

DURABILITY STUDIES OF CONTROLLED LOW STRENGTH MATERIAL
USING NATIVE SOILS AS FINE AGGREGATES

by

DURGA PRAVEEN REDDY VANGA

Presented to the Faculty of the Graduate School of
The University of Texas at Arlington in Partial Fulfillment
of the Requirements
for the Degree of

MASTER OF SCIENCE IN CIVIL ENGINEERING

THE UNIVERSITY OF TEXAS AT ARLINGTON

May 2013

Copyright © by Durga Praveen Reddy Vanga, 2013

All Rights Reserved

ACKNOWLEDGEMENTS

First of all, I would like to thank my advisor, Dr. Anand J. Puppala, and the other members of my thesis committee: Dr. Chao, and Dr. Xinbao Yu for their esteemed guidance to accomplish the effective end product out of my thesis work. It is my pleasure to pursue my graduate studies in the School of Civil Engineering, University of Texas Arlington, where I have the opportunity to work directly with and learn from a group of very talented people. I thank my supervisor, Dr. Anand J. Puppala for giving an opportunity to pursue M.S in his group. I extend my sincere thanks and exceptional gratitude to him for providing the freedom to work in an area that I like to contribute on, immense support and incessant motivation throughout the research. He had always been the acme of motivation, dedication and hard work. I am indebted to him and grateful forever for the kind of help extended to me during my master's program at UTA. I would like to thank TRWD and Fugro Consultants Inc; for giving me an opportunity to work on the present research project.

I am extremely grateful and obliged to Dr. Bhaskar Chittoori, for his unprecedented guidance and unwaivering support throughout the course of this research. Special thanks to him for unlocking my door when I got struck for technical support of my thesis. I would like to acknowledge graduate students in our group Naga Sreenivasu Talluri, Aravind Pederla, Tejo Vikash Bheemasetti, Minh Le, Pinit (Tom) Ruttanaporamakul, Raju Acharya, Ujwal Patil, Justin Thomey, Chatupat (Book) Siavagamin, Priya Lad and Anil Raavi. Rajini kanth Reddy Karduri, Although most of them did not collaborate on a same research topic, the numerous discussions with them are delightful and helpful.

I am indebted to Mom, Dad, Laxmi Kumari and Vivekananda Reddy Vanga for their faith in me and for their unending encouragement and excellent support. Furthermore, I would like to thank

my sister Swathi Koppula, brother-in-law Veeranna Reddy Koppula, who helped me by sharing my responsibilities whenever needed in the home country during my course of study. Special thanks to K.V Rao, Pradeep Kumar Bhattacharjee, Vijay, Jagadesh, Ramu and long list of my fathers's friends for their encouragement and timely support for higher education in USA.

Last but not the least, cheers to my dearest best buddies Srinivas Kumar Vanga, Rajkumar Janga, Shiva Prasad Magapu, Vivek, Sushma Makireddy, Prashanti Sagiraju, Deepak, Sujan Mutyala, Gangadhar Mutyala, Vissu and my roomates Bhaumi Chaurasia, Bhargav Paladugu.

April 16, 2013

ABSTRACT

DURABILITY STUDIES OF CONTROLLED LOW STRENGTH MATERIAL USING NATIVE SOILS AS FINE AGGREGATES

Durga Praveen Reddy Vanga, M.S.

The University of Texas at Arlington, 2013

Supervising Professor: Anand J. Puppala

Controlled Low Strength Material is a self compacted cementitious material used in the field as backfill material, bedding material, trench filling material, bridge abutment and embankment materials. CLSM using native soils as fine aggregates is an effective option in addressing issues relating to strength requirements, sustainability, and project costs. Using native soil in the place of conventional aggregate will reduce the overall project costs and will enhance the sustainability of the project as it eliminates dumping of excavated material in a landfill. CLSM mixes, designed for the particular flowing characteristics as well as the compressive strength requirements should maintain targeted engineering properties throughout its design life period to minimize maintenance costs. Though CLSMs do meet the short term strength requirements, their long-term performance should be verified in order to be successfully used at the actual site, especially when these materials are subjected to seasonal variations such as wetting and drying periods.

This research attempts to assess the long-term performance of CLSM through durability studies. CLSMs using native soils from Woodbine, Eagle Ford, Austin Chalk and Queen City

Sand geological formations were analyzed in terms of unconfined compressive strength, volumetric strain changes, weight changes and calcium concentration loss through wetting/drying and leachate collection. The effects of soil type and calcium concentration loss on the long-term performance of CLSMs are addressed. Comparative studies between test results on field and laboratory prepared CLSM specimens are conducted to study the effects of preparation methods on the performance of CLSMs.

A total of six different CLSM mixes including four CLSMs prepared in the field and two prepared in the laboratory with mix designs developed by a local geotechnical firm were studied in this research. Each of these samples were subjected to durability studies comprising of both wetting/drying durability and leaching. Test results and analysis indicated that CLSM with high plasticity clay was less durable when compared with CLSMs of other soil types. Further recommendations are made for field monitoring of the CLSM sections to validate the laboratory test results.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS	iii
ABSTRACT	v
LIST OF ILLUSTRATIONS.....	xii
LIST OF TABLES	xvi
Chapter	Page
1 INTRODUCTION.....	1
1.1 General.....	1
1.2 Project Particulars and Research Objectives.....	2
1.3 Thesis Organization and Summary.....	3
2 LITERATURE REVIEW.....	5
2.1 Introduction.....	5
2.2 Historical Background	5
2.3 Advantages of CLSM	6
2.4 State of Practice of CLSM.....	8
2.4.1 Bridge Replacement.....	8
2.4.1.1 Case Histories.....	9
2.4.2 Backfill Application	9
2.4.2.1 Case Histories.....	10

2.4.3 Void Filling.....	11
2.4.3.1 Case Histories.....	11
2.4.4 Utility Bedding	12
2.4.4.1 Case History.....	13
2.5 Substantial Material Reusability	15
2.5.1 West Sacramento Force Main Project	15
2.5.2 Arden Parallel Force Main Project	16
2.5.3 Geysers Recharge Project No. 1- Healdsburg North and South .	17
2.5.4 Geysers Recharge Project No. 2- Llano Mark West.....	18
2.6 CLSM – Properties.....	19
2.6.1 Flowability	20
2.6.2 Unconfined Compressive Strength	20
2.7 Durability of CLSM	21
2.7.1 Freezing-and-Thawing Study	21
2.7.2 Corrosion.....	22
2.8 Durability of Stabilized soils	25
2.8.1.1 Standard Approach	27
2.8.1.2 Modified Approach	27
2.8.2 Leachate Studies	29
2.8.2.1 Calcium Determination by EDTA Method (Leachate Studies).....	31
2.9 Summary.....	32

3 LABORATORY TESTING PROGRAM	33
3.1 Introduction.....	33
3.2 Soil Selection.....	33
3.3 Classification Tests on Native Soils	36
3.3.1 Sieve Analysis.....	36
3.3.2 Hydrometer Analysis	37
3.3.3 Atterberg Limits	37
3.4 Field Prepared Specimens.....	38
3.4.1 Specimen Preparation.....	39
3.5 Laboratory Prepared CLSM Specimens	41
3.5.1 Specimen preparation	41
3.6 Durability Studies on Field Specimens	46
3.6.1 Wetting/Drying Procedure.....	46
3.6.1.1 Volumetric Change.....	47
3.6.1.2 Weight Changes.....	48
3.6.2 Leachate Studies	49
3.6.2.1 Calcium Concentration Determination	50
3.6.3 Unconfined Compressive Strength	52
3.7 Summary.....	53
4 TEST RESULTS AND DISCUSSION OF CLSM DURABILITY STUDIES	54
4.1 Introduction.....	54

4.2 CLSM Samples Prepared in the Field.....	54
4.2.1 Volumetric Strain Changes	58
4.2.1.1 Woodbine Soil CLSMs	58
4.2.1.2 Eagle Ford Soil CLSMs.....	59
4.2.1.3 Austin Chalk Soil CLSMs	60
4.2.1.4 Queen City Sand CLSMs.....	61
4.2.2 Sample Weight Changes	62
4.2.2.1 Woodbine Soil CLSMs	62
4.2.2.2 Eagle Ford Soil CLSMs.....	63
4.2.2.3 Austin Chalk Soil CLSMs	64
4.2.2.4 Queen City Sand CLSMs.....	65
4.2.3 Leachate Calcium Concentration.....	66
4.2.3.1 Woodbine Soil CLSMs	67
4.2.3.2 Eagle Ford Soil CLSMs.....	67
4.2.3.3 Austin Chalk Soil CLSMs	68
4.2.3.4 Queen City Sand CLSMs.....	69
4.2.4 Unconfined Compressive Strength	70
4.2.5 Field Samples Testing Summary	75
4.3 Laboratory CLSM Specimens	78
4.3.1 Volumetric Strain Changes	80
4.3.1.1 Austin Chalk Soil CLSMs	80

4.3.1.2 Eagle Ford Soil CLSMs.....	80
4.3.2 Sample Weight Changes	81
4.3.2.1 Austin Chalk Soil CLSMs	81
4.3.2.2 Eagle Ford Soil CLSMs.....	82
4.3.3 Leachate Calcium Concentration.....	83
4.3.3.1 Austin Chalk Soil CLSMs	83
4.3.3.1 Eagle Ford Soil CLSMs.....	83
4.3.4 Unconfined Compressive Strength	85
4.3.5 Laboratory Sample Testing Summary	87
4.4 Analysis of Test Results.....	89
4.4.1 Effects of Soil Type on Long Term Performance of the CLSMs...	90
4.4.2 Effects of Calcium Concentration Loss on the Strength of CLSMs	94
4.4.3 Comparisons between Field and Laboratory Prepared CLSMs ...	99
4.5 Summary and Findings	104
5 SUMMARY AND CONCLUSIONS.....	106
5.1 Introduction.....	106
5.2 Summary and Conclusions	106
5.3 Future Studies and Recommendations.....	108
REFERENCES.....	109
BIOGRAPHICAL INFORMATION	113

LIST OF ILLUSTRATIONS

Figure	Page
2.1 Shows the Quick Discharge of CLSM	8
2.2 Bridge Replaced with Culverts and Flowable Fill	9
2.3 Bridge Abutment Backfill with Flowable Fill	10
2.4 CLSM as Bedding Material for Narrow Trench	13
2.6 Test Section of CLSM (Finney et al., 2008)	16
2.7 Small On–Site Batch Plant for CLSM Mixing (Finney et al.,1998)	17
2.8 CLSM Discharge into trench from Ready -Mix Truck (Finney.,1998)	18
2.9 Schematic of Combined Device (Priya, 2011)	28
2.10 Leachate Apparatus Set up.....	29
2.11 Schematic of the leachate process (Chitoori, 2008)	31
3.1 Source and Location of Soils	35
3.2 Pulverized Soil Samples from Four Different Geological Formations.....	36
3.3 Showing the clsm preparation in field (a) Shredder for processing soil material (b) Feeding Portable Concrete Mixer (c)Trench Filling with CLSM using a portable concrete mixer(d) CLSM mix in waxed cardboard cylinder molds.	40
3.4 Showing sample preparation (a) shows the soil, additive and water (b) Dough mixer with dry mix (c) Dough mixer with wet mix. (d) Plastic cylinders with CLSM mix.....	42
3.5 Plastic Cylinder and Acrylic Plate for Flow Test.....	43
3.6 Flow Diameter Measurement of CLSM mix	44
3.7 Cylindrical Plastic Mold for Casting Specimens.....	45

3.8 (a) Wetting of CLSM Specimen (b) Drying of CLSM Specimen	47
3.9 (a) shows Vertical Measurement (b) Diameter Measurement	48
3.10 (a) Weight after Wetting Cycle (b) Weight after Drying Cycle.....	48
3.11 Combined Device with Leachate Apparatus	49
3.12 Typical wetting/leachate collection process (a) CLSM specimen	
(b) CLSM specimen with latex membrane, top cap and o-rings (c) Specimen	
wetting and application of confinement (d) Leachate collection	51
3.13 Showing EDTA titration stages (a) Represents Starting point.	
(b) Represents the color change before endpoint (c) Represents the end point.....	52
3.14 UCS Test Setup with Data Acquisition System.....	53
4.1 Field Prepared Queen City Sand CLSM Specimen at (a) After 28 Days Curing	
(b) Drying cycle (c) Wetting Cycle.	57
4.2 Volumetric Strains for Field Prepared Woodbine Soil CLSMs.....	59
4.3 Volumetric Strain for Field Prepared Eagle Ford Soil CLSMs	60
4.4 Volumetric Strain for Field Prepared Austin Chalk Soil CLSMs.....	61
4.5 Volumetric Strain for Field Prepared Queen City Sand CLSMs.	62
4.6 Sample Weight Changes for Field Prepared Woodbine Soil CLSMs	63
4.7 Sample Weight Changes for Field Prepared Eagle Ford Soil CLSM.....	64
4.8 Sample Weight Changes for Field Prepared Austin Chalk Soil CLSMs.	65
4.9 Sample Weight Changes for Field Prepared Queen City Sand CLSMs.....	66
4.10 Variation of Calcium Concentration for Field Prepared Woodbine Soil CLSMs	67
4.11 Variation of Calcium Concentration for Field Prepared Eagle Ford Soil CLSMs.....	68
4.12 Variation of Calcium Concentration for Field Prepared Austin Chalk Soil CLSMs	69
4.13 Variation of Calcium Concentrations for Field Prepared Queen City Soil CLSMs.....	70
4.14 Variation of UCS Strength for Field Prepared Woodbine Soil CLSMs	72
4.15 Variation of UCS Strength for Field Prepared Eagle Ford Soil CLSMs	73

4.16 Variation of UCS strength for Field Prepared Austin Chalk Soil CLSMs	74
4.17 Variation of UCS Strengths for Field Prepared Queen City Sand CLSMs.....	75
4.18 Laboratory Prepared Eagle Ford Soil CLSM at (a) after 28 days curing (b) Drying Cycle (c) Wetting Cycle.....	79
4.19 Volumetric Strain for Laboratory Prepared Austin Chalk Soil CLSMs.	80
4.20 Volumetric Strain for Laboratory Prepared Eagle Ford Soil CLSMs.....	81
4.21 Sample Weight Changes for Laboratory Prepared Austin Chalk Soil CLSMs.....	82
4.22 Sample Weight Changes for Laboratory Prepared Eagle Ford Soil CLSM	83
4.23 Variation of Calcium Concentration for Laboratory Prepared Austin Chalk Soil CLSMs	84
4.24 Variation of Calcium Concentration for Laboratory Prepared Eagle Ford Soil CLSMs.....	85
4.25 Variation of UCS Strength for Laboratory Prepared Austin Chalk Soil CLSMs	86
4.26 Variation of UCS Strength for Laboratory Prepared Eagle Ford Soil CLSMs.....	87
4.27 Effect of Soil Type on Retained Strengths of Field Prepared CLSMs.	91
4.28 Effect of Soil Type on Volumetric Strain Changes of Field Prepared CLSMs.	92
4.29 Effect of Soil Type on Weight Changes of Field Prepared CLSMs.....	93
4.30 Effect of Soil Type on Calcium Concentration Loss of Field Prepared CLSMs	94
4.31 Effect of Calcium Concentration Loss on the Strengths of Field prepared CLSMs	95
4.32 Calibration Chart Developed for Determination of Cement Content (%)	96
4.33 Cement Concentration Loss of Field Prepared CLSMs.....	98
4.34 Effect of Cement Loss on the Strength of Field Prepared CLSMs	98
4.35 Variation of UCS Strengths for Eagle Ford Field and Laboratory Prepared CLSMs	100

4.36 Variation of USC Strength for Austin Chalk Field and Laboratory Prepared CLSMs	101
4.37 Comparison of Retained Strength for Eagle Ford and Austin Chalk Soil CLSMs	102
4.38 Comparison of Volumetric Strain Changes for Eagle Ford and Austin Chalk Soil CLSMs	103
4.39 Comparison of Weight Changes for Eagle Ford and Austin Chalk Soil CLSMs	103
4.40 Comparison of Calcium Concentration Loss for Eagle Ford and Austin Chalk Soil CLSMs	104

LIST OF TABLES

Table	Page
Table 2.1 CLSM Application and Relevant Properties (NCHRP report 597)	14
Table 3.1 Summary of Basic Soil Tests	38
Table 3.2 Additive content % for Different Soils.....	39
Table 4.1 Summary of Additive Types and Dosages for Each Field Prepared CLSMs.....	55
Table 4.2 Summary of UCS strengths for Field Prepared CLSMs.	76
Table 4.3 Summary of Volumetric Strains for Field Prepared CLSMs.....	76
Table 4.4 Summary Weight Changes for Field Prepared CLSMs.	77
Table 4.5 Summary of Calcium Concentration Loss for Field Prepared CLSMs.....	77
Table 4.6 Summary of UCS strengths for Laboratory Prepared CLSMs	88
Table 4.7 Summary of Volumetric Changes for Laboratory Prepared CLSMs	88
Table 4.8 Summary of Weight Changes for Laboratory Prepared CLSMs.....	89
Table 4.9 Summary of Calcium Concentration Loss for Laboratory Prepared CLSMs	89

CHAPTER 1

INTRODUCTION

1.1 General

Typical pipe installation process involves several activities such as excavation, bedding preparation, placing of the pipe and backfilling. Excavation generates large quantities of soil material in any major pipeline construction process. Reuse of the excavated material in the pipe trench constructions as backfill, bedding and haunch materials will result in economical and environmentally friendly construction. The potentiality of reusing the excavated native material, contribute to the sustainability of the pipeline project.

Controlled Low Strength Material (CLSM) using native soil as fine aggregate is an effective option to address the following issues relating to 1) reuse potential of the excavated material; 2) strength requirement for bedding and haunch portions; 3) proper compaction in the haunch zone without damage of the pipe. Using native soil in the place of conventional fine aggregate will greatly reduce the overall project costs and will enhance the sustainability of the project as it eliminates dumping of excavated material in a landfill. Due to flowability and strength characteristics, CLSM is an effective alternative as haunch and bedding material.

Previous research at UTA aimed at the design of CLSMs using native soils, that can be used as bedding and backfill materials to support the large pipeline project. Test results and analysis from the research conducted by Raavi (2012) was successful in establishing the design mix using high plasticity clay as fine aggregates. Though CLSMs do meet the specifications in the short-term, their long-term performance should be verified in order to be successfully used in the actual site, especially when these materials are subjected to seasonal changes such as wetting and drying. Amount of additive leach out due to fluctuations of the water table, rainfall infiltration helps to assess the long term performance of the material.

This research attempts to assess the long-term performance of CLSM through durability studies. Durability of the CLSMs refers to its ability to maintain its desired engineering properties during the design life period. CLSMs using native soils from Woodbine, Eagle Ford, Austin Chalk and Queen City Sand geological formations are analyzed in terms of unconfined compressive strength, volumetric strain changes, weight changes and calcium concentration loss through wetting/drying and leachate collection studies.

1.2 Project Particulars and Research Objectives

The Tarrant Regional Water District (TRWD) with the City of Dallas Water Utilities (DWU), are currently engaged in the planning, design and implementation of a 350-Million Gallons per Day (MGD) raw water transmission system. The transmission system will be constructed across north central Texas from Lake Palestine to Lake Benbrook with connections to Cedar Creek Reservoir, Richard Land Chambers Reservoir, and a Dallas delivery point. Collectively, the system constitutes approximately 145-miles of 84-in. to 108-in. diameter pipeline, a 5-mile 120-inch diameter tunnel, six 100 to 350-MGD pump stations, one 300-MGD balancing reservoir, and ancillary facilities. The program developed by TRWD to accomplish these improvements is called the Integrated Pipeline Project (IPL).

The main objective of this thesis research is to assess the efficacy of CLSM mix design by conducting durability studies on various CLSMs prepared by using native soils from different geologic formations. This study will better understand the long-term behavior of native soil CLSM by assessing its performance under wetting/drying and leaching conditions. Another objective of this study is to compare the performance differences between laboratory and field prepared native soil CLSMs. This type of comparison will identify the differences in sample preparation methods and their effect on long-term performance of these CLSM mixes.

Various tasks involved in addressing the above mentioned research objective are listed below:

Evaluate the variation in physical characteristics-strength, volumetric strains and weight changes during wetting and drying processes.

1. Study the chemical characteristics and effect of leaching on the strength of CLSM specimens by monitoring the amount of cement leached out of the CLSM specimens after each leachate cycle.
2. Compare the physical and chemical characteristic of CLSMs prepared in the field and laboratory conditions.

For this purpose soils from four different geological formations along the IPL pipeline alignment were selected and tested in this research. The original CLSM mix designs for these soils were conducted by Fugro Consultants Inc; and the same mix designs were used to prepare the CLSM specimens both in the field and laboratory. Also, a comparative study was conducted using two soils from Eagle Ford and Austin Chalk formations to study the performance difference based on preparation method. The results of these studies and their analyses are presented in detail in the following chapters.

1.3 Thesis Organization and Summary

Chapter 2 provides a comprehensive literature review of Controlled Low Strength Material (CLSM) including its historical background, advantages over conventional compacted fill, case histories. Previous research studies conducted by various researchers to establish CLSM mix design using native soils including high plastic lay (CH) soil are presented. Leachability and durability related issues in soil stabilization, durability of CLSM along with various methods to perform durability testing are discussed.

Chapter 3 explains the criteria followed in the selection of soils, mix design procedures followed for CLSM specimen preparation. The experimental program along with the various testing procedures followed in this research are described. Details of testing equipment and procedures adopted in conducting durability and leachate studies on both field and laboratory CLSMs are discussed.

Chapter 4 includes test results and comprehensive analysis of the durability studies conducted on CLSMs. Physical and chemical characteristics including unconfined compressive strength, volumetric strain changes, weight changes, and calcium concentration loss for each soil are discussed. Leachability potential and its impact on strength loss, effects of soil type on various engineering variables of CLSM are analyzed. Also, details of the comparative study between field and laboratory prepared CLSMs to study effects of preparation methods on long term performance of CLSM are discussed

Chapter 5 presents the summary and conclusions of the observations and findings obtained from the research study. Also, recommendations are provided for future study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides a comprehensive literature review of Controlled Low Strength Material (CLSM) including its historical background, range of applications and advantages over conventional compacted fill. Discussions are presented on CLSMs, prepared using native soils as fine aggregates. Previous research studies conducted by various researchers to establish CLSM mix design using native soils classified as Lean Clay (CL), Silty Sand (SM), Poorly Graded Sand (SP) are presented. Also, details of the recent research study at UTA that focused on developing CLSM design mixes using high plasticity clay (CH) soil from Eagle Ford formation is presented (Raavi et al., 2012). Discussions are presented on leachability and durability related issues in soil stabilization, durability of CLSM along with various methods to perform durability testing. Background and literature review presented in this chapter is based on the reports from the American Concrete Institute (ACI), National Cooperative Highway Research Program (NCHRP), Materials journals, ASTM special publication and Transportation Research Record (TRB) as well as conventional library resources.

2.2 Historical Background

Till early 1970's soil-cement has been widely used in most of the geotechnical engineering practices. An alternative to compacted granular fill, utilizing fly ash and concrete batching techniques was developed by the Detroit Edison Company, in collaboration with Kuhlman Corp., a ready- mix concrete producer in Toledo, Ohio. This backfill material, which was composed principally of fly ash and 4 to 5 percent cement along with appropriate amount of water lead to the discovery of low strength material (Brewer 1994). Unlike the compacted backfills, this material was proven economical, exhibited characteristic features of cohesiveness

when being placed and formed a steep angle of repose when placed either above or under the water.

In the later years a company known as K-Krete Inc. was formed and started producing material similar to Controlled Low Strength Material. In 1977, four patents including mixture design, backfill technique, pipe bedding, and dike construction were issued to Brewer et al., 1994. Later, Content, Inc in Minneapolis bought these patents and ceded the patent rights to the National Ready Mix Concrete Association (NRMCA) with the condition that these rights may not be used in a proprietary manner. Since then for most construction projects, the contractors, concrete producers have utilized materials similar to K-Krete without infringing the regulations of law. The emergence of K-Krete as a replacement material for conventional compacted fill led to development and usage of similar material throughout United States and Canada. However, to avoid the confusion and reluctance among the engineering community to use these materials and also in response to the proposal of Brewer, ACI Committee 229 formed in 1984 approved term "Controlled Low Strength Material or CLSM"

In 1998, American Society for Testing and Material (ASTM) published a book titled "The Design and Application of Controlled Low Strength Materials" represented the state of the art and practice of CLSM in the field and in research laboratory at that time. The following year, revised edition of the ACI Committee 229 report called "Controlled Low Strength Materials (CLSM)" was published and defined CLSM as a self-compacted, cementitious material used primarily as a backfill alternative to compacted fill. Typically components of CLSMs include binder, water and aggregates. Over the years CLSM is considered as the best alternative for conventional backfill in different field applications due to its inherent qualities and advantages.

2.3 Advantages of CLSM

This section lists the several advantages of using controlled low strength material over the conventional backfill or compacted fill in backfill, utility bedding, void fill and bridge approach applications. Advantages of CLSM as a bedding material include solid, uniform pipe support,

reduced labor costs, reduced trench preparation time, reduction of water ingress to the bedding–pipe interface. The following points detail the advantages of CLSMs over conventional backfill.

1. The self-leveling properties and the lack of need for compaction, benefits in reducing labor and equipment cost.
2. CLSM typically requires no compaction (consolidation) to achieve the desired strength.
3. The ability of CLSM to use wide range of local material, including by product material in a range of applications.
4. The relatively low strength of CLSM is advantageous because it allows for future excavation, if required. CLSM having the compressive strength of 0.3 to 0.7 MPa (50 to 100 psi) is easily excavated using conventional digging equipment, yet is strong enough for most backfilling needs.
5. Requires no storage, as the ready-mixed concrete trucks deliver CLSM in required quantities to the job site whenever material is needed.
6. Though CLSM is slightly more expensive than conventional backfill, inherent properties of CLSM allow reduction of trench dimensions and thereby, reduces the cost below that of conventional backfill.
7. Cost saving could be achieved using waste foundry sand as fine aggregate in CLSM mixtures (Bhat et.al,1996).
8. Unlike the conventional soil backfills, CLSM does not require extensive field testing for sufficient compaction after each lift during placement.
9. Use of CLSM in the underground structures improves worker safety.
10. Like most concrete, CLSM may be mixed in central-mix concrete plants, ready-mixed concrete trucks or pugmills. Once CLSM is transported to the jobsite, the mixture may be placed using chutes, conveyors, buckets, or pumps depending upon the application and its accessibility.



Figure 2.1 Shows the Quick Discharge of CLSM (Source:www.cement.org)

2.4 State of Practice of CLSM

CLSMs have a wide range of applications in construction works that include backfill, structural fills, insulating and isolating fills, pavement bases, conduit bedding, erosion control, and nuclear facilities. Engineered CLSM properties depend on application type. Four major applications of CLSM including Bridge replacement, Backfill, Utility Bedding and Void Fill along with their case histories are discussed in the following sections.

2.4.1 Bridge Replacement

In the case of converting old and deteriorated bridges into culverts or other structure without demolishing them, CLSM as construction material is used to fully fill the original space beneath the bridge.



Figure 2.2 Bridge Replaced with Culverts and Flowable Fill (Source: FHWA/Flowable fill)

2.4.1.1 Case Histories

The Iowa DOT developed a creative process to replace abandoned bridges. This process involved installing metal culverts, pipes, or reinforced box culverts under the bridges. Soil was used as forms at both ends of the bridge. The space between the bottom of the bridge and the top of the culvert was backfilled with CLSM. Also Iowa DOT engineers developed flowable mortar, which includes sand, Portland cement, fly ash and water, to convert 10 bridges into culverts. US Route 30 was kept open to normal traffic most of the time. The cost was one-third less than that of routine repairs (AASHTO 1985).

Six narrow bridges were replaced with a 9-mile length of U. S. Route 30 between Woodbine and Logan in Harrison County, Iowa (Buss 1989). Four of these bridges were modified by using flowable mortar with concrete pipe culverts. The installation of pipe culvert with CLSM cost only one-third of a reinforced-concrete box culvert and one fourth of conventional bridge replacement (Buss 1989).

2.4.2 Backfill Application

Backfill refers to the use of CLSM in filling the openings formed during the installation or repair of utility. The material is only utilized to cover the utility components and transfer loads above, no structural support is provided to utilities in this case. One common application of

CLSM is to replace conventional compacted backfill. The high flowability of CLSM eliminates or decreases the dependence on accessibility of compaction of the equipment, crew productivity, and degree of compaction verification. Granular or site-excavated backfill, even when compacted properly in the required layer thickness may not achieve the uniformity of CLSM. Also the fluidity of CLSM makes it a rapid and efficient backfill material compared to conventional compaction. The backfilling rate of CLSM is about 50 times that of manual compaction by a laborer. RS Means (1995) estimated that the five common laborers could backfill at a rate of 46 m³/day including compaction of soil whereas CLSM can be placed at a rate of 60 m³/hour which is significantly higher than conventional backfill (Sullivan 1997).



Figure 2.3 Bridge Abutment Backfill with Flowable Fill
(Source: FHWA/ Flowable fill)

2.4.2.1 Case Histories

Because of severe settlement problems with soil backfill, the city of Peoria, Illinois, tested CLSM for backfilling utility trenches in 1988. As a result, the city changed its backfilling procedure to require the use of CLSM on all street openings (ACI 1994).

During the construction of Edison's 1350 MW Belle River plant, 122,570 m³ of flowable fly ash were used in trench fill and 84,267 m³ was used in the power house area. The project estimates indicated that more than \$1million were saved through the use of the cement-stabilized ash (Funston 1997). In one tilt-up construction project in Denver, it was estimated that approximately two days of construction time were saved by using CLSM for floor construction

(Hook 1998). In Des Moines County, Iowa, CLSM was used to fill a void along a wooden culvert, where access for conventional repairs was not available (Larsen 1993). Controlled-density fill was utilized to completely fill an underslab void for the US Navy at Rough & Ready Island, Stockton, California. The total cost was less than 20 percent of the amount authorized by the owner for placing and compacting conventional granular backfill (Mason 1998)

2.4.3 Void Filling

Voids are formed due to the continuous erosion of fill material mainly due to run off water in case of approach slabs or due to tidal currents in case of seawalls. Underground structures or other voids that have been taken out of service have the potential to fail and can cause damage to surrounding structures. Also conventional granular backfill material is almost impossible to install and compact in these kinds of situations. CLSM was found to be viable option as it needs no compaction and easy to operate in voids when compared to other conventional methods because of its flowability. CLSM is an excellent material to fill the voids inside and/or between objects and is used widely to fill the tunnel shafts, sewers, basements, and other underground structures.

2.4.3.1 Case Histories

According to the case study referred by Mason (1998), The United States Navy at Rough & Ready Island, Stockton, CA, installed a number of wharfs along the San Joaquin River side. During the installation works, it was noticed that there was a large void under the slab, running its entire length (183 m). The US Navy used controlled density fill (CDF) material to fill the void. A visual inspection showed that there was no settlement of the material. The total costs were reduced by more than 80% of the amount estimated for placing and compacting conventional granular backfill. The U.S. Army Corps of Engineer Waterways Experiment Station (WES) used CLSM in a microtunneling application on a trial basis (Green et al. 1998). The CLSM mixture consists of Class C fly ash and water. A fly ash based CLSM without aggregate is easier to pump on the microtunneling machine. During the microtunneling field material,

CLSM was used to stabilize a tunnel excavation while retracting the microtunneling machine through unstable, flooded, running sand (Green et al. 1998). The void left by the retracted tunnel machine was filled with the CLSM to provide continuous support to the excavation and avoid settlement of the ground surface. Reentry of the microtunneling machine was easy due to the low strength development of CLSM.

CLSM was used to fill an abandoned sewer and a deserted tunnel that passed under the Menomonee River in downtown Milwaukee. The material was reported to flow 72 meters and 92 meters, respectively. Only four hours were needed to fill an exploratory shaft 36.6 m deep, 3.7 m in diameter with a 9.2 m long branch tunnel. A total of 602 cubic meters of CLSM was cast.

In LaSalle, Illinois, 306 m³ of CLSM was pumped to fill the basement of a building. In Seattle, Washington, 19,150 m³ voids over each bus station in a tunnel was filled with CLSM. CLSM has also been used to fill abandoned underground tanks (ACI 1994)

CLSM was chosen to fill the an abandoned pipeline beneath a critical segment of Interstate 70 near Officers Gulch, immediately east of Copper Mountain, Colorado (Hook et al. 1998). Flowable fly ash was used to fill abandoned gasoline tanks, tunnels, pits, and sewers (Krell 1989).

2.4.4 Utility Bedding

Proper bedding for pipes and utilities are critical for pipe performance. Proper compaction in the haunch zone is difficult to achieve using the conventional soil fill. Because of the flow ability and strength characteristics of CLSM, it can be served as a better alternative to both concrete and granular material for bedding applications.



Figure 2.4 CLSM as Bedding Material for Narrow Trench (Source: FHWA/Flowable fill)

2.4.4.1 Case History

A study to evaluate field performance of CLSM as embedment and backfill for flexible pipeline proved that the CLSM gives a higher resistance to deflection than compacted soil. The installation was part of the Ridges Basin Inlet Conduit of the Animas-La Plata Project, a pumped storage system being built by the U. S. Bureau of Reclamation (Howard and Bowles, 2008). Flowable fill was selected as the embodiment material because of speed of installation and to limit potential excessive deflection of the flexible CMP pipe. Measurements were recorded after the placing flowable fill and before backfilling to check circularity of pipe. Years after installation and backfilling, the pipe diameters were again measured to verify the circularity and to see how the CLSM had performed. The measurements showed that the CMP pipe experienced very little deflections.

In another case study, quick setting CLSM fill was chosen by Seattle Public Utilities, Washington to replace an old 914-mm water main that was located under numerous train tracks in downtown Seattle to expedite the construction activity. With the use of CLSM the work under each track was completed in short time. This resulted in reduction of the project duration and thereby advancing construction activites (Finney et al. 2008).

Due to increased awareness of the benefits of CLSM over compacted fill, use of CLSM has grown considerably in recent years. According to EPA (1998), 95% of the 3,000 ready-mixed concrete producers in the United States produce some kind of flowable fill. Increased usage of CLSM has resulted in increased laboratory and field research to better understand the effect of material properties on performance.

CLSM properties that may impact the performance in four target application are presented in Table 2.1.

Table 2.1 CLSM Application and Relevant Properties (NCHRP report 597)

CLSM Application	Important Properties	Potentially Important Properties
Backfill	Flow Compressive Strength Excavatability Hardening time Settlement Corrosion of metal utilities Subsidence	Freeze- thaw resistance Leaching and environmental impact
Utility Bedding	Flow Compressive Strength Hardening time Corrosion of metal utilities	Freeze- thaw resistance Leaching and environmental impact Thermal Conductivity
Void fill	Flow Subsidence Settlement	Unconfined Compressive Strength
Bridge Approaches	Flow Compressive Strength Hardening time Shaer Strength Resilient Modulus/CBR Settlement Freeze- thaw resistance	Leaching and environmental impact

The properties tabulated helps in developing the laboratory testing program based on CLSM application.

2.5 Substantial Material Reusability

Several sustainability issues of large construction projects can be evaluated and implemented through proper geotechnical engineering practices. As a part of the sustainability endeavor, the potential reuse of local excavated native material should be thoroughly evaluated as this alone will have heavy impacts on the sustainability efforts. Hence, it is imperative to explore ways to cut down the materials costs by evaluating the potential reuse of excavated material for various pipe zone and foundation applications such as bedding, haunch and backfilling zones.

Usage of CLSM proved to be the best option to address the above issues relating to sustainability. The conventional aggregates complying with ASTM C 33 are generally used in CLSMs. Use of native soils in place of conventional aggregates is the cheapest viable alternative for large projects as it greatly reduces the dumping of excavated material which eventually saves land space and transportation cost.

Use of native soil has been successfully implemented for four pipeline projects in Northern California. Cases where native soil is used to create CLSM for pipeline backfill are discussed in the following sections

2.5.1 West Sacramento Force Main Project

The West Sacramento Force project (WSFM) is a part of the Lower North West Interceptor which includes the construction of 6.4 km (4 mi.) long pipeline through the urban portion of the City of West Sacramento, California. The soils encountered along the proposed twin welded steel pipe (WSP) and reinforced concrete cylinder pipe (RCCP) alignment were typically sandy silt, lean clay (CL) and fat clay(CH). The contractor Mountain Cascade, Inc. of Livermore, California submitted a contractor-initiated change proposal (CICP) to use trench side soil in CLSM instead of commercial aggregate. The cost proposal was approved with the

conditions, that the contractor should perform a successful trial demonstration to meet the specified CLSM strength requirement.(minimum strength of 350 kPa at 7days and maximum strength of 1000 kPa at 28 days). The contractor used a specially designed mobile mixing plant to prepared CLSM at the side of the trench. A trail section of CLSM as shown in Figure 2.5 was prepared to permit observations and sampling. From 28-day unconfined compressive test results it was observed that approximately 65% of test results were above 350 kPa (50 psi). The average strength gain of 70% between the samples of the same batch at 7 and 28 days was observed.



Figure 2.5 Test Section of CLSM (Finney et al., 2008).

2.5.2 Arden Parallel Force Main Project

The Arden Parallel Force Main (APFM) project involved the installation of 3.2 km (2 mi.) of 1520 mm (60 in.) WSP parallel to American River to provide additional system capacity and redundancy to the primary sewage conveyance across the American River in Sacramento,

California. Subsurface conditions along the pipe alignment consisted of sandy silt and silty sand, underlain by poorly and well graded sands with occasional silt lenses.

As per the contract, CLSM with commercial aggregates were to be used to meet the specified compressive strength of 350 kPa (50 psi) minimum at 7 days and between 690 to 1000 kPa (100 to 150 psi) at 28 days. But the contractor elected to use excavated native sandy soils to make the CLSM. The contractor used a small on-site batch plant as shown in Figure 2.6 and selected the excavated material to make the CLSM. From the 28-day compressive strength test result, it was observed that nearly 100% of test results were above 350 kPa (50 psi) , 13% above 1000 kPa (150 psi).



Figure 2.6 Small On–Site Batch Plant for CLSM Mixing (Finney et al.,1998).

2.5.3 Geysers Recharge Project No. 1- Healdsburg North and South.

The Healdsburg section of Geysers Recharge Project (GRP) involved the installation of 10.9 km (6.8 mi.) of 1220 mm (48-inch) WSP through Sonoma County, California in the vicinity of Healdsburg. The goal of the GRP was to deliver treated wastewater to a well field at the

Geysers geothermal plant. Subsurface conditions along the pipe alignment mainly consisted of rounded gravel, sand, silt and clay sandy silt and silty sand.

The contract permitted to use CLSM with native soils with a maximum particle size of 1 in. and minimum sand equivalent of 15 to meet the specified compressive strength of 350 kPa (50 psi) minimum at 7 days and 1400 kPa (200 psi) at 28 days. The contractor elected to use CLSM for both bedding and pipe zone fill. The contractor used a small on-site batch plant to make the CLSM and transported it to the trench side using the ready mix truck as shown in Figure 2.7. From the 28-day compressive strength results it was observed that nearly 80% of test results were above 350 kPa (50 psi). The average strength gain of 30% was observed between the samples of the same batch at 7 and 28 days.



Figure 2.7 CLSM Discharge into trench from Ready -Mix Truck (Finney.,1998)

2.5.4 Geysers Recharge Project No. 2- Llano Mark West

The Llano Mark West section of Geysers Recharge Project (GRP) involved the installation of 11.1 km (6.9 miles) of 1220 mm (48 in.) WSP through Sonoma County, California in the vicinity of Sebastopol. The goal of the GRP was to deliver treated wastewater to a well field at the Geysers geothermal plant. Subsurface conditions along the pipe alignment mainly consisted of stiff sandy silts, dense clayey sands and fine gravels.

The contract permitted to use CLSMs with native soils with a maximum particle size of 1 in. and minimum sand equivalent of 15 to meet the specified compressive strength of 350 kPa (50 psi) minimum at 7 days and 1400 kPa (200 psi) at 28 days. The contractor elected to use CLSM for both bedding and pipe zone fill. The contractor used a portable trench side pug mill to mix selected soils with required water and cement. From 28-day compressive strength result, it was observed that nearly 90% of test results were above 350 kPa (50 psi) at 28 days, average strength gain of 70% was achieved between the samples of the same batch at 7 and 28 days.

Over the years several researchers have attempted to use the native soil as aggregate in Controlled Low Strength Material (CLSM) for pipeline backfill. One among such attempts was conducted at UTA. The research aimed at developing CLSM design mix using soils with low workable characteristics. Experimental program performed by replacing the conventional aggregates with the native high plasticity soil was successful in formulating a CLSM mix design that meets the specified properties for an effective backfilling material.(Raavi, 2012). Test results and analysis indicated that high plasticity clay can be successfully used as aggregate in CLSM mixes (Raavi, 2012).

Different components that can be used for preparation of CLSM design mix are binders (cement, cement Kiln Dust, lime, fly ash, Dry scrubber ash, Wooden ash), water, coarse aggregates, conventional fine aggregates (concrete sand, foundry sand) and alternative fine aggregate (scrap tire rubber, recycled glass) and admixtures. The components of controlled low strength material differ and they depend on the availability of component materials as well as on requirements and application area of CLSMs.

2.6 CLSM - Properties

This section provides information on the properties of CLSM that most affect its performance in key applications. Based on application-specific properties and combined with a synthesis of available literature, CLSM properties were grouped into 3 categories: 1. Important CLSM properties (flow, setting time, unconfined compressive strength, corrosion) 2. Potentially

important CLSM properties (excavatability, subsidence, Freezing and thawing, segregation and bleeding, triaxial shear, CBR, resilient modulus, water permeability, dry shrinkage Leaching/environmental impact) and 3. Less important CLSM properties (direct shear strength, air/gas permeability, consolidation and thermal conductivity).

According to Folliard et al. (2008), fresh properties of CLSM are flowability, segregation, bleeding, setting time and subsidence while hardened CLSM properties include compressive strength, excavatability, permeability, shear strength, resilient modulus, consolidation, shrinkage and thermal conductivity. In case of pipeline application properties such as flowability, compressive strength are of major importance. Hence, this literature search mainly focused on gathering information on these fundamental fresh and hardening properties of CLSM.

2.6.1 Flowability

One of the most important attributes of CLSM is its ability to flow easily into confined areas, without the need for conventional placing and compacting equipment. Its self-leveling property greatly reduces the labor and also increases the speed of construction. ASTM D 6103, "Flow Consistency of Controlled Low Strength Material" is the most commonly accepted test procedure. A plastic cylinder with dimensions 150 mm (6 in.) and 76 mm (3 in.) inside diameter is lifted, allowing the CLSM to slump and increase in diameter. The final diameter is typically used to differentiate between various degrees of flowability. A final diameter of 203 mm (8 in.) or higher is the typical value of a flowable mixture.

2.6.2 Unconfined Compressive Strength

Unconfined compressive strength is the significant property measured and is most commonly found in state DOT specifications. CLSM compressive strength values are often used as an index for excavatability or digibility, when future excavation may be required. Materials and mixture proportions must be selected to ensure that these strength values are not exceeded in the long term.

The development of CSLM compressive strength is different from conventional concrete in that it is thought to have two components of strength: particulate and nonparticulate (Bhat and Lovell, 1996). The non-particulate component of strength results from the cementitious reaction of cement and fly ash with water, whereas the particulate component of strength is similar in the nature to that of granular soil. Water-cement ratio plays an important role in the development of unconfined compressive strength (Bhat and Lovell, 1996).

ASTM D 4832, "Preparation and Testing of Controlled Low-Strength Material (CLSM) Test Cylinders" is the most common method used by state DOTs for evaluating CLSM strength. The characteristic low strength of CLSM creates problems in testing cylinders because the many load frames used by researchers are in the range of 1,300 to 2,200 kN (Folliard et al. 1999). But, for these cylinders with compressive strength of 1.0 MPa, the maximum load at failure is only about 18 kN, approximately 1 percent of the load frame capacity which makes the precision of the load frame doubtful (Folliard et al. 2008). This problem can be eliminated when smaller diameter of cylinders is used (Folliard et al. 2008).

Also, durability of CLSM is important in terms of the strength variations with time. The following sections explain durability related issues on stabilized soils.

2.7 Durability of CLSM

Since, the evolution of CLSM is relatively recent, there have not yet been significant durability problems identified in the field applications. Durability problems typically takes years to manifest, there is some concerns over the long term durability of CLSM. Therefore, it is essential to study the durability characteristics of CLSMs as a construction material. The following sections describe various durability tests performed to evaluate long term performance of CLSM.

2.7.1 *Freezing-and-Thawing Study*

Several studies have focused on the resistance of CLSM to freezing and thawing (Bernard and Tansley 1981; Krell 1989; Burns 1990; Nantung 1993; Gress 1996). The unique

structure of CLSM creates some intriguing challenges when its freezing and thawing resistance is being assessed. First, CLSM may be damaged by both internal hydraulic pressure and frost heave when exposed to freezing and thawing cycles. Second, test methods that have been developed for conventional concrete have been found to be too severe for testing CLSM. In 1993, Nantung proposed modification to AASTHTO T-161 (common method for concrete), to provide less severe freezing conditions to better simulate field conditions.

Gress (1996) performed laboratory and field testing of CLSM and found that CLSM can survive freezing and thawing damage. Gress proposed for removal of top 50 to 150 mm of CLSM trenches after set and backfilled with a frost heave-compatible base material to ensure uniform heaving of pavement and trench. When laboratory test methods to assess frost resistance of CLSM are being considered, the potential for frost heave damage can not be overlooked. In this modified method CLSM samples were exposed to temperature change from -18°C to 23°C for each cycle.

The freezing and thawing cycles can cause damage by internal hydraulic pressure and frost heave (Du, 2001). The possible damage of CLSM due to freezing and thawing may be a concern, especially if it leads to a change in volume of the material. There has been very little field evidence suggesting that this is a problem with CLSM, but research was needed to assess the laboratory performance of CLSM, and to determine if a suitable method could be recommended. Based on the preliminary findings, ASTM D 560, "Freezing and Thawing of Compacted Soil Cement Mixtures," proved to be a more viable test and has been used to measure the freeze-thaw resistance of CLSM (Janardhanam et al. 1992).

2.7.2 Corrosion

Very few studies have focused on the corrosion of metals in CLSM (Abelleira et al. 1998; Brewer 1991), but considerable information and data exist on the corrosion of metals in soils. Corrosion deterioration of metal pipes placed in CLSM has not yet surfaced as a serious problem in field applications. But, because of the long-term nature of corrosion and other

durability problems, it could prove to be an important aspect of CLSM durability. Since durability of CLSM has not been proven yet, Utility agencies and municipalities are often not willing to use CLSM due fear of the significant efforts and cost required to repair pipes, disruption to the public as a result of the loss of service or road closure resulting from failures caused by corrosion. Hence research to evaluate the corrosion performance of commonly used pipe materials embedded in CLSM gained importance.

The following section summarizes studies on steel corrosion in CLSM, as well as in conventional compacted fill, with particular emphasis on the mechanisms of corrosion likely to occur in CLSM. NCHRP took the initiative in establishing guidelines on the corrosion performance of metallic materials embedded in CLSM (Folliard et al. 2008). Existing guidelines on the corrosivity of soils around metallic materials, which do not consider the characteristics of a cementitious material (i.e., CLSM), often indicate that CLSM could be detrimental to the corrosion performance of pipes embedded in CLSM.

The most common methods used to determine the corrosivity of soils around ductile iron pipes is the ANSI/AWWA C105/A21.5, "American National Standard for Polyethylene Encasement for Ductile-Iron Pipe Systems." This standard, assigns points for various soil backfill characteristics (such as pH, resistivity, moisture content, etc.), and, if the sum of the points from all characteristics is more than 10, the soil is assumed to be corrosive. For soils with pH values greater than 8.5, the standard notes that these soils are generally quite high in dissolved salts, resulting in lower resistivity values and higher assigned point values. However, the high pH of the CLSM results from the hydroxyl ions and alkalis present in the pore solution and not from dissolved salts. High-pH pore solutions have been well documented to result in stable, protective, passivating oxide films on iron products (Broomfield 1997).

Several key CLSM parameters affect the likelihood of corrosion, including permeability, pH, resistivity, buffering capacity, presence of chlorides, and exposure conditions (i.e., type and nature of native soil, etc.). The permeability of CLSM to water and oxygen is critical because

both water and oxygen are required for the corrosion process to occur. The migration rate of chloride is critical because these ions can significantly increase localized corrosion. Water permeability tests (ASTM D 5084), air permeability tests, and chloride diffusion data can be used to design CLSMs to protect metals from corroding. In addition, the absorption capacity of CLSM may also be measured using ASTM C 642, "Density, Absorption, and Voids in Hardened Concrete," to determine the degree of moisture available for corrosion in CLSM mixtures.

At high pH values, iron is passivated, with a very low corrosion rate, but as the pH decreases, the corrosion rate increases rapidly. Because CLSM typically exhibits a pH (from extracted pore water) of greater than 11.5, corrosion is not expected to be a severe problem. However, the pH of CLSM has been measured to drop when high dosages of fly ash are used, and when some types of foundry sand are used (FHWA 1997). ASTM G 51, "Measuring the pH of Soil for Use in Corrosion Testing," has been used to assess the pH of CLSM. However, pH values by themselves are not sufficient to predict or design against corrosion, but can be very effective in conjunction with other basic test results. Resistivity measurements indicate the relative ability of an electrolytic material to carry electrical currents. When metallic samples are placed in a medium, the ability of the medium to conduct electrical currents will influence the degree of corrosion activity.

For soils, resistivity is one parameter used to determine the "corrosivity." The Wenner four-electrode method (ASTM G 57) is typically used to determine soil resistivity and can be easily used to measure CLSM resistivity. The rate of chloride diffusion through CLSM is an important parameter that can provide important information about CLSM applications in saline environments. Although this type of testing has not been reported in the literature for CLSM applications, it is widely recognized for concrete applications. This test could be accomplished by following the typical approach for concrete, in which chloride profile data can be used by Fick's Second Law to predict the rate of chloride penetration through CLSM. Because CLSM is

used in a range of applications, the exposure conditions and corrosion resistance will vary widely.

For trench backfill and bedding applications, the corrosion activity of embedded metallic piping systems can be increased by the development of galvanic cells (NCHRP report 597). Galvanic cells can develop when the metallic pipe is embedded in two different material types. For trench backfill applications, a typical scenario includes a lateral pipe across the trench. For pipe bedding applications, galvanic cells can develop when the metallic pipe displaces the CLSM bedding material and rests on the original soil. Because the CLSM is often significantly different than the original soil conditions, the potential for high corrosion rates may exist.

Test methods typically used to measure corrosion in concrete may be applied to CLSM, including ASTM G 109, "Determining the Effects of Chemical Admixtures on the Corrosion of Embedded Steel Reinforcement in Concrete Exposed to Chloride Environments"; ASTM G 59, "Conducting Potentiodynamic Polarization Resistance Measurements"; and ASTM G 1, "Preparing, Cleaning, and Evaluating Corrosion Test Specimens." In addition, Abeleirra et al. (1998) have proposed a simple test method that measures the corrosion of metal coupons immersed in CLSM. With this test method, CLSM, as compared to a conventional fill, shown less the corrosion of metallic pipe. The method, however, did not study the galvanic effects of metals embedded in both CLSM and soil. Significant research, including both laboratory and field study evaluations, was performed under this NCHRP project to evaluate the potential for corrosion of metals in CLSMs. Information gleaned from these efforts was ultimately integrated into recommended test methods and specifications for CLSM.

2.8 Durability of Stabilized soils.

Chemical additives including cement, fly-ash, lime stabilizes the soil temporarily, the effectiveness of Chemical stabilizers will be is lost over a period of time (McCallister and Petry, 1992) due to various factors such as rainfall, fluctuation of the water table, dry season, etc. As a

result, the soil mass after losing the stabilizer does not perform according to the designed standards and exhibits premature failures (McCallister and Petry, 1992; Chittoori et al. 2011).

Durability refers to the permanency of chemical stabilization i.e., the ability of the soil particles and the stabilizers to hold together and remain intact for a long period of time. In the case of soil stabilization the strength and stiffness will increase over the time with the formation of pozzolanic reactions and cementitious bonds between particles. The stabilized material should be able to withstand climatic stresses, such as being subjected to severe wetting and drying. The action of wetting and drying plays an important role in the durability of soils (DoT, 1986).

Durability studies are conducted on soil samples, either with or without stabilizers, to duplicate field climatic conditions in the laboratory within a shorter time period. ASTM D 559 provides a testing guideline to replicate moisture and temperature fluctuations occurring in the field. Each wet-dry cycle consists of submerging the two soil samples in water for 5 hours and then placing them in a 70°C oven for 42 hours. After removal from the oven, one specimen was subjected to volume change and moisture content measurements. The second specimen was subjected to leachate tests to determine the chemical additive loss. The test is then continued until 12 wetting/drying cycles are completed or until the sample failed.

Chittoori (2008) investigated highly expansive soils from various regions in Texas. Soils were subjected to accelerated curing since better results were achieved within a short period of time rather than the standard curing test provided by ASTM. Durability studies were conducted on all soils by alternating wetting and drying cycles. Both volumetric changes and strength loss were monitored and presented for all soil samples at various cycles to evaluate the swell/shrink related volume changes.

Few studies have been conducted on the leach test of chemically-treated soils to understand the leaching of chemicals from moisture flows (Barenberg, 1970; McCallister, 1990). Barenberg (1970) reported leach tests on lime, cement and fly ash-treated soil samples

compacted at optimum moisture contents. Leach tubes of 2 ft long and 4 in. diameter were filled with chemically-treated soils that were subjected to water leaching at a rate comparable to the estimated local rainfall. The process was performed for ten days and the leachate and soil samples were then chemically analyzed. This analysis showed that small amounts of chemical stabilizer leached out during these tests.

2.8.1.1 Standard Approach

The wetting and drying of soil specimens are typically carried out on the basis of ASTM D 559. This test procedure determines the soil-cement losses, weight and volumetric changes produced by repeated drying and wetting of hardened soil-cement specimen. This method simulates field conditions, similar to that of wetting and drying conditions, within a short period of time. According to the ASTM D 559 method the prepared soil specimens were cured and then submerged in water for 5 hours and then oven dried at 160°F for 42 hours to complete one wetting/drying cycle. The soil specimens were studied for volumetric strain change measurements before and after the completion of wetting/drying cycles. Dial gauges and pi tape were used to measure the vertical deformations and the diametrical changes respectively. Dial gauge readings were monitored to assess the effectiveness of stabilization with time. The soils were subjected to unconfined compressive strengths at 0, 3,7 and 14 cycles of wetting/drying. The test was continued until 14 wetting/drying cycles are completed or until the sample fails.

2.8.1.2 Modified Approach

A new device developed by Priya (2011) at UTA combines the wetting/drying and leachate studies in a single setup instead of two separate tests. The schematic of the combined device to evaluate stabilization durability of soils is shown in Figure 2.8. This modified approach not only reduce the test duration including time for collection of leachate, but also avoids the preparation of two samples, each to be used for wetting/drying cycles and leachate studies. Thus allowing more efficient and effective usage of material and time when compared to the standard approach.

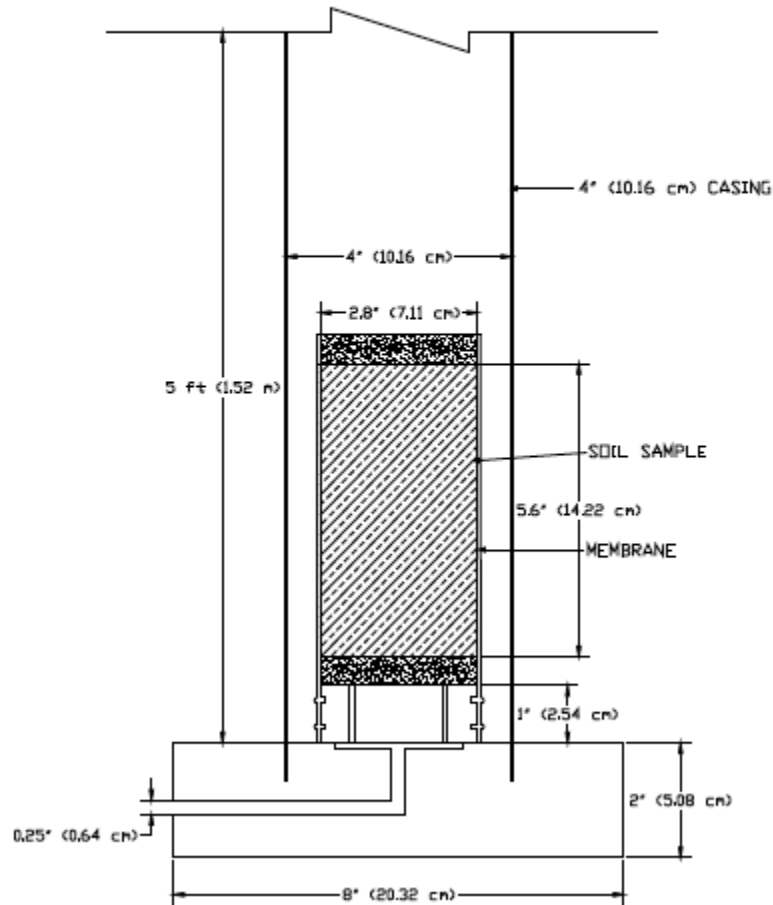


Figure 2.8 Schematic of Combined Device (Priya, 2011).

Soil specimens were prepared in accordance to ASTM D559. The cured samples were then submerged in water for 5 hours and dried at 160° F for 24 hours to complete one wetting /drying cycle. Volumetric and weight changes are recorded both before and after the completion of each wetting/drying cycle using vernier calipers and a balance, respectively. Leachate was also collected through the outlet located at the bottom after the specimen has undergone one wetting cycle. The following section covers leachate studies performed in the literature.

2.8.2 Leachate Studies

Leachability of a soil is the parameter used to measure the permanency of the stabilizer. Leachate studies were introduced by McCallister (1990) to address the permanency of chemical stabilization of water percolating through a soil specimen from rainfall and moisture migration. From the research conducted by Thompson (1968), it was found that the leaching had a direct influence on the soil properties such as soil pH, percentage base saturation and calcium/magnesium ratio due to the reduction of soil-cement reactivity in areas of high permeability. Information obtained from leachability studies such as the calcium oxide (CaO) content can be very useful in accessing the potential reactivity and effects of long term strength gain of stabilized soils.

McCallister and Petry (1992) performed leachate tests on lime-treated clays in specially fabricated flexible cells as shown in Figure 2.9. Several variables including soil types, curing conditions and flow pressures were studied. The apparatus consists of a pressure cylinder, an acrylic cell to hold the specimen in confinement. The confinement of the soil specimen was higher than the pressure of the water, which is sent through the soil specimen. The leachate coming out of the soil specimen was collected and is tested for calcium and pH studies.



Figure 2.9 Leachate Apparatus Set up.

Nishida et al. (2003) conducted a study on stabilized soil columns beneath the surface, to study the effects of leaching phenomenon. It was found out that the soil had lost some of its

strength due to Ca ions leaching. The needle penetration test was used in order to evaluate the unconfined compressive strength of the soil. Also a numerical modeling was used to create an ion migration model due to Ca ions leaching. It was concluded that the strength loss in lime columns was slightly influenced by Ca ions leaching.

Yong and Ouhadi (2007) showed that the leaching has considerable influence on the strength of the soil specimen. Studies were conducted on soil specimens with distilled water to study the effect of leaching on strength and found that the strength of the soil sample decreased when leached.

Chittoori (2008) performed two series of moisture conditioning tests on highly expansive soils from various locations in Texas. The first test addresses issues correlating with rainfall infiltration whereas the second test observes the volumetric and strength changes of soil to evaluate the swell/shrink related volume changes during wetting and drying cycles from seasonal changes. A simulation of water inflow into the soil due to rainfall was replicated with the help of leachate apparatus. The leachate process was depicted in Figure 2.10. Accelerated curing technique was adopted for the study. The cured soil specimen were subjected to moisture flow from a water tank at a constant heat. Preliminary tests were conducted to finalize the pressures to be applied to the water flow. These pressures differed from soil to soil as the goal is to complete one leaching cycle in one day. One leaching cycle here is defined as the amount of leachate volume collected that is equal to one soil specimen's void volume. Leachate samples were collected based on the pore volume of the sample and tested for pH. Based on the test results it concluded that calcium ion loss is due to probable loss of stabilizer.

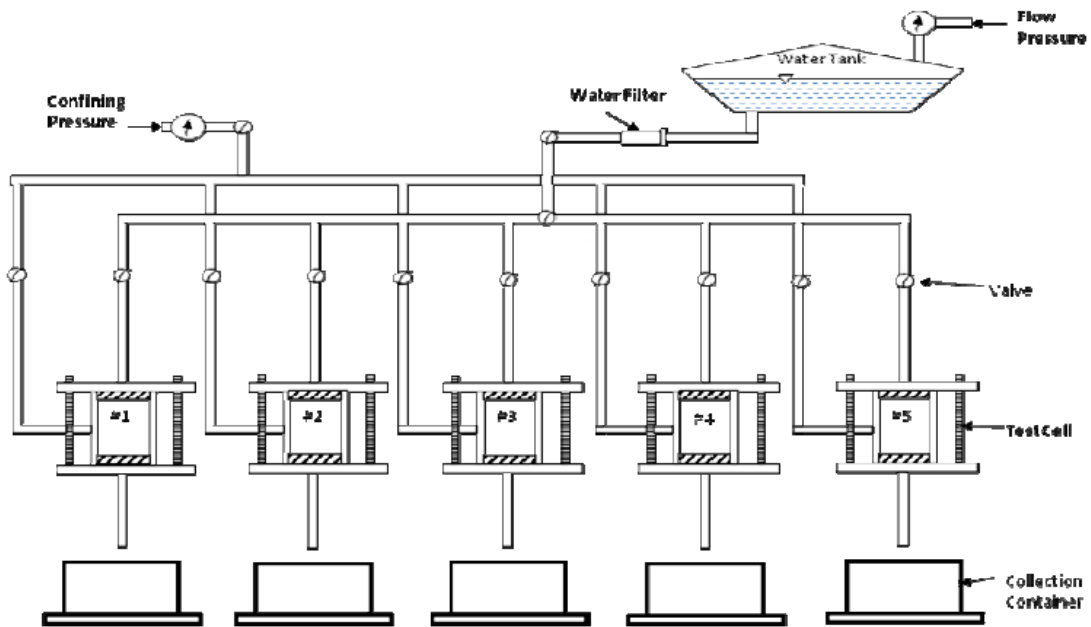


Figure 2.10 Schematic of the leachate process (Chitoori, 2008).

Priya (2012) used new setup to conduct the leachate studies. Samples are prepared according to ASTM D 559 and re cured for 28 days. The samples were then subjected to wetting and drying process. The samples were submerged in water for 5 hours and dried at 160° F for 24 hours to complete one wetting and drying cycle. Leachate collected through the outlet at the bottom plate after certain wetting/drying cycles were tested for calcium concentration loss. The amount of calcium concentration loss at each cycle was determined using EDTA titrations.

2.8.2.1 Calcium determination by EDTA Method (Leachate Studies)

By determining the amount of additive loss, the variation in strength and stiffness parameters can known. In order to determine the loss of chemical additive, the Leachate collected from each soil specimen was subjected to calcium leachate tests after the completion of the desired number of cycles. A small sample representative, 25 ml, of the collected leachate was taken and placed in an Erlenmeyer flask. The contents of a Calver2 Calcium Indicator

pillow packet were poured into the flask and swirled around. Whereas, if the solution turns violet upon addition of the Calver2, TitraVer Hardness Titrant was added slowly until the solution turns blue. The start point and end point of the titrant is noted. The difference in these numbers provides the amount of titrant required to reach the solutions endpoint. A multiplier was applied to convert the ml to mg/L of Calcium. Furthermore, this number was converted to ppm of a stabilizing agent leached out.

2.9 Summary

This chapter explains a brief history and development of CLSM materials, advantages of CLSM over conventional soil backfill, state of art and current practices with their relevant case studies. Some of the application areas of CLSM such as backfills, structural fills, pipelines, bridge approaches, void filling are discussed here.

Durability of Stabilized soils through wetting/drying and leachate studies along with standard and modified approaches to perform durability tests are discussed. Durability of CLSM along with various testing procedures such as thawing-freezing, corrosion, wetting/drying studies to access long term durability potential of CSLM material are also presented.

CHAPTER 3

LABORATORY TESTING PROGRAM

3.1 Introduction

The objective of this research study is to assess the long term performance of CLSMs prepared with native soils by conducting the durability and leachability studies. CLSMs prepared in the field by Fugro Consultants Inc., a local geotechnical company using soils from Eagle Ford, Queen City Sand, Woodbine and Austin Chalk geological formations. Specimens from these mixes were prepared and then subjected to durability studies. These results were compared against laboratory prepared soil samples to understand the differences between the laboratory and field prepared CLSM samples. Several properties including unconfined compressive strength, volumetric strain changes, weight changes and the concentration of calcium leached out of the sample were studied.

This chapter describes the experimental program along with the various testing procedures followed in this research. Details of testing equipment and procedures adopted in conducting Durability studies on both field and laboratory CLSMs are discussed. Also, all the engineering tests performed here are in compliance with the American Society of Testing and Materials (ASTM) standards.

3.2 Soil Selection

The pipeline project involves the design and installation of a 147 mile pipeline extending from Lake Palestine to Lake Benbrook with connection to Cedar and Richland–Chamber Reservoirs. The backfill along the pipeline alignment has varying geology and includes several geological formations. The backfill study–Integrated Pipeline (IPL) comprises of two phases. The first phase of this project was conducted by Karduri (2011) and focused on the selection

and sampling of soils from multiple locations along the pipeline alignment to assess the reusability potential of these materials as bedding and backfill materials for the pipeline.

The second phase of the backfill study consists of two tasks. Task 1 comprises of conducting mix design for stabilizing five high plasticity soils along the integrated pipe alignment, whereas task 2 involves performing six CLSM mix designs using two high plasticity native soils as fine aggregates.

Mix designs were formulated using native CH type soil, proving that high plastic clay can also be successfully used as fine aggregate in CLSM mixes and can be an effective backfill material for pipeline (Raavi, 2012). However, durability studies were not performed to evaluate the long term behavior and strength parameters of the native CLSMs.

To assess the long-term behavior of native soil CLSM, soils from various geological formations were chosen along the pipeline profile. Since the native soils vary considerably, among the various geological formations along the alignment of the proposed pipeline project, some major formations were chosen to give guidance to the construction needs for placing CLSM around the pipeline. Figure 3.1 shows the geological formations along the pipeline alignment from which soils are selected.

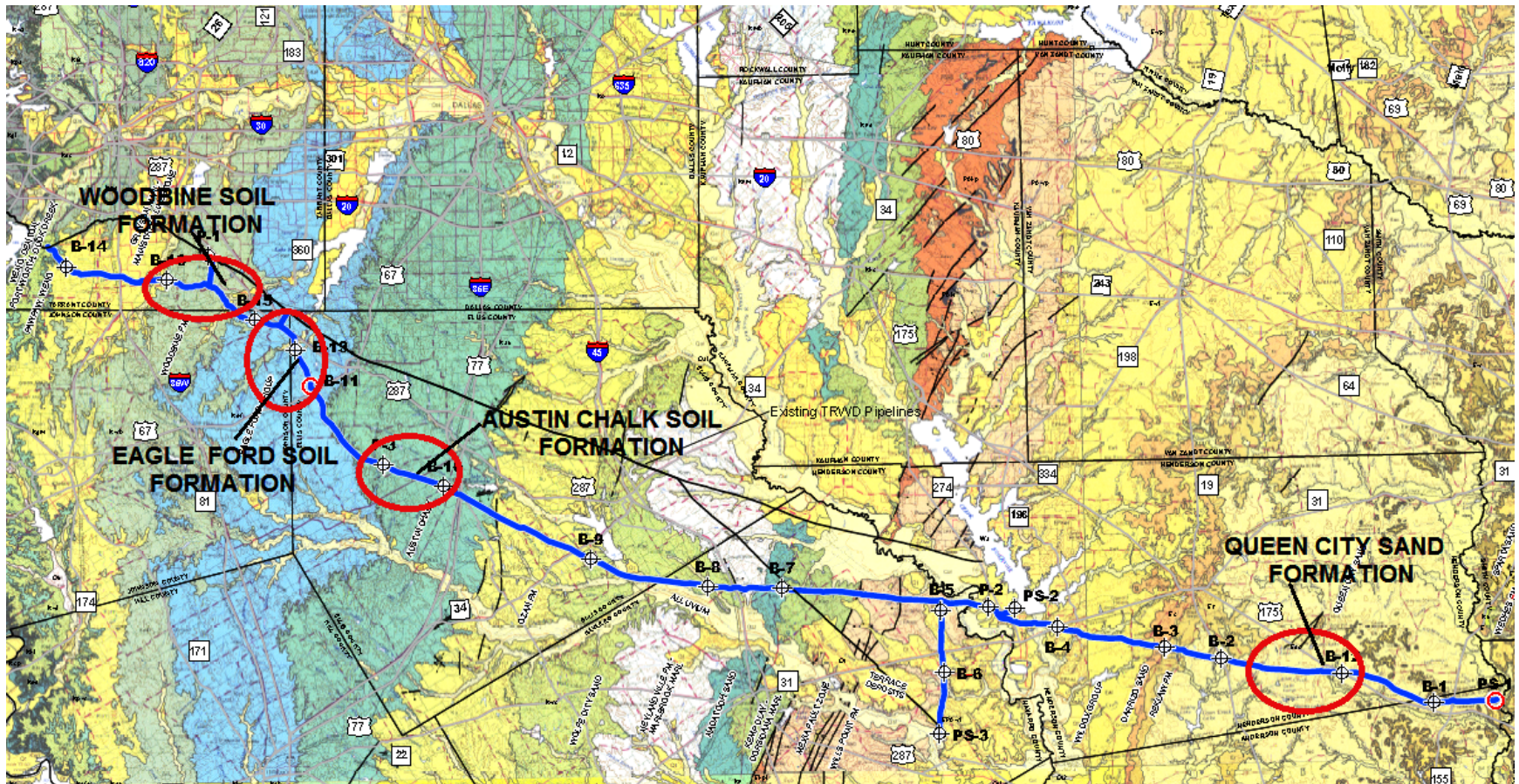


Figure 3.1 Source and Location of Soils.

The soil samples from four different geological formations including Austin Chalk, Woodbine, Queen City Sand, and Eagle Ford are represented in Figure 3.2.



Figure 3.2 Pulverized Soil Samples from Four Different Geological Formations

3.3 Classification Tests on Native Soils

Basic soil tests such Sieve analysis and Hydrometer tests were performed to determine the particle size gradation of soils. Further, Atterberg limits tests including Liquid Limit, and Plastic Limit tests were also performed for each soil to determine corresponding Plasticity Index values. Based on the results from these basic tests, classification details regarding the soil type are determined. The following section explains the test procedures that were carried out to know the physical properties of soil that are used to classify soils.

3.3.1 Sieve Analysis

This test was conducted to obtain the grain-size distribution of soils. The test was conducted according to the ASTM D 422 method. A soil sample representative of the region

from which it was collected was passed through No. 200 sieve using water. The distribution of particle size of the sample portion retained on the No. 200 sieve was determined by sieve analysis, while the sample portion passed through No. 200 sieve was determined by hydrometer analysis. Sieve analysis establishes the percentage of the coarse fraction of the soil (Gravel and Sand) while hydrometer analysis establishes the percentage of fine fraction in the soil specimens (Silt and Clay).

3.3.2 Hydrometer Analysis

Hydrometer Analysis was carried out to study the fine particle distribution of silt and clay fractions present in the field soil. This test was performed as per ASTM D 422 method. The procedure involved taking 50 g of the oven dried portion that passed No. 200 sieve (explained in the previous section) and mixed with a solution containing a 4% deflocculating agent (Sodium Hexametaphosphate) and soaking for about 8 to 12 hours. The prepared soil was thoroughly mixed in a mixer cup and all the soil solids inside the mixing cup were transferred to a 1000 cc graduated cylinder and filled to make using distilled water.

The hydrometer readings were recorded at a cumulative time of 0.25 min., 0.5 min., 2 min. 4 min., 8 min., 15 min., 20 min., 2 hr., 4 hr., 8 hr., 12 hr., 24 hr., 48 hr., and 72 hr. After taking the readings initially for the first 2 minutes, the hydrometer was taken out and kept in another cylinder filled with distilled water. Necessary temperature corrections, zero corrections and meniscus corrections were made in the hydrometer readings as per procedure.

3.3.3 Atterberg Limits

If the soil steadily dries, depending on its moisture content, it will behave like a plastic, semisolid, or solid material. To determine the water content boundaries between these states, it is important to perform Atterberg limits. These boundaries are known as shrinkage limit (SL), plastic limit (PL) and liquid limit (LL); they divide the soil states in the following order: dry, semi-solid, plastic, and liquid. Of the three states, LL and PL are the most crucial factors; the

mathematical difference in these values is known as plasticity index (PI). PI characterizes the plasticity of soil numerically. The higher the PI, the more plastic the soil is.

The test results here describe the gradation and consistency limits of each soils. Soil classification based on Unified Soil Classification System (UCSC) was performed to characterize the type of soil. The soil properties for different soils are shown in Table 3.1.

Table 3.1 Summary of Basic Soil Tests

Soil Formation	Standard Gradation				Plasticity Index (%)	Soil Type based on USCS
	Sieve Analysis		Hydrometer			
	%Gravel	% Sand	% Silt	% Clay		
Wood Bine	4.3	65.5	10.2	20	0	SM
Eagle Ford	0.5	6.5	43	50	32	CH
Austin Chalk	15	24	31	30	13	CL
Queen City	3	78	15	4	0	SM

Soil classification tests show that Eagle Ford and Austin Chalk soils are plastic soils whereas as Woodbine and Queen City Sand are non plastic soils. Using these soils the CLSM design mix was established to meet the strength requirement The following section explains the CLSM specimen preparation procedure adopted in the field.

3.4 Field Prepared Specimens

A local geotechnical consulting company performed a study on Controlled Low Strength Material (CLSM) to evaluate the feasibility of using native material along the alignment of the Integrated Pipeline (IPL) project as authorized by the IPL program management team. Fugro consulting Inc. conducted mix designs using native Queen City , Woodbine, Austin Chalk, and Eagle Ford soils to meet CLSM specifications for pipe bedding and haunch zone (28 day minimum strength of 50psi and maximum strength of 150 psi). The purpose of design mix was to quantify the amount of cementitious material and water for the different soil types along the IPL alignment in a controlled environment. Portland cement was used as the additive in the

CLSM design mix. Table 3.2 below presents the dosage of cement used by Fugro Inc; in the preparation of the CLSM specimens.

Table 3.2 Additive content % for Different Soils

Soils Name	Additive Dosage%
Woodbine Soil (SM)	8
Eagle Ford Soil (CH)	18
Austin Chalk Soil (CL)	8
Queen City Sand (SM)	4

Eagle Ford (CH) material is a high plasticity clay and exhibits low workable characteristics. To enhance the strength and workability of Eagle Ford soil, 18% of cement was used for mix preparation. The CLSMs using Austin Chalk and Woodbine soils were prepared in the field with 8% cement. In the case of Queen City Sand material which is coarser among all soils, 4% of additive was used for the mix design.

3.4.1 Specimen Preparation

In the field, native soils were shredded (pulverized) into ½-in. to 1-1/2-in. clods using a shredder as shown in Figure 3.3 (a). Water content for CLSM mix was obtained from standard test method for flow consistency (ASTM D 6103). The native soil clods, portland cement, and water were added to the a portable concrete mixer as shown in Figure 3.3 (b) for mixing. After intimate mixing, the CLSM mix was quickly discharged into the pipe trench. The Figure 3.3(c) shows the placement of CLSM mix into the trench. As shown in the Figure 3.3(d) the specimens were casted in a waxed cardboard 3x6 inch cylinder mold for compressive strength testing. The specimens were left on the site for one two days and then transported and placed in moisture room for curing.



(a)



(b)



(c)



(d)

Figure 3.3 Showing the CLSMs preparation in field (a) Shredder for processing soil material (b) Feeding Portable Concrete Mixer (c) Trench Filling with CLSM using a Portable concrete mixer (d) CLSM mix in waxed cardboard cylinder molds.

After 28 days of curing, these fields prepared specimens were cured and transported to study the long term performance of the material by wetting/ drying and leachate studies. The specimens were subjected to durability studies in the laboratory using combine device. The basic idea behind performing these short term durability studies in the laboratory, is to simulate actual site conditions and to study the premature failures due to moisture changes that are expected with active depth of pipe alignment. The tests on these field prepared CLSMs are intended to measure hardened properties and durability characteristics. During the durability

testing, the specimens are tested for unconfined compressive strength, volumetric change, weight changes and leachability at the completion of desired wetting/drying cycles.

3.5 Laboratory Prepared CLSM Specimens

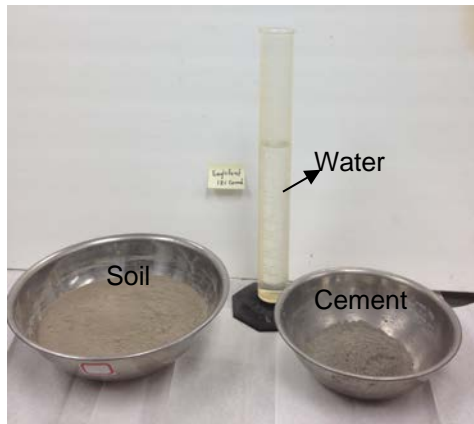
The field CLSMs were designed to meet the TRWD specifications for strength requirement of 50 to 150 psi, after 28 days of curing. Similarly the laboratory CLSMs specimens are designed with same additive dosages as that of field CLSMs in order to have a comparative study with field prepared specimens. Water quantity was established based on trial and error procedure until CLSM flowability (8-12 in.) is achieved.

3.5.1 *Specimen preparation*

Test procedure adopted by Folliard et al. (2008) was closely followed in preparing specimens for flowability, durability and Unconfined Compressive Strength (UCS) tests. Most of the preparation procedure discussed below was extracted from Folliard et al. (2008). To obtain a uniform soil-binder mixture, the bulk and undisturbed soil samples were first oven dried (at 60°C) and pulverized to obtain the fraction passing through US Sieve 40 (0.425 mm). The procedure followed for soil-binder mixing and specimen preparation is explained in following steps.

Approximate quantity of representative pulverized soil required for preparing desired number of soil samples is obtained. Several trial mixings were performed to determine approximate water demand for a target flow of 203 to 254 mm. The water content determined based on flowability test was used for design mix. The measured quantities of material and water used for design mix are shown in Figure 3.4(a). The additive was mixed with soils in dry conditions and then mixed in a dry state in a commercially available dough mixer as shown in Figure 3.4 (b). Water content established based on flowability test was slowly introduced into the soil-binder mix and allowed mixing for 8 to 10 minutes as shown in Figure 3.4(c). The mixing rate of the outer spindle was at 60 rpm whereas the inner spindle had a rotational speed of 152 rpm to avoid the formation of soil binder lumps. Flexible spatula was also used to avoid the soil

from sticking to the sides and bottom of the mixing bowl to ensure that there were no soil-binder lumps. Finally, the wet soil binder mixture was transferred into a bowl for flow test.



(a)



(b)



(c)



(d)

Figure 3.4 Showing sample preparation (a) shows the soil, additive and water (b) Dough mixer with dry mix (c) Dough mixer with wet mix (d) Plastic cylinders with CLSM mix.

The flow test was conducted as per ASTM D 6103 method to determine the workability of the CLSM material and its ability to flow into confined areas. A flow resulting in a circular type spread to a diameter of (203 to 254 mm) as measured by ASTM D6103 was considered an appropriate criterion for backfill and haunch application.

The apparatus used for flow test include flow cylinder, sampling and mixing receptacle, filling apparatus, nonporous surface, straight edge and a measuring tape. A plastic cylinder with dimensions 150 mm (6 in.) height and 76 mm (3 in.) inside diameter as shown in Figure 3.5 was used as the flow cylinder. The cylinder interior has a smooth surface and it is open at both ends. A 0.6 m (2 ft) square, acrylic plate was used to allow the spread of the CLSM from the flow cylinder. A stiff metal straight edge of a convenient length was used to level the surface of the material in the flow cylinder.



Figure 3.5 Plastic Cylinder and Acrylic Plate for Flow Test.

The acrylic plate was placed on a flat, level surface. The flow cylinder was damped with water and placed on the acrylic plate and was held firmly while filling the material. The center portion of the CLSM material in the receptacle was scooped and poured into the flow cylinder until full. The excess of the material on the surface of the cylinder was removed using the straight edge. The cylinder was then raised quickly in a vertical direction by 15 cm (6 in.) within 5 seconds of filling and strike off. The entire test of filling through removal of flow cylinder without interruption was completed within a time of 1½ minutes. A plastic tape is used to measure the flow diameter of the CLSM patty as shown in Figure 3.6. Two diameters perpendicular to each other of the patty were measured. The average of the two was considered as the flow diameter of the CLSM material.



Figure 3.6 Flow Diameter Measurement of Eagle Ford Soil CLSM mix.

After satisfying the flowability criteria the mix is transferred into a cylindrical plastic mold as shown in Figure 3.7 with a closed bottom and open top. The cylindrical mold was 6 in. in height with 3 in. inner diameter. To avoid sticking of CLSM to the walls of cylindrical plastic mold lubricating grease was applied along the inner surface. After mixing the CLSM mix, samples were prepared by filling the plastic cylinder with wet mix and tapping lightly on the sides to

remove large entrapped air voids. Then the filled cylinders are left on the countertop for the first week and later moved to a moist-curing or “fog” room, which was maintained at 100% relative humidity (RH) and 23° C for 28 days curing. The type of curing method adopted was similar to the one outlined in NCHRP report 597 by Folliard et al. 2007.

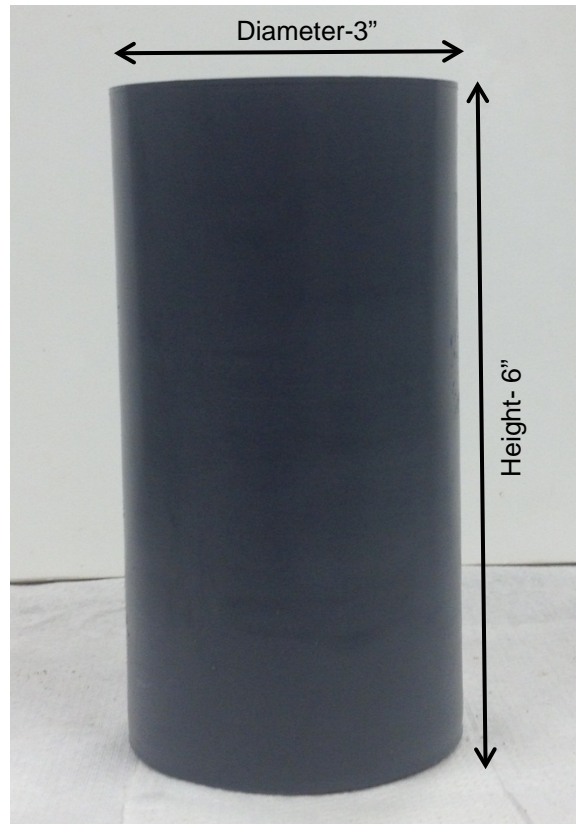


Figure 3.7 Cylindrical Plastic Mold for Casting Specimens.

These laboratory specimens after curing for 28 days were also subjected to durability studies using the modified approach method. The test procedure and apparatus used for the determining unconfined compressive strength (UCS), weight changes, volumetric changes and loss of calcium concentration for both field and laboratory specimens are explained in this chapter. Durability studies conducted on field prepared CLSM specimens are explained in the next section.

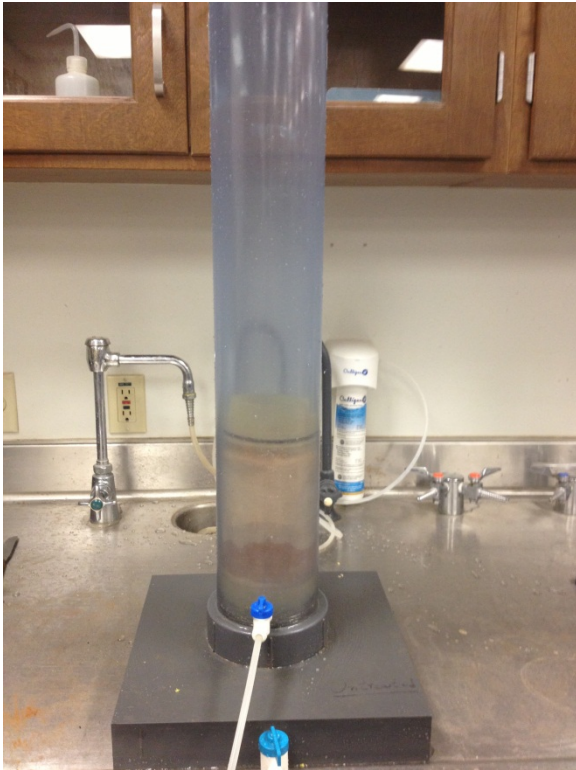
3.6 Durability Studies on Field Specimens

Durability studies were conducted by subjecting the soil specimens to alternative wetting and drying cycles. The standard method used to conduct these wet/dry cycles is ASTM D 559 method. A modified approach using a new device was used. The device is proven to be an integral solution for conducting durability studies due to effective and efficient uses of material and time. The device accurately simulate the moisture fluctuations that are expected seasonal changes (Priya 2011). Volumetric strains, weight changes and strength parameters were studied during a selected cycle to understand how the soil responds to the stabilizing additive and its dosage. The following section explains the wetting/ drying procedure.

3.6.1 *Wetting/Drying Procedure*

Compared to conventional concrete, CLSM typically has a very high water-cement ratio and water content. The standard concrete method to measure drying shrinkage, AASHTO T 160 may not be appropriate for CLSM. The wetting and drying of soil specimens are typically carried out on the basis of ASTM D 559. This method simulates field conditions, similar to that of wetting and drying conditions, within a short period of time. The wetting process was carried by submerging the CLSM specimen in water for 5 hours. The water was maintained at constant head of 5ft in the combined device as shown in Figure 3.8 (a) throughout the wetting process.

Drying process starts after the completion of each wetting cycle. In this process the specimens are dried in drying oven at 160° F for 24 hours as shown in Figure 3.8 (b).The alternative wetting and drying process is continued until 14 cycles are completed or until the sample fails. The soil specimens are studied for volumetric change and weight change measurements before and after the completion of wetting/drying cycles. Vernier Callipers is used to measure the vertical deformations and diametrical changes, whereas the weight measurements were recorded using weighing balance



(a)



(b)

Figure 3.8 (a) Wetting of CLSM Specimen (b) Drying of CLSM Specimen.

At the completion of the desired wetting cycle the specimens were subjected to unconfined compressive strengths. The following sections describe the procedures followed in the determination of unconfined compressive strength, volumetric changes, weight changes and calcium concentration from the leachate collection during durability studies.

3.6.1.1 Volumetric Changes

Samples were subjected to seasonal changes for the measurement of the drying and shrinkage of CLSM. The prepared soil specimens which are initially 6 in. in height and 3 inch measure diametrically were tested by subjecting them to alternating wetting and drying cycle as per durability studies. The changes in height and diameter of the soil specimen at the end of each drying and wetting cycle gives an indication of volumetric changes due to moisture

fluctuation. Soil specimens were measured using vernier callipers before and after each wetting/drying cycle as shown in Figures 3.9 (a) and (b).



(a)



(b)

Figure 3.9 (a) shows Vertical Measurement (b) Diameter Measurement.

3.6.1.2 Weight Changes

Soil specimens were weighed using a balance before and after each drying and wetting cycle. Figures 3.10 (a) and (b) show the weighing of the wet and dried soil specimens.



(a)



(b)

Figure 3.10 (a) Weight after Wetting Cycle (b) Weight after Drying Cycle.

3.6.2 Leachate Studies

As noted earlier, the device developed by Priya et al (2011) which enables both wetting/drying and leachate studies on a single test specimen as shown in Figure 3.11 was used in this research study. Simulation of water inflow into the CLSM samples due to rainfall was replicated with this apparatus. The advantages of using the modified approach method over standard approaches includes reduction in the duration for leachate collection, and avoiding the repetition of sample preparation for wetting/drying and leachate studies separately.



Figure 3.11 Combined Device with Leachate Apparatus.

Specimen of each soil formation after curing as shown in Figure 3.12 (a) are subjected to moisture flow at constant head. The CLSM specimen with latex membrane as confinement, top cap, O rings are placed over the bottom plate as shown in Figure 3.12(b). The main purpose of the confinement was to prevent water from percolating through the sides of the soil

specimen. The water was allowed to fill the casing till 5 ft through the inlet opening of the casing. The water level in the casing was kept constant by closing the inlet valve. With the help thin tube the water filled in casing was allowed to flow into the bottom plate to simulate the moisture flow. The Figure 3.12(c) shows the wetting of the specimen in the combined device. After submerging the specimen in water for 5 hours, the water in the casing was drained out by releasing the inlet valve. At the end, a representative amount of leachate was collected through the opening in the bottom plate. Figure 3.13(d) shows the collection of leachate from outlet in the bottom plate. The leachate coming out of the soil specimen was collected and tested for Calcium ions present in the leachate.

3.6.2.1 Calcium Concentration Determination

Information such as the loss of Calcium content of cement can be very helpful in assessing the potential reactivity and the effects on long term strength gain. Leachate collected from each soil specimen was subjected to calcium determination test after the completion of the desired number of cycles. The calcium concentration of the leachate coming out of the soil specimen was determined at different cycles using the standard EDTA method.

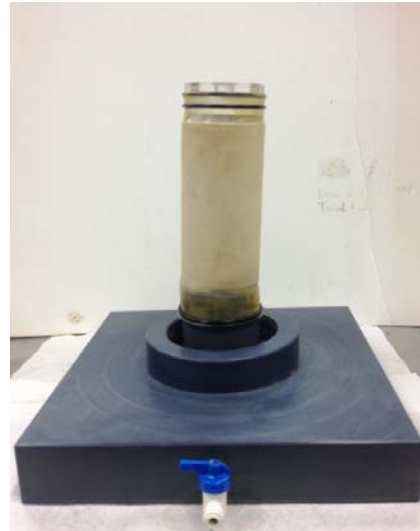
This test procedure involves the following steps.

1. A small sample representative, 25 ml, of the collected leachate is taken and placed in an Erlenmeyer flask.
2. The contents of a Calver2 Calcium Indicator pillow packet are poured into the flask and swirled around.
3. Upon addition of 4-5 drops of 8 N Potassium Hydroxide Solution the solution turns purple as shown in figure 3.13 (a)
4. Titrant TitraVer (EDTA) Standard Solution 0.010M is added slowly until the solution turns blue as shown in figure 3.13(c).
5. The start point and end point of the titrant is noted. The difference in these numbers provides the amount of titrant required to reach the solutions endpoint.

6. A suitable multiplier is applied to convert the ml to mg/L of Calcium. Furthermore, this number is converted to ppm of an additive leached out.
7. Using the calibration chart the amount of additive loss % is determined.



(a)



(b)



(c)



(d)

Figure 3.12 Typical wetting/leachate collection process (a) CLSM specimen (b) CLSM specimen with latex membrane, top cap and o-rings (c) Specimen Wetting and application of confinement (d) Leachate collection.



(a)

(b)

(c)

Figure 3.13 Showing EDTA titration stages (a) Represents Starting point. (b) Represents the color change before endpoint (c) represents the end point.

3.6.3 Unconfined Compressive Strength

The Compressive Strength (or Unconfined Compressive Strength) of CLSM is the most common hardened property measured and is most commonly found in state Department of Transportation (DOT) specification. As per ASTM D 4832 the load application at constant rate should fail the cylinder in not less than 2 minutes. Since little guidance regarding load rate is given by ASTM D 4832, the Unconfined Compressive Strength (UCS) test performed on the CLSM soil specimens is ASTM D 2166 which is close to ASTM D 4832. This test is conducted on cast soil specimens under unconfined conditions. At the completion of desired number of wetting/drying cycles (0,3,7,14) the soil specimen is placed on a platform and then raised at a constant strain rate, using the controls of the UCS set up, until it comes in contact with the load cell. Once the specimen is loaded at a constant strain rate of 1.27 mm/sec, and as the load approaches the ultimate load, failure cracks begin to appear on the surface of the soil specimen. Deformation and corresponding axial loads of the soil specimen are recorded using the Data Acquisition System (DAS).

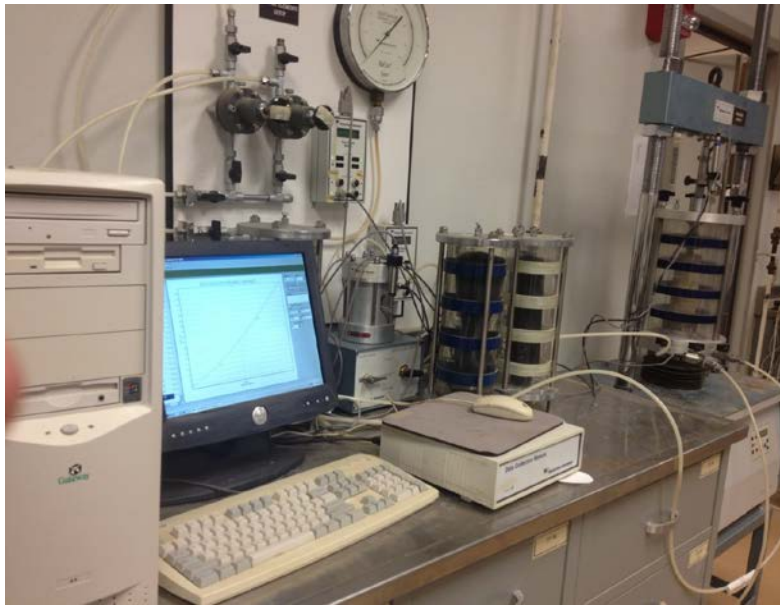


Figure 3.14 UCS Test Setup with Data Acquisition System.

Using the data obtained from the UCS tests, stress-strain graphs are plotted to determine the unconfined strength and stiffness properties of the specimen after desired cycles.

3.7 Summary

This chapter explains criteria for soil selection from different geological formations used for this research study. Basic soil test performed on native soils, details of specimen preparation in the field; durability and leachate studies performed on field prepared CLSMs are discussed. Also the test procedures involved in the preparation of laboratory specimens using two clay soils for comparative study are presented. Engineering variable such as unconfined compressive strength (UCS), volume change, weight changes and calcium loss are explained along with their test procedures for both field and laboratory specimens. Additionally, the procedure to find out the calcium concentration from a given leachate using EDTA titration is described in detail.

A comprehensive analysis on durability and leachate test results obtained from the above stated tests that are conducted on the CLSMs is presented in the following chapter.

CHAPTER 4

TEST RESULTS AND DISCUSSION OF CLSM DURABILITY STUDIES

4.1 Introduction

This chapter presents the test results and comprehensive analysis of the durability studies conducted on CLSMs prepared from four different geological formations along the IPL alignment. The CLSMs prepared in the field using soils from Eagle Ford, Queen City Sand, Woodbine and Austin Chalk geological formations were subjected to durability studies. The results obtained along with their analysis are presented in this chapter. CLSMs prepared in the laboratory using Eagle Ford(CH) and Austin Chalk(CL) soils are compared with field prepared CLSMs. The testing procedures of various tests conducted on CLSMs were explained in Chapter 3. In this chapter unconfined compressive strength, volumetric strain changes, weight changes, and calcium concentration determination from leachate are discussed for both field and laboratory prepared specimens. Effects of soil type, preparation method and additive loss on the long term performance of CLSMs soil are analyzed using the test results, followed by the summary and findings.

4.2 CLSM Samples Prepared in the Field

As a part of IPL backfill study Fugro Consultants Inc. established CLSM design mixes using native soils from four different locations. The optimum additive (cement) dosage to be used for a successful CLSM mix design for Woodbine, Eagle Ford, Austin Chalk and Queen City soil formations were found to be 8%, 18%, 8% and 4% respectively. Table 4.1 presents summary of these results including soil classification, additive percentage and additive type used for each field CLSM specimen.

Table 4.1 Summary of Additive Types and Dosages for Each Field Prepared CLSMs

Geological Formation Soil	UCSC Classification	Additive Type	Additive Amount (% by weight)
Eagle Ford	CH	Cement	18
Woodbine	SM	Cement	8
Austin Chalk	CL	Cement	8
Queen City Sand	SM	Cement	4

The CLSM specimens prepared using the field design mix met the initial strength requirement as per the TRWD standards. However, durability studies were not conducted to assess the long-term performance of these CLSM mixtures. Hence, durability studies were conducted on each of these mixes in the current research to address their longterm performance.

Durability studies are generally conducted in two stages, stage 1 consists of replicating the volumetric changes that occur due to moisture ingress and digress and this process are imitated by conducting wetting/drying studies in the laboratory as explained in chapter 3. The second stage consists of replicating the rainfall infiltration which can sometimes leach the additive and reduce soil strength; this process is replicated in the laboratory by conducting leachate studies as explained in chapter 3. Typically these two stages are conducted on two separate samples. However, in this research, rather than using the conventional method where two separate samples are prepared for each stage of durability, a modified approach was and implemented. The modified approach uses a combined device; combined meaning that both wetting/drying cycles and leachate collection can be performed on the same soil specimen, thus effectively and efficiently using time and materials. Leachate collections were completed for the same treated CLSMs specimens, in the same device, to examine the permanency of the

additives by observing the leaching of chemical stabilizer through moisture movements. The loss of chemical stabilizers may have serious implications on the durability and sustainability of the chemical treatment. Chemical stabilizers can be lost due to seasonal changes and runoff flow conditions.

Each mix design and their samples were subjected to a maximum of 14 durability cycles, unless they fail before 14 cycles. During these cycles the soil samples were monitored for volumetric strain and weight changes by measuring the height and diameter of the sample at the end of the each cycle along with the sample weight. The soil samples were tested for unconfined compression strength at '0' wetting, 3, 7 and 14 cycles. Also, calcium loss in the CLSM specimen was determined by collecting leachate samples at the end of selected wetting cycle. Figure 4.1(a),(b) and (c) depicts different stage of durability cycles for field prepared Queen City Sand CLSM. These photographs typically represent the state of the soil that had undergone changes during durability process.

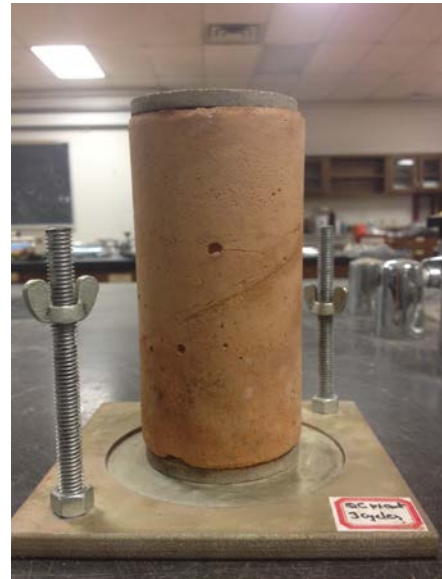
Discussions on various test results from durability studies on each field prepared CLSM are presented in the following sections. Various tasks performed for obtaining results in terms of engineering parameters-unconfined compressive strength, volumetric strain changes, weight change and calcium concentration loss for field specimens during durability cycles are briefly discussed in the next paragraphs.

At the completion of selected wetting/drying cycles ('0' wetting, 3,7,14 cycles) and leachate collection, the field prepared CLSM specimens were subjected to UCS test. The unconfined compressive strength (UCS) test performed was in accordance with ASTM D 2166 which is close to ASTM D 4832. Immediately 2 hours after the completion of the desired wetting cycle, the CLSM were tested for unconfined compressive strength in saturated conditions. The values from unconfined compressive strength were represented graphically to know the variation of strengths during the 14 durability cycles. The unconfined compression strength

values at 0,3,7,14 cycles helps in knowing the retained strength% and long term strength performance of the CLSM.



(a)



(b)



(c)

Figure 4.1 Field Prepared Queen City Sand CLSM Specimen at (a) After 28 Days Curing (b) Drying cycle (c) Wetting Cycle.

4.2.1 Volumetric Strain Changes

Volumetric strain change characteristics of CLSMs are best studied when the soil specimen are subjected to alternative drying and wetting. The changes in diameter and height of the specimen were used to determine volumetric strain changes. Vernier Calipers was used to measure the changes after and before each drying and wetting cycle. For both height and diameter, the measurements were taken at 3 different positions and their average values were considered for volume calculations. The volumetric strain changes are represented graphically and the volumetric strain corresponding to drying and wetting regions are represented as negative and positive values, respectively. The total volumetric strain is a combination of the percentage change for one wetting and drying durability cycle.

4.2.1.1 Woodbine Soil CLSMs (Field)

Based on USCS classification, Woodbine formation soil is classified as a silty clayey sand (SM) and exhibits non-plastic soil behavior. The Woodbine soil CLSM specimens prepared in the field using 8% cement as additive dosage were collected and then cured for 28 days. The Woodbine soil CLSMs were then subjected to alternate wetting and drying processes. Before and after each wetting and drying cycle, the volume related measurements of the soil specimens were recorded. These results are used in terms of percentage of volumetric strains at different cycles and they are represented in Figure 4.2.

The Woodbine soil specimen with 8% cement survived for 14 durability cycles with average volumetric change of 0.3% where maximum volumetric change and minimum volumetric strain changes are 0.8% and 0.1%. Thus the volumetric strain changes in field prepared Woodbine soil CLSMs through the drying/wetting studies are found to be significantly low

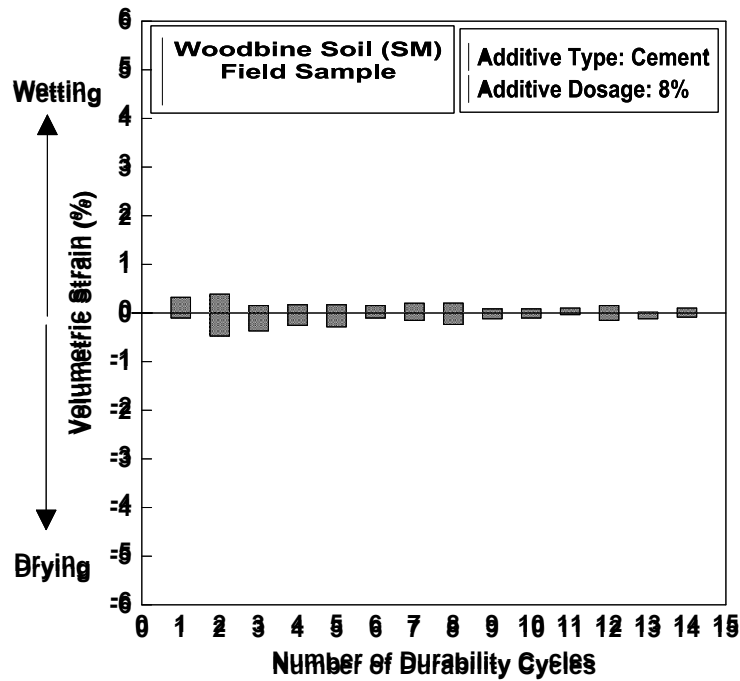


Figure 4.2 Volumetric Strain for Field Prepared Woodbine Soil CLSMs.

The design mix with 8% cement proved to be successful on the field prepared Woodbine CLSMs to withstand the 14 durability cycles. Low volumetric strain changes were noticed, the soil specimen survived for 14 cycles of wetting and drying with maximum volumetric change of 0.8%

4.2.1.2 Eagle Ford Soil CLSMs (Field)

Based on USCS classification, Eagle Ford soil is high plasticity clay (CH) and exhibits low workable characteristics. The Eagle Ford CLSM specimens prepared in the field using 18% cement as additive dosage were cured for 28 days. These field prepared CLSMs were subjected to alternative wetting and drying cycles. Volumetric strains changes were recorded and the results are presented in Figure 4.3.

The Eagle Ford soil CLSMs with 18% cement survived for 14 durability cycles with maximum volumetric change of 6.6%. Thus the volumetric strain changes in field prepared CLSMs using CH as native material are found to be relatively higher.

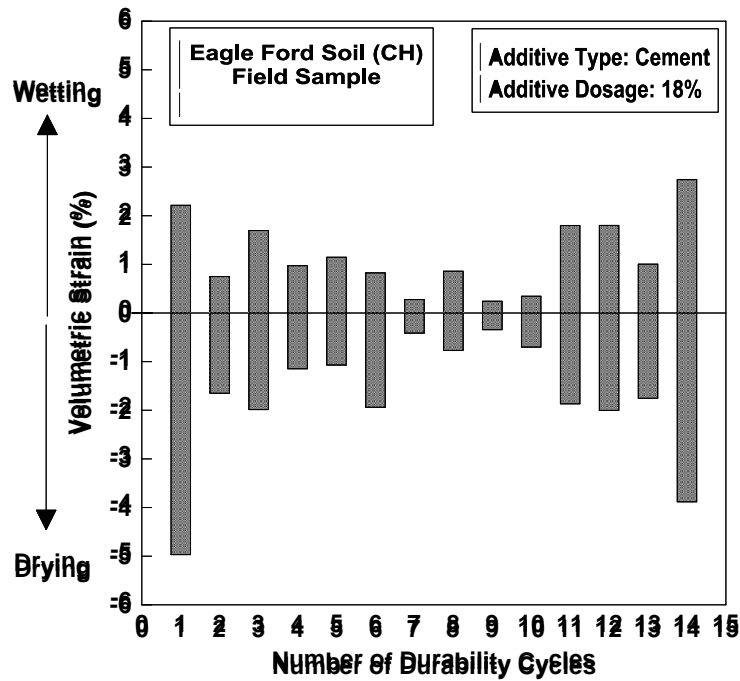


Figure 4.3 Volumetric Strain for Field Prepared Eagle Ford Soil CLSMs.

The CLSM design mix with 18% cement proved to be successful on the field prepared Eagle Ford soil CLSMs to withstand the durability cycles. Though relatively higher volumetric strain changes were noticed for CH soil with 18% cement content, the soil specimen survived for 14 cycles of wetting and drying with maximum volumetric change of 6.6%

4.2.1.3 Austin Chalk Soil CLSMs (Field)

Based on USCS classification, Austin Chalk soil is low plasticity clay (CL) with PI -13. The Eagle Ford CLSM specimens prepared in the field using 8% cement as additive dosage were cured for 28 days. These field prepared CLSMs were subjected to alternative wetting and drying cycles. Volumetric strains changes were recorded and the results are presented in Figure 4.4.

The Austin Chalk CLSMs with 18% cement survived for 14 durability cycles with maximum volumetric change of 3.7%. Thus the volumetric strain changes in field prepared CLSMs using CL soil are found to be low.

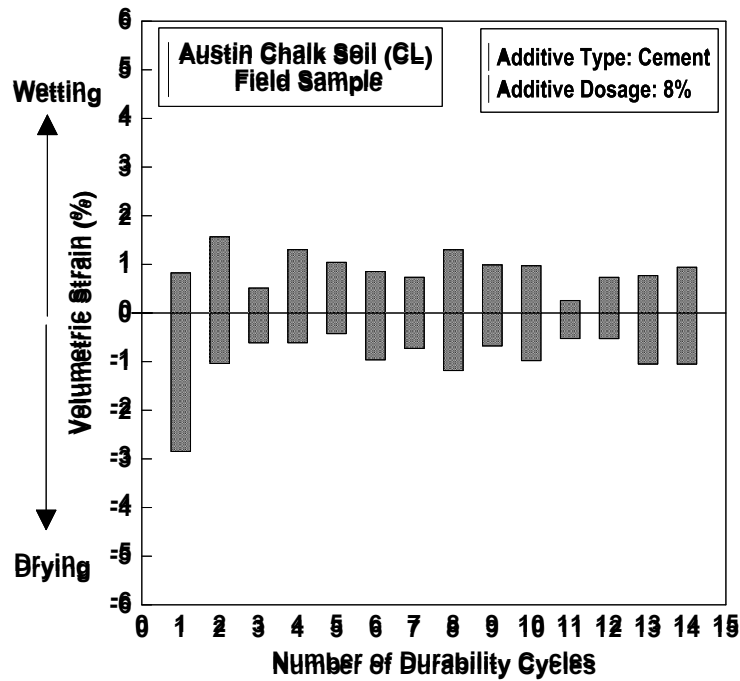


Figure 4.4 Volumetric Strain for Field Prepared Austin Chalk Soil CLSMs.

The design mix with 8% cement proved to be successful on the field prepared Austin Chalk soil CLSMs to withstand the durability cycles. Low volumetric strain changes were noticed for CL soil with 18% cement, the soil specimen survived for 14 cycles of wetting and drying with maximum volumetric change of 3.7%

4.2.1.4 Queen City Sand CLSMs (Field)

Based on USCS classification, Queen City Sand formation soil is silty sand (SM) material and exhibits non plastic behavior. The Queen City Sand CLSMs prepared in the field using 4% cement as additive dosage were cured for 28 days and were subjected to alternative wetting and drying cycles. Volumetric strains changes during the durability cycles were recorded and the results are presented in Figure 4.5

The Queen City Sand CLSMs with 8% cement survived for 14 durability cycles with maximum volumetric change of 2.4%. Thus the volumetric strain changes in field prepared Woodbine CLSMs through the drying/wetting studies are found to be significantly low.

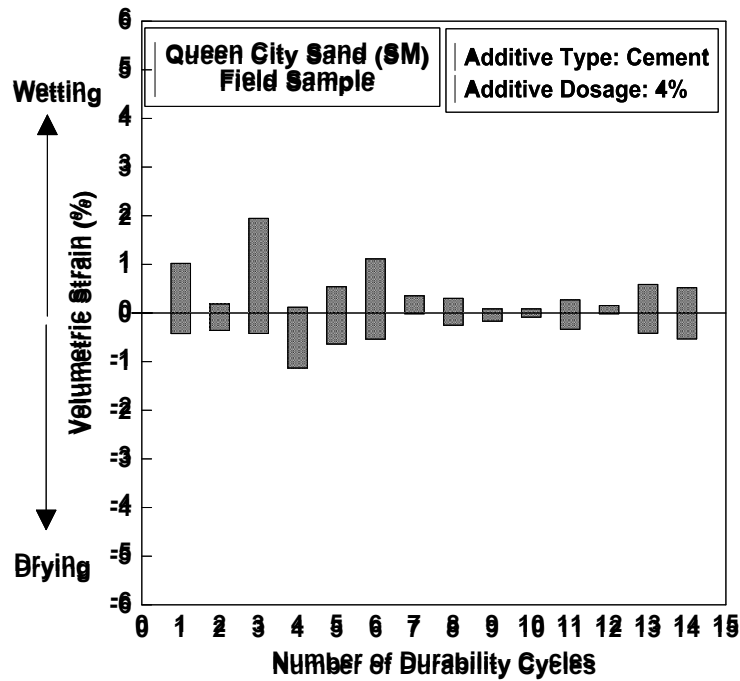


Figure 4.5 Volumetric Strain for Field Prepared Queen City Sand CLSMs.

4.2.2 Sample Weight Changes

Weighing scale was used to measure the changes in weight before and after each drying and wetting cycle. Furthermore, the maximum weight change is a combination of the percent change for wetting and drying of one cycle of durability; this means that the drying (negative) is subtracted from the wetting (positive) to get the total change (wetting change - (-drying change) = total sample weight change).

4.2.2.1 Woodbine Soil CLSMs (Field)

Woodbine soil has no PI value and is a non plastic sand. Soil specimens were prepared, cured for 28 days and subjected to alternate wetting and drying cycles. Volumetric strain changes were recorded; the results are presented in Figure 4.6.

Woodbine field prepared CLSMs with 8% cement survived for 14 cycles of wetting and drying with a maximum weight change of 54.5%.

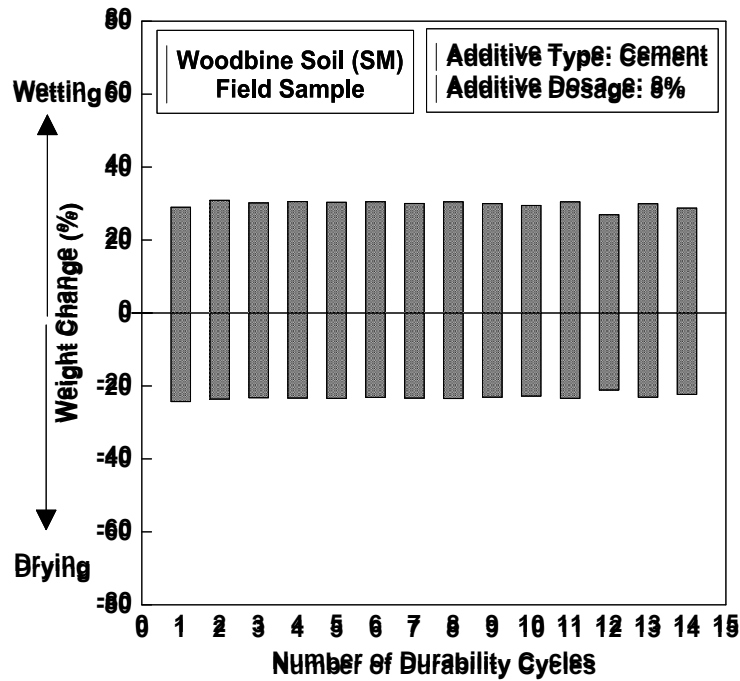


Figure 4.6 Sample Weight Changes for Field Prepared Woodbine Soil CLSMs.

The CLSM design mix with 8% cement proved to be successful on the prepared soil specimen to withstand 14 durability cycles. Consistent in weight change was noticed for the SM soil. The field prepared Woodbine CLSMs with 8% cement survived for 14 cycles of wetting and drying with a maximum weight change of 54.5%

4.2.2.2 Eagle Ford Soil CLSMs (Field)

Eagle Ford formation soil has a PI of 32- a moderately high plasticity. To counterbalance the plasticity and to improve the workable characteristics, 18% of cement was used in CLSM design mix. Soil specimens were prepared, cured for 28 days, and subjected to alternate wetting and drying cycles. Sample weight changes were recorded using weighing scale and the results are presented in Figure 4.7.

The field prepared Eagle Ford soil CLSM survived for 14 cycles of wetting and drying with a maximum weight change of 54.8%.

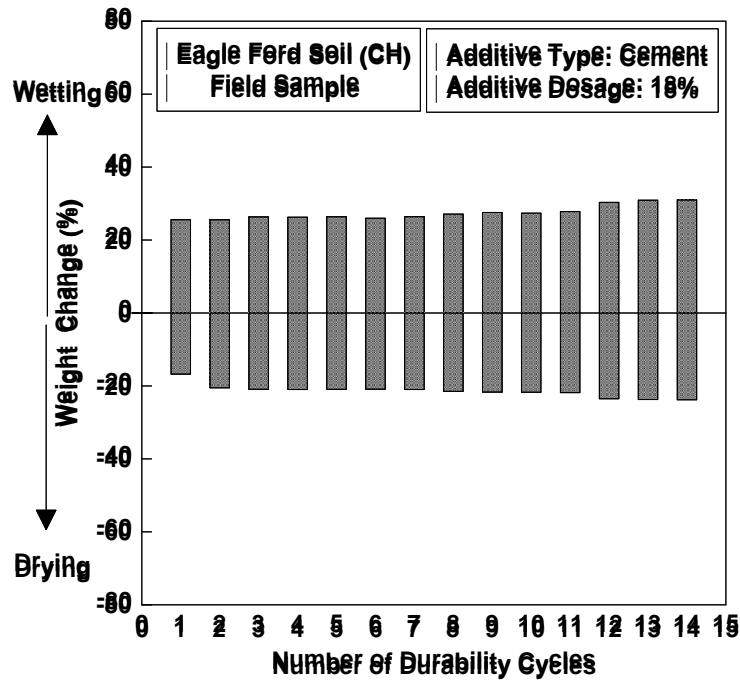


Figure 4.7 Sample Weight Changes for Field Prepared Eagle Ford Soil CLSMs.

The CLSM design mix with 18% cement proved to be successful as it withstands all durability cycles. A moderately low weight change was noticed for this CH soil. The field prepared Eagle Ford soil CLSMs with 18% cement survived for 14 cycles of wetting and drying with a maximum weight change of 54.8%

4.2.2.3 Austin Chalk Soil CLSMs (Field)

Eagle Ford formation soil has a PI of 13 and hence termed as a low plasticity clay. CLSM specimens with 8% of additive (cement) were prepared, cured for 28 days, and subjected to alternate wetting and drying cycles. Sample weight changes were recorded using weighing scale and the results are presented in Figure 4.7.

The field prepared Austin Chalk soil CLSMs survived for 14 cycles of wetting and drying with a maximum weight change of 79.0%.

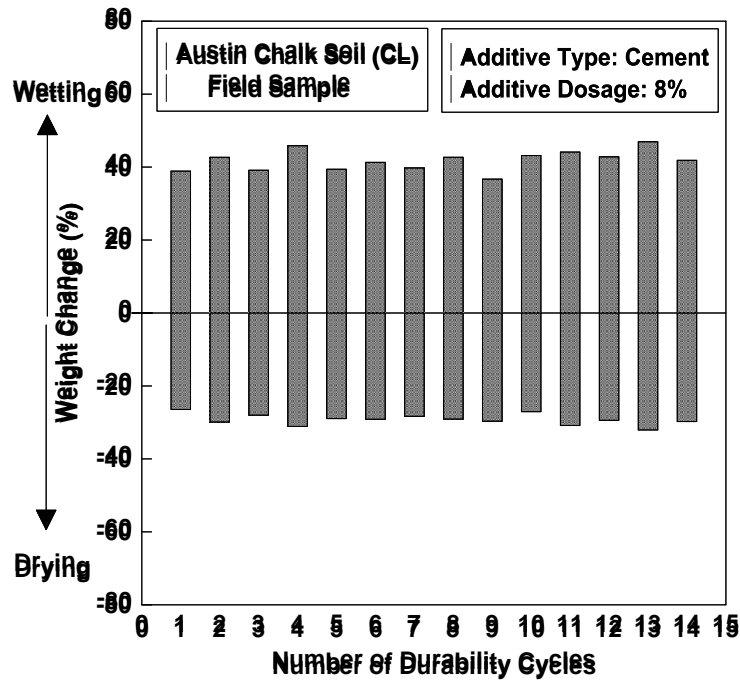


Figure 4.8 Sample Weight Changes for Field Prepared Austin Chalk Soil CLSMs.

The CLSM design mix with 8% cement proved to be successful on the field prepared soil specimen to withstand durability cycles. However, high weight change were noticed for the CL soil. The field prepared Eagle Ford soil CLSMs with 18% cement survived for 14 cycles of wetting and drying with a maximum weight change of 79.0%

4.2.2.4 Queen City Sand CLSMs (Field)

The CLSM design mix with 4% cement proved to be successful on the prepared soil specimen to withstand durability cycles. A low weight change was noticed for the SM soil. The field prepared Queen City Sand CLSMs with 4% cement survived for 14 cycles of wetting and drying with a maximum weight change of 41.0%

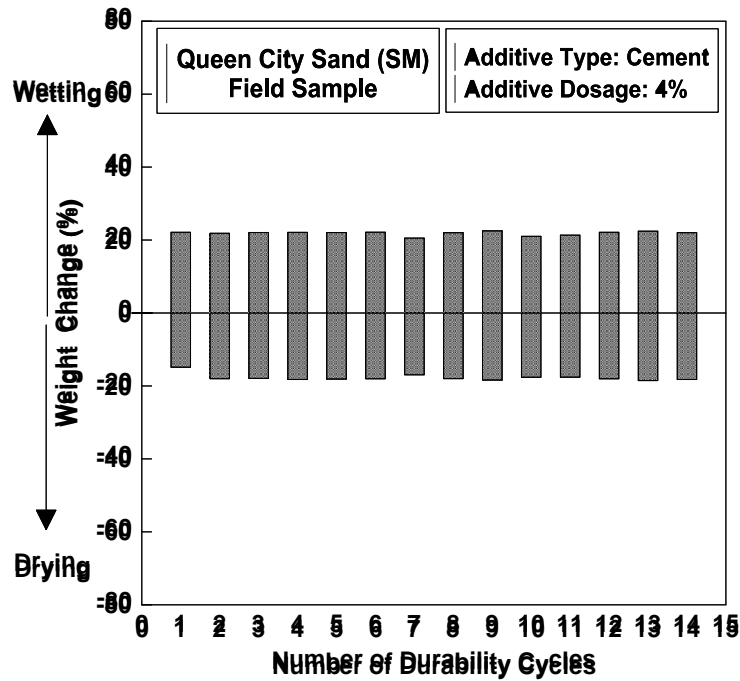


Figure 4.9 Sample Weight Changes for Field Prepared Queen City Sand CLSMs.

The CLSM design mix with 4% cement proved to be successful to withstand durability cycles. Low weight changes were noticed for this SM soil. The field prepared Austin Chalk soil CLSMs with 4% cement survived for 14 cycles of wetting and drying with a maximum weight change of 41.0%

4.2.3 Leachate Calcium Concentration

Leachate samples collected from each of the soil specimens at different cycles of durability were studied for calcium concentrations. One full leachate cycle is defined as the time required to collect one pore volume of leachate through the soil specimen; the time typically varied due to a changing pore volume. The procedure used for determining the calcium concentration of a prepared soil specimen by EDTA was provided in Chapter 3. The concentration of calcium in ppm was determined and plotted against durability cycles to study the variation of calcium leaching out during each cycle. The results obtained from all tests on each site location are presented in Figures 4.15 through 4.18.

4.2.3.1 Woodbine Soil CLSMs (Field)

The concentration of calcium in ppm was determined from EDTA titration method and the values are plotted against durability cycles to study the variation of calcium leaching out during each cycle. Figure 4.10 represents the calcium ion concentration changes versus the number of durability cycles of Woodbine soil CLSM. It can be observed that the soil remained intact for all 14 cycles of durability. The calcium ion concentration leached out at 1, 3, 7 and 14 cycle were 440, 580, 540 and 500 ppms. Total calcium concentration leached out from the field prepared Woodbine soil CLSM with 8% cement is 7210 ppm.

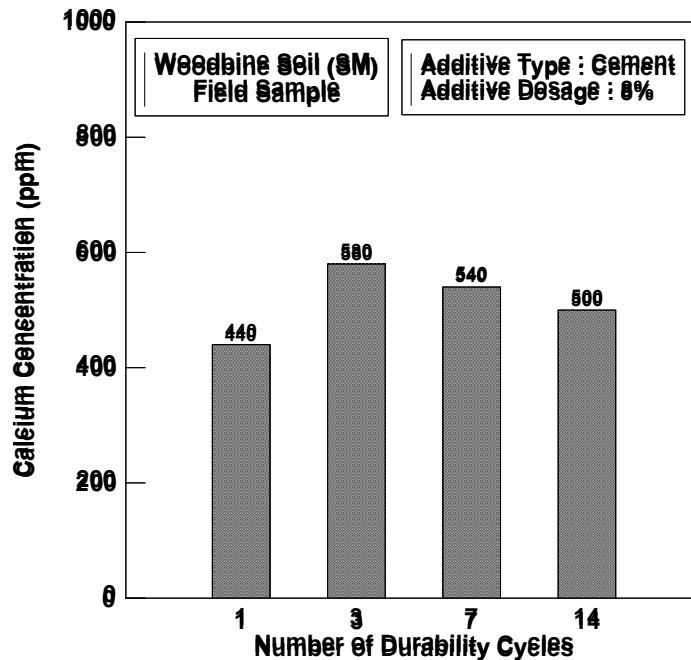


Figure 4.10 Variation of Calcium Concentration for Field Prepared Woodbine Soil CLSMs

4.2.3.2 Eagle Ford Soil CLSMs (Field)

The concentration of calcium in ppm was determined from EDTA titration method and the values are plotted against durability cycles to study the variation of calcium leaching out during each cycle. Figure 4.11 presents the calcium concentration loss during the durability cycles for field specimen. The initial calcium ion concentration leached out was approximately

560 ppm, which increased to 860 ppm at 14 cycles. Thus an increase of 300 ppm was observed from initial concentration to final concentration of calcium ions. The increase in calcium concentration loss indicates the possibility of more leaching. For Eagle Ford soil CLSMs with 18 % Cement, the total calcium concentration obtained after 14 drying/wetting cycles is 10150 ppm.

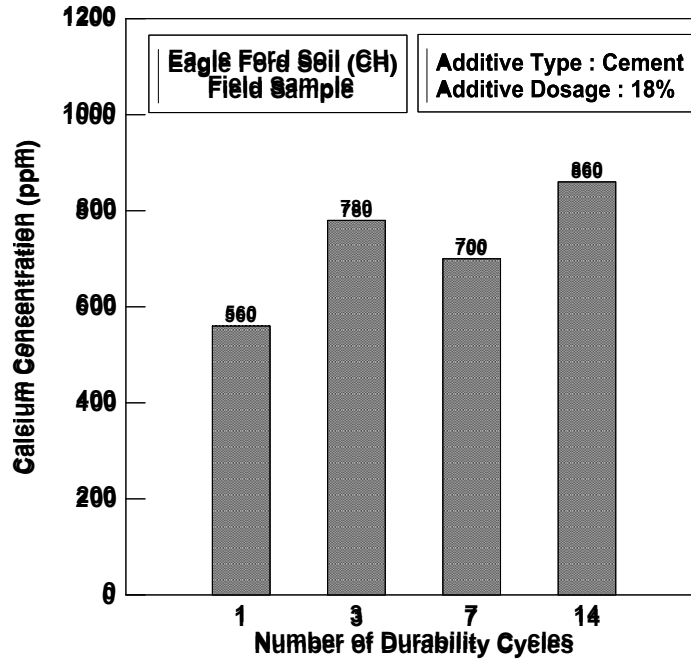


Figure 4.11 Variation of Calcium Concentration for Field Prepared Eagle Ford Soil CLSMs.

4.2.3.3 Austin Chalk Soil CLSMs (Field)

The calcium concentrations(ppm) from the collected leachate solution were determined from EDTA titration and the values were plotted against durability cycles as shown in Figure 4.12.. The total calcium concentration(ppm) leached out at the end of 14 cycles is calculated by multiplying the average of calcium concentrations values obtained at 1,3,7 and 14 cycles with a multiplication factor 14. Thus for Austin Chalk CLSMs with 8 % cement the total calcium concentration obtained after 14 drying/wetting cycles is 7980 ppm

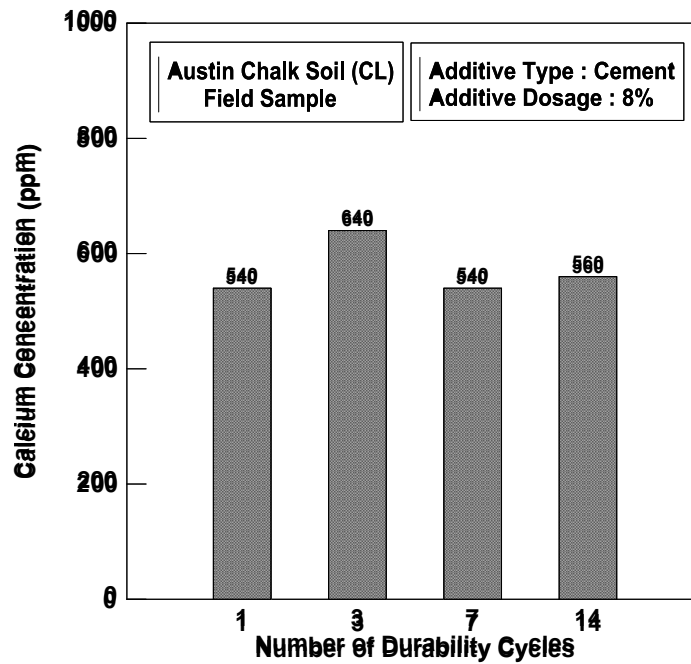


Figure 4.12 Variation of Calcium Concentration for Field Prepared Austin Chalk Soil CLSMs

4.2.3.4 Queen City Sand CLSMs (Field)

The concentrations of calcium in ppm after selected cycles were determined and were plotted against durability cycles to study the variation of calcium leaching out during each cycle. Figure 4.13 presents the variation of calcium concentration with number of durability cycles. The total calcium concentration(ppm) leached out from Queen City Sand CLSMs at the end of 14 durability cycles is 3570 ppm.

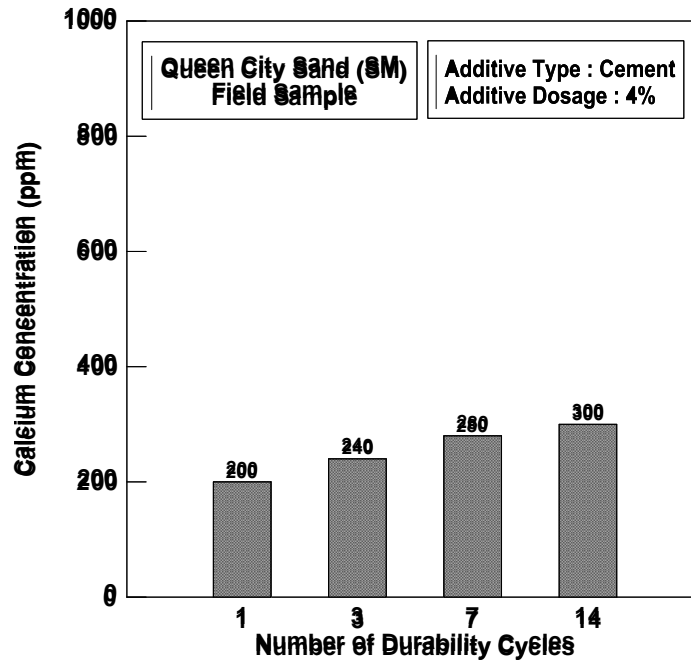


Figure 4.13 Variation of Calcium Concentrations for Field Prepared Queen City Sand CLSMs

4.2.4 Unconfined Compressive Strength Changes

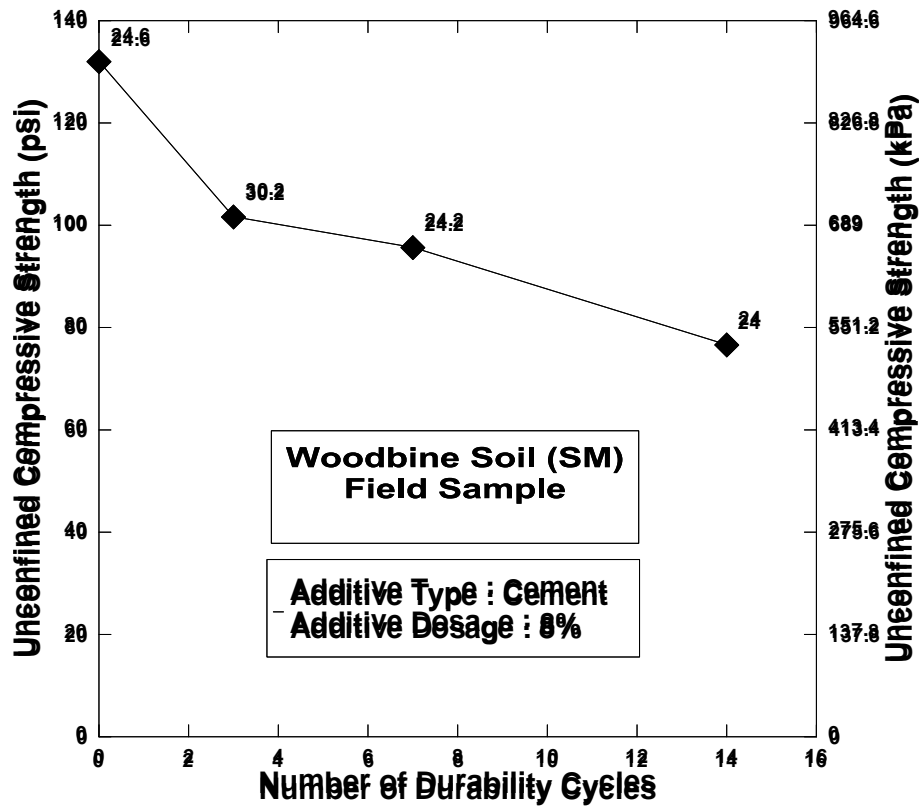
At the completion of the selected wetting/drying cycles and leachate collection, the soil specimens were subjected to UCS testing in accordance to ASTM D 2166. Immediately after their last wetting cycle the specimens are tested in saturated conditions. Graphical representations of the strength values are shown in Figures 4.14 through 4.17 for four soils.

Figure 4.14 presents the variation of unconfined compressive strength with number of durability cycles for field prepared Woodbine CLSMs. At the completion of selected wetting/drying cycles (‘0’ wetting, 3,7,14 cycles) and leachate collection, the field prepared Woodbine CLSM specimens were subjected to UCS testing. Initially, at ‘0’ cycles (wetting) the Woodbine CLSM exhibited 132.0 psi (910.2 kPa) of UC strength whereas at the end of 14 cycles UCS value of 76.6 psi (528.5 kPa) was observed. The decrease in strength values resulted in a strength loss of 41.9%. Thus, 58.1% of the initial strength value is retained after the completion of 14 cycles.

Figure 4.15 presents the variation of unconfined compressive strength with number of durability cycles for field prepared Eagle Ford soil CLSM with 18% cement. At '0' wetting cycles the specimen exhibited 92.1 psi (634.8 kPa) of unconfined compressive strength whereas at the end of 14 cycles low UCS value of 10.1 psi (69.3 kPa) was recorded. This resulted in the high strength loss of 89.1 %. In other words only 10.9% of the initial strength value is only retained at the completion of 14 durability cycles. The values in the brackets provide the moisture content at which the sample was tested for UCS strength.

Figure 4.16 presents the variation of unconfined compressive strength with number of durability cycles for field prepared Austin Chalk CLSMs with 8% cement. Immediately 2 hours after the completion of the desired wetting cycles ('0' wetting, 3.7.14) the specimens were tested for unconfined compressive Strength. Austin Chalk soil CLSMs showed 83.8 psi (577.9 kPa) and 37.9 psi (261.4 kPa) of unconfined compressive strengths at '0' wetting and 14 cycles. The decrease in the strength values indicates the strength loss of 54.8%. Thus 45.2% of the initial strength value is retained at the completion of durability testing.

Figure 4.17 presents the variation of unconfined compressive strength with number of durability cycles for field prepared Queen City Sand CLSMs with 4% cement. Immediately 2 hours after the completion of the desired wetting cycles ('0' wetting, 3.7.14) the specimens were tested for unconfined compressive Strength. Initially, at '0' wetting cycles the Queen City soil CLSM exhibited 55.9 psi (385.3 kPa) of unconfined compressive strength. At the end of 14 cycles UCS value of 28.5 psi (196.2 kPa) was observed. The decrease in strength resulted in the strength loss of 49.1%. Thus, 50.9% of the initial strength value is retained at the completion of 14 durability cycles.



Note: The value next to data points represents moisture contents (%) at the time of UCS testing

Figure 4.14 Variation of UCS Strength for Field Prepared Woodbine Soil CLSMs

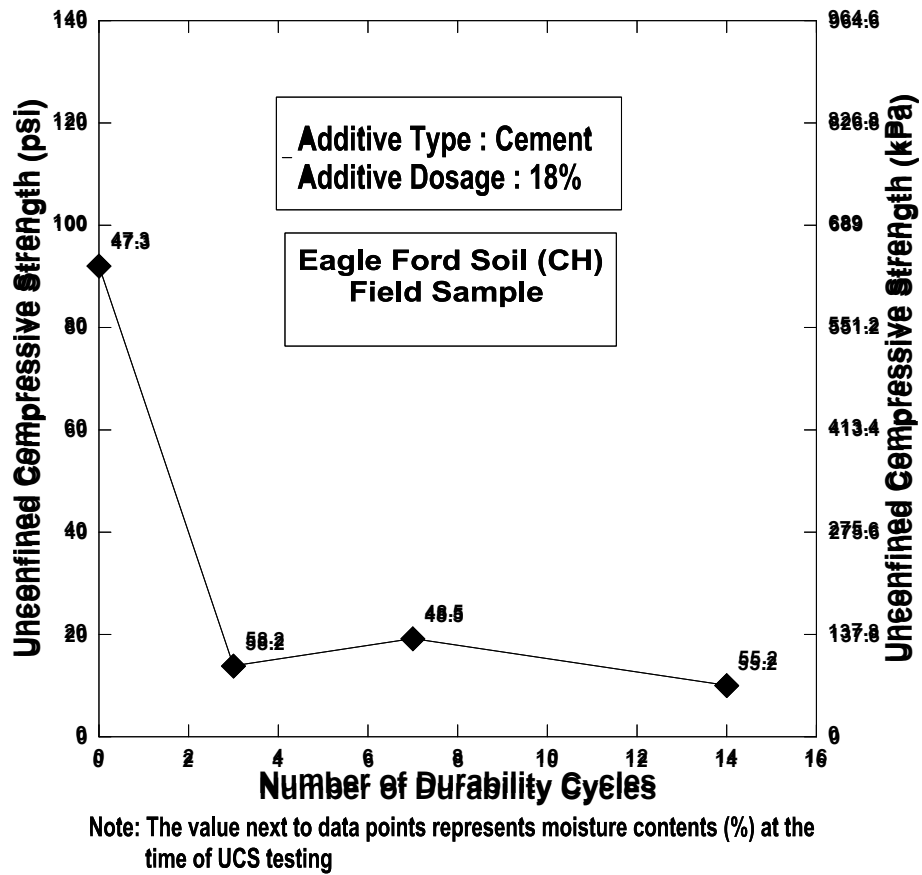
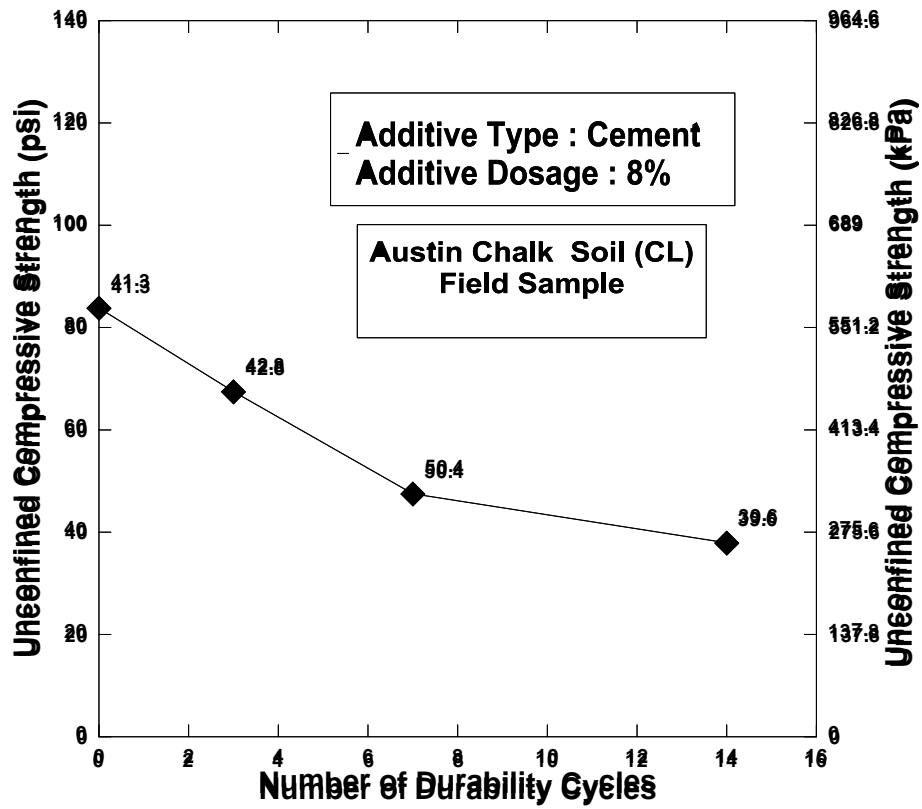


Figure 4.15 Variation of UCS Strength for Field Prepared Eagle Ford Soil CLSMs



Note: The value next to data points represents moisture contents (%) at the time of UCS testing

Figure 4.16 Variation of UCS strength for Field Prepared Austin Chalk Soil CLSMs

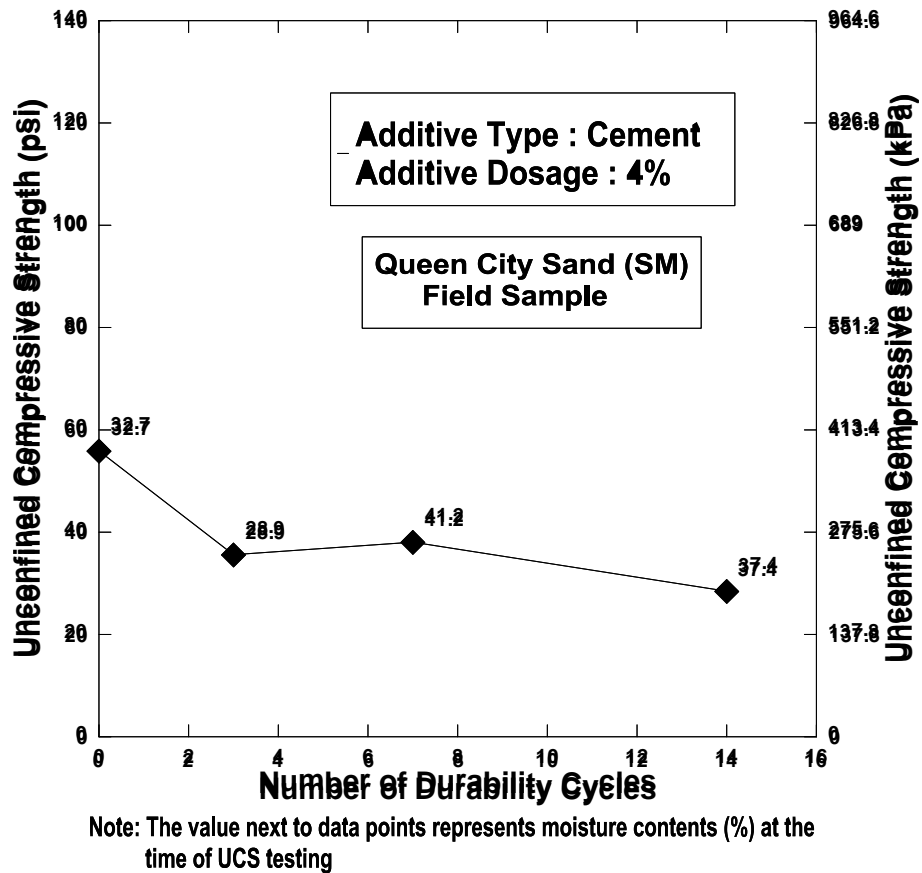


Figure 4.17 Variation of UCS Strengths for Field Prepared Queen City Sand CLSMs

4.2.5 Field Samples Testing Summary

This section summarizes the results obtained from the tests conducted on field prepared CLSM specimens. Test results for unconfined compressive strengths after wetting at selected cycles, volumetric and weight changes before and after each drying/wetting cycle along with amount of additive leached out through the durability testing are tabulated.

Table 4.2 presents the unconfined compressive strength values of 4 different Field CLSMs that were tested with details of the soil type, additive type and additive amount.

Table 4.2 Summary of UCS strengths for Field Prepared CLSMs.

Soil	Soil Type based on USCS	Additive type and Additive Dosage (%)	Unconfined Compressive Strength (psi)		%Retained Strength
			After '0' wetting cycles	After 14 cycles	
Wood Bine	SM	8% Cement	132.0	76.6	58.0
Eagle Ford	CH	18% Cement	92.0	10.0	10.9
Austin Chalk	CL	8% Cement	83.8	37.9	45.2
Queen City	SM	4% Cement	55.8	28.4	50.9

The Woodbine and Queen City field specimens at the end of 14 cycles, retained more than 50% of their initial strength whereas Eagle Ford and Austin Chalk failed to retain half their initial strength. The percent retained strength values for high plastic Eagle Ford and low plastic Austin Chalk based CLSMs are 10.9% and 45.2%, respectively.

The volumetric strains changes measured from field specimens during the wetting/drying process are summarized in Table 4.3.

Table 4.3 Summary of Volumetric Strains for Field Prepared CLSMs.

Soil	Soil Type based on USCS	Additive type and Additive Dosage (%)	Volumetric Strain Changes %		
			Maximum	Minimum	Average
Wood Bine	SM	8% Cement	0.8	0.1	0.3
Eagle Ford	CH	18% Cement	6.6	0.6	2.8
Austin Chalk	CL	8% Cement	3.7	0.7	1.9
Queen City	SM	4% Cement	2.4	0.2	0.9

It can be observed from Table 4.3 that Eagle Ford and Austin Chalk CLSMs experienced more volumetric deformations compared to Woodbine and Queen City. This may probability due the soil type of CLSM specimens.

The weight changes in % with respect to original weight of the soil specimen measured from four field prepared specimens are summarized in Table 4.4.

Table 4.4 Summary Weight Changes for Field Prepared CLSMs.

Soil Formation	Soil Type based on USCS	Additive Type and Additive Dosage (%)	Weight Changes %		
			Maximum	Minimum	Average
Wood Bine	SM	8% Cement	54.5	48.05	52.9
Eagle Ford	CH	18% Cement	54.8	42.3	48.9
Austin Chalk	CL	8% Cement	79.0	65.3	71.1
Queen City	SM	4% Cement	41.0	37.00	39.6

It can be observed from this table that Austin Chalk CLSMs experienced highest maximum weight change while Queen City sand CLSMs experienced the lowest weight change. This possibly indicates that Austin chalk samples are the most porous with more pore spaces while Queen City sand CLSMs had the least pores.

Table 4.5 summarizes the leachate concentration results for all the field prepared CLSMs tested in this research.

Table 4.5 Summary of Calcium Concentration Loss for Field Prepared CLSMs

Soil	Soil Type based on USCS	Additive type and Additive Dosage (%)	Calcium Concentration Leached Out (ppm)	Amount of Cement Leached out %
Wood Bine	SM	8% Cement	7210	4.0
Eagle Ford	CH	18% Cement	10150	5.7
Austin Chalk	CL	8% Cement	7980	4.3
Queen City	SM	4% Cement	3570	2

The calcium concentration obtained after each durability cycle is summed for 14 cycles and are presented in Table 4.5. The total amount of calcium ion concentration leached out from Eagle Ford field, Austin Chalk, Woodbine and Queen City soil based CLSMs are 10150, 7980,

7210 and 3570 ppms, respectively. Among the field CLSMs, Eagle Ford soil exhibited highest amount of calcium concentration loss.

The percent amount of cement leached out from the CLSMs are also presented here. These values are obtained from the calcium calibration chart developed based on calcium ion concentration. The more details about the calibration chart used for estimating the additive loss are presented in the analysis section of chapter 4.

4.3 Laboratory CLSM Specimens

To have a comparative study, the field prepared CLSMs were compared with the laboratory prepared CLSMs. The percent strength retained after completion of 14 wetting/drying cycle for Eagle Ford and Austin Chalk field CLSMs were found to be less than 50%. Because of this reason, these two soils were selected for comparative studies.

For the preparation of laboratory CLSM samples, additive dosage and optimum water content are required. The additive dosage was specified by consulting geotechnical company. In order to establish the optimum moisture content satisfying the flow test criteria (ASTM D 6103-97) several trails were performed in the laboratory. These CLSMs specimens after 28 days of curing satisfied the TRWD strength requirements (unconfined compressive strengths of 70psi-150psi). Durability testing was performed on these soils to assess the long term behavior and the results obtained are compared with field CLSMs results for further analysis. Figure 4.18(a) and (b) represents different durability cycles for laboratory prepared Eagle Ford CLSM specimens. Discussions on various test results from durability studies on each laboratory prepared CLSMs are presented in the following sections.



(a)



(b)



(c)

Figure 4.18 Laboratory Prepared Eagle Ford Soil CLSM at (a) after 28 days curing (b) Drying Cycle (c) Wetting Cycle.

4.3.1 Volumetric Strain Changes

4.3.1.1 Austin Chalk Soil CLSMs (Lab)

The Austin Chalk laboratory specimens after 28 days of curing were subjected to alternative wetting and drying. The measurements of the specimens were recorded before and after each cycle and were represented in Figure 4.19 in terms of a volumetric strain%. The laboratory prepared CLSMs with 8% cement as an additive survived for 14 drying/wetting cycles with maximum, minimum and average volumetric changes of 3.9%, 1.5% and 3.1% .

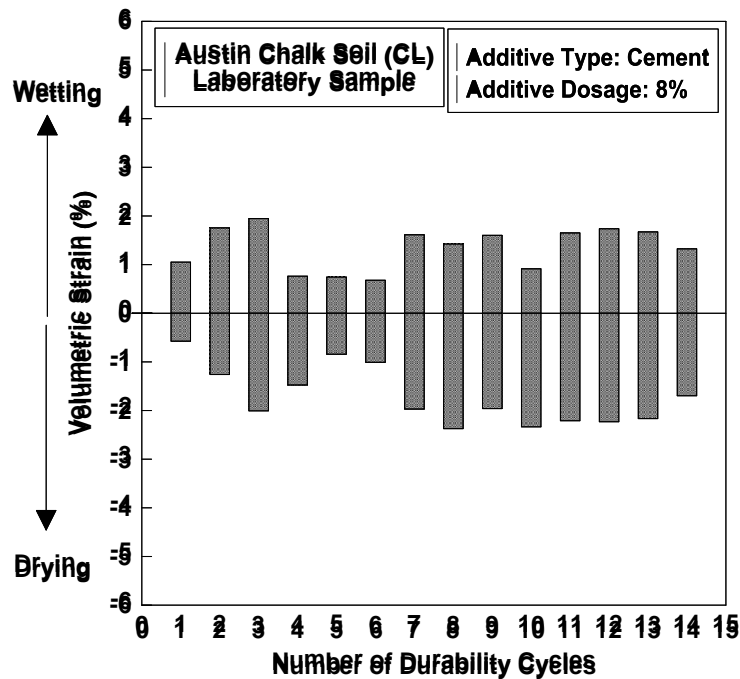


Figure 4.19 Volumetric Strain for Laboratory Prepared Austin Chalk Soil CLSMs.

4.3.1.2 Eagle Ford Soil CLSMs (Lab)

The volumetric measurements of laboratory prepared Eagle Ford soil specimens were recorded before and after each drying and wetting cycle and the results are graphically represented in Figure 4.20. The laboratory prepared Eagle Ford soil CLSMs endured for 14 drying/wetting cycles with average volumetric strain changes of 2.6%.

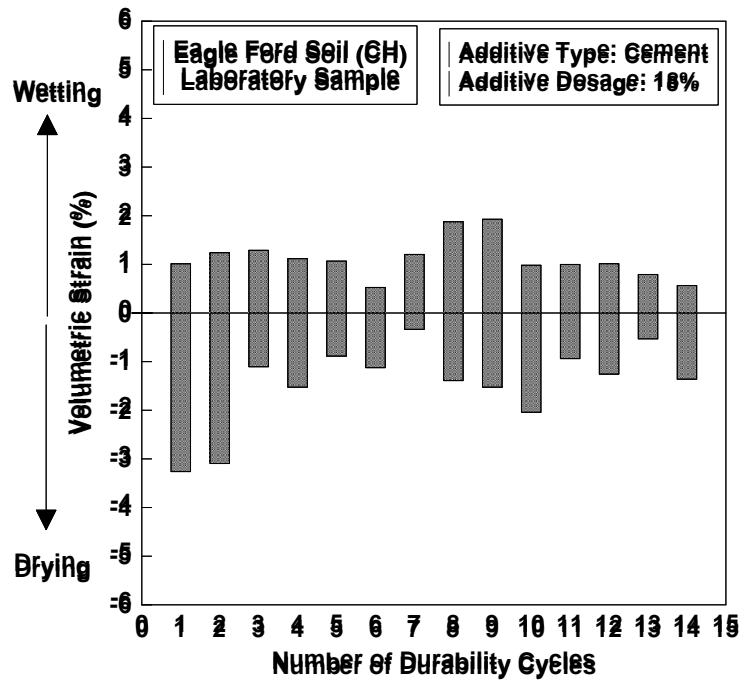


Figure 4.20 Volumetric Strain for Laboratory Prepared Eagle Ford Soil CLSMs.

4.3.2 Sample Weight Changes

4.3.2.1 Austin Chalk Soil CLSMs (Lab)

Weight changes were recorded and the results for Austin Chalk soil are represented graphically in Figure 4.21. The laboratory prepared CLSM specimens with 8% cement survived for 14 drying/wetting cycles with an average weight change of 70.5%. Also the maximum and minimum weight change % values are reported as 78.6% and 62.1%.

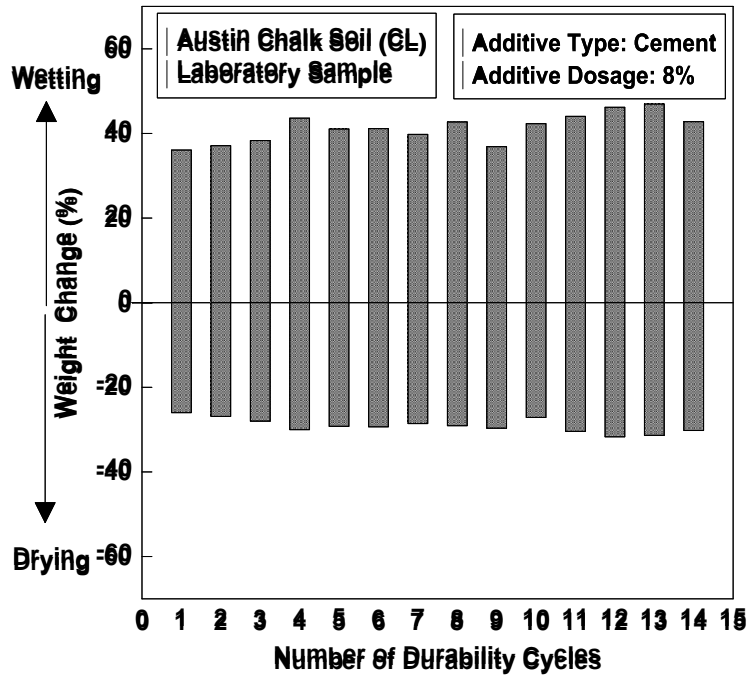


Figure 4.21 Sample Weight Changes for Laboratory Prepared Austin Chalk Soil CLSMs.

4.3.2.2 Eagle Ford Soil CLSMs (Lab)

The specimens were subjected to alternative wetting and drying process. Before and after each cycle the weights were recorded. The weigh changes during the durability cycles are shown graphically in Figure 4.22. The Eagle Ford soil CLSM specimens with 18% cement lasted till the completion of 14 cycles with average Weight Change of 76.4%.

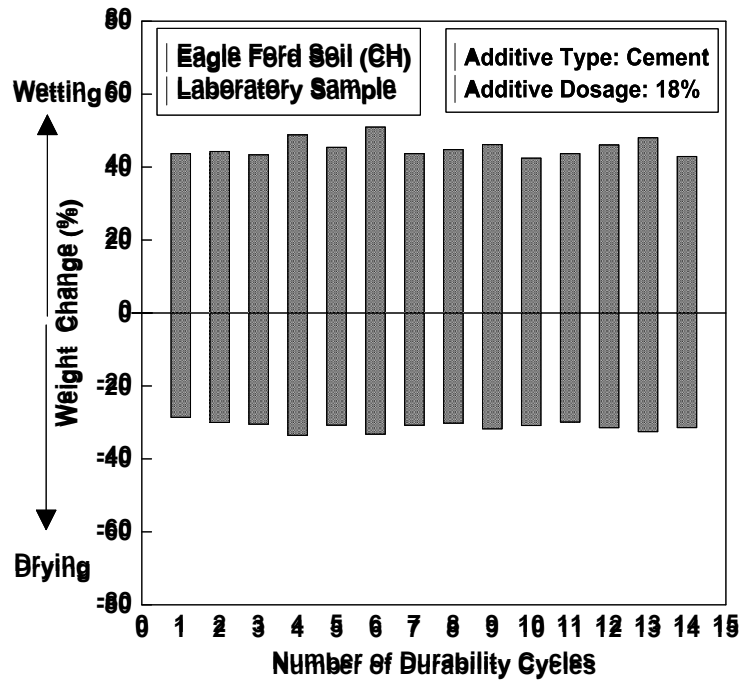


Figure 4.22 Sample Weight Changes for Laboratory Prepared Eagle Ford Soil CLSMs.

4.3.3 Leachate Calcium Concentration

4.3.3.1 Austin Chalk Soil CLSMs (Lab)

The calcium concentrations (ppm) from the collected leachate solution were determined from EDTA titration and the values obtained were plotted against durability cycles as shown in Figure 4.23. Laboratory prepared Austin Chalk soil CLSMs with 8 % cement leached out 6860 ppm calcium concentration during the 14 durability cycles.

4.3.3.2 Eagle Ford Soil CLSMs (Lab)

At the completion of 1, 3, 7, 14 cycles the amount of calcium ion loss was determined from EDTA titration of collected leachate. The calcium concentrations (ppm) from the collected leachate solution were determined and the values obtained were plotted against durability cycles as shown in Figure 4.24. For field prepared Eagle Ford soil CLSMs with 8 % cement, the total calcium concentration obtained after 14 drying/wetting cycles is 7720 ppm.

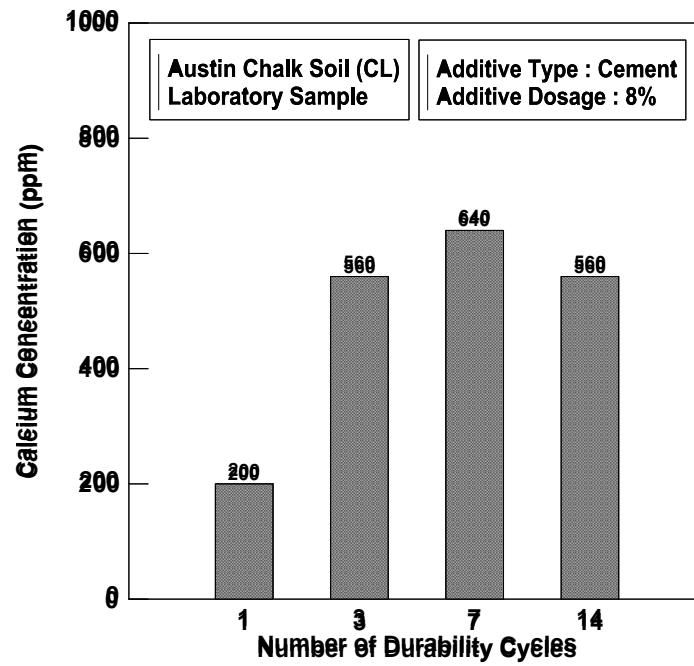


Figure 4.23 Variation of Calcium Concentration for Laboratory Prepared Austin Chalk Soil

CLSMs

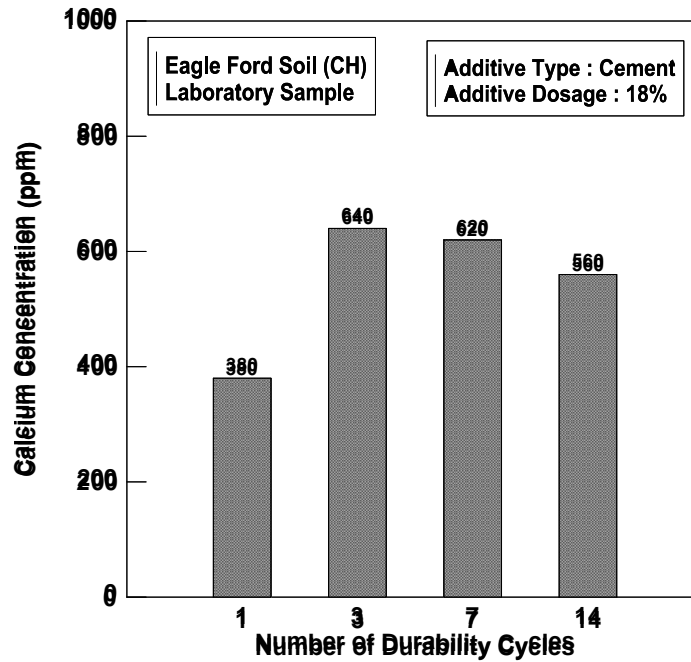


Figure 4.24 Variation of Calcium Concentration for Laboratory Prepared Eagle Ford Soil CLSMs.

4.3.4 Unconfined Compressive Strength

At the completion of '0' wetting, 3, 7, and 14 cycles, the Austin Chalk soil specimens were subjected to UCS test. Immediately 2 hours after the completion of the selected wetting cycles, the specimens were tested for unconfined compressive strength in saturated conditions. The strength variations for laboratory prepared Austin Chalk soil CLSMs with 8% Cement as additives are depicted in Figure 4.19. At '0' cycles (Wetting) the Austin Chalk soil CLSM exhibited 60.5 psi (417.2 kPa) of unconfined compression strength whereas, at the end of 14 cycles UCS value of 29.6 psi (204.2kPa) was observed. The decrease in strength values indicates the strength loss of 51.0%. Thus 48.9% of the initial strength value is retained at the completion of 14 cycles

The variation of unconfined compressive strength with number of durability cycles for laboratory prepared Eagle Ford soil CLSM are shown in Figure 4.23. Initially, at '0' wetting

cycles, the Eagle Ford soil CLSM exhibited 101.8 psi (701.6 kPa) of unconfined compressive strength whereas, at the end of 14 cycles UCS value of 17.6 psi (121.3kPa) was observed. The decrease in strength values indicated strength loss of 82.8%. Thus only 17.3% of the initial strength value is retained at the completion of 14 cycles.

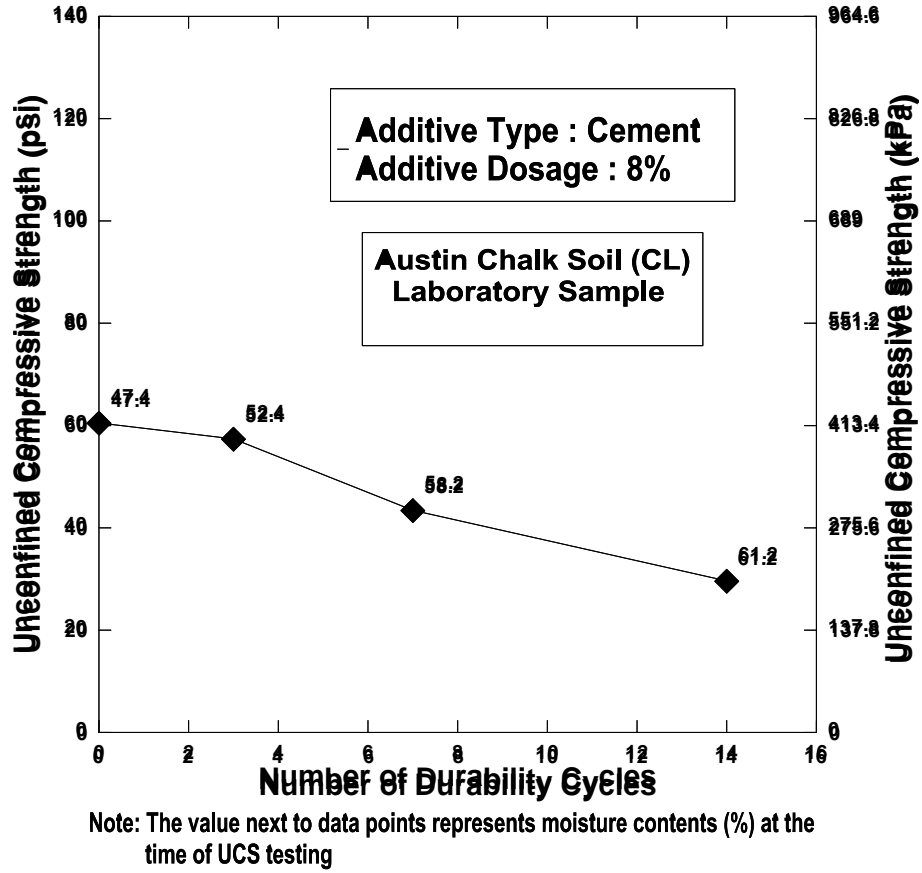


Figure 4.25 Variation of UCS Strength for Laboratory Prepared Austin Chalk Soil CLSMs.

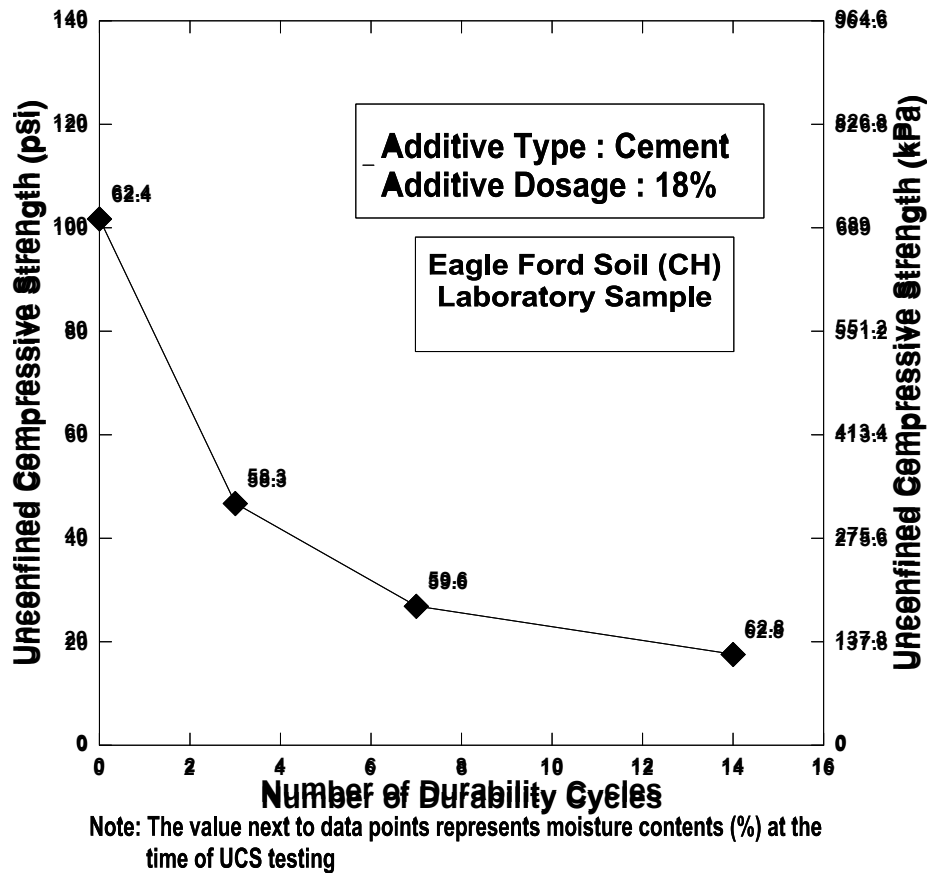


Figure 4.26 Variation of UCS Strength for Laboratory Prepared Eagle Ford Soil CLSMs.

4.3.5 Laboratory Sample Testing Summary

This section summarizes the results obtained from the tests conducted on laboratory prepared CLSM specimens. Test results for unconfined compressive strengths after wetting at selected cycles, volumetric and weight changes before and after each drying/wetting cycle along with amount of additive leached out through the durability testing are tabulated in the following Tables.

Table 4.6 summarizes unconfined compressive strength values of laboratory CLSMs that were tested with soil type, additive type and additive amounts.

Table 4.6 Summary of UCS strengths for Laboratory Prepared CLSMs

Soil	Soil Type based on USCS	Additive type and Additive Dosage (%)	Unconfined Compressive Strength (psi)		%Retained Strength
			After '0' wetting cycles	After 14 cycles	
Eagle Ford	CH	18% Cement	101.8	17.6	17.2
Austin Chalk	CL	8% Cement	60.5	29.6	48.9

Like the Field prepared Eagle Ford and Austin Chalk soil CLSMs, the laboratory prepared specimens also failed to retain half their initial strengths. The retained strength % values for high plasticity Eagle Ford soil and low plasticity Austin Chalk soil CLSMs are 17.2% and 48.9% respectively.

Table 4.7 provides the summary of volumetric strain changes of laboratory prepared CLSM from Austin Chalk and Woodbine formations.

Table 4.7 Summary of Volumetric Changes for Laboratory Prepared CLSMs

Soil Formation	Soil Type based on USCS	Additive type and Additive Dosage (%)	Volumetric Strain Changes %		
			Maximum	Minimum	Average
Eagle Ford	CH	18% Cement	4.3	1.3	2.6
Austin Chalk	CL	8% Cement	4.0	1.5	3.1

Eagle Ford and Austin Chalk soil CLSMs successfully endured for 14 durability cycle with lower volumetric strains. It can be observed that maximum, average and minimum strain changes are almost close in values.

Table 4.8 provides the summary of weight changes for laboratory prepared CLSMs from Austin Chalk and Woodbine formations.

Table 4.8 Summary of Weight Changes for Laboratory Prepared CLSMs

Soil Formation	Soil Type based on USCS	Additive type and Additive Dosage (%)	Weight Changes %		
			Maximum	Minimum	Average
Eagle Ford	CH	18% Cement	84.2	72.3	76.4
Austin Chalk	CL	8% Cement	78.3	62.1	70.5

Table 4.8 shows the maximum, minimum and average change in weights for Laboratory CLSMs. Among the two laboratory prepared specimens, Eagle Ford soil specimen experienced higher weight changes.

The leachate study results, in terms of the amount of calcium concentration loss (ppm) at the completion of 14 durability cycles are shown in Table 4.9

Table 4.9 Summary of Calcium Concentration Loss for Laboratory Prepared CLSMs

Soil Formation	Soil Type based on USCS	Additive type and Additive Dosage (%)	Calcium Concentration Leached out (ppm)	Amount of Cement Leached out (%)
Eagle Ford	CH	18% Cement	7700	4.2
Austin Chalk	CL	8% Cement	6860	3.8

Eagle Ford laboratory CLSMs lost total calcium concentration of 7700 ppm whereas, in the case of Austin Chalk soil, the total calcium concentration leached out is 6860 ppm.

4.4 Analysis of Test Results

This section presents the analysis of the test results obtained from the durability studies that are performed on both field and laboratory CLSMs. Three important aspects are addressed as a part of analysis of test results:

1. The effects of soil type on the long-term performance of CLSMs using different soils.
2. Effects of calcium concentration loss on the long term durability and strength of CLSMs.

3. Effects of preparation methods on the performance of CLSMs through comparative study between field and laboratory prepared specimens.

The following subsections explain the analysis performed on experimental test results.

4.4.1 Effects of Soil Type on Long Term Performance of CLSMs.

To assess the implications made on the long-term performance of CLSMs, the effect of soil type on four engineering parameters—unconfined compressive strength, volumetric strain changes, weight changes and calcium ion loss are analysed. The strength retained values at increasing durability cycles acts as a good indicator to know the effective performance of CLSM.

Figure 4.27 represents the percent retained strength values for different soil types. The retained strength values of field prepared CLSMs at the end of 14 durable cycles give us a better understanding about influence of soil type on the strength of the CLSM. It can be observed that from the graph that CH soil has less retained strength with 10.9% whereas, (SM) soils retained almost more than 50% of its initial strength with 58.0%. Though, the clay soils (Eagle Ford and Austin Chalk) successfully endured 14 durability cycle, they failed to retain more than 50% of its initial strength values. On the other hand both the non-plastic soils (Queen City Sand and Woodbine) retained more 50% of its initial strength value. Among the 4 different soils, CH soils experienced a higher strength loss % while (SM) soils showed lower strength loss %. Eagle Ford and Austin Chalk have more clay proportions when compared to other soils. Hence for CLSMs with soils having higher clay % and PI%, the strength retained% can be lower.

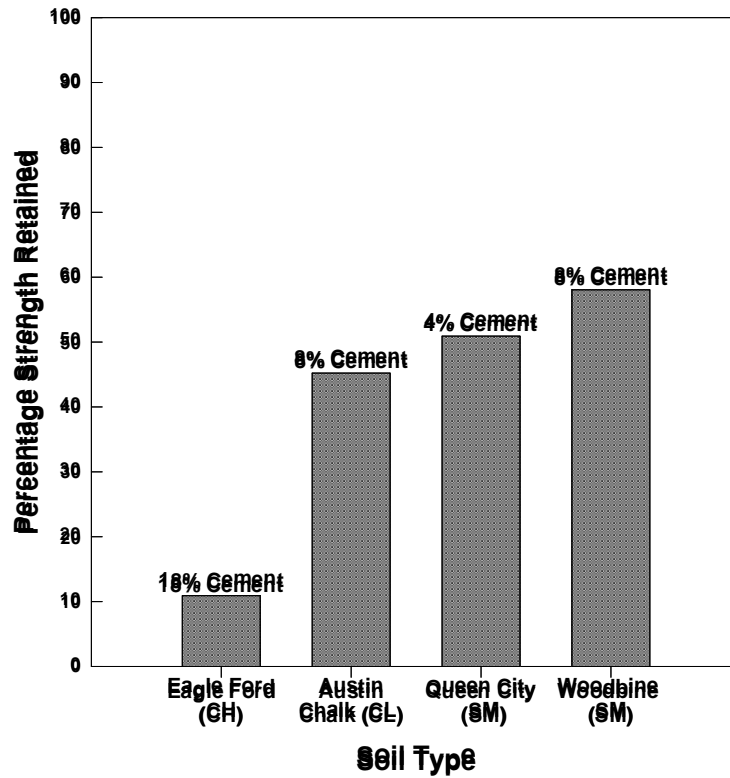


Figure 4.27 Effect of Soil Type on Retained Strengths of Field Prepared CLSMs.

Volumetric strain changes for the four field prepared CLSMs using different soil types are graphically represented in Figure 4.28. Maximum volumetric strain changes experienced by the each field prepared CLSMs are considered for this analysis. Eagle Ford soil CLSM with high plasticity clay experienced higher volumetric deformation, whereas the SM CLSMs experienced less volumetric changes. Also it can be observed that Eagle Ford (CH) and Austin Chalk (CL) soil samples exhibited more volumetric strains when compared with non plastic soils. The above test results substantiate that CLSMs with clayey material experiences more volumetric strain changes when compared to those of non plastic soils.

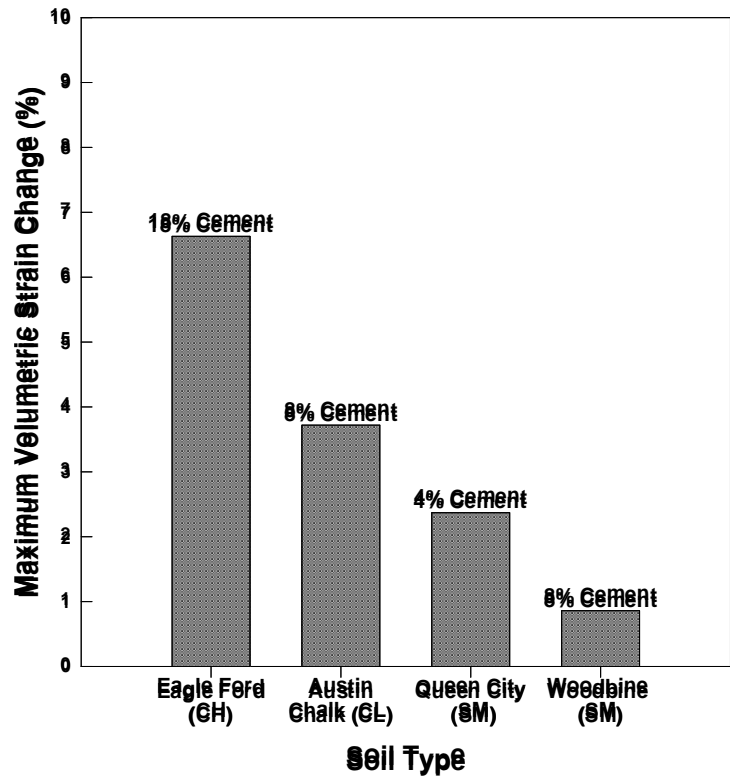


Figure 4.28 Effect of Soil Type on Volumetric Strain Changes of Field Prepared CLSMs.

Maximum weight changes experienced by the field prepared CLSMs containing different soil types are represented graphically in Figure 4.29. Maximum weight change is the summation of the changes in weight during both wetting and drying process in one particular durability cycle. For this analysis the maximum weight change values are considered instead of average weight strain changes. From the weight changes% for each field prepared CLSM, soil type influence on weight changes are studied. The Austin Chalk soil CLSM with low plastic clay as fine aggregates experienced higher weight change, whereas the Queen City soil CLSMs with silty clayey sand experienced lower changes. Here the weight changes for high plastic Eagle Ford specimen is less than low plastic Austin Chalk CLSM. Also, it can be observed that the maximum weight change values for Eagle Ford and Woodbine soil CLSMs are almost equal. Based on weight change results, no significant trend has been observed to know

influence of soils type on weight changing behavior of CLSMs in other word, irrespective of soil type, weight changes can be higher

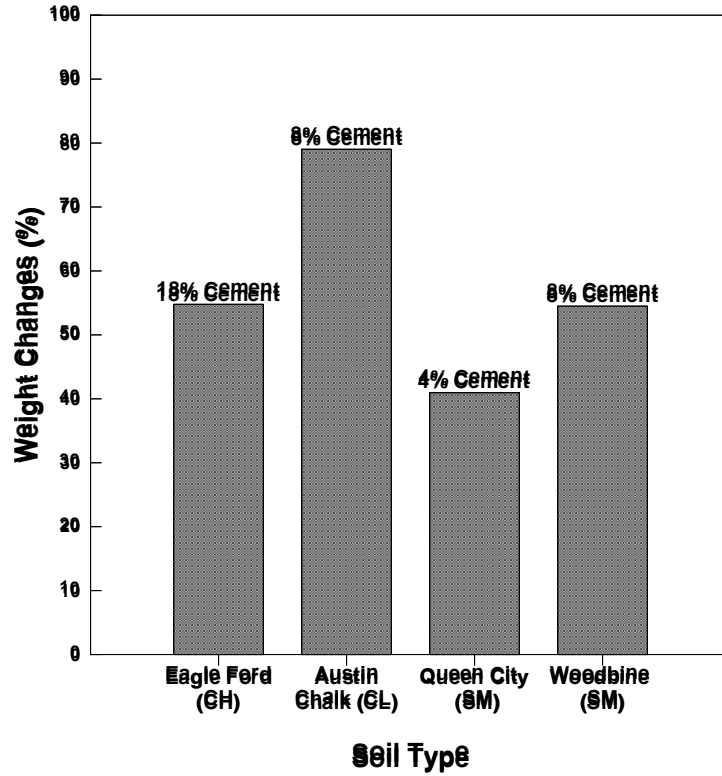


Figure 4.29 Effect of Soil Type on Weight Changes of Field Prepared CLSMs.

Figure 4.30 represents the calcium concentration loss experienced by the field prepared CLSMs using different soil types. The total amount of calcium concentration leached out from CH CLSM is higher, while the Queen City sand CLSMs experienced lower calcium loss. This clearly indicates that the magnitude of calcium concentration loss varies with soil type of the CLSM. Hence, CLSMs with high plastic soils can have higher calcium loss when compared to CLSM specimens with other soil types.

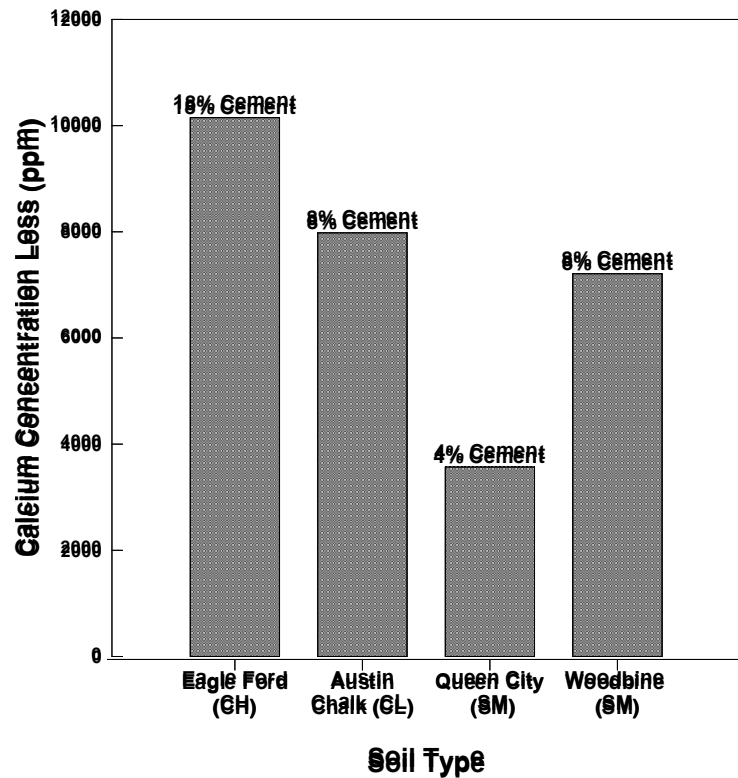


Figure 4.30 Effect of Soil Type on Calcium Concentration Loss of Field Prepared CLSMs.

4.4.2 Effects of Calcium Concentration Loss on the Strength of CLSMs

Leachability of a CLSM is the parameter used to measure the permanency of the chemical additive. In actual site conditions this permanency decreases with time due to environmental effects like surface runoff. Also rainfall infiltration can sometimes leach the additive and reduce the soil strength. In the laboratory, replication of rainfall infiltration can be achieved by conducting the Leachate Studies. In this research study, a combine device using a modified approach was performed for durability studies. A modified approach method which is more efficient and effective in terms of material usage and time, simulates actual field moisture fluctuations by wetting and drying process. The combined device helps to collect leachate after every desired wetting cycle. The small representative amount of this collected leachate solution is used for the calcium ion determination. This can be achieved by titrating the leachate solution with EDTA. The total calcium concentration (ppm) leached out throughout the 14 cycles is

calculated by multiplying the average of calcium concentrations values obtained at 1,3,7 and 14 cycles with a multiplication factor 14.

The total concentration of calcium leached out from each field prepared CLSM and corresponding strength retained % at the completion of 14 cycles are shown in Figure 4.31. It can be observed that for Eagle Ford(CH) CLSM, the retained strength is low at 10.9%. The Eagle Ford CLSM has lost 10150 ppm of calcium during the durability studies. The strength loss in the eagle ford CLSMs may be due higher calcium ion loss. The Queen City Sand (SM) and Woodbine(SM) CLSMs retained more than 50% of their initial strength value with 3570 and 7210 ppm loss of Calcium concentration. The Austin Chalk CLSM at 7980 ppm manages to retain 45.2% of its original strength.

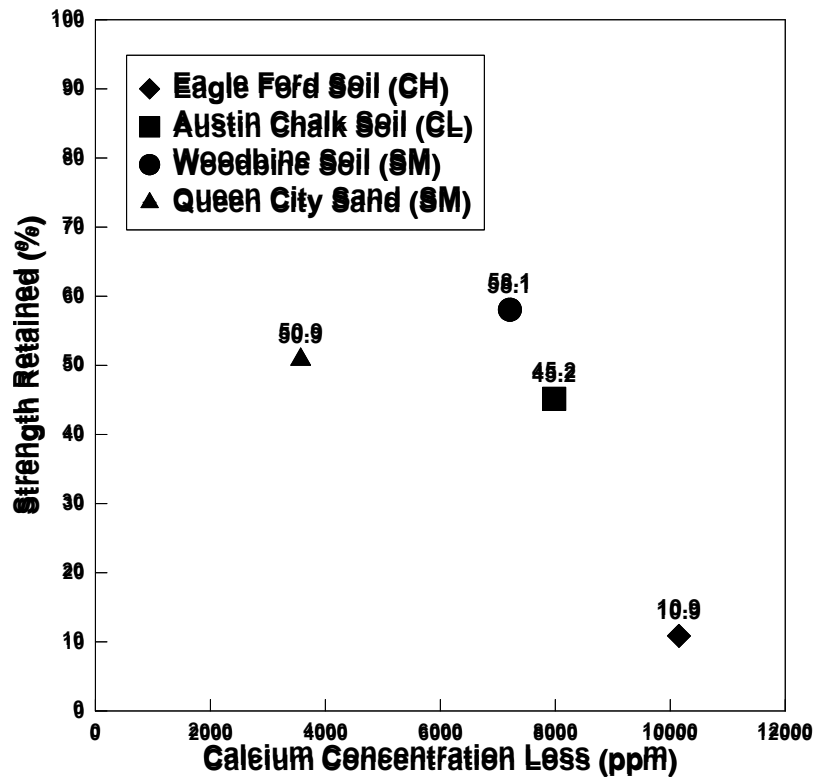


Figure 4.31 Effect of Calcium Concentration Loss on the Strengths of Field prepared CLSMs.

Further, to determine the approximate amount of additive (cement) loss from CLSM specimen a Calibration Chart is developed. Determination of % cement leached out helps in

better understanding the factors responsible for strength loss for strength loss. CLSMs. Calcium calibration chart helps to assess the total percentage of additives (cement) loss at the end of 14 durability cycles. The chart was developed by plotting known cement contents values as X-Coordinates and their corresponding calcium concentrations as Y-Coordinates. Details about the development of calcium calibration chart are discussed in the following paragraph.

Initially 0.25, 0.5, 0.75, 1, 1.25 and 1.5 grams of oven dried Portland cement (Type-II) corresponds to 1%, 2%, 3%, 4%, 5%, and 6% of cement were mixed with 25ml of deionized water to form a cement solution. These solutions were then subjected EDTA titrations to know the amount of calcium concentration in terms of calcium carbonate. Upon determining the calcium concentrations (ppm) for each of six known cement solutions, a chart as shown in Figure 4.32 is developed with the cement (%) as Abscissa and Calcium Carbonate (ppm) as ordinate.

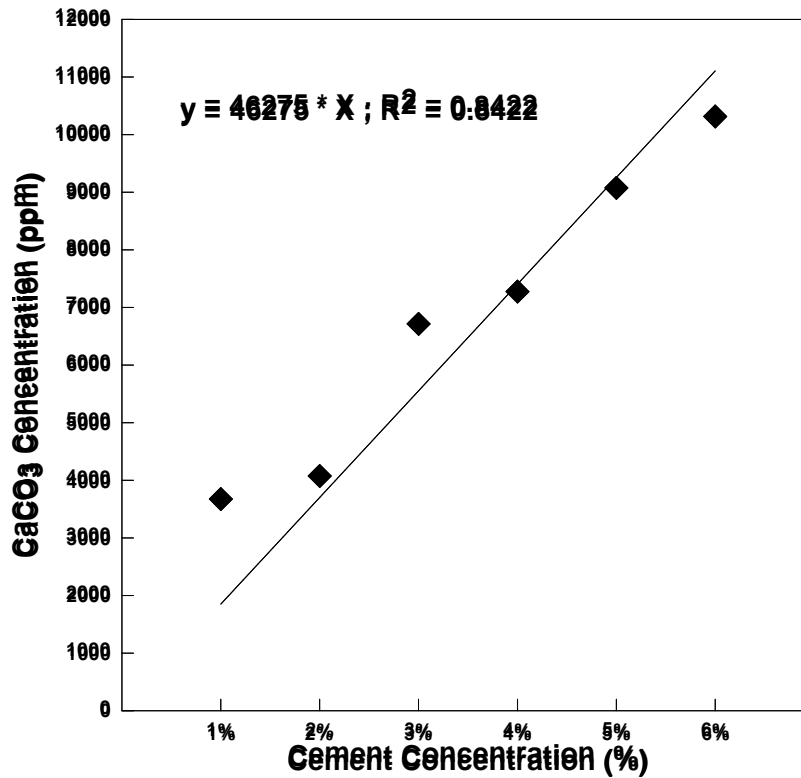


Figure 4.32 Calibration Chart Developed for Determination of Cement Content (%).

Using the calibration chart, amount of additive loss can be assessed. Upon knowing the total calcium loss at the end of 14 cycles, the amount of cement% leach out from each specimen can be obtained, correspondingly from calibration graph. The percentage loss of cement for each soil are presented graphically in Figure 4.33. It can be observed that Eagle Ford recorded a highest additive loss whereas Queen City lost less additive. Amount of additive retained (%) can be calculated by subtracting amount additive (%) loss from the initial dosage %

The effect of cement % loss on the retained strength at the completion of 14 cycles are also analyzed. Figure 4.34 shows the cement concentration loss and their corresponding retained strength. Eagle Ford CLSM with 18 % cement lost 5.7% at the end of 14 cycles. Though, Eagle Ford lost only 1/3rd of its initial dosage, the retained strength% obtained is very low. Austin Chalk and Woodbine specimens lost 4.3% and 4% out of their initial cement dosage of 8% with 45.2% and 58.1% as strength retained% values. Queen City Sand CLSM retained half of its initial strength at end of 14 cycle by losing exactly half of its additive dosage %. The analysis yielded significant implications on strength loss due to the effect of additive loss.

The analysis yielded significant implications on strength loss due to the effect of additive loss.

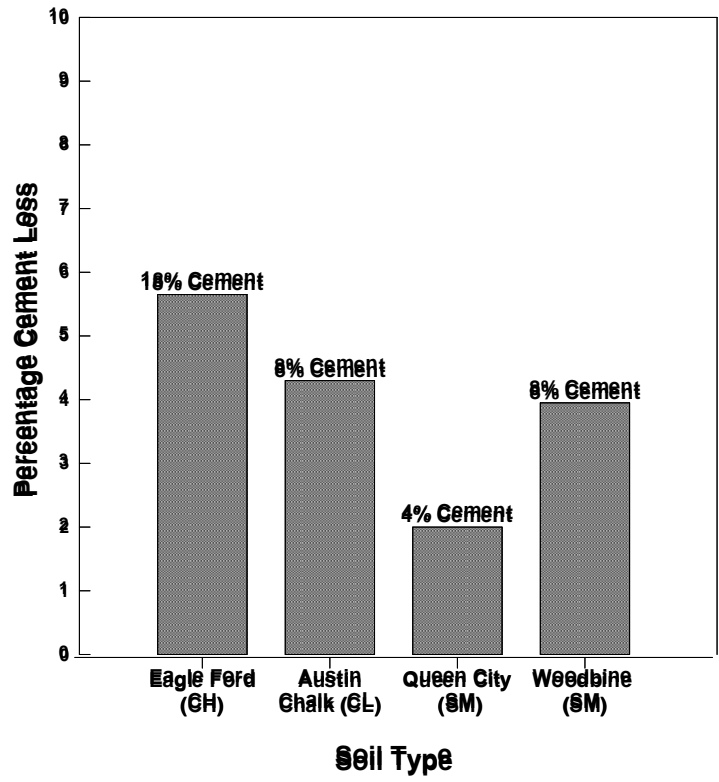


Figure 4.33 Cement Concentration Loss of Field Prepared CLSMs.

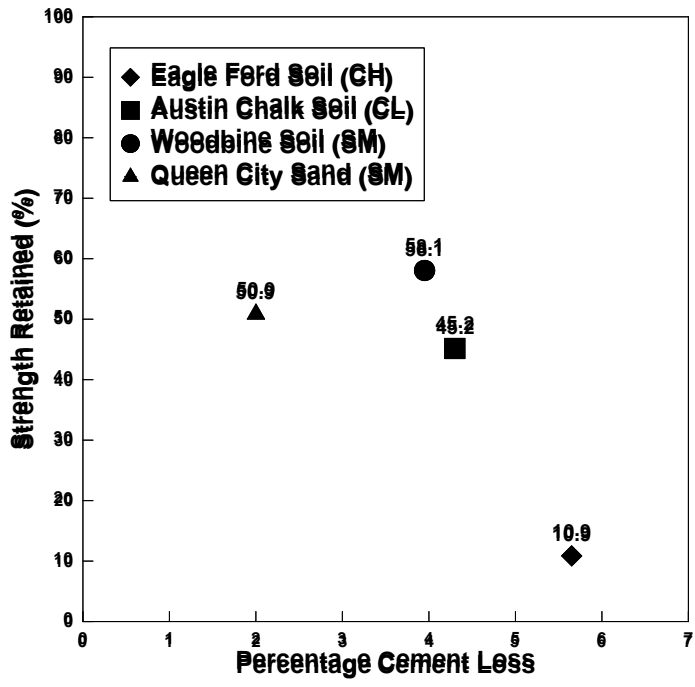


Figure 4.34 Effect of Cement Loss on the Strength of Field Prepared CLSMs.

4.4.3 Comparisons between Field and Laboratory Prepared CLSMs

To analyze, how the CLSM design mix preparatory methods at different conditions effects its long term performance, a comparative study was conducted between field and laboratory prepared CLSM using Eagle Ford and Austin Chalk Formations.

As a part of comparative study, unconfined compressive strength, volumetric strain changes, weight changes and calcium loss results obtained from durability studies are compared. The comparison between field and laboratory prepared CLSMs using Eagle Ford and Austin Chalk soils are presented here.

Graphical representations of field and laboratory strength values are shown in Figures 4.35 and 4.36 for Eagle Ford and Austin Chalk CLSMs respectively. Figure 4.35 shows variation of unconfined compressive strength for field and laboratory prepared Eagle Ford CLSMs. The unconfined compressive strength values for field prepared CLSMs at '0' wetting, 3, 7 and 14 cycles are 92.1 psi (635 kPa), 13.9 psi (95.8 kPa), 19.2 psi (132.3 kPa), and 10.0 psi (68.9 kPa) respectively, whereas for laboratory prepared specimens these values are 101.7 psi (701.1 kPa), 46.2 psi (318.5 kPa), 26.9 psi (185.4 kPa) and 17.5 psi (120.6 kPa) respectively. The strength values for laboratory prepared specimens are marginally higher than that of field prepared CLSMs. Also the percent retained strength (%) value at 14 cycles is higher for laboratory prepared CLSMs.

Figure 4.36 shows variation of unconfined compressive strength for field and laboratory prepared Austin Chalk soil CLSMs. The unconfined compressive strength values for field specimens at 0, 3.7 and 14 cycles are 83.8 psi (577.7 kPa), 64.4 psi (444 kPa), 47 psi (324.0 kPa), and 37.9 psi (261.3 kPa) respectively, whereas for laboratory prepared specimens these values are 60.5 psi (417.1 kPa), 57.3 psi (395.0 kPa), 43.4 psi (299.23 kPa) and 29.6 psi (204.0 kPa) respectively. The strength values for field prepared CLSMs are slightly higher than that of laboratory specimens.

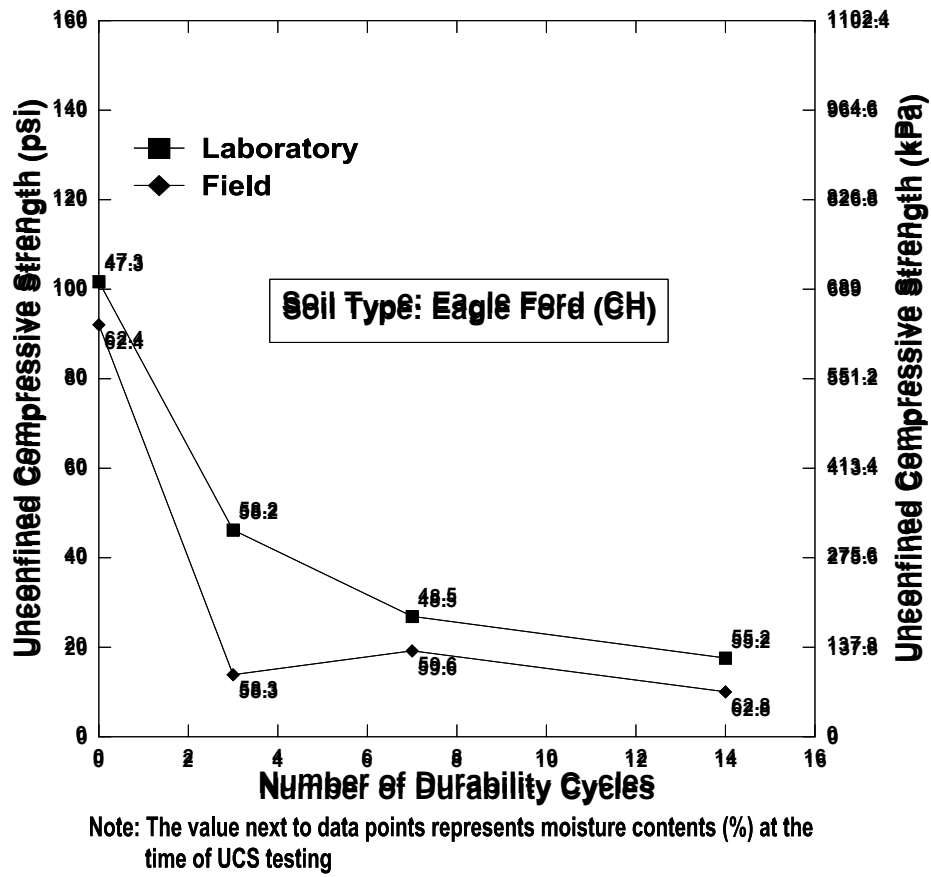


Figure 4.35 Variation of UCS Strengths for Eagle Ford Soil Field and Laboratory Prepared CLSMs.

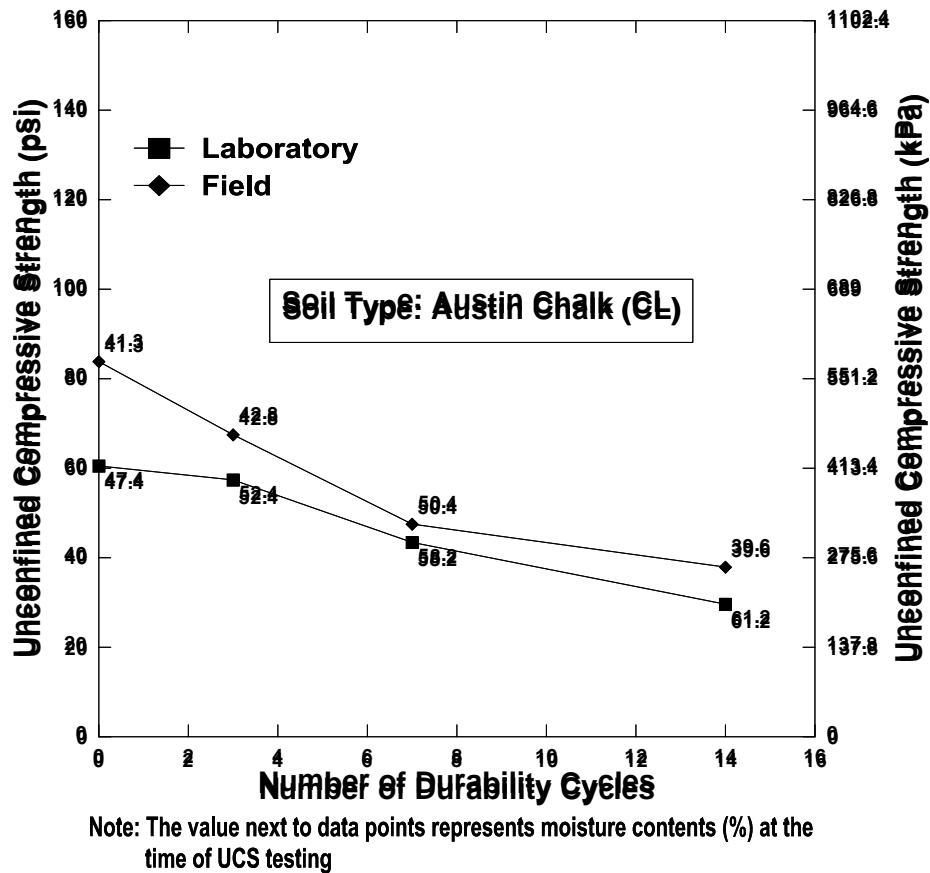


Figure 4.36 Variation of USC Strengths for Austin Chalk Soil - Field and Laboratory Prepared CLSMs.

Figure 4.37 through 4.40 graphically represents the comparison between field and laboratory prepared CLSM in term of retained strengths, volumetric deformation, weight changes and calcium concentration loss for both Eagle Ford and Austin Chalk soils. Though the difference in values are small, the retained strength % are higher for laboratory prepared specimen for both soils when compare to field specimen. Volumetric strain changes for field prepared Eagle Ford soil CLSMs are higher than laboratory CLSMs. On the other hand, in the case of Austin Chalk soil specimen, volumetric strain changes are higher for laboratory specimen. Weight changes for laboratory prepared Eagle Ford CLSMs are higher than laboratory specimens. On the other hand, in the case of Austin Chalk specimen, maximum weight changes for field and laboratory specimen are almost equal. Calcium Concentration Loss

for laboratory prepared Eagle Ford and Austin Chalk CLSMs are lower than that of field prepared specimens.

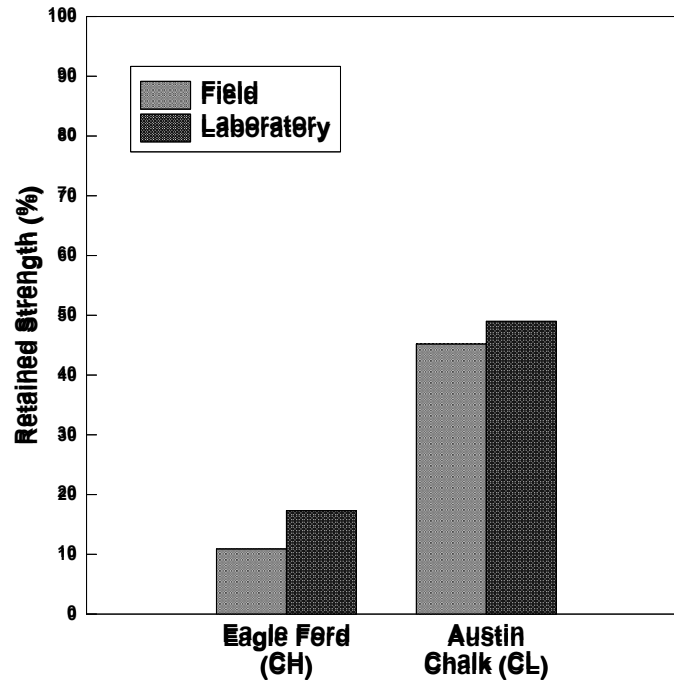


Figure 4.37 Comparison of Retained Strength% for Eagle Ford and Austin Chalk Soil CLSMs.

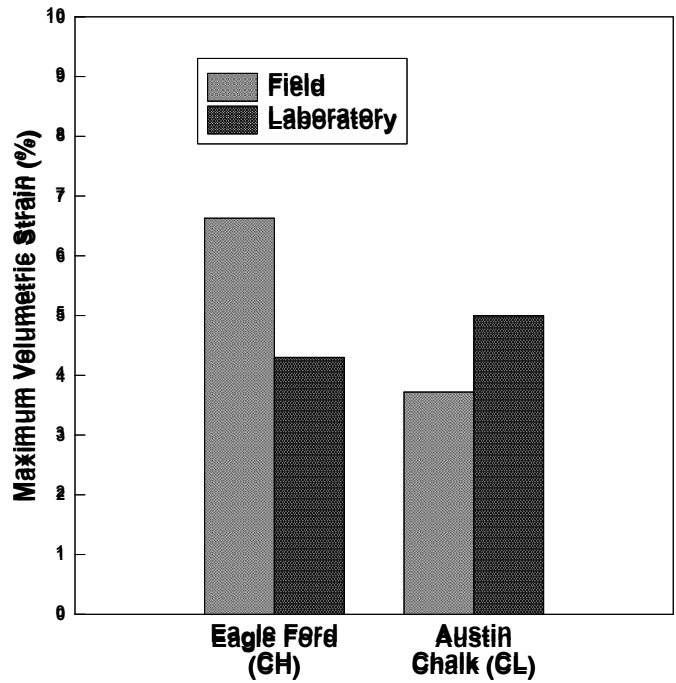


Figure 4.38 Comparison of Volumetric Strain Changes for Eagle Ford and Austin Chalk Soil CLSMs.

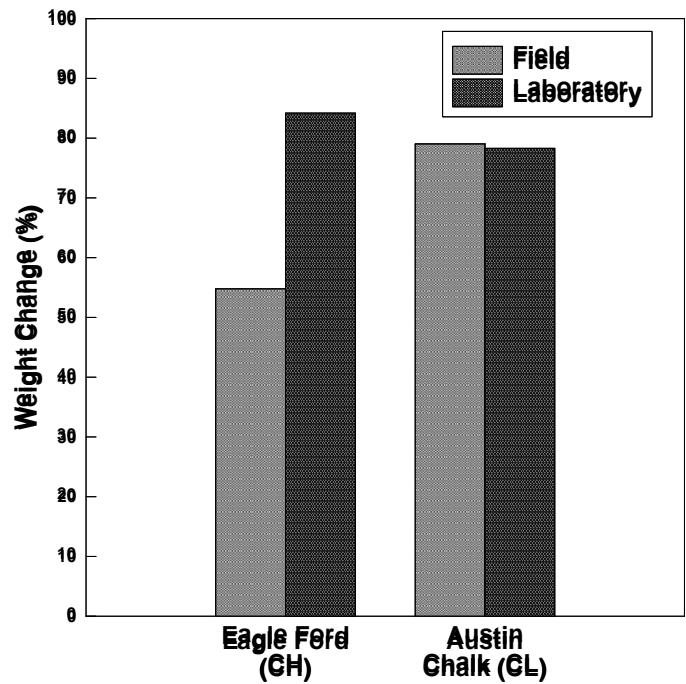


Figure 4.39 Comparison of Weight Changes for Eagle Ford and Austin Chalk Soil CLSMs.

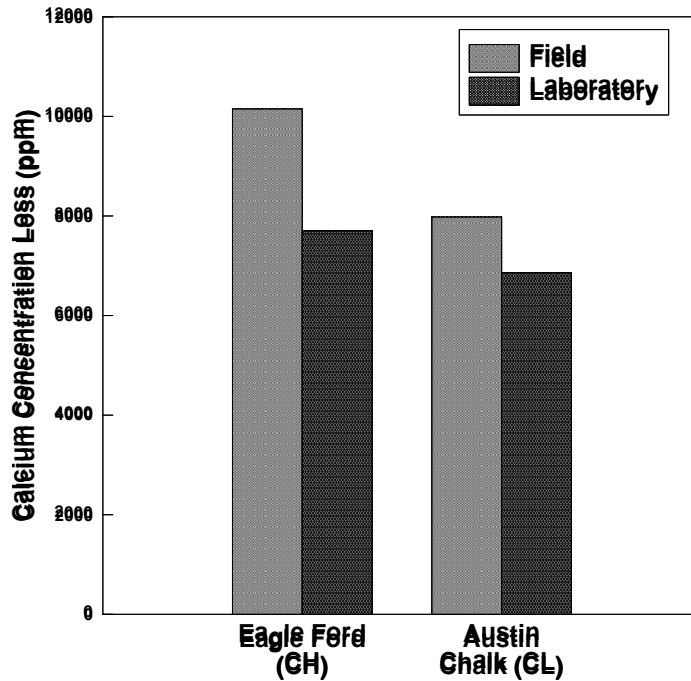


Figure 4.40 Comparison of Calcium Concentration Loss for Eagle Ford and Austin Chalk Soil CLSMs.

4.5 Summary and Findings

Four native soils along the IPL project alignment were selected for evaluating the long-term performance of CLSM design mix. The assessment of long term performance of CLSMs were conducted using combined durability studies. This testing method incorporates both wetting/drying and leachate collection process in a single device. The results of the combined durability tests that were conducted on the field prepared and laboratory prepared soil specimens were discussed. Volumetric strains (diameter and vertical height) and sample weight changes were collected over the course of alternating wetting and drying cycles with a vernier caliper, and weigh scale. Additionally, leachate samples were collected at select cycles (1, 3, 7,14) and tested for calcium concentration (ppm) using a titration process. The amount of calcium concentration obtained predicts the amount of cement that had leached out. Three important aspects are addressed as a part of analysis of the test results.

The effect of the soil type on the long-term performance of CLSMs using native soils as fine aggregates are analyzed in term of strength, volumetric stain changes, weight changes and calcium Loss. It has been observed that from both Field and Laboratory tests the CLSMs with high plasticity index and high clay proportion experienced more strength loss when compared non plastic soil CLSMs. Also, volumetric strains exhibited by Eagle Ford (CH) and Austin Chalk(CL) soil specimens when compared with non-plastic Queen City and Woodbine soil CLSMs are high. The magnitudes of calcium concentration loss varied with soil type. CLSMs with high plasticity clay leached out more concentration of calcium when compared to CLSM specimens with other soil types.

Effect of calcium concentration loss on the long term durability and strength of CLSMs are analyzed in this chapter. Calcium ion concentration leachates out indicates corresponding additive loss from the specimen. The decline in the strength of the CLSMs over time can be attributed to additive loss. Though Eagle Ford lost only 1/3rd of its initial dosage, the strength loss% was very high. In the case of Austin Chalk, Woodbine and Queen City soil CLSMs, it was observed that the strength retained was proportionate to the amount of additive retained.

Effects of preparation methods on the performance of CLSMs through comparative study between field and laboratory prepared specimens using Eagle Ford and Austin Chalk soils are also analyzed. Various Engineering parameters are compared to understand how preparation methods affect the long term performance of CLSM. The analysis showed, slightly higher retained strength % values for laboratory prepared specimen when compared to field specimen. Also calcium concentration loss for laboratory prepared CLSMs are lower than that of field prepared specimens. This may be due to better quality control in laboratory compared to that of field.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Introduction

In this research an attempt is made to assess the long term performance of CLSM using a combined device, which combines both stages of durability– wetting/drying cycles and leachate collection to address the long-term performance and permanency of additive in Controlled Low Strength Material. The efficacies of CLSM mix design using native soils from different geologic formations were assessed to identify how the properties of CLSM's constituents influence its long term performance. CLSMs are analyzed in terms of unconfined compressive strength, volumetric strain changes, weight changes and leachate concentration through wetting/drying cycles and leachate collection. Wetting/drying studies focused on replicating the volumetric changes that occur due to moisture ingress and digress whereas leachate collection focused on replicating the rainfall infiltration that can sometimes leach the additive and reduce soil strength. Another objective of this study was to compare the performance differences between laboratory and field prepared native soil CLSMs. This type of comparisons will identify the differences in sample preparation methods and their effect on long-term performance of these CLSM mixes.

5.2 Summary and Conclusions

The results and conclusions derived from this research are summarized as follows.

- All CLSMs, prepared using native soils from four different geological formations satisfied the TRWD strength requirements after 28 days of curing. Also, during the durability studies, all the field and laboratory prepared specimens survived 14 durability cycles with varying percent retained strengths. In the case of field prepared CLSMs, Queen City Sand with 50.9% and Woodbine soils with 58.0% have retained more than 50% of

their initial strengths at the completion of 14 cycles whereas, Eagle Ford soil with 10.9% and Austin Chalk soil with 45.2% failed to retain at least 50% strength at the end of durability cycles.

- The dosage of cement used for the Eagle Ford, Woodbine, Austin Chalk and Queen City soils are 18%, 8%, 8%, and 4% respectively. In the case of field prepared CLSM samples there is no control over the water content whereas in the case of laboratory prepared CLSMs, optimum moisture content was established based on the Flow Test in accordance with ASTM D 6103 method.
- Since field prepared Eagle Ford and Austin Chalk soil CLSMs proved unsuccessful in retaining 50% strength, laboratory CLSMs were prepared and tested for a comparative study analysis. From this study, it was observed that the laboratory CLSMs exhibited similar trends in terms of strength retention as the field treated CLSMs. The retained strength in % for Eagle Ford and Austin Chalk soil CLSMs are 17.2% and 48.9%, respectively.
- The retained strengths after 14 durability cycles are higher for Woodbine and Queen City soil CLSMs whereas Austin Chalk and Eagle Ford soil have shown low retaining strengths.
- In the case of durability studies on field CLSMs, Eagle Ford soil specimens experienced relatively higher volumetric strains when compared to Austin Chalk, Woodbine, and Queen City soil specimens.
- Among the field CLSMs, Austin Chalk soils exhibited highest average weight change% with 71.0% while Queen City Sand soil showed the lowest weight changes with 39.0%. On the other hand laboratory prepared Eagle Ford CLSM experienced highest weight change with average weight change of 76.4%. The weigh changes are higher for clayey CLSMs when compared to non-clayey CLSMS of this research.

- Austin Chalk and Woodbine soils retained 3.7% and 4.0% out of their initial cement content of 8% with calcium loss of 7980 and 7210 ppms, while the Queen City Sand CLSM lost half of its initial 4% additive content with the calcium concentration loss of 3570 ppm.

5.3 Future Studies and Recommendations

1. Long term field monitoring studies in terms of volumetric change , weight change, additive loss and strength are to be performed to validate the laboratory durability results.
2. The potential for corrosion of metallic pipe embedded in CLSM can be low due to the reduced permeability of CLSM, beneficial changes in pH and resistivity of pore solution in the CLSM micropores. Since corrosion activity tends to be a long term phenomenon, research on how CLSM affects corrosion of metallic pipe should be tracked.
3. CLSM is a product whose future performance is best predicted by the past performance in similar situation for similar conditions. So the specimens of the CLSM should be collected from actual project site at different time intervals in their design life so that long term properties of CLSM can be assessed under real field conditions. Agencies should consider developing performance tracking method for CLSM application.
4. Information about field performance of various constituent materials in CLSM should be gathered and synthesized to better quantify the service life in various environments.
5. Life Cycle Cost Analysis of CLSMs are needed to quantify the economic benefits.

REFERENCES

- 1) American Concrete Institute (ACI) Committee 229. (1994). "Controlled Low-Strength Materials", Report 229.94, Vol.16, No.7, American Concrete Institute, Framington Hills, 55-64.
- 2) Ardani, A., (1987) "Bridge Approach Settlement," Colorado Department of Highways Report No. CDOH-DTP-R-87-06.
- 3) AASHTO, " A Look at What Some States Are Doing," AASHTO Quaterly, Vol.64,No.4.
- 4) American Concrete Institute, 2005, Controlled Low-Strength Materials, ACI 229R-99, Reapproved 2005, 15 p
- 5) Brewer, W. E., 1994, "Durability Factors Affecting CLSM", Controlled Low-Strength Materials, STP-150, American Concrete Institute, Michigan, 41-43.
- 6) Buss, W.E., "Iowa Flowable Mortar Saves Bridges and Culverts," Transportation Research Record, No. 1234.
- 7) Chittoori, B. C. S. (2008). Clay mineralogy effects on long-term performance of chemically treated expansive clays. (PhD thesis). Retrieved from ProQuest Dissertations and Thesis. (Accession Order No. AAT 3339038).
- 8) Design and Application of Controlled Low-Strength Materials (Flowable Fill), ASTM STP 1331, A.K. Howard and J.L. Hitch, Eds., American Society for Testing and Materials.
- 9) Du, L., Folliard, K. J., and Trejo, D., (2002) "Effects of Constituent Materials and Quantities on Water Demand and Compressive Strength of Controlled Low-Strength Material", ASCE Journal of Materials in Civil Engineering, Vol. 14, No.6, 485-495.
- 10) Du, L., Miquel, K., Folliard, K. J., Soheil, N., and Trejo, D., (2006) "Rapid-Setting CLSM for Bridge Approach Repair", ACI Materials Journal, Vol. 103, No. 5, 312-318.
- 11) Finney, A. J., Shorey, E. F., Anderson, J., (2008) "Use of Native Soil in Place of Aggregate in Controlled Low Strength Material (CLSM)", Pipeline Congress, ASCE Journal of Materials in Civil Engineering.

- 12) Folliard, K. J., Trejo, David, and S. A. Sabol (1999) "Controlled Low-Strength Material for Backfill, Utility Bedding, Void Fill, and Bridge Approaches", NCHRP 24-12 Phase I Interim Report, Delaware Transportation Institute, University of Delaware, Newark.
- 13) Folliard, K. J., Du, Lianxiang and Trejo, David, (2003) "Effect of Curing Conditions on Strength Development of Controlled Low-Strength Material", ACI Materials Journal, Vol.100, No.1, 79-85.
- 14) Folliard, K. J., Trejo, David, Sabol, S. A., and Leshchinsky, D., (2008) "Development of a Recommended Practice for Use of Controlled Low-Strength Material in Highway Construction", NCHRP 597 Report, 5-39.
- 15) Fougere, K. A., " Evaluation of Flowable Fill for Use in Highway and Bridge Application," Technical Paper 94-6, Maine Department of Transportation, Maine.
- 16) Fesenmaier, T., "CLSM for New England Thruway", Concrete International Vol. 10, No.7.
- 17) Funston, J.J., Krell, W.C. And Zimmer, F.V., "Flowable Fly Ash, A New Cement Stabilized Backfill", Civil Engineering.
- 18) Gardner, M. R., (1998) "Developing controlled Low-Strength Materials to Meet Industry and Construction Needs," *The Design and Application of Controlled Low-Strength Materials (Flowable Fill)*, ASTM STP 1331.
- 19) Green, B. H., Staheli, K., Bernett, D., and Walley, D. M., (1998). "Fly-Ash-Based Controlled Low-Strength Material (CLSM) Used for Microtunneling Applications", *The Design and Application of Controlled Low-Strength Materials (Flowable Fill)*, ASTM STP 1331, A. K. Howard and J. L. Hitch, Eds., American Society for Testing and Materials.
- 20) Hook, W. and Clem, D. A., (1998) "Innovative Uses of Controlled Low-Strength Material (CLSM) in Colorado", *The Design and Application of Controlled Low-Strength Materials (Flowable Fill)*, ASTM STP 1331, A. K. Howard and J. L. Hitch, Eds., American Society for Testing and Materials.

- 21) Howard, A. K., 1996, Pipeline Construction: Relativity Publishing, Lakewood, CO, Chapter 13, Soil-Cement Slurry, 1-18.
- 22) Howard, A. K., and Bowles, L., (2011) "Flowable Fill and the Ridges Basin Inlet Conduit", Pipeline Congress, ASCE Journal of Materials in Civil Engineering.
- 23) Hoyos, L.R., Laikram, A., and Puppala, A.J (2005). "Assessment of Seasonal Effects on Engineering Behavior of Chemically Treated Sulfate Rich Expansive Clay." *Proc., GEOPROB2005: International Conference on Problematic Soils*, 25-27.
- 24) Kawasaki, H., Horiuchi, S., Akatsuka, M and Sano, S., (1992) "Fly- Ash Slurry Island, I. Theroetical and Experiemental Imvestigation." *Journal of Materials in Civil Engineering* , Vol 4, No.2.1992.
- 25) Karduri, R. K. R. (2011). Sustainable Reutilization of Excavated Trench Material. (Master thesis). Retrieved from ProQuest Dissertations and Theses. (Accession Order No. AAT 1506300).
- 26) Larsen, R.L., "Sound Use of CLSMs in the Environment," *Concrete International*, Vol. 15, No.7.
- 27) Lad, Priya Pravin. (2012). Development of a new device to evaluate stabilization durability of expansive soils by addressing wetting/drying and leachate issues.(Master thesis). Retrieved from ProQuest Dissertations and Theses. (Accession Order No. AAT 1513512).
- 28) Larsen, R. L., (1988). "Use of Controlled Low Strength Materials in Iowa," *Concrete International*, Vol. 10, No. 7.
- 29) Little, D.N. (2009). "Recommended Practice for Stabilization of Subgrade Soils and Base Materials." *NCHRP-114*. College Station, TX.
- 30) McCallister, L. D. (1990). The Effects of Leaching on Lime-Treated Expansive Clays. (Doctorial dissertation). Retrieved from ProQuest Dissertations and Thesis. (Accession Order No. AAT 9033489)

- 31) Naik, T.R., Ramme, B.W. And Lolbeck , H.J., "Filling Abandoned Underground Facilities with CLSM Fly Ash Slurry," Concrete International, Vol.12, No.7.
- 32) Pedarla, A. (2009). "Durability Studies on Stabilization Effectiveness of Soils Containing Different Fractions of Montmorillonite." (Master thesis). Retrieved from ProQuest Dissertations and Theses. (Accession Order No. AAT 1474224)
- 33) Raavi, Anil Kumar. (2012). Design of Controlled Low Strength Material for bedding and backfilling using high plastic clay. (Master thesis). Retrieved from ProQuest Dissertations and Theses. (Accession Order No. AAT 1529424).
- 34) Swaffer, K.M and Price, H.R., " Tunnel Saved by Fly Ash," Civil Engineering, Vol. 57,No.9.
- 35) Trejo, D., Folliard, K., and Du, L., (2003) "Alternative Capping Materials for Evaluating the Compressive Strength of Controlled Low-Strength Materials", ASCE Journal of Materials in Civil Engineering, Vol.15, No.5, 474-490.
- 36) Veisi, M., Chittoori, B., Celaya, M., Nazarian, S., Puppala, A.J., and Solis, C. (2010). "Accelerated Stabilization Design of Subgrade Soils." *TxDOT Technical Research Report 0-5569-1*. El Paso, TX.
- 37) Wu, J. Y., Eng., E., (2005) "Soil Based Flowable Fill for Pipeline Construction", "Pipelines Optimizing Design, Operations, and Maintenance", Pipeline Division Specialty Conference.
- 38) http://www.cement.org/basics/concreteproducts_clsm.asp
- 39) <http://www.fhwa.dot.gov/pavement/recycling/fach05.cfm>
- 40) <http://www.digitaldutch.com/unitconverter/>

BIOGRAPHICAL INFORMATION

Durga Praveen Reddy Vanga was born on 19th July 1987 in Andhra Pradesh, India. He had his Bachelor's degree in Civil Engineering from Andhra University. He had 3 years of experience as an associate of IL&FS Engineering and Construction Company Limited, a leading construction company in India, where he worked as an Engineer in several departments- Structural, Quantity Survey/ planning for National Highway Authority of India (NHAI) project.

His quest for academic excellence propelled him to embark Masters degree abroad. In 2011 August, he joined College of Engineering at The University of Texas, Arlington for his Master's program in Civil Engineering. Under the tutelage of Distinguished Professor Dr. Anand Jagadesh Puppala, he completed his Master thesis and subsequently his Master Degree. During the course of the study the author worked as a Graduate Research Assistant (GRA) and had an opportunity to work on several new research and corporate projects. The author has F.E (E.I.T) certification from NCEES.