Treatment Guidelines for Soils and Base in Pavement Structures

Materials & Tests Division

Soils & Aggregates Section

August 2019

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INTRODUCTION

This document provides a basic overview of selecting additives for treatment of soil and base materials used in pavements. The information in this document will provide personnel with all levels of experience with enough information to determine project suitability, identify candidate additives, perform a mixture design, and identify appropriate construction processes. The information in this document is applicable to both construction and maintenance. More specific and detailed information can be found in other sources, which include but are not limited to the following:

- TxDOT Materials & Tests Division (MTD) website.
- TxDOT *2014 Standard Specification for Construction and Maintenance of Highways, Streets and Bridges*.
- TxDOT Test Methods, Series 100-E and 400-A.
- TxDOT *Guide Schedule of Sampling and Testing*.
- the Soils and Aggregates Section within MTD.

For questions or comments, call 512-506-5907.

ADDITIVE SELECTION

OVERVIEW

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

- Shear strength — the ability to resist shear stresses developed as a result of traffic loading.
- Modulus and 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 physical volume and mass when subjected to load or moisture.
- Durability — the ability to maintain long term 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 that contain subgrade or base material layers that are inadequate for current traffic loading. Shortages of high-quality aggregate sources are becoming more and more common. To achieve specified properties, subgrade, select fill, and base materials, frequently require treatment with additives such as cement, lime, asphalt, fly ash, lime-fly ash, or other treatments. To achieve a permanently stabilized layer to provide a structural improvement, each of these materials must be properly designed in the lab using the procedures in this document.

GOALS OF TREATMENT

The goals for treatment are determined by individual project conditions. Generally, one of two goals may be achieved for treatment:

- Modification of project materials to provide a temporary working platform.
- Stabilization of materials for long-term strength gain to meet traffic conditions and/or reduce the pavement thickness.

The goal of treatment has a great impact on selecting the type and percentage of additive required. Treatments are often used for one or more of the following reasons:

- Reduce shrink or swell of expansive soils or existing materials.
- Increase strength to provide long-term support for the pavement structure.
- Reduce pavement thickness.
- Reduce moisture susceptibility and migration.
- Use local materials.
- Bind salvaged materials used on pavement rehabilitation projects.

- Provide a working platform for construction of subsequent layers by drying out wet areas.
- Provide a working platform for construction of subsequent layers by temporarily increasing strength properties.

Laboratory testing is essential to determine that a project is suitable for treatment. The type and percentage of additive required to meet specific project conditions and performance criteria must be determined in the laboratory before starting construction. 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. To test representative samples of project material, ensure proper sampling procedures are followed based on the material being treated. Recommended sampling procedures are provided later in this document.

Once the evaluation of the treated material and engineering properties shows a treatment strategy is effective in meeting project requirements and treatment goals, structural credit for the treated layer may be assigned. Structural credit is discussed in the TxDOT *Pavement Design Manual*. No structural benefit should be used for any treated layers unless the guidelines presented in this document are followed and the strength requirements met.

To determine the additive best suited for a project, it is necessary to have a basic understanding of how each additive works as well as the impact of soil or base properties on potential treatment effectiveness. Coating particles, binding particles 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 (generally present in clays) to react with soil particles. 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 treatment, cost, treatment mechanism, material composition, and reaction time must all be considered when selecting a project for treatment.

LIME TREATMENT

Generally, projects with elevated-plasticity materials are candidates for lime treatment. With soils, lime treatment can reduce shrink-swell potential, provide increased strength and a working platform for construction, and increase the thickness of better material in the pavement. With base materials, lime treatment is generally considered to increase the material strength and reduce susceptibility to moisture for better performance under traffic.

Lime is formed by the decomposition of limestone at elevated temperatures. When lime is combined with water, it creates a high-pH environment, which solubilizes silica and alumina (present in clays), and a chemical reaction occurs forming new compounds. When combined with water and soil material, lime's primary mechanism is alteration of the soil particle structure and increased resistance to shrink-swell and moisture susceptibility. A secondary result is binding of the particles and strength gain through pozzolanic reaction. Since alteration of particle structure occurs slowly, a mellowing period from 1 to 4 days is required to obtain a homogeneous, friable mixture. There is no limitation in TxDOT's specifications on the amount of time allowed to complete compaction.

Lime can be applied as pebble (quicklime), dry (hydrated), or slurry. Figure 1 shows application of pebble, dry, and slurry lime.

Figure 1. Pebble (Quicklime) (Left), Dry (Hydrated) Lime (Center), and Lime Slurry (Right).

Table 1 summarizes the unique benefits and drawbacks of each type. Figure 2 illustrates how the lime-soil reaction increases the workability of high-plasticity-index (PI) materials, regardless of the type of lime used.

Table 1. Benefits and Drawbacks of Types of Lime.

Type of Lime	Benefits	Drawbacks
Quicklime (pebble)	Contains highest percentage of active lime among any lime type. Can rapidly dry out excessively wet materials.	Must exercise extra safety precautions due to heat given off when exposed to water. May require extra water, mixing, and mellowing.
Dry (hydrated)	Commonly available. Can dry out wet materials.	Prone to dusting.
Slurry	Minimizes dusting. Helps obtain good dispersion in mixture and faster and more complete reaction.	May run off if applied topically and surface is not pre-scarified.

Figure 2. Clay Soil before and after Treatment with Lime.

If a project has materials high in sulfate content (e.g., gypsum), special considerations must be taken when the use of lime is an option. This is due to the potential for sulfate-induced soil heave, where the lime reacts with sulfates and can result in significant swelling of the pavement. The appendix contains procedures to follow when project materials contain sulfates.

CEMENT TREATMENT

Generally, projects needing structural improvements may be candidates for cement treatment. With base materials, cement is generally considered to increase the material strength, reduce moisture sensitivity, and provide increased structural capacity or reduce total required pavement thickness. With soils, cement is generally considered to modify low-to moderate-PI materials for strength gain and reduced moisture sensitivity.

Hydraulic cement is manufactured 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.

Cement can be plant-mixed in a pug mill with material and then delivered to the jobsite. In a rehabilitation setting, cement is generally applied as a dry powder on top of the pavement and then mixed into the plan treatment depth by a recycler. Figure 3 illustrates the typical blown application and the less common spreader application of dry cement. Generally, the spreader should allow more precise control of the application rate.

Figure 3. Blown (Left) and Spread (Right) Cement Application.

Approximately 2 hours after the cement-treated 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 through reactions with clays can continue for several days.

Depending on the composition of the cement and the soil mineralogy, a chemical reaction can occur between calcium hydroxide and soluble silica and alumina (present in clays), resulting in alteration of particle structure and increased resistance to shrink-swell, analogous to treatment with lime. However, with high-PI soils, cement is generally not as effective as lime to obtain the required pulverization in the field. With high-PI soils, cement also does not diffuse into the soil as much as lime, so caution should be exercised if considering cement applications in highly plastic soils.

If a project has materials high in sulfates, special considerations must be taken for use of cement due to the potential for sulfate heave, where the cement reacts with sulfates and can result in significant swelling of the pavement. The appendix contains procedures to follow when project materials contain sulfates.

ASPHALT TREATMENT

Generally, projects needing structural improvement with relatively low-PI materials may be candidates for asphalt treatment. Asphalt is a temperature-sensitive material that coats and binds particles together rather than inducing a chemical reaction or the formation of new compounds. With base materials, asphalt treatment is generally considered to increase the material strength, reduce moisture sensitivity, and provide increased structural capacity or reduce total required pavement thickness.

Asphalt can be applied by passing a material through a central plant or applied in place using emulsion or foamed asphalt treatments. Figure 4 shows asphalt emulsion and foamed asphalt. Emulsion uses water as the delivery mechanism for the asphalt, coating particles in the treated mixture. Emulsion cures by the evaporation of the water. Foamed asphalt requires hot oil (generally 320 to 340 °F) to be injected into a nozzle with an expansion chamber. A small amount of water is also injected, and then the heat of the oil combined with the small amount of water causes the asphalt to temporarily foam or expand multiple times its original volume. Key factors to consider when selecting which asphalt treatment type to use are cost, existing moisture conditions, and climate.

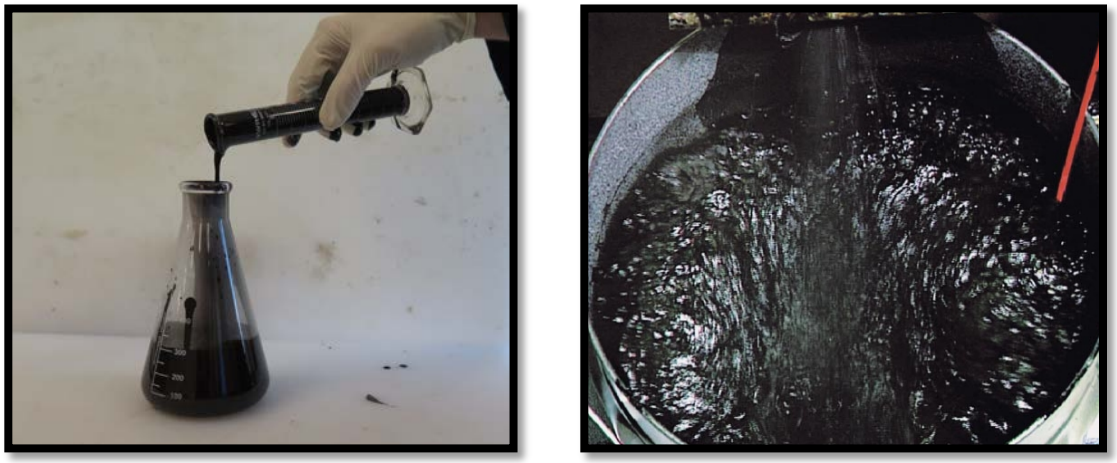

Figure 4. Asphalt Emulsion (Left) and Foamed Asphalt (Right).

Asphalt treatment is not generally considered for soils, although the treatment may be appropriate with low-PI soils to reduce moisture susceptibility and provide a working platform. However, historically, asphalt treatment of soils has proven cost prohibitive.

FLY ASH TREATMENT

Generally, projects with materials needing strength or moisture sensitivity improvement may be candidates for treatment with fly ash. Depending on the material PI, Class CS ash (for low-PI material) or Class FS (for elevated-PI materials) may be considered to attain these improvements.

Fly ash is a by-product of coal combustion. Its components vary depending upon the specific coal combustion process. Class FS is a pozzolan (source of alumina and silica) that generally requires an activator such as lime or cement. Class CS is a combination of a pozzolan and self-setting material. When these materials are 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 those by cement but more rapidly than those by lime. Compaction must be completed within 6 hours of application.

COMBINATION OF TREATMENTS

Under certain circumstances, blending one or more of the available additives may be beneficial to meet project requirements. The combination of treatments must pass the strength requirements from the predominate additive being used. Examples of treatment combinations could include pretreatment of clay soils with lime before an application of cement or fly ash, or combinations of cement or lime with asphalt-based additives in Full Depth Reclamation (FDR) operations to facilitate early opening to traffic. Figure 5 contrasts identical salvage base materials, both pretreated with lime. The first is treated with asphalt emulsion, and the second is treated with foamed asphalt.

Figure 5. Base Materials Treated with Dual Treatments: Asphalt Emulsion (Left) and Foamed Asphalt (Right).

Generally, dual treatments using lime plus another treatment require two passes, where the lime is mixed in first. Other examples of treatment combinations are possible.

OTHER TREATMENTS

Other treatments are available that currently do not have TxDOT-approved test methods for developing mixture design. These treatments may include, but are not necessarily limited to, enzymes, polymers, acids, resins, and lignosulfonates. Contact MTD when considering one of these treatments.

MIXTURE DESIGN

After a project is selected for treatment, the type and percentage of additive required to meet specific project requirements must be determined from a laboratory mixture design. Steps to develop this mixture design include material sampling, additive selection, and mixture design procedures. It is important that mixture design, pavement design, and anticipated project sequencing collaborate for developing the best solutions for the project.

Table 2 presents a generalized framework for developing modification or stabilization designs. The steps for modification or stabilization mixture design generally parallel each other, with the exception that stabilization designs require a minimum strength requirement, while modification designs may be based on less stringent or no strength criteria and prior experience. Figure 6 illustrates these general steps. Material samples must be obtained, basic materials tests performed, candidate treatments selected, and then mixture designs performed to determine additive options and treatment application rates to meet the goals of modification or stabilization and project requirements.

Table 2. General Steps for Modification or Stabilization Mix Design.

Step	Description	Action
1	Material sampling	Obtain material samples representing anticipated project materials in enough quantity for the anticipated number of mixture designs.
2	Basic materials tests	Determine the moisture content, particle size analysis, PI, classification, and sulfate and organic content.
3	Treatment selection	Select candidate treatments based on goals of treatment, project requirements, material availability, and additive treatment selection guide.
4	Mixture design	Perform mixture design based on goals of modification or stabilization.
5	Reporting	Select and report the lowest additive content meeting project requirements and the associated maximum density and optimum moisture content.

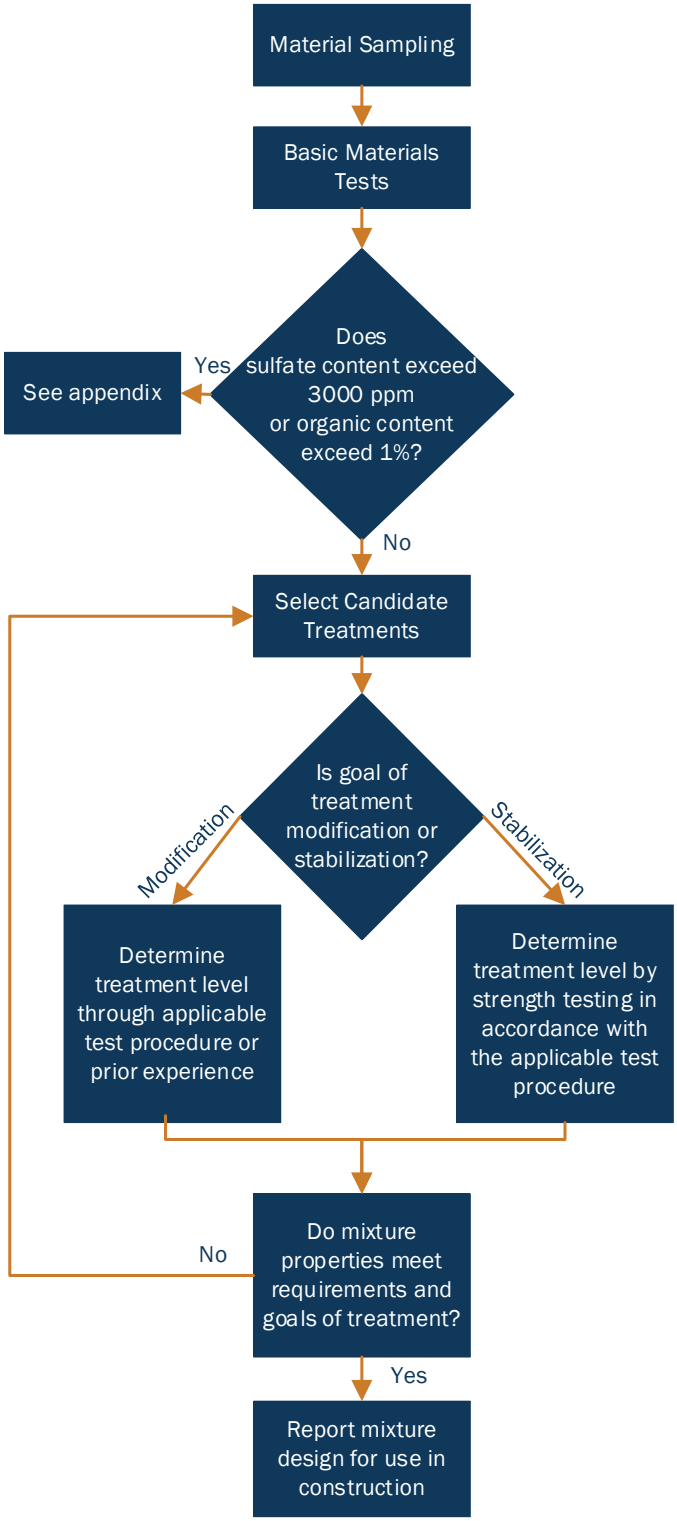

Figure 6. Steps for Developing Mixture Design.

MATERIAL SAMPLING

The first step in developing a mixture design is to obtain material samples. These may be soils or base materials and may be from in-situ or stockpile locations. If exploring in-situ soils, the U.S. Department of Agriculture soil survey (https://websoilsurvey.sc.egov.usda.gov/) can provide a useful tool for identifying locations for sampling. Figure 7 shows an example web soil survey map. From the map, estimates of PI, gypsum (sulfates) and organic content can be obtained.

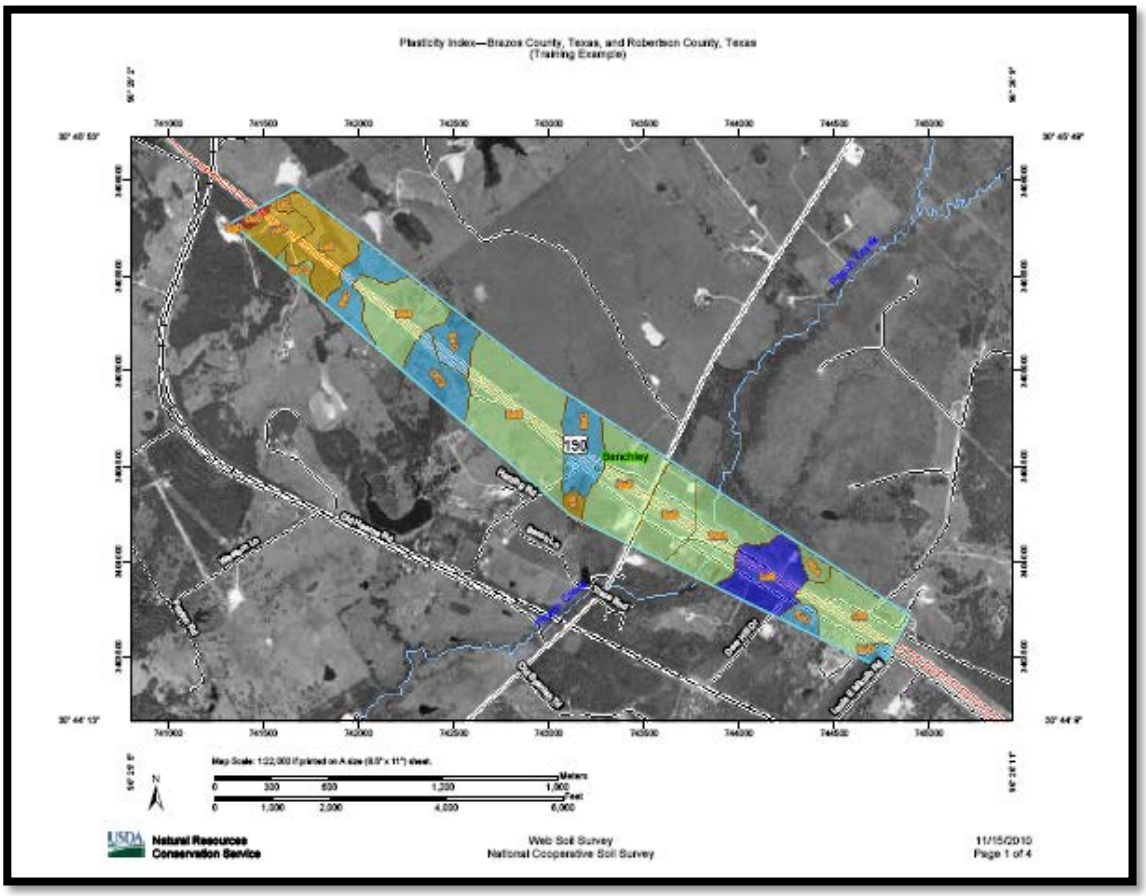

Figure 7. Example Web Soil Survey Map.

General guidance on sampling, soil investigation, and characterization can be found in Test Method Tex-100-E and in Chapter 3, Section 2 of the TxDOT *Pavement Design Manual*.

Soil Sampling

Soils should be sampled in accordance with Tex-100-E and following the guidelines of Table 3.5 in the TxDOT *Pavement Design Manual*. Generally, obtain at least 400 pounds of each soil requiring a mixture design. If multiple soil types are expected on a project, obtain a sample of each expected soil type including borrow sources. Table 3 presents approaches for sampling soils.

Table 3. Sampling Soils.

Step	Recommended Approach	Acceptable Approach
1	Obtain and review soil maps for 2 feet below the proposed subgrade crown.	Follow Tex-100-E and Table 3.5 of the TxDOT *Pavement Manual*.
2	Identify limits of different soil properties based on expected PI, sulfate content, and organic content.	Collect samples at a minimum of 1-mile intervals to represent common soils on the project.
3	Collect a sample from each soil type representing the expected range of PI, sulfate content and organic content.	Review the sample locations and identify any additional sampling locations needed based on the soil properties from the soils maps.
4	If borrow sources will be used, collect a representative sample from each borrow source.	If borrow sources will be used, collect a representative sample for each borrow source.

Sampling Stockpiled Flexible Base

Samples should be collected in accordance with Tex-400-A, Section 5.3. Generally, obtain at least 500 pounds of a single source of base material requiring a mixture design. Table 4 presents approaches for sampling stockpiled flexible base. Figure 8 illustrates the recommended steps to sample flexible base from the stockpile.

Table 4. Sampling Stockpiled Flexible Base.

Step	Recommended Approach	Acceptable Approach
1	Identify the source of the flexible base.	Identify the source of the flexible base.
2	Follow Tex-400-A to obtain a representative stockpile sample.	Work with the material producer to determine a location in the stockpile that most represents the produced material.
3	Sample the quantity estimated for the required laboratory work.	Use a wheel loader, backhoe, or shovels to obtain the sample.

Figure 8. Sampling a Stockpile of Flexible Base.

Sampling Roadway Materials

Many projects selected for treatment employ road-mixed processes. For these projects, identifying and sampling the expected range of materials are critical for ensuring the mixture designs are suitable for anticipated project variability. Table 5 summarizes the recommended approach and

an alternative acceptable approach for sampling roadway materials. Figure 9 illustrates some of the methods suitable for sampling roadway materials.

Table 5. Sampling Roadway Materials.

Step	Recommended Approach	Acceptable Approach
1	Obtain historic plans. Conduct a ground-penetrating radar (GPR) survey.	Obtain plans and maintenance history.
2	Using plans and the GPR survey, determine critical locations for sampling. Cover the expected range of recycled asphalt pavement (RAP) and total pavement thickness.	Unless otherwise determined from plans and maintenance history, perform drill logs at 1-mile spacing of the pavement structure including at least the top 10 inches of subgrade. For short projects (< 1 mile), sample and log a minimum of three locations.
3	Sample and log each location to include at least the top 10 inches of subgrade.	Review drill logs. Select locations representing significantly different materials for follow-up bulk sampling.
4	At each location of significantly different materials, use a small recycler or auger to obtain samples of materials expected in the road mix. Typically, the top 8 to 10 inches of pavement contain these materials.	At each location of significantly different materials, use a small recycler or auger to obtain samples of materials expected in the road mix. Typically, the top 8 to 10 inches of pavement contain these materials.
5	If RAP exceeds 2 inches in the existing pavement, maintain the RAP and salvage base separately.	If RAP exceeds 2 inches in the existing pavement, maintain the RAP and salvage base separately.
6	Collect approximately 400 pounds of sample for each set of different materials requiring a mixture design.	Collect approximately 400 pounds of sample for each set of different materials requiring a mixture design.

Figure 9. Sampling Roadway Materials.

BASIC MATERIALS TESTS

The following tests should be performed to help select candidate treatments:

- Moisture Content (Tex-103-E),
- Particle Size Analysis (Tex-110-E),
- Liquid Limit, Plastic Limit and Plasticity Index (Tex-104-107-E),
- Classification (Tex-142-E),
- Sulfate Content (Tex-145-E), and
- Organic Content (Tex-148-E).

Generally, soil materials should always be tested for sulfates and organics; such testing is generally not needed for base materials unless reason exists to suspect the base material contains sulfates. For materials with sulfate contents exceeding 3000 parts per million (ppm) or organic content exceeding 1 percent, the appendix contains procedures to follow for developing possible treatment options.

SELECTING TREATMENTS

The selection of treatments includes many factors:

- goals of treatment (modification or stabilization),
- desired engineering and material properties (strength and modulus),
- design life and anticipated traffic,
- environmental conditions (drainage, water table, and annual rainfall),
- mechanisms of additives,
- mineralogy and content (types of mineral composition, sulfates, and organics),
- classification (gradation and PI), and
- engineering economics (cost savings versus benefit).

While all the factors must be considered to select a treatment, generally by the time materials have been sampled, the decision has been made that the project may be a candidate for treatment, and that treatment is likely compatible with project goals, desired material properties, pavement design and traffic, environment, and economics. Thus, at this point, the compatibility of the treatment mechanism with the material mineralogy generally serves as the initial screen for selecting candidate treatments. Simple index tests such as gradation and PI serve as a surrogate for this initial screening.

Figure 10 presents general guidelines for selecting candidate treatments based on material type and PI. Figure 10 lists treatments generally in decreasing order of preference. While this chart provides general guidelines, exceptions will exist where a material may be compatible with an additive not listed, and where a passing mix design may not be obtained even when an additive is listed as compatible with a material. Additionally, other design and traffic-handling factors, such as early opening to traffic, may influence the choice of treatments.

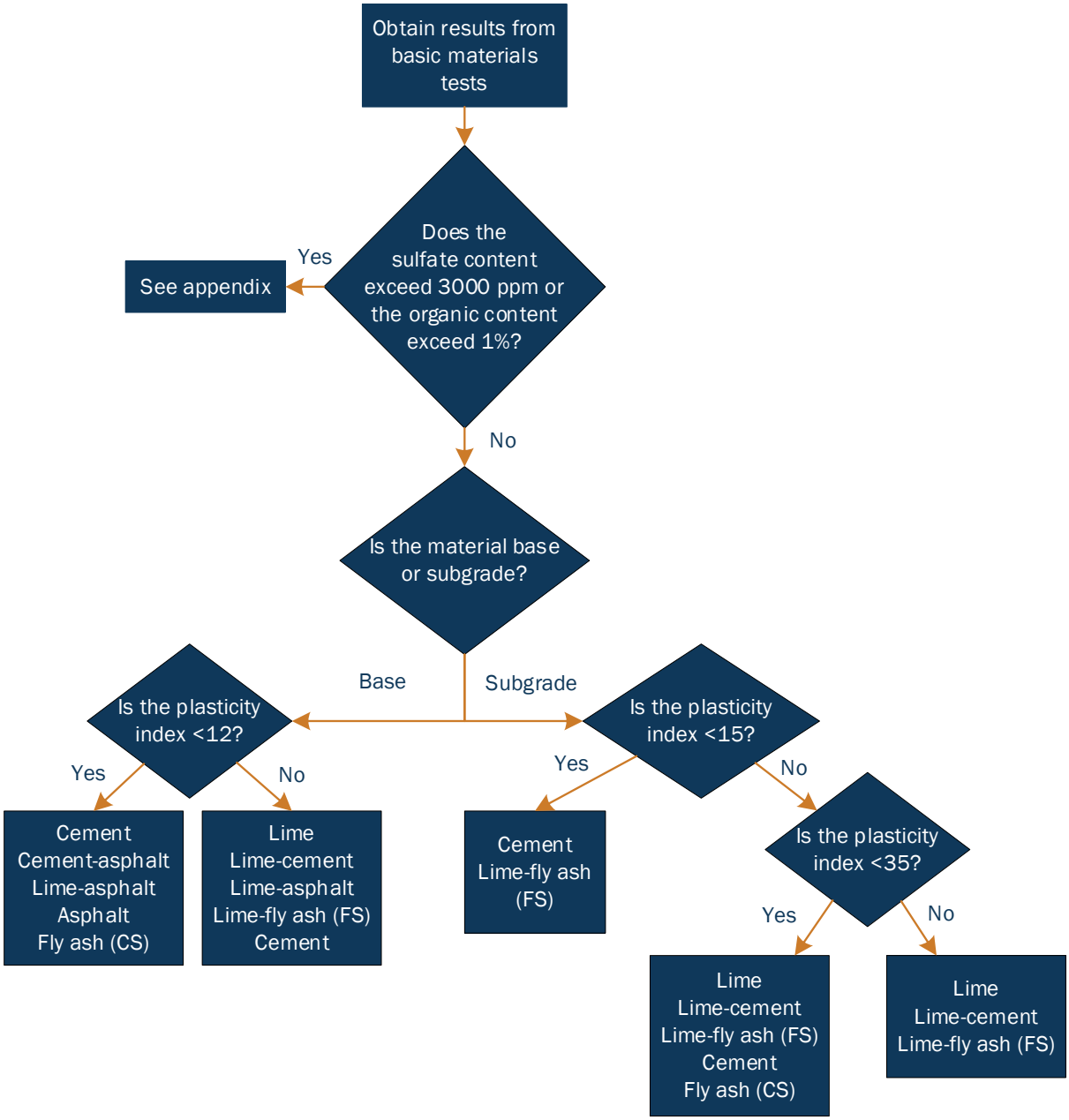

Figure 10. Selecting Treatments.

MIXTURE DESIGN STEPS

The laboratory mixture design determines whether the selected treatments achieve the goals and meet project requirements with the available materials at the prescribed treatment rate. The mix design:

- ensures the optimization of the percentage of additives used,
- optimizes the engineering and materials properties,
- measures the treatment effectiveness using moisture conditioning,
- observes the effectiveness of the additives with a specific soil and its inherent mineralogy,

- provides density and moisture control parameters for construction, and
- mitigates cracking and other distresses associated with material behavior.

Follow the steps of Table 6 as applicable to the project materials and requirements to develop mixture designs in the laboratory.

Table 6. Mixture Design Steps.

Step	Description	Action
1	Definition of goal	Define whether the goal of treatment is modification or stabilization.
2	Collection of samples of treatments	Obtain samples of selected treatments in enough quantity for the anticipated number of mixture designs. If possible, use local sources likely to be used in the project.
3	Moisture-density relationship	Determine the maximum density and optimum moisture content in accordance with the test procedure required by the governing construction specification.
4a	Modification mixture design	Determine the treatment level through the applicable test procedure or based on prior experience with the project materials. This level will generally be 2 to 3%.
4b	Stabilization mixture design	Determine the treatment level by strength testing in accordance with the applicable test procedure: ▪ Cement: Tex-120-E. ▪ Lime: Tex-121-E. ▪ Emulsion: Tex-122-E. ▪ Lime-Fly Ash: Tex-127-E. ▪ Foamed Asphalt: Tex-137-E.
5	Reporting	Select and report the lowest additive content meeting project requirements and the associated maximum density and optimum moisture content.

CONSTRUCTION

Determining a suitable mixture design does not guarantee project success. Construction processes must adequately produce, place, compact, and cure the treated material before placing the next course. These construction processes require the interaction of specifications, agency and contractor staff roles, proper compaction and acceptance, and curing before placement of the next course.

ROLES AND RESPONSIBILITIES

Successful projects require partnership between the Department and Contractor. Table 7 presents key roles during construction for each party.

Table 7. Key Roles and Responsibilities for Construction.

Contractor	Department
Provide mix design if required.	Provided mix design if required.
Provide experienced staff as required.	Authorize proceeding to construction.
Quality control for depth, gradation, proper application of additive, and required moisture content.	Quality assurance for gradation, thickness and treatment rate as applicable.
Place or treat only where mixing, compaction, and finishing can be completed in required time frame.	Inspect process for moisture content, finish and stability, and enforce any time requirements as applicable.
Obtain required compaction.	Quality assurance for density.
Finish surface in required time.	Enforce any time and weather restrictions, as applicable.
Cure, seal, place next course, or open to traffic in required time.	Direct opening to traffic or placement of next course as applicable.

GOVERNING SPECIFICATIONS

It is imperative both the Department and Contractor familiarize themselves with key requirements for pulverization, weather or temperature restrictions, and required timelines for placing, mixing, compacting, curing, and placing the next course under the applicable construction specification. Table 8 summarizes the applicable construction specifications, which contain full details for these topics. Table 8 also presents special requirements that are unique to each specification.

Table 8. Governing Specifications.

Spec.	Treatment	Special Requirements
Item 260	Lime (road mixed)	Begin mixing within 6 hours of application of lime. Special mellowing requirements apply depending on the type of lime and sulfate content of the material. When necessary, resume mixing after mellowing until a homogenous, friable mixture is obtained. Quicklime requires remixing after mellowing. Special curing requirements apply based on material PI.
Item 263	Lime (plant mixed)	Begin placing immediately upon delivery to the roadway in lifts not to exceed 8 inches. Cure at least 7 days by sprinkling or by asphalt membrane.
Item 265	Fly ash or lime-fly ash (road mixed)	Mixing time and mellowing time requirements apply based on use of lime and sulfate content. Complete compaction within 6 hours of application of Class FS ash and within 2 hours of application of Class CS ash. Cure FS ash 7 days; CS at least 24 hours. With CS ash, treated course must dry at least 48 hours before prime.
Item 275	Cement (road mixed)	Complete compaction in one lift within 2 hours after the application of water to the mixture of the material and cement. Microcrack to reduce shrinkage cracks when shown on plans. Cure at least 3 days by sprinkling or asphalt membrane; when microcracking, cure an additional 2 days after microcracking. Continue curing until placing the next course.
Item 276	Cement (plant mixed)	Begin placing immediately upon delivery to the roadway. Place in an area only where compaction and finishing can be completed during the same working day. Microcrack to reduce shrinkage cracks when shown on plans. Cure at least 3 days by sprinkling or asphalt membrane; when microcracking, cure an additional 2 days after microcracking. Continue curing until placing the next course.
SSXXXX*	Emulsion (road mixed)	SB102 is required to perform sampling and testing during the project. The emulsion supplier is to provide a representative on site at the start of treatment to determine adequate mixing and curing. Construct a control strip before full construction when directed. Apply emulsion only where mixing and compaction can be completed during the same day. Complete mixing in one pass, with the exception of pre-shaping. Compact in one lift. Cure to 2 percentage points below optimum before placing the next course.
SSXXXX*	Foamed Asphalt (road mixed)	SB102 is required to perform sampling and testing during the project. Construct a control strip before full construction when directed. Apply foamed asphalt only where mixing and compaction can be completed the same day. Complete mixing in one pass, with the exception of pre-shaping. Compact in one lift. Cure a minimum of 2 hours.

*Contact MTD. At the time of writing, applicable Special Specifications are being approved by MTD.

TREATMENT DELIVERY METHODS

Treatments can be delivered in dry or liquid form. The delivery form influences how to accomplish mixing. Generally, suppliers deliver lime, cement and fly ash dry, while lime and sometimes cement are also available in slurry (liquid) form. Asphalts are only available as liquids.

Figure 11 illustrates common application techniques for these delivery methods. Table 9 summarizes application notes and typical treatments available for each technique.

Figure 11. Dry, Slurry and Mixer-Injection Applications.

Table 9. Application Notes and Available Treatments for Different Application Techniques.

	Dry Application	Slurry	Mixer-Injection
Application notes	The standard method. Common treatments widely available. Can help dry out excessively wet in-situ materials. May result in dusting. Application uniformity may be difficult to control. Vane spreaders may be used to more precisely control application rate.	Minimize dusting. Promote faster and more complete reaction. Can help attain required moisture if in-situ materials are unusually dry. Can result in excessively wet material if in-situ materials are already close to optimum. May run off if applied topically and the surface is not pre-scarified. May offer improvements in application uniformity, especially if applied through injection.	Potentially offers the most precise and uniform application. Minimize dusting. Requires more specialized field equipment and experience. The only method for asphalt treatment application. Compatible with lime and cement slurries, although particularly with cement slurry caution must be exercised regarding the slurry age and machine cleanout.
Available treatment(s)	Lime, cement, fly ash	Lime, cement	Emulsion, foamed asphalt, lime slurry, cement slurry

MELLOWING VERSUS CURING

All specifications using treatments require curing. However, some specifications also require mellowing. The difference is as follows:

- **Mellowing** is a *temporary* construction process where the mixed, treated material is sealed (generally by ordinary compaction and a pneumatic roller) for some duration of time to allow initial reactions to occur between the treatment and the material. Mellowing is normally used to achieve improvements in the workability of the material, reduce the PI so proper sizing can be achieved, and react away sulfates *before* final processing and compaction. Mellowing most frequently applies to road-mixed treatments that include application of lime.
- **Curing** is a *final* construction process after final compaction and finishing to create conditions that advance the treatment mechanism and make sure the completed, treated layer gains adequate strength for the placement of the next course and traffic.

APPENDIX:
TREATMENT OF SULFATE AND ORGANICS-BEARING MATERIALS

OVERVIEW

Materials containing sulfate contents in excess of 3000 ppm, or organic contents in excess of 1% can prove problematic in treatment. This appendix provides methods to assess the risk and develop potential treatment solutions for these materials.

SULFATE HEAVE

In general, the use of calcium-based additives (lime, cement, and Class CS fly ash) to treat soils and bases has been performed with success for many years. Over the past 20 years, a phenomenon has surfaced in which many subgrade soils treated with calcium-based additives experience heaving problems due to the chemical reactions with sulfate or sulfide minerals and calcium-modified soils, as illustrated in Figure 12. Field observations indicate that the reactions can be very rapid and occur overnight following a single rainfall event. In other cases, the reaction is delayed and may take years to manifest in terms of excessive pavement roughness. Research has revealed the rate of the reaction is due to the particle size of the sulfate crystals (finer-grained sulfates produce a faster reaction), the amount of water present in the system (more water produces a faster reaction), and the concentration of the reagents (higher concentration produces a faster reaction).

Figure 12. Sulfate Heave.

Steps to Evaluate Risk of Sulfate Heave

Early detection of sulfates provides the best opportunity to minimize the risk of sulfate heave. Risk assessment can include:

- district experience,
- analysis of soils maps from the online Web Soil Survey,
- field visual investigation (generally observed as crystals but may not be visible depending on particle size),

- field soil conductivity survey using VERIS mobile testing equipment (consult with MTD for assistance and additional information), and
- measurement of sulfate content in materials (Tex-145 and Tex-146-E).

If the District knows sulfates are common in the project area, soils maps indicate the possible presence of elevated sulfate levels, or sulfates are visually identified in the field, contact MTD for further evaluation. Materials must be sampled and tested for sulfate content; and, if appropriate, MTD can deploy a near-full coverage conductivity tool to map out the potentially highest-risk locations and help identify locations to collect material samples.

When sulfate contents exceed 3000 ppm, alternative treatment strategies must be developed. Consideration must be given to the fact that oftentimes borrow sources or even virgin base materials may have high sulfate contents.

Mixture Design with Sulfate-Bearing Materials

Figure 13 provides a general strategy selection process for developing treatment designs with sulfate-bearing materials. Follow the general steps in Table 10 to evaluate treatment mixture designs with materials containing sulfates.

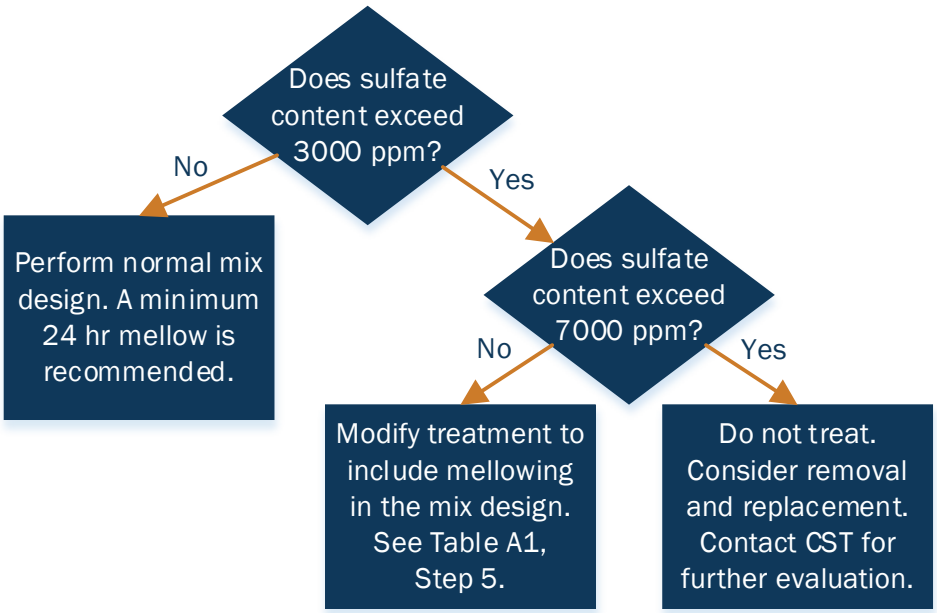

Figure 13. Determining Treatments for Sulfate-Bearing Materials.

Table 10. Performing Mixture Design with High-Sulfate Materials.

Step	Action	Applicable Stabilizer(s)
1	Based on District experience, soils maps and field assessment determine if the project has risk of materials with high sulfates.	All.
2	Contact MTD and select locations to sample materials.	
3	Perform material sampling and measure the sulfate content of samples in accordance with Tex-145-E.	
4	For sulfate concentrations less than 3000 ppm, perform mixture design as normal. For lime treatment, a minimum 24 to 48-hour mellowing period is recommended.	
5	For sulfate concentrations between 3000 and 7000 ppm, perform Tex-121-E Part I using a single application of lime and a material sample representing the highest measured sulfate content. Mellow the mixture for at least 7 days. Consider adding additional moisture during the mellowing.	Lime only. For any other stabilizers, follow Step 6.
5a	After 7 days of mellowing, measure the sulfate content of the mixture in accordance with Tex-145-E. If the sulfate content is less than 3000 ppm, proceed with normal mix design procedures and verify the treated, mellowed mixture meets project requirements.	
5b	If, after 7 days of mellowing, the sulfate content still exceeds 3000 ppm, continue to mellow the mixture and measure the sulfate content until the sulfate content is below 3000 ppm. Record this time as the minimum required mellowing time and use that mellowing time to proceed with normal mix design procedures and verify the treated, mellowed mixture meets project requirements.	
5c	A new moisture-density relationship may need determination after completion of the mellowing time.	
6	For sulfate concentrations exceeding 7000 ppm, consider removal and replacement or changing the pavement design to not treat the sulfate-bearing material. If those strategies are cost prohibitive or not feasible, contact MTD for further evaluation of the material.	All.

Basis of Table 10

Research and field experience have shown soils with sulfate levels of 3000 ppm or less pose low potential for sulfate heave. Sulfate reaction still occurs in these types of soils, but with adequate mixing and moisture, the effects are typically not detrimental.

Research and some cursory field data have shown that soils with sulfate levels greater than 3000 ppm but less than or equal to 7000 ppm can be successfully treated with lime. Since research to date has only produced data using lime as an additive, Table 10 recommendations

are **for lime treatment only.** Use of other additives is not recommended without first performing extensive laboratory testing through MTD.

For soils with sulfate contents higher than 7000 ppm, the normal recommendation is to remove and replace. In many areas of Texas, this is very costly; in those cases, other options include using Tex-145-E to define the minimum mellowing time to reduce the sulfate content to less than 3000 ppm and then applying a second lime treatment. In this case, the 3D swell test (Tex-149-E) must be performed to validate that the recommended treatment protocol and construction methods result in a total volumetric swell of less than 6 percent. Figure 14 shows the moisture conditioning and swell measurements.

Figure 14. Performing the 3D Swell Test.

Full details of sample preparation, moisture conditioning, and swell measurements can be found in Tex-149-E. The goal of the test procedure is to define acceptable construction practices to minimize the risk of sulfate heave. An example of recommendations from this test could be, "Apply 6 percent lime to the in-situ soil, mellow for 5 days, and wet and remix the soil each day. After 5 days, treat the soil with 3 percent fly ash and then proceed to final compaction."

Contact MTD for assistance in determining strategies to treat soils with sulfate contents exceeding 7000 ppm.

ORGANIC INTERFERENCES WITH TREATMENT

TxDOT has reported difficulty stabilizing soils bearing concentrations of organic matter. This circumstance typically involves elevated-PI materials treated with lime. Problems include the stabilizer disappearing over time and rough pavement due to poor subgrade support. Research showed that humic acid (a major component of organic matter) prevents the lime from reacting with clay minerals in the soil. Humic acid concentrations above 1 percent by weight can interfere with treatment. These organic interferences cause decreased effectiveness of lime and cement in altering the engineering properties (such as PI, strength, and shrink-swell potential) of the material.

Steps to Evaluate Risks of Organic Interferences

Early detection of organics provides the best opportunity to minimize the risk of interferences and plan accordingly for the project. Risk assessment can include:

- district experience,
- analysis of soils maps from the online Web Soil Survey,

- field visual investigation (generally observed as dark matter oftentimes accompanied by odor), and
- measurement of the organic content of materials (Tex-148-E).

The goal of the risk assessment process is to reveal potential problem areas within a project. If there is a probable risk for organic matter affecting permanent treatment within the project, the appropriate level of exploration, testing, and controls can be applied.

If the District knows organics are common in the project area, soils maps indicate the possible presence of elevated organic levels, or field visual investigation suggests the presence of organics, contact MTD for further evaluation. Materials must be sampled and tested. When organic contents exceed 1 percent by weight, alternative treatment strategies must be developed if they cannot be overcome when determined by laboratory testing.

Mixture Design with Organic-Bearing Materials

Figure 15 presents a generalized decision tree to determine possible treatment options of varying levels of organics.

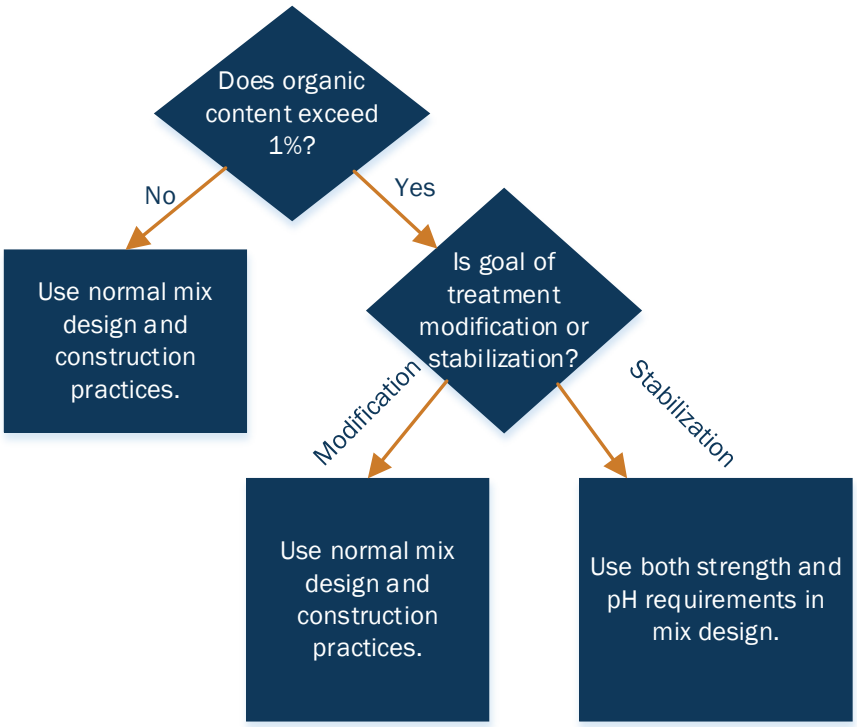

Figure 15. Decision Tree for Treatment of Varying Organic Contents.

Follow the general steps of Table 11 to evaluate treatment mixture designs with materials containing organics.

Table 11. Performing Mixture Design for Organic-Bearing Materials.

Step	Action
1	Based on District experience, soils maps, and field assessment, determine whether the project has a risk of materials with high organics.
2	Sample the material of the soil to be treated and measure the organic content of samples in accordance with Tex-148-E.
3	For organics concentrations, less than 1%, perform mixture design as normal.
4	For organics concentrations exceeding 1%, select a material sample from the project representing the highest anticipated organics content and determine the pH of the soil-lime mixture at varying lime contents in accordance with Tex-121-E Part III.
5	If a pH of 12.4 is achieved, perform mixture designs in accordance with Tex-121-E using the lowest lime content that achieved a pH of at least 12.4 and determine whether the mixture meets project requirements.
6	If a pH of 12.4 is not achieved or the mixture fails to meet project requirements, treatment is not recommended. Consider removal and replacement or changing the pavement design to not use treatment of the high-organics material.

Basis of Table 11

Research and field experience have shown soils with organic contents of less than 1% pose low potential for interfering with soil modification or stabilization. Standard construction and mix design practices can be use with these materials. Reactions with organic acids may still occur in these types of soils; however, the effects are typically not detrimental.

When organic content exceeds 1%, laboratory testing should be performed to determine the amount of lime required for treatment. In some cases, lime will not perform. The National Lime Association outlines the following procedure to determine the approximate lime demand:

- Purpose: Determine the minimum amount of lime required for treatment.
- Procedure: Use ASTM D 6276 [15] procedures. This procedure is also known as the Eades and Grim test.
- Criteria: The lowest percentage of lime in the soil that produces a pH of 12.4 is the minimum lime percentage for stabilizing the soil.
- Additional considerations:
    - ASTM D 6276 includes additional provisions for cases in which the measured laboratory pH is 12.4 or less.
    - Lime can react with moisture and carbon dioxide and lose its effectiveness.
    - Careful storage is required to maintain lime's integrity and produce reliable results.

Tex-121-E Part III is similar in concept to the Eades and Grimm test.