Design Manual and Test Protocols to Accelerate Mix Design of Stabilized Subgrades

Products P1 and P2

Project 0-5569

Design Manual and Test Protocols to Accelerate Mix Design of Stabilized Subgrades
Products P1 and P2

by

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Research Project 0-5569

Accelerated Stabilization Design

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CHAPTER ONE – INTRODUCTION

This document establishes recommended evaluation criteria to select stabilization type and content, methods of evaluating the effectiveness of stabilization, and methods for moisture conditioning of samples to accelerate the mix design process and to evaluate the effectiveness of stabilization. This revised procedure is an adaptation of the current guidelines for subgrade stabilization, with the addition of chemical analysis of the soil fines to identify clay mineralogy, accelerated curing and moisture conditioning to minimize to time to achieve the mix design and wetting-drying cycles as means of durability indicators. In addition a static compaction method for preparing fine-grained soil specimens is recommended.

CHAPTER TWO – MIX DESIGN PROCEDURE

2.1 INTRODUCTION

This chapter presents the accelerated procedure to perform the mix design of stabilized subgrades. The goal for any treatment of subgrades is to modify some properties of the layer. The most common reasons for treatment include:

- Reduce shrink/swell of expansive soils
- Increase strength to provide long-term support for the pavement structure
- Reduce moisture susceptibility and migration
- Provide a working platform for construction of subsequent layers by drying out wet areas and/or temporarily increasing strength properties

The flowchart in Figure 1 provides an illustration of the steps required under current TxDOT specifications. The guideline divides the overall process into three steps: (1) Soil Exploration, Material Sampling, Soil Classification and Acceptance Testing, (2) Additive Selection, and (3) Mix Design. Retrieved soils are characterized based on the gradation and plasticity. Based on the gradation and plasticity, the type of the stabilizer is selected. The specifications that govern the placement of stabilized materials fall under Items 260, 263, 265, 275 and 276. The mix design (determination of optimal stabilizer content) is carried out using one of the following test methods:

- Tex-120-E Protocol (lime)
- Tex-121-E Protocol (cement)
- Tex-127-E Protocol (fly ash and lime-fly ash)

These protocols require 7 or 17 days to obtain the mix design, depending on the type of stabilizing agent. Based on the outcome of this study, a modified procedure is proposed to address the following issues:

- o Reduce the time required to perform the mix design when warranted
- o Include additional procedures to ensure the long-term durability of the stabilized subgrade.
- o Provide a consistent method for comparing stabilization agents

These modifications are discussed below.
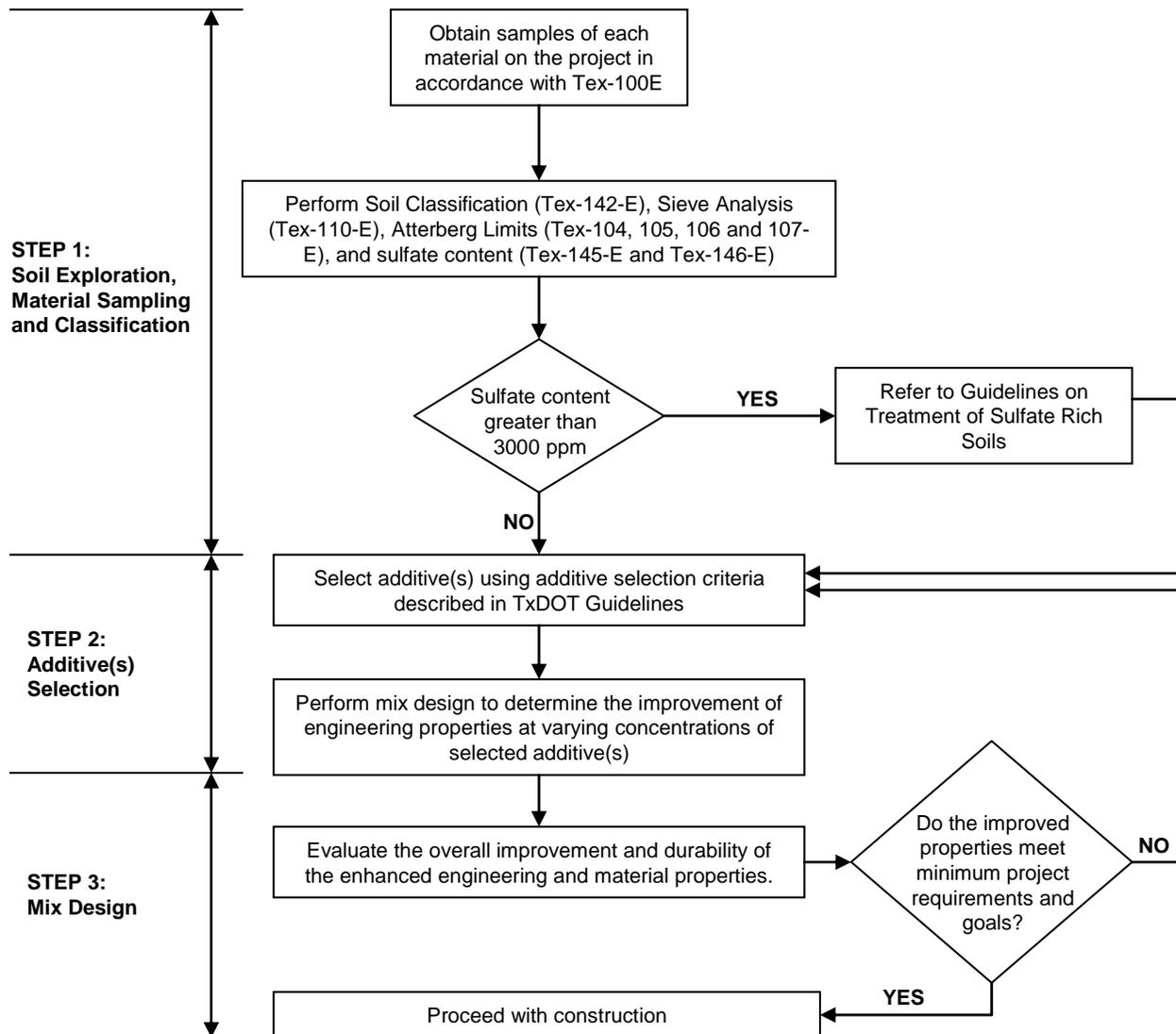
Figure 1 – Flowchart for Subgrade Soil Treatment (from Current TxDOT Guidelines)

2.2 PROPOSED STABILIZATION SPECIFICATIONS

Figure 2 summarizes the recommended stabilization flowchart for subgrade soil treatment. This figure illustrates the same flowchart as in Figure 1 with the insertion of some additional chemical analyses and an accelerated mix design steps. In this study, it was found that the selection of type and concentration of additives based on gradation and plasticity may not be adequate. For example, two subgrades with the same plasticity indices (PIs) react vastly differently to the same stabilizer depending on the dominant clay type in the fines. A lack of a more refined soil classification that considers the clay mineralogy creates a dilemma whether a certain chemical treatment method could be used for all types of clayey subgrades. Hence, better and more reliable strategies are needed for screening clay mineralogy for successful use of a given stabilizer.

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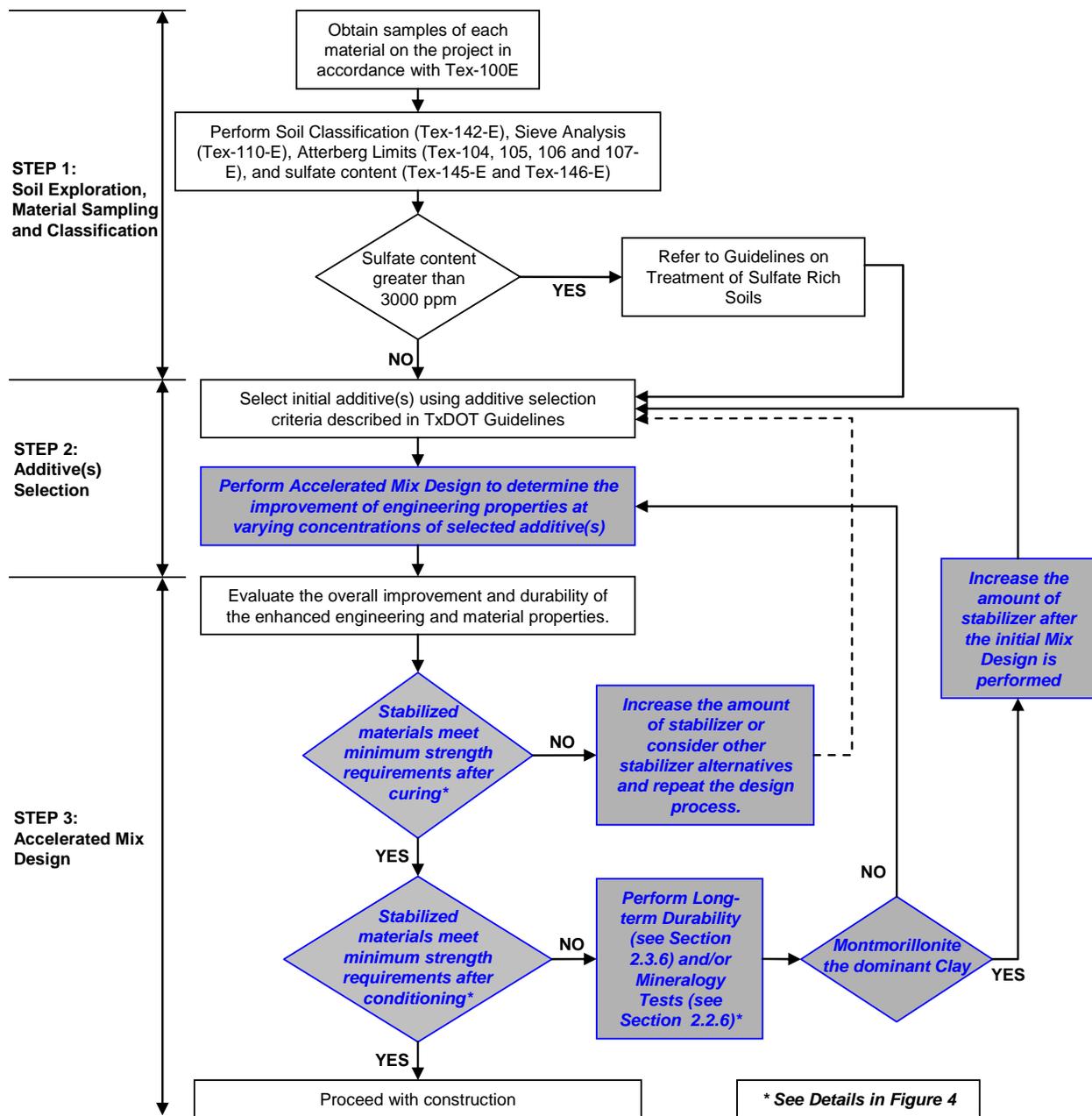
Figure 2 – Proposed Flowchart for Subgrade Soil Treatment

Also the length of time required for the mix design may encourage the users to use their past experience to specify the stabilizer types and concentration with potential short and long term negative implication on the performance of the completed project. As such, accelerated protocols have been developed so that the mix design can be completed in a reasonable amount of time.

A step-by-step procedure is proposed herein.

2.2.1 Soil Exploration and Material Sampling

Soil exploration is vital, as it provides material for testing and also reveals conditions in underlying strata that can affect the performance of the pavement structure and treated layers, such as soil mineralogy, water table proximity, and soil strata variation. Material sampling and testing are critical and are required to characterize the physical properties that can affect the performance of the pavement structure. It is important to obtain bulk samples large enough to perform multiple mix designs and soil classifications, if necessary. It is recommended to obtain at least 500 lb of each soil requiring a mix design.

2.2.2 Additive Selection Criteria

The selection of appropriate additive(s) is affected by many factors, including:

- Soil mineralogy and content (sulfates, organics, etc…)
- Soil classification (gradation and plasticity)
- Goals of treatment
- Mechanisms of additives
- Desired engineering and material properties (strength, modulus, etc…)
- Design life
- Environmental conditions (drainage, water table, etc…)
- Engineering economics (cost vs. benefit)

Current TxDOT stabilization guideline (as shown in Figure 3) provides a reasonably good reference for the preliminary selection of additives. The Plasticity Index (PI) and gradation are necessary but not sufficient criteria. Further validation testing must be performed to verify whether the selected additive accomplishes the goals and requirements of the treated soil.

Figure 3 – Additive Selection Criteria for Subgrade Material Using Soil Classification

2.2.3 Gradation

The gradation of the raw material should be determined as per Tex-110-E.

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2.2.4 Plasticity Index

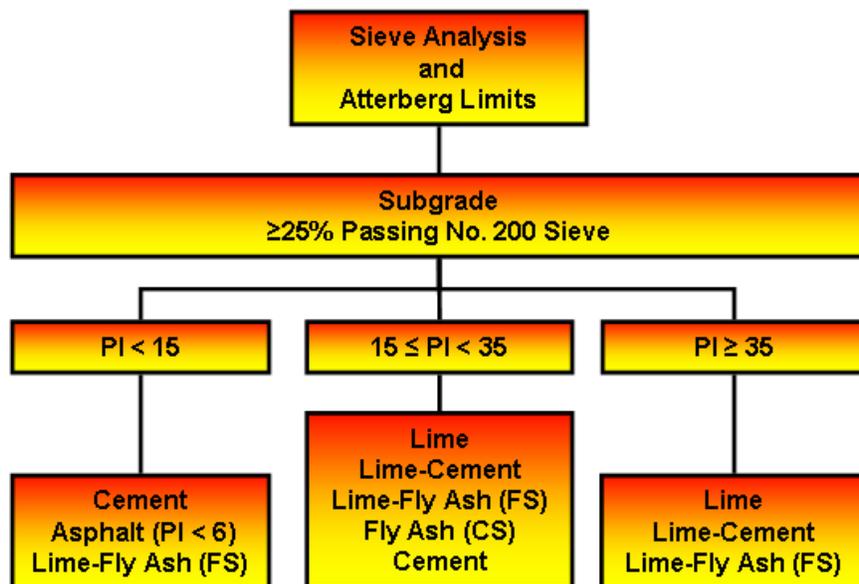Plasticity index is commonly used as an indication of soil shrink/swell properties and constructability. If a soil has the ability to attract and drive off large amounts of moisture, this results in large volumetric change and material instability. The PI can be obtained in accordance with Tex-106-E.

2.2.5 Sulfate and Organic Testing

It is of utmost importance to estimate the sulfate and organic contents of the subgrade. If the sulfate or organic contents are higher than recommended in the current TxDOT guidelines, special care should be taken in selecting the type of stabilizer or no stabilizer should be added.

The sulfate and organics contents should be measured to ensure that they are within acceptable levels. The sulfate concentration is estimated using Tex-145-E. If the sulfate levels are above 3000 ppm, the 'Guidelines on Stabilization of Sulfate Rich Soils' should be consulted for further recommendations and guidelines.

Organic soil is a soil that would be classified as a clay or silt except that its liquid limit after oven drying (dry sample preparation) is less than 75% of its liquid limit before oven drying (wet sample preparation). The organic content should be estimated in accordance with ASTM D-2974 ("Standard Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils"). If the organics content exceeds 1%, additional additive may be needed to counter the cationic exchange capacity of the organic material.

2.2.6 Determination of Clay Mineralogy

Aside from the gradation and PI, the clay mineralogy impacts the concentration of the additives the most. It is desirable to include these tests in the day-to-day operation of TxDOT.

The minerals of interest in Texas soils are Kaolinite, Illite and Montmorillonite. If the dominant clay mineral is Montmorillonite, additional steps need to be carried out to ensure a durable stabilized subgrade.

Direct measurements of the clay mineralogy utilizing X-Ray Diffraction (XRD) and Scanning Electron Microscope (SEM) are preferred. These tests are not practical for day-to-day use since they are expensive to perform and require advanced instrumentation. A set of simple indirect methods, such as cationic exchange capacity (CEC), specific surface area (SSA) and total potassium (TP) are proposed to estimate the dominating clay minerals in the subgrades. The test protocols for thee methods are provided in Appendices A through C. The cost of devices, accessories and chemicals needed to perform these three tests is approximately around $3000 (US). Majority of the initial costs will be due to the costs of Spectrophotometer. For routine estimation of clay mineralogy, the following process is proposed:

Step 1: Determine percent Illite (*%I*) by measuring the total potassium (TP) using Equation 1:

$$\%I = \left[\frac{TP}{6} \right] \times 100 \tag{1}$$

If Illite is the dominant clay mineral, (i.e., the percent is more than 50), then the rest of the mineralogy of the clay is not of a concern, and further mineralogical tests are not necessary (Step 2 can be neglected).

Step 2: Determine percent Montmorillonite (*%M*) and percent Kaolinite (*%K*) by measuring the cationic exchange capacity (CEC) and specific surface area (SSA) using Equations 2 and 3:

$$\%M = -2.87 + 0.08 \times SSA + 0.26 \times CEC \tag{2}$$

$$\%K = 100 - \%I - \%M \tag{3}$$

The above formulations are developed based on an extensive database of clayey soils sampled across the State.

2.3   MIX DESIGN

Mix design is essential to optimize the material properties, calculate the optimum percent of additive, measure effectiveness and engineering properties and provide density and moisture control parameters for construction. The steps to achieve the mix design are discussed below. The proposed accelerated design process includes the following steps:

- Estimating the preliminary additive content
- Developing moisture density curve (M/D) with and without additives to obtain the optimum moisture content (OMC) and the maximum dry density (MDD).
- Preparing specimens
- Curing of specimens
- Accelerated moisture conditioning
- Strength testing before and after moisture conditioning, and
- Determining the lowest modifier content to satisfy strength and durability requirements.

2.3.1   Estimating Preliminary Additive Content

For treatments requiring lime, the pH of the soil-lime environment is critical because high pH (basic) mixtures increase the ability of the lime to react with soil minerals, like silica and alumina, which also require high pH levels to dissolve. The preliminary amount of additive content should be determined following the Eades-Grimm method in accordance to Tex-121-E, Part III.

The additive concentration obtained in that manner is preliminary. Actual concentration should be determined based on more rigorous tests described below.

Establishing Moisture Density (MD) Curve

The determination of the MD curve for preparing specimens and for establishing field density control is carried out in accordance with Tex-114-E. It is not uncommon that the OMC and MDD of the materials change with the concentration of the additives. The MD curve should be obtained by adding the preliminary concentration of the additive estimated from pH tests.

It is prudent that the specimens prepared for establishing the MD curve is wrapped in cellophane paper or covered with a membrane for 24 hours and then subjected to the unconfined compressive tests (UCS). In the course of this and other similar studies, it has been found that:

- o If the maximum UCS obtained in that manner is substantially[1] less than the target strength[2], the effectiveness of the additive in stabilizing the soil is doubtful.
- o The variation in UCS with moisture is an indication of the robustness of the mix to construction. If the UCS vary significantly with moisture[3] (especially at moisture contents wet of optimum), additional inspection efforts are needed to ensure a quality final product.

2.3.2 Compacting of Clayey Materials
The specimens should be prepared at a moisture content equal to the OMC and to a density equal to the MDD. The use of a static compactor is recommended in Appendix D for the preparation of the clayey specimens (see Report 0-5569-1 for justification). Briefly, the appropriate amount of soil, additive and moisture is combined and mellowed in accordance with the current Tex-114-E. The material is then placed in one lift into the static compaction mold and pressed to the desired density using a number of plungers (see Appendix D for details).

2.3.3 Curing of Specimens
The most representative curing method found in this study consists of placing the specimens in a 104 ºF (40 ºC) oven for 48 hours.

2.3.4 Moisture Conditioning of Specimens
Backpressure saturation as described in Appendix E is recommended to accelerate the moisture conditioning of prepared specimens. This method can typically moisture condition the specimens to saturation in less than 24 hours with the distribution of moisture within the specimen being more uniform as compared to the capillary moisture conditioning method currently used. Another alternative is to use vacuum saturation as explained in Appendix F.

2.3.5 Establishing Final Stabilizer Content based on Performance Indicators
The primary performance indicator recommended is the unconfined compressive strength (UCS) <u>before and after</u> moisture conditioning. Another parameter that is considered is the retained strength defined as

$$\mathrm{Re}\,tained\ strength = \frac{Strength\ after\ Moisture Conditioning}{Strength\ after\ Curing} \qquad (4)$$

The secondary parameters are the modulus and the long-term durability of the mix. The optimum stabilizer content is defined as the lowest stabilizer content necessary to satisfy the project requirements as summarized in Figure 4. Specimens with stabilizer contents ranging from the stabilizer content equal to that obtained from the pH tests to up to 4% above the content obtained from the pH tests should be considered.

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[1] preliminary 50%
[2] currently 50 psi for lime
[3] preliminarily more than 25% at moisture contents ±2% of optimum moisture content
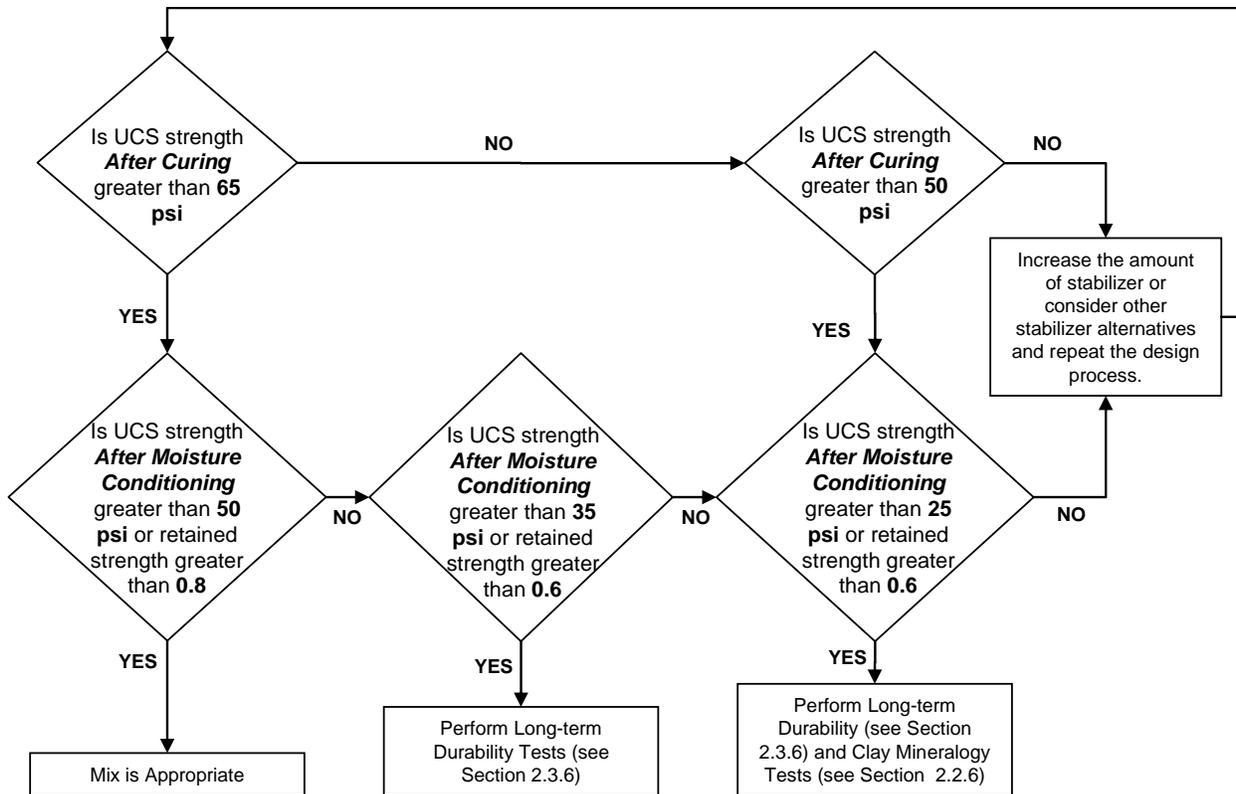
Figure 4 – Recommended Flowchart to Determine Adequacy of Stabilizer Content

2.3.6 Durability Studies (Wetting-Drying Cycles)

To address the durability of chemical treated soils, a series of specimens prepared as per Section 2.3.2 should be subjected to various cycles of wetting and drying processes as specified in Appendix G. During wetting and drying periods changes in the sample dimensions are measured vertically and radially. The wetting/drying is continued for 21 cycles. After 3, 7, 14 and 21 cycles the samples are subjected to the UCS tests. A good preliminary relationship between the retained strength and the durability has been observed. Since this test procedure may take more than a month to determine if the additive is durable, this test can be performed when the retained strength as described in table above is less than 0.8 but greater than 0.6.

2.3.7 Establishing Modulus

The resilient modulus (AASHTO T-307, etc.) of the material is needed for pavement design. Currently, TxDOT is not fully equipped to perform these tests routinely. The free-free resonant column (proposed Texas test method) tests can be used in the absence of the resilient modulus test set up to estimate the modulus of the mix. The specimens prepared for the UCS tests in Section 2.3.5 can be used for this purpose. Half the value obtained from the FFRC tests can be used as an estimate of the modulus of the layer.

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APPENDIX A. CATION EXCHANGE CAPACITY[4]

Section 1

Overview

Use this method to obtain the cation exchange capacity of treated and untreated soil specimens in the laboratory.

Units of Measurement

The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

Section 2

Definitions

ppm   —   Parts per million; measure of concentration.
meq   —   Milliequivalent
Filtrate   —   (Soil/water) material that has passed through a filter.
nm   —   Nanometer

Section 3

Apparatus

The following apparatus are required:

- Mortar and pestle.
- Crusher.
- Volumetric flask (glass or plastic), 250 ml.
- Erlenmeyer side arm glass flasks, 500 ml.
- Graduated cylinder (glass or plastic), 25 ml.
- Oven, capable of maintaining a temperature of $60 \pm 5°C$ ($140 \pm 9°F$).
- Wide-mouth round high-density poly ethylene (HDPE) bottles, 250 ml (8 oz.).
- Buchner Funnel (glass or plastic), 5 cm diameter with short wide stems.
- Filter paper (fine porosity), 5 cm diameter.
- 25 ml glass pipettes.
- 1 ml glass pipettes.

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[4] **This protocol does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.**

- Wide-mouth round high-density poly ethylene (HDPE) bottles, 250 ml (8 oz.).
- Wash bottle, 500 ml (16 oz.), for distilled or de-ionized water.
- Latex gloves.
- Tweezers.
- Pans, brush, and spatula.
- Spectrophotometer.

Section 4

Material

- Distilled or de-ionized water
- One molar Ammonium Acetate (NH_4OAc) saturating solution: Dilute, in a chemical hood, fifty seven milliliters glacial acetic acid (99.5%) with ~800 ml of distilled water in a one liter volumetric flask. Add sixty eight milliliters of concentrated Ammonium Hydroxide (NH_4OH) mix and cool to room temperature. Adjust pH of the sample to 7.0 using NH_4OH and dilute to one liter using distilled water. (Shelf life: 5 years if stored in cool dark place at room temperature)
- One molar Potassium Chloride (KCl) replacing solution: Completely dissolve 74.5 g KCl (reagent grade) in distilled water and dilute to a final volume of one liter. (Shelf life: 5 years if stored in cool dark place at room temperature)
- Isopropyl alcohol or 2-propanal, 95%. (Shelf life: Poor under normal conditions)

Preparation of Material

The following procedure describes preparing soil samples for determining cation exchange capacity in the laboratory:

Sample Preparation	
Step	**Action**
1	Dry the soil sample (1000 g) in a 60 ± 5°C (140 ± 9°F) oven and allow it to cool to 25 ± 3°C (77 ± 5°F) in a desiccator.
2	After drying, crush, grind, and split to obtain approximately a 500 g (1 lb) representative sample that passes the 4.75 mm (No. 4) sieve.
3	Pulverize 500 g soil sample to pass the 425 μm (No. 40) sieve.
4	Split the sample to obtain three 50 g representative sample and weigh to the nearest 0.1 g.

Test Procedure

Follow the steps below to obtain the CEC of the soil:

Determination of Cation Exchange Capacity	
Step	**Action**
1	Weigh 25 g to the nearest 0.1 g of oven-dried soil and place the soil in a 250 ml (16 oz)

	HDPE bottle.
2	Add 125 ml of the 1 M ammonium acetate (NH$_4$OAc) and shake thoroughly and allow it to stand for a minimum time period of 12 hours.
3	Take a 500 ml side arm glass flask.
4	Place the Buchner funnel on top of the 500 ml flask and tighten with the help of a rubber stopper which has a hole in the center for the stem of the Buchner funnel to go through.
5	Place a retentive filter paper (# 40) in the funnel and wet the paper and apply light suction (<0.5 psi) to the stem of the Erlenmeyer flask using a rubber tubing.
6	Filter the soil solution from step 2 through the Buchner funnel into the 500 ml flask.
7	Leach the soil in the Buchner funnel four times by adding 25 ml of ammonium acetate, NH$_4$OAc using a pipette, allowing each addition to filter through but not allowing the soil to crack or dry.
8	Leach the soil in the Buchner funnel eight times by adding 10 ml of 95% 2-propanol using a pipette allowing each addition to filter through but not allowing the soil to crack or dry. (Discard the leachate and clean the receiving flask).
9	Leach the soil in the Buchner funnel eight times by adding 25 ml of potassium chloride (KCl) using a pipette allowing each addition to filter through but not allowing the soil to crack or dry.
10	Discard the soil and transfer the leachate to a 250 ml volumetric flask.
11	Fill the flask up to the mark with additional KCl.
12	Determine the amount of Ammonia (NH$_4$) in the solution by using the spectrophotometer.

Calculations:

Use the following formula to calculate the CEC of the soil sample:

If the concentration ammonia is expressed as ppm of Ammonia Nitrogen (NH$_3$-N), then CEC can be calculated as follows:

$$CEC(meq/100g) = \frac{\text{NH}_3 \text{ - N (ppm)}}{14} \times 4$$

If the concentration ammonia is measured (also expressed as Ammonium (NH$_4$)) in ppm, then CEC can be determined with the following expression:

$$CEC(meq/100g) = \frac{\text{NH}_4 \text{ (ppm)}}{18} \times 4$$

APPENDIX B. SPECIFIC SURFACE AREA[5]

Section 1

Overview

Use this method to obtain the specific surface area of treated and untreated soil specimens in the laboratory.

Units of Measurement

The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

Section 2

Apparatus

The following apparatus are required:

- Mortar and pestle.
- Crusher.
- Oven, capable of maintaining a temperature of $60 \pm 5°C$ ($140 \pm 9°F$).
- Oven, capable of maintaining a temperature of $110 \pm 5°C$ ($230 \pm 9°F$).
- Oven, capable of maintaining a temperature of $210 \pm 5°C$ ($410 \pm 9°F$).
- Latex gloves.
- Vacuum desiccator (25 cm or larger in diameter)
- Vacuum pump
- Aluminum container (7.5 cm in diameter and 2.5 cm in height)
- Culture chambers (Glass dishes with cover, 20 cm diameter And 7.5 cm height)
- Hardware cloth
- Tweezers.
- Pans, brush, and spatula.
- Dessication chamber.

Section 3
Material

- Distilled or de-ionized water
- Ethylene Glycol Monoethyl Ether (EGME) reagent grade
- Calcium Chloride ($CaCl_2$), Passing 40 mesh (0.425 mm opening) anhydrous reagent grade.

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[5] **This protocol does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.**

Preparation of Material

The following procedure describes preparation of CaCl$_2$-EGME Solvate for determining the specific surface area in the laboratory:

\multicolumn{2}{c}{**Preparation of CaCl$_2$-EGME Solvate**}	
Step	**Action**
1	Weigh 120 g of calcium chloride, CaCl$_2$ into a beaker and oven dry at 210°C for 1hr and then weigh 100 g after oven drying.
2	Weigh 20 g of EGME into a 400 ml beaker and add the calcium chloride, CaCl$_2$ immediately after taking out from oven and mix with a spatula to make a solvate.
3	After the solvate is cooled to room temperature, transfer it to a culture chamber (glass dish with a cover) and spread it uniformly over the bottom of the chamber and store it in a desiccator.

The following procedure describes preparing soil samples for determining specific surface area in the laboratory:

**Sample Preparation**	
Step	**Action**
1	Dry the soil sample (500 g) in a 60 ± 5°C (140 ± 9°F) oven and allow it to cool to 25 ± 3°C (77 ± 5°F) in a desiccators.
2	After drying, crush, grind, and split to obtain approximately a 250 g (0.5 lb.) representative sample that passes the 4.75 mm (No. 4) sieve.
3	Pulverize the 250 g sample to pass the 425 μm (No. 40) sieve.
4	Split the sample to obtain three 50 g representative sample and weigh to the nearest 0.1 g.

Test Procedure

Follow the steps below to obtain the SSA of the soil:

\multicolumn{2}{c}{**Determination of Specific Surface Area**}	
Step	**Action**
1	Weigh 1.1 g to the nearest 0.001 g of oven-dried soil and place the soil in an aluminum container.
2	Place the container in an oven at 110°C (230° F) for 24 hours until constant weight is reached.
3	Weigh the dried sample taking care not to adsorb atmospheric water (W_s).
4	Add 3 ml of EGME to the sample and mix it thoroughly.
5	Place the container with slurry (EGME/Soil) into the culture chamber containing CaCl$_2$-EGME solvate onto the hardware cloth in the culture chamber.

6	Close the lid of the chamber and place it in a dessiccator containing $CaCl_2$.
7	Wait for 30 minutes and evacuate it for 45 minutes and close the stopcock.
8	After 6 to 7 hours, release the vacuum.
9	Weigh the soil sample in the aluminum can along with the lid.
10	Repeat weight measurements for every 2 to 4 hours until there is no further decrease in the weight (W_a). The weight will typically stabilize within 12 hrs.

Calculations:

Use the following formula to calculate the specific surface area, A, of the soil sample:

$$A = \frac{W_a}{W_s * 0.000286} m^2 / g$$

where,

W_a = Final weight of the soil sample after stabilizing with ethylene glycol monoethyl ether, EGME

Ws = Dry weight of the soil sample before mixing ethylene glycol monoethyl ether, EGME
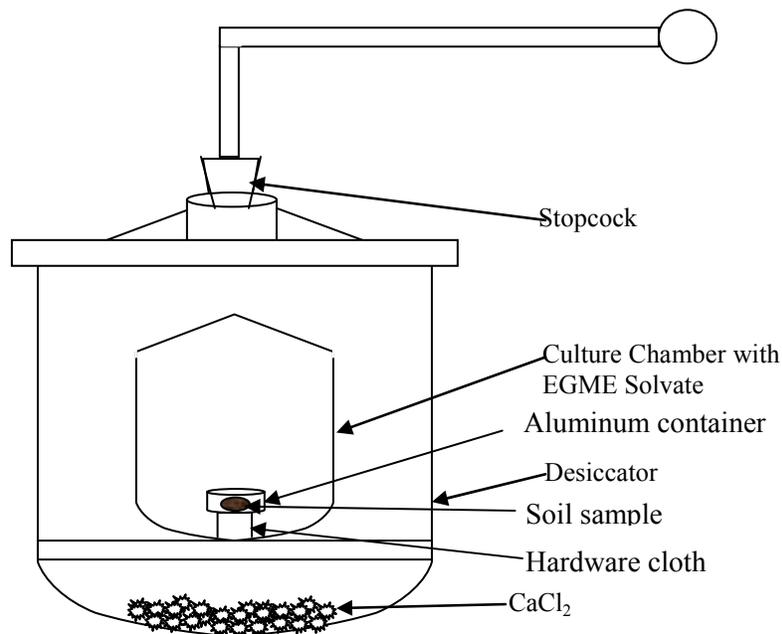
Figure 1 – Schematic of the Specific Surface Area Apparatus

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Table 1 – Work Sheet for SSA Measurements

SNo.	SOIL NAME	EMPTY WT. OF CONTAINER, W1	WT OF CONTAINER WITH DRIED SOIL SAMPLE, W2	Wa = W1-W2	INNITIAL WT. AFTER ADDING EGME	STABILIZED WEIGHT				WS=FINAL STABILIZED WT – W1	SSA
						After 6 hrs	After 8 hrs	After 10 hrs	After 12 hrs		
1											
2											
3											
4											

APPENDIX C. TOTAL POTASSIUM[6]

Section 1

Overview

Use this method to obtain the total potassium of treated and untreated soil specimens in the laboratory.

Units of Measurement

The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

Section 2

Definitions

ppm   —   Parts per million; measure of concentration.
Filtrate —   (Soil/water) material that has passed through a filter.
nm   —   Nanometer

Section 3

Apparatus

The following apparatus are required:

- Mortar and pestle.
- Crusher.
- Volumetric flask (glass or plastic), 50 ml.
- Graduated cylinder (glass or plastic), 25 ml.
- Oven, capable of maintaining a temperature of $60 \pm 5°C$ ($140 \pm 9°F$).
- 25 ml glass pipettes.
- 1 ml glass pipettes
- Wash bottle, 500 ml (16 oz.), for distilled or de-ionized water.
- Latex gloves.
- Tweezers.
- Pans, brush, and spatula.

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[6] **This protocol does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.**

- Teflon digestion vessel, 60ml
- Hotplate, capable to rise temperatures to 200°C
- Chemical hood
- Spectrophotometer.

Section 4

Material

- Distilled or de-ionized water
- 65% Hydrofluoric acid
- 70% Perchloric acid
- 6 N Hydrochloric acid

Preparation of Material

The following procedure describes preparing soil samples for determining total potassium in the laboratory:

|	Sample Preparation
Step	**Action**
1	Dry 500 g of soil sample in a $60 \pm 5°C$ ($140 \pm 9°F$) oven and allow it to cool to $25 \pm 3°C$ ($77 \pm 5°F$) in a desiccator.
2	After drying, crush, grind, and split to obtain approximately a 250 g (0.5 lb) representative sample to pass the 4.75 mm (No. 4) sieve.
3	Pulverize the 250 g sample to pass the 75 μm (No. 200) sieve.
4	Split the sample to obtain three 5 g representative sample and weigh to the nearest 0.1 g.

Test Procedure

Follow the steps below to obtain the total potassium of the soil:

|	Determination of Total Potassium
Step	**Action**
1	Weigh 0.1 g to the nearest 0.001 g of the 5 g sample and place the soil in a Teflon digestion vessel.
2	Wet the soil with few drops of water and then add 5 ml of hydrofluoric acid* (HF) and 0.5 ml of perchloric acid ($HClO_4$) to the vessel.
3	Place the soil-acid mixture in a chemical hood and heat on hot plate until fumes of perchloric acid, $HClO_4$ appear or heat until the temperature is more than 200°C (392°F).
4	Cool the vessel to room temperature and then add 5 ml of hydrofluoric acid, HF.
5	Place the vessel on a hot plate and cover nine tenths of the vessel top using the ported closure.

6	Heat the vessel to 200-225° C (392-437° F) and evaporate the solution to dryness.
7	Again cool the vessel to room temperature and add 2 ml of water and a few drops of perchloric acid, $HClO_4$.
8	Replace the vessel on the hot plate and evaporate until dry.
9	Remove the vessel from the hot plate and bring the contents to room temperature and add 5 ml of 6N hydrochloric acid, HCl, and 5 ml of water to the vessel.
10	Place the vessel back on the hot plate and boil it slightly. If the sample doesn't dissolve repeat the steps 2 through 10.
11	Once the residue completely dissolves in HCl transfer the sample to 50 ml volumetric flask, and dilute the contents to 50 ml volume.
12	Determine the amount of potassium (K^+) in the solution by using the spectrophotometer.

- - Caution is needed while handling this acid; This acid is required to dissolve the silicate minerals in the soils, which in turn will release potassium ions that are expected within the silicate minerals.

Calculations

Use the following formula to calculate the TP of the soil sample:

$$TP,\% = Conc.of K^+ * 0.05$$

where,

TP   = % of total potassium
Conc. of K^+ = Concentration of potassium ion from Step 12 above

APPENDIX D. LABORATORY COMPACTION OF CLAY SPECIMENS BY STATIC METHOD[7]

Section 1

Overview

Use this method to compact clay specimens with and without calcium-based additives in the laboratory.

To perform test, a clay specimen is prepared in the laboratory using a static compactor in one single lift. The specimen measures 6 in. (150 mm) in height and 4 in. (100 mm) in diameter. The optimum moisture content (OMC) and maximum dry density (MDD) of the clay need to be obtained as per Tex-114-E.

Units of Measurement

The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

Section 2

Apparatus

The following apparatus are required:

- A hollow metallic mold 13.0 in. (330 mm) in height and 4.0 in. (100 mm) inner diameter
- Three solid metallic blocks 3.9 in. (97 mm) in diameter and 4.05 in. (103 mm), 2.45 in. (62 mm) and 0.50 in. (13 mm) high, respectively
- Static compactor (a loading frame for Unconfined compressive strength tests can be used)
- Balance, with a minimum capacity of 15 lbs (7 kg), accurate and readable to 0.001 lb (0.5 g) or 0.1% of the test mass, whichever is greater
- Hydraulic press and a metal ring to extrude molded specimens
- Drying oven, maintained at $230 \pm 9^{o}F$ ($110 \pm 5^{o}C$)
- Metal pans, wide and shallow for mixing and drying materials
- No. 4 (4.75 mm) sieve
- Lubricant Agent (WD40 or similar)

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[7] **This protocol does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.**

Section 3

Laboratory Compaction of Clay Specimen

This part uses a static compactor to prepare a 4 in. (100 mm) by 6 in. (150 mm) clay specimen. The clay passing through No. 4 sieve is used to prepare clay specimens.

Preparation of Material

Follow the steps below to prepare material for compaction:

Material Preparation for Compaction	
Step	**Action**
1	Crush clay material fine enough so that it passes through No. 4 sieve. Crush enough material to prepare several specimens (Approximately 10 lbs, 4.5 kg).
2	Sieve crushed material through No. 4 sieve. Use the material passing through No. 4 sieve and discard the remaining material.
3	Dry sieved material in an oven at $230 \pm 9^{o}F$ ($110 \pm 5^{o}C$) for no less than 24 hours.
4	Cool the material and measure approximately 6 lbs (3 kg) of material per specimen in a container.
5	Calculate the mass of the water to be added based on the air-dry mass of the material. (e.g. if you wish to prepare specimen at 20% moisture content then add 6*0.20 = 1.20 lbs of water).
6	Weigh out this amount of water into a tared sprinkling jar.
7	Sprinkle water onto the soil during mixing, in increments.
8	Thoroughly mix each specimen to ensure even distribution of water throughout specimen.
9	Cover the mixed sample and allow sample to stand and cure for at least 12 hr before compacting. When the PI is less than 12, the curing time may be reduced to not less than 3 hr.

Preparation of Specimen

Follow the steps below to prepare specimen for testing:

Specimen Preparation for Testing	
Step	**Action**
1	Measure the amount of material required based on its dry density, degree of compaction and the moisture content at which the specimen is to be prepared using Equation1 in calculations. (e.g. if dry density = 112 pcf, degree of compaction = 95% and the moisture content = 20%, then the amount of material required to prepare one specimen =

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	$112 * 0.95 * \dfrac{\pi}{4} * 4^2 * \dfrac{6}{12^3} * (1 + 0.20) = 5.571 lb$
2	Clean the inside of the mold with the lubricant agent to ease extraction of the specimen after compaction is completed.
3	Place the 2.45 in. (62 mm) thick metal block at the bottom of the mold and pour the weighed soil inside the mold.
4	Place the 4.05 in. (103 mm) thick solid block on top of the soil in mold and place this assembly in static compactor.
5	Compact the specimen until the top block becomes flush with the mold (the compaction speed should be approximately 2 in./min).
6	Maintain the pressure for one minute and then release the pressure from the mold.
7	Flip the mold so that 2.45 in. (62 mm) thick block is facing up.
8	Place the 0.5 in. (13 mm) thick solid block on top of 2.45 in. (62 mm) solid block.
9	Start the static compactor again and apply pressure until the 0.5 in. (13 mm) thick solid block becomes flush with the mold.
10	Maintain the pressure for one minute and then release the pressure from the mold.
11	Take out the mold and remove the metal blocks from it.
12	Center the mold on top of a hydraulic jack with a plunger to extract the specimen from the mold.
13	Cover the specimen with a rubber membrane.

Note:

- Just before preparing the specimen the mix should be weighed. The mix should weigh the same as it was initially prepared, if not add additional water in it to make up for the moisture loss.

Calculations

Use the following formula to calculate the weight of the wet material required for preparing one specimen:

$$W = DD \times C \times V \times (1 + OMC) \tag{8}$$

where,

W = Weight of the wet material required for preparing one specimen in lbs
DD = Dry density of the material in pcf
C = Degree of compaction
V = Volume of the specimen in ft^3 = $\left(\dfrac{\pi}{4}\right) * (diameter\,(in))^2 * \dfrac{height\,(in)}{12^3}$
OMC = Optimum moisture content for the specimen as per Tex-114-E

APPENDIX E. ACCELERATED MOISTURE CONDITIONING OF SPECIMENS WITH BACKPRESSURE METHOD[8]

Section 1

Overview

Use this method to moisture condition soil specimens in laboratory applying backpressure. The test can also be used to measure permeability of a material after the specimen under test is saturated.

To perform test, a soil specimen is prepared in laboratory using Tex-114-E or Static Compaction[9]. The specimen measures 6 in. (150 mm) or 8 in. (200 mm) in height and 4 in. (100 mm) in diameter.

Units of Measurement

The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

Section 2

Apparatus

The following apparatus are required:

- Permeameter, with the following requirements[10]:
  o A calibrated cylinder of 1.25 inches ± 0.02 inches (31.75 mm ± 0.5 mm) inner diameter graduated in millimeters and capable of dispensing 500 ml of water.
  o A confining chamber, which is a hollow plastic mold 12.0 in. (300 mm) in height and 4.25 in. (106 mm) inner diameter with a hose barb fitting in the middle of the mold. The confining chamber should be retrofitted with a flexible latex membrane 0.025 inches (0.635 mm) thick and 14 inches long.
  o An upper clamp assembly for supporting the graduated cylinder and expanding an o-ring against the confining chamber. The opening in the upper cap shall have the same diameter as the inner diameter of the calibrated cylinder mentioned previously.
  o A lower pedestal plate for supporting the soil specimen and expanding o-ring against the confining chamber. The lower pedestal should have a drainage port to allow water flushed through the specimen to be collected.

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[8] This protocol does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

[9] See Appendix D of this document

[10] We have identified a manufacturer that can provide this set up for less than $1,200.

- An outlet pipe with an open/close drainage valve connected to the bottom of the lower pedestal to collect water flushed through the specimen.
- O-ring of sufficient diameter and thickness for maintaining a seal against the confining chamber.
- Sealing Agent (vacuum grease).
- A pipette graduated in millimeters and capable of collecting 500 ml of water.
- pH meter with temperature gauge (optional).
- Vacuum and pressure pump, including manometer.
- A pressure cap fitting the top of the graduated cylinder that is also connected to an external pressure pump. This pump provides the backpressure to the system.
- Stopwatch.
- Balance, with a minimum capacity of 15 lbs (7 kg), accurate and readable to 0.001 lb (0.5 g) or 0.1% of the test mass, whichever is greater.
- Two porous stones of 4 in. (100 mm) in diameter and 0.25 in. (6 mm) in thickness.
- Filter paper.

Section 3

Preparation of Soil Specimen

Preparation of Material

Prepare the material according to 'Part II, Preparing Samples for Compaction and Triaxial Tests' of Test Method "Tex-101-E, Preparing Soil and Flexible Base Materials for Testing."

Preparation of Specimen

Prepare specimen according to Test Methods "Tex-114-E, Laboratory Compaction Characteristics and Moisture-Density Relationship of Subgrade, Embankment Soils, and Backfill Material" or "Tex-xxx-E[11], Laboratory Compaction of Clay Specimens by Static Compaction Method."

Section 4

Moisture Conditioning of Specimen

The following table lists the steps necessary to achieve specimen moisture conditioning. The complete test is divided into Specimen Preparation and Test Procedure. The setup is also capable of measuring water permeability of the prepared specimen.

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[11] See appendix D of this document

Specimen Preparation for Testing	
Step	**Action**
1	Evacuate the air from the confining chamber/membrane cavity. Use a vacuum pump for this purpose. Complete evacuation can be achieved by slightly pinching and pulling away the membrane from the hose barb fitting while the pump is being actuated.
2	Place one of the porous stones on top of the lower plate and center it. Place a filter paper on top of the stone. Weigh the specimen and place it on top of the porous stone and center it. In the same way, place a filter paper on top of the specimen and the other porous stone above it.
3	Place the confining chamber over the specimen and the lower pedestal. Make sure that the chamber is oriented so that the hose barb fitting is located between the o-rings on the upper cap and the lower pedestal.
4	Insert the top cap assembly into the confining chamber and let it rest on top of the porous stone. The process is aided if the graduated cylinder is already inserted into the upper cap assembly, so it can be used as a handle.
5	Install the two clamp assemblies onto the permeameter frame and evenly tighten each of the locking screws, applying a moderate pressure to the upper cap assembly. This action seals the o-ring against the membrane and confining chamber.
6	Inflate the membrane using the hand pump up to a pressure of 10 ± 0.5 psi (70 ± 3.5 kPa). Maintain the pressure throughout the tests using the pump if the system loses pressure. The specimen is ready to start the test.

Moisture Conditioning Test Procedure	
Step	**Action**
1	Fill the graduated cylinder to a level of 650 mm and start the timing device.
2	Secure the top of the graduated cylinder with the pressure cap and apply desired backpressure on top of the graduated cylinder. This pressure should be smaller than the confining pressure to prevent water from migrating through the side of the specimen and to prevent internal damage to the specimen. A backpressure of no more than 5 psi (35 kPa) is recommended.
3	Record the water height in the top graduated cylinder every 2 to 4 hours to evaluate the moisture conditioning progress. The difference in the water height before and after the initiation of the test indicates the amount of water absorbed by the specimen (see Equation 1 in Calculations section).
4	Continue the test until the water is discharged out of the outlet pipe. As soon as the amount of water drop in the graduated cylinder is roughly equal to the water discharged from outlet, the specimen is considered moisture conditioned.
5	Continue the test, if the permeability of the material needs to be calculated.
6	After the test is completed, release the pressure cap from the top of the graduated cylinder and remove all remaining water from the cylinder. Release pressure from the confining chamber. Remove the cap assemblies, upper cap and specimen and measure the final weight of the specimen to measure total absorbed water.

Permeability Test and pH Measurement Procedures (optional)	
Step	**Action**
1	Follow Steps 1 through 5 in Moisture Conditioning procedure.
2	Measure the height of water in the top graduated cylinder (h_1) and record the time (t_1).
3	Measure the height of the water in the top graduated cylinder (h_2) after a certain elapsed time (t_2) after the first measurement.
4	Calculate the permeability of the specimen using Equation 2 in the Calculation Section
5	To estimate the discharge of the additive, measure the pH of the discharged water at regular intervals using test procedure Tex-128-E.
6	After the test is completed, release the pressure cap from the top of the graduated cylinder and remove all remaining water from the cylinder. Release pressure from the confining chamber Remove the cap assemblies, upper cap and specimen and measure the final weight of the specimen to measure total absorbed water.

Calculations

The amount of water absorbed by the specimen at any time is given by:

$$W_a = \frac{a * (h_i - h_t)\gamma_w}{1728} \tag{1}$$

where:

W_a = Water absorbed by the specimen at any time, lbs
a = Inside cross-sectional area of the graduated cylinder, in.^{2}
h_i = Initial height of water in the graduated cylinder (65 cm or 25.6 in. recommended), in.
h_t = Height of water in the graduated cylinder at time t, in.
γ_w = Unit weight of water, 62.4 pcf

The water absorbed can be transformed to moisture content in the specimen with the equation:

$$MC_t = MC_i + \left(\frac{W_a + W_{Ti}}{\left(\frac{W_{Ti}}{1 + MC_i} \right)} - 1 \right) \tag{2}$$

where:

MC_t = Moisture content of specimen at time t, %
MC_i = Initial moisture content of specimen, %
W_a = Water absorbed by the specimen, lbs
W_{Ti} = Initial total weight of specimen, lbs

In addition, to calculate the theoretical moisture content of the specimen when saturation is reached (MC_{sat}), the following equation needs to be applied:

$$MC_{sat} = \frac{\gamma_w(1 + MC_i)}{\gamma_{Ti}} - \frac{1}{G_S} \tag{3}$$

where:

MC_{sat}　= Theoretical moisture content of specimen at saturation, %
γ_w　　= Unit weight of water, 62.4 pcf
G_S　　= Specific Gravity of soil
γ_{Ti}　　= Initial wet (total) unit weight of soil, pcf

The coefficient of permeability, k, is determined by the following equation:

$$k = \frac{aL}{A\Delta t} \ln\left(\frac{h_1 + \Delta h}{h_2 + \Delta h}\right) C * 2.54 \tag{4}$$

where:

k　　= Coefficient of permeability, cm/s
a　　= Inside cross-sectional area of the graduated cylinder, in.^{2}
L　　= Average height of the test specimen, in.
A　　= Average cross-sectional area of the specimen, in.^{2}
h_1　　= Height of water in the graduated cylinder measured from bottom of specimen at time t_1, in.
h_2　　= Height of water in the graduated cylinder measured from bottom of specimen at time t_2, in.
Δh　　= Equivalent height due to backpressure, in.
t_1　　= Time when h_1 was measured
t_2　　= Time when h_2 was measured
Δt　　= $t_2 - t_1$, s
C　　= Temperature correction for viscosity of water; see Table 1. A temperature of 68ºF (20ºC) is used as the standard
ln　　= Natural Logarithm

In addition, Δh (in inches) can be obtained from:

$$\Delta h = \frac{BP}{\gamma_w} * 1728 \tag{5}$$

where:

BP　　= Backpressure applied to the system (in psi)
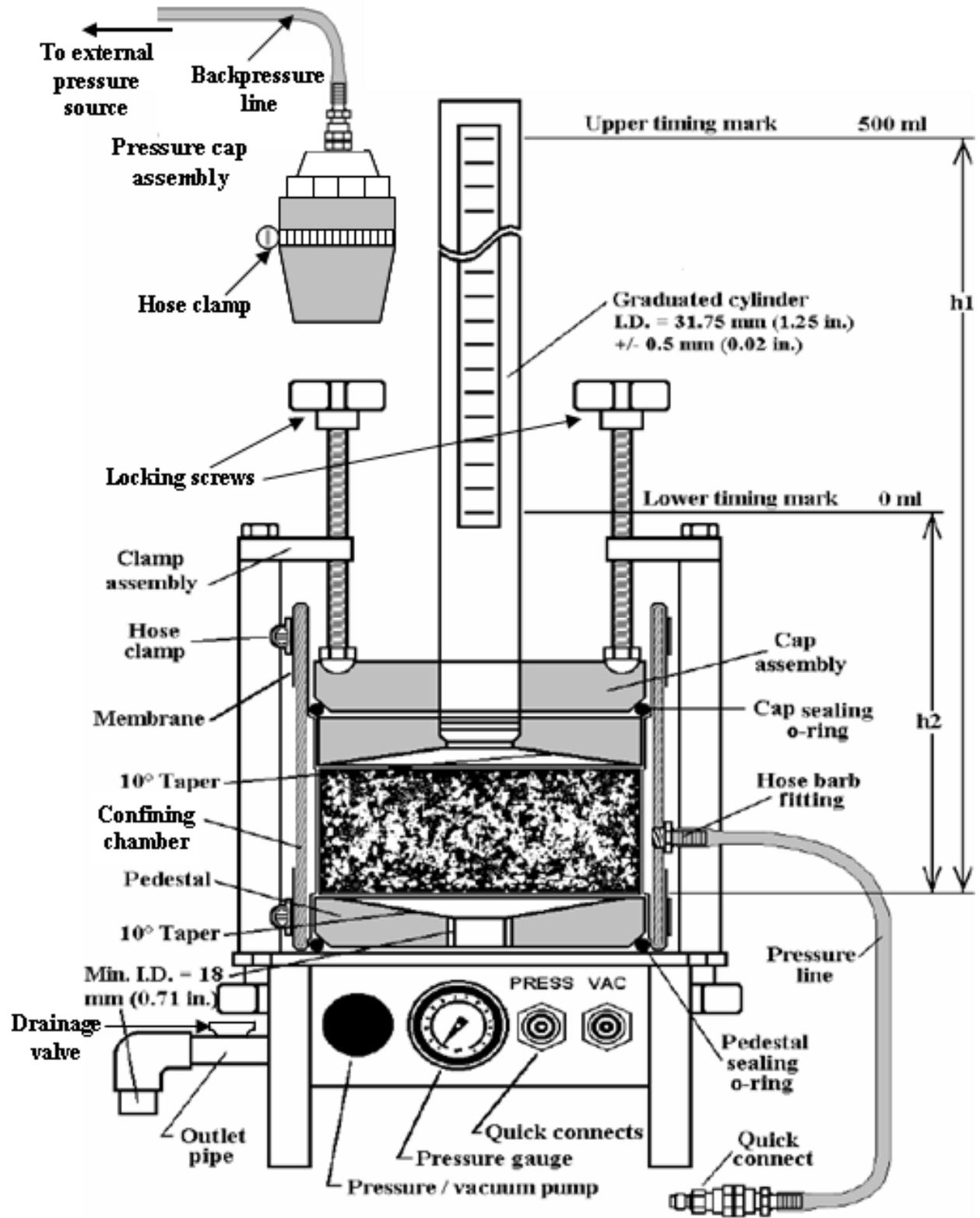γ_w　　= Unit weight of water, 62.4 pcf

Figure 1 – Permeability Testing Apparatus

Table 1 – Temperature Correction for Viscosity of Water, ºF

ºF	0.0	0.2	0.4	0.6	0.8
50	1.30	1.30	1.29	1.29	1.28
51	1.28	1.28	1.27	1.27	1.26
52	1.26	1.26	1.25	1.25	1.24
53	1.24	1.24	1.23	1.23	1.23
54	1.22	1.22	1.21	1.21	1.21
55	1.20	1.20	1.20	1.19	1.19
56	1.19	1.18	1.18	1.17	1.17
57	1.17	1.16	1.16	1.16	1.15
58	1.15	1.15	1.14	1.14	1.14
59	1.13	1.13	1.13	1.12	1.12
60	1.12	1.11	1.11	1.11	1.10
61	1.10	1.10	1.10	1.09	1.09
62	1.09	1.08	1.08	1.08	1.07
63	1.07	1.07	1.06	1.06	1.06
64	1.06	1.05	1.05	1.05	1.04
65	1.04	1.04	1.04	1.03	1.03
66	1.03	1.02	1.02	1.02	1.02
67	1.01	1.01	1.01	1.01	1.00
68	1.00	1.00	0.99	0.99	0.99
69	0.99	0.98	0.98	0.98	0.98
70	0.97	0.97	0.97	0.97	0.96
71	0.96	0.96	0.96	0.95	0.95
72	0.95	0.95	0.94	0.94	0.94
73	0.94	0.93	0.93	0.93	0.93
74	0.92	0.92	0.92	0.92	0.92
75	0.91	0.91	0.91	0.91	0.90
76	0.90	0.90	0.90	0.89	0.89
77	0.89	0.89	0.89	0.88	0.88
78	0.88	0.88	0.88	0.87	0.87
79	0.87	0.87	0.86	0.86	0.86
80	0.86	0.86	0.85	0.85	0.85
81	0.85	0.85	0.84	0.84	0.84
82	0.84	0.84	0.83	0.83	0.83
83	0.83	0.83	0.82	0.82	0.82
84	0.82	0.82	0.81	0.81	0.81
85	0.81	0.81	0.81	0.80	0.80
86	0.80	0.80	0.80	0.79	0.79
87	0.79	0.79	0.79	0.79	0.78
88	0.78	0.78	0.78	0.78	0.77
89	0.77	0.77	0.77	0.77	0.77
90	0.76	0.76	0.76	0.76	0.76
91	0.76	0.75	0.75	0.75	0.75
92	0.75	0.75	0.74	0.74	0.74
93	0.74	0.74	0.74	0.73	0.73
94	0.73	0.73	0.73	0.73	0.72
95	0.72	0.72	0.72	0.72	0.72

APPENDIX F. ACCELERATED MOISTURE CONDITIONING OF SPECIMENS WITH VACUUM METHOD[12]

Section 1

Overview

Use this method to moisture condition soil specimens in laboratory by applying vacuum.

To perform test, a soil specimen is prepared in laboratory using Tex-114-E or Static Compaction as per Tex xxx-E[13]. The specimen measures 6 in. (150 mm) or 8 in. (200 mm) in height and 4 in. (100 mm) in diameter.

Units of Measurement

The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

Section 2

Apparatus

The following apparatus are required:

- Permeameter, with the following requirements[14]:
  - A calibrated cylinder of 1.25 inches ± 0.02 inches (31.75 mm ± 0.5 mm) inner diameter graduated in millimeters and capable of dispensing 500 ml of water.
  - A confining chamber, which is a hollow plastic mold 12.0 in. (300 mm) in height and 4.25 in. (106 mm) inner diameter with a hose barb fitting in the middle of the mold. The confining chamber should be retrofitted with a flexible latex membrane 0.025 inches (0.635 mm) thick and 14 inches high.
  - An upper clamp assembly for supporting the graduated cylinder and expanding an o-ring against the confining chamber. The opening in the upper cap shall have the same diameter as the inner diameter of the calibrated cylinder mentioned previously.
  - A lower pedestal plate for supporting the soil specimen and expanding o-ring against the confining chamber. The lower pedestal should have a drainage port to allow water flushed through the specimen to be collected.
  - An outlet pipe with an open/close drainage valve connected to the bottom of the lower

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[12] **This protocol does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.**

[13] See Appendix D of this document

[14] We have identified a manufacturer that can provide this set up for less than $1,200.

pedestal. The pipe is also connected on the other side to a water container through a flexible plastic tube.

- O-ring of sufficient diameter and thickness for maintaining a seal against the confining chamber.
- Sealing Agent (vacuum grease).
- A water container capable of storing at least 500 ml of water.
- pH meter with temperature gauge (optional).
- Vacuum and pressure pump, including manometer.
- A vacuum pump or supply.
- A pressure cap fitting the top of the graduated cylinder that is also connected to an external vacuum pump. This pump provides the vacuum suction to the system.
- Stopwatch.
- Balance, with a minimum capacity of 15 lbs (7 kg), accurate and readable to 0.001 lb (0.5 g) or 0.1% of the test mass, whichever is greater.
- Two porous stones of 4 in. (100 mm) in diameter and 0.25 in. (6 mm) in thickness.
- Filter paper.

Section 3

Preparation of Soil Specimen

Preparation of Material

Prepare the material according to 'Part II, Preparing Samples for Compaction and Triaxial Tests' of Test Method "Tex-101-E, Preparing Soil and Flexible Base Materials for Testing."

Preparation of Specimen

Prepare specimen according to Test Methods "Tex-114-E, Laboratory Compaction Characteristics and Moisture-Density Relationship of Subgrade, Embankment Soils, and Backfill Material" or "Tex-xxx-E[15], Laboratory Compaction of Clay Specimens by Static Compaction Method."

Section 4

Moisture Conditioning of Specimen

The following table lists the steps necessary to achieve specimen moisture conditioning. The complete test is divided into Specimen Preparation and Test Procedure.

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[15] See Appendix D of this document

Specimen Preparation for Testing	
Step	**Action**
1	Evacuate the air from the confining chamber/membrane cavity. Use a vacuum pump for this purpose. Complete evacuation can be achieved by slightly pinching and pulling away the membrane from the hose barb fitting while the pump is being actuated.
2	Place one of the porous stones on top of the lower plate and center it. Place a filter paper on top of the stone. Weigh the specimen and place it on top of the porous stone and center it. In the same way, place a filter paper on top of the specimen and the other porous stone above it.
3	Place the confining chamber over the specimen and the lower pedestal. Make sure that the chamber is oriented so that the hose barb fitting is located between the o-rings on the upper cap and the lower pedestal.
4	Insert the top cap assembly into the confining chamber and let it rest on top of the porous stone. The process is aided if the graduated cylinder is already inserted into the upper cap assembly, so it can be used as a handle.
5	Install the two clamp assemblies onto the permeameter frame and evenly tighten each of the locking screws, applying a moderate pressure to the upper cap assembly. This action seals the o-ring against the membrane and confining chamber.
6	Inflate the membrane using the hand pump up to a pressure of 10 ± 0.5 psi (70 ± 3.5 kPa). Maintain the pressure throughout the tests using the pump if the system loses pressure. The specimen is ready to start the test.

Moisture Conditioning Test Procedure	
Step	**Action**
1	Before the test is started, the top water level in the water container should be at the same height as the bottom of the specimen tested. This avoids adding extra pressure to the moisture conditioning. In addition, the drainage valve of the outlet pipe needs to be closed and the plastic tube, outlet pipe and opening in the pedestal plate should be filled with water before the test is started.
2	Secure the top of the graduated cylinder with the pressure cap and apply vacuum suction on top of the graduated cylinder. The vacuum is applied by the external pump.
3	Start the test opening the drainage valve of the outlet pipe.
4	Continue the test until the water reaches the top of the specimen. At this point water should become visible at the bottom of the graduated cylinder and the specimen is considered moisture conditioned.
5	After the test is completed, stop the vacuum pump, release the pressure cap from the top of the graduated cylinder, close the drainage valve of the outlet pipe and remove any remaining water from the cylinder. Release pressure from the container. Remove the cap assemblies, upper cap and specimen and measure final weight of the specimen to measure total absorbed water.

pH Measurement Procedures (optional)	
Step	**Action**
1	Follow Steps 1 through 4 in Moisture Conditioning procedure.
2	Continue the test until a considerable amount of water is collected in the graduated cylinder. 150 ml of water are considered enough and this amount corresponds to a height in the graduated cylinder close to the lower timing mark or 0 mm mark.
3	After the test is completed, stop the vacuum pump, release the pressure cap from the top of the graduated cylinder, close the drainage valve of the outlet pipe and collect all water from the cylinder in a separate container to measure pH.
4	To estimate the discharge of the additive, measure the pH of the discharged water using test procedure Tex-128-E.
5	Release pressure from the container. Remove the cap assemblies, upper cap and specimen and measure final weight of the specimen to measure total absorbed water.

Calculations

The water absorbed by the specimen after the test is completed can be transformed to moisture content with the equation:

$$MC_f = MC_i + \left(\frac{W_{Tf}}{\left(\frac{W_{Ti}}{1 + MC_i} \right)} - 1 \right) \tag{6}$$

where:

MC_f = Final moisture content of specimen, %
W_{Tf} = Final total weight of specimen, lbs
MC_i = Initial moisture content of specimen, %
W_{Ti} = Initial total weight of specimen, lbs

In addition, to calculate the theoretical moisture content of the specimen when saturation is reached (MC_{sat}), the following equation needs to be applied:

$$MC_{sat} = \frac{\gamma_w (1 + MC_i)}{\gamma_{Ti}} - \frac{1}{G_S} \tag{7}$$

where:

MC_{sat} = Theoretical moisture content of specimen at saturation, %
γ_w = Unit weight of water, 62.4 pcf
G_S = Specific Gravity of soil
γ_{Ti} = Initial wet (total) unit weight of soil, pcf
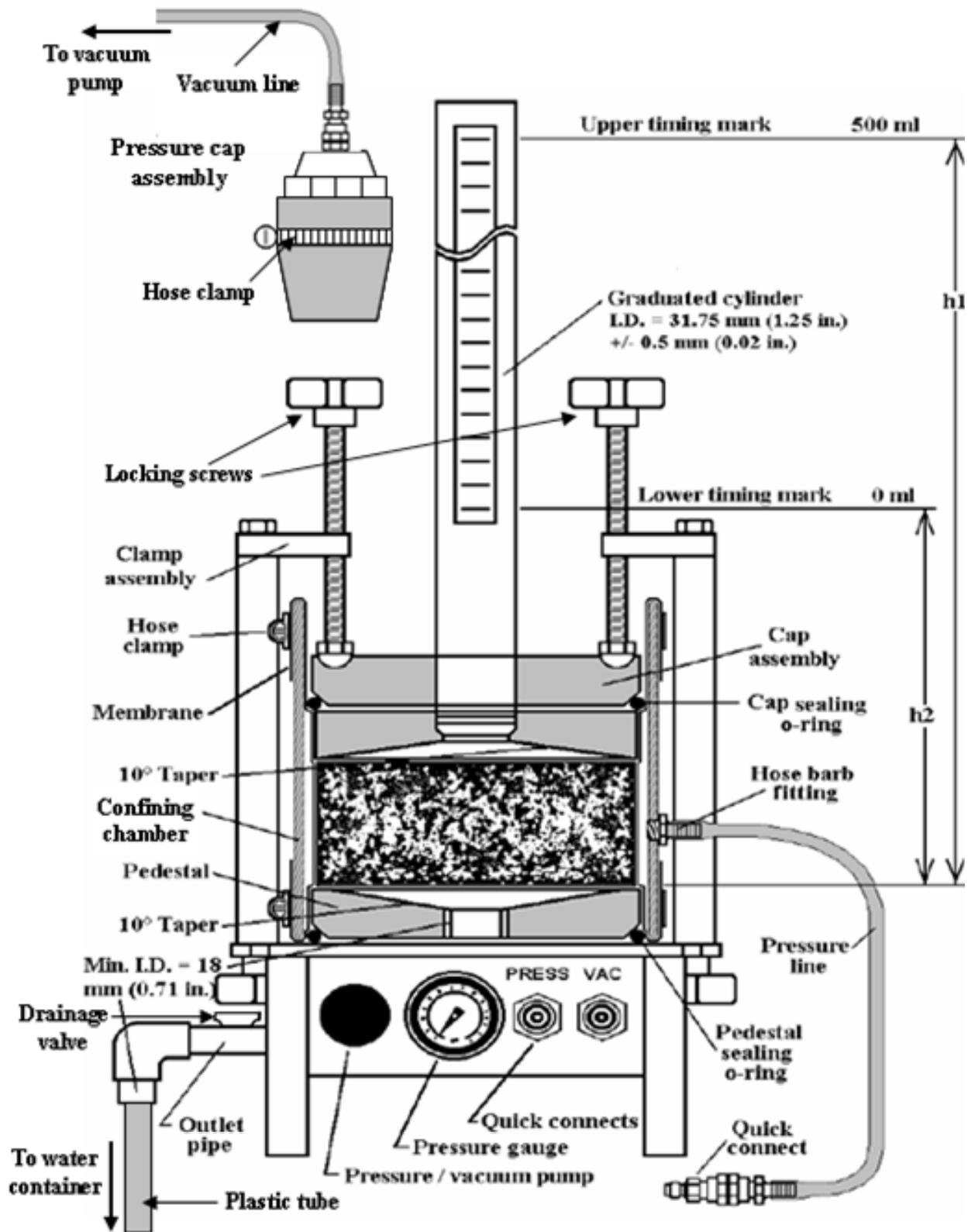
Figure 2 – Vacuum Testing Apparatus

APPENDIX G. WETTING-DRYING CYCLES[16]

Section 1

Overview

Use this method to conduct wetting/drying studies on soil specimens in laboratory.

To perform test, a soil specimen is prepared in laboratory using Tex-114-E or Static Compaction as per Tex xxx-E[17]. The specimen measures 15 cm (6 in.) in height and 10 cm (4 in.) in diameter.

Units of Measurement

The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

Section 2

Apparatus

The following apparatus are required:

- Balance, with a minimum capacity of 7 kg (15 lbs), accurate and readable to 0.5 g (0.001 lb) or 0.1% of the test mass, whichever is greater.
- Two porous stones of 10 cm (4 in.) in diameter and 0.6 cm (0.25 in.) in thickness.
- Dial gauge with a least count of 0.0025 cm (0.001 in.).
- Cylindrical mold with a stand to fix the dial gauge.
- 'Pi' tape.

Section 3

Preparation of Soil Specimen

Preparation of Material

Prepare the material according to 'Part II, Preparing Samples for Compaction and Triaxial Tests' of Test Method "Tex-101-E, Preparing Soil and Flexible Base Materials for Testing."

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[16] **This protocol does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.**
[17] See Appendix D of this document

Preparation of Specimen

Prepare specimen according to Test Methods "Tex-114-E, Laboratory Compaction Characteristics and Moisture-Density Relationship of Subgrade, Embankment Soils, and Backfill Material" or "Tex-xxx-E[18], Laboratory Compaction of Clay Specimens by Static Compaction Method."

Section 4

Wetting/Drying tests on Specimen

The following table lists the steps necessary to conduct wetting/drying studies on the soil specimen.

Specimen Preparation for Testing	
Step	**Action**
1	Place the soil specimen in a cylindrical mold over a porous stone.
2	Place another porous stone on the top and attach the dial gauge such that gage tip rests on the top porous stone.
3	Take the initial dial gauge reading.
4	Place the assembly in an oven at 70°C (160°F) for 42 hrs.
5	Take the dial gauge reading at regular intervals (5 to 6 readings over 42 hours).
6	Take the final dial gauge reading and remove the sample out of the oven and let it cool.
7	Measure the diameter of the specimen using a 'pi' tape.
8	Put a neoprene membrane on the soil sample so that sample does not disintegrate during wetting process.
9	Place the assembly soaked under water for 5 hrs and take the dial gauge reading at intervals of 1 hr.
10	Take the soil specimen out of the membrane and measure its diameter with a 'pi' tape.
11	This completes one cycle of wetting and drying.
12	Repeat steps 1 through 11 until 21 cycles of drying and wetting are completed.
13	Conduct unconfined compression test according to Tex 117E at every 5 cycles.
14	Plot the results of retained strength versus number of cycles of wetting/drying and determine the number of cycles at which the retained strength is 80% or above.

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[18] See Appendix D of this document