STABILIZATION

HANDBOOK FOR PREPARING A SOLID DRIVING FOUNDATION

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TABLE OF CONTENTS


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INTRODUCTION

STABILIZATION DEFINED

"Soil and base stabilization refer to the improvement of pertinent soil engineering properties by the addition of additives so that the soil can effectively serve its function in the construction and life of a pavement."

- Purdue University, School of Civil Engineering

Today's engineers recognize that stabilization can be used to treat a wide range of inferior soil and aggregate conditions from highly expansive clays to more granular materials. Stabilization can be achieved through a variety of additives including Portland cement, lime, fly ash, bituminous binders, chemicals, and even additional soil and aggregate. Proper sampling, design, and testing is an important component of any stabilization project as it allows for the establishment of design criteria as well as the determination of the proper type and amount of additive to be used to achieve the desired engineering properties.

BENEFITS OF THE STABILIZATION PROCESS CAN INCLUDE:

- **Higher strength values including CBR, modulus, compressive strength, and resistance (R) value**
- **Increased load-bearing capacity**
- **Reduction in plasticity**
- **Lower permeability**
- **Potential reduction of pavement thickness with proper design**
- **Elimination of excavation, material hauling and handling, and base importation**
- **Improved compaction**
- **Providing for "all-weather" access onto and within projects sites**

Another form of soil treatment closely related to soil stabilization is soil *modification*, sometimes referred to as mud drying, soil conditioning, or soil amending. Although some stabilization inherently occurs in soil modification, the distinction is that soil modification is merely a means to reduce the moisture content and plasticity of a soil to expedite construction, whereas stabilization can substantially increase the shear strength of a material such that it can be incorporated into the project's structural design. The determining factors associated with soil modification versus soil stabilization may be the existing moisture content, the end use of the soil structure and ultimately the cost benefit provided.

Equipment for both the soil modification and stabilization processes typically includes the following, which may be supplemented with other construction equipment as dictated by specific job requirements:

- **Additive spreaders/distributors**
- **Soil mixers (reclaimers/pulverizers)**
- **Portable pneumatic storage containers**
- **Water trucks**
- **Compaction equipment, depending on lift thickness, materials and project requirements**
- **Motor graders**

Through stabilization, projects are built more cost effectively, perform better, and ultimately last longer. Stabilization helps to improve inferior subgrade and subbase materials, often resulting in an overall reduction of the final pavement thickness, and ultimately reducing the costs associated with the most expensive layers in a pavement structure.

In addition, the use of stabilization helps to alleviate a number of environmental concerns. By treating the soils found on the project, the amount of construction materials that need to be transported on local roads are reduced, with a subsequent reduction in damage to these roads, and a protection of natural resources through the reduction in use of virgin aggregate or soil sources. Vehicle emissions are also greatly reduced as less material hauling is required.

Typical construction steps for soil stabilization are shown below, although they may vary somewhat depending on the moisture content and composition of the in-place soil and/or aggregates.

- **Check and calibrate all equipment.**
- **If necessary, pre-wet dry soils to aid pulverization, or dry wet soils by aeration.**
- **Scarify if necessary to aid subsequent pulverization.**
- **Distribute stabilizing additive in dry form with mechanical spreader or in slurry form from distributor truck equipped with agitation system.**
- **Mix with traveling rotary mixer or pulverizer, adding water if necessary, until a homogeneous, friable mixture is obtained that will meet the specified pulverization requirements.**
- **Compact stabilized material with appropriate compaction equipment.**
- **Shape the area to final crown, cross-section and grade.**
- **Cure the treated materials as appropriate until the next pavement layer is constructed.**

CHAPTER ONE

THE PROCESS OF STABILIZATION

The goal of stabilization is to improve material properties for pavement or foundation design purposes or to overcome deficiencies in available construction materials. Although ideal soils are sought during the design process, the reality of less than ideal soils has created the need for ways to stabilize existing conditions.

There are many different additives that are routinely used to stabilize soils in need of improvement, and they can fall into a number of separate categories as follows:

- **Cementitious (including portland cement, lime, fly ash, ground granulated blast furnace slag, and kiln dust)**
- **Bituminous (including emulsions and expanded (foamed) asphalt)**
- **Chemical (including calcium chloride, sodium chloride, and magnesium chloride)**
- **Mechanical (including soil, aggregate, crushed concrete, and reclaimed asphalt product (RAP))**
- **Biological (such as microbes and enzymes)**
- **Proprietary combinations or blends (including cement/lime, lime/fly ash, and bitumen/cement)**

In the selection of a stabilizing additive, factors that must be considered are the type of soil to be stabilized, the purpose for which the stabilized layer will be used, the type of soil improvement desired, the required strength and durability of the stabilized layer, and the economic and environmental impacts. As mentioned, due to the wide array of stabilizers available for soil stabilization, a detailed discussion of every one would not be possible in this brochure. This section will cover the more commonly used stabilizing disciplines - cementitious, bituminous, chemical, and mechanical - with the intent of offering a good understanding of how these processes differ and compare to each other.

1.1 CEMENTITIOUS STABILIZATION

The use of cementitious additives in soil stabilization is intended to improve the treated soil's properties including increased stiffness, higher strength, enhanced freeze/thaw durability, decreased permeability, lowered plasticity, reduced swelling potential, and tighter control of moisture content and compaction. Three commonly used cementitious stabilizers are portland cement, lime, and fly ash.

PORTLAND CEMENT

The incorporation of portland cement into soils produces an engineered material most commonly referred to as soil-cement. The best soil-cement product is the one best suited for its intended application – modification or stabilization.

Many problems can occur during construction when silt and clay soils are encountered, particularly when wet. These soils can be soft, plastic, and difficult to compact. Cement-modified soil (CMS) is used to improve the engineering properties and construction characteristics of silt and clay soils by reducing the plasticity and enhancing the compaction and strength of the material. With 1 to 3 percent (by dry weight of soil) cement used to modify the soil, the final product is an improved construction material.

Principal Benefits of CMS include:

- **Improved constructability of marginal on-site soils**
- **Reduced plasticity and improved strength**
- **Less susceptible to damaging effect of water**
- **An all-weather work platform**
- **Use of on-site soil rather than removal and replacement with expensive select fill material**
- **Permanent soil modification (does not leach)**
- **No waiting (mellowing) period required**

Cement-treated base (CTB) is a general term that applies to all hardened soil-cement that meets the project specified minimum durability and strength requirements. However, CTB generally uses more cement than CMS resulting in a strong, durable, frost resistant layer for the pavement structure. Typical cement contents for mixed-in-place CTB range from 2 to 10 percent, (by dry weight of soil) resulting in recommended 7-day unconfined compressive strengths ranging from 200 up to 500 psi (1.4 to 3.4 MPa).

LIME

Adding lime to soil can have a number of beneficial effects, both during construction and over the life of the pavement or soil structure.

Lime can effectively be used for:

- **Drying – reducing the amount of moisture in the soil**
- **Modification – reducing the soil plasticity, aiding compaction, and increasing the soil strength.**
- **Soil Stabilization – increasing the strength, plasticity reduction, and expansion characteristics**

Because lime chemically combines with water, it can be used very effectively to dry wet soils – often within a matter of hours. The "dry-up" of wet soil at construction sites is one of the widest uses of lime for soil treatment.

Lime modification rapidly and significantly improves soil workability by reducing soil plasticity, making the soil more friable and easier to compact. Lime modified soil is much stronger than untreated soil

and can provide an all-weather working platform. Lime modification works best in clay soils and may or may not be permanent. Generally, between 1 and 4 percent lime (by dry weight of soil) is used for both drying and modification.

Lime stabilization changes the characteristics of a wide range of soils to produce permanent long-term strength, plasticity reduction, and stability. The mineralogical properties of the soils will determine their degree of reactivity with lime and the ultimate strength that the stabilized layers will develop. Fine-grained soils containing clay are good candidates for subgrade and base stabilization, generally using 2 to 6 percent lime (by dry weight of soil)

KILN DUST

Soils with high moisture contents can be dried effectively and economically with kiln dust. These materials react with water, chemically absorbing excess moisture while also producing heat that causes evaporation. In many cases, simply mixing a small percentage of kilm dust into wet and unworkable soils will bring the soil characteristics into specification, thereby eliminating the need to bring in fill material, typically resulting in substantial savings.

Kiln dusts also work well as soil stabilizers. When expansive clay soils are combined with kiln dust, the result is a more granular soil that has reduced plasticity and sensitivity to moisture changes, increased durability to wet-dry and freeze-thaw cycles, and increased compressive and load-bearing strength. Depending on their chemical composition – which vary depending upon the kiln and time frame from which they were derived – kiln dusts may be used alone or in combination with other additives in stabilized base mixtures, typically at rates from 3 to 10 percent (by dry weight of soil).

CLASS C FLY ASH

The self-cementing properties of sub-bituminous coal fly ashes (Class C fly ash) can be used effectively in both soil modification and soil stabilization applications. These applications include drying of soils to facilitate compaction and to reduce shrink-swell potential of high plasticity clays. Not to be confused with Class F fly ash which alone does not have cementitious properties, Class C fly ash has also been used to improve shear strength and subgrade support, and to reduce compressibility of both cohesive soils and granular materials.

In soil modification, Class C fly ash can reduce the moisture contents of soils to facilitate mechanical compaction. The reduction in moisture content occurs immediately and moisture contents can be adjusted to the desired range by varying the amount of ash incorporated. Since the drying effect is rapid, this method can be of great benefit when adverse weather conditions prevent moisture reduction by aeration or replacement with drier soils.

In soil stabilization, Class C fly ash creates a more stable section for paving operations and reduces the potential for subgrade damage due to construction traffic or adverse weather conditions. The cementitious properties of a particular Class C fly ash depend upon the mineralogy of both the ash and the soil being stabilized. For ash contents up to 18 percent (by dry weight of soil) the resulting 7-day unconfined compressive strengths can approach 500 psi (3.4 MPa) or more.

1.2 BITUMINOUS STABILIZATION

Bitumen stabilized materials – either through emulsion or expanded asphalt stabilization – create a flexible and fatigue resistant pavement layer. The addition of bituminous stabilizing additives is a proven cost-effective way of improving the strength and controlling the moisture of inferior in-place subgrade or subbase soils. In addition, bituminous stabilization can be combined with small amounts of portland cement or lime to decrease cure time, improve or eliminate stripping problems, and improve retained strength characteristics.

EMULSION

Asphalt emulsions are an ideal way to stabilize subgrade and subbase materials. This water-based additive mixes and binds easily with soils and aggregates, and the cured asphalt increases the material's load bearing capacity, stiffness, and resistance to weathering. Materials for emulsion stabilization include gravel, sand, silt, and clay. Some of the factors determining a stabilized material's ability to carry loads include gradation, plasticity, density, moisture content, drainage, and type and frequency of traffic.

Bituminous emulsions are widely used because of their low cost, low environmental impacts, and ease of construction. Generally, the most viscous bitumen material that can be readily mixed with the materials to be stabilized should be specified. The amount of bitumen used will vary with the material type, local conditions, and intended use, and will normally range from 1 to 10 percent (by dry weight of soil), with the higher amounts used with the finer grained soils.

EXPANDED (FOAMED) ASPHALT

Another technique used to homogenously incorporate bitumen into in-place subgrade and subbase material is expanded (foamed) asphalt. Asphalt foaming occurs when small amounts of water come into contact with hot asphalt. Each tiny foam bubble is a carrier of a thin film of asphalt. Typically 2 percent by mass of asphalt is the required amount of water to foam standard penetration-grade asphalt. This small amount of water will evaporate off immediately after reaction and not become part of the asphalt.

Expanded asphalt material can be placed, shaped, compacted and opened to traffic immediately after mixing and remains workable for extended periods of time. Materials having insufficient fines will not mix well with the expanded bitumen. The tiny particles of bitumen distributed by the expanded bubbles adhere to the finer gradations, producing asphalt-enhanced filler that acts as a mortar or mastic to bind the larger gradations together.

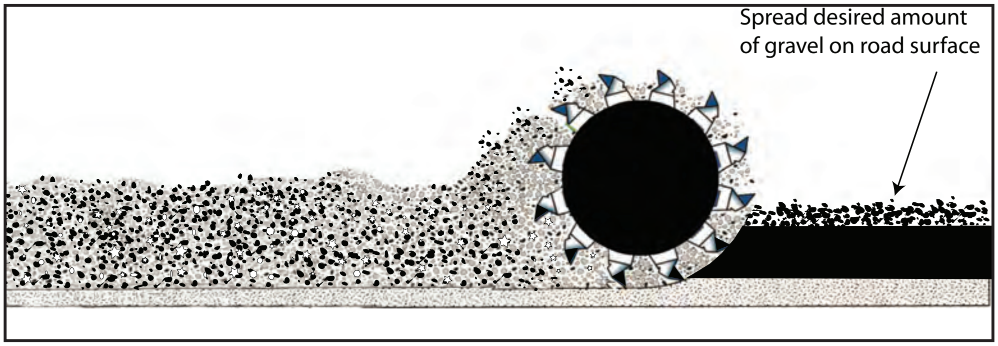
1.3 CHEMICAL STABILIZATION

Chemical stabilization is an effective and economical process in which the use of certain additives react chemically to improve specific properties of less than ideal in-place soils. Calcium chloride – a common chemical soil stabilizer – can be applied either dry or in a liquid form, resulting in some strength gain through cementitious action. The calcium effectively stabilizes soils through the attraction of moisture and subsequent evaporation resistance, providing a strong and durable base material.

The calcium penetrates into the soil material, coating the finer particles and binding them together. Calcium chloride's attraction for and strong retention of water provide several benefits in base stabilization including:

- **Achieving greater density with less compactive effort, resulting in labor, equipment, and equipment maintenance savings.**
- **Achieving and maintaining optimum moisture content to avoid delays waiting for subgrades and bases to dry out or for water to be added.**
- **Extending and controlling the curing period which enhances stability.**
- **Promoting a better bond between subgrade or subbase layers and subsequent pavement courses.**
- **Providing greater surface uniformity and reducing maintenance during stage construction.**

While obviously providing some cementitious action to the soil particles, the biggest impact of calcium chloride soil stabilization is the lowering of the treated material's freezing point, which ultimately reduces the number of freeze/thaw cycles in the treated layer. Calcium chloride's ability to depress the freezing point of water results in a roadway material with considerable resistance to frost heave. This is extremely important as frost heave in frost susceptible soils is one of the most common causes of pavement failures in cold climate areas.



1.4 MECHANICAL STABILIZATION

In some instances, inferior subgrade and subbase soils can be sufficiently stabilized through pulverization and compactive efforts alone. However, when this approach is not adequate to meet project requirements, the permanent improvement of these materials by blending them with one or more other materials is often recommended. This type of stabilization provides a direct means of altering the particle size distribution (and plasticity in some cases) and is referred to as mechanical stabilization.

The additional equipment required for this type of stabilization is minimal and usually limited to dump trucks, graders, and aggregate spreaders (if necessary) in order to transport and place the imported stabilizing materials. Materials requiring mechanical stabilization typically have properties which make them deficient to be used as base or subbase materials, including:

- **Poorly-graded products**
- **Silty sands, sandy clays, silty clays**
- **High plasticity pavement materials**

Mechanical stabilization involves mixing or blending two or more select materials in the proportions required to modify particle size distribution and/or plasticity. Mixing is performed in-place on the project prior to final shaping and compaction. Although visual inspections can often give a guide to the suitability of mechanically stabilized soils, materials produced through this discipline have properties similar to conventional unbound materials and should be evaluated by standard laboratory testing in order to ensure optimum proportioning of mixtures.

Mechanical stabilization is a very cost effective soil stabilization technique that can be utilized either solely or in combination with other stabilizing additives mentioned in this brochure.

CHAPTER TWO

PROJECT DESIGN PHILOSOPHY

There are two main components essential to the design and proper performance of stabilized pavement materials – the mix design prepared for the stabilized materials and the structural design of the pavement into which the stabilized materials will be incorporated. These two factors are interrelated, as the performance of the stabilized materials is dependent upon the thickness and composition of the pavement structure in which it will be used. Likewise, the structural design of the pavement system depends on the characteristics of the stabilized materials.

The design procedures for stabilized materials require thorough investigation and knowledge of both the pavement material to be stabilized and the stabilizing additives available. A few desirable material characteristics and assessment requirements for some stabilizing additives were discussed in Chapter 1 of this brochure. The structural design of pavements incorporating stabilized layers should be done in accordance with pavement design procedures recommended by the governing project authority.

2.1 PAVEMENT INVESTIGATION AND SAMPLING

The following information should be reviewed whenever a project location is being evaluated for in-place stabilization work:

- **The thickness of materials**
- **The composition and quality of materials**
- **The uniformity of materials**
- **The moisture content of materials**
- **The presence of any culverts or drainage structures**
- **The presence of any utility fixtures (both in ground and overhead)**
- **Drainage problems**

It is important in any type of stabilization work that the materials are thoroughly examined and their interactions with the specific additive to be used in the stabilization work be properly supported by laboratory analysis and testing before any actual field work begins. Although a review of previous construction documents or history can provide useful information, actual project samples are essential for proper evaluation.

The easiest way to obtain laboratory samples is to dig small "test pits." For example, one or more 1 foot by 1 foot (300 mm by 300 mm) sections of areas to be stabilized, excavated down to the full depth of proposed stabilization, will provide the materials necessary for most mix designs, and when exposed will provide a good picture of what the actual in-place materials look like.

The frequently with which samples should be taken depends on how variable the existing project location is. Enough material should be obtained to ensure a good representative sample of the materials to be stabilized. Sampling can usually be accomplished using a shovel, auger, or post-hole digger. From a representative location, a sample of material to be stabilized should be taken back to the laboratory to perform a mix design.

2.2 STABILIZER SELECTION AND EVALUATION

In order to obtain some preliminary information as to the type of stabilization required for a particular pavement or foundation material, particle size distribution and Atterberg limits are frequently used. The commonly accepted range of suitability of various types of stabilizers is often based on the percentage of material passing the No. 200 (0.075 mm) sieve and the plasticity index (PI) of that material. This approach simply provides a guide for a more detailed analysis with particular materials and particular stabilizers.

The information provided in Table 1 gives initial guidance in the evaluation of a stabilizer type. **Remember that this information should be taken as a broad guideline only.** For further information it is recommended that reference be made to trade literature and published research.

TABLE 1 – GUIDE TO SELECTING A STABILIZATION METHOD

	More than 25% Passing No. 200			Less than 25% Passing No. 200	
Type of Stabilizer	$PI \leq 10$	$10 < PI < 35$	$PI \geq 35$	$PI \leq 10$	$PI > 10$
Portland Cement	GOOD	GOOD	POOR	GOOD	GOOD
Lime	POOR	GOOD	GOOD	POOR	GOOD
Kiln Dust	POOR	GOOD	GOOD	POOR	GOOD
Class C Fly Ash	POOR	FAIR	GOOD	POOR	GOOD
Emulsion	GOOD	FAIR	POOR	GOOD	FAIR
Expanded Asphalt	GOOD	FAIR	POOR	GOOD	FAIR
Calcium Choride	POOR	FAIR	GOOD	FAIR	GOOD
Soils	GOOD	POOR	POOR	GOOD	FAIR
Aggregates	GOOD	FAIR	POOR	GOOD	FAIR

The ASTM International (ASTM) test procedures shown in Table 2 are to help determine the stabilizer amount necessary for achieving adequate structural strength when added to the in-place materials. Due to the extreme variations in characteristics and moisture content that are encountered on soil stabilization projects, it is usually necessary that the project structural design be based on the "worst case scenario" in order to help prevent pavement or foundation failures.

For portland cement, lime, and fly ash, testing procedures and design parameters are well established. In the case of bituminous stabilization, Hveem, Marshall, and The Asphalt Institute mix design methods have been modified for use in cold mixtures. No standard mix design is currently available for expanded asphalt but procedures similar to those for emulsion are generally used.

TABLE 2 – TESTING METHODS TO EVALUATE STABILIZED MATERIALS

Type of Stabilizer	Applicable Testing Procedures
Portland Cement Class C Fly Ash	ASTM D558 – Moisture-Density (Unit Weight) Relations of Soil-Cement Mixtures ASTM D559 – Wetting and Drying Compacted Soil-Cement Mixtures ASTM D560 – Freezing and Thawing Compacted Soil-Cement Mixtures ASTM D1633 – Compressive Strength of Molded Soil-Cement Cylinders
Lime	ASTM D698 – Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3)) ASTM D4318 – Liquid Limit, Plastic Limit, and Plasticity Index of Soils ASTM D5102 – Unconfined Compressive Strength of Compacted Soil-Lime Mixtures
Kiln Dust	ASTM D5050 – Commercial Use of Lime Kiln Dusts and Portland Cement Kiln Dusts
Emulsion Expanded Asphalt	ASTM D3203 – Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures ASTM D4867 – Effect of Moisture on Asphalt Concrete Paving Mixtures
Calcium Chloride	ASTM D698 – Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3)) ASTM D4318 – Liquid Limit, Plastic Limit, and Plasticity Index of Soils
Soil Aggregate	ASTM D698 – Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3)) ASTM D4318 – Liquid Limit, Plastic Limit, and Plasticity Index of Soils

Upon completion of all analysis and testing, there may be a number of acceptable stabilization methods that meet the project requirements. In many cases, the decision as to which stabilizer to use is generally a financial one, especially when initial construction costs and life cycle costs of all the considered alternatives are compared. Other things to consider are the past performance of a chosen stabilizer in similar work as well as the availability of materials, equipment, and qualified construction personnel.

2.3 WEATHER LIMITATIONS

Climate can have a significant impact on the selection of stabilizing additives. For instance, in wetter areas where the moisture content of the in-place materials is high, it is important to ensure that the wet strength of the stabilized materials is acceptable and susceptibility to moisture variations is low.

The recommended atmospheric and materials temperatures and conditions for properly stabilizing soils are governed by the type of stabilizer being used as shown in Table 3. Stabilization work should not be completed if it is raining or if rain appears likely. Rain can cause dilution of asphalt emulsions and premature chemical reactions in dry stabilizers spread on the surface, resulting in reduced or non-existent stabilized material strength.

TABLE 3 – CLIMATIC LIMITATIONS FOR STABILIZERS

Type of Stabilizer	Climatic Limitations for Construction
☐ Portland Cement	Do not perform work when stabilized material can be frozen. Air temperature in the shade should be no less than 40° F (4° C) and rising. Complete stabilization should be at least one month before the first hard freeze.
☐ Lime ☐ Class C Fly Ash ☐ Kiln Dust	Do not perform work when stabilized material can be frozen. Air temperature in the shade should be no less than 40° F (4° C) and rising. Complete stabilization should be at least one month before the first hard freeze. Two weeks minimum of warm to hot weather is desirable after completing the stabilization work.
☐ Emulsion ☐ Expanded Asphalt	Do not perform work when stabilized material can be frozen. Air temperature in the shade should be no less than 60° F (16° C) and rising. Asphalt emulsion stabilization should not be performed if foggy or when other high humidity (>80%) conditions exist. Warm to hot dry weather is preferred for all types of asphalt stabilization involving cold mixtures due to improved binder dispersion and curing.
☐ Calcium Chloride	Do not perform work when stabilized material can be frozen. Air temperature in the shade should be no less than 40° F (4° C) and rising. Complete stabilization should be at least one month before the first hard freeze.
☐ Soil ☐ Aggregate	Do not perform work when stabilized material can be frozen. Air temperature in the shade should be no less than 40° F (4° C) and rising.

SUMMARY

When the need for roadway stabilization exists, the selection of the correct technique and additive is very important. As discussed in this brochure, stabilization comes in the form of numerous disciplines and the factors to be considered when selecting the most appropriate method include:

- **Type of material to be stabilized**
- **Proposed use of the stabilized material**
- **Availability of suitable equipment, materials, and personnel**
- **Relative costs**

In addition, there are cases where two or more stabilizers can be used together to improve the soil characteristics for a given project. The use of combinations, or blends, of the additives mentioned in this brochure is quite common. As with all stabilization additives, when using pre-blended combinations care should be taken to ensure that proper ratios and consistency are maintained. Other stabilizing additives including slag, chlorides, microbes, enzymes, and numerous proprietary products have also been used with varying degrees of success to stabilize problem soils either alone or in combination.

Both modification and stabilization are needed for several reasons, primarily to supplement unsatisfactory road materials including poor subgrade, subbase, and base. Applying the correct additive or technique improves the engineered properties of the less than perfect material. By improving weaker materials, significant economic benefits are also seen. These economic benefits come from lowered costs associated with hauling better materials to the site, reducing surface thickness design, and also by accelerating construction times. The degree of need for stabilization will vary greatly and depend on a wide variety of circumstances that should be evaluated on a case-by-case basis.

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