Durability studies of lime stabilized clayey soils
Durabilité des études Lime Stabilized sols argileux

B. S. Chittoori
Parsons and Brinckerhoff Americas Inc., USA
A. J. Puppala
The University of Texas at Arlington, USA
S. Saride
The University of Texas at Arlington, USA
S. Nazarian
The University of Texas at El Paso, USA
L. R. Hoyos,
The University of Texas at Arlington, USA

ABSTRACT

The proper selection of type and concentration of the stabilization of a soil should consider the complex interaction between the mineralogy of the materials and additives, the presence or absence of moisture in soils and the long-term durability of the stabilization process. One measure of the durability of a stabilized material is to study the strength and volumetric strain potentials of the treated material by subjecting them to different wetting and drying cycles. In this research, two clays with known plasticity characteristics were considered. Stabilizer design was first performed based on strength and pH criterion. At these designed stabilizer dosage levels, samples were prepared and subjected to durability related wetting and drying cycles. At select cycles, mechanical tests including volume change measurements and strength tests were performed. Both volumetric stability and strength variations with respect to wetting and drying cycles were then analyzed. Influence of clay mineralogy and its impact on the mechanical performance of treated soils are explained. Importance of clay mineralogy on durability treatments is addressed.

RÉSUMÉ

Le bon choix du type et de la concentration de la stabilisation des sols devrait examiner l'interaction complexe entre la minéralogie des matériaux et des additifs, la présence ou l'absence d'humidité dans les sols et la durabilité à long terme du processus de stabilisation. Une mesure de la durabilité d'un matériau stabilisé est d'étudier la résistance et la déformation volumétrique potentiels du matériau traité en les soumettant à différents cycles de mouillage et de séchage. Dans cette recherche, deux plateaux avec des caractéristiques de plasticité ont été examinés. Stabilisateur de conception a été effectuée selon le critère de la force et le pH. Lors de ces stabilisateur conçu doses, les échantillons ont été préparés et soumis à la durabilité liés cycles de mouillage et de séchage. Lors de sélectionner les cycles, les essais mécaniques, y compris des changements de volume des mesures et essais de résistance ont été effectuées. Les deux volumétrique stabilité et la solidité des variations en ce qui concerne les cycles de mouillage et de séchage ont ensuite été analysés. Influence de l'argile de minéralogie et de son impact sur les performances mécaniques des sols traités sont expliqués. Importance de minéralogie de l'argile sur la durabilité des traitements est adressée.

Keywords: Soil stabilization, Mineralogy, Durability, Lime

1. INTRODUCTION

Extensive research was documented with regard to the engineering properties, reliability and durability of various types of stabilized materials. Different testing methods, design, construction, and quality assurance/quality control (QA/QC) methodologies have been developed for these stabilized materials. Many pavement projects constructed with stabilized materials have achieved satisfactory results. However, challenges remain in the optimal use of these stabilized materials. These challenges include developing better understanding of the long-term performance of the stabilized materials, better construction methods and using proper quality assurance/quality control procedures that are effective predictors of the long-term performance of pavement infrastructure with minimal distress problems (Little et al., 2000).

Many state Departments of Transportation (DOTs) in the United States have had problems with subgrade failure due to a loss of stabilizer over time, or a stabilizer being ineffective in some soils while other soils with the same index properties respond well to that stabilizer (Little et al. 2000; McCallister, 1990). In some cases the amount of stabilizer was not sufficient to produce a good subgrade foundation system for the pavement structure. These problems are attributed to the limitations of the current procedures for selecting the optimal additive content for pavement subsoil layers. One such limitation is the lack of understanding of the complex interactions between the mineralogy of the soil and the additives. Also, the design procedure is time consuming and hence the specifications are bypassed and the design is conducted based on the local experience. However, several premature failures of pavements on stabilized subsoils and poor long term performance of them have prompted a research to incorporate both clay mineralogy aspects into the pavement design practices and address durability issues in the original stabilizer design. In this paper, results obtained from the durability studies attempted on chemically treated soils are presented. The impact of dominating clay mineral and its impact on the durability performance is also presented.

1.1 *Durability Issues of Chemical Stabilization*

Moisture fluctuations from seasonal changes and their impact on the performance of these soils is an important aspect of

Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering
M. Hamza et al. (Eds.)

doi:10.3233/978-1-60750-031-5-2208

durability of chemical stabilization. This aspect is often studied in soil stabilization projects as a part of the durability studies. Wet-dry tests are typically conducted according to ASTM D 559 method. Several studies have been performed on the wet-dry cycle related tests (Rao et al., 2001; Hoyos et al., 2005; Khattab et al., 2007) to address the durability issues on the performance of stabilizers in arid conditions where the above mentioned moisture fluctuations occur.

Rao et al. (2001) conducted a study to assess the long term performance of stabilized black cotton soils. These black cotton soils are stabilized with waste materials such as wood ash and organic matter (known as ash modified soils) and also with lime. This study is conducted primarily to understand the relative effectiveness of ash modified soils and lime treated black cotton soils. They observed that the ash modified soil became more porous due to cyclic wetting and drying and consequently collapsed significantly. They also found that due to cyclic wetting and drying the beneficial effects of lime treatment were partially lost.

Hoyos et al. (2005) performed a series of wet and dry cyclic tests on different types of chemically-treated sulfate soils to evaluate the strength, stiffness and volume change property variations with respect to these cycles. Khattab et al. (2007) conducted both wetting drying studies and leaching studies on FoCa bentonite (FoCa represents the first two letters of the two towns between which this type of soil is excavated: Fourgues and Cahaignes) stabilized with 4% lime. They observed that during wetting/drying processes, the samples that started with initial wetting stage had lower swell potentials than the samples that started with an initial drying stage. They also observed that leaching did not have much influence on the efficiency of the lime treatment. In this paper, an attempt is made to assess the long term effectiveness of lime stabilization by investigating durability issues by simulating field environmental conditions close to local conditions. A testing program was hence designed to test soils from Texas region, and details of this program and descriptions of the test materials used are described in the next section. Also, chemical tests were conducted on the soils to determine the mineral content of the soils to study the effect of mineralogy on the long-term performance of chemically stabilized soils.

2. MATERIALS AND METHODS

2.1 *Soil and Stabilizer*

Two natural expansive clayey soils were sampled from different locations in Texas. This was done with the help of Texas Department of Transportation (TxDOT). The soils were selected such that their plasticity index (PI) values were similar but have different mineralogies to study the effect of mineralogy on the long-term performance of stabilized soils. A soil from Bryan, Texas with a PI value of around 31 and a soil from Fort Worth with a PI value of around 29 were selected. Both soils were treated with lime stabilizer. X-ray diffraction and chemical studies were conducted on both the soils to obtain their mineralogical and chemical properties. It was observed that the soil from Bryan was dominant in the mineral kaolinite (50%) and the soil from Fort Worth was dominant in the mineral montmorillonite (50%). Optimum moisture content (OMC) and maximum dry density (MDD) (refer to Table 1) values were obtained by conducting standard Proctor tests as per ASTM standard procedures (ASTM D-698).

Hydrated lime ($Ca(OH)_2$) was used to stabilize both the soils. This lime additive contained around 72% of CaO and 23% chemically mixed water (MSDS-Hydrated Lime). Stabilization design for both soils was conducted as per the Texas Department of Transportation (TxDOT) manual of test procedures (TX 120-E). Lime percent was selected as per Eades and Grim's test method and the final percent lime was selected when the pH value of the treated soil was close to 12.4. The optimum lime content was then determined for both the soils (refer to Table 1).

Table 1 Properties of the selected soils

Soil Location	Atterberg Limits			OMC		MDD, pcf	
	LL	PL	PI	UT	T	UT	T
Bryan	45	14	31	19	22 (8)	97.7	95.3 (8)
Fort Worth	61	32	29	24	23 (6)	91.5	90.8 (6)

Note: UT - Untreated, T - Treated, Values in braces are % lime added

2.2 *Wetting/Drying Durability Studies*

An important test to address the durability of chemical treated soils in arid environments is by exposing the treated soil specimens to various cycles of wetting and drying processes. During these processes, both the volume change and soil strength and stiffness can be determined. These properties will provide insights into the effects of seasonal moisture fluctuations on the soil property variations. ASTM D 559 method is the standard method often used to perform these wet-dry cycles investigations.

The procedure outlined by ASTM D 559 method was followed in this research to reflect both wet and dry cycle conditions close to Texas conditions in a reasonably short time period. According to this method each wet-dry cycle consisted of submerging the soil sample in water for 5 hours and then placing them in a 70°C oven for 42 hours. During each wetting and drying process the vertical movements were measured and the volumetric changes were measured after each wetting and drying cycles.

The test was then continued until the completion of twenty one (21) wet-dry cycles or the failure of soil specimen. During wetting and drying periods sample size changes were measured in all the three dimensions. Vertical movement was measured with the help of a dial gauge and radial movement was measured using a "pi tape". After 3, 7, 14 and 21 cycles, the samples were subjected to UCS tests.

2.3 *Mineralogical studies*

Mineral quantification was conducted as per the method outlined by Chittoori et al. (2008). In this method, properties such as cation exchange capacity, specific surface area and total potassium of the soil were used to quantify the minerals such as Kaolinite, Illite and Montmorillonite, which generally dominate the clay mineral portion of soils. This procedure was based upon the assumption that each mineral component in a clay sample contributes linearly to its content to a measured property (say CEC) of the soil sample.

Based on the tests performed, the dominating clay mineral in Bryan soil was Kaolinite and the same in Fort Worth clayey soil was Montmorillonite. Clay mineral information was used to address the property variations from durability studies.

3. RESULTS AND DISCUSSIONS

3.1 *Wet/Dry (W/D) Cycles Results*

Wetting/Drying (W/D) related durability studies were conducted on 7-day cured soil specimens following the procedures outlined in the above section. Both untreated Bryan and Fort Worth soil specimens lasted only one W/D cycle, while the treated soil specimens lasted 21 and 10 W/D cycles. The treated Fort Worth soil specimens also showed a significant decrease in soil strength. Bryan clay specimens endured 21 cycles without any considerable loss of soil strength.

3.2 *Volumetric Strain Changes*

Volumetric strain changes for both soils studied during these durability tests are presented in Figure 1. The treated sample from Bryan which had similar PI did not show any significant volumetric changes (Figure 1a) indicating that the treatment was quite effective on this soil. Volumetric swelling in the untreated Fort Worth clay (Figure 1b) is considerable (> 15%) after one W/D cycle and the volumetric swelling in the treated clay is almost equal to that of untreated soil after 7 cycles, implying that the swelling behavior of a treated soil after seven W/D cycles will be similar to that of an untreated soil indicating the loss of stabilization with W/D cycles.

3.3 *Strength Loss*

Figure 2 shows the loss of soil strength (measured in terms of UCS) in both untreated and treated soils.

In the case of Bryan clay (Figure 2a), specimens did not show considerable swelling, and hence loss of strength was insignificant. Table 2 summarizes the percent strength retained with the number of wetting/drying cycles for both the soils studied. Fort Worth soil specimens (Figure 2b) did not survive the entire proposed W/D duration cycles, i.e. 21 cycles. Strength loss is quite high from the third to tenth cycle, and beyond the tenth cycle, the soil specimen had lost its cohesive property and then collapsed.

The reason for the diverse behaviors among soils can be attributed to the presence and dominance of the mineral montmorillonite in the clay fraction of the Fort Worth soil. Soil from Bryan does not have high amounts of montmorillonite mineral, and this might have resulted in the survival of this clay up to 21 cycles.

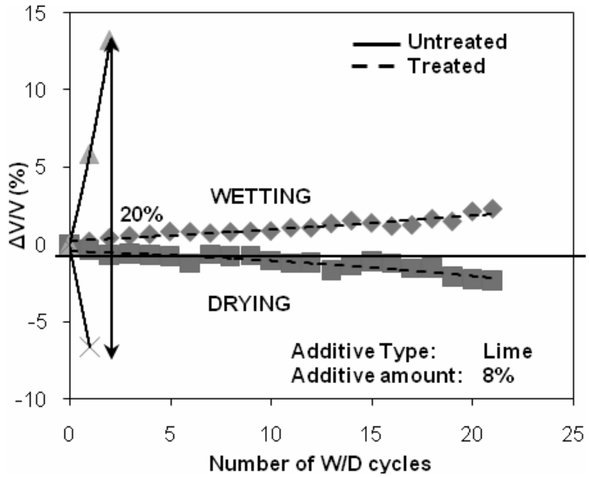
Loss of strength in clays rich with montmorillonite is attributed to hydration of montmorillonite minerals leading higher expansion. This opens up the clay matrix for more volume changes and softening of the stabilizer bonds in the treated soils. This is an important finding as it shows the influence of clay mineralogy on the durability of chemical stabilization as soils with the same PI, but different clay mineralogy will not undergo similar effectiveness. Hence, the current approach of PI based chemical stabilizer design has not provided sufficient insights into the appropriate selection of chemical stabilizers for soils and their performance for longer periods.

A few other studies on other soils with distinct PI values, but different clay mineralogy yielded similar findings, indicating the importance of incorporation of clay mineralogy in the stabilizer selection. In addition, this also shows the fallacy in the stabilizer selection guides where PI is always used to select a stabilizer and its dosage. Based on the research findings, a few modifications are suggested in their stabilizer selection guidelines.

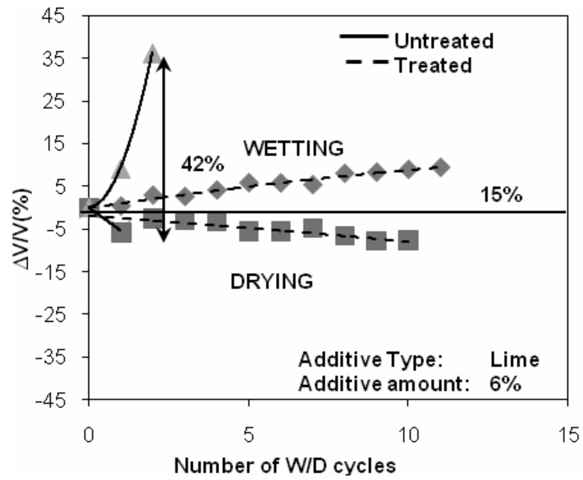
Table 2 Percent strength retained in both samples and the cycles survived along with the dominant clay mineral

Soil Name	Dominating Clay Mineral	%M	No. of cycles sample survived	% Retained Strength
Bryan	Kaolinite	20	21	90
Fort Worth	Montmorillonite	50	10	0

Note: %M – Percent Montmorillonite



a)



b)

Figure 1 Volumetric changes with W/D cycles for treated and untreated a) Bryan b) Fort Worth soil specimens

4.0 SUMMARY AND CONCLUSIONS

A series of tests related to durability studies were conducted to address the permanency of the lime treatments. The first method explored the leaching problems associated with rainfall moisture infiltration and the second method addressed the volumetric and strength changes of the soils subjected to different wetting and drying cycles simulating seasonal changes. Effects of clay mineralogy are included in the analyses of test results.

Wetting/Drying studies were conducted on 7-day cured lime treated soil specimens. Results from the Fort Worth clay soils show that untreated soils lasted for one (1) W/D cycle while treated soils lasted for ten (10) cycles. Bryan clay results show that the untreated soils lasted for one W/D cycle while treated soils lasted for all twenty one (21) cycles.

The main reason for this diverse behavior can be attributed to the dominance of the clay mineral present in the soils. The dominating clay mineral in Fort Worth clay was montmorillonite and the same in Bryan clay was Illite. Overall, it can be concluded that the stabilized soils with montmorillonite as a dominant mineral are more susceptible to durability problems in particular when these soils are exposed to volume changes caused by swell and shrink related volume changes.

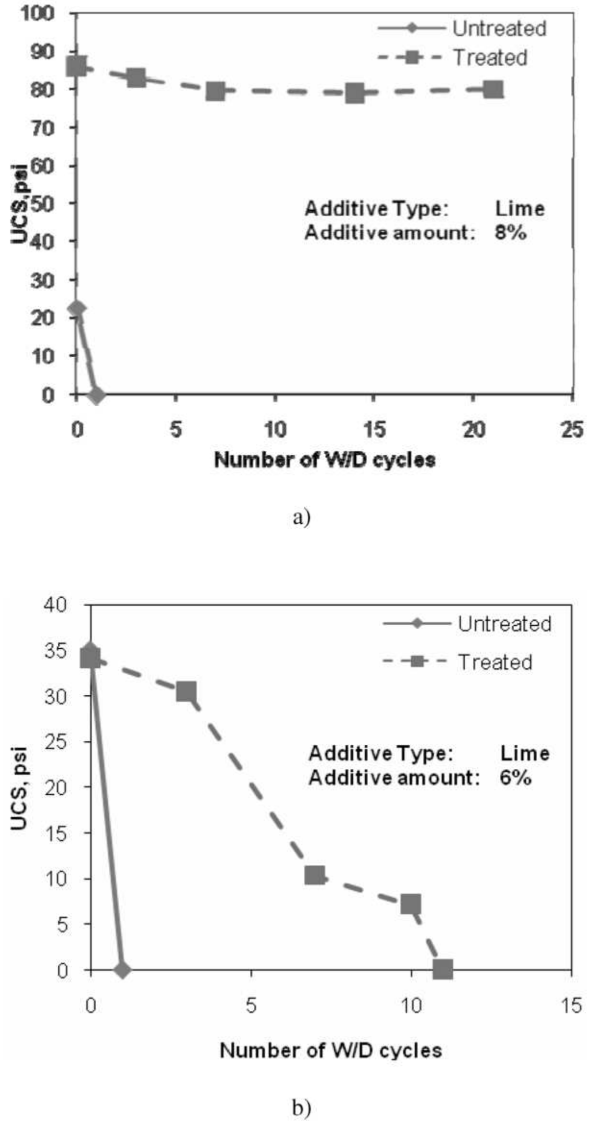


Figure 2 Strength changes with W/D cycles for treated and untreated a) Bryan b) Fort Worth soil specimens

The current approach of PI based chemical stabilizer has not provided any insights into the appropriate selection of chemical stabilizer and its permanency. This research showed the importance of clay mineral on the effective treatment of soils in real conditions and hence recommends the inclusion of clay mineralogy into the current PI based stabilizer design. Such approach would provide better answers with respect to the permanency and leachability of the stabilizer.

ACKNOWLEDGEMENTS

Authors would like to acknowledge Texas Department of Transportation (TxDOT) for providing financial support to this project under TxDOT Project No. 0-5569. We would like to acknowledge the help of Mr. Mark McDaniel, PE of Texas DOT and several others who assisted in this research.

REFERENCES

Chittoori, B.C.S. 2008. *Clay Mineralogy Effects on Long-term Performance of Chemically treated Expansive Clays.* Ph.D. thesis, University of Texas at Arlington. Arlington, Texas.

Hoyos, L., Laikram, A., Puppala, A.J. 2005. *Assessment of Seasonal Effects on Engineering Behavior of Chemically Treated Sulfate Rich Expansive Clay.* Chapter 33, Expansive Soils: Recent Advances in Characterization and Treatment, Taylor and Francis, Balkema Publications, Editors: Amer Al-Rawas and Mattheus Goosen, pp. 483-504.

Khattab, S. A. A., Al-Mukhtar, M., and Fleueau, J. M. 2007. *Long-Term Stability Charecteristics of a Lime-Treated Plastic Soil.* Journal of Materials in Civil Engineering. Vol. 19. No. 4. April, pp. 358-366.

Little, D.N., Males, E.H., Prusinki, J.R., and Stewart, B. 2000. *Cementitious Stabilization, Transportation in the New Millennium.*

McCallister, L.D. 1990. *The Effects of Leaching on Lime-Treated Expansive Clay*. Ph.D. Thesis, The University of Texas at Arlington, Arlington, Texas.

MSDS-Hydrated Lime, http://www.uslm.com/ProductServices/HydratedLime.htm.

Rao, S. M., Reddy, B. V. V. and Muttharam, M. 2001. *The Impact of Cyclic Wetting and Drying on the Swelling Behavior of Stabilized Expansive Soils.* Engineering Geology. 60. pp. 223-233.