Texas
Department
of Transportation

Guidelines for Modification and Stabilization of Soils and Base for Use in Pavement Structures

Construction Division
Materials & Pavements Section
Geotechnical, Soils & Aggregates Branch

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Chapter 1
Overview

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Section 1

Disclaimer

The Texas Department of Transportation, in conjunction with Dallas Little, P.E. and Tom Scullion, P.E., has developed this document to serve as guidance for TxDOT personnel for soil and base modification and stabilization. The information and guidance provided herein reflects the authors' knowledge and experience and may not reflect the views of others. Special thanks are extended to the Lime Association of Texas, the Cement Council of Texas, the Texas Coal Ash Utilization Group, the Texas Asphalt Pavement Association, and Pat Harris for their review and comment. Although much research has been conducted on the subject of soil and base modification during the past several decades, materials, design, and construction techniques are continuing to evolve. This document will likewise evolve.

Direct questions regarding these guidelines to the Geotechnical, Soils, and Aggregates Branch of the Construction Division at 512-506-5907.

Section 2

Overview

Pavement performance can be largely attributed to the performance of its foundation, which is comprised of the subgrade and base layers. Base and subgrade layers must provide the following:

- shear strength – the ability to resist shear stresses developed as a result of traffic loading;
- modulus (stiffness) – the ability to respond elastically and minimize permanent deformation when subjected to traffic loading;
- resistance to moisture – the ability to resist the absorption of water, thus maintaining shear strength and modulus, and decreasing volumetric swell;
- stability – the ability to maintain its physical volume and mass when subjected to load or moisture, and
- durability – the ability to maintain material and engineering properties when exposed to environmental conditions such as moisture and temperature changes.

Frequently, in-situ soils and local base materials do not meet project-specific requirements. Texas has some of the most expansive soils in the country, which cause distresses in many pavements around the state. A large portion of pavement construction currently performed consists of rehabilitating existing roads which frequently contain subgrade or base material layers that are inadequate for current traffic loading demands. Shortages of high quality aggregate sources are becoming more and more common. In order to achieve specified properties, subgrade, select fill and base materials frequently require treatment with additives such as asphalt, cement, fly ash, and lime. Each of these materials must be properly designed to determine the most appropriate additive to achieve the desired improvement.

Section 3

Goals of Treatment

Individual project conditions dictate different reasons for treatment. These will have great impact on the type and percentage of additive required. Common reasons for treatment include the following:

1. Reduce shrink/swell of expansive soils or existing materials.
2. Increase strength to provide long-term support for the pavement structure.
3. Reduce pavement thickness.
4. Reduce moisture susceptibility and migration.
5. Utilize local materials.
6. Bind salvaged materials used on pavement rehabilitation projects.
7. Provide a working platform for construction of subsequent layers by drying out wet areas and/or temporarily increasing strength properties.

Laboratory testing is essential to determine the type and percentage required to meet specific project conditions and performance criteria. Soil and base properties can vary drastically within a district, as well as within a project. Multiple additives can and should be specified on a project when material variation warrants it.

Once the evaluation of the treated material and engineering properties show a treatment strategy is effective in meeting project requirements and treatment goals, consideration in assigning the treated layer structural credit can be performed. Structural credit is discussed in TxDOT’s Pavement Design Manual.

Section 4

Mechanisms of Additives

In order to determine the additive best suited for a specific application, it is necessary to have a basic understanding of how each additive works as well as the impact of soil properties. Coating particles, binding particles together, and formation of new compounds are the main mechanisms that can occur when using an additive. The degree and speed of the mechanism depends on the composition of the additive and the material being treated. Some additives work independently, while others require water or water plus silica and alumina present in clays, to perform. The mineralogy, quantity, and particle size of fines in the soil or base can greatly impact the performance of individual additives. The goal of the soil or base treatment and the additive mechanism, composition, and reaction time must all be considered when selecting the best additive for a specific application.

Asphalt is a visco-elastic material that coats and binds particles together rather than inducing a chemical reaction or the formation of new compounds. It can increase strength and stiffness and reduce moisture susceptibility.

Fly ash is a by-product of coal combustion and its components vary depending upon the specific coal combustion process. Class FS is a pozzolan that often requires an activator such as lime or cement. Class CS is a combination of a pozzolan and self-setting material. When combined with water, a cementitious reaction occurs, which results in binding of particles together. Depending on the chemical composition, alteration of particle structure and increased resistance to shrink-swell and moisture susceptibility can occur. The reactions prompted by fly ash occur more slowly than cement but more rapidly than lime. Compaction must be completed within six hours of application.

Hydraulic cement is a product manufactured to meet a variety of performance criteria by controlling the relative proportions of calcium, silica, alumina, and iron compounds. When combined with water, hydration occurs, resulting in the formation of new compounds, most of which have strength-producing properties. When mixed with soil or base, particles become bound together and the mixture increases in strength and moisture resistance. Depending on the composition of the cement and the soil mineralogy, a chemical reaction can occur between calcium hydroxide and the soluble silica and alumina present in clay, resulting in alteration of particle structure and increased resistance to shrink-swell. Approximately two hours after the soil-cement mixture is exposed to moisture, the soil particles are bound together and compaction must be complete. Additional handling of the treated material will break the bonds that have been established. Strength gain can continue for several days. Particle alteration at this stage of the reaction process is inhibited because of the bound state.

Lime is formed by the decomposition of limestone at elevated temperatures. When lime is combined with water and the soluble silica and alumina present in clay, a chemical reaction occurs, resulting in the formation of new compounds. When combined with water, its primary function is alteration of particle structure and increased resistance to shrink-swell and moisture susceptibility. A secondary result is binding of particles (when combined with clay) and strength gain. Since alteration of particle structure occurs slowly, depending upon the type of clay present, a mellowing period from 1 to 4 days is allowed to obtain a homogeneous, friable mixture. There is no limitation in the specifications on the amount of time allowed to complete compaction.

Chapter 2
Subgrade Treatment

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Section 1

Overview & Flowchart

There are many variables to consider for subgrade treatment, especially when treatment is performed with the intent that it will have a long-term effect. The flowchart in Figure 1 provides a simplified illustration of the steps required for successful subgrade treatment.

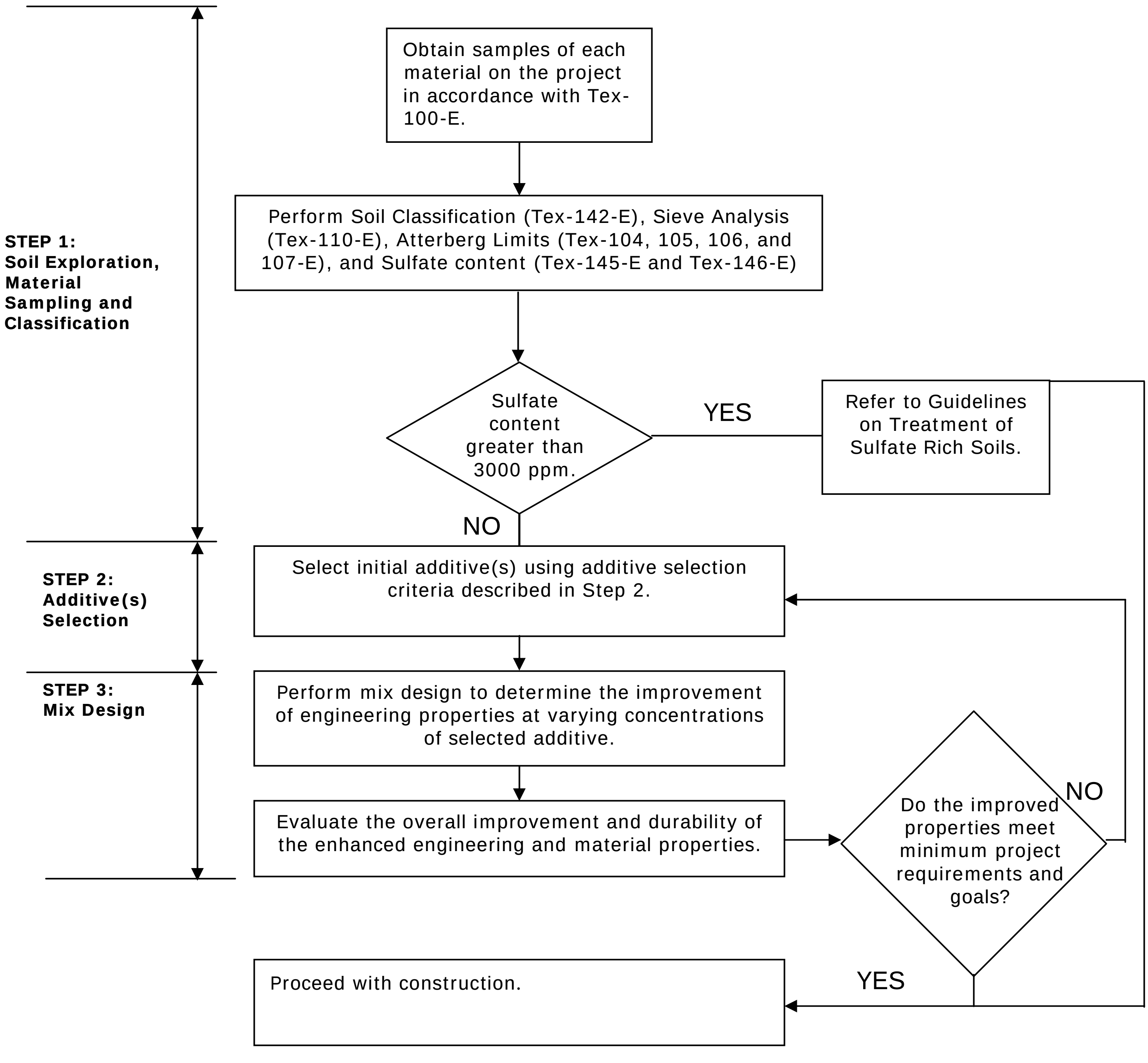

Figure 1: Flowchart for Subgrade Soil Treatment.

Section 2

Step 1: Soil Exploration, Material Sampling, and Soil Classification

Soil exploration is vital, as it provides material for testing and also reveals conditions in underlying strata that can affect the performance of the pavement structure and treated layers, such as soil mineralogy, water table proximity, and soil strata variation. It is important to obtain bulk samples large enough to perform multiple mix designs and soil classifications. As a rule of thumb, obtain at least ten 50 lb. bags of each soil requiring a mix design.

Soil investigations, classification, and characterization are discussed in TxDOT's Pavement Design Manual.

Section 3

Step 2: Additive Selection Criteria

The selection of an appropriate additive(s) is based on many factors, including:

- soil mineralogy and content (sulfates, organics, etc…)
- soil classification (gradation and plasticity)
- goals of treatment
- mechanisms of additives
- desired engineering and material properties (strength, modulus, etc…)
- design life
- environmental conditions (drainage, water table, etc…)
- engineering economics (cost savings vs. benefit).

Figure 2 provides a modified decision tree derived from charts developed by Currin, et al. in 1976, A. Smith and J. Epps in 1975, and D. N. Little, et al. in 1995. To select an additive(s), soil classification information from soil exploration results in Step 1 are required. The information from this chart applies to most, but not all cases. The decision tree serves as a good rule of thumb in selecting an initial additive(s). Validation testing must be performed to verify whether the selected additive(s) accomplishes the goals and requirements of the treated soil. Also, engineering economics, such as material availability, construction costs, construction time, and the overall benefit of the improved structural and construction performance, need to be factored into the selection of an additive.

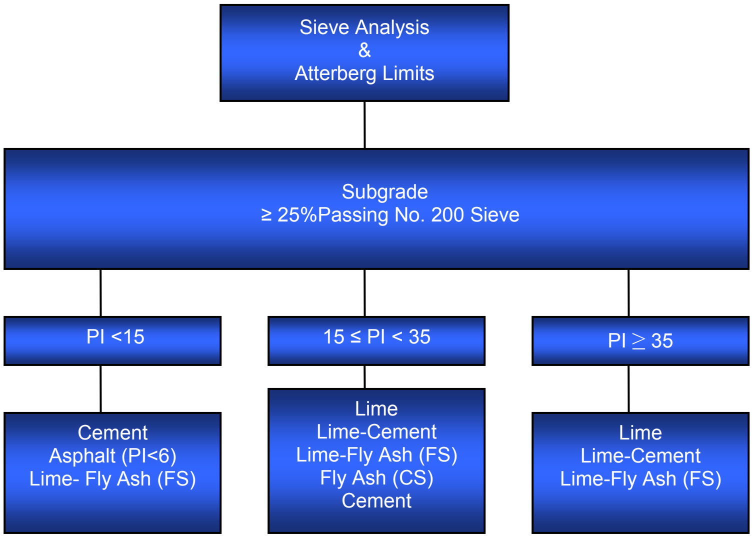

Figure 2: Additive Selection for Subgrade Soils Using Soil Classification.

Section 4

Step 3: Mix Design

Performing mix designs is essential in order to:

- ensure the optimization of percent additive(s) used
- optimize the engineering and materials properties
- measure the effectiveness of these material and engineering properties using moisture conditioning
- observe the effectiveness of the additive(s) with a specific soil and its inherent mineralogy
- provide density and moisture control parameters for construction
- mitigate cracking and other distresses associated with material behavior.

Improvements are soil-dependent given varying mineralogy and soil chemical compositions. Perform the steps below as applicable to the 'Goals of Treatment.'

Step 1:	Sulfate and Organic Testing	Verify that the sulfate and organics contents are within acceptable levels. This testing should be performed during the soils investigation phase, but verification testing ensures the soil does not contain detrimental levels. Measure the sulfate and organics content prior to addition of additive. Determine the sulfate concentration in accordance to Tex-145-E. If the sulfate levels are above 3000 ppm, then refer to the 'Guidelines on Stabilization of Sulfate Rich Soils' for further recommendations and guidelines. Organic soil is a soil that would be classified as a clay or silt except that its liquid limit after oven drying (dry sample preparation) is less than 75% of its liquid limit before oven drying (wet sample preparation). Determine the organic content in accordance with ASTM D-2974. If the organics content exceeds 1%, additional additive will need to be added to counter the cationic exchange capacity of the organic material.
Step 2:	M/D Curve	Determine the moisture/density relationship for field density control in accordance with the test procedure required by the governing specification.
Step 3:	pH	For treatments requiring lime**,** the pH of the soil-lime environment is critical because high pH (basic) mixtures increase the ability of the lime to react with soil minerals, like silica and alumina, which also require high pH levels to dissolve. Performing Tex-121-E, Part III, determines the ability and minimum amount of lime to treat a specific soil by pH testing. Using the specific soil in question is vital since minerals and organics can have large effects on the solubility of the lime and the overall pH of the mixture.

Step 4:	PI	Plasticity index is commonly used as an indication of soil shrink/swell properties and constructability. The plasticity index of a soil measures the moisture content at which a soil begins to exhibit plastic and liquid physical states. If a soil has the ability to attract and drive off large amounts of moisture, this results in large volumetric change and material instability.
Step 5:	Strength Testing	When required, perform strength testing in accordance with the test procedure required by the governing specification.
Step 6:	Modifier Percentage Selection	Select the lowest modifier content necessary to satisfy the project requirements.

Chapter 3

Base Material Treatment

Contents:

Section 1

Overview & Flowchart

There are many variables to consider for base material treatment. The flowchart in Figure 3 provides a simplified illustration of the steps required for successful base material treatment.

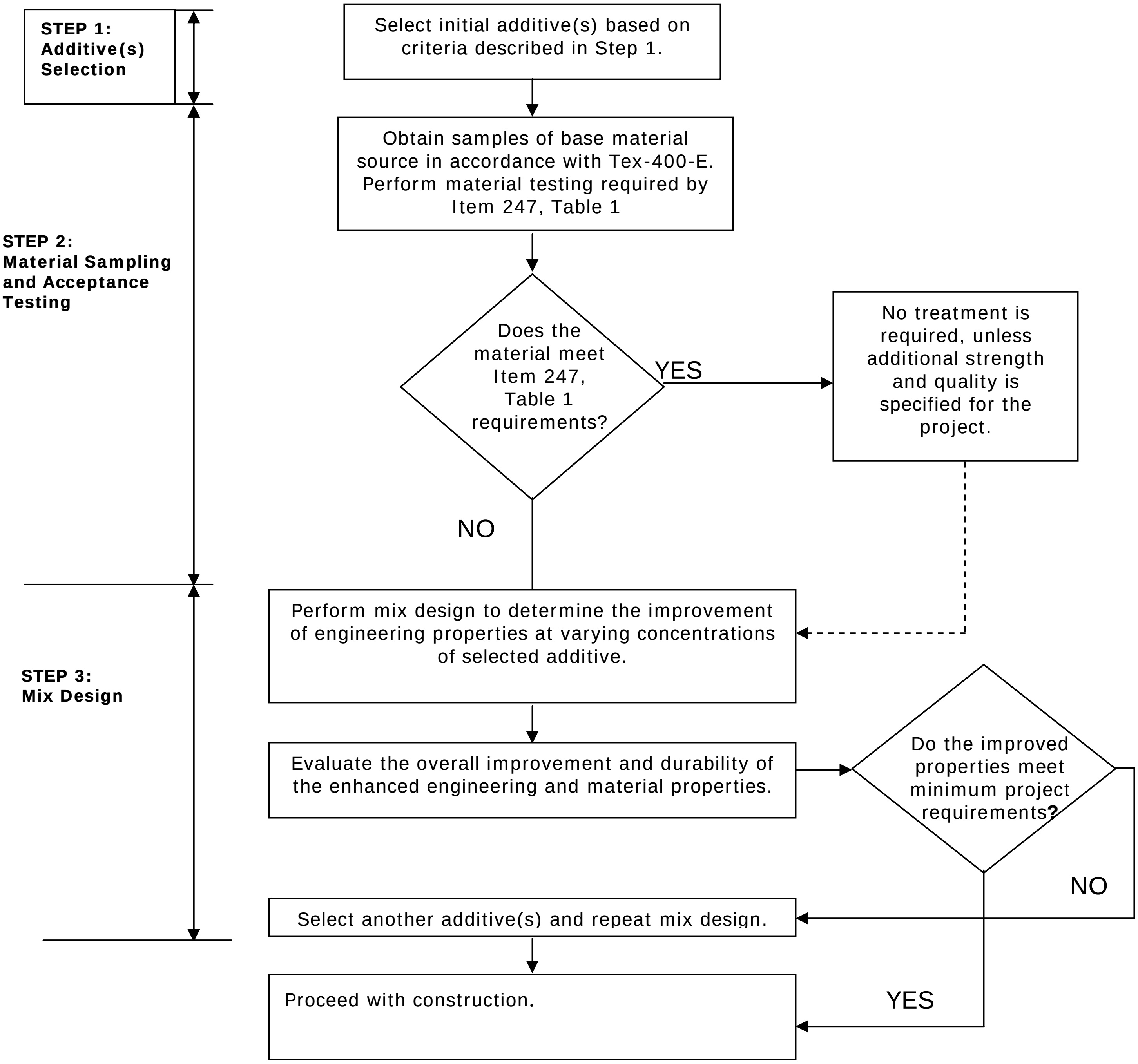

Figure 3: Flowchart for Base Treatment.

Section 2

Step 1: Additive Selection Criteria

The selection of an appropriate additive(s) is based on many factors, such as:

- soil classification (gradation and plasticity)
- goals of treatment
- mechanisms of additives
- desired engineering and material properties (strength, modulus, etc…)
- design life
- environmental conditions (drainage, water table, etc…)
- engineering economics (cost savings vs. benefit).

Figure 4 provides a modified decision tree derived from charts developed by Currin, et al. in 1976, A. Smith and J. Epps in 1975, and D. N. Little, et al. in 1995. To select an additive(s), base characterization from material acceptance test results in Step 1 is required. The information from this chart applies to most, but not all cases. The decision tree serves as a good rule of thumb in obtaining an initial additive(s). Validation testing must be performed to verify whether the selected additive(s) accomplishes the goals and requirements of the treated base. Also, engineering economics, such as material availability and construction costs, and the overall benefit of the improved structural and construction performance, need to be factored into the selection of an additive.

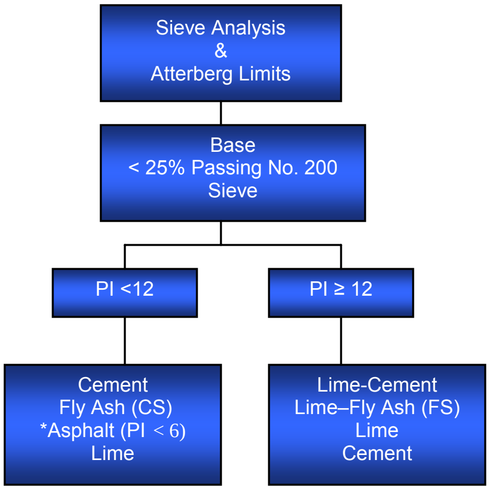

Figure 4: Additive Selection for Base Materials Using Soil Classification.

Section 3

Step 2: Material Sampling and Acceptance

Material sampling and testing is critical and is required to characterize material and physical properties that can affect the performance of the pavement structure. Sample base material in accordance with Tex-400-A.

It is important to obtain bulk samples large enough to perform multiple mix designs. As a rule of thumb, obtain at least ten 50 lb. bags of each source requiring a mix design.

Section 4

Step 3: Mix Design

Performing mix designs is essential in order to:

- ensure the optimization of percent additive(s) used
- optimize the engineering and materials properties
- measure the effectiveness of these material and engineering properties using moisture conditioning
- observe the effectiveness of the additive(s) with a specific base and its inherent mineralogy
- provide density and moisture control parameters for construction.

Perform the steps below as applicable to the 'Goals of Treatment.'

Step 1	Sulfate and Organic Testing	Some flexible base materials have been found to contain unacceptable levels of sulfate concentrations. Determine the sulfate concentration in accordance to Tex-145-E. Measure the sulfate content prior to the addition of an additive. If the sulfate levels are above 3000 ppm, use of a different base material is recommended.
Step 2	M/D Curve	Determine the moisture/density relationship for field density control in accordance with the test procedure required by the governing specification.
Step 3	PI	Plasticity index is commonly used as an indication of the soil binder properties. If the soil binder has the ability to attract large amounts of moisture, moisture migration and poor cohesion can become problems.
Step 4	Strength Testing	When required, perform strength testing or triaxial classification in accordance with the test procedure required by the governing specification.
Step 5	Modifier Percentage Selection	For treatments requiring lime**,** the pH of the soil-lime environment is critical because high pH (basic) mixtures increase the ability of the lime to react with soil binder minerals, like silica and alumina, which also require high pH levels to dissolve. Performing Tex-121-E, Part III, determines the ability and minimum amount of lime to treat a specific soil by pH testing. Select the lowest additive content necessary to satisfy the project requirements.

Chapter 4

Rehabilitation of Salvaged Existing Materials

Contents:

Section 1

Overview & Flowchart

There are many variables to consider for treatment of salvaged existing materials. The flowchart in Figure 5 provides a simplified illustration of the steps required for successful treatment.

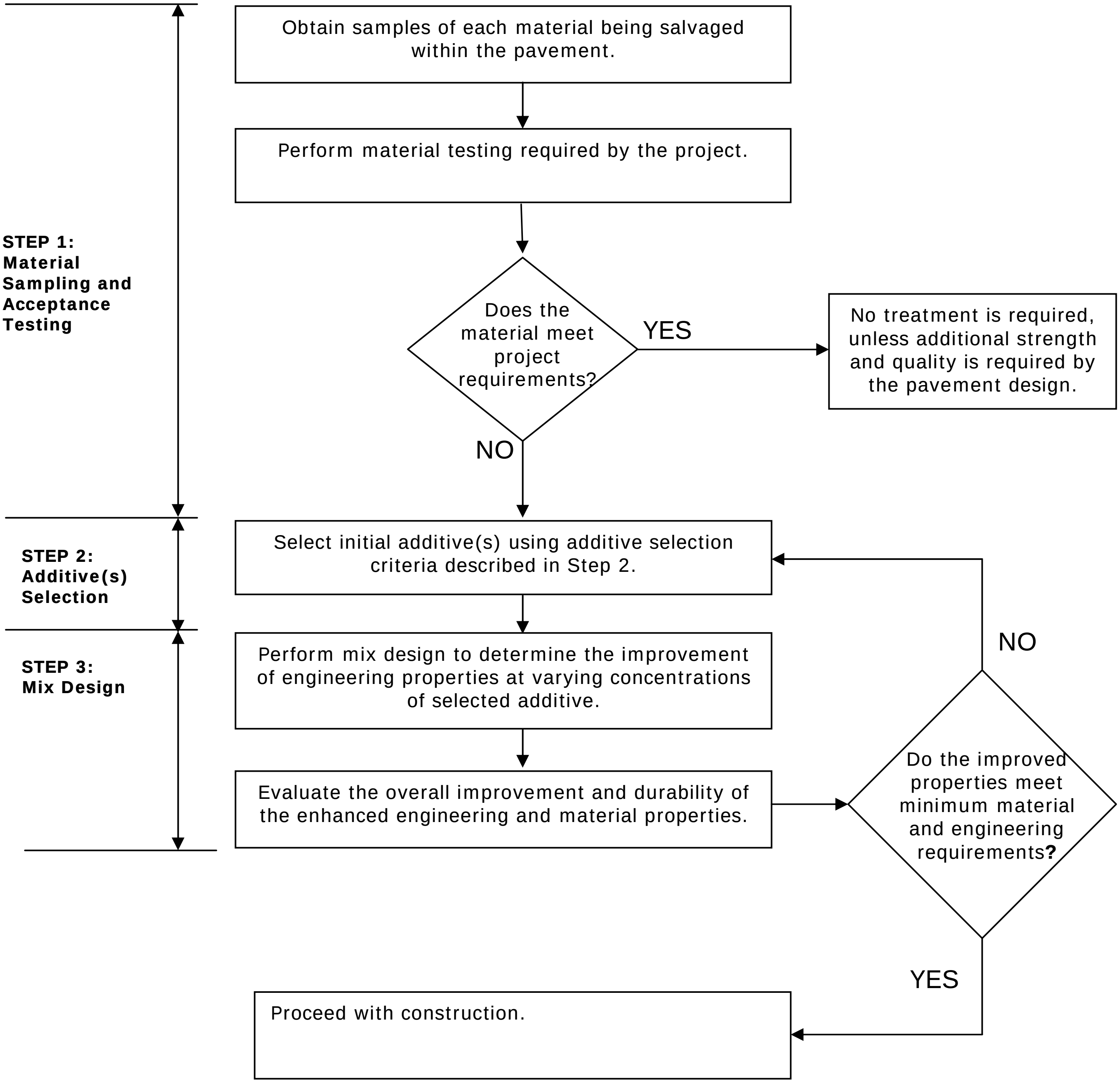

Figure 5: Flowchart for Rehabilitation of Salvaged Existing Materials.

Section 2

Step 1: Material Sampling and Acceptance

Treatment of salvaged road mix materials is dependent on the material variability of the existing material being incorporated in the final blended mix. With more processing, the gradation becomes finer, and it will be difficult to attain the required strength. Over-processed material becomes prone to experiencing shrinkage cracking. For this reason, obtaining a representative sample of the existing material in the correct proportion is critical to characterizing the modified engineering and material properties. Sampling and processing the existing material to the same degree in which it will materialize during construction is difficult, especially if plastic subgrade soils are incorporated. For confidence of permanence of this type of material when plastic soils are incorporated, the assurance of the adequate reduction of the plasticity of the material must be certain.

After performing a mix design using material sampled prior to construction, sample road mix that has been pulverized to the level that will be performed during typical construction operations. Test to determine compliance with gradation requirements in the governing item. Quality assurance testing must be performed on the field processed materials to verify the mix design moisture-density relationships and strength properties required by the project.

It is important to obtain bulk samples large enough to perform multiple mix designs. As a rule of thumb, obtain at least ten 50 lb. bags of a single source of base material requiring a mix design. Sample according to Tex-400-A.

Section 3

Step 2: Additive Selection Criteria

The selection of an appropriate additive(s) for salvaged road mix material is based on many factors, such as:

- soil mineralogy and content (sulfates, organics, etc…)
- soil classification (gradation and plasticity)
- goals of treatment
- mechanisms of additives
- desired engineering and material properties (strength, modulus, etc…)
- design life
- environmental conditions (drainage, water table, etc…)
- engineering economics (cost savings vs. benefit).

Figure 6 provides a modified decision tree derived from charts developed by Currin, et al. in 1976, A. Smith and J. Epps in 1975, and D. N. Little, et al. in 1995. To select an additve(s), base characterization from material acceptance test results in Step 1 is required. The information from this chart applies to most, but not all cases. The decision tree serves as a good rule of thumb in obtaining an initial additive(s). Validation testing must be performed to verify whether the selected additive(s) accomplishes the goals and requirements of the treated salvaged road mix materials.

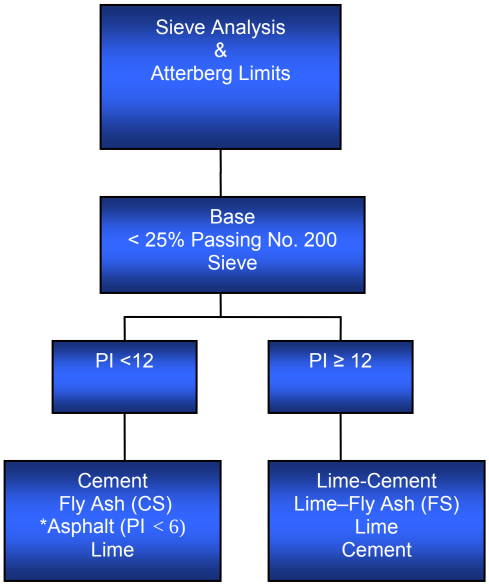

Figure 6: Additive Selection for Salvaged Existing Materials Using Soil Classification.

Section 4

Step 3: Mix Design

Performing mix designs is essential in order to:

- ensure the optimization of percent additive(s)
- optimize the engineering and material properties and observe the effectiveness of the selected additive with induced moisture conditioning
- observe the effectiveness of the additive(s) with a specific soil and its inherent mineralogy
- provide density and moisture control parameters for construction.

Perform the steps below as applicable to the ‘Goals of Treatment.’

Step 1:	Sulfate and Organic Testing	Verify that the sulfate and organics contents are within acceptable levels. This testing should be performed during the soils investigation phase, but verification testing ensures the soil does not contain detrimental levels. Measure the sulfate and organics content prior to addition of additive. Determine the sulfate concentration in accordance to Tex-145-E. If the sulfate levels are above 3000 ppm, then refer to the ‘Guidelines on Stabilization of Sulfate Rich Soils’ for further recommendations. Organic soil is a soil that would be classified as a clay or silt except that its liquid limit after oven drying (dry sample preparation) is less than 75% of its liquid limit before oven drying (wet sample preparation). Determine the organic content in accordance with ASTM D-2974. If the organics content exceeds 1%, additional additive will need to be added to counter the cationic exchange capacity of the organic material.
Step 2:	M/D Curve	Determine the moisture/density relationship for field density control in accordance with the test procedure required by the governing specification.
Step 3:	PI	Plasticity index is commonly used as an indication of the soil binder properties. If the soil binder has the ability to attract large amounts of moisture, moisture migration and poor cohesion can become problems.
Step 4:	Strength Testing	When required, perform strength testing or triaxial classification in accordance with the test procedure required by the governing specification.

Step 5:	pH	For treatments requiring lime**,** the pH of the soil-lime environment is critical because high pH (basic) mixtures increase the ability of the lime to react with soil binder minerals, like silica and alumina, which also require high pH levels to dissolve. Performing Tex-121-E, Part III, determines the ability and minimum amount of lime to treat a specific soil by pH testing.
Step 6:	Modifier Percentage Selection	Select the lowest modifier content necessary to satisfy the project requirements.

After performing a mix design using material sampled prior to construction, sample road mix that has been pulverized to the level that will be performed during typical construction operations. Test to determine compliance with gradation requirements in the governing item. Quality assurance testing must be performed on the field processed materials to verify the mix design moisture-density relationships and strength properties required by the project.