Appendix B Soil Stabilization Testing Manual

Chapter B-1 Introduction

B-1.1 Purpose

The purpose of this manual is to guide the engineer and laboratory through the process of sampling and testing soil for the design of chemical soil stabilization. Guidance is also provided for verification testing during construction.

B-1.2 Specific Procedures

This manual does not provide the specifics of all the testing procedures (e.g., AASHTO or ASTM) but only the references for particular standards and helpful guidance in their application. Specific testing procedures should be found in the referenced standards or in the testing agency's own testing protocols based on those standards.

Chapter B-2 Subsurface Exploration, Sampling, and Storage

Sampling and storage procedures are critical to obtain high quality results for subgrade stabilization projects. Proper sampling provides results that are representative of the soil conditions. Proper storage will maintain consistency in the soil samples throughout the testing process and will reduce variation related to environmental conditions.

B-2.1 Subsurface Exploration for Subgrade Stabilization

In most cases, a subsurface exploration will be performed in accordance with the agency's policies and practice. On projects where subgrade stabilization may be required, it is critical that the subgrade soils be tested. At each boring location, the SPT testing depths should be adjusted so that a sample is obtained starting at the planned subgrade elevation, if known at the time of testing. The subsurface exploration should also measure the water content of all samples obtained from the planned subgrade elevation. Classification tests (grain size and Atterberg limits) will also benefit planning for subgrade stabilization.

The evaluation of pavement subgrades can be performed by a variety of means during subsurface exploration, including natural moisture content (w_n) and corrected SPT blow count (N_{60}). Proof rolling can also be used if the subgrade is already exposed (ODOT 2021). If the natural moisture content of a subgrade is more than 3% above the standard Proctor optimum, it will likely be unstable during construction. The optimum moisture content can be measured or estimated based on soil type and Atterberg limits. Values of w_n likely to indicate instability are provided by soil type in Table B-1.

Table B-1 Indication of Instability and Usefulness of Chemical Treatment by Soil Type (after ODOT 2021)

Soil Type	**Instability Likely if w_n Exceeds:**	**Chemical Treatment Useful To:**
A-2 (silty or clayey sand or gravel)	≈ 13%	Reduce susceptibility to sloughing and frost heave
A-4 (low liquid limit silt)	≈ 13% or ≈ PL – 2%	Reduce susceptibility to sloughing and frost heave
A-5 (high liquid limit silt)	---	Reduce moisture sensitivity
A-6 (low liquid limit clay)	≈ 17% to 19% or ≈ PL – 2%	Reduce moisture content and improve compaction
A-7 (high liquid limit clay)	≈ 18% or PL	Reduce moisture sensitivity and shrink / swell potential
LL > 65%	---	Reduce shrink / swell potential

Alternatively, the SPT results or proof rolling can be used with Table B-2 to determine if chemical treatment will be effective for improving unstable subgrade conditions. Very soft to soft subgrades usually cannot be chemically treated unless the soft layer is very thin. Conventional undercutting and replacement are required for soft to very soft subgrades. Geosynthetics can be used to reduce the undercut depth. Chemical treatment of stiff subgrades with N_{60} greater than 12 is only necessary if the natural moisture content is more than 3% above optimum (ODOT 2021).

Some of the soil types listed in Table B-1 can be problematic in subgrades, even if the soils are stable during construction. As indicated in the third column of Table B-1, chemical treatment can be used to reduce the potential for sloughing, frost heave, moisture sensitivity, and shrink/swell behavior.

Table B-2 Use of SPT or Proof Rolling for Subgrade Evaluation (after ODOT 2021)

Soil Consistency	Representative N_{60} (blows/ft)[1]	Proof Roll Rut Depth (in)	Chemical Subgrade Treatment
Very soft	< 2	NA	Usually ineffective, undercutting required
Soft	2 to 4	> 12	
Medium stiff	4 to 8	6 to 12	Can use chemical treatment with a depth of 14 inches
Stiff	8 to 12	2 to 6	Can use chemical treatment with a depth of 14 inches
	12 to 15	< 2	Can use chemical treatment with a depth of 12 inches, only if moisture content is more than 3% above optimum

[1] Representative N_{60} is the average for a group of borings of the lowest values of N_{60} in the upper 6 ft of the subgrade.

B-2.2 Planning for Subgrade Stabilization Sampling

B-2.2.1 Number of Samples Required

The number of samples will be dictated by the variability of the subgrade conditions at the project site. At least one sample should be obtained for each major soil type encountered at the project site. The minimum sampling frequency is one sample for every 5000 square yards of treated subgrade. Section 2-700.00 of the TDOT Geotechnical Manual (TDOT 2020) should also be followed.

B-2.2.2 Amount of Soil Required Per Sample

An adequate quantity of soil must be collected for each mix design. Typically, the soil samples will be bulk samples, most often obtained using excavation equipment. If necessary, hand shoveling can be used.

The amounts of soil required for various types of tests used for subgrade stabilization studies are summarized in Table B-3.

Table B-4 can be used to estimate the size of the soil sample required. The quantity of tests required in Phases I and II must be estimated at this stage. For each trial percentage of admixture tested in Phase I, a one-point Standard Proctor and three unconfined compression tests are recommended. After a single admixture percentage is selected, at least nine unconfined compression tests and three CBR tests are recommended. Additional tests may be required to explore strength gain with time or to provide replicate CBR specimens.

After the test quantities are determined in Table B-4, the quantities should be multiplied by the dry weight in the fourth column to determine the total dry weight for each test. The values in the fifth column can then be summed to determine the total dry weight required. A loss factor of at least 25% is recommended to provide an extra sample. In most cases, the soil will be obtained based on moist weight or volume. The final step is to multiply by the estimated water content to obtain the moist sample weight required.

For the minimum amount of testing recommended in this manual, the total dry sample weight including a loss factor of 25% is about 215 lb. Assuming a water content of 20%, a total weight of about 260 lb is required. This is approximately equal to four to five full 5-gallon buckets of soil.

Table B-3 Required Soil Amounts by Test

Type of Test	Approx. Dry Weight Required per Test
Standard Proctor (one-point)	5 lb
Standard Proctor (full)	35 lb
Index Tests: Sieve Analysis, Hydrometer, Atterberg Limits, Specific Gravity, Sulfate content, Organic content by Loss on Ignition, and Eades Grim (assumes max. particle size of 1 inch)	8 lb
Unconfined Compression (set of three 2.8”×5.6” specimens)	7 lb
California Bearing Ratio (one specimen)	10 lb

B-2.3 Sampling and Processing

Generally following the principles in AASHTO T2 (ASTM D75), soil samples should be obtained to be as representative of the subgrade conditions as possible. Segregation of the soil should be avoided.

The samples should be obtained from the planned subgrade elevation or up to 2 ft below. This will be the soil that forms the subgrade and will be stabilized.

In many cases, the excavation process used to obtain a soil sample will result in soil from different elevations in the subgrade. In addition, the stabilization process will mix the soil from various depths. For uniform results, the entire sample should be thoroughly combined and mixed in the laboratory. This can be accomplished by mixing the soil from all of the containers on a clean concrete floor or other work surface. Large clumps of soil should be broken apart into pieces acceptable for compaction.

After the sample is mixed, it should be progressively quartered and split until the portions are small enough to fit in the desired storage containers. Each container should be labeled for record-keeping purposes. The quartering process will promote uniformity among the different parts of the overall sample.

B-2.4 Storage

Complete drying of soils, especially clays, can cause irreversible change to the soil mineralogy. This change in mineralogy can result in different Atterberg limits and compaction characteristics. For this reason, it is most appropriate to store the soil in a moist condition. This can be accomplished over short to moderate time scales using plastic buckets with tight-sealing lids. Measures to actively maintain the soil moisture may be required if the storage time extends beyond a few months.

Table B-4 Worksheet to Calculate Required Soil Sample Weight

Phase	Test	Qty.	Dry Weight	Total Dry Weight by Test
Untreated	Standard Proctor (full)	1	35 lb	35 lb
	Index Tests	1	8 lb	8 lb
	Unconfined compression	1 set	7 lb/set	7 lb
	CBR	1	10 lb	10 lb
Phase I	Standard Proctor (one point) (≥3)		5 lb	
	Unconfined compression (≥3 sets)		7 lb/set	
Phase II	Standard Proctor (full)	1	35 lb	
	Unconfined compression (≥3 sets)		7 lb/set	
	CBR (≥3)		10 lb	
A. Total Dry Weight Required, W_{dry}:				
B. Loss Factor, L, (25% recommended):				
C. Total Dry Sample Weight Required: $W_{d+L} = W_{dry} \times (1+L/100)$:				
D. Estimated or Measured Water Content Factor, w (%):				
E. Total Moist Sample Weight Required: $W_t = W_{d+L} \times (1+w/100)$:				

Note: A set of three 2.8” by 5.6” UCS specimens requires about 7 lb of dry soil.

Chapter B-3 Untreated Soil Testing

The specific testing procedures are discussed in further detail in 0This manual assumes that the user is familiar with the prescribed testing methods.

B-3.1 Initial Testing

After the soil has been sampled, mixed, and placed in appropriate storage, the as-received moisture content should be determined to use as a starting point for further testing. The screening tests for organics (AASHTO T267, ASTM D2974) and sulfates (AASHTO T290, ASTM C1580) should be completed as soon as possible. If there is an indication that these properties may limit the effectiveness of stabilization, further testing should wait until the organic and/or sulfate content is known. Sulfates are typically limited to 3000 ppm (0.3%) or less for general soil stabilization. The use of lime may be appropriate for sulfate contents between 3000 and 7000 ppm (0.3 to 0.7%). Similarly, organic contents above a few percent can be problematic.

B-3.2 Index Testing

The Atterberg Limits (AASHTO T90, ASTM D4318) of the untreated soil should be determined for all stabilization designs because Atterberg Limits are used for admixture selection. The Eades-Grim test (ASTM D6276) should also be completed for any soil where lime may be a viable admixture. Both tests use the fraction of soil that passes the #40 sieve. Efficiency is gained by preparing the soil for both tests simultaneously.

The grain size distribution (AASHTO T88, ASTM D6913) of the untreated soil is useful but is not essential to the design of chemical soil stabilization. Without the grain size distribution, the soil must be classified using the Visual-Manual procedure (supplemented with Atterberg Limits) rather than the full USCS or AASHTO classification.

The specific gravity (AASHTO T100, ASTM D854) of the untreated soil may be determined but is not essential to the design of chemical stabilization.

B-3.3 Compaction Testing

The compaction (a.k.a., moisture-dry unit weight, moisture-density) curve for the untreated soil should be determined using AASHTO T99 (ASTM D698). The optimum compaction condition will be used for the compaction of the strength and stability tests on the untreated soil. If necessary for time or budget constraints, the maximum dry unit weight and optimum water content can be determined using the one-point test procedure.

B-3.4 Strength and Stability Testing

The strength and stability of the untreated soil must be determined for comparison to the treated soil. The criteria used to select the appropriate admixture percentage consider both the shear strength of the treated soil and the increase in strength caused by chemical stabilization.

Three unconfined compressive strength specimens should be compacted. The water content of the specimens should be within 1% of w_{opt}, and Standard Proctor energy should be applied.

The specimens may be tested immediately after compaction. Some past research (e.g., Seed and Chan 1957) has noted time-dependent strength gain in compacted clays; however, this effect is often ignored. If desired, a curing period of seven days can be used for the untreated specimens if significant strength gain with time is anticipated. If curing is used, the specimens should be wrapped in plastic and placed within a moisture-proof bag or container during the cure period.

At least one California Bearing Ratio (CBR) test should be performed on untreated soil. The water content of the CBR specimen should be within 1% of w_{opt} and Standard Proctor energy should be applied. The CBR should be determined for the soaked condition. The compacted specimen may be cured in the mold, if desired. A surcharge equivalent to the anticipated pavement overburden should be used.

B-3.5 Workflow

A suggested workflow for sampling and testing of the untreated soil is provided in Figure B-1.

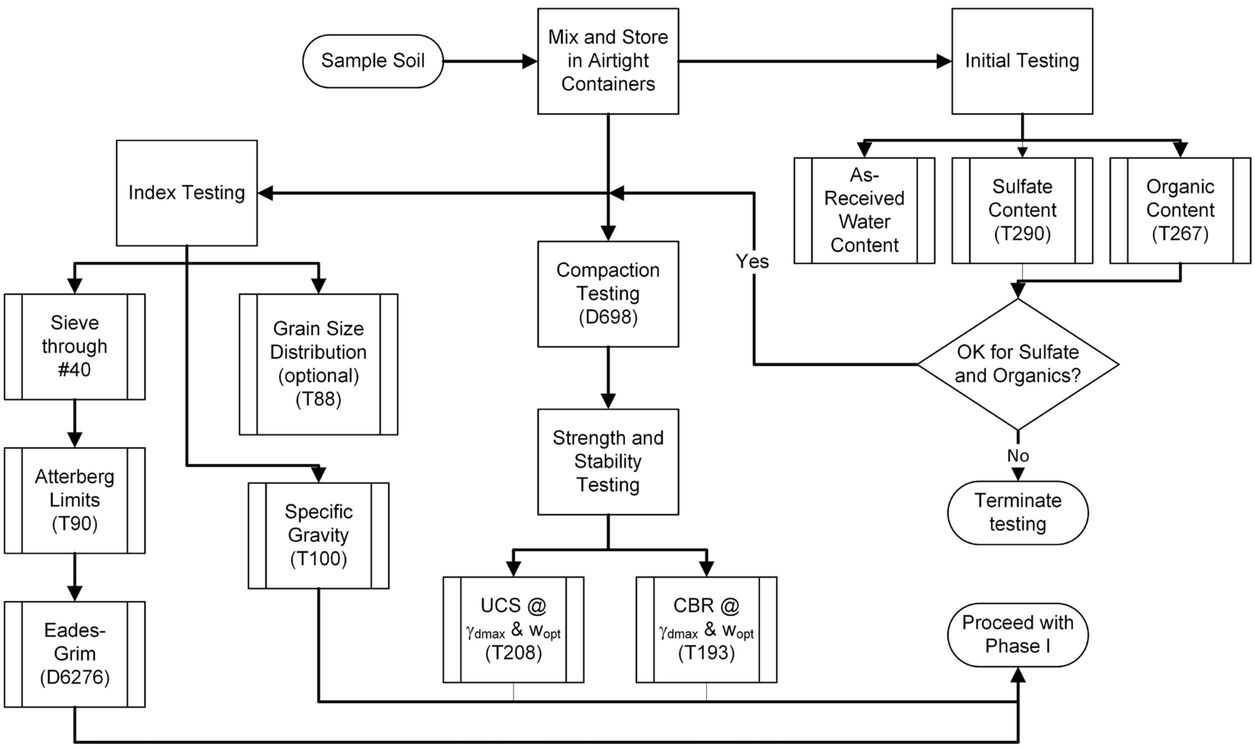


Figure B-1 Suggested Workflow for Untreated Soil Testing

Chapter B-4 Phase I – Trial Admixture(s) and Percentages

The purpose of the Phase I testing is to determine an appropriate type and percentage of admixture for the soil and project. The following steps should be completed for each type of admixture being evaluated.

B-4.1 Admixture Selection and Quality

The admixture(s) should be selected by the Engineer based on the soil type and availability of materials. Typical trial percentages are provided for cement and lime in Table B-5.

Table B-5 Soil Stabilization Index System (SSIS) Criteria for Admixture Selection (after FHWA 1992)

Percent Fines (Passing #200)	Plasticity Index (PI)	Preferred Admixture (Trial Percentages)
<25%	< 10	Cement (3%, 5%, and 7%)
	> 10	Cement (3%, 5%, and 7%)
		Lime (MLP, MLP + 2%, MLP + 4%)
> 25%	< 10	Cement (3%, 5%, and 7%)
	10 < PI < 30	Lime (MLP, MLP + 2%, MLP + 4%)
		Cement (3%, 5%, and 7%)
	> 30	Cement with prior addition of lime to reduce PI < 30
		Lime (MLP, MLP + 2%, MLP + 4%)
Note: Current experience is with Type I Portland cement. The results of this project suggest that Type IL cement typically produces lower strength compared to Type I. Higher percentages of Type IL appear to be required to obtain similar strengths; however, the recommended range of 3 to 7% is likely adequate.		

Cement and lime should be fresh and uncarbonated. If there is doubt concerning the reactivity of the materials, lime and cement can be tested using thermo-gravimetric analysis (TGA), and cement can also be tested for the strength activity index as a measure of reactivity (ASTM C311). If possible, the source of admixture that would be used for production should be used for laboratory testing.

B-4.2 Mixing and Mellowing

Admixtures are added based on the dry weight of the soil. Prior to mixing, the water content (w) of the soil should be verified. A representative sample of the soil should be weighed into a mixing container, and the total weight (W_t) should be measured. The dry weight of solids (W_s) should be determined as:

$$W_s = \frac{W_t}{1 + \frac{w}{100\%}}$$

The weight of admixture (W_X) that should be added is found by:

$$W_X = W_s \cdot \left(\frac{X}{100\%}\right) = \left(\frac{W_t}{1 + \frac{w}{100\%}}\right) \cdot \left(\frac{X}{100\%}\right)$$

where X is the percentage of the admixture to be added.

The admixture should be mixed into the soil using a mechanical mixer of sufficient size to adequately mix the soil without overflowing the mixing blow. Hand mixing is not recommended.

If lime is used, a mellowing period is required for the lime to react with the soil. Mellowing allows time for chemical reactions to occur between the lime and the clay minerals in the soil. Typically, the mellowing period for laboratory testing is 24 hours. After the mellowing period is complete, test specimens can be formed. In some cases, other admixtures, such as cement or fly ash, are used in addition to lime. The additional cementitious material should be added after the mellowing period.

If a cementitious admixture is used, test specimens should be compacted within two hours after mixing.

B-4.3 Compaction Testing

The maximum dry unit weight and optimum water content should be estimated or measured for each admixture percentage. The Phase I unconfined compression specimens will be compacted at the peak of the compaction curve. The peak of the Standard Proctor curve ($\gamma_{d,max}$ and w_{opt}) can be determined either using the full Standard Proctor test (ASTM D698) or the one-point Proctor procedure (see Section B-8). Each compaction test point requires about 4.5 lb of soil (total weight plus admixture).

B-4.4 Unconfined Compression Testing (with Capillary Soak)

Triplicate test specimens should be compacted for unconfined compression testing. Each specimen should be compacted at a water content within 1% of w_{opt} using Standard Proctor energy. The value of w_{opt} determined for the soil plus admixture should be used. Note that the addition of stabilizing materials tends to reduce the water content of soil. The soil must often be prepared to a water content about 1 to 2% above w_{opt} prior to addition of the admixture. Figure B-2 can be used to determine the approximate amount of moist soil that must be prepared per specimen. The water content of the sample should be determined separately during compaction.

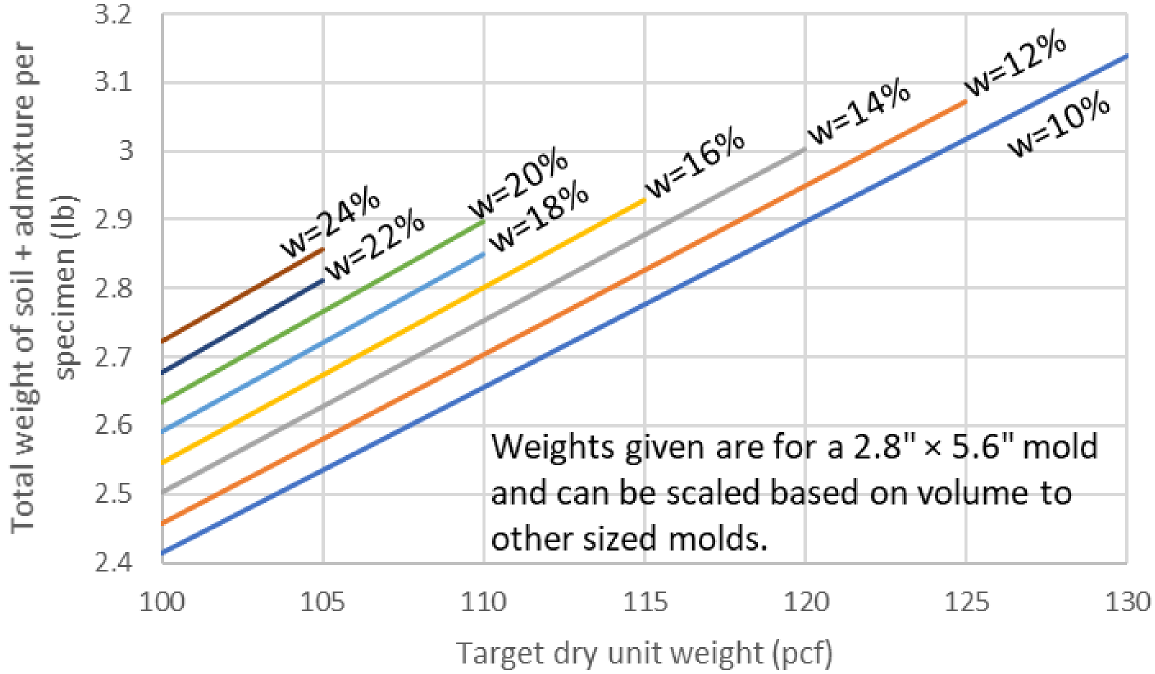


Figure B-2 Specimen Weight Required for Typical Dry Unit Weight and Water Content Combinations (10% extra included for waste)

After compaction, the weight and dimensions of the specimens should be determined to evaluate the as-compacted unit weight. The specimens then should be moist cured for seven days at a temperature of 73° F. It is sufficient to wrap the specimens in plastic wrap and place them within sealed plastic bags.

After curing, the weight and dimensions of the specimens are remeasured, prior to the capillary soak. To soak the specimens, they are placed on saturated porous stones in pans of water. The top of the stones should extend above the water surface so that the specimens are not immersed (ODOT 2011, NCHRP 2009). The specimens are wrapped in moist towels or burlap that extends into the water. The soaking allows expansion potential to be evaluated but is not as extreme as unconfined immersion in a water bath. After 24 hours of capillary soaking, the specimens should be weighed and measured a third time to evaluate expansion and change in water content due to soaking. The unconfined compression test should be completed immediately after repeating these measurements.

B-4.5 Evaluation and Selection

For each specimen, the percent volume change following curing (ΔV_{cured}) should be calculated as:

$$\Delta V_{cured} = \frac{V_{cured} - V_{compacted}}{V_{compacted}} \times 100\%$$

where V_{cured} is the specimen volume after curing and $V_{compacted}$ is the specimen volume after compaction. The percent volume change following soaking (ΔV_{soaked}) is found as:

$$\Delta V_{cured} = \frac{V_{soaked} - V_{cured}}{V_{cured}} \times 100\%$$

where V_{soaked} is the specimen volume after soaking.

A summary table should be prepared that compares the untreated unconfined compressive strength to the average and range of unconfined compressive strength for each percentage of admixture. Plots or tables should be also be prepared of compressive strength and ΔV_{soaked} vs. admixture percentage. It is useful to plot the threshold selection criteria, such as minimum unconfined strength and maximum ΔV_{soaked} on these plots or tables.

For each admixture tested, the minimum percentage required to exceed the minimum 7-day UCS can be determined or interpolated from the Phase I test results. If more than one admixture has been tested, the cost and availability of the admixtures should be evaluated along with the required percentage of each. To account for variability during construction, the design admixture percentage (X_{design}) should be increased by adding 1%. For example, if 3% lime is determined to provide sufficient strength in Phase I, the design percentage should be selected as 4%.

B-4.6 Workflow

The suggested workflow for the Phase I testing is illustrated in Figure B-3.

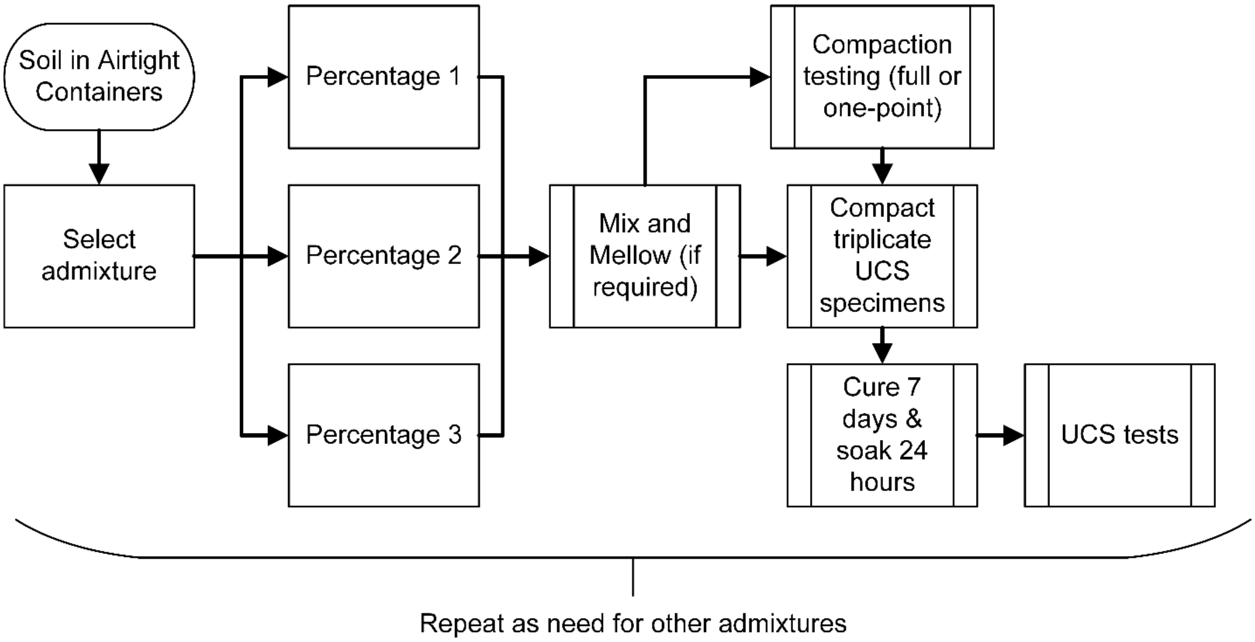


Figure B-3 Suggested Workflow for Phase I Soil Testing

Chapter B-5 Phase II – Pavement Design Testing

Mixing and mellowing should be performed for Phase II using the approach described in Section B-4.2. The design admixture percentage, X_{design}, is used for all tests.

B-5.1 Standard Proctor

A full Standard Proctor test should be performed on the soil mixed with the design admixture. The results of this test will supplement the approximate one-point compaction testing in Phase I. The maximum dry unit weight ($\gamma_{d,X}$) and optimum water content ($w_{opt,X}$) of the treated soil will be used to define the compaction conditions for the strength and stability tests.

B-5.2 Atterberg Limits Testing

Atterberg limits can also be determined on the treated soil, especially when lime is used to lower the plasticity index. While the Atterberg limits are not used directly in the design, they provide useful indication of the effectiveness of the stabilization. Soils treated with cement and lime admixtures exhibit a time-dependent reduction in plasticity index as the curing/mellowing period increases. In other words, the plasticity index will tend to decrease with time after mixing. However, as an expedient indicator of the change in plasticity, a 24-hour curing/mellowing period is recommended herein before testing treated soil samples for the Atterberg limits. The sample of the untreated soil should pass the #40 sieve prior to mixing.

B-5.3 Unconfined Compression Testing

Table B-6 provides guidelines for the preparation of unconfined compressive strength tests to evaluate the effectiveness of the selected admixture percentage. Compaction at a range of water contents assesses the impact of moisture variation that is likely to occur during construction. The 28-day UCS will be used as the design value; however, the 7-day and 90-day strengths demonstrate the improvement with additional curing.

Table B-6 Guidelines for Phase II Unconfined Compressive Strength Testing

Compactive Effort	Water content	Unconfined Compressive Strength		
		7-day cure + 1 day soak	**28-day cure + 1 day soak**	**90-day cure + 1 day soak**
Standard (D698)	$w_{opt,X}$ – 2%	1 or 2 specimens (optional)	2 specimens (optional)	Not required
	$w_{opt,X}$	1 or 2 specimens (recommended)	2 specimens (required)	1 or 2 specimens (recommended)
	$w_{opt,X}$ + 2%	1 or 2 specimens (optional)	2 specimens (optional)	Not required

After curing, the specimens should be subjected to a 24-hour capillary soak. See Section B-4.4 for details. Similar to Phase I, the specimens should be weighed at each step (after compaction, after curing, and after capillary soak) to evaluate any volume change tendency.

B-5.4 California Bearing Ratio Testing

Soaked CBR testing should be performed on cured specimens of treated soil to determine the subgrade support properties of the stabilized soil for design. Compaction at a range of water contents assesses the impact of moisture variation that is likely to occur during construction. At least one CBR test specimens should be compacted to each of three water contents ($w_{opt,X}$ – 2%, $w_{opt,X}$, $w_{opt,X}$ + 2%).

The CBR following a 28-day cure will be used as the design value as recommended by AASHTO (2020). Correlations between CBR and resilient modulus will allow design at Level 2 in the MEPDG system.

The CBR specimens should be moist cured using a method similar to that used for the unconfined specimens. Because the CBR specimens must remain in the molds during curing, a large, watertight container is required to cure each specimen. The typical dial gauge apparatus used to assess swell during soaking probably is not appropriate for the curing phase. Prior to curing, the distance from the top of the mold to the surcharge weight should be determined. This distance should also be measured at the end of curing to evaluate the volume change during curing.

B-5.5 Resilient Modulus Testing

If required for pavement design, the resilient modulus of the stabilized soil can be measured by direct testing. This will provide Level 1 design input in the MEPDG system (AASHTO 2020). Specimens for resilient modulus testing can be compacted at one or more water contents, such as the range recommended for the UCS and CBR tests. If more limited testing is desired, the UCS and CBR results can be used to determine the worst-case compaction state to use for compaction of the resilient modulus specimens.

B-5-6 Workflow

The workflow for the Phase II testing is illustrated in Figure B-4.

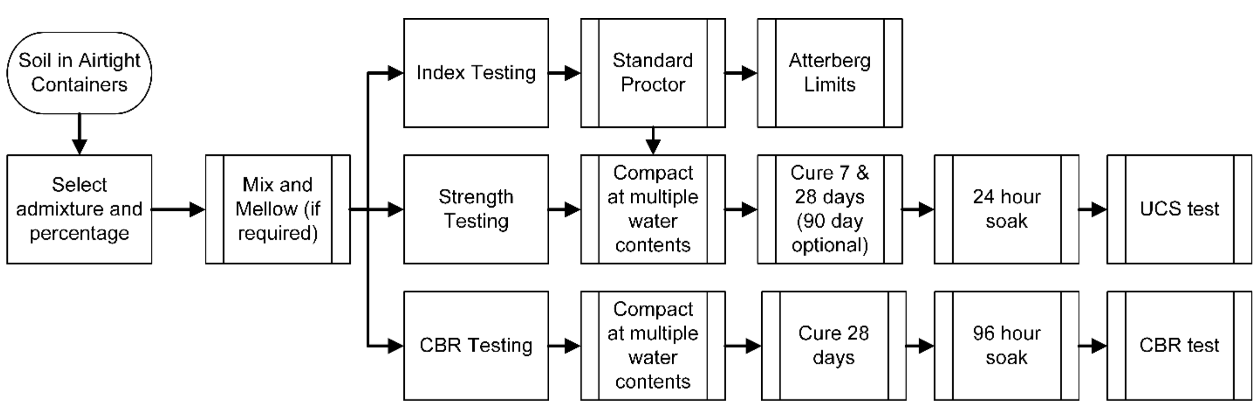


Figure B-4 Suggested Workflow for Phase II Soil Testing

Chapter B-6 Mix Design Reporting

The following sections describe the minimum reporting requirements for a soil stabilization design. Additional information may be required in particular cases or where other procedures are followed. These requirements focus on how to summarize the results. The supporting data for individual test results should be reported in compliance with the appropriate ASTM or AASHTO standards.

B-6.1 Sampling and Storage – Reporting

The sampling and storage procedures should be listed, including:

- Location from which sample was obtained
- Method of sampling and transport
- Mixing or processing procedures used, e.g., pulverized, split and quartered, etc.
- Storage method

If possible, also include an aerial photo and any pertinent information about the subgrade soil from the USDA Soil Survey.

B-6.2 Characterization – Reporting

The results of the characterization testing should be presented in a list or tabular format along with the applicable test standards used, including:

- As-received water content
- Grain size distribution (if determined)
- Specific gravity of solids (if determined)
- Atterberg limits
- Eades-Grim minimum lime percentage
- Sulfate content
- Organic content
- Standard Proctor – w_{opt} and γ_{dmax}
- Unconfined compression
- CBR

These results provide the comparison values for the Phase I and II testing.

B-6.3 Phase I – Reporting

In some cases, the Phase I testing may be reported in a preliminary report, which allows the specifying agency (e.g., TDOT or other) to provide feedback on the selected admixture and design percentage.

The Phase I testing should be summarized by describing the types of admixtures evaluated and the percentages of each. The summary table and plots described in Section B-4.5 should be included. These should include data for:

- One-Point Proctor – w_{opt} and γ_{dmax}
- Volumetric expansion after curing
- Volumetric expansion after soaking
- Range and mean UCS for each admixture and rate

Comparison of the results to the design thresholds should be discussed to justify selection of the design percentage or application rate, X_{des}.

The source and production date of each admixture should be reported.

B-6.4 Phase II – Reporting

In some cases, the Phase II testing will be completed and presented after a preliminary report. In this case, the Phase II testing should be reported along with the results on the untreated soil and Phase I testing.

The Phase II testing should be summarized by describing the range of compaction conditions, water contents, and curing times that were evaluated. At a minimum, the results of 28-day testing should be presented, unless an alternate curing period has been selected for design. The treated Standard Proctor and Atterberg limits results should be reported. A summary table should be prepared that includes the compacted unit weight, water content, and relative compaction of all UCS and CBR specimens. In addition, the volume change measurements for each test should be reported. If UCS tests are performed at multiple curing times, the variation in UCS with time should be plotted.

The report should conclude by recommending a design CBR (or resilient modulus) to be used for pavement design over the stabilized subgrade. The design value should consider potential variation in compaction. The design value should be based upon both the measured CBR (or resilient modulus) and correlations to UCS.

Chapter B-7 Field Observation and Testing

B-7.1 General

The major QA/QC tasks for the observation and testing of subgrade stabilization are checking for appropriate weather conditions, checking and recording the admixture percentage, evaluating uniformity of mixing and moisture content, verifying compaction and stabilization depth, monitoring the curing process, and proof rolling. Test specimens can be field compacted for confirmatory UCS testing. Additional guidance can be found in the PCA's *Soil-Cement Inspector Manual* (2001).

B-7.2 Weather Conditions

In general, the ambient temperature should be above 40° F in order for subgrade stabilization to be effective. The subgrade must not be frozen. In addition, stabilization should not be attempted in the rain because of the difficulty with moisture control. Excessively windy conditions can cause difficulty with spreading and mixing admixtures.

B-7.3 Applied Admixture Percentage

The contractor should have clear, written plan for achieving the design admixture percentage. This plan should include a demonstrable means of measuring the total amount of admixture used and total volume of soil treated each time period.

The volume of soil treated over a given time period is found by the treated area ($A_{treated}$) and the treatment depth (d) as:

$$V_{treated} = A_{treated} \times d$$

The dry weight of the solids and admixture can be found from the volume and the average dry unit weight of treated, compacted subgrade ($\gamma_{d,treated}$):

$$W_{s+admix} = V_{treated} \times \gamma_{d,treated}$$

The weight of admixture for a given time period is then calculated from the applied admixture percentage ($X_{applied}$) as:

$$W_{admix} = W_{s+admix} \left(\frac{X_{applied}}{1 + X_{applied}} \right)$$

Combining and rearranging, the applied admixture percentage can be calculated as:

$$X_{applied} = \frac{W_{admix}}{W_{s+admix} - W_{admix}} = \frac{W_{admix}}{A_{treated} \cdot d \cdot \gamma_{d,treated} - W_{admix}}$$

The applied admixture percentage can be compared to confirm that it meets or exceeds the design value.

In addition to checking the application percentage over each specified time period, spot checking can be used if the dry method is employed for spreading the admixture. Spot checking is completed by placing a large pan or piece of plywood on the subgrade in front of the spreader. The weight of admixture spread over the pan or wood must be carefully measured. The area spreading rate (W/A) is found as:

$$\left(\frac{W}{A}\right)_{applied} = \frac{W_{sheet}}{A_{sheet}}$$

The required area spreading rate (pounds per square yard) based on the design admixture percentage (X_{design}) is found as:

$$\left(\frac{W}{A}\right)_{required} = d \cdot \gamma_{d,treated}\left(\frac{9\,S.F.}{S.Y.}\right)\left(\frac{X_{design}}{1+X_{design}}\right)$$

B-7.3.1 Admixture Application Percentage Worksheet

An example worksheet to use for the calculation of $X_{applied}$, $(W/A)_{applied}$, and $(W/A)_{required}$ is provided in Table B-7. The worksheet is set up for spreading rates of pounds per square yard. Other units can be used with appropriate conversion factors.

B-7.3.2 Example

This section provides a brief example of the calculations for field verification of admixture rates. Assume that the project has an area to be treated of 900,000 S.F. or 100,000 S.Y. and that the treated dry unit weight of the soil is 110 pcf. The design admixture percentage is 5%. The treatment depth is 1.5 feet. The basic variables can be calculated as:

- d = 1.5 ft
- X_{design} = 5% = 0.05
- $V_{treated}$ = (900,000 S.F.)(1.5 ft) = 1,350,000 C.F.
- $\gamma_{d,treated}$ = 110 pcf

The weights of the materials involved are calculated as:

- $W_{s+admix}$ = (1,350,000 C.F.) (110 pcf) = 148,500,000 lb
- W_{admix} = (148,500,000 lb)[0.05/(1+0.05)] = 7,071,429 lb = 3536 tons
- W_s = 148,500,000 lb – 7,071,429 lb = 141,428,571 lb

The required spreading rate is found as:

- $(W/A)_{required}$ = (1.5 ft)(110 pcf)(9 S.F./S.Y.)[0.05/(1+0.05)] = 71 lb/S.Y.

Assume that a sheet with an area of 6 S.F. is used to check the spreading rate during construction. If the sheet is placed on the subgrade and 48 lb of admixture are spread on it, the applied spreading rate is:

- (W/A)applied = (48 lb) / (6 S.F. / 9 S.F./S.Y.) = 72 lb/S.Y.

This rate approximately matches the design spreading rate.

Table B-7 Admixture Spreading Rate Worksheet

Laboratory Test Results and Mix Design			
Stabilization depth, d (ft):			
Design admixture rate, X_{design} (%):			
Standard Proctor maximum dry unit weight, γ_{dmax} (pcf):			
Minimum relative compaction, R.C. (%):			
Design compacted dry unit weight, $\gamma_{d,treated} = R.C \times \gamma_{dmax}$ (pcf):			
Required Spreading Rate, W/A			
Multiply 9	by $\gamma_{d,treated} \times d$	by $X_{design} / (1+X_{design})$	= Required W/A
Field Spreading Rate by Truckload			
Truck #	Weight of Admixture, W_{admix} (lb) (COL. A)	Subgrade Area Treated, $A_{treated}$ (S.Y.) COL. B)	Spreading Rate by Truckload, W/A (lb / S.Y.) (COL. A / COL. B)
Spot Checking Results			
Check #	Weight of Admixture on Pan, W_{pan} (lb) (COL. A)	Area of Pan, A_{pan} (S.Y) COL. B)	Spreading Rate by Spot Check, W/A (lb / S.Y.) (COL. A / COL. B)
1			
2			
3			
4			
5			

B-7.4 Depth and Uniformity of Mixing

The depth and uniformity of mixing must be evaluated during and after the stabilization process. This is primarily accomplished by digging trenches or holes through the full depth of the stabilized soil at regular intervals. The exposed soil should be visually inspected to verify that the color is uniform. Streaked soil color indicates that the mixing process is inadequate. The loose treated soil layer should be about 30 to 50% thicker than the required compacted thickness. The percentage of bulking during mixing will depend on the soil. Depending on the consistency of the soil underlying the treated layer, it may be possible to evaluate the thickness of the loose soil using a metal probe.

Holes should also be excavated regularly through the compacted subgrade to measure the compacted thickness of the stabilized soil layer. If loose and compacted thickness measurements are completed at the same location, an estimate of the bulking factor can be determined.

In addition to visual observation of the soil color, a pH indicator, such as phenolphthalein or dilute hydrochloric acid, can be used to evaluate stabilization depth. The phenolphthalein will turn purple in the presence of the basic admixtures. Hydrochloric acid will effervesce (fizz). In either case, a uniform reaction to the indicator should be present through the full depth of stabilization.

Transverse joints must be created at the end of each day of construction by cutting a vertical surface into the compacted, stabilized subgrade. The joints are full depth and provide another opportunity to check the stabilization depth. The construction of these joints should be documented.

B-7.5 Field Compaction

The compaction of the stabilized subgrade should be evaluated by comparison of the compacted dry unit weight and water content to the Standard Proctor maximum dry unit weight determined by the laboratory. The compaction control testing frequency should meet or exceed the frequency specified in TDOT's standard procedures. The compacted water content and dry unit weight should be determined by a nuclear gauge, sand cone, or other approved method. Appropriate methods for gravel correction should be used, as needed.

Unless indicated otherwise by the mix design, the relative compaction of the stabilized subgrade should be 100% or greater. The compacted water content should be within 2% of the laboratory optimum value.

Special attention should be given to the compaction of the stabilized subgrade at the transverse construction joints. Additional compaction control tests are warranted to document adequate mixing and compaction at these locations.

B-7.6 Field Verification of Strength and Stability

The compressive strength should be verified for each lot of compacted subgrade. A lot is defined as 40,000 square yards or the area stabilized in one day, whichever is less. The stabilized soil should be sampled after the admixture and any additional water are mixed with the soil, but prior to compaction.

Following ODOT (2011), three samples should be obtained from randomly selected locations within the lot. Each of the three samples should be sufficiently large to compact one specimen for unconfined compressive testing.

The specimens should be compacted at the project site on rigid surface (e.g., pavement or concrete slab) using Standard Proctor energy, unless another energy level is being used as the standard for the project. The specimens can be compacted as described in ASTM D1632; however, it may be difficult to approximate Standard Proctor energy and additional equipment is required. Alternatively, a Standard Proctor hammer can be used with 2.8 by 5.6-inch split mold. A separate water content measurement should be made on part of each sample to evaluate the as-compacted water content prior to curing.

After compaction, the specimens should be measured, weighed, wrapped in plastic wrap, and sealed in separate airtight plastic bags for curing. See Section B-8.4 for guidance on curing. Following curing, the specimens should be subjected to a 24-hr capillary soak and then tested in unconfined compression as described in Section B-4.4.

It is possible to prepare field compacted CBR specimens. However, stabilized subgrade stability will typically be evaluated by (1) verifying the field UCS meets or exceeds the mix design and (2) proof rolling. For this reason, field compacted CBR specimens have not been recommended.

B-7.7 Curing

The moisture present in the stabilized soil at compaction must be retained to allow for ongoing chemical reactions with the soil, water, and admixtures. Thus, chemical curing using emulsified asphalt, or a curing compound is required for at least 5 days following compaction. The surface of the subgrade should be moist when the curing compound is applied.

The surface moisture condition prior to application of the curing compound should be documented. Uniform coverage of the curing compound should be recorded and checked throughout the curing period.

B-7.8 Proof Rolling

Proof rolling is used to evaluate the stability of the stabilized subgrade after the curing period is complete. The stabilized subgrade should not rut or deflect visibly during proof rolling. Regions exhibiting deflection should be identified and remediation of such areas should be documented.

B-7.9 Workflow and Reporting

A suggested workflow for the field verification observation and testing is provided in Figure B-5. An example field observation summary sheet is provided in Table B-8.

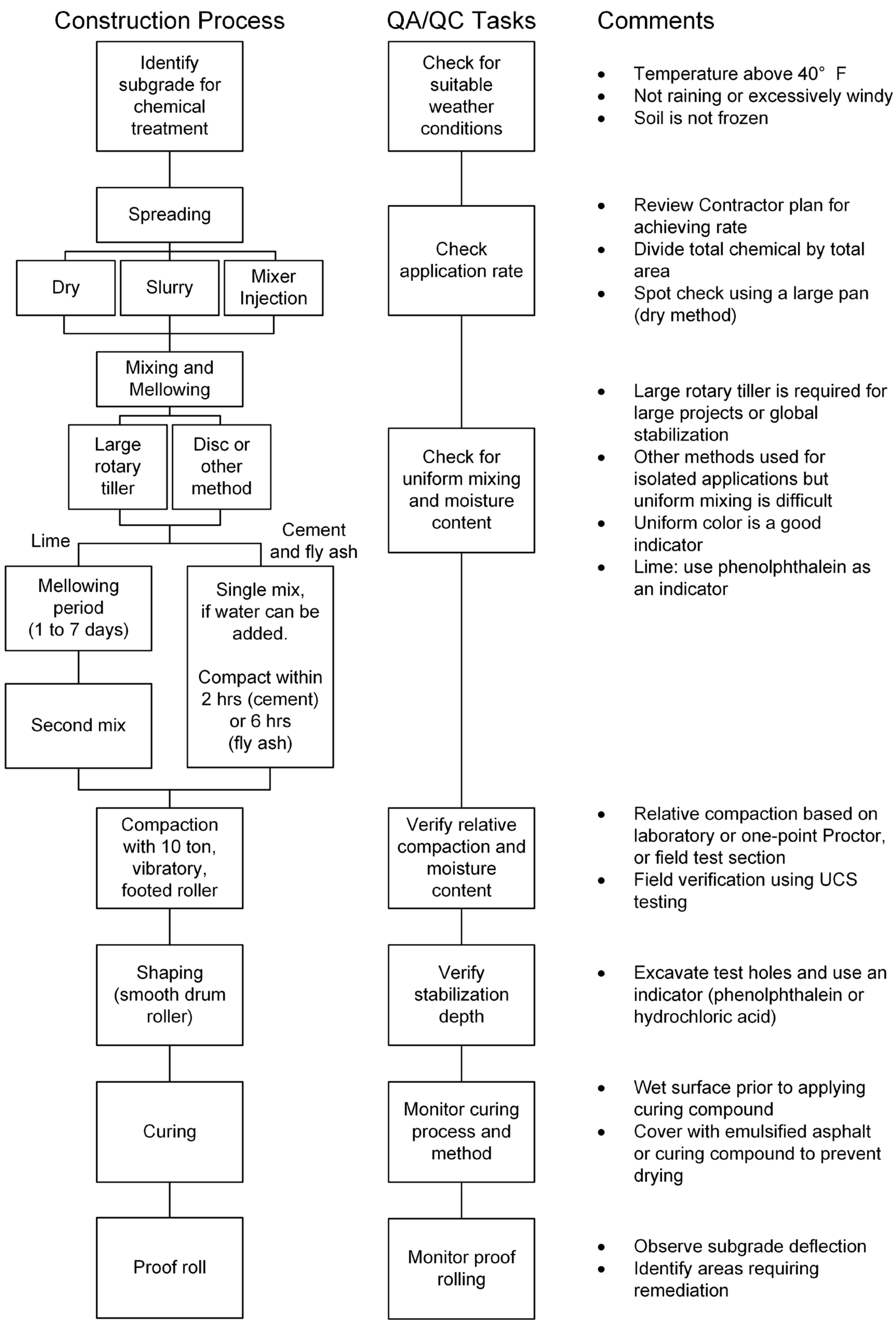


Figure B-5 Field Observation Workflow

Table B-8 Field observation summary sheet

SUBGRADE STABILIZATION FIELD OBSERVATION SUMMARY SHEET

Project: ______________________ Location: ______________________

Observed by: ______________________

Stabilized Subgrade Construction - Mixing

Station - From: To:	Date mixed:	
Soil Description:	Weather:	
Equipment used for moisture conditioning, spreading, and mixing:		
Admxiture Type and Percentage:	Target Spreading Rate:	
Spot check rate: (attach documentation)	Measured Daily rate:	
Visual description of mixed soil:		
Design thickness:	Loose depth of mixed soil:	# of check locations:
Second mix (lime) - Date:	Observations:	

Stabilized Subgrade Construction - Compaction

Date compacted:	Weather:	
Equipment and process used for compaction:		
Lab γ_{dmax} (pcf):	Lab w_{opt} (%):	Specified R.C.:
Range γ_{dfield} (pcf):	Range w (%):	Range of R.C.:
Attach results of individual compaction control tests on separate documentation.		
Design thickness:	Final stabilized depth:	# of check locations:

Stabilized Subgrade Construction - Curing

Surface condition of stabilized subgrade:	Date:			
Type of curing compound:	Reported application rate:			
Visual description of curing compound application:				
Follow-up checks -	Day 2:	Day 3:	Day 4:	Day 5:

Stabilized Subgrade Construction - Proof Rolling

Date:	Equipment used:
General description of subgrade response:	
Areas of concern:	
Date and method of remediation:	

Chapter B-8 Laboratory Guidance

This chapter provides commentary on the particular test procedures used in the design of soil stabilization. The pertinent AASHTO and ASTM procedures are referenced. Because these are mostly common geotechnical tests, it is assumed that the reader is familiar with the test procedure and that internal laboratory protocols will be used to complete the tests. In a few cases, more detail is provided because the test is less common.

B-8.1 As-Received Water Content

After mixing and splitting into storage containers, the water content of the sample should be obtained according to AASHTO T208 (ASTM D2166). This water content will be useful as an approximate starting point for many of the testing procedures.

B-8.2 Screening Tests

These tests screen for problematic soil conditions that can limit the usefulness of chemical stabilization, including sulfate content and organic content.

B-8.2.1 Sulfate Content

While chemical subgrade treatment has proven effective in multiple situations, water soluble sulfate in the soil can potentially prove to be a deleterious substance during and after stabilization. Available sulfate can react with available calcium and aluminate compounds to form calcium sulfo-aluminate phases. These phases, such as ettringite, cause expansive pressures within the soil, ultimately leading to heaving and premature pavement failure. Sulfate content below 3000 ppm (0.3%) are not typically problematic.

Sulfate testing is performed using AASHTO T290 (ASTM C1580). A representative soil sample is dried, mixed with deionized water, and filtered. The filtrate is mixed with barium chloride and placed in a photometer to determine turbidity. An instrument specific calibration process is required to relate the turbidity to the sulfate concentration.

B-8.2.2 Organic Content

Organics in soil, particularly organic acids, can inhibit the chemical reactions required for adequate stabilization. Organics most commonly slow the rate of formation of stable compounds, requiring more mellowing or excess addition of chemical stabilizers. There is some disagreement in the literature about the threshold at which organics become problematic for stabilization.

Many methods are available to measure organic content; however, the most commonly available in geotechnical and materials laboratories is the loss on ignition (LOI) test (AASHTO T267, ASTM D2974). In the LOI test, the soil is first oven-dried at 105 C to remove the free water. After the dry weight is determined, the soil is placed in an ignition oven and heated to a higher temperature. For measurement of organics for stabilization, heating to 440 C (Method C) is appropriate. The difference in mass between the soil sample at the two temperatures is interpreted to be organic matter. However, two factors can complicate this interpretation (e.g., Hoogsteen et al. 2015). First, water that is structurally bonded in clay minerals can be released at temperatures above 105 C. Second, at temperatures above 600 C, carbonate compounds in soil can decompose. These can lead to an organic content from loss on ignition that is too high. Designers and testing labs should be aware that LOI may indicate organic contents that are 1 to 2% too high, which is significant for soils with little to no true organics.

The LOI measured using AASHTO T267 ($LOI_{measured}$) and a temperature of 440 C can be corrected for structural water loss using the following correction:

$$LOI_{corr} = LOI_{measured} - 0.025 \cdot CF$$

where LOI_{corr} = corrected LOI and CF = clay fraction (% finer than 2 μm). Note that the constant increases for higher temperatures (Hoogsteen et al. 2015).

B-8.3 Index Tests

The index tests allow the soil to be classified according to AASHTO and USCS. The tests also provide valuable connection to past experience with similar soils.

B-8.3.1 Specific Gravity

Specific gravity is helpful for a full characterization of the subgrade soil. However, its measurement is not absolutely required. Specific gravity must be estimated for the hydrometer test, if it is not measured.

B-8.3.2 Sieve Analysis and Hydrometer

The grain size distribution found using the sieve analysis and hydrometer allows the soil to be classified and compared with past experience with stabilization of similar soils. The hydrometer allows the clay fraction and activity to be determined, which may be useful for estimating the clay mineralogy. If necessary, the grain size distribution can be estimated rather than directly measured.

The grain size distribution of the coarse fraction should be determined using AASHTO T88 (ASTM D6913), as for any other soil. For the fine-grained soils that are more commonly stabilized, it will likely be appropriate to determine the percent passing the No. 200 sieve by washing (AASHTO T11, ASTM D1140) prior to the sieve analysis. For these soils, single sieve-set sieving (Method A) will likely be suitable. The hydrometer analysis, if performed, should follow AASHTO T88 (ASTM D7928).

The grain size distribution can also be determined for soils that have been stabilized, especially with lime. The stabilization will increase the grain sizes as the particles are bonded together.

B-8.3.3 Atterberg Limits

The liquid and plastic limits should be determined according to AASHTO T90 (ASTM D4318). The plasticity index is commonly used to decide between lime and cement stabilization for cases where only one admixture type is evaluated.

It is preferable to determine the Atterberg limits on soil that has not been previously oven-dried. The moist sample should be processed through a No. 40 sieve. If water is introduced during the sieving process, the sample will need to be carefully air-dried until the water content is near the liquid and plastic limits. The Eades-Grim test described in the next section also requires soil that has sieved through the No. 40 sieve. It is efficient to prepare sufficient soil for both tests at one time.

B-8.3.4 Eades-Grim (Minimum Lime Percentage)

Where lime stabilization may be used, the Eades-Grim test (ASTM D6276) can be used to determine the minimum percentage of hydrated lime. The minimum lime percentage (MLP) is the lowest percentage of lime that will produce a lime-soil pH of at least 12.4. This pH is the level required for the clay minerals to dissociate and for the plasticity of the soil to be effectively altered.

In this test, a similar quantity of soil is placed in multiple containers along with varying percentages of lime (by dry weight), including a sample without lime. Each sample is mixed with distilled water and shaken every 10 minutes for one hour. The pH of each mixture is determined. The variation of pH with lime percentage is then observed.

The MLP is not necessarily the optimum percentage of lime for stabilization, but rather the starting point for studying the stabilizing effect of lime. Typically, the MLP and a few trial percentages higher than the MLP are evaluated by the mix design process.

B-8.4 Curing

Curing is an important part of the subgrade stabilization process and the laboratory testing used to evaluate stabilization. Curing provides time for chemical reactions to occur between the admixture and the soil in the presence of adequate moisture. Much research has been performed on the effects of elevated temperatures on curing. However, this manual recommends the use of curing at room temperature of approximately 73° F so that special facilities are not required to complete the curing and testing.

B-8.4.1 Seven-Day Curing – UCS Specimens

Many of the tests require a seven-day curing period. During this relatively short period of time, a high relative humidity can be maintained in a plastic, zipper-sealed bag.

UCS test specimens cured for seven days should be wrapped in plastic wrap immediately after removal from the compaction mold. Each specimen should be placed in an airtight, plastic, zipper-sealed bag. The bags should be labeled with the specimen's identifying information. After the curing period, specimens should be examined, and signs of drying should be noted.

B-8.4.2 Longer Curing Periods

Curing periods of at least 28 days are recommended for the Phase II testing. During this length of time, moisture can migrate out of plastic bags used for the UCS specimens. Other methods of curing are recommended in order to maintain adequate moisture for extended curing.

One suggested method is to cure the UCS specimens over water-filled gravel in a large sealable bucket or container. To use this approach, a layer of poorly graded gravel is placed in the bottom of the container. The void space in the gravel is filled with water nearly to the upper surface of the gravel. After an initial cure of one to seven days in plastic bags, the specimens can be labeled and transferred to the buckets for the remainder of the curing period. The water in the gravel will keep a high relative humidity in the container and can be replenished if necessary. CBR specimens can also be cured in this manner for 28 days as required for Phase II.

The use of a high humidity curing room is also an acceptable means for long-term curing. Specimens should be placed inside of plastic bags to prevent free moisture from accessing the specimens.

B-8.5 Compaction Testing

B-8.5.1 Full Standard Proctor Test

The Standard Proctor test (AASHTO T99, ASTM D698) is used to assess the effects of compaction on the soil. In locales or for projects where Modified Proctor (AASHTO T180, ASTM D1557) energy is more common, it may be used instead. The Standard Proctor maximum dry unit weight, $\gamma_{d,max}$, and optimum water content, w_{opt}, will be used to determine the appropriate compaction conditions for the strength and stability tests.

The full Proctor test requires compaction at multiple water contents, often four or five, to define the compaction curve. This represents a substantial effort and time commitment. An alternative is the one-point Standard Proctor test, which is described in the next section.

B-8.5.2 One-Point Standard Proctor Test

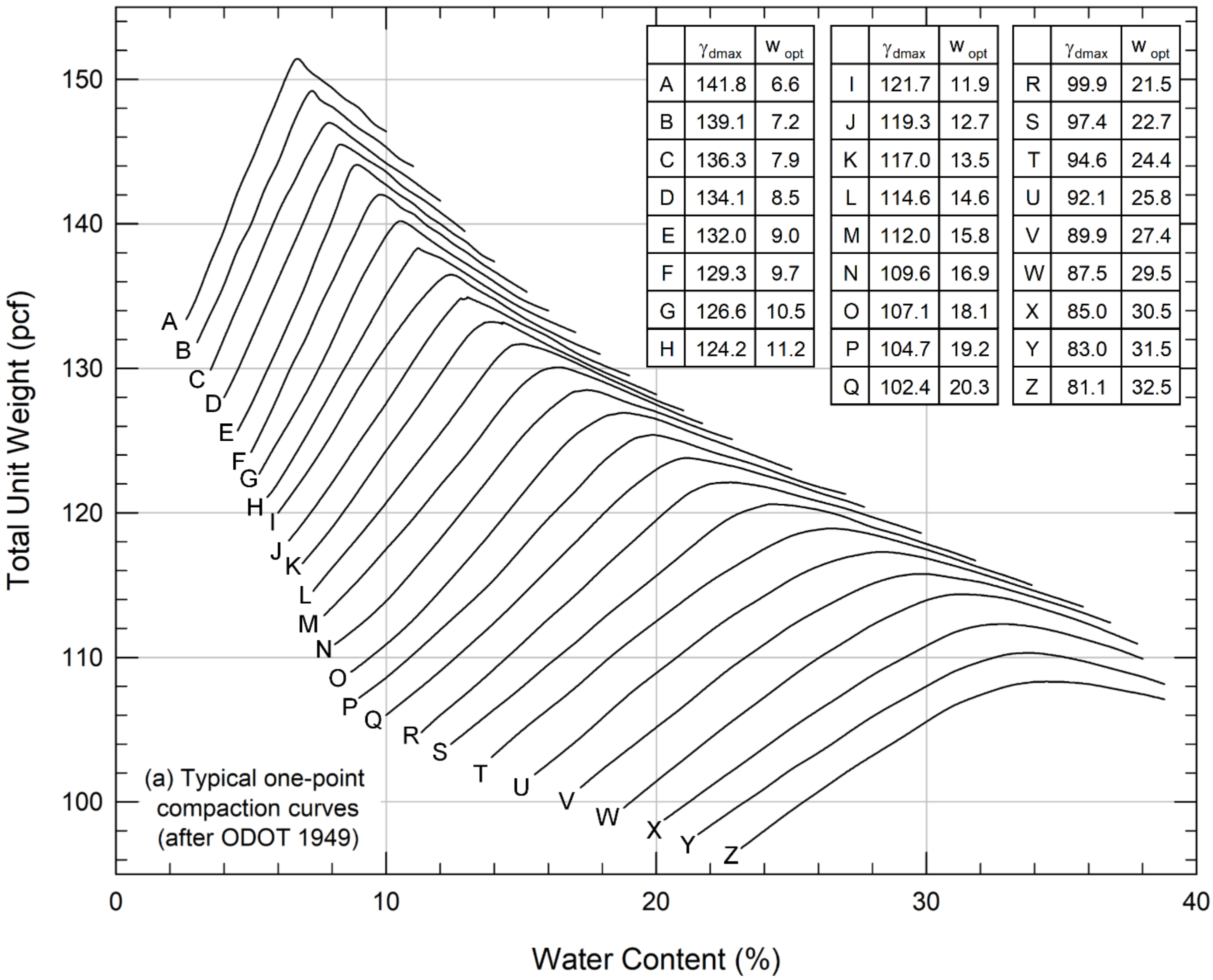
The one-point Standard Proctor test leverages the fact that the compaction curves for most soils follow a consistent trend, as shown in Figure B-6. Compaction of a single test specimen at a water content dry of optimum allows the values of $\gamma_{d,max}$ and w_{opt} to be estimated. This process is similar to that described in AASHTO T272.

The one-point compaction test involves the following steps:

1. Estimate the optimum water content of the soil or soil plus admixture.
2. Prepare a soil or soil-admixture sample to a water content that is a few percentage points below optimum.
3. Compact a test specimen using Standard Proctor energy.
4. Determine the compacted total unit weight and measure the water content.
5. Plot the total unit weight vs. water content on Figure B-6 or a similar region-specific set of one-point curves.
6. Select the curve closest to the compacted point and determine the estimated $\gamma_{d,max}$ and w_{opt} for the letter corresponding to the selected curve.

For example, assume the compaction characteristics must be determined for a soil with an estimated $\gamma_{d,max}$ of 105 pcf.

- Based on Figure B-6, the soil will likely correspond to about Curve P and the w_{opt} will be about 19%.
- A sample is prepared at a water content of 16%.
- After compaction using Standard Proctor energy, the total unit weight is found to be 116 pcf.
- The point (16%, 116 pcf) falls on Curve Q.
- The estimated $\gamma_{d,max}$ is 102.4 pcf and the estimated w_{opt} is 20.3%.



	γ_{dmax}	w_{opt}		γ_{dmax}	w_{opt}		γ_{dmax}	w_{opt}
A	141.8	6.6	I	121.7	11.9	R	99.9	21.5
B	139.1	7.2	J	119.3	12.7	S	97.4	22.7
C	136.3	7.9	K	117.0	13.5	T	94.6	24.4
D	134.1	8.5	L	114.6	14.6	U	92.1	25.8
E	132.0	9.0	M	112.0	15.8	V	89.9	27.4
F	129.3	9.7	N	109.6	16.9	W	87.5	29.5
G	126.6	10.5	O	107.1	18.1	X	85.0	30.5
H	124.2	11.2	P	104.7	19.2	Y	83.0	31.5
			Q	102.4	20.3	Z	81.1	32.5

Figure B-6 One-Point Proctor Curves

B-8.5.3 Rapid Compaction Test

A third option for determining the compaction curve is ASTM D5080. This method uses three compacted specimens and thus represents an intermediate effort. Water is added to the soil and approximate water contents are determined. The method assumes that the compaction curve is a parabola, and the calculations are more complicated. The method takes about one to two hours to complete.

B-8.6 Strength and Stability Testing

Strength and stability tests are used as indicators of the subgrade's support characteristics both with and without stabilization. The two primary tests used by most stabilization design procedures are the unconfined compression test and the California Bearing Ratio (CBR) test.

B-8.6.1 Unconfined Compression Test

The unconfined compression (UC) test is a useful indicator of the undrained shear strength of the compacted soil, both treated or untreated. The UC test loads the specimen in triaxial compression with no confining stress.

The axial stress at failure is referred to as the unconfined compressive strength (UCS). The undrained shear strength (s_u) is half of this value. The UC test should be performed in accordance with AASHTO T208 (ASTM D2166).

AASHTO T296 (ASTM D1633) (soil-cement) and AASHTO T220 (ASTM D5102) (soil-lime) may also be used to determine the UCS of stabilized soil mixtures. These standards have two primary differences from AASHTO T208 (ASTM D2166). First, they include reference to curing and soaking procedures prior to compression testing. Second, they allow use of specimens with a height to diameter ratio less than 2.

Specimens compacted in Proctor molds can be used for UC testing according to T296 and T220. These specimens have a height to diameter ratio close to 1. UCS from this sized specimen can be used as an index of strength. The UCS values obtained in this manner are not directly comparable to strength obtained on specimens with an aspect ratio of 2, because of end effects during testing.

Compacted specimens with a height to diameter ratio of about 2 can be prepared using a variety of compaction molds of various sizes. Guidance for the compaction of specimens is found in Table B-8.

Table B-8 Guidance for Unconfined Specimen Compaction

Diameter × Height	Volume (ft^3)	Blows using T99 (D698) Hammer			
		Total Number of Blows	Blows per Lift (5 lifts)	Blows per Lift (8 lifts)	Blows per Lift (10 lifts)
1.4″ × 2.8″	0.00249	Use Harvard Compactor or smaller tamper			
2″ × 4″	0.00727	16	3	2	2
2.8″ × 5.6″	0.01996	45	9	6	4
4″ × 8″	0.05818	131	26	16	13

B-8.6.2 California Bearing Ratio Test

The California Bearing Ratio (CBR) test is commonly used to evaluate the subgrade support characteristics. The CBR test is performed in accordance with AASHTO T193 (ASTM D1883). A surcharge should be applied to apply a pressure approximately equivalent to the anticipated pavement overburden pressure.

The CBR is sometimes correlated to the resilient modulus for use in pavement design. One common correlation comes from NCHRP Report 128 in nomograph form. The relationship in the nomograph can be approximated by:

$$M_r = 1.925 \cdot CBR^{0.686}$$

where M_r is the resilient modulus in ksi.

The CBR specimen is the same size as a 6-inch diameter (Method C) Proctor test. Standard Proctor energy corresponds to compaction in three lifts with 56 blows per lift.

B-8.6.3 Resilient Modulus

The resilient modulus, M_r, is used by many agencies for pavement design, because it takes into account the cyclic nature of traffic loading. The resilient modulus is the ratio of an applied cyclic stress to the recoverable elastic strain after many loading cycles (FHWA 2006). M_r is measured in a cyclic triaxial tests. The magnitude of M_r is dependent both on confining stress and shear stress level.

B-8.7 Example Raw Data Sheets

Some of the tests described herein require special procedures not typically performed in the geotechnical lab, or special mixing procedures. In Figures B-7 to B-10, supplementary raw data sheets are provided for Eades-Grim; One-Point Standard Proctor; admixture measurements for preparation of specimens for Standard Proctor, unconfined compression, and CBR; and expansion measurements for unconfined compressive strength specimens.

EADES-GRIM RAW DATA SHEET

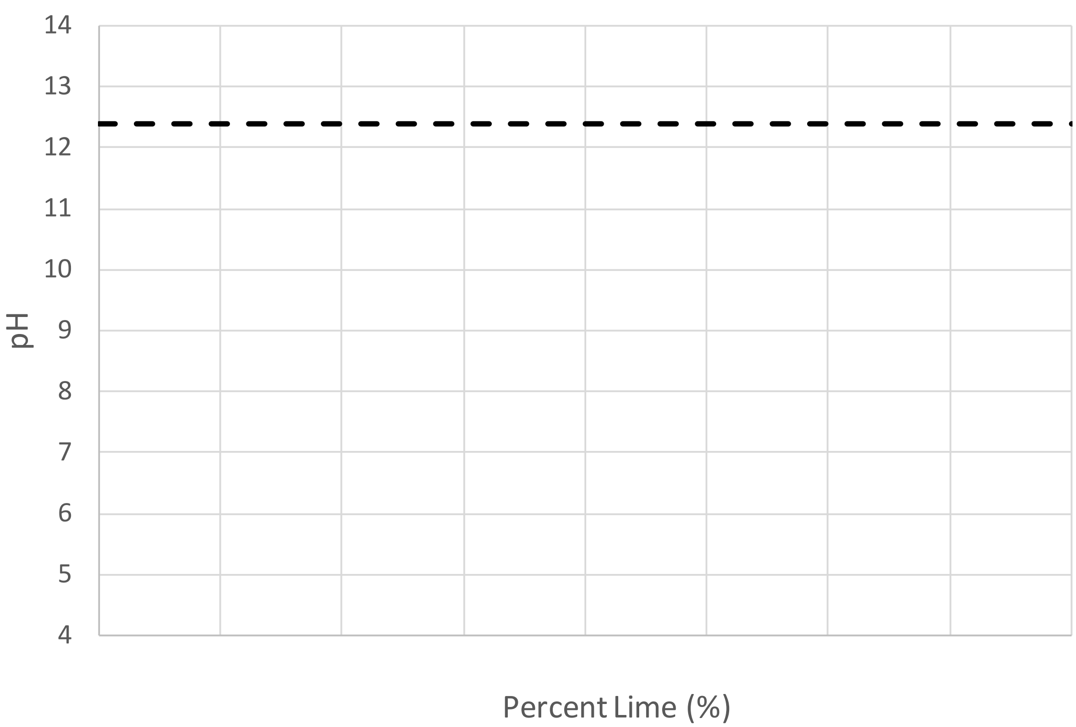
Project: ______________________ Location: ______________

Tested by: ______________________

Soil Description:

Container	Dry mass of soil ( )	Percent lime	Mass of lime ( )	Start Time	End Time	pH
		0	0			

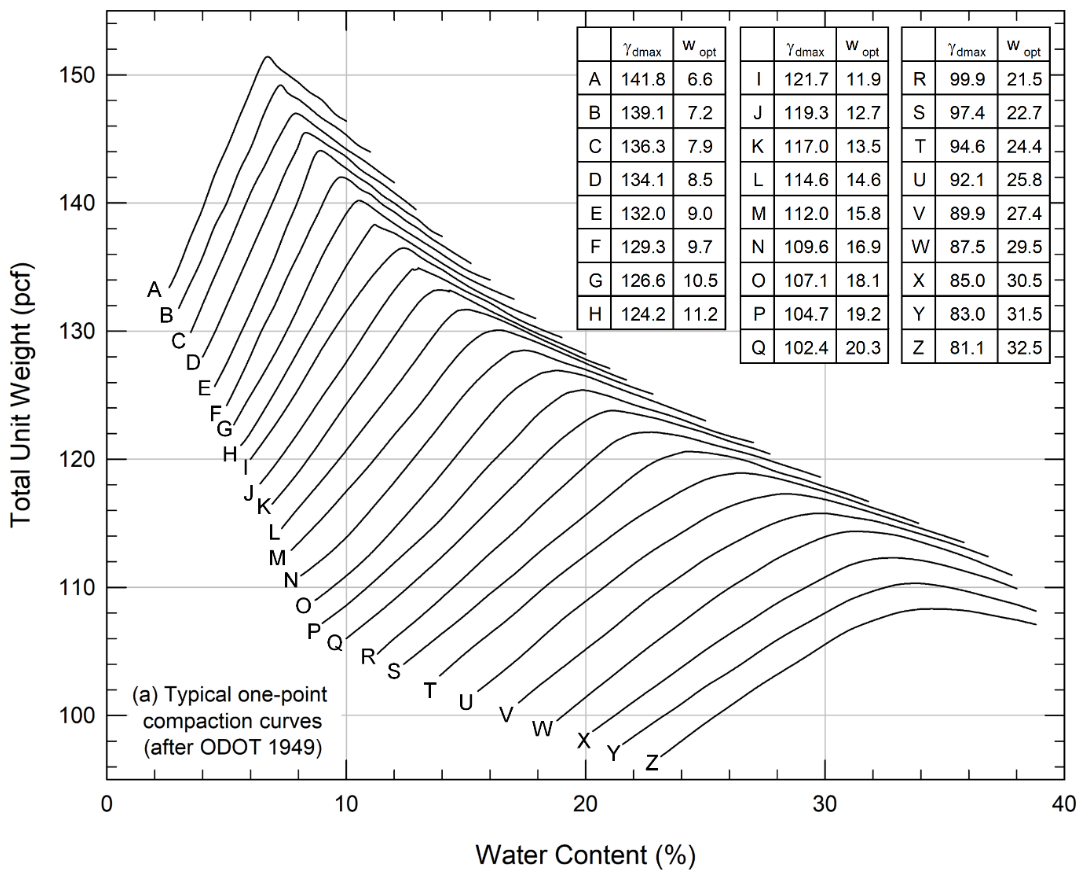
Fill in x-axis with lime percentages. Plot results from above tests.
The lime percentage required to reach pH = 12.4 is the Minimum Lime Percentage



Minimum Lime Percentage, MLP =	

Figure B-7 Eades-Grim Raw Data Sheet

ONE-POINT STANDARD PROCTOR CALCULATION SHEET



Soil: ______________________________

Admixture: ______________________________

Admixture %	Compacted Total Unit Weight (pcf)	Compacted Water Content (%)	Selected One-Point Curve Letter	Maximum Dry Unit Weight (pcf)	Optimum Water Content (pcf)

Instructions:
Plot each combination of compacted total unit weight and water content from one-point Proctor tests on the graph above. Select the letter for the curve that matches most closely. Estimate the maximum dry unit and optimum water content from the provided values.

Figure B-8 One-Point Proctor Raw Data Sheet

SAMPLE MIXING CALCULATIONS		
Project: ______	Location: ______	
Tested by: ______		
Soil Description:	Current water content, w_n (%):	
Test prepared for:	Current water content, w_{tar} (%):	
Admixture Type:	Target Admixture Percentage, X_{ad}:	
Target compacted dry unit weight:	A =	pcf
Specimen volume:	B =	ft^3
Target dry sample weight + 10%:	C = 1.1 × A × B =	lb
Admixture weight:	D = X_{ad} × C =	lb
Moist weight at w_n:	E =C × (1+w_n/100) =	lb
Moist weight at w_{tar}:	F = (C+D) × (1+w_{tar}/100) =	lb
Amount of water needed:	G = F - E =	lb
Mix the following using a mechanical mixer:		
Moist weight at w_n:	E =	lb
Admixture weight:	D =	lb
Additional water:	G =	lb
Note, if G is negative, the soil will need to be dried prior to mixing in the admixture.		

Figure B-9 Sample Mixing Raw Data Sheet

UNCONFINED COMPRESSION TEST SPECIMEN MEASUREMENTS			
Project:		Location:	
Tested by:		Start date:	
Specimen No.:		Admixture & Percentage:	
Initial Dimensions following Compaction			
H_1 =	in	D_1 =	in
H_2 =	in	D_2 =	in
H_3 =	in	D_3 =	in
Average H =	in	Average D =	in
Total weight:	lb	Volume:	in^3
Dimensions following Curing			
H_1 =	in	D_1 =	in
H_2 =	in	D_2 =	in
H_3 =	in	D_3 =	in
Average H =	in	Average D =	in
Total weight:	lb	Volume:	in^3
Dimensions following Soaking			
H_1 =	in	D_1 =	in
H_2 =	in	D_2 =	in
H_3 =	in	D_3 =	in
Average H =	in	Average D =	in
Total weight:	lb	Volume:	in^3

Figure B-10 Unconfined Compression Dimensions Data Sheet

Chapter B-9 Summary

This laboratory manual for chemical subgrade stabilization has discussed appropriate sampling procedures as well as initial (untreated) testing requirements. After determining the untreated subgrade soil properties, the Phase I testing is used to determine an appropriate admixture percentage to generate the desired improvement. A final field design percentage is chosen.

Once the design value is selected, the Phase II testing is completed to provide design parameters for the treated subgrade as inputs to the pavement design. Phase II can be skipped if the admixture is used solely for subgrade modification and will not be assigned structural properties in the pavement design.

Reporting requirements were summarized in Chapter B-6. Information on field observation and testing is provided in Chapter B-7. Guidance for laboratory testing procedures is detailed in Chapter B-8.