC or SM-SC	(1) Bituminous	PI not to exceed 10	Not to exceed 30% by weight	
		(2) Portland cement	--[b]		
		(3) Lime	PI not less than 12		
		(4) Lime-cement-fly ash	PI not to exceed 25		
2A	GW or GP	(1) Bituminous			Well-graded material only
		(2) Portland cement			Material should contain at least 45% by weight of material passing No. 4 sieve
		(3) Lime-cement-fly ash	PI not to exceed 25		
2B	GW-GM or GP-GM or GW-GC or GP-GC	(1) Bituminous	PI not to exceed 10		Well-graded material only
		(2) Portland cement	PI not to exceed 30		Material should contain at least 45% by weight of material passing No. 4 sieve
		(3) Lime	PI not less than 12		
		(4) Lime-cement-fly ash	PI not to exceed 25		
2C	GM or GC or GM-GC	(1) Bituminous	PI not to exceed 10	Not to exceed 30% by weight	Well-graded material only
		(2) Portland cement	--[b]		Material should contain at least 45% by weight of material passing No. 4 sieve
		(3) Lime	PI not less than 12		
		(4) Lime-cement-fly ash	PI not to exceed 25		
3	CH or CL or MH or ML or OH or OL or ML-CL	(1) Portland	LL less than 40 and PI less than 20		Organic and strongly acid soils falling within this area are not susceptible to stabilization by ordinary means
		(2) Lime	PI not less than 12		

[a] Soil classification corresponds to MIL-STD-619B. Restriction on liquid (LL) and plasticity index (PI) is in accordance with Method 103 in MIL-STD-621A.

[b] $PI \leq 20 + \frac{50 - \text{percent passing No. 200 sieve}}{4}$

Caution: If using cement, lime, or lime-cement-fly ash, it is critical that materials be stabilized well in advance of freezing. Chemical reactions will not occur for lime-stabilized materials when the soil temperature is less than 60 °F and is not expected to increase for a month. Significant additional research was recently conducted by the U.S. Army Engineer and Research Development Center; results are discussed in Rollings et al. (internal CRREL report 2002).

Table C.2a—Portland Cement (Note: Do not use cement-stabilized material for surfacing)

Portland Cement
Screening tests for organic matter and sulfates.
Organic compounds: Organic compounds of low molecular weight, such as nucleic acid and dextrose, both retard hydration and reduce strength. *If organic compounds are suspected, a pH test should be conducted as described in table E.1, appendix E (Army 1994)*. If the pH of a 10:1 mixture by weight of soil and cement is at least 12 (15 minutes after mixing), organics will probably not adversely affect hardening. **Sulfates:** Sulfate-clay reactions can cause deterioration of fine-grained soil cement. *If sulfate is suspected, a procedure for determining percent SO_4 should be conducted as outlined in appendix E (Army 1994).* If either of these test positive, you may have problems; try an alternate stabilizer.
The procedure for determining quantity of additive (by conducting strength tests on trial specimens of varying cement content) follows.
Proceed to appropriate steps in modifying or improving strength characteristics box, depending on objective.
Determining cement content for modification.
Improve plasticity ■ For reducing plasticity, trial-and-error is recommended. ■ For reducing PI, successive samples should be prepared at various treatment levels, and the PI for each determined using ASTM D 423 and D 424. Select the minimum cement content that yields the desired PI. Because this was determined based on the minus 40 fraction of the soil, an adjustment must be made to determine the design cement content based on total sample weight: A=100BC where: A = design cement content, percent total weight of soil. B = percent passing #40 sieve, expressed as a decimal. C = percent cement required to obtain desired PI of minus 40 material, expressed as a decimal. **Improve gradation**—Determine gradation (ASTM D 422) at various treatment levels and select lowest cement content that yields acceptable gradation. **Reduce swell potential**—Portland cement is not as effective as lime for reducing swell potential, and will probably be expensive. However, the quantity required can be determined by molding several samples at various cement content, and soaking along with untreated samples for 4 days. Design cement content is the minimum cement content that reduces swell characteristics to a minimum. **Frost considerations**—Extreme caution must be exercised if used in areas subject to seasonal freezing. See Department of the Army, Navy, and Air Force (1994) or Rollings et al. (2002) for details if it must be used in frost situations.

Table C.2a—Portland Cement (Note: Do not use cement-stabilized material for surfacing) continued

Determining cement content for stabilization (for improved strength characteristics).

1. **Determine the classification (ASTM D 422) and gradation (ASTM D 2487) of the untreated soil**. (This was probably already determined when deciding if a stabilizer was needed at all.)
2. **Using the table immediately below, select an estimated trial cement content for moisture density tests.**

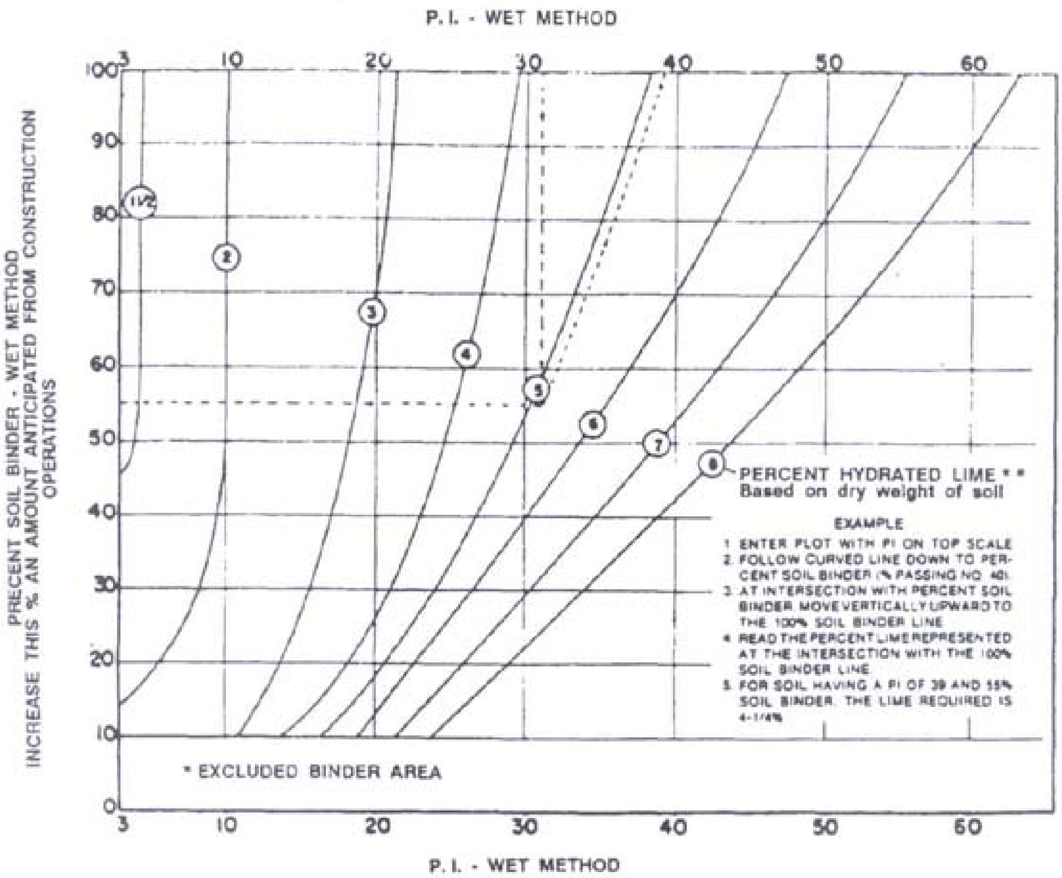
Cement requirements for various soils

Soil Classification	Initial Estimated Cement Content percent dry weight
GW, SW	5
GP, GW-GC, GW-GM, SW-SC, SW-SM	6
GC, GM, GP-GC, GP-GM, GM-GC, SC SM, SP-SC, SP-SM, SM-SC, SP	7
CL, ML, MH	8
CH	11

3. **Prepare soil-cement mixture according to ASTM D 558.**
4. **Conduct moisture-density tests to determine maximum dry density and optimum water content of the soil-cement mixture in accordance to ASTM D 1557.**
5. **Prepare three samples in accordance with ASTM D 1632** (exception: if more than 35 percent is retained on the #4 sieve, a 4-inch diameter mold should be used to prepare the specimen) – one each at the cement content determined in steps 4, at 2 percent above that cement content and at 2 percent below that cement content. Water content and density should be approximately the same as expected in the field.
6. **Cure in a humid room for 7 days.**
7. **Test specimens using unconfined compression tests in accordance with ASTM D 560.**
8. **The lowest cement content that yields an unconfined compressive strength of 250 psi is the design cement content. If results do not meet this criterion, the steps 3 through 7 should be repeated at higher cement contents.**

Table C.2b—Lime

Lime
The procedure for determining quantity of additive (by conducting strength tests on trial specimens of varying lime content) is provided below.
Proceed to appropriate steps in modifying or improving strength characteristics box, depending on objective.
Lime content for lime-modified soil.
The same trial-and-error process is used to determine quantities to modify using lime as were used to modify using cement.
Lime content for lime stabilization (for improved strength characteristics).
1. **Determine initial design lime content via figure C.2. An example problem is provided in the figure's key.** 2. **Prepare soil lime mixture in accordance with ASTM D 3351, using the initial design lime content determined in step 1.** 3. **Conduct moisture-density tests in accordance with ASTM D 1557.** 4. **Prepare three samples in accordance with ASTM D 3551.** (If less than 35 percent is retained on the #4 sieve, samples should be approximately 2 inches in diameter and 4 inches high. If more than 35 percent is retained on the #4 sieve, samples should be approximately 4 inches in diameter and 8 inches high.) Samples should be one each at the lime content determined above, at 2 percent above that lime content and at 2 percent below that lime content. Water content and density should be approximately the same as expected in the field. 5. **Cure specimens at approximately 73 ºF for 28 days in a sealed metal can or plastic bag to prevent moisture loss and lime carbonation.** 6. **Test specimens using unconfined compression tests in accordance with ASTM D 560.** 7. **The lowest lime content that yields an unconfined compressive strength of 250 psi is the design cement content. If results do not meet this criterion, process should be repeated at higher cement contents.**



* Exclude use of chart for materials with less than 10% - No. 40 and cohesionless materials (P. I. less than 3)

** Percent of relatively pure lime usually 90% or more of Ca and/or Mg hydroxides and 85% or more of which pass the No. 200 sieve. Percentages shown are for stabilizing subgrades and base courses where lasting effects are desired. Satisfactory temporary results are sometimes obtained by the use of as little as 1/2 of above percentages. Reference to cementing strength is implied when such termes as "Lasting Effects" and "Temporary Resulst" are used.

Figure C.2—Initial lime content.

Table C.2c—Lime-Fly Ash (LF) and Lime-Cement Fly Ash (LCF)

Lime-Fly Ash and Lime-Cement Fly Ash
The procedure for determining quantity of additive (by conducting strength tests on trial specimens of varying lime content) is provided below.
Proceed to appropriate steps in modifying or improving strength characteristics box, depending on objective.
Lime content for lime-modified soils.
The same trial-and-error process is used to determine quantities to modify using lime as were used to modify using cement.
Lime content for lime stabilization (for improved strength characteristics)
1. **Determine initial design lime content via figure C.2. An example problem is provided in the figure's key.** 2. **Prepare soil lime mixture in accordance with ASTM D 3351, using the initial design lime content determined in step 1.** 3. **Conduct moisture-density tests in accordance with ASTM D 1557.** 4. **Prepare three samples in accordance with ASTM D 3551**. (If less than 35 percent is retained on the #4 sieve, samples should be approximately 2 inches in diameter and 4 inches high. If more than 35 percent is retained on the #4 sieve, samples should be approximately 4 inches in diameter and 8 inches high.) Samples should be one each at the lime content determined above, at 2 percent above that lime content and at 2 percent below that lime content. Water content and density should be approximately the same as expected in the field. 5. **Cure specimens at approximately 73 ºF for 28 days in a sealed metal can or plastic bag to prevent moisture loss and lime carbonation.** 6. **Test specimens using unconfined compression tests in accordance with ASTM D 560.** 7. **The lowest lime content that yields an unconfined compressive strength of 250 psi is the design cement content. If results do not meet this criterion, process should be repeated at higher cement contents.**

Table C.2d—Bitumen/asphalt

Bitument/Asphalt
The type of bitumen (asphalt cement, black asphalt, or asphalt emulsion) to be used depends on type of soil to be stabilized, construction method, and weather conditions. **Frost areas:** Tar should be avoided for use as a binder because it is highly sensitive to temperature. Asphalts are slightly less affected by temperature; best results can be obtained by using the most viscous liquid asphalt that can be readily mixed into the soil. **Construction:** Bituminous stabilization can be performed in place – the bitumen is applied directly on the soil, and it is mixed and compacted immediately. Liquid asphalts, cutbacks, and emulsions can be used. However, emulsions are preferred because of pollution control efforts. Bitumen type and grade depends on characteristics of the aggregate, type of construction equipment, and climate. General guidelines follow: Open-graded aggregate. ■ Rapid- and medium-curing liquid asphalts RC-250, RC-800, and MC-3000. ■ Medium-setting asphalt emulsion MS-2 and CMS-2. Well-graded aggregate with little or no material passing the #200 sieve. ■ Rapid- and medium-curing liquid asphalt RC-250, RC-800, MC-250, and MC-800. ■ Slow-curing liquid asphalts SC-250 and SC-800. ■ Medium-setting and slow-setting asphalt emulsions MS-2, CMS-2, SS-1, and CSS-1 Aggregate with a considerable percentage of fine aggregate and material passing the #200 sieve. ■ Medium-curing liquid asphalt MC-250 and MC-800. ■ Slow-curing liquid asphalts SC-250 and SC-800. ■ Slow-setting asphalt emulsions SS-1, SS-01h, CSS-1, and CSS-1h. The easiest type of bitumen stabilization is the application of liquid asphalt to the surface of an aggregate-surfaced or unsurfaced road, in which case slow- and medium-curing liquid asphalts SC-70, SC-250, MC-70, and MC-250 are used. The table immediately below provides recommended subgrade soil gradation.

Recommended subgrade soil gradation	
Sieve Size	***Percent Passing***
3 in	100
#4	50-100
#30	38-100
#200	2-30

Table C.2d—Bitumen/asphalt continued.

For subgrade stabilization, the preliminary quantity of cutback can be estimated by:

$$P = \frac{.002(a) + 0.07(b) + 0.15(c) + 0.20(d)}{(100\text{-}S)} \times 100$$

where:

p = percent cutback asphalt by weight of dry aggregate

a = percent of mineral aggregate retained on #50 sieve

b = percent of mineral aggregate passing #50 sieve and retained on #100 sieve

c = percent of mineral aggregate passing #100 and retained on #200 sieve

d = percent of mineral aggregate passing #200 sieve

S = percent solvent

The table immediately below provides the preliminary quantity of emulsified asphalt to be used in stabilizing subgrades.

Emulsified Asphalt Requirements

Percent Passing #200 Sieve	Pounds of Emulsified Asphalt per 100 pound of Dry Aggregate at Percent Passing #10 Sieve					
	<50	**60**	**70**	**80**	**90**	**100**
0	6.0	6.3	6.5	6.7	7.0	7.2
2	6.3	6.5	6.7	7.0	7.2	7.5
4	6.5	6.7	7.0	7.2	7.5	7.7
6	6.7	7.0	7.2	7.5	7.7	7.9
8	7.0	7.2	7.5	7.7	7.9	8.2
10	7.2	7.5	7.7	7.9	8.2	834
12	7.5	7.7	7.9	8.2	8.4	8.6
14	7.2	7.5	7.7	7.9	8.2	8.4
16	7.0	7.2	7.5	7.7	7.9	8.2
18	6.7	7.0	7.2	7.5	7.9	7.9
20	6.5	6.7	7.0	7.2	7.5	7.6
22	6.3	6.5	6.7	7.0	7.2	7.5
24	6.0	6.3	6.5	6.7	7.0	7.2
25	6.2	6.4	6.6	6.9	7.1	7.3

Table C.2d—Bitumen/asphalt continued.

Final quantities of emulsified or cutback asphalts can be selected based on results of the Marshall Stability test procedure. Detailed procedures vary from agency to agency, and State to State; however, typical procedures are available in MS-02, Asphalt Institute (1997).

If an increase in stability is not exhibited by adding reasonable amounts of bituminous materials, the soil should either be modified or a different bituminous material should be used. The soil can be modified by adding material passing the #200 sieve.

Table C.2e—Lime-Cement and Lime-Bitumen

Lime-Cement and Lime-Bitumen

Lime-Cement: Lime can serve as an additive to the primary stabilizer, cement, to reduce soil plasticity for improved workability.

Design lime quantity is the minimum amount that achieves desired workability.

Design cement quantity is determined as outlined above under cement.

Lime-Bitumen: Lime can serve as an additive to the primary stabilizer, asphalt, to act as an antistripping agent and improve workability.

Design lime quantity is 1-2 percent.

Design quantity for asphalt is determined as outlined above under bitumen/asphalt stabilization.

Table C.2f—Lime Treatment of Expansive Soils

Expansive soils are defined as those that exhibit swelling of 3 percent or greater. The table immediately below shows swell potential of soils, based on plasticity characteristics.

Swell Potential of Soils

Liquid Limit	Plasticity Index	Potential Swell
>60	>35	High
50-60	25-35	Marginal
<50	<25	Low

Lime may reduce swell in expansive soils to varying degrees. The amount to be added is the minimum that will reduce swell to acceptable limits. Swell tests can be conducted in accordance with ASTM D 1883.

APPENDIX D

ASTM Soil Tests

APPENDIX D

Table D.1—Testing the soil. From Transportation Research Circular E-C086: Evaluation of Chemical Stabilizers, State-of-the-Practice Report, Transportation Research Board of the National Academies, Washington, D.C., 2005, Table 2, pages 6-8. Reprinted with permission of TRB.

Properties	1983 Circular ASTM/ AASHTO	2000 ASTM	2000 AASHTO	Title ASTM or AASHTO
Atterberg Limits	D 423	None	None	Liquid Limit of Soils
	D 424	None	None	Plastic Limit and Plasticity Index of Soils
	None	D 4318-98	T 89-90, T 90-97	Liquid Limit, Plastic Limit, and Plasticity Index of Soils, Test Method for
Bearing Ratio	D 1883	D 1883-99	T 193-81 (1990)	CBR (California Bearing Ratio) of Laboratory Compacted Soils, Test Method for
	None	D 4429-93	None	CBR (California Bearing Ratio) of Soils in Place, Test Method for
	D 3668	D 3668-78 (1985)	None	Bearing Ratio of Laboratory Compacted Soil-Lime Mixtures, Test Method for
	(4)	None	None	Iowa K-Test
Classification	D 2487	D 2487-98	None	Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
	None	D 420-98	T 86-90	Guide to Site Characterization for Engineering, Design and Construction Purposes
	D 3282	D 3282-93 (1997)	None	Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
	None	D 448-98	M 43-88	Classification for Sizes of Aggregate for Road and Bridge Construction
Color	D 2488	D 2488-93	None	Description and Identification of Soils (Visual-Manual Procedure), Practice for
	D 1535	D 1535-97	None	Specifying Color by the Munsell System, Practice for
	D 1729	D 1729-96	None	Visual Appraisal of Color and Color Differences of Diffusely-Illuminated Opaque Materials
Compaction Characteristics	D 698	D 698-91 (1998)	T 99-90	Laboratory Compaction Characteristics of Soil Using Standard Effort [12,400 ft*lbf/ft^3 (600kN*m/m^3)], Test Method for
	D 1557	D 1557-91 (1998)	T 180-90	Laboratory Compaction Characteristics of Soil Using Modified Effort [56,000 ft*lbf/ft^3 (2,700kN*m/m^3)], Test Method for
Compressive Strength	D 2166	D 2166-98a	T 208-90	Unconfined Compressive Strength of Cohesive Soil
	AASHTO T 234	D 2850-95	T 234-85 (1990)	Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression, Test Method for
Durability	None	D 5312-92	None	Evaluation of the Durability of Rock for Erosion Control under Freezing and Thawing
	None	D 5313-92	None	Evaluation of the Durability of Rock for Erosion Control under Wetting and Drying Conditions
	None	D 4644-92	None	Slake Durability of Shales and Similar Weak Rocks
	None	None	T 210-96	Aggregate Durability Index

(continued)

Table D.1—Testing the soil. From Transportation Research Circular E-C086: Evaluation of Chemical Stabilizers, State-of-the-Practice Report, Transportation Research Board of the National Academies, Washington, D.C., 2005, Table 2, pages 6-8. Reprinted with permission of TRB (continued).

Properties	1983 Circular ASTM/ AASHTO	2000 ASTM	2000 AASHTO	Title ASTM or AASHTO
Elastic Properties	C 469	C 469-94	None	Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression, Test Method for
Flexural Strength	D 1635	D 1635-95	None	Flexural Strength of Soil-Cement Using Simple Beam with Third-Point Loading, Test Method for
Grain Size Distribution	D 422	D 422-63 (1998)	T 88-90	Particle-Size Analysis of Soils, Test Method for
Mineralogy	D 934	D 934-80 (1999)	None	Identification of Crystalline Compounds in Water-Formed Deposits by X-Ray Diffraction, Practices for
	E 168	E 168-99	None	General Techniques of Infrared Quantitative Analysis, Practices for
	E 14	None	None	Thermal Analysis of Metals and Alloys
Organic Content	D 2974	D 2974-87 (1995)	None	Moisture, Ash, and Organic Matter of Peat and Other Organic Soils, Test Methods for
	AASHTO T194	None	T 194-87	Determination of Organic Matter in Soils by Wet Combustion
	C 40	C 40-99	T 21-87	Organic Impurities in Fine Aggregates for Concrete, Test Method for
Permeability	D 2434	D 2434-68 (1994)	T 215-70 (1990)	Permeability of Granular Soils (Constant Head), Test Method for
	None	None	None	Permeability of Cohesive Soils (Falling Head)
pH Value	D 2976	D 2976-71 (1998)	None	pH of Peat Materials, Test Method for
	G 51	G 51-95 (2000)	None	Measuring pH of Soil for Use in Corrosion Testing, Test Method for
	None	D 4972-95a	None	pH of Soils, Test Method for
Rain Erosion	*(3)*	None	None	
Resilient Modulus	None	None	T 292-91	Resilient Modulus of Subgrade Soils and Untreated Base/Subbase Materials
Shear Strength	D 3080	D 3080-98	T 236-84 (1990)	Direct Shear Test of Soils Under Consolidated Drained Conditions, Test Method for
	AASHTO T 234	D 2850-95	T 234-85 (1990)	Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression, Test Method for
Shrinkage Potential	D 427	D 427-98	T 92-88	Shrinkage Factors of Soils by the Mercury Method, Test Method for
	None	D 4943-95	None	Shrinkage Factors of Soils by the Wax Method, Test Method for
	D 559	D 559-96	None	Wetting and Drying Compacted Soil-Cement Mixtures, Test Methods for
Specific Gravity	D 854	D 854-98	T 100-90	Specific Gravity of Soils, Test Method for
	None	D 5550-94	None	Specific Gravity of Soil Solids by Gas Pycnometer, Test Method for

(continued)

APPENDIX D

Table D.1—Testing the soil. From Transportation Research Circular E-C086: Evaluation of Chemical Stabilizers, State-of-the-Practice Report, Transportation Research Board of the National Academies, Washington, D.C., 2005, Table 2, pages 6-8. Reprinted with permission of TRB (continued).

Properties	1983 Circular ASTM/ AASHTO	2000 ASTM	2000 AASHTO	Title ASTM or AASHTO
Swell Potential	AASHTO T258	None	T 258-81	Determining Expansive Soils
	D 559	D 559-96	None	Wetting and Drying Compacted Soil-Cement Mixtures, Test Methods for
Tensile Strength	C 496-71	C 496-96	T 198-86	Splitting Tensile Strength of Cylindrical Concrete Specimens, Test Method for
	(5)	None	None	Static Double Punch Test
Traffic Erosion	*(3)*	None	None	
Wind Erosion	*(3)*	None	None	

APPENDIX E

pH and Sulfate Tests

APPENDIX E—PH AND SULFATE TESTS

Table E.1—pH Test on Soil-Cement Mixtures (Army 1994)

Materials	Portland cement to be used for soil stabilization.
Apparatus	Apparatus used are the pH meter (the pH meter must be equipped with an electrode having a pH range of 14), 150 milliliter plastic bottles with screw-tops lids, 150-milliliter plastic beakers, distilled water, balance, oven, and moisture cans.
Procedure	a. Standardization: Standardize the pH meter with a buffer solution of 12.00. b. Representative samples: Weigh to the nearest 0.01 grams, representative samples of air-dried soil, passing the #40 sieve and equal to 25.0 grams of oven dried soil. c. Soil samples: Pour the samples into 150-milliliter plastic bottles with screw-top lids. d. Portland cement: Add 2.5 grams of the Portland cement. e. Mixture: Thoroughly mix soil and Portland cement. f. Distilled water: Add sufficient distilled water to make a thick paste. (Caution: Too much water will reduce the pH and produce an incorrect result.) g. Blending: Stir the soil-cement and water until thorough blending is achieved. h. Transferal: After 15 minutes, transfer part of the paste to a plastic beaker and measure the pH. Interference: If the pH is 12.1 or greater, the soil organic matter content should not interfere with the cement stabilizing mechanism.

APPENDIX E

Determination of Sulfate in Soils Gravimetric Method (Army 1994)

a. Scope. Applicable to all soil types with the possible exception of soils containing certain organic compounds. This method should permit the detection of as little as 0.05 percent sulfate as SO,.

b. Reagents. Reagents include barium chloride, 10 percent solution of $BaCl_2 \cdot 2H_2O$ (Add 1 milliliter 2 percent HCl to each 100 milliliter of solution to prevent formation of carbonate.); hydrochloric acid, 2 percent solution (0.55 N); magnesium chloride, 10 percent solution of $MgCl_2 \cdot 6H_2O$; demineralized water; and silver nitrate, 0.1 N solution.

c. Apparatus. Apparatus used are a beaker, 100 milliliter; burner and ring stand; filtering flask, 500 milliliter; Buchner funnel, 90 milliliter; filter paper, Whatman No. 40, 90 millimeter; filter paper, Whatman No. 42, 90 millimeter; Saran Wrap; crucible, ignition, or aluminum foil, heavy grade; analytical balance; and aspirator or other vacuum source.

d. Procedure.

(1) Select a representative sample of air-dried soil weighing approximately 10 grams. Weigh to the nearest 0.01 gram. (Note: When sulfate content is anticipated to be less than 0.1 percent, a sample weighing 20 gram or more may be used.) (The moisture content of the air-dried soil must be known for later determination of dry weight of the soil.)

(2) Boil for 1-1/2 hours in beaker with mixture of 300-milliliter water and 15-milliliter HCl.

(3) Filter through Whatman No. 40 paper, wash with hot water, dilute combined filtrate and washings to 50 milliliter.

(4) Take 100 milliliter of this solution and add $MgCl_2$ solution until no more precipitate is formed.

(5) Filter through Whatman No. 42 paper, wash with hot water, dilute combined filtrates and washings to 200 milliliter.

(6) Heat 100 milliliter of this solution to boiling and add $BaCl_2$ solution very slowly until no more precipitate is formed. Continue boiling for about 5 minutes and let stand overnight in warm place, covering beaker with Saran Wrap.

(7) Filter through Whatman No. 42 paper. Wash with hot water until free from chlorides (filtrate should show no precipitate when a drop of $AgNO_3$ solution is added).

(8) Dry filter paper in crucible or on sheet of aluminum foil. Ignite paper. Weight residue on analytical balance as $BaSO_4$.

e. Calculation.

$$\text{Percent SO,} = \frac{\text{Weight of residue}}{\text{Oven-dry weight of initial sample}} \times 411.6$$

where

Oven-dry weight of initial sample

$$= \frac{\text{Air-dry weight of initial sample}}{1 + \dfrac{\text{Air-dry moisture content (percent)}}{100 \text{ percent}}}$$

Note: If precipitated from cold solution, barium sulfate is so finely dispersed that it cannot be retained when filtering by the above method. Precipitation from a warm, dilute solution will increase crystal size. Due to the absorption (occlusion) of soluble salts during the precipitation by $BaSO_4$, a small error is introduced. This error can be minimized by permitting the precipitate to digest in a warm, dilute solution for a number of hours. This allows the more soluble small crystals of $BaSO_4$ to dissolve and recrystallize on the larger crystals.

Determination of Sulfate in Soils Turbidimetric Method (Army 1994)

a. Reagents. Reagents include barium chloride crystals (Grind analytical reagent grade barium chloride to pass a 1-millimeter sieve.); ammonium acetate solution (0.5 N) (Add dilute hydrochloric acid until the solution has a pH of 4.2); and distilled water.

b. Apparatus. Apparatus used are a moisture can; oven, 200-milliliter beaker; burner and ring stand; filtering flask; Buchner funnel, 90 millimeter; filter paper, Whatman No. 40, 90 millimeter; vacuum source; spectrophotometer and standard tubes (Bausch and Lombe Spectronic 20 or equivalent) and pH meter.

c. Procedure.

(1) Take a representative sample of air-dried soil weighing approximately 10 grams, and weight to the nearest 0.01 grams. (The moisture content of the air-dried soil must be known for later determination of dry weight of the soil.)

(2) Add the ammonium acetate solution to the soil. (The ratio of soil to solution should be approximately 1:5 by weight.)

(3) Boil for about 5 minutes.

(4) Filter through Whatman No. 40 filter paper. If the extracting solution is not clear, filter again.

(5) Take 10 milliliter of extracting solution (this may vary, depending on the concentration of sulfate in the solution) and dilute with distilled water to about 40 milliliter. Add about 0.2 gram of barium chloride crystals and dilute to make the volume exactly equal to 50 milliliter. Stir for 1 minute.

(6) Immediately after the stirring period has ended, pour a portion of the solution into the standard tube and insert the tube into the cell of the spectrophotometer. Measure the turbidity at 30-second intervals for 4 minutes. Maximum turbidity is usually obtained within 2 minutes and the readings remain constant thereafter for 3-10 minutes. Consider the turbidity to be the maximum reading obtained in the 4-minute interval.

(7) Compare the turbidity reading with a standard curve and compute the sulfate concentration (as SO_4) in the original extracting solution. (The standard curve is secured by carrying out the procedure with standard potassium sulfate solutions.)

(8) Correction should be made for the apparent turbidity of the samples by running blanks in which no barium chloride is added.

d. Sample calculation.

Given: Weight of air-dried sample = 10.12 grams
Water content = 9.36 percent
Weight of dry soil = 9.27 grams
Total volume of extracting solution = 39.1 milliliters

10 milliliters of extracting solution was diluted to 50 milliliters after addition of barium chloride (see step 5). The solution gave a transmission reading of 81. From the standard curve, a transmission reading of 81 corresponds to 16.0 parts per million. (See fig C-l)

Concentration of original extracting solution = 16.0 x 5 = 80.0 parts per million.

$$\text{Percent } SO_4 = \frac{80.0 \times 39.1 \times 100}{1{,}000 \times 1{,}000 \times 9.27} = 0.0338 \text{ percent}$$

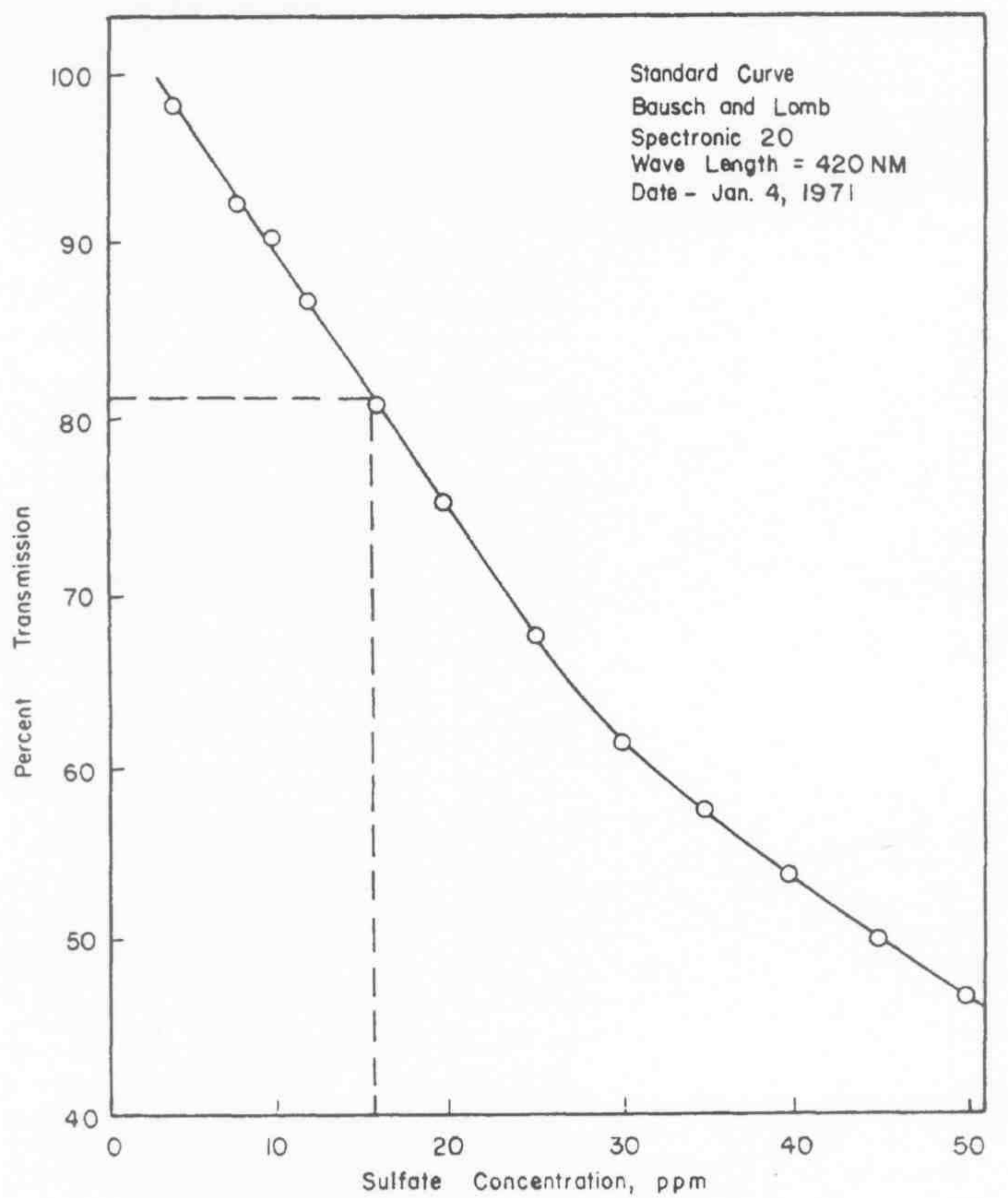
e. Determination of standard curve.

(1) Prepare sulfate solutions of 0, 4, 8, 12, 16, 20, 25, 30, 35, 40, 45, and 50 parts per million in separate test tubes. The sulfate solution is made from potassium sulfate salt dissolved in 0.5 N ammonium acetate (with pH adjusted to 4.2).

Determination of Sulfate in Soils Turbidimetric Method (Army 1994)
(continued)

(2) Continue steps 5 and 6 in the procedure as described in Determination of Sulfate in Soil by Turbidimetric Method.

(3) Draw standard curve as shown in figure C-1 by plotting transmission readings for known concentrations of sulfate solutions.



APPENDIX F

Evaluation of Stabilizers

Evaluation of Stabilizers

Many chemical stabilizers have been evaluated by the U.S. Army Corps of Engineers Research and Development Centers, Texas Transportation Institute, and State departments of transportation. The following publications provide comprehensive summaries of such evaluation procedures, results, and related information (Petry and Sobhan 2005). It is recommended that the following selected publications be reviewed prior to undertaking evaluations of a product or expanding upon baseline evaluations.

Chemical

- Special Product Evaluation List published by FHWA (FHWA 1975).
- Similar information published by TRB (TRB 1977).
- University of Arizona (Sultan 1976).
- Iowa State (Hoover and Handy 1978).
- Summaries for evaluating chemical stabilizers and performance-based testing of stabilized soils (Petry 1997, Petry and Das 2001).

Testing Properties Before and After Chemical Stabilization

Laboratory Testing To Aid in Selection of Chemical Stabilizer

Tables D-1 and F-1 (Petry and Sobhan 2005) provide ASTM, AASHTO and other procedures for testing various properties of the chemical stabilizer and soil to be treated, respectively.

Laboratory and Field Testing To Determine Effectiveness of Chemical Stabilizer

Table F-2 provides similar and additional procedures for testing the effectiveness of the stabilizer (Petry and Sobhan 2005).

Monitoring To Determine Long-Term Performance

Field monitoring is recommended to determine long-term performance. In addition to observing properties that were intended to be modified by stabilization (i.e., does the increased strength last, or does road deteriorate), one should be alert to (anticipated or unanticipated) beneficial or detrimental effect of stabilizer on surrounding vegetation, culverts, etc.

APPENDIX F

Table F.1—Testing the chemicals (From Transportation Research Circular E-C086: Evaluation of Chemical Stabilizers, State-of-the-Practice Report, Transportation Research Board of the National Academies, Washington, D.C., 2005, Table 1, pages 4-5) (Reprinted with permission of TRB)

Properties	1983 Circular ASTM/ AASHTO	2000 ASTM	2000 AASHTO	Title ASTM or AASHTO
Chemical Constituents	C 25	C 25-99	None	Chemical Analysis of Limestone, Quicklime, and Hydrated Lime
	None	C 1164-92 (1997)e1	None	Evaluation of Limestone or Lime Uniformity from a Single Source
	None	C 110-00	None	Physical Testing of Quicklime, Hydrated Lime, and Limestone, Test Methods for
	None	C 977-95	M 216-84 (1990)	Specifications for Quicklime and Hydrated Lime for Soil Stabilization
	C 146	C 146-94a (1999)	None	Chemical Analysis of Glass Sand, Test Methods for
	C 471	C 471M-96	None	Chemical Analysis of Gypsum and Gypsum Products [Metric], Test Methods for
	None	C 472-99	None	Physical Testing of Gypsum, Gypsum Plasters, and Gypsum Concrete, Test Methods for
	C 575	None	None	Chemical Analysis of Silica Refractories
	D 1570	D 1570-95	None	Sampling and Chemical Analysis of Fatty Alkyl Sulfates, Test Methods for
Color	D 1535	D 1535-97	None	Specifying Color by the Munsell System, Practice for
	D 1729	D 1729-96	None	Visual Appraisal of Colors and Color Differences of Diffusely Illuminated Opaque Materials, Practice for
Odor	E 679	E 679-91	None	Determination of Odor and Taste Thresholds by a Forced-Choice Ascending Concentration Series Method of Limits, Practice for

(continued)

Table F.1—Testing the chemicals (continued)

Properties	1983 Circular ASTM/ AASHTO	2000 ASTM	2000 AASHTO	Title ASTM or AASHTO
pH Value	E 70	E 70-97	T 200-79 (1990)	pH of Aqueous Solution with the Glass Electrode, Test Methods for
	D 2081	D 2081-92 (1998)	None	pH of Fatty Quaternary Ammonium Chlorides, Test Methods for
	E 70	E 70-97	T 200-79 (1990)	pH of Aqueous Solution with the Glass Electrode, Test Methods for
	D 2081	D 2081-92 (1998)	None	pH of Fatty Quaternary Ammonium Chlorides, Test Methods for
	None	D 2076-92 (1998)	None	Acid Value and Amine Value of Fatty Quaternary Ammonium Chlorides, Test Methods for
	D 3643	D 3643-98	None	Acid Number of Certain Alkali-Soluble Resins, Test Methods for
	D 2379	D 2379-99	None	Acidity of Formaldehyde Solutions
	C 110	C 110-00	None	Physical Testing of Quicklime, Hydrated Lime, and Limestone, Test Methods for
Specific Gravity	D 3142	D 3142-97	T 227-89	Density of Liquid Asphalts (Hydrometer Method), Test Methods for
	D 70	D 70-97	T 228-90	Density of Semi-Solid Bituminous Materials (Pycnometer Method), Test Method for
	None	D 3289-97	None	Density of Semi-Solid and Solid Bituminous Materials (Nickel Crucible Method), Test Method for
	D 3505	D 3505-96	None	Density or Relative Density of Pure Liquid Chemicals, Test Method for
	AASHTO T228	D 70-76	T 228-90	Density of Semi-Solid Bituminous Materials (Pycnometer Method), Test Method for
Toxicity	D 1345	None	None	Evaluating Acute Toxicity of Water to Fresh-Water Fishes
	None	E 1440-91	None	Guide for Acute Toxicity Test With the Rotifer Brachionus
	None	E 729-96	None	Guide for Conducting Acute Toxicity Test on Test Materials with Fishes, Macroinvertebrates, and Amphibians
Viscosity	D 88	D 88-94 (1999)	T 72-90	Saybolt Viscosity, Test Method for
	None	D 2161-93 (1999)	None	Conversion of Kinematic Viscosity to Saybolt Universal Viscosity or to Saybolt Furol Viscosity
	D 445	D 445-97	None	Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity), Test Method for
	D 1725	D 1725-62 (1996)	None	Viscosity of Resin Solutions, Test Method for
	D 2393	None	T 201-90	AASHTO: Kinematic Viscosity of Asphalts

APPENDIX F

Table F.2—Testing treated soil (From Transportation Research Circular E-C086: Evaluation of Chemical Stabilizers, State-of-the-Practice Report, Transportation Research Board of the National Academies, Washington, D.C., 2005, Table 3, pages 12-14) (Reprinted with permission of TRB)

Properties	1983 Circular ASTM/ AASHTO	2000 ASTM	2000 AASHTO	Title ASTM or AASHTO
Cyclic Wetting/ Drying	D 559	D 559-96	T 135-76	Wetting and Drying Compacted Soil-Cement Mixtures, Test Methods for
Deformation/ Cohesion	D 1560	D 1560-92	T 246-82 (1990)	Resistance to Deformation and Cohesion of Bituminous Mixtures by Means of a Vheem Apparatus, Test Methods for
Density	None	D 2922-91	None	Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)
Elastic Properties	C 469	C 469-94	None	Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression, Test Method for
	(6)	None	None	Dynamic Modulus of Elasticity by Cyclic Double-Punch Test
Falling Weight Deflectometer	None	D 4694-87	None	Deflections with a Falling-Weight-Type Impulse Load Device
Flexural Strength	D 1635	D 1635-95	None	Flexural Strength of Soil-Cement Using Simple Beam with Third-Point Loading, Test Method for
	C 78	C 78-94	T 97-86	Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading), Test Method for
	None	C 293-94	T 177-81 (1990)	Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)
Mixing	D 3551	D 3551-90 (1996)	None	Laboratory Preparation of Soil-Lime Mixtures Using a Mechanical Mixer
Penetration	D 5	D 5-97	T 49-89	Penetration of Bituminous Materials, Test Method for
Permeability	D 3637	None	None	Permeability of Bituminous Mixtures
Plastic Flow	D 1559	None	None	Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus, Test Methods for
	None	D 5581-96	T 245-90	Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus (6-in. Diameter Specimen), Test Method for
Rainwater Erosion	*(3)*	None	None	None
Resistance/ Expansion	D 2844	D 2844-94	T 190-90	Resistance R-Value and Expansion Pressure of Compacted Soils, Test Method for
Road Rater	None	D 4602-93	None	Nondestructive Testing of Pavements Using Cyclic Loading Dynamic Deflection Equipment
Shear Strength	D 3080	D 3080-98	T 236-84 (1990)	Direct Shear Test of Soils Under Consolidated Drained Conditions, Test Methods for
	AASHTO T234	D 2850-95e1	T 234-85 (1990)	Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression, Test Method for

(continued)

Table F.2—Testing treated soil (continued)

Properties	1983 Circular ASTM/ AASHTO	2000 ASTM	2000 AASHTO	Title ASTM or AASHTO
Shrinkage	D 427	D 427-98	T 92-88	Shrinkage Factors of Soils by the Mercury Method, Test Methods for
	None	D 4943	None	Shrinkage Factors of Soils by the Wax Method, Test Method for
	None	D 3877-96	None	One-Dimensional Expansion, Shrinkage, and Uplift Pressure of Soil-Lime Mixtures, Test Methods for
	D 559	D 559-96	T 135-76	Wetting and Drying Compacted Soil-Cement Mixtures, Test Methods for
Skid Resistance	None	E 274-90	T 242-96	Skid Resistance of Paved Surface Using a Full-Scale Tire
Soluble Salts	None	D 4542-93	None	Pore water Extraction and Determination of the Soluble Salt Content of Soils by Refractometer
	None	None	T 290-95	Determining Water-Soluble Sulfate Ion Content in Soil
	None	None	T 291-94	Determining Water-Soluble Chloride Ion Content in Soil
Specific Gravity	AASHTO T166	None	T 166-88	Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens
Surface Roughness	None	E 274-93	None	Measuring Pavement Roughness Using a Profilograph
Swell Potential	AASHTO T258	None	T 258-81	Determining Expansive Soils
	D 559	D 559-96	T 135-76	Wetting and Drying Compacted Soil-Cement Mixtures, Test Methods for
Tensile Strength	C 496	C 496-96	T 198-88	Splitting Tensile Strength of Cylindrical Concrete Specimens, Test Method for
	(5)	None	None	Static Double-Punch Test
Traffic Erosion	(3)	None	None	None
Water Absorption	D 915	None	None	Method of Testing Soil-Bituminous Mixtures
Water Effect	D 1075	D 1075-96	T 165-86 (1990)	Effect of Water on Compressive Strength of Compacted Bituminous Mixtures, Test Method for
Wind Erosion	(3)	None	None	None

APPENDIX G

Nontraditional Stabilizers

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005)

CHLORIDES

GENERAL INFORMATION

Generic Name(s): Chlorides, Salts, Calcium Chloride ($CaCl_2$), Magnesium Chloride ($MgCl_2$), Sodium Chloride ($NaCl_2$)

Trade Names: $CaCl_2$: Dowflake, LiquidDow, Roadmaster; $MgCl_2$: Dust-Off, Dus-Top, DustGuard, etc.

Product Description: Chlorides are the most commonly used products for dust suppression in unbound road surfacings. These compounds, which contain chloride salts, can be mixed with other ingredients and are applied either in a liquid or solid state flakes or pellets. Chlorides draw moisture from the air to keep the road surface moist (i.e., hydroscopic) and help resist evaporation of road surface moisture (i.e., deliquescent). By keeping the road surface moist, chlorides reduce the amount of dust generated. Chlorides also facilitate compaction and promote soil stabilization.

Product Suppliers: Cargill Salt, P.O. Box 5621, Minneapolis, MN, 55440-5621, (888) 385-7258, www.cargillsalt.com;

The Dow Chemical Company, P.O. Box 1206, Midland, MI, 48642, (800) 447-4369, www.dow.com; and

Tetra Chemicals, P.O. Box 73087, Houston, TX, 77273, (281) 367-1983, www.tetratec.com.

APPLICATION

Typical Use: Dust suppressant.

Traffic Range: Very low. Chlorides can be used on unbound road surfacing with higher traffic volumes, but more frequent applications are required.

Restrictions:

Traffic: Required application frequency will increase with increased truck traffic or increased vehicle speed.

Climate: Chlorides are not effective in very arid or very wet climates. $MgCl_2$ requires a relative humidity greater than 32 percent at 25 ºC (77 °F) and $CaCl_2$ requires a relative humidity greater than 29 percent at 25 ºC (77 °F) to be effective. $CaCl_2$ performs better at higher humidity; $MgCl_2$ performs better during long dry spells. Chlorides can be leached from an unbound surfacing by rainfall, thus requiring frequent reapplication in very wet climates. $CaCl_2$ will not be leached by rainfall as easily as $MgCl_2$.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

Weather: Unbound road surfacings, including those treated with chlorides, are very susceptible to adverse weather conditions. They will soften significantly in very wet weather and during periods of thaw. Chlorides can reduce the number of freeze-thaw cycles experienced by a surfacing by reducing the freezing temperature of the moisture contained within the unbound material.

Terrain: Unbound road surfacings treated with chlorides can become slippery when wet and should not be used on road sections with steep grades or tight curves.

Soil type: Chlorides should be used in conjunction with competent unbound road surfacing materials (e.g., well-graded gravels). A moderate amount of fines is required to facilitate retention of the chlorides (10 to 25 percent range).

Other: None.

Other Comments: $CaCl_2$ is slightly more effective than $MgCl_2$ at absorbing water and decreasing evaporation. Chlorides can cause corrosion damage to vehicles. Sodium chloride is not as effective as $CaCl_2$ or $MgCl_2$ and is typically only used in cases when other chloride products are not available.

DESIGN

SLC: N/A

Other Design Values: N/A

Base/Subbase Requirements: Unbound road surfacings, including those treated with chloride, should be designed with adequate base and/or subbase support.

Other Comments: Chlorides work best on engineered aggregate surfaces rather than native or uncontrolled, variable materials.

CONSTRUCTION

Availability of Experienced Personnel: Chlorides are a commonly used dust suppressant and experienced contractors are, in general, widely available. Availability may be limited for projects in remote areas. Maintenance crews are used by some agencies for chloride application.

Materials: Chloride additives, which contain chloride salts, can be mixed with other ingredients and are applied either in a liquid or solid state (flakes or pellets). $MgCl_2$ is more readily available in the western United States and $CaCl_2$ is more readily available in the central and eastern United States.

Equipment: Equipment required for chloride application includes: haul vehicles, spreader (for flakes or pellets) or tanker with spray bar (for liquid), grading equipment (i.e., bulldozer or motor grader), water truck (for flakes or pellets), and pneumatic tire roller. Equipment is widely available in urban areas, but availability may be limited in remote areas.

Manufacturing/Mixing Process: Chlorides are obtained from natural brine deposits or as a byproduct of other manufacturing processes. Flakes or pellets are commonly provided in bulk or in 36 or 45 kg (80 or 100 lb) bags. Liquid chloride solutions are transported by rail car or tanker truck. Pellets have the highest chloride concentration, followed by flakes and liquid solution. As an

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

alternative to sprayed-on or in-place mixing, the chloride additive can be mixed with the unbound surfacing material in a pug mill prior to placement.

Placement Process: Chlorides are typically sprayed on. The road surface should be graded to promote drainage and prevent ponding on the road surface that can soften the road surface and underlying subgrade. The top 50 to 100 mm (2 to 4 in) of the road surface may be scarified and loosened, either with a disc or grading equipment, before chloride application. Scarifying the surface allows the chlorides to penetrate evenly and quickly into the road surface. The unbound surfacing material should be moist prior to chloride application if flakes or pellets are used. The chloride additive is applied uniformly using a spreader for pellets or flakes or a tanker with a spray bar for liquid chloride solutions. A water truck must be used to spray the surface and dissolve all flakes and pellets, when used. Chlorides can be blended with the surfacing material using a disc or grading equipment to improve performance, but is generally not as cost effective as the sprayed-on application. If the surface is scarified, a pneumatic tire roller should be used to compact the surfacing material after the chloride additive is applied and mixed.

Weather Restrictions: Do not apply chlorides if rain is likely within 24 hours or during periods of prolonged subfreezing temperatures.

Construction Rate: Chloride application rates can typically be about 3,300 to 5,000 m^2/hr (4,000 to 6,000 yd^2/hr).

Lane Closure Requirements: If the roadway surface is scarified prior to treatment, the roadway lane(s) being treated are closed during construction, so adequate traffic control is needed. The roadway can be opened to traffic as soon as the construction equipment is cleared from the roadway. If the chloride is applied to the surface without scarifying the surface, lane closures are not required.

Other Comments: None.

SERVICEABILITY

Reliability and Performance History: Chlorides are commonly used dust suppressants and have been used on roadway projects for more than 50 years; an extensive amount of research, design and construction information, and project experience is available.

Life Expectancy: Life expectancy varies depending on traffic and rainfall. The life expectancy decreases with increasing traffic, vehicle speed, and rainfall. Based on one published survey (Birst and Hough, 1999), $CaCl_2$ is effective for 3 to 6 months (71 percent) and 6 to 12 months (21 percent). $MgCl_2$ is effective for 3 to 6 months (33 percent) and 6 to 12 months (42 percent). In the majority of the cases, no benefit is seen after 1 year.

Ride Quality: Chloride additives do not affect initial ride quality of the unbound road surfacing; however, chlorides help to decrease the rate of serviceability loss due to potholes and washboarding by reducing the amount of surface particle loss.

Main Distress/Failure Modes: Rutting, washboarding, potholes, dust.

Preservation Needs: All unbound road surfacings should be inspected on a regular basis and maintenance undertaken as appropriate. Periodic grading can correct surface rutting. Regrading can be difficult due to flaking of the treated surfacing.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

SAFETY

Hazards: During construction, exposure to chlorides can cause skin and eye irritation. Loose aggregate chips can create a windshield hazard.

Skid Resistance: Unbound road surfacings generally have poor to average skid resistance. Unbound road surfacings treated with chlorides can become slippery when wet

Road Striping Possible?: No.

Other Comments: Chlorides can increase visibility by reducing dust generation by 50 percent or more.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Chlorides are obtained from natural brine deposits or as a byproduct of other manufacturing processes.

Delivery and Haul Requirements: Chlorides must be hauled from the nearest manufacturer or supplier. Chlorides are generally widely available; however, haul distances may be significant for remote sites. $MgCl_2$ is more readily available in the western United States and $CaCl_2$ is more readily available in the central and eastern United States.

Potential Short-Term Construction Impacts: Chlorides act as a defoliant and may impact vegetation adjacent to the roadway during construction.

Potential Long-Term Environmental Impacts:

Leachate: There is a potential for leaching of chlorides from the road surface in moderate to heavy rains.

Surface runoff: The amount of surface runoff will be determined by the unbound surfacing material and will not be significantly affected by the chlorides.

Erosion: Chlorides will reduce the amount of erosion compared to an untreated unbound surfacing.

Water quality: Water quality can be impacted by chlorides when leaching occurs unless an adequate buffer zone is provided. Public drinking water standards require chloride levels not to exceed 250 mg/L (ppm). Chlorides should not be used when shallow ground water conditions exist because it may cause ground water contamination.

Aquatic species: Chlorides can potentially impact aquatic species if a buffer zone is not provided. A buffer zone of at least 8 m (25 ft) is recommended between chloride-treated roads and bodies of water. Criteria for protection of aquatic species require levels of less than 600 mg/L (ppm) for chronic exposure and 1,200 mg/L (ppm) for short-term exposure. Trout can be affected by concentrations as low as 400 mg/L (ppm).

Plant quality: Chlorides can potentially impact certain plant species; susceptible species include alder, birch, pine, hemlock, larch, poplar, ash, spruce, ornamentals, maple, and numerous species of shrubs and grasses. Chloride use should be restricted within 8 to 9 m (25 to 30 ft) of susceptible vegetation.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

Air quality: Chlorides reduce dust generation by 50 percent or more.

Other: Chlorides can initiate corrosive effects in steel and aluminum alloys.

Ability to Recycle/Reuse: Chloride-treated roadway materials can be fully recycled as a pavement construction material. Potential environmental impacts should be considered prior to reuse of chloride-treated materials.

Other Environmental Considerations: Heat is generated by mixing $CaCl_2$ flakes or pellets with water. For unbound road surfacings, tire/road noise depends on the gradation and surface roughness, but is generally high.

AESTHETICS

Appearance: Chlorides do not significantly alter the appearance of the road surfacing, which will be determined by the unbound surfacing aggregate type and source; however, chlorides may darken the appearance of the surfacing. The surfacing may also appear mottled or blotchy due to segregated fines absorbing more of the chlorides.

Appearance Degradation Over Time: All unbound road surfacing deteriorate over time. Chlorides do not affect the change in appearance over time.

COST

Supply Price: $360 to $450/Mg ($400 to $500/ton).

Supply+Install Price: \$0.30 to \$0.60/m^2 (\$0.25 to \$0.50/yd^2) for surface treatment.

EXAMPLE PROJECTS

Buenos Aires National Wildlife Refuge, AZ.

Deschutes National Forest, OR.

Winema National Forest, OR.

SELECT RESOURCES

Birst, S.; Hough, J. 1999. Chemical Additive Usage on Unpaved Roads in Mountain Plains States, UGPTI Department Publication No. 130, Upper Great Plains Transportation Institute, North Dakota State University, 119 p.

USDA Forest Service. 1999. Dust Palliative Selection and Application Guide, San Dimas Technology and Development Center, 23 p.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

CLAY ADDITIVES

GENERAL INFORMATION

Generic Name(s): Clay Additives, Clay Filler, Bentonite, Montmorillonite

Trade Names: Central Oregon Bentonite, Pelbron, Stabilite, Volclay, and others.

Product Description: Clay additives are naturally occurring soils composed of the mineral montmorillonite. Montmorillonite is a highly plastic clay mineral with a high affinity for water. Clay additives are typically used to stabilize nonplastic crushed aggregates; the cohesive properties of the clay additive help to bind the aggregate particles and prevent raveling and washboarding. The clay additive will also attach to fines in the aggregate mix to reduce fugitive dust. Some dust is still to be expected with clay-stabilized aggregates, so additional dust suppressants are also used in conjunction with the clay additive when dust is an important concern.

Product Suppliers: American Colloid Company, 1500 West Shure Drive, Arlington Heights, IL 60004, (800) 426-5564, www.colloid.com.

Representative product suppliers and trade names are provided for informational purposes only. Inclusion of this information is not an endorsement of any product or company. Additional suppliers and clay additive products are available.

APPLICATION

Typical Use: Dust suppressant, soil stabilizer.

Traffic Range: Very low to low (AADT < 250). Above this traffic range, the surface will require more frequent product mixing and surface grading.

Restrictions:

Traffic: None.

Climate: None; however, wet and/or cold climates will lead to more rapid deterioration and more frequent maintenance requirements.

Weather: Clay-stabilized aggregate roads are very susceptible to adverse weather conditions. They can quickly become impassable in very wet weather and, in areas subject to freezing temperatures, will soften significantly during thaw periods.

Terrain: None.

Soil type: The effectiveness of clay additives is affected by the aggregate mineralogy; negatively charged montmorillonite will adhere well to limestone, but will be repelled by a negatively charged igneous rock aggregate. Clay additives generally provide no benefit for high plasticity soils or soils with more than 20- to 30-percent fines.

Other: None.

Other Comments: None.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

DESIGN

SLC: 0.10 to 0.14.

Other Design Values: None.

Base/Subbase Requirements: The road should be designed as a unbound gravel/aggregate road. The need for a subbase layer will depend on subgrade characteristics and traffic loading.

Other Comments: The road surface should be sloped to promote surface drainage and prevent ponding on the road surface that can promote softening of the treated materials.

CONSTRUCTION

Availability of Experienced Personnel: Clay additive application is relatively straightforward and qualified contractors are, in general, widely available. Maintenance crews often can be used by agencies for clay additive applications.

Materials: Clay additives are naturally occurring soils composed of the mineral montmorillonite. Material is mined from sources in the northwestern United States and Mississippi. Clay additives can be applied in a dry form or as a slurry.

Equipment: Equipment required for clay additive application includes: tanker or water truck with spray bar, grading equipment (i.e., bulldozer or motor grader), and roller. A pugmill can be used to achieve more uniform mixing. Equipment is widely available in most areas, but availability may be limited in remote areas.

Manufacturing/Mixing Process: Thorough mixing is required to create a uniform mixture. The clay additive can be mixed with the aggregate in a pugmill (results in most uniform mixture) or in-place using a pulverizer, disc, or blade mixing.

Placement Process: For new construction projects where the aggregate must be hauled to the site, the clay additive (dry) should be thoroughly mixed with the aggregate in a pugmill before the aggregate is shipped to the site. This method provides the most uniform mixing. Alternatively, if the aggregate is in place, the aggregate should be loosened to the desired treatment depth. The clay additive is then applied uniformly to the loosened aggregate surface. If the additive is applied in dry form, a spreader is used; if the additive is applied in slurry form, a spray truck is used. Once applied, the clay additive is mixed with the aggregate using a pulverizer, disc, or by blade mixing. For the dry additive, a water truck is used to wet the mixture; water is provided to get the material to an optimum moisture content for compaction. Soda ash (dispersing agent) can be added to the water to reduce clumping when higher percentages (greater than 5 percent) of clay additive are applied. Once mixed, the treated material is graded and compacted.

Weather Restrictions: Avoid construction during rain or snow events and when the subgrade is saturated or frozen.

Construction Rate: Clay additive construction rates are in the range of 2,000 to 5,000 m^2/day (2,400 to 6,000 yd^2/day) for a mixing depth of 100 mm (4 in).

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

Lane Closure Requirements: The roadway lane should be closed during construction, but can be opened to traffic once construction is complete.

Other Comments: The required application rate will vary based on the characteristics of the material to be treated and the degree of stabilization desired. Test sections are recommended to determine/verify the appropriate application rate.

SERVICEABILITY

Reliability and Performance History: Clay additives are commonly used in some regions of the United States, but not in other areas; limited research, design and construction information, and documented project experience are available.

Life Expectancy: Life expectancy varies depending on traffic and weather conditions. Typical life expectancy is 2 to 4 years. Life expectancy could be longer if routine maintenance is performed.

Ride Quality: Ride quality depends on the aggregate used for surface material. Clay additives do not provide any improvement in ride quality; however, clay additives can reduce the rate of deterioration over the serviceable life. By reducing particle loss and washboarding, surface distress is reduced and ride quality is preserved.

Main Distress/Failure Modes: Rutting, washboarding, potholes, raveling.

Preservation Needs: Periodic grading/reshaping/compaction and localized repair may be required, typically every 3 to 6 months. Regrading does not negatively affect the clay additive's performance.

SAFETY

Hazards: Clay additives can contain a small amount of crystalline silica (typically 1 to 3 percent); crystalline silica dust can be an inhalation hazard for construction crews. Proper construction practices and engineering controls should be utilized to minimize exposure risks.

Skid Resistance: Excessive quantities of clay additives in a treated aggregate or a wet climate can cause roads stabilized with clay additives to become slippery. No noticeable change in skid resistance was noticed in a study where the clay additive application rate was varied between 3 and 12 percent.

Road Striping Possible?: No.

Other Comments: Clay additives can typically reduce road dust by 20 percent (1.5-percent clay additive treatment) to 70 percent (9-percent clay additive treatment). Studies have shown that clay additives can reduce road dust by 60 to 70 percent the first year, 40 to 50 percent the second year, and 20 to 30 percent the third year. In some cases, the driving public may not perceive any reduction in road dust generation because the improvement is not as dramatic as the dust reduction associated with some other dust control products. Clay additives can reduce the amount of flying aggregate particles by binding the surface particles.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Clay additives are naturally occurring materials that are mined for commercial use.

Delivery and Haul Requirements: Clay additives must be transported to the site from the distributor. Haul distances may be significant for remote sites.

Potential Short-Term Construction Impacts: Construction process can damage vegetation adjacent to the road, but offsite impacts can be mitigated by careful application.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface runoff: Clay additives can reduce the permeability of the surface material and, thus promote more surface runoff. However, surface runoff water quality is not generally impacted by clay additives.

Erosion: Clay additives reduce the erodibility of the unbound roadway surface by binding surface particles together.

Water quality: None.

Aquatic species: None.

Plant quality: None.

Air quality: None.

Other: None.

Ability to Recycle/Reuse: The treated aggregate can be reused as an aggregate for appropriate applications, considering the modified properties and gradation of the treated material.

Other Environmental Considerations: Clay additives are natural materials, and therefore are typically nontoxic, nonhazardous, noncorrosive, and generally environmentally friendly.

AESTHETICS

Appearance: The addition of clay additives does not significantly alter the appearance of an aggregate road. The appearance will be of an aggregate surface with the overall color determined by the aggregate type and source.

Appearance Degradation Over Time: Without maintenance, clay-treated aggregate roads deteriorate over time in terms of surface uniformity.

COST

Supply Price: $145 to $181/Mg ($160 to $200/ton).

Supply+Install Price: $10.60 to $14.10/m^3 ($8.10 to $10.80/yd^3) for an aggregate stabilized with clay.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

EXAMPLE PROJECTS

Minuteman Missile Access Roads in Colorado, Montana, Nebraska, and Wyoming.

SELECT RESOURCES

Bergeson, K.L.; Brocka, S.G. 1996. "Bentonite Treatment for Fugitive Dust Control," Proceedings of the 1996 Semisesquicentennial Transportation Conference, Ames, IA.

ELECTROLYTE EMULSIONS

GENERAL INFORMATION

Generic Name(s): Electrolyte Stabilizers, Ionic Stabilizers, Sulfonated Oils, Electrochemical Stabilizers, Acids.

Trade Names: CBR Plus, Condor SS, Road Bond EN-1, SA-44 System, Terrabond Clay Stabilizer, Terrastone, and others.

Product Description: Many of the emulsions for dust suppression and/or soil stabilization are proprietary in nature and the exact composition and stabilization mechanisms are not publicly available; therefore, it is often difficult to group or classify the various emulsions accurately.

Electrolyte emulsions contain chemicals that affect the electro-chemical bonding characteristics of soils and replace water molecules within the soil structure. The treated soil loses its affinity for water. When applied at low application rates to the surface of the unbound road surface, electrolyte emulsions perform well for dust suppression. They bond soil particles together and so reduce dust generation. At higher application rates, electrolyte emulsions can be used to stabilize soils. When applied and compacted properly, the treated soil can be stabilized to form a firm to hard bound layer that can be used as a road surfacing.

Most of the information available on electrolyte emulsions comes from brochures and literature provided by the manufacturer. Therefore, it may be difficult to find independent test information for a particular product. The performance and applicability of electrolyte emulsions can vary from one product to the next. In addition, products are frequently reformulated; so, historical case studies may no longer be representative of a current product. As a result, product-specific testing and/or performance verification is recommended when selecting an electrolyte emulsion.

Product Suppliers: CBR Plus North America, 580 Hornby Street, Suite 640, Vancouver, BC, Canada, V6C3B6, (604) 683-0430, www.cbrplus.com; and

C.S.S. Technology, Inc., P.O. Box 1618, Granbury, TX 76048, (817) 279-1136, www.csstech.com.

Representative product suppliers and trade names are provided for informational purposes only. Inclusion of this information is not an endorsement of any product or company. Additional suppliers and electrolyte emulsion products are available.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

APPLICATION

Typical Use: Dust suppressant, soil stabilizer.

Traffic Range: Very low to low (AADT < 250).

Restrictions:

Traffic: Required application frequency will increase with increased truck traffic or increased vehicle speed. Additional traffic loading restrictions may be required depending on the material being treated (e.g., the load-carrying capacity of a clay soil is typically much less than that of a granular material).

Climate: None.

Weather: Minor grading/reshaping and localized repair may be required after heavy rainfalls.

Terrain: None.

Soil type: Categorically speaking, electrolyte emulsions work on a variety of soils as long as a minimum amount of clay particles are present (greater than 10 percent) and the plasticity index is greater than 10. Electrolyte emulsions generally work best on soils with 10- to 20-percent clay, but are effective on soils with higher clay contents as well.

Other: None.

Other Comments: None.

DESIGN

SLC: N/A for dust suppression applications; typically 0.08 to 0.14 (increases with increased quality of treated material) for stabilization applications.

Other Design Values: Electrolyte emulsions can increase the soil strength by 30 to 50 percent, in terms of CBR, for example. Stabilized natural soil road surfacings are for very low traffic applications, and generally are designed empirically and are not subject to structural analysis.

Base/Subbase Requirements: Roadway should be designed with adequate base and/or subbase support. In cases where natural soils are stabilized in situ, no subbase layer is provided.

Other Comments: The road surface should be graded to promote surface drainage and prevent ponding on the road surface that can promote softening of the treated materials.

CONSTRUCTION

Availability of Experienced Personnel: Electrolyte emulsions are a commonly used dust suppressant and soil stabilizer and experienced contractors are, in general, widely available. Maintenance crews are used by some agencies for spray-on applications.

Materials: Electrolyte emulsion products are typically purchased in liquid concentrate form. Water is required to dilute the electrolyte concentrate once it is delivered to the site.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

Equipment: Equipment required for electrolyte emulsion application includes: tanker or water truck with spray bar, grading equipment (i.e., bulldozer or motorgrader), and roller. Equipment is widely available in most areas, but availability may be limited in remote areas.

Manufacturing/Mixing Process: Electrolyte concentrate must be mixed with water to achieve the desired concentration level prior to application. Dilution ratios of 1 part electrolyte concentrate mixed with 100 to 600 parts water or more are common.

Placement Process: Electrolyte emulsions can be applied by a sprayed-on method or mixed-in method, but mixed-in method is most common. Recommended mixing depth for dust suppression and stabilization ranges from 25 to 50 mm (1 to 2 in) and 100 to 200 mm (4 to 8 in), respectively. The moisture content of the soil prior to treatment should be below optimum for compaction so that the soil moisture content will be near optimum once the electrolyte emulsion is added, considering the water provided by the emulsion; if the material is very dry or saturated, processing to achieve moisture content adjustments is recommended prior to treatment. For dust suppression applications, scarifying the surface allows the electrolyte emulsion to penetrate evenly and quickly into the road surface. For soil stabilization applications, the soil is loosened to the desired treatment depth. The electrolyte emulsion is then applied uniformly using a tanker or water truck with a spray bar and mixed with the loose soil. The electrolyte emulsion is often applied in multiple passes to get better overall mixing. Once mixed, the treated material is graded and compacted.

Weather Restrictions: Do not apply electrolyte emulsions if is raining or if temperatures are below freezing.

Construction Rate: Electrolyte emulsion application rates are in the range of 2,000 to 5,000 m^2/day (2,400 to 6,000 yd^2/day).

Lane Closure Requirements: The roadway lane should be closed during construction, but can be opened to traffic once construction is complete.

Other Comments: The required application rate will vary based on the characteristics of the material to be treated and the degree of stabilization desired. Test sections are recommended to determine/verify the appropriate application rate.

SERVICEABILITY

Reliability and Performance History: Electrolyte emulsions are a common dust suppressant and soil stabilizer and were initially developed more than 40 years ago. Research, design and construction information, and project experience are available. Performance can vary significantly between different products and is influenced by traffic, soil type, weather conditions, application method and rate, and contractor performance. As a result, product specific testing and/or performance verification is recommended when selecting an electrolyte emulsion.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

Life Expectancy: Life expectancy varies depending on traffic and weather conditions. Typical life expectancy is 3 to 5 years for stabilization applications, with some treated surfaces still in service after 15 years or more. Electrolyte emulsions do not leach from the soil; therefore, the treatment is “permanent,” in theory. When an effective electrolyte emulsion product is applied in the proper situation, constructed properly, and maintained, good performance and long life expectancies are realized.

Ride Quality: Ride quality depends on the treated aggregate. Ride quality deteriorates over the serviceable life. Electrolyte emulsions do not provide any improvement in ride quality; however, the rate of deterioration is less than the rate for untreated surfaces. By reducing particle loss and washboarding, surface distress is reduced and ride quality is preserved. Electrolyte emulsions can reduce aggregate loss by 50 percent or more.

Main Distress/Failure Modes: Dust, rutting, washboarding, potholes.

Preservation Needs: Periodic grading may be required, typically every 6 months to 1 year. For dust suppression applications, grading should be performed in a manner such that the stabilized “surface crust” is not broken.

SAFETY

Hazards: Some electrolyte products are highly acidic in their concentrated form. Proper handling and mixing procedures should be followed when mixing the concentrated liquid with water to create an emulsion.

Skid Resistance: Electrolyte emulsion-treated materials form a firm to hard, skid resistant surface.

Road Striping Possible?: No.

Other Comments: Electrolyte emulsions can typically reduce road dust by 60 to 80 percent.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Electrolyte emulsions are typically byproducts or intermediate products of various manufacturing processes. Sulfonated D-limonene and sulfonated naphthalene are two of the chemicals that can be primary components of electrolyte emulsions.

Delivery and Haul Requirements: Electrolyte concentrate must be hauled to the site from the distributor. Haul distances may be significant for remote sites. Hauling requirements are reduced somewhat by the fact that the product is shipped in concentrated form and can be mixed with water at the site.

Potential Short-Term Construction Impacts: Spills or runoff during the emulsion mixing process could have a negative impact on nearby vegetation, water quality, or aquatic species.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface runoff: Electrolyte emulsion-treated soil is relatively impermeable, which promotes surface runoff. However, surface runoff water quality generally is not impacted by electrolyte emulsion treatments.

Erosion: Electrolyte emulsions reduce the erodibility of the unbound roadway surface by binding surface particles together.

Water quality: None.

Aquatic species: None.

Plant quality: None.

Air quality: None.

Other: None.

Ability to Recycle/Reuse: The treated soil/aggregate can be reused in any manner similar to the untreated material.

Other Environmental Considerations: Environmental impacts of electrolyte emulsions may vary between different proprietary products; specific product information should be collected and reviewed prior to product use. Once diluted to normal application rates, electrolyte emulsions are typically nontoxic, nonhazardous, noncorrosive, and generally environmentally friendly.

AESTHETICS

Appearance: The addition of electrolyte emulsion does not alter significantly the appearance of a soil or aggregate road. The appearance will be of a soil/aggregate surface with the overall color determined by the soil/aggregate type and source. The treated soil /aggregate will have a slightly darker appearance than the parent material.

Appearance Degradation Over Time: Without maintenance, electrolyte emulsion-treated roads deteriorate over time in terms of surface uniformity.

COST

Supply Price: N/A

Supply+Install Price: \$0.40 to \$0.80/m^2 (\$0.35 to \$0.70/yd^2).

EXAMPLE PROJECTS

City of Calgary, Canada.

Ozark National Forest, AR.

SELECT RESOURCES

Scholen, Douglas E. 1992. Non-Standard Stabilizers, FHWA-FLP-92-011, U.S. Department of Transportation, Washington, D.C., 113 p.

USDA Forest Service. 1999. Dust Palliative Selection and Application Guide, San Dimas Technology and Development Center, 23 p.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

ENZYMATIC EMULSIONS

GENERAL INFORMATION

Generic Name(s): Enzymatic Emulsions, Enzymes

Trade Names: Bio Cat 300-1, EMC SQUARED, Perma-Zyme 11X, Terrazyme, UBIX No. 0010, and others.

Product Description: Many of the emulsions for dust suppression and/or soil stabilization are proprietary in nature and the exact composition and stabilization mechanisms are not publicly available; therefore, often it is difficult to group or classify the various emulsions accurately.

Enzymatic emulsions contain enzymes (protein molecules) that react with soil molecules to form a cementing bond that stabilizes the soil structure and reduces the soil's affinity for water. Categorically speaking, enzymatic emulsions work on a variety of soils as long as a minimum amount of clay particles are present. When applied at low application rates to the surface of the unbound road surface, enzymatic emulsions perform well for dust suppression. They bond soil particles together and so reduce dust generation. At higher application rates, enzymatic emulsions can be used to stabilize soils. When applied and compacted properly, the treated soil can be stabilized to form a dense, firm to hard, water-resistant bound layer that can be used as a road surfacing.

Most of the information available on enzymatic emulsions comes from brochures and literature provided by the manufacturer. Therefore, it may be difficult to find independent test information for a particular product. The performance and applicability of enzymatic emulsions can vary from one product to the next. In addition, products are frequently reformulated; so, historical case studies may no longer be representative of a current product. As a result, product-specific testing and/or performance verification is recommended when selecting an enzymatic emulsion.

Product Suppliers: C.S.S. Technology, Inc., P.O. Box 1618, Granbury, TX 76048, (817) 279-1136, www.csstech.com.

Representative product suppliers and trade names are provided for informational purposes only. Inclusion of this information is not an endorsement of any product or company. Additional suppliers and enzymatic emulsion products are available.

APPLICATION

Typical Use: Dust suppressant, soil stabilizer.

Traffic Range: Very low to low (AADT < 250).

Restrictions:

Traffic: Required application frequency will increase with increased truck traffic or increased vehicle speed. Additional traffic loading restrictions may be required depending on the material being treated (e.g., the load-carrying capacity of a clay soil is typically much less than that of a granular material).

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

Climate: None.

Weather: Enzymatic emulsion-treated surfaces can become slippery when wet, particularly with soils with high clay content (greater than 20 or 30 percent). Minor grading/reshaping and localized repair may be required after heavy rainfalls.

Terrain: None.

Soil type: Categorically speaking, enzymatic emulsions work on a variety of soils as long as a minimum amount of clay particles are present (greater than 10 percent) and the plasticity index is greater than 8. Enzymatic emulsions generally work best on soils with 12- to 24-percent clay and a plasticity index between 8 and 35. Enzymatic emulsions work best when the moisture content is 2- to 3-percent below optimum moisture content for compaction.

Other: None.

Other Comments: None.

DESIGN

SLC: N/A for dust suppression applications; typically 0.08 to 0.14 (increases with increased quality of treated material) for stabilization applications.

Other Design Values: Enzymatic emulsions can increase the soil strength by 30 to 300 percent.

Base/Subbase Requirements: Roadway should be designed with adequate base and/or subbase support.

Other Comments: The road surface should be graded to promote surface drainage and prevent ponding on the road surface that can promote softening of the treated materials.

CONSTRUCTION

Availability of Experienced Personnel: Enzymatic emulsions are not as commonly used as some other dust suppressant and soil stabilizer products, but experienced contractors are, in general, available.

Materials: Enzymatic emulsion products are typically purchased in liquid concentrate form. Water is required to dilute the enzymatic concentrate once it is delivered to the site.

Equipment: Equipment required for enzymatic emulsion application includes: tanker or water truck with spray bar, grading equipment (i.e., bulldozer or motorgrader), and roller. Equipment is widely available in most areas, but availability may be limited in remote areas.

Manufacturing/Mixing Process: Enzymatic concentrate must be mixed with water to achieve the desired concentration level prior to application. Dilution ratios of 1 part enzymatic concentrate mixed with 100 to 500 parts water are common.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

Placement Process: Enzymatic emulsions can be applied by a sprayed-on method or mixed-in (windrowing) method, but mixed-in method is most common. Recommended mixing depths for dust suppression and stabilization range from 25 to 50 mm (1 to 2 in) and 100 to 200 mm (4 to 8 in), respectively. The moisture content of the soil prior to treatment should be below optimum for compaction so that the soil moisture content will be below or near optimum once the enzymatic emulsion is added, considering the water provided by the emulsion; if the material is very dry or saturated, processing to achieve moisture content adjustments is recommended prior to treatment. For dust suppression applications, scarifying the surface allows the enzymatic emulsion to penetrate evenly and quickly into the road surface. For soil stabilization applications, the soil is loosened to the desired treatment depth. The enzymatic emulsion is then applied uniformly using a tanker or water truck with a spray bar and mixed with the loose soil. The enzymatic emulsion is often applied in multiple passes to get better overall mixing. Once mixed in place, the treated material is graded and compacted.

Weather Restrictions: Do not apply enzymatic emulsions if rain is likely within 24 hours or if temperatures are below 4 °C (40 °F) or 16 °C (60 °F), depending on the product used.

Construction Rate: Enzymatic emulsion construction rates are in the range of 2,000 to 5,000 m^2/day (2,400 to 6,000 yd^2/day).

Lane Closure Requirements: The roadway lane should be closed during construction, but can be opened to light traffic once construction is complete. The stabilized material should be allowed to cure for 2 to 3 days before normal traffic, including heavy loads, are allowed onto the surface.

Other Comments: The required application rate will vary based on the characteristics of the material to be treated and the degree of stabilization desired. Test sections are recommended to determine/verify the appropriate application rate.

SERVICEABILITY

Reliability and Performance History: Enzymatic emulsions are still relatively new compared to some other commonly used dust suppressant and soil stabilizer products. Limited research, design and construction information, and project experience are available. Performance can vary significantly between different products and is influenced by traffic, soil type, weather conditions, application method and rate, and contractor performance. As a result, product specific testing and/or performance verification is recommended when selecting an enzymatic emulsion.

Life Expectancy: Life expectancy varies depending on traffic and weather conditions. Typical life expectancy is 5 to 7 years for stabilization applications, with some treated surfaces still in service after 12 years or more. When an effective enzymatic emulsion product is applied in the proper situation, constructed properly, and maintained, good performance and long life expectancies are realized.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

Ride Quality: Ride quality depends on the treated aggregate. Ride quality deteriorates over the serviceable life. Enzymatic emulsions do not provide any improvement in ride quality; however, the rate of deterioration is less than the rate for untreated surfaces. By reducing particle loss and washboarding, surface distress is reduced and ride quality is preserved. Enzymatic emulsions can reduce aggregate loss by 50 percent or more.

Main Distress/Failure Modes: Dust, rutting, washboarding, potholes.

Preservation Needs: Periodic grading may be required, typically every year and possibly after heavy rainfalls. For dust suppression applications, grading should be performed in a manner such that the stabilized "surface crust" is not broken. For soil stabilization applications, additional sprayed-on applications may be required periodically to extend the serviceable life.

SAFETY

Hazards: Proper handling and mixing procedures should be followed when mixing the concentrated liquid with water to create an emulsion.

Skid Resistance: Enzymatic emulsion-treated materials form a firm to hard, skid resistant surface. However, the road can become slippery when wet when the surface contains high clay content (greater than 20- or 30-percent clay).

Road Striping Possible?: No.

Other Comments: Enzymatic emulsions can typically reduce road dust by a significant amount.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Enzymes are natural materials that are manufactured from natural materials or obtained as byproducts of the food processing and manufacturing industries.

Delivery and Haul Requirements: Enzymatic concentrate must be hauled to the site from the distributor. Haul distances may be significant for remote sites. Hauling requirements are reduced somewhat by the fact that the product is shipped in concentrated form and can be mixed with water at the site.

Potential Short-Term Construction Impacts: Spills or runoff during the emulsion mixing process could have a negative impact on nearby vegetation, water quality, or aquatic species.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface runoff: Enzymatic emulsion-treated soil is relatively impermeable, which promotes surface runoff. However, surface runoff water quality is not generally impacted by enzymatic emulsion treatments.

Erosion: Enzymatic emulsions reduce the erodibility of the unbound roadway surface by binding surface particles together.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

Water quality: None.

Aquatic species: None.

Plant quality: None.

Air quality: None.

Other: None.

Ability to Recycle/Reuse: The treated soil/aggregate can be reused in any manner similar to the untreated material.

Other Environmental Considerations: Environmental impacts of enzymatic emulsions may vary between different proprietary products; specific product information should be collected and reviewed prior to product use. Once diluted to normal application rates, enzymatic emulsions are typically biodegradable, nontoxic, nonhazardous, noncorrosive, and generally environmentally friendly.

AESTHETICS

Appearance: The addition of enzymatic emulsion does not significantly alter the appearance of a soil or aggregate road. The appearance will be of a soil/aggregate surface with the overall color determined by the soil/aggregate type and source. The treated soil/aggregate will have a slightly darker appearance than the parent material.

Appearance Degradation Over Time: Without maintenance, enzymatic emulsion-treated roads deteriorate over time in terms of surface uniformity.

COST

Supply Price: N/A

Supply+Install Price: \$2.40 to \$4.80/m^2 (\$2.00 to \$4.00/yd^2) for mixing to a depth of 150 mm (6 in.).

EXAMPLE PROJECTS

Laguna Atascosa National Wildlife Refuge, Rio Hondo, TX.

Auto Tour Roads, Buenos Aires National Wildlife Refuge, Pima County, AZ.

SELECT RESOURCES

Scholen, Douglas E. 1992. Non-Standard Stabilizers, FHWA-FLP-92-011, U.S. Department of Transportation, Washington, D.C. 113 p.

USDA Forest Service. 1999. Dust Palliative Selection and Application Guide, San Dimas Technology and Development Center. 23 p.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

LIGNOSULFONATES

GENERAL INFORMATION

Generic Name(s): Lignosulfonates, Lignin, Lignin Sulfate, Lignin Sulfides

Trade Names: Dustac, RB Ultra Plus, Polybinder, DC-22, Calbinder, and others.

Product Description: Lignosulfonates are derived from the lignin that naturally binds cellulose fibers together to give trees firmness. They have cementitious properties that bind the road surface particles together. Lignosulfonates also draw moisture from the air to keep the road surface moist (i.e., hydroscopic). When applied at low application rates to the top 25 mm (1 in) of an unbound road surfacing, lignosulfonates are well suited for dust suppression because they bond soil particles together and help to maintain a moist road surface, and so reduce dust generation. At higher application rates and deep mixing, typically 100 to 200 mm (4 to 8 in), lignosulfonates can be used to stabilize subgrade or base materials containing fines. Lignosulfonates increase the compressive strength and load bearing capacity of the treated material, bind materials to reduce particle loss, and provide a firm to hard dust-free surface.

Product Suppliers: Representative list of manufacturers and suppliers can be obtained from: Lignin Institute, 5775 Peachtree-Dunwoody Road, Suite 500-G, Atlanta, GA 30342, (404) 252-3663, www.lignin.info.

APPLICATION

Typical Use: Dust suppressant, soil stabilizer.

Traffic Range: Very low to low (AADT < 250).

Restrictions:

Traffic: Required application frequency will increase with increased truck traffic or increased vehicle speed. Additional traffic loading restrictions may be required depending on the material being treated (e.g., the load-carrying capacity of a clay soil is typically much less than that of a sand or gravel).

Climate: Lignosulfonates work best in arid to moderate precipitation areas; they perform poorly in extremely wet regions.

Weather: Lignosulfonate-treated surfaces can become slippery when wet, particularly with soils with high fines content or plasticity. Minor grading/reshaping and localized repair may be required after heavy rainfalls.

Terrain: Because lignosulfonate-treated surfaces can become slippery when wet, they are not recommended for areas with steep terrain and regular precipitation.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

Soil type: Lignosulfonates can be used for a variety of soil types, but are most cost effective for soils having 8 to 30 percent fines and a plasticity index greater than 8. They do not work as well for sandy soils; permeable soils allow rapid leaching of product. For soils with high clay contents, the treated soils tend to remain slightly plastic, permitting reshaping and additional compaction under vehicle loads. Some studies have shown little to no improvement for soils with a high plasticity index (i.e., greater than 20).

Other: None.

Other Comments: None.

DESIGN

SLC: N/A for dust suppression applications; typically 0.08 to 0.14 (increases with increased quality of treated material) for stabilization applications.

Other Design Values: Lignosulfonates can increase the dry strength of soils by a factor of 2 or 3.

Base/Subbase Requirements: Roadway should be designed with adequate base and/or subbase support.

Other Comments: The road surface should be graded to promote surface drainage and prevent ponding on the road surface that can promote leaching and softening of the treated materials. For soil stabilization applications, a thin asphalt surface treatment (e.g., chip seal) can be placed on top of the stabilized layer to reduce surface water infiltration into the stabilized material and, thus, reducing leaching of the lignosulfonates.

CONSTRUCTION

Availability of Experienced Personnel: Lignosulfonates are a commonly used dust suppressant and soil stabilizer and experienced contractors are, in general, widely available. Maintenance crews are used by some agencies for spray-on applications.

Materials: Lignosulfonates are a waste by-product of the pulp and paper industry. The main component of lignosulfonates is lignin, which comes from trees. Lignosulfonates can be purchased in liquid concentrate or dry powder form. Water is required to dilute the lignosulfonate once it is delivered to the site.

Equipment: Equipment required for lignosulfonate application includes: tanker or water truck with spray bar, grading equipment (i.e., bulldozer or motorgrader), and steel drum vibratory roller. Equipment is widely available in most areas, but availability may be limited in remote areas.

Manufacturing/Mixing Process: Lignosulfonates must be mixed with water to achieve the desired concentration level prior to application.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

Placement Process: When used for dust suppression, lignosulfonates can be applied by a sprayed-on method or mixed-in method, with mixed-in being more effective, but more costly. When used for soil stabilization, the mixed-in method is used. Recommended mixing depth for dust suppression and stabilization ranges from 25 to 50 mm (1 to 2 in) and 100 to 200 mm (4 to 8 in), respectively. The moisture content of the soil prior to treatment should be close to optimum for compaction; if the material is very dry or saturated, processing to achieve moisture content adjustments is recommended prior to treatment. For dust suppression applications, scarifying the surface allows the lignosulfonates to penetrate evenly and quickly into the road surface. For soil stabilization applications, the soil is loosened to the desired treatment depth. The lignosulfonate is then applied uniformly using a tanker or water truck with a spray bar and mixed with the loose soil. The lignosulfonate is often applied in multiple passes to get better overall mixing. Once mixed, the treated material is graded and compacted.

Weather Restrictions: Do not apply lignosulfonates if rain is likely within 24 hours or if the soil/aggregate is frozen.

Construction Rate: Lignosulfonate application rates are in the range of 3,300 to 5,000 m^2/hr (4,000 to 6,000 yd^2/hr) for spray-on applications.

Lane Closure Requirements: For spray-on applications, the road may remain open during application, although it is preferable to allow some time for the lignosulfonate to infiltrate into the surface material. For mixed-in applications, the lane should be closed during construction, but can be opened to traffic once construction is complete.

Other Comments: The required application rate will vary based on the characteristics of the material to be treated and the degree of stabilization desired. Higher application rates are needed for higher clay contents. Multiple applications are often required to obtain the desired performance. Test sections are recommended to determine/verify the appropriate application rate.

SERVICEABILITY

Reliability and Performance History: Lignosulfonate is a very common dust suppressant and soil stabilizer and has been used on projects for more than 50 years. Research, design and construction information, and project experience are available. Performance can vary significantly based on traffic, soil type, weather conditions, application method and rate, contractor performance, and manufacturer.

Life Expectancy: Life expectancy varies depending on traffic and rainfall. Typical life expectancy can range from several months to more than a year for dust suppressant applications and 3 to 5 years for stabilization applications.

Ride Quality: Ride quality depends on the material being stabilized. Lignosulfonates do not provide any improvement in ride quality; however, they can reduce the rate of deterioration over the serviceable life. By reducing particle loss and washboarding, surface distress is reduced and ride quality is preserved. Lignosulfonates can reduce aggregate loss by 50 percent or more.

Main Distress/Failure Modes: Dust, rutting, washboarding, potholes.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

Preservation Needs: For dust suppressant applications, little to no preventative maintenance is required due to the short life expectancy. For soil stabilization applications, additional sprayed-on lignosulfonate applications may be required periodically, yearly to several times per year. Periodic patching or road grading may also be required. For mixed-in applications, regrading should not reduce lignosulfonate effectiveness.

SAFETY

Hazards: Concentrated lignosulfonate is corrosive to aluminum due to its acidity.

Skid Resistance: When dry, lignosulfonate-treated materials form a firm to hard, skid resistant surface. However, the surface can become slippery when wet, particularly with soils with high fines content or plasticity.

Road Striping Possible?: No.

Other Comments: Lignosulfonates can typically reduce road dust by more than 50 percent.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Lignosulfonates are a waste byproduct of the paper pulp industry. The main component of lignosulfonates is lignin, which comes from trees.

Delivery and Haul Requirements: Lignosulfonate products must be hauled to the site from the distributor. Haul distances may be significant for remote sites. Delivery and haul requirements will vary depending on whether the lignosulfonate is purchased in liquid concentrate or dry powder form.

Potential Short-Term Construction Impacts: Spills or runoff into surface water or infiltration into ground water during construction can lower dissolved oxygen levels, possibly resulting in fish kills or increases in ground water concentrations of iron, sulfur compounds, and other pollutants.

Potential Long-Term Environmental Impacts:

Leachate: Lignosulfonates are water soluble, so products can be leached from the road surface, particularly during heavy or sustained periods of rainfall.

Surface runoff: The percentage of surface runoff versus infiltration into the road surface will vary depending on the treated soil type and gradation.

Erosion: Lignosulfonates reduce the erodibility of the unbound roadway surface by binding surface particles together.

Water quality: Lignosulfonates applied as a dust palliative have a minimal impact on water quality. Lignosulfonates discharged at high-level concentrations into water bodies have been shown to increase the biological oxygen demand (BOD) of the water body. The BOD of small streams may be increased by leaching of lignosulfonates from the road surface.

Aquatic species: At normal application rates, lignosulfonates are not expected to impact aquatic species; however, leaching of lignosulfonates from the road surface during extended heavy rain events may increase the BOD of small streams, which may negatively impact aquatic species.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

Plant quality: None.

Air quality: None.

Other: None.

Ability to Recycle/Reuse: With time, the lignosulfonates will degrade or leach from the soil. The treated soil/aggregate can be reused in any manner similar to the untreated material.

Other Environmental Considerations: Environmental impacts of lignosulfonates may vary between different proprietary products; specific product information should be collected and reviewed prior to product use. At normal application rates, lignosulfonates are typically biodegradable, nontoxic, nonhazardous, noncorrosive, and generally environmentally friendly. Few studies are available that document the affects of leaching of surface-applied lignosulfonates on the BOD of streams or the rate at which lignosulfonates move through soil. Best Management Practices (BMPs) should be employed to prevent lignosulfonates from reaching water bodies.

AESTHETICS

Appearance: The addition of lignosulfonate does not significantly alter the appearance of a soil or aggregate road. The appearance will be of a soil/aggregate surface with the overall color determined by the soil/aggregate type and source.

Appearance Degradation Over Time: Without maintenance, lignosulfonate-treated roads deteriorate over time in terms of surface uniformity.

COST

Supply Price: N/A

Supply+Install Price: \$0.30 to \$0.60/m^2 (\$0.25 to \$0.50/yd^2) for surface application (spray-on method).

EXAMPLE PROJECTS

Buenos Aires National Wildlife Refuge, Pima County, AZ.

CR-12/29, Larimer County, CO.

SELECT RESOURCES

Lignin Institute, (404) 252-3663, www.lignin.info

Lunsford, Lt. G.D.; Mahoney, J. 2001. Dust Control on Low-Volume Roads: A Review of Techniques and Chemicals Used, Report No. FHWA-LT-01-002, Federal Highway Administration, Washington, D.C. 58 p.

USDA Forest Service. 1999. Dust Palliative Selection and Application Guide, San Dimas Technology and Development Center. 23 p.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

SYNTHETIC POLYMER EMULSIONS

GENERAL INFORMATION

Generic Name(s): Synthetic Polymer Emulsions, Polyvinyl Acetate, Vinyl Acrylic

Trade Names: Aerospray 70A, Earthbound, Liquid Dust Control, PolyPavement, PX-300, Soil Sement, TerraBond, and more.

Product Description: Many of the emulsions for dust suppression and/or soil stabilization are proprietary in nature and the exact composition and stabilization mechanisms are not publicly available; therefore, it is often difficult to group or classify the various emulsions accurately.

Synthetic polymer emulsions primarily consist of acrylic or acetate polymers that are specifically produced for dust control or soil stabilization, or are by-products from the adhesive or paint industries. The polymers cause a chemical bond to form between soil particles, creating a dense and water-resistant road surface. In general, polymer emulsions can be used on most soils; however, certain products are more effective on specific soil types. When applied at low application rates (sprayed-on or mixed-in) to the surface of the unbound road surface, synthetic polymer emulsions perform well for dust suppression. They bond soil particles together and so reduce dust generation. At higher application rates (mixed-in), synthetic polymer emulsions can be used to stabilize soils. Graded aggregates can be stabilized to form a very hard bound layer that can be used as a road surfacing.

Most of the information available on synthetic polymer emulsions comes from brochures and literature provided by the manufacturer. Therefore, it may be difficult to find independent test information for a particular product. The performance and applicability of synthetic polymer emulsions can vary from one product to the next. In addition, products are frequently reformulated; so, historical case studies may no longer be representative of a current product. As a result, product specific testing and/or performance verification is recommended when selecting a synthetic polymer emulsion.

Product Suppliers: Enviroseal Corporation, 1019 SE Holbrook Ct., Port Saint Lucie, FL 34952, (800) 775-9474, www.enviroseal.com; and

Midwest Industrial Supply, Inc., P.O. Box 8431, Canton, OH 44711, (800) 321-0699, www.midwestind.com.

Representative product suppliers and trade names are provided for informational purposes only. Inclusion of this information is not an endorsement of any product or company. Additional suppliers and synthetic polymer emulsion products are available.

APPLICATION

Typical Use: Dust suppressant, soil stabilizer.

Traffic Range: Very low to low (AADT < 250).

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

Restrictions:

Traffic: Required application frequency will increase with increased truck traffic or increased vehicle speed. Additional traffic loading restrictions may be required depending on the material being treated (e.g., the load-carrying capacity of a clay soil is typically much less than that of an aggregate material).

Climate: Synthetic polymer emulsions require a period of dry weather after construction to dry out and begin curing. In extremely wet climates, a sufficient dry spell may not occur for the initial drying of the stabilized material.

Weather: For extended periods of wet weather (greater than 2 weeks), some materials treated with synthetic polymer emulsion will soften and have reduced abrasion resistance.

Terrain: None.

Soil type: Categorically speaking, synthetic polymer emulsions provide effective dust control and soil stabilization on a variety of soils, including sands, silts, and clays. Certain manufacturers may recommend which soil types their product is best suited for. In general, synthetic polymer emulsions work best for silty sand materials with fines content between 5 and 20 percent and plasticity index below 8. For granular materials with little to no fines (less than 2 percent), an excessive amount of polymer may be required for stabilization.

Other: Surfaces treated with synthetic polymer emulsions are susceptible to damage by snowplowing operations. Well-maintained surfaces are less susceptible to damage than worn surfaces and mixed-in applications are less susceptible than sprayed-on applications.

Other Comments: None.

DESIGN

SLC: N/A for dust suppression applications; 0.05 to 0.20 for soil stabilization. Value will vary with soil type, synthetic polymer product, and application rate. Laboratory mixing should be performed to determine the strength of the stabilized material. Using laboratory strength testing results, an estimate of the SLC can be made using correlations or engineering judgment.

Other Design Values: The unconfined compressive strength of soils stabilized with synthetic polymers can range from 5.5 to 15.1 MPa (800 to 2,200 psi). Synthetic polymer emulsions can increase the soil strength by up to 200 percent.

Base/Subbase Requirements: Roadway should be designed with adequate base and/or subbase support to prevent rutting, potholes, etc.

Other Comments: The road surface should be graded to promote surface drainage and prevent ponding on the road surface that can promote softening of the treated materials.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

CONSTRUCTION
Availability of Experienced Personnel: Contractors experienced in the application of dust suppressants and soil stabilizers are, in general, widely available. Contractors with experience using a particular product may be limited in a certain area. Contractors should work closely with the product supplier's technical representative to ensure that the product is applied properly. **Materials:** Synthetic polymer emulsions are typically purchased in liquid concentrate form. Water is required to dilute the polymer concentrate once it is delivered to the site. **Equipment:** Equipment required for synthetic polymer emulsion application includes: tanker or water truck with spray bar, disc or rotary mixer, grading equipment (i.e., bulldozer or motor grader), and roller. Equipment is widely available in most areas, but availability may be limited in remote areas. **Manufacturing/Mixing Process:** Synthetic polymer concentrate must be mixed with water to achieve the desired concentration level prior to application. **Placement Process:** Synthetic polymer emulsions can be applied by a sprayed-on method or mixed-in method. Recommended mixing depths for dust suppression and stabilization ranges from 25 to 50 mm (1 to 2 in) and 100 to 200 mm (4 to 8 in), respectively. For dust suppression applications, scarifying the surface allows the synthetic polymer emulsion to penetrate evenly and quickly into the road surface. For soil stabilization applications, the soil is loosened to the desired treatment depth. The synthetic polymer emulsion is then applied uniformly using a tanker or water truck with a spray bar and mixed with the loose soil using a disc, rotary mixer, or blading equipment. The synthetic polymer emulsion is often applied in multiple passes to get better overall mixing. Once mixed, the treated material is graded and compacted. Even when the mixed-in method is used, some of the emulsion (up to 40 percent) is saved for a spray-on application prior to compaction. This spray-on application is applied to ensure that a good crust is formed at the surface. **Weather Restrictions:** Do not apply synthetic polymer emulsions if rain is likely within 48 hours or if temperatures are below 6 °C (42 °F). **Construction Rate:** Synthetic polymer emulsion application rates are in the range of 2,000 to 5,000 m^2/day (2,400 to 6,000 yd^2/day). **Lane Closure Requirements:** For sprayed-on applications, the roadway can remain open, although emulsion splash/spray on vehicles can be a problem. For mixed-in applications, the roadway lane should be closed during construction, but can be opened to traffic once the stabilized material has dried, typically after less than 1 or 2 hours (warm, sunny weather) to 1 day (cool, cloudy weather). Synthetic polymer emulsions will take approximately 30 days to cure completely and develop their full strength. **Other Comments:** The required application rate will vary based on the characteristics of the material to be treated and the degree of stabilization desired. Laboratory tests and/or test sections are recommended to determine/verify the appropriate application rate.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

SERVICEABILITY

Reliability and Performance History: Synthetic polymer emulsions are commonly used dust suppressant and soil stabilizer products. Limited research, design and construction information, and project experience are available. Performance can vary significantly between different products and is influenced by traffic, soil type, weather conditions, application method and rate, and contractor performance. As a result, product specific testing and/or performance verification is recommended when selecting a synthetic polymer emulsion.

Life Expectancy: Life expectancy varies depending on application rate and depth, traffic, and weather conditions. Typical life expectancy is 6 months to 1 year for dust suppression applications. Typical life expectancy is 5 to 10 years for stabilization applications.

Ride Quality: Ride quality depends on the material being stabilized. Synthetic polymer emulsions do not provide any improvement in ride quality; however, they can reduce the rate of deterioration over the serviceable life. By reducing particle loss and washboarding, surface distress is reduced and ride quality is preserved. Synthetic polymer emulsions can reduce aggregate loss by 50 percent or more.

Main Distress/Failure Modes: Dust, rutting, washboarding, potholes.

Preservation Needs: For soil stabilization applications, additional light sprayed-on applications may be required periodically to extend the serviceable life. The first maintenance application is typically 1 to 1.5 years after initial construction; subsequent applications typically occur every 2 to 3 years. Localized patching and repair work may be required periodically.

SAFETY

Hazards: Proper handling and mixing procedures should be followed when mixing the concentrated liquid with water to create an emulsion. Rutting can lead to water accumulation on the pavement surface, causing a driving hazard.

Skid Resistance: Synthetic polymer emulsion-treated materials form a firm to hard, skid resistant surface.

Road Striping Possible?: No.

Other Comments: Synthetic polymer emulsions can typically reduce road dust by a significant amount. Field tests have shown that a particular synthetic polymer product reduced fugitive dust by at least 95 percent after 3 months and at least 80 percent after 11 months.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Synthetic polymer emulsions primarily consist of acrylic or acetate polymers that are specifically produced for dust control or soil stabilization, or are by-products from the adhesive or paint industries.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

Delivery and Haul Requirements: Synthetic polymer concentrate must be hauled to the site from the distributor. Haul distances may be significant for remote sites. Hauling requirements are reduced somewhat by the fact that the product is shipped in concentrated form and can be mixed with water at the site.

Potential Short-Term Construction Impacts: Construction processes may impact vegetation adjacent to the roadway.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface runoff: Tests have shown that synthetic polymer emulsions can reduce surface runoff by about 20 percent compared to the untreated soil.

Erosion: Synthetic polymer emulsions reduce the erodibility of the unbound roadway surface by binding surface particles together. Sediment loading in surface runoff water can be reduced by 50 percent.

Water quality: None.

Aquatic species: None.

Plant quality: None.

Air quality: None.

Other: None.

Ability to Recycle/Reuse: The treated soil/aggregate can be reused in any manner similar to the untreated material.

Other Environmental Considerations: Environmental impacts of synthetic polymer emulsions may vary between different proprietary products; specific product information should be collected and reviewed prior to product use. Categorically speaking, synthetic polymer emulsions are typically nontoxic, nonhazardous, noncorrosive, and generally environmentally friendly.

AESTHETICS

Appearance: The addition of synthetic polymer emulsion does not significantly alter the appearance of a soil or aggregate road. The appearance will be of a soil/aggregate surface with the overall color determined by the soil/aggregate type and source.

Appearance Degradation Over Time: Without maintenance, synthetic polymer emulsion-treated roads deteriorate over time in terms of surface uniformity.

COST

Supply Price: $0.80 to $4.25/L ($3.00 to $16.00/gal)

Supply+Install Price: $2.40 to $14.30/m^2 ($2.00 to $12.00/yd^2) for mixing to a depth of 150 mm (6 in).

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

EXAMPLE PROJECTS

Kelso Dunes Access Road, Mojave National Preserve, CA.

Auto Tour Roads, Buenos Aires National Wildlife Refuge, Pima County, AZ.

SELECT RESOURCES

USDA Forest Service. 1999. Dust Palliative Selection and Application Guide, San Dimas Technology and Development Center, 23 p.

TREE RESIN EMULSIONS

GENERAL INFORMATION

Generic Name(s): Tree Resin Emulsions, Tall Oil Emulsions, Pitch Emulsions, Pine Tar Emulsions

Trade Names: Dustbinder, Dustrol EX, Enduraseal 200, RESIN PAVEMENT, RESINPAVE, ROAD OYL, TerraPave, and others.

Product Description: Tree resin emulsions are derived from tree resins (mainly pine, fir, and spruce) combined with other additives to produce an emulsion that can be used for dust suppression or soil stabilization. When applied at low application rates to the top 25 mm (1 in) of an unbound road surfacing, tree resin emulsions are well suited for dust suppression because they bond soil particles together and so reduce dust generation. At higher application rates and deep mixing, typically 100 to 200 mm (4 to 8 in), tree resin emulsions can be used to stabilize subgrade or base materials containing fines. Graded aggregates (typical maximum particle size less than 10 mm [3/8 in]) can be stabilized to form a relatively hard surface layer that can be used as a road surfacing; the stabilized aggregate is purported to be up to three times stronger than asphalt concrete. The bound aggregate surfacing is usually 50 mm (2 in) thick.

Most of the information available on tree resin emulsions comes from brochures and literature provided by the manufacturer. Therefore, it may be difficult to find independent test information for a particular product. The performance and applicability of tree resin emulsions can vary from one product to the next. In addition, products are frequently reformulated; so, historical case studies may no longer be representative of a current product. As a result, product specific testing and/or performance verification is recommended when selecting a tree resin emulsion.

Product Suppliers: ARR-MAZ Products, LP, 621 Winter Haven, FL 33880, (800) 541-8926, www.roadproductscorp.com.

Representative product suppliers and trade names are provided for informational purposes only. Inclusion of this information is not an endorsement of any product or company. Additional suppliers and tree resin emulsion products are available.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

APPLICATION

Typical Use: Dust suppressant, soil stabilizer.

Traffic Range: Very low to low (AADT < 250); above this traffic range, the surface will require more frequent product applications and surface grading.

Restrictions:

Traffic: Required application frequency will increase with increased truck traffic or increased vehicle speed. Additional traffic loading restrictions may be required depending on the material being treated (e.g., the load-carrying capacity of a clay soil is typically much less than that of a sand or gravel material).

Climate: Tree resin emulsions can be used in all climates, but work best in areas with arid or moderate precipitation conditions.

Weather: For extended periods of wet weather (greater than 2 weeks), some materials treated with tree resin emulsion will soften and allow ruts to form.

Terrain: Surfaces treated with tree resin emulsions can become slippery when wet, particularly with soils with high fines content or high plasticity; therefore, tree resin emulsions are not recommended for steep terrain applications in wet climates.

Soil type: Categorically speaking, tree resin emulsions provide effective dust control and soil stabilization on a variety of soils, including sands, silts, and clays. Certain manufacturers may recommend which soil types their product is best suited for. In general, tree resin emulsions work best for silty sand materials with fines content between 5 and 30 percent and plasticity index below 8. Tree resin emulsions provide little to no improvement for soils with high plasticity (plasticity index greater than 30). For granular materials with little to no fines (less than 2 percent), an excessive amount of tree resin emulsion may be required for stabilization.

Other: Surfaces treated with tree resin emulsions are susceptible to damage by snowplowing operations. Well-maintained surfaces are less susceptible to damage than worn surfaces and mixed-in applications are less susceptible than sprayed-on applications.

Other Comments: None.

DESIGN

SLC: N/A for dust suppression applications; 0.10 to 0.30 for soil stabilization (lower values for clay soils, higher values for granular materials). Value will vary with soil type, tree resin product, and application rate. Laboratory mixing should be performed to determine the strength of the stabilized material. Using laboratory strength testing results, an estimate of the SLC can be made using correlations or engineering judgment.

Other Design Values: Tree resin emulsions can increase the unconfined compressive strength of clay soils by 25 to 75 percent or more. The compressive strength of granular materials treated with tree resin emulsions can be 3 times greater than hot asphalt concrete pavement.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

Base/Subbase Requirements: Where local soils are treated with tree resin emulsion to form a stabilized surfacing, it is unlikely that an imported base/subbase layer would be provided. The stabilized zone and underlying soil should be designed to provide adequate structural support for traffic.

Other Comments: The road surface should be sloped to promote surface drainage and prevent ponding on the road surface that can promote softening of the treated materials.

CONSTRUCTION

Availability of Experienced Personnel: Contractors experienced in the application of dust suppressants and soil stabilizers are, in general, widely available. Contractors with experience using a particular product may be limited in a certain area. Contractors should work closely with the product supplier's technical representative to ensure that the product is applied properly.

Materials: Tree resin emulsions are typically purchased in liquid concentrate form. Water is required to dilute the resin concentrate once it is delivered to the site.

Equipment: Equipment required for tree resin emulsion application includes: tanker or water truck with spray bar, disc or rotary mixer, grading equipment (i.e., bulldozer or motor grader), and roller. For treatment of aggregates, a pugmill for mixing is recommended. Equipment is widely available in most areas, but availability may be limited in remote areas.

Manufacturing/Mixing Process: Tree resin concentrate must be mixed with water to achieve the desired concentration level prior to application. For stabilization of aggregates, mixing the aggregate and emulsion in a pugmill is recommended.

Placement Process: Tree resin emulsions can be applied by a sprayed-on method or mixed-in method. Recommended mixing depths for dust suppression and stabilization ranges from 25 to 50 mm (1 to 2 in) and 100 to 200 mm (4 to 8 in), respectively. For dust suppression applications, scarifying the surface allows the tree resin emulsion to penetrate evenly and quickly into the road surface. For soil stabilization applications, the soil is loosened to the desired treatment depth. The tree resin emulsion is then applied uniformly using a tanker or water truck with a spray bar and mixed with the loose soil using a disc, rotary mixer, or blading equipment. The tree resin emulsion is often applied in multiple passes to get better overall mixing. Once mixed, the treated material is graded and compacted. Even when the mixed-in method is used, some of the emulsion (up to 40 percent) is saved for a spray-on application prior to compaction. This spray-on application is applied to ensure that a good crust is formed at the surface.

For mixing with aggregates to form a bound surfacing, the aggregate and emulsion are mixed in a pugmill, spread onto the prepared base, and compacted. The surface is then sprayed with a light spray-on application of tree resin emulsion.

Weather Restrictions: Do not apply tree resin emulsions if rain is likely within 48 hours or if temperatures are below 6 °C (42 °F).

Construction Rate: Tree resin emulsion application rates are in the range of 2,000 to 5,000 m^2/day (2,400 to 6,000 yd^2/day).

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

Lane Closure Requirements: For sprayed-on applications, the roadway can remain open, although emulsion splash/spray on vehicles can be a problem. For mixed-in applications, the roadway lane should be closed during construction, but can be opened to traffic once the stabilized material has dried, typically after 1 to 4 days. Tree resin emulsions will take approximately 30 days to cure completely and develop their full strength.

Other Comments: The required application rate will vary based on the characteristics of the material to be treated and the degree of stabilization desired. Laboratory tests and/or test sections are recommended to determine/verify the appropriate application rate. Some project managers have reported that tree resin emulsions are messy and difficult to work with.

SERVICEABILITY

Reliability and Performance History: Tree resin emulsions are commonly used dust suppressant and soil stabilizer products. Limited research, design and construction information, and project experience are available. Performance can vary significantly between different products and is influenced by traffic, soil type, weather conditions, application method and rate, and contractor performance. As a result, product-specific testing and/or performance verification is recommended when selecting a tree resin emulsion.

Life Expectancy: Life expectancy varies depending on application rate and depth, traffic, and weather conditions. Typical life expectancy is 6 months for dust suppression applications. Typical life expectancy is 5 to 10 years or more for stabilization applications.

Ride Quality: Ride quality depends on the material being stabilized. Synthetic polymer emulsions do not provide any improvement in ride quality; however, they can reduce the rate of deterioration over the serviceable life. By reducing particle loss and washboarding, surface distress is reduced and ride quality is preserved. Tree resin emulsions can significantly reduce aggregate loss.

Main Distress/Failure Modes: Dust, rutting, washboarding, potholes.

Preservation Needs: For soil stabilization applications, additional light sprayed-on applications may be required periodically to extend the serviceable life. The first maintenance application is typically 1 to 1.5 years after initial construction; subsequent applications typically occur every 2 to 3 years. Localized patching and repair work may be required periodically.

SAFETY

Hazards: Proper handling and mixing procedures should be followed when mixing the concentrated liquid with water to create an emulsion. Rutting can lead to water accumulation on the pavement surface, causing a driving hazard.

Skid Resistance: Tree resin emulsion-treated materials form a firm to hard, skid resistant surface. However, surfaces treated with tree resin emulsions can become slippery when wet, particularly with soils with high fines content or high plasticity.

Road Striping Possible?: No.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

Other Comments: Tree resin emulsions typically can reduce road dust by a significant amount. Field tests have shown that a particular tree resin emulsion product reduced fugitive dust by at least 70 percent after 3 months, 50 percent after 6 months, and 30 percent after 12 months.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Tree resin emulsions are derived from tree resins (mainly pine, fir, and spruce) combined with other additives. The tree resins are a byproduct of the pulp and paper industry.

Delivery and Haul Requirements: Tree resin concentrate must be hauled to the site from the distributor. Haul distances may be significant for remote sites. Hauling requirements are reduced somewhat by the fact that the product is shipped in concentrated form and can be mixed with water at the site.

Potential Short-Term Construction Impacts: Construction processes may impact vegetation adjacent to the roadway. Large tree resin emulsion spills during construction could potentially impact water quality and aquatic species in nearby streams. A spill prevention and containment plan should be in place to reduce the probability of spills and offsite runoff.

Potential Long-Term Environmental Impacts:

Leachate: None once the product has cured.

Surface runoff: Tree resin emulsions can reduce the permeability of surface materials, resulting in an increase in surface runoff. However, surface runoff water quality is not generally impacted by tree resin emulsion-treated surfacings. In parking areas, oil and other vehicle fluids can be collected by surface runoff, affecting the water quality.

Erosion: Tree resin emulsions reduce the erodibility of the unbound roadway surface by binding surface particles together. Sediment loading in surface runoff water can be significantly reduced.

Water quality: None.

Aquatic species: None.

Plant quality: None.

Air quality: None.

Other: None.

Ability to Recycle/Reuse: The treated soil/aggregate can be reused in any manner similar to the untreated material.

Other Environmental Considerations: Environmental impacts of tree resin emulsions may vary between different proprietary products; specific product information should be collected and reviewed prior to product use. Categorically speaking, tree resin emulsions are typically nontoxic, nonhazardous, noncorrosive, and generally environmentally friendly.

Table G.1—Nontraditional stabilizers (from FHWA Surfacing Context Sensitive Roadway Surfacing Selection Guide 2005) (continued)

AESTHETICS

Appearance: The addition of tree resin emulsion does not significantly alter the appearance of a soil or aggregate road. The appearance will be of a soil/aggregate surface with the overall color determined by the soil/aggregate type and source.

Appearance Degradation Over Time: Without maintenance, tree resin emulsion-treated roads deteriorate over time in terms of surface uniformity.

COST

Supply Price: N/A

Supply+Install Price: \$21.40 to \$53.60/m^2 (\$18.00 to \$45.00/yd^2) for 50 mm (2 in) thick stabilized aggregate layer.

EXAMPLE PROJECTS

Chicago Center for Green Technology, Chicago, IL.

SELECT RESOURCES

USDA Forest Service. 1999. Dust Palliative Selection and Application Guide, San Dimas Technology and Development Center. 23 p.

APPENDIX H

Mechanical Stabilization Techniques

Table H.1—Mechanical stabilization techniques (from FHWA surfacing context sensitive roadway surfacing selection guide 2005)

CELLULAR CONFINEMENT

GENERAL INFORMATION

Generic Name(s): Cellular-Confined Aggregate, Geocell, Cellular Confinement System

Trade Names: Geoweb, Hyson Cells

Product Description: Cellular-confined aggregate, sometimes referred to as geocells, are constructed with a geosynthetic product that forms a honeycomb-like cellular structure that is infilled with aggregate to create a stabilized aggregate layer. Cellular-confined aggregate improves the load distribution characteristics of the granular material due to the reinforcement provided by the geosynthetic, the passive resistance of material in adjoining cells, and the transfer of vertical stresses to adjoining cells. High friction values between the infill material and cell walls are developed by the use of geocells with textured or perforated walls. Perforated-wall geocells have the added advantage of allowing lateral drainage through the granular layer, which is beneficial when the cellular-confined aggregate is founded on low permeability, cohesive soil.

Product Suppliers: GeoProducts, LLC, 8615 Golden Spike Lane, Houston, TX 77086, (281) 820-5493, www.geoproducts.org; and

Presto Products Company, P.O. Box 2399, Appleton, WI 54912-2399, (800) 548-3424, www.prestogeo.com.

Representative product suppliers and trade names are provided for informational purposes only. Inclusion of this information is not an endorsement of any product or company. Additional suppliers and geocell products are available.

APPLICATION

Typical Use: Soil reinforcement, road surfacing.

Traffic Range: As a reinforced base, cellular-confined aggregate can be used for very low to high traffic volume applications. As a road surfacing, cellular-confined aggregate can be used for very low to medium traffic volume applications.

Restrictions:

- **Traffic:** None.
- **Climate:** None; however, use in wet and/or cold climates will lead to more frequent deterioration and more frequent maintenance.

Table H.1—Mechanical stabilization techniques (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

Weather: None.

Terrain: None.

Soil type: N/A

Other: None.

Other Comments: Cellular-confined aggregate can be used to reduce the required granular layer thickness in a roadway design, allow the use of locally available marginal materials, or reduce the maintenance requirements of a gravel road over its design life. Depending on the infill material used, geocells can support grass growth where a more natural appearance is desired.

DESIGN

SLC: 0.35 (geocell with granular infill).

Other Design Values: None.

Base/Subbase Requirements: Roadway should be designed with adequate base and/or subbase support. For low volume applications, geocells can be constructed directly on the subgrade unless heavy loads dictate the need for greater subbase/subgrade support. Subgrade and base materials should be compacted and graded to provide a uniform working platform prior to geocell placement. When built over fine-grained, cohesive soils, a nonwoven geotextile is placed on the subgrade surface as a separation layer to prevent the migration of fines into the cellular-confined aggregate.

Other Comments: The road surface should be graded to promote surface drainage and prevent ponding on the road surface that can promote softening of the reinforced materials, although the infill materials are usually quite permeable. Cellular-confined aggregate can be constructed with a thickness of 100 to 200 mm (4 to 8 in). Lower-quality granular materials can be used for applications where driving speeds are slow and ride quality is not critical. High-quality granular materials should be used for roads that have higher driving speeds and ride quality is more important. Cellular-confined aggregate is usually covered with a surface course. A minimum of 50 mm (2 in) of dense-graded crushed granular material that has good rut resistance is recommended as a surface course above the cellular-confined aggregate. If a hot asphalt concrete pavement layer is used for road surfacing, a minimum of 25 mm (1 in) of cover aggregate over the geocells is recommended.

CONSTRUCTION

Availability of Experienced Personnel: Cellular-confined aggregate is not a commonly used surfacing, but the installation is relatively simple. Qualified contractors are, in general, locally available in large urban areas and regionally available in remote areas.

Materials: The geocell geosynthetic product and aggregate are required for construction of cellular-confined aggregate. Aggregate infill material should be granular with a maximum particle size of 50 mm (2 in). The aggregate material should have less than 10 percent fines content and a plasticity index below 6.

Table H.1—Mechanical stabilization techniques (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

Equipment: Equipment required for cellular-confined aggregate construction includes: backhoe, excavator, or front-end loader, grading equipment, and compaction equipment. Equipment is widely available in most areas, but availability may be limited in remote areas.

Manufacturing/Mixing Process: N/A

Placement Process: The geocell sections are placed on the prepared subgrade/base, stretched out to their design length, and staked to hold the sections in place. If the geocell sections are placed on a fine-grained material, a nonwoven geotextile should be placed prior to the geocell sections to act as a separation layer to prevent aggregate/subgrade mixing. Adjacent geocell sections are laid out and connected with adjoining sections. Once the geocell sections are in place, the geocells are infilled with aggregate. When infilling, the aggregate drop height should be less than 0.9 m (3 ft). The geocell sections should be overfilled by 25 to 50 mm (1 to 2 in) to allow for settling and compaction. The infill material is then compacted using tamping equipment. The cover aggregate can then be placed, compacted, and graded.

Weather Restrictions: Avoid construction during heavy rain or snow events and when the soil is frozen.

Construction Rate: Cellular-confined aggregate construction rates are in the range of 200 to 400 m^2/day (240 to 480 yd^2/day).

Lane Closure Requirements: The roadway lane should be closed during construction, but can be opened to traffic once construction is complete.

Other Comments: None.

SERVICEABILITY

Reliability and Performance History: Cellular-confined aggregate was developed by the U.S. Army Corps of Engineers in the late 1970s. Cellular-confined aggregate has been used on a variety of projects, but it is not a commonly used surfacing material. Research, design and construction information, and project experience are available.

Life Expectancy: Life expectancy varies depending on traffic, subgrade support, and weather conditions. Cellular-confined aggregate should not be used as a permanent surfacing material; some aggregate cover is required to protect the geocells from traffic abrasion. Typical life expectancy for cellular-confined aggregate, assuming that an aggregate surface course is placed over the cellular-confined aggregate, is expected to be 15 to 20 years. However, considerably longer lives are possible with regular maintenance.

Ride Quality: Cellular-confined aggregate can provide fair to good ride quality if a thin aggregate surface course is placed over the geocells. Ride quality deteriorates over the serviceable life.

Main Distress/Failure Modes: Surface erosion, aggregate/subgrade mixing (that effectively reduces the aggregate thickness providing structural support), edge failures.

Table H.1—Mechanical stabilization techniques (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

Preservation Needs: When covered with a surface course, the cellular-confined aggregate layer generally does not require maintenance. The aggregate surface course will require periodic grading (typically every 6 months) and the periodic placement of additional aggregate (typically every 1 to 2 years).

SAFETY

Hazards: Loose aggregate can create a windshield hazard. Large quantities of fugitive dust, which reduces driver visibility, can be produced by untreated surfacings during dry weather conditions.

Skid Resistance: Unbound gravel/aggregate road surfacings can provide poor-to-good skid resistance, depending on the type of aggregate and gradation. Hard, durable crushed aggregates can provide good skid resistance. The wearing course must also be well graded and compacted to reduce the amount of loose particles on the surface that can reduce skid resistance.

Road Striping Possible?: No.

Other Comments: None.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Geocells are manufactured from polypropylene. Aggregates may be naturally occurring or quarried, but either requires mechanical processing (crushing, sizing) before they can be used.

Delivery and Haul Requirements: Geocells must be transported to the site from the distributor. Geocell sections collapse into a compact configuration to minimize the haul space required. Delivery distances may be significant for remote sites. If quality aggregates are not locally available, they must be transported to the site also.

Potential Short-Term Construction Impacts: Construction process can damage vegetation adjacent to the road.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface runoff: The amount of surface runoff will depend on the permeability of the surface material. Water infiltration into a dense, well-graded unbound wearing course that is adequately sloped will generally be small, with the majority of the water becoming surface runoff. However, if the surfacing is permeable, surface runoff will be reduced.

Erosion: Cellular-confined aggregate helps to reduce erosion of poorly graded and compacted gravel/aggregate material. Dense, well-graded wearing course materials are generally less susceptible to erosion. Surface water control and management should be considered in the road design to minimize the potential for surface erosion.

Water quality: None. However, sediment loading from erosion of gravel/aggregate surfacings can possibly impact water quality. A buffer zone should be provided between the roadway and nearby bodies of water and the road surface should be properly maintained to minimize erosion of surface particles.

Table H.1—Mechanical stabilization techniques (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

Aquatic species: None. However, sediment loading from erosion of gravel/aggregate surfacings can possibly impact aquatic species. A buffer zone should be provided between the roadway and nearby bodies of water and the road surface should be maintained properly to minimize erosion of surface particles.

Plant quality: None. However, dust generated from untreated gravel/aggregate surfacings can impact plant quality by covering the leaves and reducing the amount of sunlight received by the plant.

Air quality: None. However, dust generated from untreated gravel/aggregate surfacings can have a long-term impact on air quality.

Other: None.

Ability to Recycle/Reuse: The aggregate infill can be reused as a construction material. Geocell geosynthetic material is not recyclable.

Other Environmental Considerations: Cellular-confined aggregate is particularly useful on sections of gravel roads subject to periodic flooding or overtopping. The geocells help to retain the gravel infill from wash out.

AESTHETICS

Appearance: Cellular-confined aggregate is typically covered with a wearing surface, so the geocell product does not alter the appearance of an aggregate material. The appearance will be of an aggregate surface with the overall color determined by the aggregate material type and source.

Appearance Degradation Over Time: Cellular-confined aggregates do not experience appearance degradation over time. Without maintenance, unbound aggregate surfacings deteriorate over time in terms of surface uniformity.

COST

Supply Price: N/A

Supply+Install Price: \$36 to \$42/m^2 (\$30 to \$35/yd^2).

EXAMPLE PROJECTS

Overflow Parking Lot, Brazoria National Wildlife Refuge, Brazoria County, TX.

Stone Mountain Park, Stone Mountain, GA.

SELECT RESOURCES

Presto Products Company, www.prestogeo.com.

Table H.1—Mechanical stabilization techniques (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

FIBER REINFORCEMENT

GENERAL INFORMATION

Generic Name(s): Fiber-Reinforced Soil, Fiber-Reinforced Sand

Trade Names: Geofibers

Product Description: Fiber reinforcement can be used to stabilize clays, sands, and sandy gravel soils. It can increase the shear strength, stiffness, and bearing capacity of the material being treated. Fibers can be natural or man made. Materials that have been used for fiber reinforcement include metallic, polypropylene, glass, wire, cellophane, straw, and hemp fibers. The fibers are mixed with the soil to create a uniformly reinforced soil mix with discrete, randomly oriented fibers. The soil is then placed and compacted. Typical fiber-application rates are 0.1 to 0.5 percent, by weight. Fiber reinforcement improves the quality and suitability of soils as road making materials.

Product Suppliers: Fiber Reinforced Soil, LLC, P.O. Box 17455, Chattanooga, TN 37415, (423) 877-9550, www.fibersoils.com.

Representative product suppliers and trade names are provided for informational purposes only. Inclusion of this information is not an endorsement of any product or company. Additional suppliers and fiber reinforcement products are available.

APPLICATION

Typical Use: Road surfacing, soil stabilizer.

Traffic Range: As a road surfacing, very low.

Restrictions:

> **Traffic:** Fiber-reinforced soils should not be used as a surfacing for high speed traffic applications.
>
> **Climate:** None; however, wet and/or cold climates will lead to more frequent deterioration and require more frequent maintenance.
>
> **Weather:** Fiber-reinforced soils are very susceptible to adverse weather conditions. They will soften significantly in very wet weather and during periods of thaw.
>
> **Terrain:** Fiber-reinforced soil surfaces should be limited to relatively flat terrains.
>
> Soil type: N/A
>
> **Other:** Fiber-reinforced surfacings are highly susceptible to damage from snowplow operations.

Other Comments: None.

Table H.1—Mechanical stabilization techniques (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

DESIGN

SLC: 0.05 to 0.20. Value will vary with soil type, fiber product, and application rate. Laboratory mixing should be performed to determine the strength of the stabilized material. Using laboratory strength testing results, an estimate of the SLC can be made using correlations or engineering judgment.

Other Design Values: Fiber reinforcement can increase the soil strength by 30 to 100 percent or more.

Base/Subbase Requirements: Roadway should be designed with adequate base and/or subbase support.

Other Comments: The road surface should be graded to promote surface drainage and prevent ponding on the road surface that can promote softening of unbound materials.

The strength and durability of fiber-reinforced soils is affected by the fiber type, length, diameter, and application rate and depth of treatment. Fiber reinforcement is also influenced by the soil type, percent fines, moisture content, and percent compaction. Typically, fines contents of up to 10 percent are preferred for granular surfacings. Polypropylene fibers are currently the most commonly used fiber type. Studies have shown that for sand soils, the optimum fiber length and application rate are 50 mm (2 in) and 1 percent by weight, respectively. At application rates below 0.6 percent, the sand acts as a strain softening material; at application rates above 0.6 percent, fiber-reinforced sands behave as a strain hardening material.

A persistent performance problem with unbound surfaces is the generation of dust as the surface dries. Several dust suppression and stabilization products have been developed to reduce the amount of fugitive dust originating from the unbound surface. Many of these products also improve the strength and durability of the surfacing and reduce surface erosion. Use of dust suppressants in conjunction with fiber-reinforced soil is recommended.

CONSTRUCTION

Availability of Experienced Personnel: Fiber-reinforced soil is not a common road surfacing, so the availability of experienced contractors may be limited. However, the construction process is relatively straightforward and experienced soil stabilization contractors should be able to successfully construct fiber-reinforced soil surfacings, with guidance from the supplier's technical representative.

Materials: Fibers are the only material required. Materials that have been used for fiber reinforcement include metallic, polypropylene, glass, wire, cellophane, straw, and hemp fibers. Polypropylene is currently the most commonly used fiber type.

Equipment: Equipment required for fiber reinforcement construction includes: rotary mixer, grading equipment (i.e., bulldozer or motorgrader), and compactor. Equipment is widely available in most areas.

Table H.1—Mechanical stabilization techniques (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

Manufacturing/Mixing Process: If the unbound surfacing material is not already in place, fibers can be mixed with the material prior to shipment to the site.

Placement Process: The fibers are spread and mixed in situ with the unbound material using several passes of a rotary mixer to obtain a uniform mixture. Uniform mixing of the fibers into the unbound material becomes more difficult as the application rate is increased. Once mixing is complete, the surface is compacted and graded. The compactive effort required for fiber-reinforced soil may be slightly greater than for unreinforced soil.

Weather Restrictions: Avoid construction during heavy rain or snow events and when the subgrade is saturated or frozen.

Construction Rate: Fiber reinforcement application rates are in the range of 2,000 to 4,000 m^2/day (2,400 to 4,800 yd^2/day).

Lane Closure Requirements: It is recommended that the roadway lane be closed during construction. The lane can be reopened once construction is completed.

Other Comments: None.

SERVICEABILITY

Reliability and Performance History: Fiber reinforcement for road surfacings is a fairly new concept that has developed within the past 20 years. Only a limited amount of information is available on design and construction and project experience.

Life Expectancy: Life expectancy varies depending on traffic, surfacing material characteristics, fiber type and application rate, and weather conditions. Fiber-reinforced surfacings will lose material annually due to erosion, mixing with subgrade, dust, and shoving. Regular maintenance and periodic applications of additional material must be performed to maintain the structural integrity of the fiber-reinforced layer. Even with regular maintenance, many fiber-reinforced surfacings must be reconstructed after 4 to 6 years; however, some roads will last much longer with regular maintenance.

Ride Quality: Fair-to-good ride quality can be achieved with fiber-reinforced surfacings. Ride quality deteriorates with time if timely maintenance is not conducted.

Main Distress/Failure Modes: Aggregate loss, rutting, erosion, washboarding, washouts.

Preservation Needs: Regrading of the road surfacing is periodically required, depending on traffic conditions; a regrading frequency of 6 months to 1 year is typical. In addition, surfacing material has to be added to repair distressed areas and replace the aggregate lost due to mixing with underlying soils, erosion, and dust. Depending on the thickness of the reinforced surface layer, new material may have to be added to the surface every 2 to 4 years.

Table H.1—Mechanical stabilization techniques (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

SAFETY

Hazards: Loose aggregate can create a windshield hazard; if sand is the surfacing material, the sand particles are usually too small to cause vehicle damage. Large quantities of fugitive dust, which reduces driver visibility, can be produced by untreated surfacings during dry weather conditions.

Skid Resistance: Fiber-reinforced soils usually provide poor-to-good skid resistance, depending on the type of material stabilized. Coarse granular soils provide better skid resistance.

Road Striping Possible?: No.

Other Comments: None.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Fibers can be natural or man made. Materials that have been used for fiber reinforcement include metallic, polypropylene, glass, wire, cellophane, straw, and hemp fibers. Polypropylene fibers are the most commonly used and are manufactured materials.

Delivery and Haul Requirements: Fibers must be delivered to the site from the supplier. Delivery distances may be significant for remote sites.

Potential Short-Term Construction Impacts: Dust generated during fiber application can damage vegetation adjacent to the road.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface runoff: None. Permeable surfacing materials, such as gravels and sands, will allow for increased infiltration into the road structure and less surface runoff.

Erosion: Poorly graded and compacted unbound surfacings can be highly susceptible to erosion. Dense, well-graded materials are generally less susceptible to erosion, but erosion is still a primary concern for these materials as well. Fiber reinforcement can help reduce erosion susceptibility to a certain extent. Surface water control and management should be considered in the road design to minimize the potential for surface erosion.

Water quality: Fiber reinforcement will reduce, but not eliminate erosion of untreated surface soils. Sediment loading from erosion of unbound surfacings can possibly impact water quality. If the surrounding environment is sensitive to sediment loading, then a buffer zone should be provided between the roadway and nearby bodies of water and the road surface should be properly maintained to minimize erosion of surface particles.

Aquatic species: Fiber reinforcement will reduce, but not eliminate erosion of untreated surface soils. Sediment loading from erosion of unbound surface materials can possibly impact aquatic species. If the surrounding environment is sensitive to sediment loading, a buffer zone should be provided between the roadway and nearby bodies of water and the road surface should be properly maintained to minimize erosion of surface particles.

Table H.1—Mechanical stabilization techniques (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

Plant quality: None. However, dust generated from untreated fiber reinforced surfacings can impact plant quality by covering the leaves and reducing the amount of sunlight received by the plant.

Air quality: Dust generated from untreated fiber-reinforced soils can have a long-term impact on air quality. Dust suppression products can be used to reduce fugitive dust generation.

Other: None.

Ability to Recycle/Reuse: Fiber-reinforced materials can be reused as a construction material. However, it is not practical to remove fibers from a fiber-stabilized material for reuse.

Other Environmental Considerations: For fiber-reinforced soils, tire/road noise will depend on the material gradation and surface smoothness, but will generally be high.

AESTHETICS

Appearance: The appearance and color will mainly be influenced by the soil type and gradation. However, the color of the fiber reinforcement, typically black for polypropylene, will also influence the appearance, depending on the amount of fibers added. The fibers will be visible in the surfacing material, with strands of fiber protruding from the soil mixture.

Appearance Degradation Over Time: Fiber-reinforced surfacings can deteriorate over time, in terms of surface uniformity. Fiber-reinforced surfaces can experience appearance degradation over time due to surface distresses, such as rutting, shoving, and material loss.

COST

Supply Price: $4.40/kg ($2.00/lb) of fiber.

Supply+Install Price: $10.00 to $16.00/m^2 ($7.70 to $12.30/yd^2) for a 200 mm (8 in) thick reinforced layer.

EXAMPLE PROJECTS

None.

SELECT RESOURCES

Santoni, R.L.; Tingle, J.S.; Webster, S.L. 2001. Engineering properties of sand-fiber mixtures for road construction. Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol. 127, No. 3. pp. 258-268.

Santoni, R.L.; Webster, S.L. 2001. Airfields and roads construction using fiber stabilization of sands. Journal of Transportation Engineering, ASCE, Vol. 127, No. 2. pp. 96-104.

Schaefer, V.R. (Ed.). 1997. 2.11- Fiber reinforced soils. Ground Improvement, Ground Reinforcement, Ground Treatment: Developments 1987-1997, Geotechnical Special Publication No. 69, ASCE, Reston, VA.

Table H.1—Mechanical stabilization techniques (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

GEOTEXTILE / GEOGRID REINFORCEMENT

GENERAL INFORMATION

Generic Name(s): Geotextile, Geogrid, Geotextile/geogrid-supported aggregate

Trade Names: Numerous products available.

Product Description: A geotextile is a flexible porous fabric constructed of synthetic fibers and designed specifically for use in applications related to soil, rock, or any other earthen materials. The geotextile can be manufactured with standard weaving machinery (referred to as a woven geotextile) or by matting fibers together in a random fashion (referred to as a nonwoven geotextile). A geogrid is manufactured from a polymer into a “fabric” with an open, grid-like structure and designed specifically for use in applications related to soil, rock, or any other earthen material. Geogrids are generally stronger, stiffer, and tougher products than geotextiles. Geotextiles and geogrids both belong to a group of synthetic products collectively referred to as geosynthetics. Geosynthetic products can be used in a wide range of applications to reinforce soils and to act as filter or separation layers in pavement construction. Geosynthetics are also used in the construction of paved roads but this product sheet only deals with their use on unpaved roads.

Product Suppliers: Representative list of manufacturers, suppliers, and contractors can be obtained from: Geosynthetic Materials Association (GMA), (800) 225-4324, www.gmanow.com.

APPLICATION

Typical Use: Soil reinforcement, road surfacing (frequently on sites with poor strength subgrades or with shortage of quality aggregates).

Traffic Range: As a reinforced base, very low to high. As a road surfacing, very low to low.

Restrictions:

Traffic: None.

Climate: None; however, wet and/or cold climates will lead to more frequent deterioration and more frequent maintenance.

Weather: Unbound road surfacings, including those reinforced with geotextiles/geogrids, are susceptible to adverse weather conditions. They will soften significantly in very wet weather and during periods of thaw.

Terrain: None.

Soil type: Geotextile/geogrid-supported aggregates should have a maximum of 15-percent fines for use as a road surfacing and 10 percent for use as a base material.

Other: None.

Table H.1—Mechanical stabilization techniques (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

Other Comments: Geosynthetics serve one of two primary functions when used with unbound aggregate layers in roadway applications: separation and/or reinforcement. Geotextiles are used primarily for separation and sometimes for reinforcement. Geogrids are used primarily for reinforcement and are more effective than geotextiles for that purpose. When used for separation, geotextiles are placed on top of a fine-grained subgrade prior to placing the aggregate layer. The purpose of the geotextile is to prevent (1) aggregate loss from the aggregate being pushed into the subgrade and (2) fines from the subgrade infiltrating into the aggregate layer and reducing the aggregate's structural and drainage properties.

For reinforcement purposes, the geotextile or geogrid is typically placed at or near the bottom of the aggregate base layer. The geosynthetic reinforces the base layer through shear interaction between the aggregate and geosynthetic, referred to as lateral base course restraint. Geogrids are considered to be better reinforcement materials than geotextiles because they are stiffer and more durable.

Geotextile separation layers have the potential to reduce aggregate requirements by 25 percent. Geotextiles and geogrids used together for reinforcement have the potential to reduce aggregate requirements by 50 percent. Therefore, geotextiles and/or geogrids can be used to reduce the thickness of aggregate layers required over soft soils or to reduce the amount of aggregate required in areas where aggregate is scarce. For the geotextile/geogrid to be beneficial as reinforcement, the geosynthetic must be stiffer than the underlying soil.

DESIGN

SLC: N/A; for low volume unpaved road design, geotextile and/or geogrid reinforcement is taken into consideration by increasing the equivalent bearing capacity of the underlying subgrade soil. For soft subgrade soils, the bearing capacity factor, NC, for unreinforced, unpaved roads is 2.8, while NC for geotextile-reinforced roads is 4.2 and NC for geogrid and geotextile-reinforced soils is 6.7. Some agencies do not include separation as a structural design consideration; it is only used to prevent aggregate/subgrade intermixing.

Other Design Values: None.

Base/Subbase Requirements: Roadway should be designed with adequate base and/or subbase support, taking into account the improved strength from the geosynthetic product.

Other Comments: The road surface should be sloped to promote surface drainage and prevent ponding on the road surface that can promote softening of the reinforced materials.

Geotextiles and geogrids are more effective when used with thin aggregate layers. As the base layer thickness increases, the stresses and strains near the bottom of the base layer decrease and the influence of the lateral base course restraint decreases as well. In addition, the mechanisms causing base/subgrade intermixing are reduced as the aggregate base thickness increases.

Table H.1—Mechanical stabilization techniques (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

CONSTRUCTION

Availability of Experienced Personnel: Geotextile/geogrid-supported aggregate is a fairly common treatment and qualified contractors are, in general, widely available.

Materials: Geotextiles and/or geogrids and aggregate are required for construction of geotextile/geogrid-supported aggregate. Geotextiles/geogrids are shipped to the site in rolls. Nonwoven geotextiles perform better than woven geotextiles; nonwoven geotextiles offer better abrasion resistance, drainage capabilities, and interface friction with aggregates. Geogrids offer higher strengths and better abrasion resistance than geotextiles.

Equipment: Equipment required for geotextile/geogrid-supported aggregate construction includes: rear or bottom dump trucks for hauling material, grading equipment (i.e., bulldozer or motorgrader), watertruck, and compactor. Equipment is widely available in most areas.

Manufacturing/Mixing Process: N/A

Placement Process: When using a geotextile, the geotextile is rolled out onto the prepared subgrade. The material should be placed so that there are no, or very few, wrinkles. Material from different rolls should be overlapped to ensure complete coverage. When using a geogrid, the geogrid is placed on the subgrade or geotextile separation layer, or after a thin lift of the aggregate material is placed. The geogrid should be placed taut and with no wrinkles. The unbound wearing course material is dumped by the haul trucks and spread using grading equipment, typically a motorgrader, until the unbound layer has a uniform and adequate thickness and is graded to the proper slope. The use of a watertruck and compaction equipment is highly recommended to adequately compact the surfacing layer.

Weather Restrictions: Avoid construction during heavy rain or snow events and when the soil is frozen.

Construction Rate: Geotextile/geogrid-supported aggregate construction rates are in the range of 8,000 to 10,000 m^2/day (9,600 to 12,000 yd^2/day).

Lane Closure Requirements: The road is closed to traffic during construction but can be opened once construction is completed.

Other Comments: None.

SERVICEABILITY

Reliability and Performance History: Geotextile/geogrid-supported aggregate is a common base and surfacing material. Research, design and construction information, and project experience are available.

Life Expectancy: Life expectancy varies depending on traffic, surfacing material characteristics, and weather conditions. Unbound gravel/aggregate surfaced roads can typically lose 25 mm (1 in) of thickness per year; a geotextile separation layer will help reduce this loss rate by preventing aggregate loss due to aggregate/subgrade intermixing. Regular maintenance and periodic

Table H.1—Mechanical stabilization techniques (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

applications of additional material must be performed to maintain the structural integrity of the unbound layer. Even with regular maintenance, many unbound gravel/aggregate surfaced roads must be reconstructed after 6 to 10 years; however, some roads will last much longer with regular maintenance.

Ride Quality: Fair-to-good ride quality can be achieved with unbound gravel/aggregate road surfacings supported by geotextile/geogrid. Ride quality deteriorates with time if timely maintenance is not conducted.

Main Distress/Failure Modes: Aggregate loss, rutting, washboarding, potholes.

Preservation Needs: The geotextile/geogrid material does not require maintenance. For unbound gravel/aggregate surfacings, regrading of the road surfacing is periodically required, depending on traffic conditions; a regrading frequency of 6 months is typical, but can easily range from 3 months to 2 years. In addition gravel has to be added to repair potholes and replace the aggregate lost due to erosion and dust. Depending on the thickness of the unbound layer, new material may have to be added to the surface every 1 to 3 years.

SAFETY

Hazards: Loose aggregate can create a windshield hazard. Large quantities of fugitive dust, which reduces driver visibility, can be produced by untreated surfacings during dry weather conditions.

Skid Resistance: Unbound gravel/aggregate road surfacings can provide poor-to-good skid resistance, depending on the type of aggregate and gradation. Hard, durable crushed aggregates can provide good skid resistance. The wearing course must also be well graded and compacted to reduce the amount of loose particles on the surface that can reduce skid resistance.

Road Striping Possible?: No.

Other Comments: None.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Geotextiles and geogrids are manufactured products for the construction industry and are made of high density polyethylene (HDPE).

Delivery and Haul Requirements: Geotextiles and/or geogrids must be transported to the site from the distributor. Haul distances may be significant for remote sites.

Potential Short-Term Construction Impacts: Construction process can damage vegetation adjacent to the road.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface runoff: None. The amount of surface runoff will depend on the permeability of the surface material. Water infiltration into a dense, well-graded unbound wearing course that is adequately sloped will generally be small, with the majority of the water becoming surface runoff.

Table H.1—Mechanical stabilization techniques (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

Erosion: None. Poorly graded and compacted gravel/aggregate surfacing material can be highly susceptible to erosion. Dense, well-graded wearing course materials are generally less susceptible to erosion. Surface water control and management should be considered in the road design to minimize the potential for surface erosion.

Water quality: None. Sediment loading from erosion of gravel/aggregate surfacings can possibly impact water quality. A buffer zone should be provided between the roadway and nearby bodies of water, and the road surface should be properly maintained to minimize erosion of surface particles.

Aquatic species: None. Sediment loading from erosion of gravel/aggregate surfacings can possibly impact aquatic species. A buffer zone should be provided between the roadway and nearby bodies of water, and the road surface should be properly maintained to minimize erosion of surface particles.

Plant quality: None. Dust generated from untreated gravel/aggregate surfacings can impact plant quality by covering the leaves and reducing the amount of sunlight received by the plant. Particularly in agricultural areas, studies have shown that dust generation from roads adjacent to farmland can significantly reduce crop outputs. Dust suppression products can be used to reduce fugitive dust generation.

Air quality: None. Dust generated from untreated gravel/aggregate surfacings can have a long-term impact on air quality. Dust-suppression products can be used to reduce fugitive dust generation.

Other: None.

Ability to Recycle/Reuse: The treated soil/aggregate can be reused as a construction material. The geotextile/geogrid material cannot be reused or recycled.

Other Environmental Considerations: For unbound gravel/aggregate surfacings, tire/road noise will depend on the material gradation and surface smoothness, but will generally be high.

AESTHETICS

Appearance: Geotextile/geogrid support does not alter the appearance of a soil/aggregate material. The color will be determined by the gravel/aggregate material type and source. The texture can vary depending on the aggregate gradation and maximum particle size, but will generally be rough (texture).

Appearance Degradation Over Time: Gravel/crushed aggregate surfaces can experience appearance degradation over time due to surface distresses, such as rutting, washboarding, and aggregate loss.

COST

Supply Price: N/A

Supply+Install Price: \$2.80 to \$5.00/m^2 (\$2.30 to \$4.20/yd^2), not including aggregate.

Table H.1—Mechanical stabilization techniques (from FHWA surfacing context sensitive roadway surfacing selection guide 2005) (continued)

EXAMPLE PROJECTS
Marshall Municipal Airport, Marshall, MO.
IWV Road, Johnson County, IA.
SELECT RESOURCES
Geosynthetic Materials Association (GMA), (800) 225-4324, www.gmanow.com.

Table H.2—Decision aid and guidelines for selecting rapid stabilization techniques for vehicle mobility on thawing ground (from Kestler et al. 1999)

	Gravel road	*Tree slash*	*Uni-Mats*	*Small pallets*	*Chunk wood*	*Tire mats*	*Tire chips*	*Geonet*	*High strength geotextile*[l]	*PVC fascine*
Overall trafficability, driver surveys 1=excellent, 5=poor	2	2–3	2–3	1–2	1–2	1–3	1–2	1–2	3–4[i]	N/A
Cornering survive ability 1=excellent, 5=poor	3	4	3	4–5	4	4–5	4	5[j]	5[j]	4[h]
Traction (slopes) 1=excellent, 5=poor	2	3–4	4–5	2–4	1	1	2	3	3	N/A
Material/vehicle interference 1=none, 5=high potential	1	5	1	1	2	2	2[k]	5[j]	5[j]	2[h]
Foot traffic 1 =easy, 5=difficult	1	5	2	2	2	4	3[g]	1	1	N/A
Material life expectancy P=permanent (>5 yr), T=temporary	P	T	T/P	T	T/P	T/P	P	T	T	T/P
Localized section (LS) for repair or entire road ?	either	LS	LS	LS	either	LS	either	either	either	LS
Material availability[a] 1=local store 5=must be ordered	1	1[b]	4–5	1–2	5[d]	4–5	4–5	3–5	3–5	2-4
Equipment required 1=standard equipments 5=special equipment	1	1	3	1	5[d]	3	1	1	1	1
Training 1=minimal, 5=special	1–2	1	2	1	3[d]	2	2	1	1	2
Material preparation 1=Easy, 5=Labor intensive	2–5[e]	5	1	4	5	1	1	1	1	4
Material placement 1=easy, 5=labor intensive	2–3	5	2–4	3	2	2–3	2–3	2–4[f]	2–4[f]	2
Material cost 1=low, 5=high	1	1	5	2	2	2	5	3	3	2

[a] Availability of proximity to forests, lumberyards, etc.
[b] If no trees, old corn husks, etc.
[c] Std equipment: dozer, loader, and dump truck.
[d] USDA Forest Service has 2 prototype woodchunkers.
[e] Including borrow pit development.
[f] Including anchoring.
[g] Pieces of metal may penetrate shoes or tires.
[h] Typically PVC fascine is surfaced with grating or wood mat.
[i] Needs cover material.
[j] If unsurfaced, geotextile can become entangled in tank tracks.
[k] Omit steel bead to run rubber tired vehicles
[l] Geosynthetics used with no surface cover.

APPENDIX I

Geosynthetics

APPENDIX I – GEOSYNTHETICS

DESIGN GUIDELINES FOR TEMPORARY AND UNPAVED ROADS

Minnesota Local Roads Research Board (LRRB) geosynthetic design guidelines (taken directly from MN/LRRB Web site, in turn taken from FHWA and Forest Service), (Referenced sections, tables, figures, etc. refer to original, not this guide):

FHWA Geosynthetic Design and Construction Guidelines (Berg et al.1998)

5.6 DESIGN GUIDELINES FOR TEMPORARY AND UNPAVED ROADS

There are two main approaches to the design of temporary and unpaved roads. The first assumes no reinforcing effect of the geotextile; that is, the geotextile acts as a separator only. The second approach considers a possible reinforcing effect due to the geotextile. It appears that the separation function is more important for thin roadway sections with relatively small live loads where ruts, approximating 50 to 100 mm are anticipated. In these cases, a design which assumes no reinforcing effect is generally conservative. On the other hand, for large live loads on thin roadways where deep ruts (> 100 mm) may occur, and for thicker roadways on softer subgrades, the reinforcing function becomes increasingly more important if stability is to be maintained. It is for these latter cases that reinforcing analyses have been developed and are appropriate.

The design method presented in this manual considers mainly the separation and filtration functions. It was selected because it has a long history of successful use, it is based on principles of soil mechanics, and it has been calibrated by full-scale field tests. It can also be adapted to a wide variety of conditions. Other methods considering reinforcement functions are described by Koerner (1994), Christopher and Holtz (1985), and Giroud and Noiray (1981). For roadways where stability of the embankment foundation is questionable (i.e., ((H)/c > 3), refer to chapter 7 for information on reinforced embankments.

The following design method was developed by Steward, Williamson, and Mohney (1977) for the Forest Service. It allows the designer to consider:

- vehicle passes.
- equivalent axle loads.
- axle configurations.
- tire pressures.
- subgrade strengths.
- rut depths.

The following limitations apply:

- the aggregate layer must be
  - compacted to CBR 80.
  - cohesionless (nonplastic).
- vehicle passes less than 10,000.
- geotextile survivability criteria must be considered.
- subgrade undrained shear strength less than about 90 kPa (CBR < 3).

As discussed in section 5.1-2, for subgrades stronger than about 90 kPa (CBR > 3), geotextiles are rarely required for stabilization, although they may provide some drainage and filtration. In this case, the principles developed in chapter 2 are applicable, just as they are for weaker subgrades where drainage and filtration are likely to be very important.

Based on both theoretical analysis and empirical (laboratory and full-scale field) tests on geotextiles, Steward, Williamson, and Mohney (1977) determined that a certain amount of rutting would occur under various traffic conditions, both with and without a geotextile separator and for a given stress level acting on the subgrade. They present this stress level in terms of bearing capacity factors, similar to those commonly used for the design of shallow foundations on cohesive soils. These factors and conditions are given in table 5.3.

Table 5.3—Bearing capacity factors for different ruts and traffic conditions both with and without geotextile separators. (after Steward, Williamson, and Mohney, 1977)

Condition	Ruts (mm)	Traffic Passes of 80 kN axle equivalents)	Bearing Capacity Factor, N_c
Without Geotextile	<50	>1,000	2.8
	>100	<100	3.3
With Geotextile	<50	>1,000	5.0
	>100	<100	6.0

The following design procedure is recommended:

STEP 1—Determine soil subgrade strength

Determine the subgrade soil strength in the field using the field CBR, cone penetrometer, vane shear, resilent modulus, or any other appropriate test. The undrained shear strength of the soil, c, can be obtained from the following relationships:

- for field CBR, c in kPa = 30 x CBR;
- for the WES cone penetrometer, c = cone index divided by 10 or 11; and
- for the vane shear test, c is directly measured.

Other in-situ tests, such as the static cone penetrometer test (CPT) or dilatometer (DMT), may be used, provided local correlations with undrained shear strength exist. Use of the Standard Penetration Test (SPT) is not recommended for soft clays.

STEP 2—Determine subgrade strength at several locations and at different times of the year

Make strength determinations at several locations where the subgrade appears to be the weakest. Strengths should be evaluated at depth of 0 to 200 mm and from 200 to 500 mm; 6 to 10 strength measurements are recommended at each location to obtain a good average value. Tests should also be performed when the soils are in their weakest condition, when the water table is the highest, etc.

STEP 3—Determine wheel loading

Determine the maximum single wheel load, maximum dual wheel load, and the maximum dual tandem wheel load anticipated for the roadway during the design period.

For example, an 8 m^3 dump truck with tandem axles will have a dual wheel load of approximately 35 kN. A motorgrader has a wheel load of 22 to 44 kN.

STEP 4—Estimate amount of traffic

Estimate the maximum amount of traffic anticipated for each design vehicle class.

STEP 5—Establish tolerable rutting

Establish the amount of tolerable rutting during the design life of the roadway. For example, 50 to 75 mm of rutting is generally acceptable during construction.

STEP 6—Obtain bearing capacity factor

Obtain appropriate subgrade stress level in terms of the bearing capacity factors in table 5.3.

STEP 7—Determine required aggregate thickness

Determine the required aggregate thickness from the Forest Service design charts (figures 5.4, 5.5, and 5.6) for each maximum loading. Enter the curve with appropriate bearing capacity factors (N_C) multiplied by the design subgrade undrained shear strength (c) to evaluate each required stress level (cN_C).

STEP 8—Select design thickness

Select the design thickness based on the design requirements. The design thickness should be given to the next higher 25 mm.

STEP 9—Check geotextile drainage and filtration characteristics

Check the geotextile drainage and filtration requirements. Use the gradation and permeability of the subgrade, the water table conditions, and the retention and permeability criteria given in chapter 2. In high water table conditions with heavy traffic, filtration criteria may also be required. From chapter 2, that criteria is:

$$AOS \leq D_{85}\text{(Wovens)} \qquad \text{(Eq. 2-3)}$$

$$AOS \leq 1.8\ D_{85}\text{(Nonwovens)} \qquad \text{(Eq. 2-4)}$$

$$k_{geotextile} \geq k_{soil} \qquad \text{(Eq. 2-7a)}$$

$$\psi \geq 0.1\ sec^{-1} \qquad \text{(Eq. 2-8c)}$$

STEP 10—Determine geotextile survivability requirements

Check the geotextile survivability strength requirements as discussed in section 5.5.

STEP 11—Specify geotextile property requirements

Specify geotextiles that meet or exceed these survivability criteria.

STEP 12—Specify construction requirements

Follow the construction recommendations in section 5.12

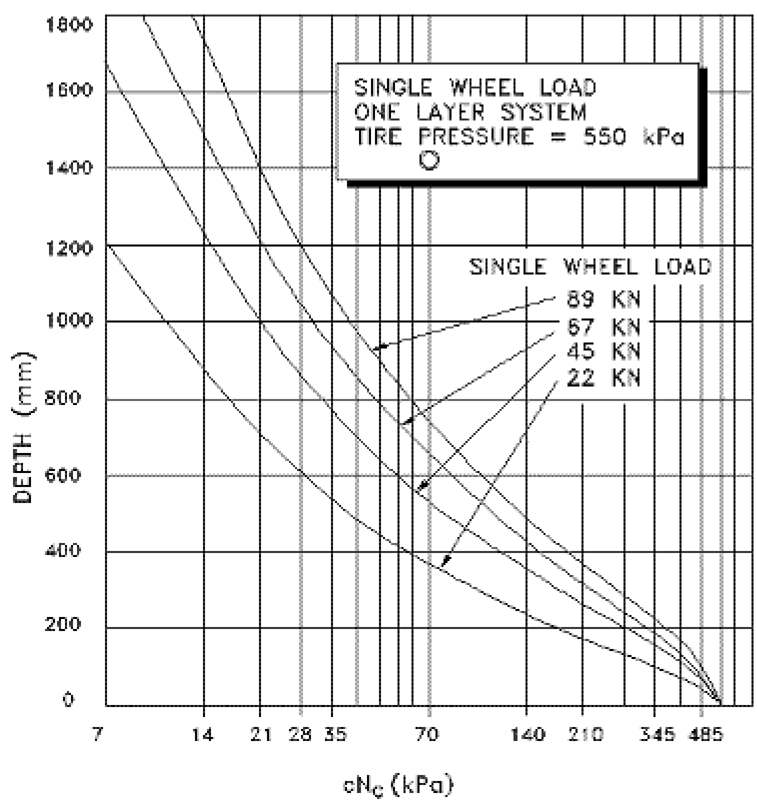


Figure 5.4—Forest Service thickness design curve for single wheel load.

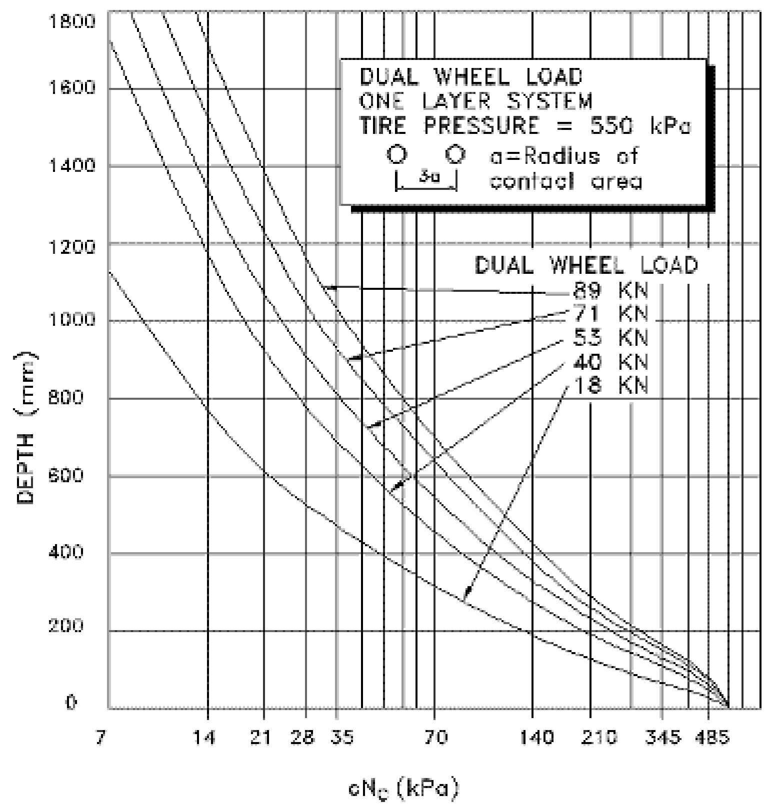


Figure 5.5—Forest Service thickness design curve for dual wheel load (Steward et al. 1977).

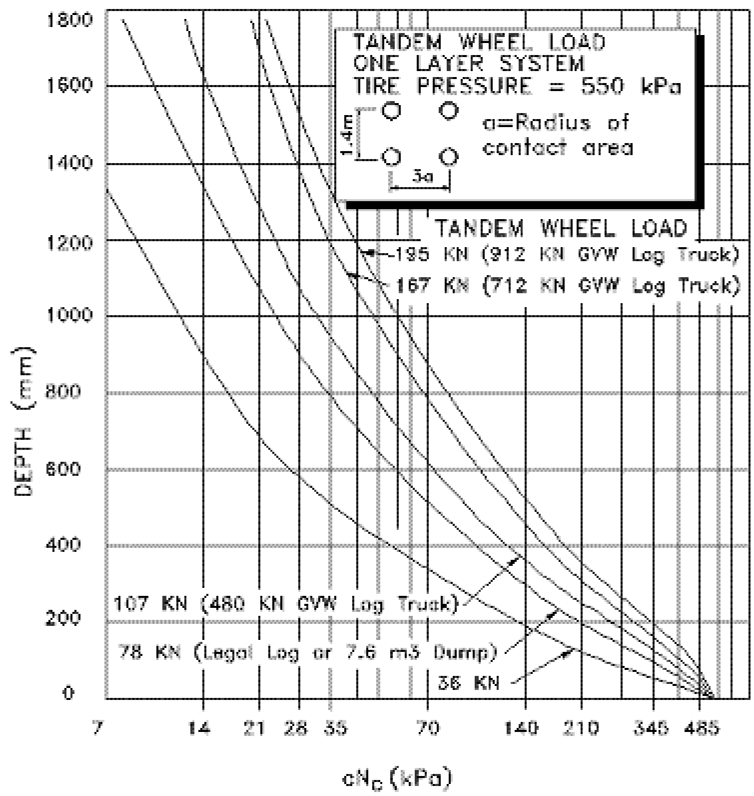


Figure 5.6—Forest Service thickness design curve for tandem wheel load (Steward et al. 1977).

TEMPORARY ROAD DESIGN EXAMPLE

DEFINITION OF DESIGN EXAMPLE

- Project Description: A haul road over wet, soft soils is required for a highway construction project.
- Type of Structure: temporary unpaved road.
- Type of Application: geotextile separator.
- Alternatives:
  - excavate unsuitable material and increased aggregate thickness.
  - geotextile separator between aggregate and subgrade.
  - use an estimated depth of aggregate and maintain as required.

GIVEN DATA

- Subgrade
  - cohesive subgrade soils
  - high water table
  - average undrained shear strength about 30 kPa or CBR = 1

- Traffic—approximately 5,000 passes
  - 90 kN single axle truck
  - 550 kPa tire pressure
- Ruts—maximum of 50 to 100 mm

REQUIRED

Design the roadway section.

Consider:

- design without a geotextile; and
- alternate with geotextile.

DEFINE

- Geotextile function(s):
- Geotextile properties required:
- Geotextile specification:

SOLUTION

- Geotextile function(s):
  - Primary - separation
  - Secondary - filtration, drainage, reinforcement
- Geotextile properties required:
  - Survivability
  - Apparent opening size (AOS)

DESIGN

Design roadway with and without geotextile inclusion. Compare options.

STEP 1—DETERMINE SOIL SUBGRADE STRENGTH

given—CBR ≈ 1

STEP 2—DETERMINE SUBGRADE STRENGTH AT SEVERAL LOCATIONS

Assume that CBR ≈ 1 is taken from area(s) where the subgrade appears to be the weakest.

STEP 3—DETERMINE WHEEL LOADING

given

—90 kN single-axle truck, with 550 kPa tire pressure

—therefore, 45 kN single wheel load

STEP 4—ESTIMATE AMOUNT OF TRAFFIC

given—5,000 passes

STEP 5—ESTABLISH TOLERABLE RUTTING

given—150 to 200 mm

STEP 6—OBTAIN BEARING CAPACITY FACTOR

without a geotextile:

—2.8 < N_C < 3.3

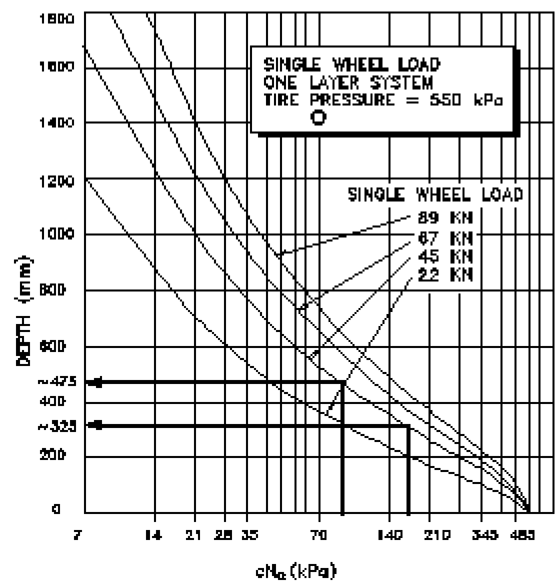
—assume $N_C \approx 3.0$ for 5,000 passes and 50 to 100 mm ruts

with a geotextile:

—5.0 < N_C < 6.0

—assume $N_C \approx 5.5$ for 5,000 passes and 50 to 100 mm ruts

STEP 7—DETERMINE REQUIRED AGGREGATE THICKNESSES



without a geotextile

—c N_C = 30 kPa x 3.0 = 90 kPa

—depth of aggregate . 475 mm

with a geotextile

—c N_C = 30 kPa x 5.5 = 165 kPa

—depth of aggregate ≈ 325 mm

STEP 8—SELECT DESIGN THICKNESS

Use 325 mm and a geotextile

STEP 9—CHECK GEOTEXTILE DRAINAGE AND FILTRATION CHARACTERISTICS

Use AOS < 0.3 mm and permittivity ≥ 0.1 sec^{-1}, per requirement of table 5.1 since soil has > 50% passing the 0.075 mm sieve. Permeability of geotextile must be greater than soil permeability.

STEP 10—DETERMINE GEOTEXTILE SURVIVABILITY REQUIREMENTS

Use table 5.2: with CBR = 1, dump truck contact pressure > 550 kPa, and 325 mm cover thickness, and find a MODERATE survivability to NOT RECOMMENDED rating.

Use a HIGH, or Class 1, survivability geotextile, or greater.

STEP 11—SPECIFY GEOTEXTILE PROPERTY REQUIREMENTS

From table 5.1; geotextile separator shall meet or exceed the minimum average roll values, with elongation at failure determined with the ASTM D 4632 test method, of:

Property	**Test Method**	**Elongation < 50%**	**Elongation > 50%**
Grab Strength	ASTM D 4632	1400	900
Sewn Seam Strength	ATSM D 4632	1200	810
Tear Resistance	ATSM D 4533	500	350
Puncture	ATSM D 4833	500	350
Burst	ATSM D 3786	3500	1700
Ultraviolet Stability	ATSM D 4355	50% strength retained after 500 hours	

The geotextile shall have an AOS < 0.3 mm, ≥ 0.1 sec^{-1}, and the permeability shall be ______.

STEP 12—SPECIFY CONSTRUCTION REQUIREMENTS

See section 5.12