# EVALUATION OF STRUCTURAL PROPERTIES OF LIME STABILIZED SOILS AND AGGREGATES

## VOLUME 3: MIXTURE DESIGN AND TESTING PROCEDURE FOR LIME STABILIZED SOILS

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# I. INTRODUCTION

Lime stabilization provides structural improvement to many soils and aggregates. This is well documented in the literature which is summarized in Volumes 1 and 2 of this study. To be confident that a lime stabilized soil layer can function as intended in a pavement designed by a mechanistic-empirical approach, it is necessary to determine strength and stiffness properties. Furthermore, it is necessary to demonstrate durability. These key properties are addressed by the following mixture design and testing procedure (MDTP):

- **Classify Soil and Determine Lime Demand.**
- **Fabricate, Cure, and Soak Samples**.
- **Determine Strength and Stiffness.**

The purpose of this study is to evaluate this MDTP.

This report is divided into six sections. The introduction is followed by a description of the MDTP. Section three presents testing results and compares them to expected properties (as defined in the synthesis of pertinent literature--see Volumes 1 and 2). Conventional unconfined compressive strength (ASTM D 5102) and conventional resilient moduli (AASHTO T 294-94) tests were evaluated for three typical candidate soils for lime stabilization. These tests followed accelerated curing and moisture conditioning.

The fourth section of the report assesses two new testing methods to provide expedient and reliable moisture sensitivity and resilient moduli data. Section five presents findings and recommendations.

Appendix A presents a plan for implementing the MDTP in conjunction with a study currently underway with the Mississippi Department of Transportation. This study will also produce lime stabilization design/analysis examples for possible use in the 2002 AASHTO Design Guide.

***Soak:*** The sample is subjected to capillary soak for 24 to 48 hours prior to strength testing. This represents the moisture state under reasonable pavement conditions.

***3.*** ***Determine Strength and Stiffness*** - Unconfined compressive strength is determined using ASTM D 5102. This study confirms that unconfined compressive strength can approximate design parameters such as flexural strength, deformation potential, and stiffness (resilient modulus). This approach can be used for most designs.

For high volume designs, however, stiffness (i.e., resilient modulus) should be measured directly. This study demonstrates that a rapid triaxial test (RaTT) can be used instead of the more time-consuming and material-intensive AASHTO T 294-94 test.

## III. COMPARING SHEAR STRENGTH, RESILIENT MODULUS, AND MOISTURE RESISTANCE OF TYPICAL LIME-STABILIZED SOILS TO EXPECTED VALUES FROM THE LITERATURE

### A. RESILIENT MODULUS AND UNCONFINED COMPRESSIVE STRENGTH TESTS

AASHTO Method T 294-94 is the generally accepted protocol for resilient modulus testing for granular and fine-grained soils and aggregates. The method consists of a conditioning phase and a testing phase. The resilient modulus is determined as a function of stress state. However, the protocol is relatively time and material intensive and is not generally amenable to standard mixture designs. Nonetheless, the resilient modulus is an essential property for structural design/analysis.

ASTM Method D 5102 is the generally accepted method for unconfined compressive strength measurement of lime-treated soils.

Three soils typical of those stabilized with lime to serve as subbases or bases were tested in this study. Unconfined compressive strengths and resilient moduli were determined following a capillary soak. The capillary soak was designed to simulate the critical moisture state of the layer in the pavement system. The soil properties and testing results are presented in Table 1.

# IV. EVALUATION OF NEW TEST METHODS

## A. EVALUATION OF THE RAPID TRIAXIAL TEST (RaTT) METHOD OF RESILIENT MODULUS TESTING

The AASHTO T 294-94 test method subjects a specimen to sixteen stress stages or regimes. The first stress regime is a conditioning stage in which a minimum of 500 to no more than 1,000 axial pulses are applied. Each of the remaining stress stages apply 100 axial loading pulses to the specimen. The values of confining and deviator stress for each regime are defined by the AASHTO T 294-94 test method.

***RaTT Testing Methodology***

The Rapid Triaxial Test (RaTT) is one instrument that embodies the requirements of AASHTO T 294-94. It was selected as a candidate for the level 2 MDTP because it offers an efficient method for determining resilient properties of the lime-stabilized soil. It is being used by the International Center for Aggregates Research (ICAR) and by the University of Illinois for unbound aggregate base course testing. The RaTT device provides a more efficient and rapid means than T 294 of determining resilient and permanent deformation properties of granular and fine-grained materials. It also has unique capabilities of measuring radial displacements simultaneously with axial displacements and of pulsing stresses in either the axial or radial directions. This device or a similar device will likely be recommended for aggregate and soil characterization associated with the 2002 AASHTO Design Guide.

The RaTT is pneumatically operated and provides independent control of axial and lateral stresses applied to a specimen during testing. The design of the RaTT hardware allows cylindrically-shaped specimens (normally 100 mm diameter and 100 mm height) to be quickly and conveniently mounted into the system for testing. Lateral stress is applied to the specimen by controlling the pneumatic pressure applied to the membrane in contact with the wall of the specimen. Axial stress is applied to the specimen from an actuator mounted in a reaction loading frame. Feedback servo-control is used for the accurate generation of both the lateral and axial stresses.

The compacted sample must be trimmed within close tolerance because test height has a critical impact on precision and accuracy. Rubber membranes surrounding the sample within the cell minimize end effects and allow use of a one-to-one height to diameter sample.

Once the sample is fabricated and placed within the cell, the complete time for resilient modulus testing across the entire range of stress states to which the specimen is subjected is about 45 minutes.

***RaTT Testing Results***

Three soils were subjected to RaTT resilient modulus testing: a low plasticity soil (LB1 with PI = 12), a moderate PI soil (MB1 with PI = 25) and a high plasticity soil (HB1 with PI = 35). The results of unconfined compressive strength (ASTM D 5102) and RaTT resilient modulus testing for these soils appear in Table 3.

These results support the following findings:

1. The RaTT resilient modulus test device provides repeatable and realistic resilient moduli for level 2 mixture design and evaluation.

2. Complete soaking (for as long as 48 hours) is needed to simulate moisture effects fully.[1]

3. Lime stabilization produces substantial improvements in unconfined compressive strength and resilient modulus based on testing using the RaTT.

[1] The resilient moduli data summarized in Table 3 are based on two different capillary soak periods: 24 and 48 hours. Originally, 24 hours was specified for this testing. However, upon observation of the samples during testing, it was apparent that the moisture rise in the highly plastic clays was incomplete (i.e., not all the way to the top of the 100 mm sample). However, the moisture rise was complete at the end of 48 hours. Because 24 hours is not enough for soils with PI above 25, for higher PI soils the moisture conditioning capillary soak period should be extended until it is apparent that the moisture has "wicked" to the top of the sample. The shorter (100 mm high) RaTT samples facilitate a shorter soaking period than conventional AASHTO T 294 testing.

Table 3 Summary of Compressive Strength and RaTT Resilient Modulus Testing on Selected Soils (With and Without Lime).

| **Soil I.D.** | **Unconfined Compressive Strength after 7-day Cure at 40ºC, kPa** | | **Unconfined Compressive Strength after 14-days Cure at 40ºC, kPa** | | **Unconfined Compressive Strength after 14-days Cure and 24-hours of Capillary Soak, kPa** | | **RaTT Resilient Modulus Testing at 100 kPa after Soak, MPa** |
|---|---|---|---|---|---|---|---|
| | **Individual** | **Average** | **Individual** | **Average** | **Individual** | **Average** | |
| LB1 | 266 | 234 | 343 | 343 | NT[3] | NT[3] | 100[1] |
| | 217 | | 345 | | NT[3] | | 12[2] |
| | 217 | | 343 | | NT[3] | | |
| MB1 | 882 | 728 | 1,596 | 1,162 | 854 | 735 | 180[1] |
| | 721 | | 1,092 | | 693 | | 85[2] |
| | 588 | | 798 | | 648 | | |
| HB1 | 1,274 | 1,113 | 2,394 | 1,874 | 420 | 294 | 91[1] |
| | 1,218 | | 1,873 | | 231 | | NT[2,3] |
| | 840 | | 1,355 | | 252 | | |
| LB1 - L | 2,835 | 2,940 | 3,528 | 3,857 | 2,953 | 3,212 | 225[1] |
| (3% hydrated lime) | 2,660 | | 4,123 | | 3,616 | | 265[2] |
| | 3,318 | | 3,927 | | 3,067 | | |
| MB1 - L | 3,318 | 5,215 | 6,188 | 6,923 | 6,517 | 6,860 | 645[1] |
| (4% hydrated lime) | 5,600 | | 7,168 | | 7,371 | | 665[2] |
| | 6,727 | | 7,420 | | 6,692 | | |
| HB1 - L | 7,308 | 7,294 | 8,897 | 9,399 | 7,994 | 7,917 | 533[1] |
| (5% hydrated lime) | 7,343 | | 9,369 | | 8,239 | | 533[2] |
| | 7,231 | | 9,931 | | 7,504 | | |

[1] Sample subjected to 24 hours of capillary soak prior to resilient modulus testing
[2] Sample subjected to 48 hours of capillary soak prior to resilient modulus testing
[3] NT = Sample not testable (too weak to test)

## B. EVALUATION OF THE TUBE SUCTION TEST (TST) METHOD OF MOISTURE SENSITIVITY TESTING

The dielectric value (DV) is a measure of the volumetric moisture content and the state of molecular bonding in a material. Low dielectric values indicate the presence of tightly absorbed and well-arranged water molecules. Granular bases or stabilized bases with low dielectric values normally have better strength properties. Dielectric values that are greater than about 16 indicate the presence of substantial "free" moisture. The electrical conductivity of a material is an indication of the amount of ions dissociated to the free water. A higher electrical conductivity is associated with more ions present in the pore water system.

### *TST Testing Methodology*

The Tube Suction Test (TST) was adapted in this study to measure the effectiveness of lime stabilization to reduce moisture sensitivity of stabilized soils. The TST was developed at Texas Transportation Institute (TTI) to determine the moisture susceptibility of base course aggregates. Applying this procedure to soils is based on the premise that lime will reduce the moisture retention and moisture sensitivity of the clay system. The test is simple to perform and has the potential to be an effective screening test for durability.

The TST is a measure of how much moisture a base will absorb through capillary rise and the state of bonding of the absorbed moisture. The test results are primarily related to the amount and type of clay in the aggregate, and secondarily to the water absorption properties of the coarse aggregate fraction. Proposed base course aggregate materials, which fail this test, would be anticipated to perform poorly under heavy wheel loads and when subjected to freezing and thawing conditions.

Previous research demonstrates the success of lime in DV reduction of caliche and clay bound siliceous aggregates (Table 2, Volume 1). Furthermore, past research shows that lime stabilization of an aggregate base with deleterious fines (i.e., fines that make the base susceptible to moisture) improves moisture resistance and increases shear strength.

### *TST Testing Results*

The TST was performed on the low, moderate, and high plasticity soils previously tested for strength and resilient modulus properties. Tube suction testing was continued until each soil reached an equilibrium DV and/or an equilibrium moisture content. All soils reached this equilibrium level within 311.3 hours of testing. Four independent readings of DV and moisture content were taken at nine different times. Tests were performed on three versions of each soil: (1) untreated, (2) lime-treated with unsealed curing, and (3) lime-treated with controlled curing

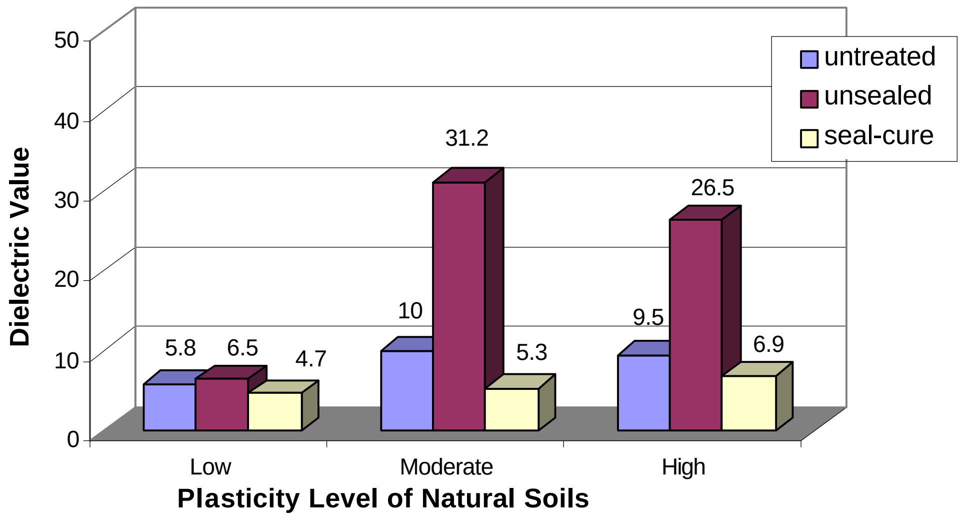


Figure 1. Comparison of Equilibrium DVs for Low, Moderate, and High Plasticity Soils

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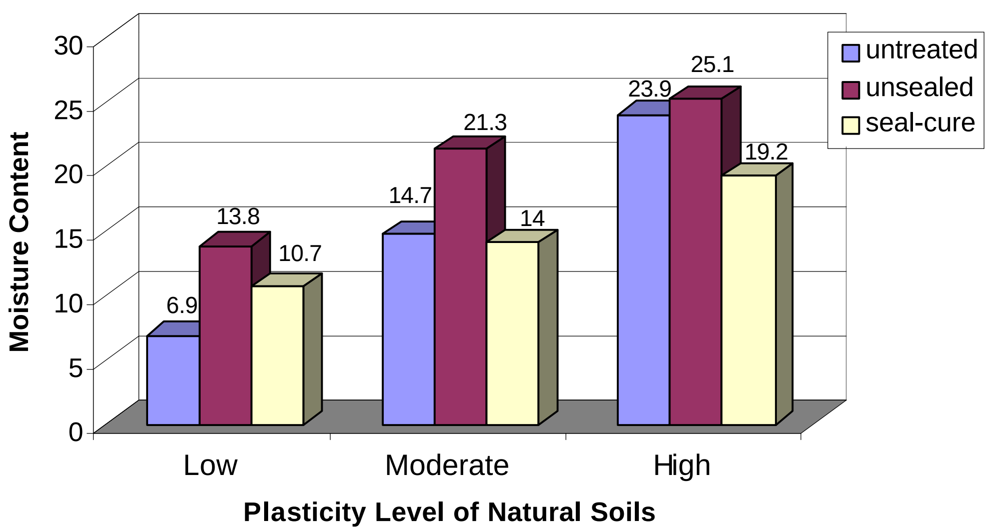


Figure 2. Comparison of Equilibrium Moisture Contents for Low, Moderate, and High Plasticity Soils.