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Anand J. Puppala, Naik Banavathu, Napat Intharasombat, and Syed Qasim

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16. Abstract

Composting is a successful method of recycling organic waste material such as yard trimmings, municipal biosolids, and animal manure into stabilized materials that could be used for bioremediation, erosion control, landscaping, and roadside vegetation. The process of composting organic wastes is expanding rapidly in the United States since landfill spaces for disposal of organic wastes are becoming scarce and expensive. If not recycled, certain composts such as Dairy Manure would potentially contaminate streams and rivers through migration. Hence, it is essential to seek new application areas for composts. Compost materials, given their moisture affinity (hydrophilic), fibrous and low permeability characteristics, could provide stabilization of natural expansive subgrades by mitigating shrinkage cracking and covering subsoil surfaces. In order to verify this stabilization, a research study is being conducted. This study has two phases, laboratory and field to evaluate the effectiveness of compost treatments to soils. This research report summarizes the first phase results, which include geotechnical characteristics of Dairy Manure and Biosolids composts and compost manufactured topsoils (CMTs). A local expansive soil from Stephenville, Texas, was used as the control soil. Laboratory test results indicate that linear shrinkage strains are reduced and strength and swell strains are increased with compost amendments. Environmental assessments of using these materials are also addressed. Construction of test plots for the second phase investigations are described. Current field monitoring of the test plots will provide better assessments of CMTs to mitigate shoulder cracking in field conditions.

17. Key Words

Composts, Expansive Soils, Transverse Cracking, Longitudinal Cracking, Pavements, Biosolids, Dairy Manure, Recycled Materials

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The Effects of Using Compost as a Preventive Measure to Mitigate Shoulder Cracking: Laboratory Studies

by

Anand J. Puppala
Professor
Department of Civil and Environmental Engineering

Naik Banavathu, Napat Intharasombat
Former Graduate Research Assistants
Department of Civil and Environmental Engineering

and

Syed R. Qasim
Professor
Department of Civil and Environmental Engineering

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The University of Texas at Arlington
Arlington, Texas 76019-0308

DISCLAIMER

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TABLE OF CONTENTS

Page

LIST OF FIGURES ix

LIST OF TABLES xii

CHAPTER 1 - Introduction 1
- **1.1 Introduction 1**
- **1.2 Research Objective 2**
- **1.3 Overview 4**

CHAPTER 2 - Literature Review 5
- **2.1 Introduction 5**
- **2.2 Recycled Materials and Their Applications 5**
- **2.3 Compost Materials 7**
  - 2.3.1 Compost - Conditions and Prerequisites 7
  - 2.3.2 Various Types of Compost Materials 11
  - 2.3.3 Biosolids 11
  - 2.3.4 Animal Manure 14
  - 2.3.5 Dairy Manure 15
- **2.4 Composts in Landscaping and Geotechnical Applications 16**
- **2.5 Composts - Environmental Implications 17**
- **2.6 Pavement cracking along shoulders 19**
  - 2.6.1 Longitudinal Cracks 21
  - 2.6.2 Transverse Cracks 21
  - 2.6.3 Potential Remedies 21
- **2.7 Scope and Focus of the Study 22**
- **2.8 Summary 23**

CHAPTER 3 - Experimental Testing Program 27
- **3.1 Introduction 27**
- **3.2 Description of Basic Properties Tests 27**
- **3.3 Sample Notations and Preparation Procedures 29**
  - 3.3.1 Sample Notations 29
  - 3.3.2 Sample Preparation Procedure 29
- **3.4 Description of Engineering Tests 30**
  - 3.4.1 One–Dimensional Free Swell Test 30
  - 3.4.2 Linear Shrinkage Bar Test 32
  - 3.4.3 Direct Shear Test 34
  - 3.4.4 Permeability Test 36
- **3.5 Basic Properties of Control Soil and Pure Compost Materials 38**
  - 3.5.1 Control Soil 38
  - 3.5.2 Dairy Manure Compost 40

3.5.3 Biosolids Compost (Dillo Dirt).. 43
3.6 Compaction Characteristics.. 45
3.7 Summary.. 47

CHAPTER 4 - Analysis of Test Results 49
4.1 Introduction..49
4.2 Basic Properties..49
4.2.1 Specific Gravity.. 49
4.2.2 Sieve Analysis and Hydrometer Analysis.. 50
4.2.3 Atterberg Limits.. 52
4.2.4 Organic Content.. 54
4.2.5 Hydrogen Ion Level (pH).. 56
4.2.6 Standard Proctor Compaction Test.. 56
4.3 Engineering Properties..58
4.3.1 Direct Shear Test.. 59
4.3.2 One-Dimensional Free Swell Test.. 63
4.3.3 Linear Shrinkage Test.. 66
4.3.4 Permeability Test.. 68
4.4 Ranking Analysis..69
4.5 Field Compaction Specifications..76
4.5.1 Compost Dosages and Compaction Moisture Content.. 76
4.5.2 Equipment Needed.. 77
4.5.3 Construction Steps.. 77
4.6 Summary..78

CHAPTER 5 – Design Method and Construction of Test Plots for Field Studies..79
5.1 Introduction..79
5.2 Design Method..79
5.3 Construction of Test Plots.. 81
5.4 Installation of Sensors..86
5.5 Data Collection..90
5.6 Summary..92

CHAPTER 6 - Summary, Conclusions, and Recommendations 95
6.1 Summary and Conclusions..95
6.2 On-going Studies..97

REFERENCES 99

APPENDIX A - Direct Shear Test Figures.. 105
APPENDIX B - One-Dimensional Free Swell Test Figures and Test Samples.. 105
APPENDIX C - Bar Linear Shrinkage Test Samples.. 109

LIST OF FIGURES

Figure 2.1 Schematic of the Processing Steps of Composted Biosolids............................14

Figure 2.2 Shoulder Cracking of SH 108 (Transverse Cracks) 20

Figure 2.3 Shoulder Cracking of SH 108...20

Figure 2.4 Example of a Road Pavement in Good Condition and a Road
Pavement in Poor Condition 21

Figure 3.1 Schematic Diagram of One-Dimensional Free Swell Test...............................31

Figure 3.2 Laboratory Setup of One-Dimensional Free Swell Test 32

Figure 3.3 Linear Shrinkage Bar Mold 33

Figure 3.4 Schematic Diagram of Direct Shear Test 35

Figure 3.5 Direct Shear Test Setup 36

Figure 3.6 Permeability Test Setup..38

Figure 3.7 Grain-size Distribution Curve of Control Soil 39

Figure 3.8 Grain-size Distribution Curve of Dairy Manure Compost...............................41

Figure 3.9 Grain-size Distribution Curve of Biosolids Compost 43

Figure 3.10 Moisture Content- Dry Unit Weight Curves of Control and Pure .
Compost Materials... 46

Figure 4.1 Grain-size Distribution Curve of Control Soil and Compost
Amended Soils 51

Figure 4.2 Plasticity Index of Control and Amended Soils 54

Figure 4.3 Organic Content of Control and Amended Soils...55

Figure 4.4 Moisture Content – Dry Unit Weight Curves of Control and
Compost Amended Soils..57

Figure 4.5 Direct Shear Test Results of a) Control Soil b) CMT 1 and CMT 2
c) CMT 3 and CMT 4 61

Figure 4.6 Shear Strength of Control Soil and CMTs at a Normal Confining Stress of 14 psi 62

Figure 4.7 Average Free Vertical Swell Strain of Control Soil 64

Figure 4.8 CMT 3 Samples – Before and After Swell Tests A) Optimum Moisture Content and B) Wet of Optimum Moisture Content....64

Figure 4.9 Swell Strains of Control and Amended Soils 65

Figure 4.10 Linear Shrinkage Strains of Control Soil and Compost Amended Soils........67

Figure 5.1 A Spreadsheet-Based Program to Compute Compost and Water Quantities...81

Figure 5.2 Maintainer to Blade the Subgrade Shoulder....82

Figure 5.3 Rotary Tiller for Tilling Operations 82

Figure 5.4 Distributing Composts on the Tilled Subgrade 83

Figure 5.5 Application of Water over the CMT Loose Mixture....84

Figure 5.6 Smooth Drum Roller Used for Soil Compaction 85

Figure 5.7 Placement of Sensors in a Test Section....87

Figure 5.8 Moisture and Temperature Data from Control Section during the First 36 Days 90

Figure 5.9 Digital Images (a) before (b) after the Analysis....92

Figure A.1 Direct Shear Test Results of DM_75....107

Figure A.2 Direct Shear Test Results of DM_100....108

Figure A.3 Direct Shear Test Results of CBS_20.... 109

Figure A.4 Direct Shear Test Results of CBS_30.... 110

Figure B.1 Free Vertical Swell Strain of CS.... .113

Figure B.2 Free Vertical Swell Strain of DM_75 .... ,114

Figure B.3 Free Vertical Swell Strain of DM_100 115

Figure B.4 Free Vertical Swell Strain of CBS_20 116

Figure B.5 Free Vertical Swell Strain of CBS_30 117

Figure C.1 Linear Shrinkage Mold of Control Soil at Optimum Moisture Content...... 121

Figure C.2 Linear Shrinkage Mold of Control Soil at Liquid Limit............................. 121

Figure C.3 Linear Shrinkage of CMT 1 (DM_75) at Optimum Moisture Content 122

Figure C.4 Linear Shrinkage Mold of CMT 1 (DM_75) at Wet of Optimum Moisture Content 122

Figure C.5 Linear Shrinkage Mold of CMT 1 (DM_75) at Liquid Limit...................... 123

Figure C.6 Linear Shrinkage Mold of CMT 2 (DM_100) at Optimum Moisture Content 123

Figure C.7 Linear Shrinkage Mold of CMT 2 (DM_100) at Wet of Optimum Moisture Content Level 124

Figure C.8 Linear Shrinkage Mold of CMT 2 (DM_100) at Liquid Limit.................... 124

LIST OF TABLES

Table 2.1 Compost Applications in Highways from Literature Review 24

Table 2.2 Production and Use of Waste Materials in Highway Applications 25

Table 3.1 Basic Soil Properties 40

Table 3.2 Properties of the Dairy Manure Compost 42

Table 3.3 Properties of Biosolids Compost 44

Table 3.4 Particle Size Details of Control Soil and Pure Compost Materials 45

Table 3.5 Compaction Moisture Levels of Control Soil and Pure Compost Materials for Engineering Tests 46

Table 4.1 Specific Gravity of Control and Amended Soils 50

Table 4.2 Particle Size Details of Control and Amended Soils 52

Table 4.3 Atterberg Limits of Control and Amended Soils 53

Table 4.4 Organic Matter Present in Control and Amended Soils 55

Table 4.5 pH of Control Soil, Compost, and Biosolids Amended Soils 56

Table 4.6 Compaction Moisture Content Levels of Control and Amended Soils 58

Table 4.7 Shear Strength Parameters of Control and Amended Soils 60

Table 4.8 Free Vertical Swell Strains of Control Soil and Compost Amended Soils 65

Table 4.9 Linear Shrinkage Strain Values for Control Soil, Compost Amended Soils, and Lime-Treated Biosolids 67

Table 4.10 Coefficient of Permeability of Control and Amended Soils 69

Table 4.11 Soil Characterization Based on the Plasticity Index of the Soils 70

Table 4.12 Soil Characterization Based on the Free Vertical Swell Strain of the Soils 71

Table 4.13 Soil Characterization Based on the Linear Shrinkage Strain of the Soils 72

Table 4.14 Soil Characterization Based on the Shear Strength of the Soils 73

Table 4.15 Soil Characterization Based on the Coefficient of Permeability of the Soils..74

Table 4.16 Ranking of Control and Amended Soils Based on Test Results......................75

Table 4.17 Recommended Moisture Contents and Their Corresponding Dry Unit Weights for Field Compaction Specifications..76

Table 5.1 CMT Materials...87

Table 5.2 Details of Test Sections 88

Table 5.3 Details of Construction 89

Table 5.4 Typical Surveying Data from Test Section 1..91

CHAPTER 1
INTRODUCTION

1.1 Introduction

Expansive subgrades are encountered in the subsoils of various districts within Texas. These natural subgrade soils support transportation infrastructure, which include pavements, parking lots, and runways. Expansive soils generally undergo large volumetric changes due to moisture fluctuations from seasonal variations. Due to this, swell and/or shrinkage related soil movements occur in the subgrade soils underneath pavement structures. These differential movements often cause cracking of pavements (Chen, 1988; Nelson and Miller, 1992).

On many highways situated in North Texas, cracking has occurred in both unpaved and paved shoulders plus travel lanes. The soil cracking represents a significant problem for the Texas Department of Transportation (TxDOT) since it will eventually propagate up through pavement structures. These cracks allow intrusion of surface water into underlying soil and aggregate base layers and hence weaken both. This eventually results in the continual deterioration of pavements by causing surface cracks in both the longitudinal and transverse directions. Annual maintenance to seal and/or repair these shoulder and highway distress problems cost several millions of dollars statewide.

Once cracks develop in the pavement shoulders, maintenance remedies must be applied immediately to reduce further damage. Otherwise, these failures will ultimately lead to travel lane damages. This explains the need to stabilize shoulder subgrades to reduce the cracking from expansive subsoils. Several chemical and mechanical treatment methods can be used to stabilize expansive shoulder soils. However, these methods have their own limitations such as durability, time, and cost issues. It is not a common practice to treat adjacent shoulder soils, which are more susceptible to leaching of treatment materials due to surface runoff, and water ingress and digress due to rainfalls.

Compost materials, given their moisture affinity (hydrophilic) and low permeability characteristics, may reduce swell and shrinkage behaviors of underlying natural expansive subgrades by encapsulating them. As a result, pavement shoulder cracking might be mitigated. However, to truly understand the effectiveness of compost covers on adjacent shoulder soils to mitigate expansive soil movements, a thorough research study was undertaken. The present research, funded by the Texas Department of Transportation, attempted to investigate the compost amendments with the shoulder soils to mitigate cracking in them and in the travel lanes.

This research was conducted in both laboratory (Phase I) and field (Phase II) conditions at the University of Texas at Arlington. Phase I investigations were conducted in the first year, and Phase II investigations are currently under progress. This report summarizes the results from the first-year investigations. One of the main tasks of the research was to use both Biosolids and Dairy Manure compost materials for the research evaluation. Texas is one of the leading states in the US that produces these composts in large quantities. Any successful applications of these materials in pavement systems will enhance recycling applications in Texas and reduce maintenance costs in highways. Hence, both these compost materials were fully evaluated in this research.

1.2 Research Objective

Compost materials were considered for use in the proposed application of covering soils adjacent to pavement shoulders to control underlying expansive soil movements only if they would exhibit sufficient engineering strength, low permeability, and low swell and shrinkage characteristics. Compost material was anticipated to maintain certain uniform moisture content levels within the soil by absorbing moisture from the atmosphere, and slow down the evaporation under the pavement structure. All these aspects and assumptions required experimental verification prior to using compost in field treatments.

Hence, it can be stated that the main objective of this proposed research was to assess the effectiveness of two locally available compost materials for better treatment and encapsulation of underlying expansive clayey soils under field conditions.

To accomplish this objective, the following tasks were planned and performed:

1. Review comprehensive literature review to explore mechanisms that cause longitudinal and transverse cracking in the pavement shoulder structures, and explore various geotechnical and environmental applications of different compost materials.
2. Perform a series of laboratory tests on both control and compost amended soils. The control soil was sampled from Stephenville, Texas, where an instrumented pad will be installed in order to study the performance of compost materials in field conditions.
3. Laboratory test results of both control and compost amended soils were first conducted and analyzed with respect to variables including compaction moisture content, dry unit weight, and confining pressures. Test results were also analyzed as per well-established parametric ranking of various soil properties and then determining the compaction moisture contents for shoulder subgrade cover materials.
4. Prepare Research Report (RR-1) after the completion of the first year.
5. Construct seventeen test plots with various compost amendments and instrument the sites to evaluate temperature and moisture patterns in soils. Elevation surveys and digital image studies will be periodically performed to assess the erosion potentials and desiccation cracking at the surfaces. Statistical ANOVA analyses will be conducted to evaluate each compost material in providing effective treatments of expansive soil.
6. Prepare a final comprehensive research report summarizing the present research findings.

1.3 Overview

This report is the first Research Report (RR-1) for the project and consists of six chapters.

Chapter 1 provides an introduction with a background history explaining the significance of the project, research objectives, and report organization to provide a schematic program of the completed work.

Chapter 2 discusses problematic soils and their formation, causes of shoulder cracking, and methods used to reduce shoulder cracks.

Chapter 3 presents information pertaining to the experimental research conducted. Such information includes physical properties of the soil materials, physical and chemical characteristics of the pure compost materials, test methods and procedures, laboratory instrumentation, sample preparation, and data analysis methods.

Chapter 4 summarizes both physical and engineering test results from tests performed on both control soil and compost materials. A comprehensive analysis of the findings from the experimental program is also covered in this chapter. A ranking analysis was performed on each compost material at two dosage levels and at two moisture content levels. This analysis was used to establish compaction moisture content levels for field cover strips.

Chapter 5 covers design and sequence of construction steps for the construction of the test plots with compost manufactured topsoil. A spreadsheet-based program is included to calculate the amount of compost needed, amount of topsoil that needs to be tilled, and the quantity of water in gallons to be added in order to mix the compost with the soils. The chapter also depicts the method of installation of sensors and typical data analysis during the course of the project.

Chapter 6 presents major conclusions of the experimental research studies and the status of ongoing research field studies.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

This chapter provides a background to the present research study by reviewing the existing literature on various topics. Since the intent of this study is to investigate compost material covers as a preventive measure of shoulder cracking, the first part of the chapter is devoted to an understanding of the recycled compost materials currently used and their applications in environmental, geotechnical, and geo-environmental engineering areas. Following this, mechanisms causing cracking of the pavement lanes and adjacent shoulder soils are discussed. This section also describes different maintenance remedies currently used to reduce paved and unpaved shoulder cracking. The last section delineates the scope of the present research study along with the objectives.

The information is gathered from several electronic databases including the Transportation Research Information Service (TRIS) and American Society of Civil Engineers (ASCE). Several publications of the National Co-operative Highway Research Program (NCHRP) and Transportation Research Board (TRB) were also reviewed.

2.2 Recycled Materials and Their Applications

A large amount of waste materials are produced in the state of Texas, and there have been numerous attempts to explore different applications to recycle these materials in highway construction (Collins and Ciesielski, 1994). The increased attention on the possibilities and prospects of utilizing recycled materials can be attributed to two important advantages that it can serve. One, the proper use of recycled materials in highway applications can lead to better quality roads at lower costs and two, it can also resolve some of the environmental problems related to industrial solid waste management and reducing landfill areas. The most commonly used recycled materials in highway construction are blast furnace slag, steel slag, plastics, coal combustion byproducts and compost materials. A few of these materials is presented in the following along with their applications in highways.

Blast furnace slag is an industrial byproduct of iron industries. The slag is produced in a blast furnace and consists mainly of silicates and alumino-silicates of lime. Three basic types of slag are produced (i.e., air-cooled, granulated, and expanded) and all three are being used in highway construction (Collins and Ciesielski, 1994). A review of the current status of recycled material applications reveals that over 22 states have used air-cooled blast-furnace slag as aggregates, and two states used granulated blast-furnace slag as a cementitious base material (Collins and Ciesielski, 1994).

Plastics constitute more than 8 percent of the total weight of the municipal waste stream and 12 to 20 percent of the municipal waste volume (Collins and Ciesielski, 1994). Several highway agencies including Colorado, Nevada, and New York have investigated the use of waste plastics in modifying asphalt binder (Ciesielski et al., 1994). Plastic aggregates and fibers have also been used to control drying shrinkage related cracks (Shelburne and DeGroot, 1995; DeGroot et al., 1995; Puppala and Punthutaecha, 2002).

Coal ash by-products resulting from coal combustion are fly ash, boiler slag and bottom ash. Fly ash reacts with calcium and water at ideal temperatures to form cementitious compounds, which can stabilize weak subgrades. It is used as a cement replacement in Portland cement concrete, as an embankment material and also as a mineral filler in asphalt (Ciesielski et al., 1994). Bottom ash, which is coarser than fly ash material, has been used as an unbound aggregate base material, embankment material (DeGroot et al., 1995), anti-skid material, and as an aggregate in stabilized base course (Ciesielski et al., 1994).

2.3 Compost Materials

Compost is disinfected and is a stable decomposed organic material obtained from the composting process of different types of wastes. Composting is a natural process of aerobic, thermophilic, and microbiological degradation of organic wastes into a stabilized, useful product that is free of odors and pathogens and can be used for a variety of purposes (Girovich, 1996). Generally, composting is applied to solid and semi-solid organic wastes such as nightsoil, sludge, animal manures, agricultural residues, and municipal refuse (Polprasert, 1989). The annual production of compost is growing at a steady rate and there are approximately 1400-yard waste composting operations in the United States, as well as 133 sewage sludge compost facilities and 18 Municipal Solid Waste (MSW) compost operations (Ciesielski et al., 1994).

Compost materials have several potential applications and can be used by a variety of segments. These include landscaping, land reclamation, erosion control, top dressing (e.g., for golf courses, park land), agriculture, residential gardening, and nurseries (Diaz et al., 1993). The physical and chemical characteristics of compost vary according to the nature of the starting material, the conditions under which the composting operation was carried out and the extent of the decomposition.

Table 2.1 summarizes some of the above waste materials and their application areas on highways.

2.3.1 Compost - Conditions and Prerequisites

Compost used for a specific purpose, or with a particular soil type, works best when it is tailor-made or specially designed (USEPA, 1997). For instance, compost that is intended to prevent erosion might not provide the best results when used to assuage soil compaction and vice versa. Technical parameters to consider when customizing a compost mixture include maturity, stability, pH level, density, particle size, moisture, salinity and organic content, all of which can be adjusted to fit a specific application and soil type. The prerequisites for obtaining proper compost are discussed below.

(i) Optimum carbon/nitrogen ratio

Microorganisms require specific nutrients in available form, adequate concentration and proper ratio for an efficient composting process. Some microorganisms cannot use certain forms of nutrients because they are unable to process them (EPA, 1997). Most microorganisms cannot easily break down large molecules, especially those with different types of bonds, and this slows down the decomposition process significantly (EPA, 1997). As a result, some types of feedstock break down more slowly than others, regardless of composting conditions (Gray et al., 1971a).

With respect to the nutritional needs of the microbes active in composting, the C:N ratio is the most important factor that requires attention (Diaz et al., 1993). High C:N ratios (i.e., high C and low N levels) inhibit the growth of microorganisms that degrade compost feedstock. Low C:N ratios initially accelerate microbial growth and decomposition. With this acceleration, however, available oxygen is rapidly depleted and anaerobic. Foul-smelling conditions result if the pile is not aerated properly. The excess N is released as ammonia gas (EPA, 1997). Extreme amounts of N in a composting mass can form enough ammonia to be toxic to the microbial population, further inhibiting the composting process (Gray et al., 1971b; Haug, 1980).

(ii) Particle size

The significance of particle size is in the amount of surface area of the waste particles exposed to microbial attack (Diaz et al., 1993). The size of feedstock materials entering the composting process can vary significantly. In general, the smaller the shreds of composting feedstock, the higher the composting rate (EPA, 1997). Smaller feedstock materials have greater surface areas in comparison to their volumes. This means that more of the particle surface is exposed to direct microbial action and decomposition in the initial stages of composting (EPA, 1997). Smaller particles within the composting pile also result in a more homogeneous mixture and improved insulation (Gray et al., 1971b). Increased insulation capacity helps maintain optimum temperatures in the composting pile. At the same time, the particles should not be too small to create too much compactness.

(iii) Oxygen

Composting can occur under aerobic (requires free oxygen) or anaerobic (without free oxygen) conditions. Nevertheless, aerobic composting is considered to be much faster than anaerobic composting. Anaerobic composting tends to generate more odors and gases such as hydrogen sulphide, and amines are produced in the absence of oxygen. Methane is also produced in the absence of oxygen (USEPA, 1997).

(iv) Moisture content

The moisture content of a composting pile is determined by many other composting parameters such as moisture content of the feedstock, microbial activity within the pile, oxygen levels, and temperature (USEPA, 1997). Microorganisms require moisture to assimilate nutrients, metabolize new cells, and reproduce. If the moisture content is below 35 to 40 percent, decomposition rates are greatly reduced and virtually stops below 30 percent. If the moisture content is too high, it leads to anaerobic conditions resulting in odor complaints (Gray et al., 1971b). For most compost mixtures, 55 to 60 percent is the recommended upper limit for moisture content (Richard 1992a).

(v) Temperature

Temperature is a critical factor in determining the rate of decomposition that takes place in a composting pile. Composting temperatures largely depend on how the heat generated by the microorganisms is offset by the heat lost through controlled aeration, surface cooling, and moisture losses (Richard, 1992a). The most effective composting temperature is between 35° and 65ºC (Girovich, 1996). If temperatures are less than 20ºC, the microbes do not propagate and the decomposition process slows down. If temperatures are greater than 59ºC, some microorganisms are inhibited or killed, and the reduced diversity of organisms results in lower rates of decomposition (Finstein et al., 1986; Strom, 1985). Microorganisms tend to decompose materials most efficiently at the higher ends of their tolerated temperature ranges. The rate of microbial decomposition therefore increases as temperatures rise until an absolute upper limit is reached. As a result, the most effective compost-managing plan is to maintain temperatures at the highest level possible without inhibiting the rate of microbial decomposition (Richard, 1992a; Rynk et al., 1992).

(vi) Hydrogen ion level (pH)

The pH of a substance is a measure of its acidity or alkalinity, described by a number ranging from 1 to 14. A pH of 7 indicates a neutral substance, whereas a substance with a pH level below 7 is considered to be acidic and a substance with a pH higher than 7 is alkaline. Bacteria prefer a pH between 6 and 7.5. Fungi thrive in a wider range of pH levels than bacteria, in general, preferring a pH between 5.5 and 8 (Boyd, 1988). If the pH drops below 6, microorganisms, especially bacteria die off and decomposition slows (Wiley, 1956). If the pH reaches 9, nitrogen is converted to ammonia and becomes unavailable to organisms (Rynk et al., 1992). This can also decelerate the decomposition process.

(vii) Source materials

Compost materials are prepared from a number of source materials (Benedict et al., 1998; Tchobanoglous et al., 1993; He et al., 1995; Oweis and Khera, 1998; Shelburne and Degroot, 1998). This includes municipal solid waste (MSW), animal manure, backyard organic waste, farm waste, Biosolids from wastewater treatment plant, and from vegetable and meat processing wastes.

The generalized chemical equation expressing reactants and products is expressed as follows:

Principal Source Material

(Cellulose, Hemicelluloses, Lignin, Carbohydrates, Protein, Amino acids)

+

O_2

Nutrients

Microorganisms

$\downarrow$

Finished compost (Principally cellulose, lignin, ash)

+ New cells + Dead cells + CO_2 + HO_2 + NO_3 + SO_4 + Heat

2.3.2 Various Types of Compost Materials

A study was conducted by Kirchoff (2002) to assess chemical and physical properties of compost and compost amended soils for its use along highways. In this study, four types of compost materials were researched. These were poultry litter, feedlot, biosolids, and dairy manure. This study showed that both Biosolids and Dairy Manure compost materials could be used for highway related composting applications. Hence, these materials are considered in the present research evaluation. Details and environmental assessments on the compost materials can be found in Kirchoff (2002).

The following sections describe different types of compost materials used in the transportation area.

2.3.3 Biosolids

Biosolids are nutrient-rich organic materials resulting from the treatment of sewage sludge. Sewage sludge is a putrefactive, concentrated, aqueous suspension of biodegradable, partially biodegradable and essentially non-biodegradable solids associated with absorbed and dissolved matter, exhibiting similar ranges of degradability characteristics (Bruce et al., 1989).

Sludge production is on the increase as sewer service areas are continuously expanding. Consequently, municipalities are upgrading from primary treatment to secondary treatment for nutrient removal, and a higher amount of storm flows is being directed for wastewater treatment plants (Shelburne and DeGroot, 1998). The major byproduct of wastewater treatment plants are Biosolids or sludge. Approximately, 282 sewage sludge incinerators operate at more than 150 wastewater treatment plants in the United States, producing 0.5 million to 1 million tons of sludge ash annually (USEPA, 1997).

Approximately eight million tons of wet sludge is generated every year in Texas, the sources being municipal water, wastewater treatment plants, and septic tanks (Texas Environmental Almanac, 1995).

The usage of sludge has been put under certain regulations developed by the Environmental Protection Agency (Texas Environmental Almanac, 1995). The Texas Commission on Environmental Quality (TCEQ) has enforced such regulations at the state level in Texas. If the liquid waste or sludge has to be disposed in municipal solid waste landfills, it can be done only after it has been thoroughly dried (Texas Environmental Almanac, 1995). Hence, the majority of permitted water treatment plants dispose of sludge only after it is dried. The lagoons with a storage capacity of five-to-ten years are used to store sludge. The sludge is then dried and applied to either land or landfills (Texas Environmental Almanac, 1995). In Texas, annually, almost 650,000 tons of dry sludge is disposed of in landfills (Texas Environmental Almanac, 1995).

In the state of Texas, several methods have been used for treating the municipal sludge. Some of them are listed below in the descending order of their preference (Texas Environmental Almanac, 1995):

- minimization of sludge production and source reduction;
- treatment of sludge to reduce pathogens and recover energy, produce beneficial byproducts, or reduce the quantity of sludge;

- marketing and distribution of sludge and sludge products;
- applying sludge to land for beneficial use; and
- reducing landfill space.

The composting of municipal sludge with brush and yard trimmings is also gaining popularity as a method for dealing with the municipal sludge. The TCEQ regulates the land application of sludge, which needs to be treated before its use. Many cities like Fort Worth, Houston, and Austin have successfully recycled tons of Biosolids from landfills to beneficial uses (Texas Environmental Almanac, 1995). Although the principal uses of sewage sludge are in agricultural areas, both dewatered sewage sludge and sludge ash are considered for potential reuse in highway construction areas (Ciesielski et al., 1994). Sewage sludge is often used for topsoil applications, such as weed control and turf establishment (DeGroot et al., 1995).

Figure 2.1 shows the schematic of the processing steps of composted Biosolids acquired from the City of Austin. This material meets both TxDOT compost requirements and EPA environmental characteristics requirements for potential use to mix with soils. Hence, this material was selected as one of the two composts for this research. The trade name of this material is “Dillo Dirt.” Another pure form of Biosolids from the Fort Worth Waste Water Treatment plant was also considered. However, this material did not meet the TxDOT compost requirements and was not included in this research.

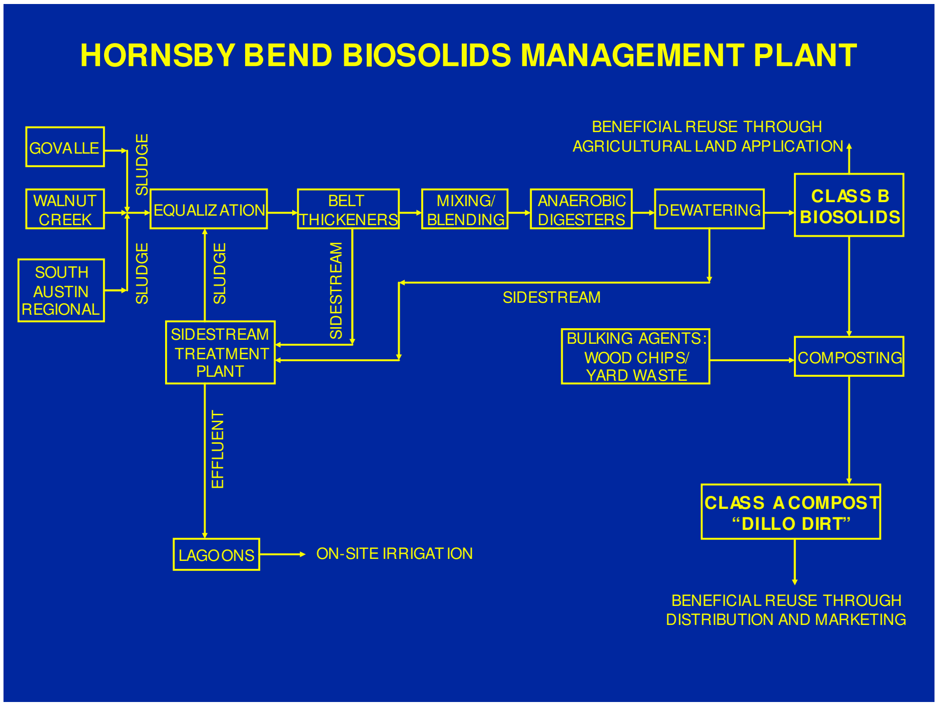


Figure 2.1 Schematic of the Processing Steps of Composted Biosolids

(Source: City of Austin, Austin, Texas)

2.3.4 Animal Manure

The annual manure production from cattle, hogs, sheep, and poultry amounts to approximately 1.6 billion tons, based on wet weight (Collins and Ciesielski, 1994). The moisture content of manure is highly variable. Much of it is produced from animals raised in confined conditions such as feedlots, dairies, or hen houses. Animal manure is tested for basic organic/nutrient content and depending on the test results necessary steps are taken to improve the source material (e.g., lime is added to increase the pH of acidic manure). Once the testing is completed, the manure is mixed with a sandy loam and stockpiled for use as a direct soil amendment or as a plant bed amendment.

Animal manure contains a lot of weed seeds, and this can be handled depending on which application the manure is used for. In the case of turf grass, the weeds are moved out over a period of a year or two; for trees, the compost is buried in deep beds;

for shallow beds, mulch is added to suppress weed growth (Shelburne and Degroot, 1998). An example of its use in a highway-related application is in the State of North Carolina, where poultry manure has been used as fertilizer on highway rights of way (Collins and Ciesielski, 1994). The Massachusetts Turnpike authority (MassPike) has been using animal manure for many years as a soil amendment (Degroot, 1996).

2.3.5 Dairy Manure

The annual production of Dairy Manure from Texas cattle amounts to approximately 400,000 tons (USDA, 2002). Mismanagement of such manure can have a substantial impact on water, air, and soil resources. The river contamination problem that occurred in central Texas explains the importance of proper methods to handle the manure disposal.

However, when used appropriately, the Dairy Manure improves biological activity, and soil - chemical properties (Schmitt and Rehm, 1998). Bacteria and humus present in Dairy Manure have the ability to increase the microbial activity in the soil. This helps to improve soil structure (Diaz et al., 1993). Composted Dairy Manure was used as a substitute for peat moss, for soil amendment during establishment of landscape shrubs. Benefits of using composted Dairy Manure are:

- use of local sources of organic matter,
- protection of the environment,
- production of quality bedding plants,
- improved production economics, and
- enhancement of physical and nutrient quality of native soils.

From literature review, no studies were available to address the application of composted Dairy Manure in soil cracking. In this research, an attempt was made to study the potential benefits of composted Dairy Manure to mitigate shoulder cracks.

2.4 Composts in Landscaping and Geotechnical Applications

Compost used in highway construction is mostly derived from yard waste, but can also be produced from other fractions of the MSW stream, either pre-source separated or commingled (Shelburne and Degroot, 1998). In addition, it can be derived from agricultural wastes (manure and crop residues) and domestic residuals such as sewage and biosolids. The major application of compost is along highways as mulch, blended topsoil replacement, commercial fertilizer supplement, and as soil amendments (DeGroot, 1996). Research work is being carried out to expand its use to control weeds and erosion (Alexander and Tyler, 1992) as well as in controlling the plant pathogens (Grebus et al., 1994).

Compost is mainly used for landscaping and topsoil applications. A review of the relevant literature reveals that currently six states use composts for these geotechnical and aesthetic applications (DeGroot, 1996). The Minnesota Department of Transportation (MnDOT) has specified compost as a standard specification item for the past nine years to use it in place of topsoil and peat moss (Mitchell, 1997). MnDOT has found better results in clay soils, better water retention in sand, and improved soil biology (Collins and Ciesielski, 1994). The State of Virginia uses compost for siltation control (Shelburne and DeGroot, 1998). The Coalition of Northeastern Governors, whose member states are Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont, has drafted specifications to use compost as compost horticultural mulch, erosion control mulch, erosion control filter berm, compost-manufactured loam, and compost amendment loam (Topsoil) manufactured in place (DeGroot, 1996).

It is also reported that the compost sewage sludge from the City of Fort Worth has been given to the Texas Highway Department for more than 10 years for landscaping highway medians and rights of way (Ciesielski et al., 1994). Currently, the EPA summarizes in a report that the state of Texas is one of the leading proponents to use composts in various highway applications (USEPA, 1997). Current data shows that TxDOT has become the largest user of compost among state DOTs in the nation. The majority of these applications are attributed to compost application programs initiated by a cooperative effort between TxDOT and TCEQ (formerly TNRCC) to address water quality issues particularly in the Bosque/Leon river watersheds located in central Texas. Table 2.1 presents various geotechnical applications of compost materials used in the U.S.

Besides these current levels of applications, it is also possible that compost can be used to enhance the biological, chemical, and physical properties of soil. Compost improves physical properties of the soil including the texture of soil (Tester and Parr, 1990). Compost reduces bulk density of soil, increases water retention capacity, infiltration, and resistance to wind and water erosion of soils (Diaz et al., 1993). Further, it increases the aeration capacity and structural and temperature stability. Compost also serves as a physical barrier between rainfall and surface soil (Diaz et al., 1993), dissipating the effect of impact energy from rainfall and minimizes erosive forces. Table 2.2 shows some applications of compost material in highway construction.

2.5 Composts - Environmental Implications

The EPA reported that more than 195 million tons of Municipal Solid Waste (MSW) and nearly 35 million tons of Yard Trimmings (YT) were produced in the United States in 1990 (USEPA, 1997). Tchobanaglous and Burton (1991) noted that “of all constituents removed by treatment, sludge is by far the largest in volume and its processing and disposal is perhaps the most complex problem facing the engineer in the field of wastewater treatment.” Much of this is due to the perception and reality of sludge as a dangerous material (DeGroot, 1996). Raw wastewater sludge is offensive due to its putrescibility and subsequent rapid generation of strong odors, but it also contains high densities of pathogenic microorganisms and possibly other harmful constituents such as heavy metals (Qasim, 1999).

Composting municipal solid waste, yard waste, sewage biosolids, agricultural residues, livestock manures, and food process related by-products is a safe and effective way to manage these materials while providing a usable recycled product (Shelburne et al., 1995). Recycling these materials is more efficient and eco-friendly than combusting or land filling, especially when landfill area is becoming scarce in many states (Shelburne et al., 1995).

Composting provides a feasible and sustainable opportunity to move large volumes of organic material from the concentrated areas to other areas that need organic soil amendments, and also keeps putrescible materials out of landfills, therefore reducing the environmental threats such as leachate and methane production (Diaz et al. 1993).

In this research, emphasis is given to recycled compost materials, because of recycling results in several applications as noted by DeGroot et al. (1995). Recycling preserves natural resources and energy, protects water and air quality by reducing the amount of wastes that are either landfilled or burned, and helps fuel economic development with manufacturing industries capable of using recyclable materials (DeGroot et al., 1995). A necessary component of achieving this goal is to develop sustainable markets for waste and recycled materials that are diverted from traditional disposable methods such as landfilling. The transportation industry has been identified as one large market where the applications of compost can be found (DeGroot et al., 1995).

Highway maintenance is a pressing issue for most of the states' DOTs including TxDOT, with millions of miles of highways to maintain. A major portion of the maintenance activity pertains to pavement cracks from expansive soil movements. Annual maintenance to repair shoulder and highway distress problems cost several millions of dollars (Perrin, 1992). Hence, it is important for state DOTs to develop low cost maintenance methods for repairing or mitigating pavement deterioration.

2.6 Pavement Cracking along Shoulders

Expansive subgrades are encountered in subsoils of various districts in Texas. The primary problem from expansive soils is that the movements are significantly higher than the elastic and plastic compressible deformations, and these heave movements result in an uneven pattern causing extensive damage to the structures and pavements resting on those soils (Nelson and Miller, 1992). Expansive soils located in regions of cool and wet periods followed by prolonged hot dry periods are more prone to such problems. After a dry period, the soils will have relatively low moisture content resulting in high swell potentials. Differential movements in the subgrade soils underneath pavement often cause cracking of shoulders and pavements (Chen, 1988; Nelson and Miller, 1992).

The shoulder cracking represents a significant problem for TxDOT, since shoulder soil cracking will eventually propagate to adjacent base and subgrade layers underneath the pavements. The initial shoulder cracks allow intrusion of surface water into adjacent soil mass and hence, weaken the base and subgrade soil layers. The shrink and heave movements of these layers will eventually result in the poor performance of traveling lanes by causing surface cracks in them. Figures 2.2 and 2.3 show cracks observed on shoulder sections of SH 108 near Stephenville, Texas. Figure 2.2 shows cracking on the unpaved soil, which propagated to the paved shoulders.

Figure 2.3 presents both paved shoulder and adjacent travel lane cracking in the longitudinal and transverse directions.

Figure 2.2 Shoulder Cracking of SH 108 (Transverse Cracks)

Figure 2.3 Shoulder Cracking of SH 108

2.6.1 Longitudinal Cracks

Longitudinal cracks are generally developed in the direction of traffic. These are generally caused by poor drainage or frost action. They usually start as a very thin line and widen and erode with age. If remedial measures are not taken such as filling, they can develop multiple cracks and become worse enough to require patching. By filling and sealing the longitudinal cracks, moisture penetration decreases and can prevent further weakening of a subgrade.

2.6.2 Transverse Cracks

Cracks running perpendicular to the roadway center line are transverse cracks. These cracks occur due to surface shrinkage caused by low temperatures or cracks in the underlying pavement layers. Transverse cracks are widely spaced and additional cracks occur with age until they are closely spaced. If timely measures are not taken, secondary or multiple cracks develop in a direction parallel to the initial crack and the crack edges can further deteriorate thus raveling and eroding the adjacent pavement (Figure 2.4).

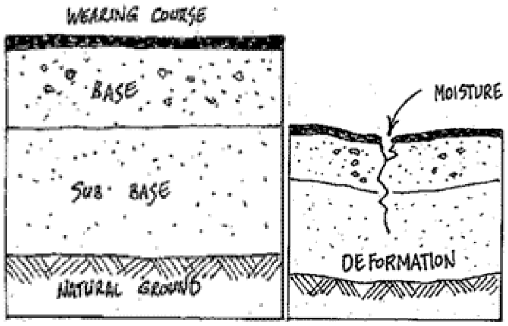


Figure 2.4 Example of a Road Pavement in Good Condition and a Road Pavement in Poor Condition (Source: www.roads.act.gov.au)

2.6.3 Potential Remedies

Once cracks are developed in the pavement shoulders, maintenance remedies must be applied immediately to reduce continuing damage. Hence, there is a need to stabilize shoulder soils to reduce cracking from expansive soils. Several chemical and mechanical treatment methods have been used to stabilize expansive soils (Hausmann, 1990; Kota et al., 1996; Viyanant, 2000). Treatment methods that are generally used to stabilize expansive soils are:

- chemical additives,
- prewetting,
- soil replacement with compaction control,
- moisture control,
- surcharge loading, and
- thermal methods.

Of all these methods, chemical and mechanical stabilization methods are frequently used as they provide faster and more efficient stabilization results (Hausmann, 1990). But these methods can be expensive and time consuming due to the cost of fill materials and the time needed for reducing swell behaviors. Due to these limitations, alternate methods are being explored for treating expansive subgrades. For example, the method of using encapsulation of expansive subgrades by geomembranes and chemical grouts yielded promising results (Nelson and Miller, 1992). However, this method is expensive due to the volume of soil needed for encapsulation.

2.7 Scope and Focus of the Study

The increasing use of waste materials and by-products in highway construction and maintenance projects has resulted in better performance of highways and enhanced recycling applications of waste materials. State highway agencies have been evaluating and studying suitable waste materials and by-products in highway construction and maintenance operations for many years. One of the recycled materials that can provide similar benefits is compost material.

Several research groups in the United States as well as in other parts of the world have effectively demonstrated the use of compost for various landscape and erosion control applications in highway constructions (Collins and Ciesielski, 1994). It can also be discerned from the review of literature that the use of compost is recommended in order to reduce the land filling of these materials. This will save cost and areas of landfilling. A method of disposing solid waste in an environmentally friendly way is to use it in highway maintenance projects to help reduce the cost of highway construction and maintenance (Shelburne and DeGroot, 1998).

Considering all the above, this research study is developed to address another application area for compost materials. This is to address the use of these compost materials for better encapsulation of shoulder soils in order to mitigate both shoulder and travel lane cracking in dry environments. This study has focused on two types of inexpensive recycled composts; Biosolids and dairy manure, both in pure and blended forms, to be used as shoulder covers to mitigate shoulder cracking**.** Results on these investigations are covered in this report.

2.8 Summary

An attempt is made in this chapter to review various recycled materials used in highway construction. From this review, the compost can be identified as a potential low cost recycled material that can be used to mitigate shoulder cracking. This, in turn, can reduce the costs required for highway maintenance. Shoulder crack mitigation is of high importance to highway maintenance. Hence, a brief discussion on various methods to mitigate shoulder cracks from expansive soil movement is described in this chapter. From the literature review, it is clear that no studies addressed the applications of compost materials to mitigate shoulder cracking. This study is a first attempt in this direction and has comprehensively addressed the potential of two compost materials for amending with topsoils in order to mitigate shoulder cracking in the field.

Table 2.1 Compost Applications in Highways from Literature Review

References	Compost Used	Application
Lewis et al., (2001)	Composted biosolids	Upland Slope Stabilization
He et al., (2001)	Amended Composts	Waste Management
Grebus et al., (1996)	Composted Yard Debris and Municipal Sewage Sludge	Erosion control, Vegetation Establishment and Slope Protection
Black et al., (1999)	Amendedand Commercially Produced Composts	Roadside Vegetation
DeGroot, (1996)	Compost derived from Yard Waste, Municipal Solid Waste and Wastewater Sludge	Highway Construction
Ghezzi et al., (1997)	Compost Consisting of Mixed Yard Debris with Municipal Sewage Sludge	Highway-related Erosion

Table 2.2 Production and Use of Waste Materials in Highway Applications (Shelburne et al., 1995; Ciesielski et al., 1994)

Waste Type	Amount Generated	Uses (by Highway Agencies)
Animal manure	1.58 billion tons	Fertilizer, Refeeding, Compost, Oil production by thermal processing
Crop wastes	400 million tons	Animal feed, Rice husks as supplementary cementing material, Cellulosic waste as asphalt extender
Sewage sludge	8 million dry tons	Land application, Compost, Stabilized dike material
Sewage sludge ash	0.5-1 million tons	Asphalt mineral filler, Concrete coarse aggregate
Compost	2.5 million tons	Mulching material
Recycled refuse from sanitary landfills	N/A	Core materials in medians Embankment construction (mixed with natural soil)

CHAPTER 3

EXPERIMENTAL TESTING PROGRAM

3.1 Introduction

As a part of the first phase of research investigations, a laboratory-based experimental program was designed and conducted to test recycled compost materials and the soil sampled from Stephenville, Texas. This soil exhibits swell behavior and was chosen as the control soil. The control soil and the compost materials were mixed at different proportions. The final products were termed as Compost Manufactured Topsoils or CMTs in this report. This chapter describes the laboratory results by presenting both physical and chemical properties of the control soil, compost materials and CMTs, laboratory tests performed, test equipment, and procedures employed in the research.

3.2 Description of Basic Properties Tests

Tests conducted to measure basic soil properties in this research were specific gravity, sieve analysis and hydrometer tests, Atterberg limits, organic content, volatile suspended solids, and standard Proctor tests. These tests were conducted at the beginning of the experimental program, and the physical soil properties of all materials including control soil, pure composts and lime-treated Biosolids are presented here. Specific gravity, which is defined as the ratio of unit weight of soil to unit weight of water, of present test materials was determined as per TxDOT procedure Tex-108-E. The distribution of the grain sizes in test materials was determined using TxDOT procedure Tex-110-E. This method was also followed to determine the amount of soils finer than the No. 200 sieve. Finer particle size analysis was performed using hydrometer analyses.

Atterberg limits of present soils were determined by performing TxDOT procedures, Tex-104-E, to determine the liquid limit and Tex-105-E to determine the plastic limit. The difference between these limits is termed as the plasticity index (PI). The plasticity index is generally used to classify the plastic nature and expansive potential of the soils. The pH of present soils was also determined by following the Tex-128-E procedure.

Organic contents of composts and CMTs were determined by following the ASTM D-2974-87 procedure. Ash content was determined by calculating the organic content. First, the soil was oven-dried for 24 hours, and the weight of the soil sample was measured and reported as ‘A’ grams. The soil was then taken in a porcelain dish and placed in a muffle furnace maintained at a constant temperature of 440oC and held there until the specimen was ashed completely. The dish was covered with an aluminum foil and placed in a desiccator until the sample cooled down completely. The weight of this ashed sample was measured and reported as ‘B’ grams. The ash content was calculated as a ratio of (B/A) expressed in percentage and the organic content was calculated in percent as “100 - Ash content in percentage.”

In order to determine the compaction moisture content and dry unit weight relationships of the soils in the present research program, it was necessary to conduct standard Proctor compaction tests on soils to establish compaction relationships. The optimum moisture content of the soil is the water content at which the soils are compacted to a maximum dry unit weight condition. Samples exhibiting a high compaction unit weight are best in supporting civil infrastructure since the void spaces are minimum and settlements will be less.

Compaction tests were conducted on both control soil samples and CMT samples to determine moisture content and dry unit weight relationships. A standard Proctor test method using the Tex-114-E procedure was followed to determine moisture content vs. dry density relationships.

3.3 Sample Notations and Preparation Procedures

3.3.1 Sample Notations

For simple identification, depending upon the proportions of the compost materials used, each soil was assigned with the following notation symbols:

CS - Control Soil
DMC - Dairy Manure Compost
BSC - Biosolids Compost
CMT 1 (DM_75) - 75% Dairy Manure Compost: 25% Control Soil
CMT 2 (DM_100) - 100% Dairy Manure Compost
CMT 3 (CBS_20) - 20% Dillo Dirt: 80% Control Soil
CMT 4 (CBS_30) - 30% Dillo Dirt: 70% Control Soil

The above proportions were considered based on the standard Proctor test results of compost materials. Details on these selections are described in the compaction test results.

3.3.2 Sample Preparation Procedure

The control soil was oven-dried prior to mixing with the compost materials. A representative dry soil was collected and weighed. The amount of compost material was calculated as a percent of dry weight of the total sample. The compost materials were not oven-dried during CMT preparation in order to preserve the same original properties. The water content needed in the compost was also calculated based on the total dry unit weight of the soil and compost mixture.

The three required components of the mixture: dry soil, compost material, and water were then added and mixed manually until a uniform mixture was obtained. All tests were performed on samples compacted from this mixture. Two moisture levels were used in the preparation of the compost – soil or CMT mixture. These were optimum moisture content and wet of optimum moisture content levels. After the preparation of soil specimens of different dimensions for different tests, the engineering tests were performed immediately on the CMT samples.

3.4 Description of Engineering Tests

Engineering tests performed in this research were the bar linear shrinkage test, direct shear test, free swell test, and permeability test. These tests have been performed as per available TxDOT procedure and at two moisture contents. For each test, a total of three identical samples of control and amended soils were tested and analyzed to understand the repeatability of the test results. Descriptions of engineering tests are given in the following sections.

3.4.1 One–Dimensional Free Swell Test

The one-dimensional free swell test measures the amount of heave in the vertical direction of a laterally confined specimen in a rigid chamber. This test is conducted as per the ASTM standard method, D-4546. The schematic diagram of the one-dimensional free swell test is shown in Figure 3.1.

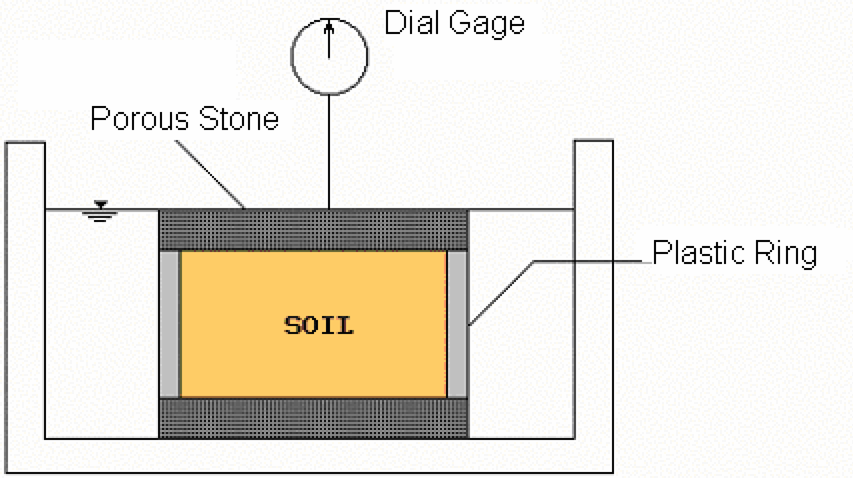


Figure 3.1 Schematic Diagram of One-Dimensional Free Swell Test

Both the control and amended soil samples of 2.5 inch diameter and 1 inch thickness were carefully prepared and placed in the plastic ring. Porous stones were placed on the top and bottom of the soil samples, which facilitates the movement of water to the soil sample. The samples were then transferred to the container, which was later filled with water in order to soak the entire sample. The amount of heave of the sample was recorded at various time intervals by a dial gauge. The displacement readings of the specimen were continued until there was no significant change in displacements for more than 24 hours. The percent swell was recorded for each sample by calculating the ratios of maximum free vertical swell to the initial height of the soil sample and is expressed with a percentage. Figure 3.2 shows a laboratory setup of a one-dimensional free swell test used in this research.

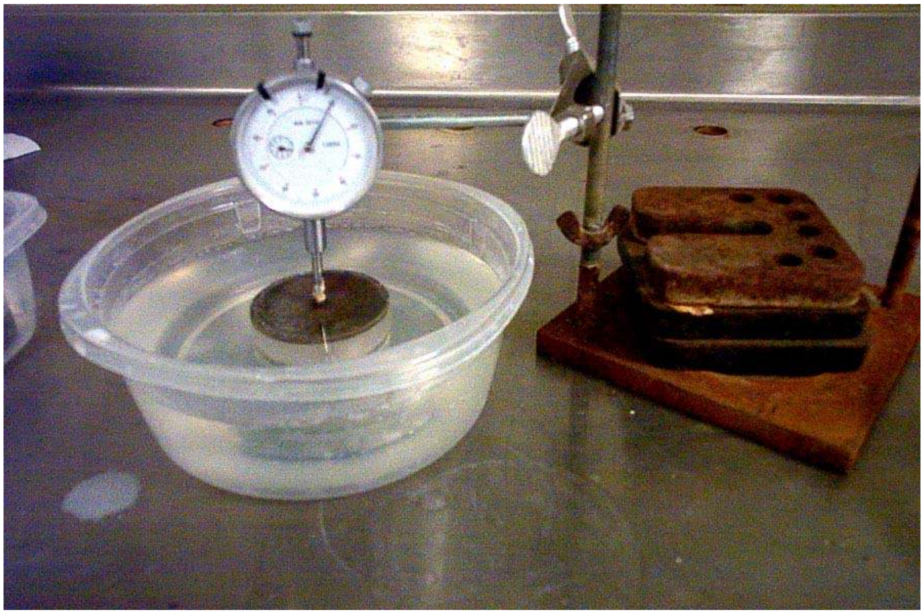


Figure 3.2 Laboratory Setup of One-Dimensional Free Swell Test

3.4.2 Linear Shrinkage Bar Test

TxDOT formulated a test procedure, the Linear Shrinkage Bar Test (Tex-107-E), to measure the linear shrinkage strains of the soils. This test provides a measure of linear shrinkage of a bar of soil paste in the bar type mold.

In this method, the soil was mixed at a moisture content level equal to the liquid limit state. Soil samples used for determining the linear shrinkage were first obtained by preparing the soil slurry at the liquid limit state. The slurry was then placed in a bar mold. Care was taken while placing the soil into the mold so that the entrapped air was removed. The sample was then air-dried at room temperature until its color changed slightly and was then placed in the oven at 110º C to reach oven dry conditions. Dried samples were removed, and their length was measured. Percent linear shrinkage of the soil specimen was then calculated as a percent of the original bar length (Figure 3.3). This research study adopted digital analysis for calculations, which gave more accurate results than the normal procedure. Digital analysis methods proposed by Katha (2002) were used for this step.

Figure 3.3 Linear Shrinkage Bar Mold

3.4.2.1 Digital Analysis

Lengths of irregular and uneven cracks in a linear shrinkage soil sample are difficult to measure with conventional measurement methods. This difficulty will always lead to manual errors in the measurement of linear shrinkage strain magnitudes. To rectify this error, a new digital image processing technique has been developed by Katha (2002). This technique was used in the present research.

The following step-by-step procedure was followed to measure the arial shrinkage strain of the control and amended soils:

1. The digital photograph taken on the shrunk sample was downloaded into the computer.
2. The digital image of the picture taken was converted into a gray scale image.

3. A threshold value was then selected so that all the cracked area becomes black, and the remnant background becomes white. In summary, the image was converted into a binary image.
4. The area (A_t) of the threshold image in pixels was calculated using the "measure" function of the Scion Image software.
5. The area (A) of the total picture in pixels was also measured using the same "measure" function of the Scion Image software.
6. The shrinkage strain was then calculated by taking the ratio or percentage of the threshold image in pixels to the total area of the image in pixels. This equation is presented in the following:

Arial Shrinkage Strain (A.S.): $$A.S. = A_t / A \qquad (3.1)$$

Where A_t = area of threshold image in square pixels

A = area of the total image in square pixels.

3.4.3 Direct Shear Test

The shear strength parameters of a soil can be determined in the laboratory by conducting a Direct Shear Test (ASTM D3080) on compacted soil samples. The test equipment consists of a metal shear box in which the soil specimen can be placed. The soil specimen was compacted and placed in a testing machine such that the top of the soil specimen can be caused to slide in relation to the bottom half of the specimen. The specimen was sheared in such a manner that the shear plane was horizontal. Figure 3.4 presents the schematic diagram of the direct shear test. A typical laboratory apparatus for the direct shear test is shown in Figure 3.5.

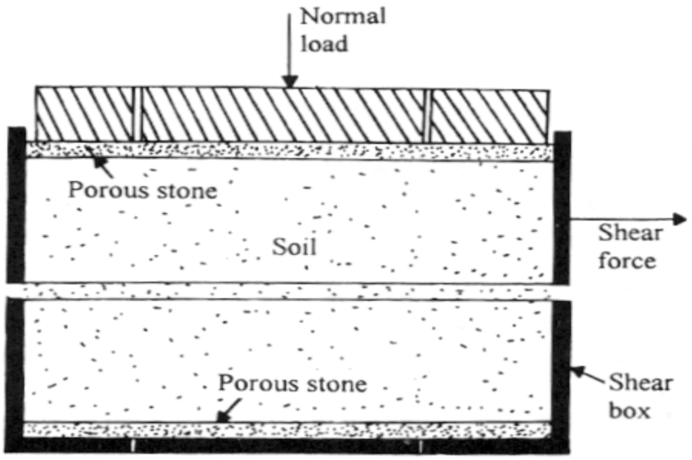


Figure 3.4 Schematic Diagram of Direct Shear Test (Das, 1997)

After the soil specimen has been carefully trimmed and fitted in the shear machine, a known confining load was applied in the direction normal to the shear plane. The sample was sheared gradually at a constant displacement rate of 0.5 mm/min. This causes shear failure along the horizontal plane. This procedure was carried out until the shear failure was observed and the corresponding shear stress was recorded at different lateral displacements. This procedure was repeated with three identical soil samples at three different normal loads. The shear stress at failure was recorded and they were used in conjunction with normal stress on σ vs. τ plot to determine shear strength parameters, c and ϕ. This test was conducted in undrained conditions and the strength parameters represent these conditions. The values of c and ϕ can be used to determine the shear strength of any soil for any confining stress using the following equation:

$$\tau = c + \sigma \tan(\phi) \tag{3.2}$$

where τ is shear stress, and σ is normal stress applied on the soil specimen.

Figure 3.5 Direct Shear Test Setup

3.4.4 Permeability Test

Permeability refers to the movement of water within the soil. The water movement will have profound effects on soil properties, drainage conditions, and moisture holding capacities. In predicting the flow of water in soils, it is imperative to evaluate the coefficient of permeability for a given sample. The setup utilizes a permeameter with the quick-disconnect coupler attached to the mold for water supply from the tank as depicted in Figure 3.6.

The following step-by-step procedure was followed to measure the coefficient of permeability of the control and amended soils:

1. The sample was compacted at the targeted moisture content level.
2. Water was then allowed to pass through the soil specimen by opening the water inlet valve.

3. The specimen was allowed to saturate fully. The time required for this step depends on the permeability of the material and the pressure applied.
4. After the sample was fully saturated, water was allowed to flow through the soil specimen.
5. Time required for a certain quantity of water to pass through the soil specimen was determined and recorded. The permeability of the soil specimen was calculated by using the following formula.

$$k = QL/AH \tag{3.3}$$

where:

k = Coefficient of permeability in cm/sec

Q = Rate of discharge in ml/sec

L = Length of the specimen in cm

H = Pressure head in cm

A = Area of specimen in sq.cm.

Figure 3.6 Permeability Test Setup

3.5 Basic Properties of Control Soil and Pure Compost Materials

3.5.1 Control Soil

The soil sampled from Stephenville, Texas, located along State Highway 108, exhibited an initial moisture content of 8% at the time of sampling. The control soil contained different ranges of coarse to fine-sized particles, which were measured from both sieve and hydrometer analyses. Figure 3.7 presents the particle size distribution plot. The physical properties of the control soil were also determined and are presented in Table 3.1.

Based on Atterberg limits and particle size distribution, this soil was classified as A-7-6 as per the AASHTO classification, and as CL as per the Unified Soil Classification System (USCS).

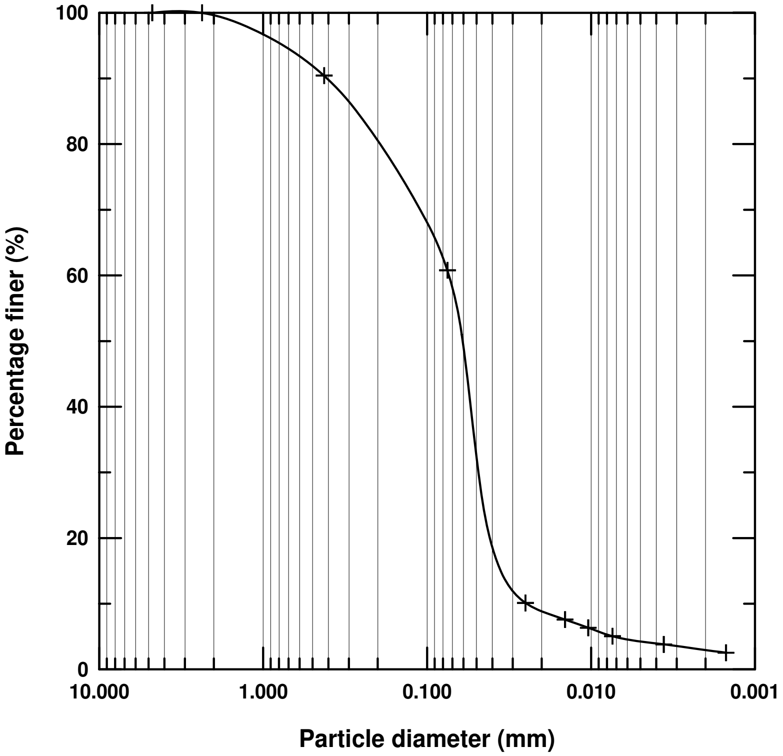


Figure 3.7 Grain-size Distribution Curve of Control Soil

Table 3.1 Basic Soil Properties

Soil Properties	Results
Organic Matter (%)	2.4
Passing # 200 (%)	60.8
Specific Gravity	2.4
Liquid Limit	44.0
Plasticity Index	28.0
Natural Moisture Content (%)	8.0
AASHTO Classification	A-7-6
USCS Classification	CL

3.5.2 Dairy Manure Compost

Dairy Manure compost used in this research work was procured from Producers Compost, Stephenville, Texas. Laboratory tests were conducted on this material in the natural moisture content state. This is to prevent the materials from losing their original properties when oven-dried. Figure 3.8 shows the particle size distribution plot of the Dairy Manure compost. Table 3.2 presents the physical properties of the Dairy Manure compost used in this research.

This material has an organic content of 6.4% and a pH of 7.4 in natural conditions. The pH value is within the acceptable limits for TxDOT specifications.

Though the organic content did not meet the requirements, the material was considered in this research as a potential compost cover in order to study the performance from geotechnical considerations. If proven effective, the material will be quite beneficial to TxDOT's recycling efforts by using it in large quantities for covering the shoulder. Based on Atterberg limits and particle size distribution, this soil was classified as A-8 as per the AASHTO classification, and as OL as per the Unified Soil Classification System.

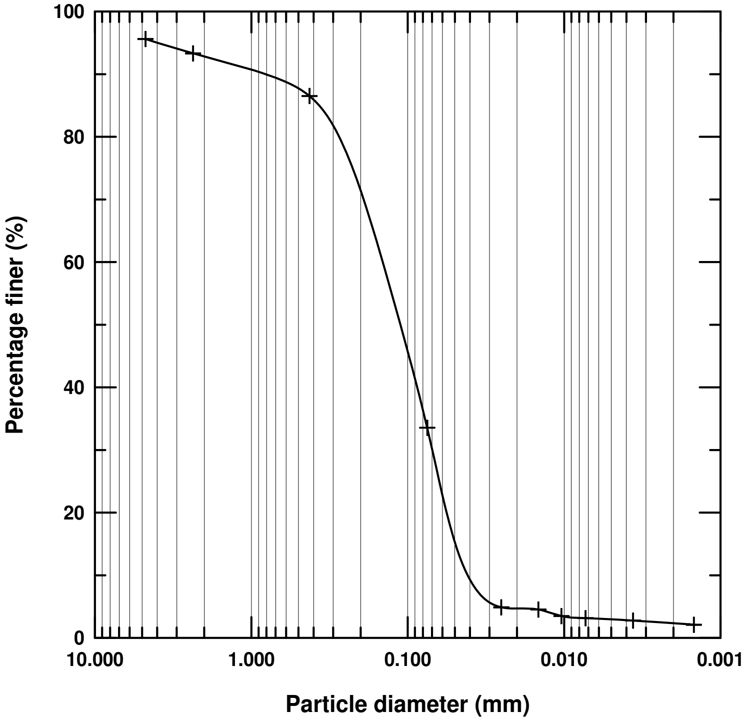


Figure 3.8 Grain-size Distribution Curve of Dairy Manure Compost

Table 3.2 Properties of the Dairy Manure Compost

Soil Properties	Results
Organic Matter (%)	6.4
Particle Size (%) Passing US Sieve # ¾ (%) Passing US Sieve # 200	 95.6 33.5
pH	7.4
Moisture Content (%)	15.0
Specific Gravity	2.3
Liquid Limit	36
Plasticity Index	12
Ash Content (%)	93.6
Volatile Suspended Solids (%)	11.2
AASHTO Classification	A-8
USCS Classification	OL

3.5.3 Biosolids Compost (Dillo Dirt)

Biosolids compost used in this research was procured from the city of Austin. This material is known as Dillo Dirt. Laboratory tests were conducted on this material at the natural moisture content state. This was to prevent the materials from losing their original properties due to oven-drying. Figure 3.9 shows the particle size distribution plot of composted biosolids. Table 3.3 presents physical properties of the composted Biosolids used in this research.

This material has an organic content of 33.8% and a pH of 5.8, which are within acceptable limits for TxDOT specifications. Based on Atterberg limits and particle size distribution, this soil was classified as A-8 as per the AASHTO classification, and as OH as per the Unified Soil Classification System.

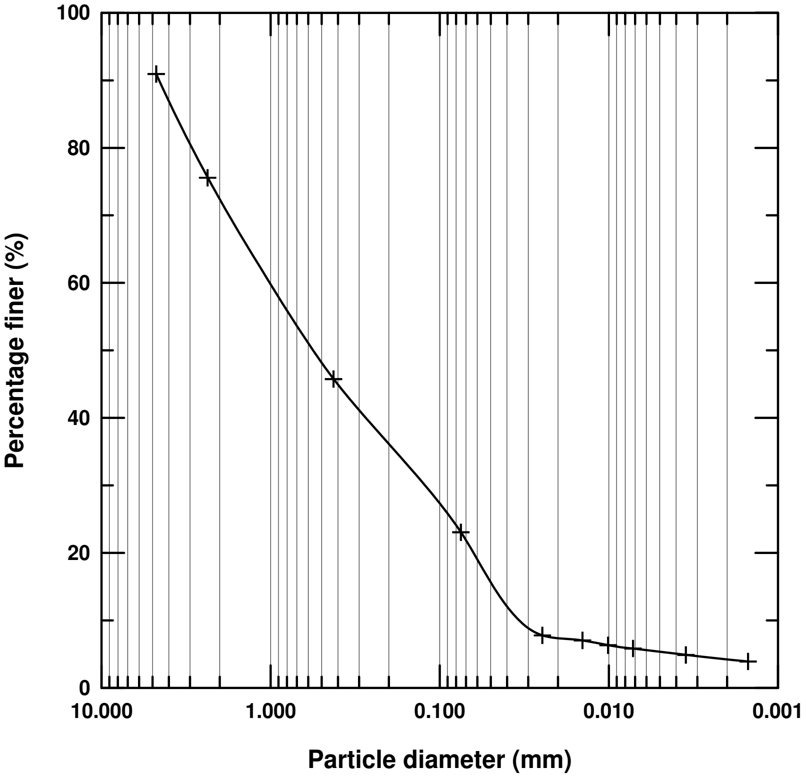


Figure 3.9 Grain-size Distribution Curve of Biosolids Compost

Table 3.3 Properties of Biosolids Compost

Soil Properties	Results
Organic Matter (%)	33.8
Particle Size (%) Passing US Sieve # ¾ (%) Passing US Sieve # 200	 90.9 23.0
pH	5.8
Moisture Content (%)[a]	98.7
Specific Gravity	1.2
Liquid Limit	122
Plasticity Index	43
Ash Content (%)	66.2
Volatile Suspended Solids (%)	38.2
AASHTO Classification	A-8
USCS Classification	OH

Note: a – Stockpile sample collected hours after rainfall event; Moisture content of CBS varies considerably

Table 3.4 was prepared, based on sieve and hydrometer analyses, by determining the coefficient of uniformity (C_u) and coefficient of curvature (C_c) along with the diameter of particle sizes.

From Table 3.4, it can be observed that the uniformity coefficient of control and amended soils varied from 3.0 to 26.3. Uniformity coefficient of Biosolids compost was high due to the presence of yard trimmings. The C_u for all soils was found to be less than 5, which implies that the soils are uniform sized particles. The biosolids compost has $C_u > 15$ and C_c between 1 and 3, which implies that BSC is a well-graded soil.

Table 3.4 Particle Size Details of Control Soil and Pure Compost Materials

Soil Description	D_{10} (mm)	D_{30} (mm)	D_{50} (mm)	D_{60} (mm)	C_u	C_c
CS	0.025	0.047	0.06	0.075	3.0	1.2
DMC	0.038	0.061	0.118	0.12	3.1	0.8
BSC	0.038	0.11	0.55	1.0	26.3	0.3

3.6 Compaction Characteristics

Table 3.5 and Figure 3.10 present test results of standard Proctor compaction tests conducted on control soil and pure compost materials. Based upon the moisture content vs. dry unit weight curves, the proportions of compost material to be used in this research were established. Materials that exhibited low density (lower than water unit weight of 62.4 pcf) and high moisture content (more than 50%) were not considered. Based on this consideration, different combinations of CMTs were established. They were presented in an earlier section.

Table 3.5 Compaction Moisture Levels of Control Soil and Pure Compost Materials for Engineering Tests

Soil Description	Optimum		Wet of Optimum	
	w %	γ_d (pcf)	w %	γ_d (pcf)
Control Soil	22.2	99.7	25.8	94.8
Dairy Manure Compost	25.9	88.7	30.7	84.3
Biosolids Compost	101.3	43.87	104.5	43.6

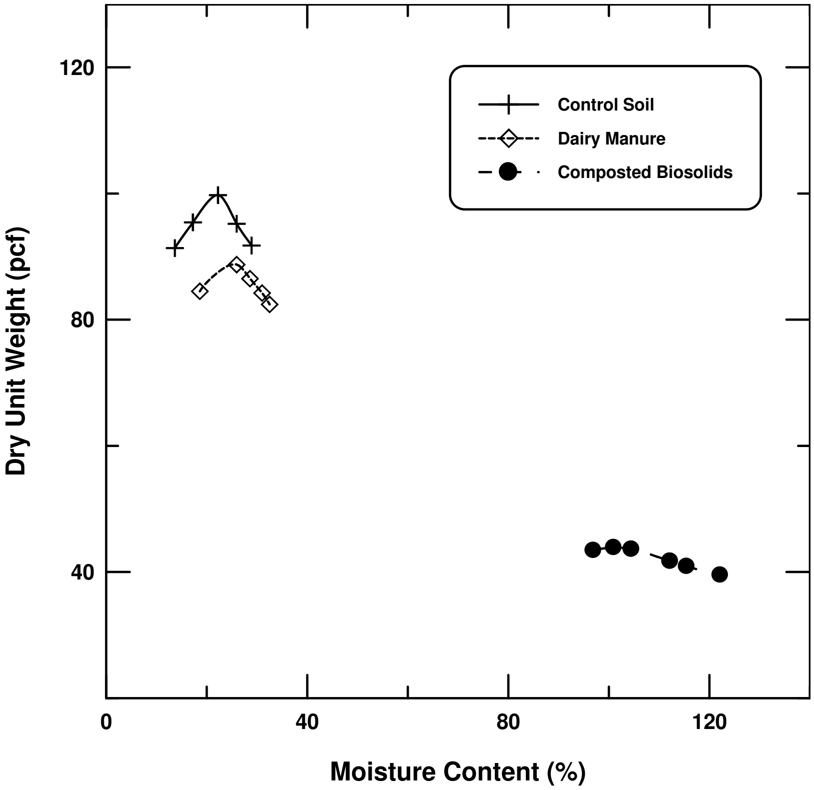


Figure 3.10 Moisture Content- Dry Unit Weight Curves of Control Soil and Pure Compost Materials

3.7 Summary

This chapter provides a comprehensive summary of the experimental program performed in this research. Test procedures and equipment used are described along with basic engineering properties and grain size distributions of the control and pure compost materials used in the experiments. Both composts contain organic content. As per unified soil classification, the DMC and BSC are classified as OL and OH, respectively. Compaction tests show high optimum moisture content for BSC materials, which is attributed to the presence of high organic content in the BSC material. It should be mentioned here that the field evaluation studies are currently under progress. These studies provide data that will be used to assess the CMTs in reducing shoulder cracking. These field results will be summarized in the final report.

CHAPTER 4

ANALYSIS OF TEST RESULTS

4.1 Introduction

This chapter presents a comprehensive analysis of both basic and engineering test results conducted in this research. This analysis evaluates the potential of each compost material to provide enhancements to soil properties. The effectiveness of each compost material and its influence on strength, permeability, swell, and shrinkage strain properties on the control soil are also explained. Ranking analysis based on targeted soil properties was performed to determine compaction moisture contents for field test sections.

4.2 Basic Properties

This section discusses basic soil properties measured in this research. These tests include specific gravity, sieve and hydrometer analyses, Atterberg limits, organic content, pH, and standard Proctor tests.

4.2.1 Specific Gravity

Specific gravity tests were conducted on the control and amended soils. The specific gravity provides an indirect explanation on possible constituents of soils and compares the unit weight of the material with respect to the unit weight of water. Table 4.1 presents specific gravity test results of all the control and amended soils.

Table 4.1 Specific Gravity of Control and Amended Soils

Soil Description	Specific Gravity
CS	2.4
CMT 1	2.3
CMT 2	2.3
CMT 3	2.2
CMT 4	2.1

Based on the specific gravity results, it can be summarized that both the control and amended soils exhibit specific gravity results in the range of 2.1 to 2.4, with high values being obtained for control soil and low values for CMT 4 soil. Low values are attributed to the presence of organic matter which decreases the specific gravity. This aspect is covered in section 4.2.4.

4.2.2 Sieve Analysis and Hydrometer Analysis

Sieve and hydrometer analyses were conducted on the control and amended soils to determine the grain size distribution of all the test materials, and these results are presented in Table 4.2. The C_u values of these soils varied between 2.6 and 4.7 with low values being obtained for CMT 3. The coefficient of curvature (C_c) values varied between 0.3 and 1.2 with low values being obtained for BSC. The pure BSC exhibited a much higher uniformity coefficient, which is attributed to larger size particles present in the Biosolids compost. Based on the uniformity coefficient values (C_u), it can be mentioned that all the control and amended soils contained uniform sized particles.

From Table 4.2, it can be concluded that the BSC has various sizes of particles, since $C_U > 15$ and C_c is between 1 and 3. The mean diameter, D_{50} of all soils varied between 0.06 and 0.55 mm with large size average particles found for pure Biosolids compost. Figure 4.1 presents the grain size distribution plots of the control and compost amended soils.

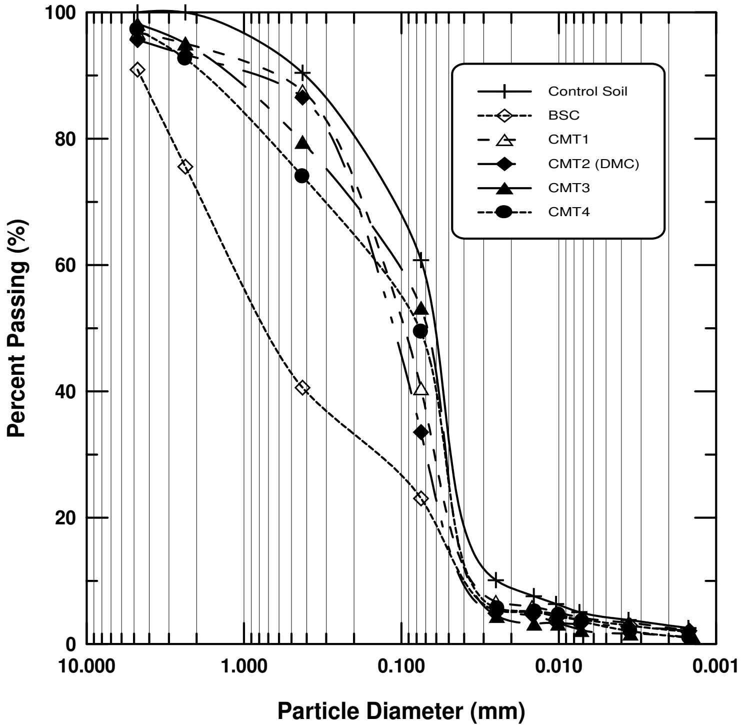


Figure 4.1 Grain-size Distribution Curve of Control and Compost Amended Soils

Table 4.2 Particle Size Details of Control and Amended Soils

Soil Description	D_{10} (mm)	D_{30} (mm)	D_{50} (mm)	D_{60} (mm)	C_u	C_c
CS	0.025	0.047	0.06	0.075	3.0	1.2
CMT 1	0.04	0.07	0.095	0.15	3.7	0.8
CMT 2 (DMC)	0.038	0.061	0.118	0.12	3.1	0.8
BSC	0.038	0.11	0.55	1.0	26.3	0.3
CMT 3	0.035	0.049	0.063	0.09	2.6	0.8
CMT 4	0.032	0.047	0.075	0.15	4.7	0.5

Note: D_{10} - Diameter of particle at which 10% is finer than that size

D_{30} - Diameter of particle at which 30% is finer than that size

D_{50} - Diameter of particle at which 50% is finer than that size

D_{60} - Diameter of particle at which 60% is finer than that size

C_u - Uniformity Coefficient; C_C - Coefficient of Curvature

4.2.3 Atterberg Limits

Atterberg limits tests explain the plastic nature of soils. Atterberg tests were conducted to measure the consistency of the control and amended soils. The plasticity indices (PI) were calculated by first measuring the liquid limit (LL) and plastic limit (PL) values, and then calculating the difference between them.

Table 4.3 and Figure 4.2 show the plasticity indices of the control and amended soils. The plasticity index values varied from 12 to 37. The CMT 2 soil exhibited low PI value, and CMT 4 exhibited high PI values. Table 4.3 shows that the plasticity index values of the dairy manure compost amended soils decreased, and plasticity index values of the Biosolids amended soils increased. The decrease in the plasticity index values are attributed to the presence of coarse sized particles. The increase in the plasticity indices are attributed to the presence of hydrophilic natured particles in biosolids.

Table 4.3 Atterberg Limits of Control and Amended Soils

Soil Description	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index
CS	44	16	28
CMT 1	38	20	18
CMT 2	36	24	12
CMT 3	60	25	35
CMT 4	72	35	37

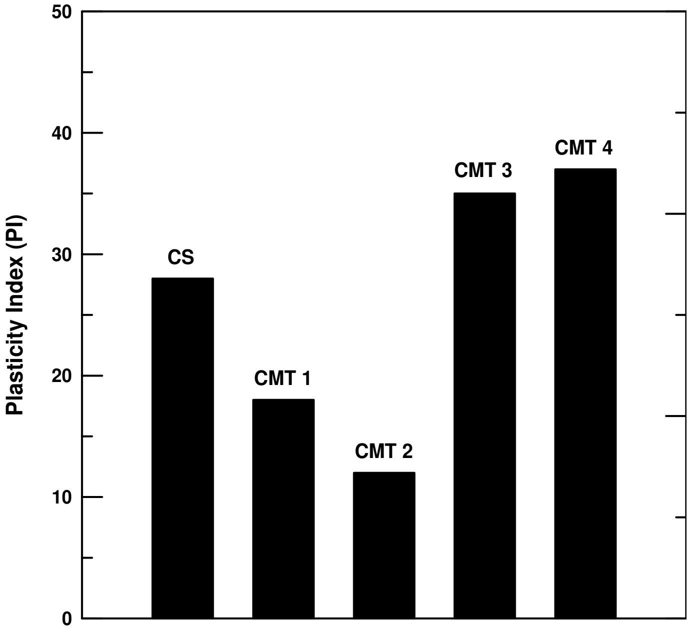


Figure 4.2 Plasticity Index of Control and Amended Soils

4.2.4 Organic Content

The organic content test was conducted to measure the amount of organic matter present in soil specimens. Table 4.4 and Figure 4.3 present the amount of organic matter present in the control and amended soils.

The following observations are noted from Table 4.4:

- All amended soils have organic matter between 5.9 and 14.2 with higher values reported for BSC amended soils.
- Organic matter present in the amended soils raised liquid and plastic limits as well as free swell strains.

Table 4.4 Organic Matter Present in Control and Amended Soils

Soil Description	Organic Content (%)
CS	2.4
CMT 1	5.9
CMT 2	6.3
CMT 3	11.3
CMT 4	14.2

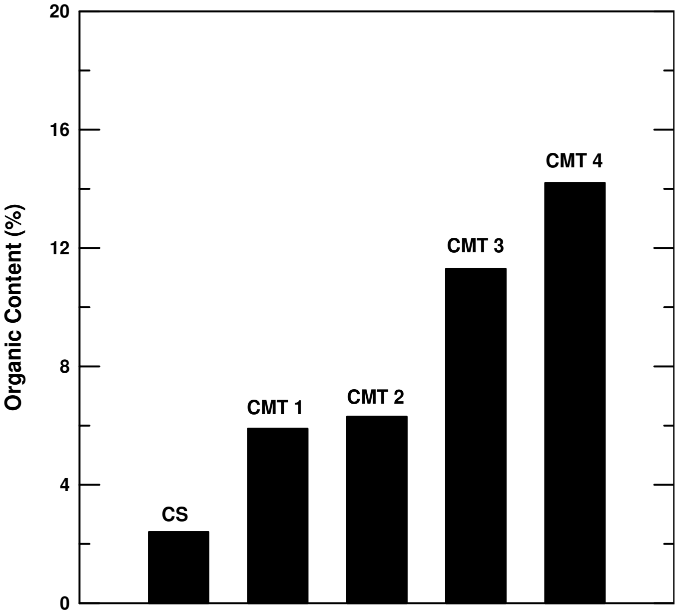


Figure 4.3 Organic Content of Control and Amended Soils

4.2.5 Hydrogen Ion Level (pH)

The pH of the soils can affect the uptake of metals by soils and plants and the mobility of elements and compounds. The effect of pH is therefore considered to be an important parameter. Table 4.5 shows the pH values of the control and amended soils. All the soils were observed to have pH values within the limits of TxDOT specifications for compost materials.

Table 4.5 pH of Control Soil, Compost, and Biosolids Amended Soils

Soil Description	pH
CS	6.7
CMT 1	7.2
CMT 2	7.4
CMT 3	6.9
CMT 4	6.8

4.2.6 Standard Proctor Compaction Test

Standard Proctor tests were conducted on the control and amended soils to determine compaction moisture content and dry unit weight relationships. Proctor tests were first conducted for various proportions of compost materials and based upon the optimum moisture content and dry unit weight results. The final proportions were established.

Figure 4.4 presents the moisture content - dry unit weight curves of the control and amended soils. Table 4.6 presents compaction moisture content levels of the control soil and compost amended soils for engineering tests.

The following conclusions can be made from results reported in Table 4.6:

- The control soil exhibited a maximum dry unit weight of 99.7 pcf at an optimum moisture content of 22.2%.
- Pure biosolids compost had a low maximum dry unit weight and high moisture content, whereas pure dairy manure compost had a high dry unit weight and low moisture content.
- From Figure 4.4, it can be observed that the pure dairy manure compost showed a dry unit weight of 88.7 pcf at an optimum moisture content of 25.9%. Therefore, for final proportions, dairy manure compost was used in high proportions such as 100% and 75% when compared to the proportions of the biosolids compost.

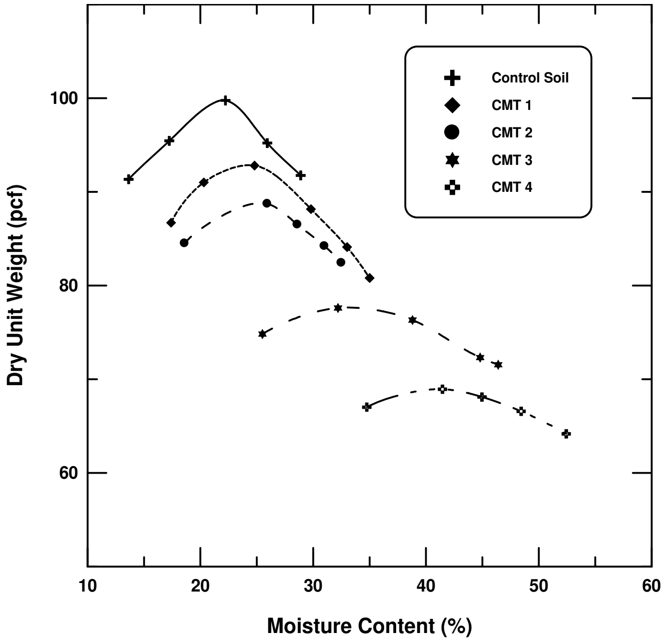


Figure 4.4 Moisture Content – Dry Unit Weight Curves of Control and Compost Amended Soils

Table 4.6 Compaction Moisture Content Levels of Control and Amended Soils

Soil Description	Optimum		Wet of Optimum	
	w %	γ_d (pcf)	w %	γ_d (pcf)
CS	22.2	99.7	25.8	94.8
CMT 1	24.8	92.8	28.0	90.5
CMT 2	25.9	88.7	30.7	84.3
CMT 3	32.2	77.6	35.3	77.3
CMT 4	41.5	68.9	44.5	68.2

4.3 Engineering Properties

This section discusses all the engineering test results conducted in this research. These tests include direct shear test, vertical free swell test, linear shrinkage test, and permeability test. All these tests were performed at two compaction moisture content levels, optimum moisture content and wet of optimum moisture content.

4.3.1 Direct Shear Test

Direct shear tests were performed to assess the shear strength parameters, cohesion and friction angles of the Control and amended soils. All soil samples were compacted and tested under undrained conditions.

Table 4.7 presents the shear strength parameters of the control and amended soils. The remaining pictures of the test are included in Appendix A. Figure 4.5 presents the direct shear test plots of the control and compost amended soils.

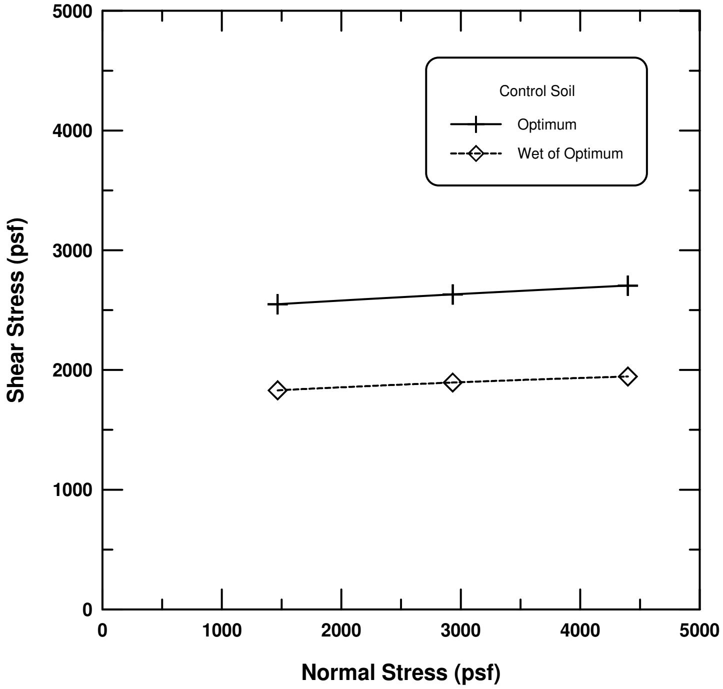
From Table 4.7, the following observations are made:

- As expected, all soils exhibited high strength values at optimum moisture content and low strength at wet of optimum moisture content.
- The cohesion values of all soils varied between 6 psi and 20.5 psi, and the friction angle varied from 2.5° to 26° .
- The control soil was observed to have a very low friction angle of 2.5° at wet of optimum moisture content. These results are consistent with those expected for medium clay.
- The biosolids compost amended soils showed high cohesion values and moderate friction angles. This can be attributed to the presence of yard trimming and coarse sized particles.
- The dairy manure compost, being coarser than the soil, exhibited low cohesion and high friction angles.
- Shear strength was calculated at a normal confining stress of 14 psi, and these results are presented in Table 4.7. Figure 4.6 presents the shear strengths of control and amended soils.
- Based on the results, the CMT 3 had the highest shear strength at optimum moisture content conditions.

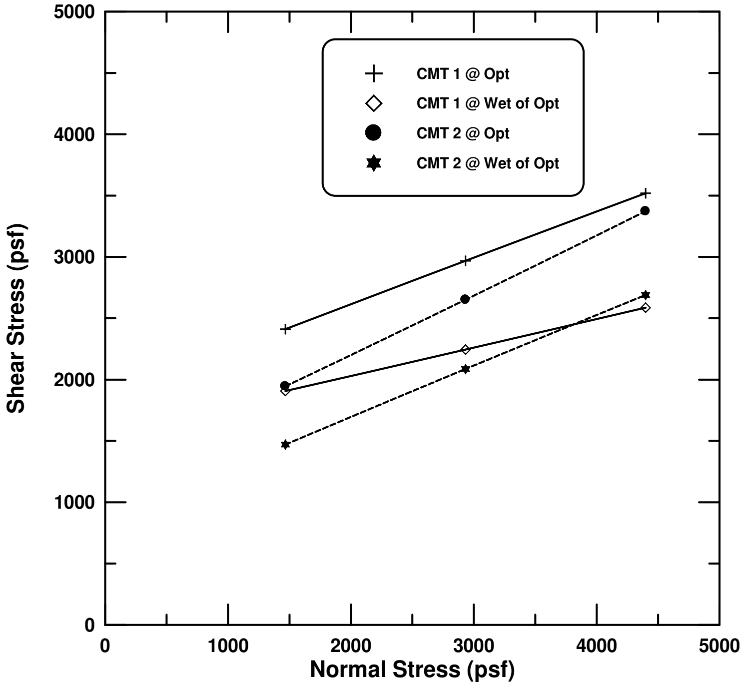
Table 4.7 Shear Strength Parameters of Control and Amended Soils

Soil Type	@ Optimum		@ Wet of Optimum		Shear Strength (psi)*	
	Cohesion (c) (psi)	Friction Angle (ϕ)	Cohesion (c) (psi)	Friction Angle (ϕ)	Optimum	Wet of Optimum
CS	17.1	3.0	12.2	2.5	17.8	12.9
CMT 1	15.5	21.0	12.4	13.0	21.1	15.7
CMT 2	8.5	26.0	6.0	23.0	15.6	12.2
CMT 3	20.8	22.5	17.4	19.0	26.9	22.4
CMT 4	16.8	23.5	16.1	19.5	23.2	21.2

. * $\tau = c + \sigma \tan(\phi)$, where $\sigma = 14$ psi

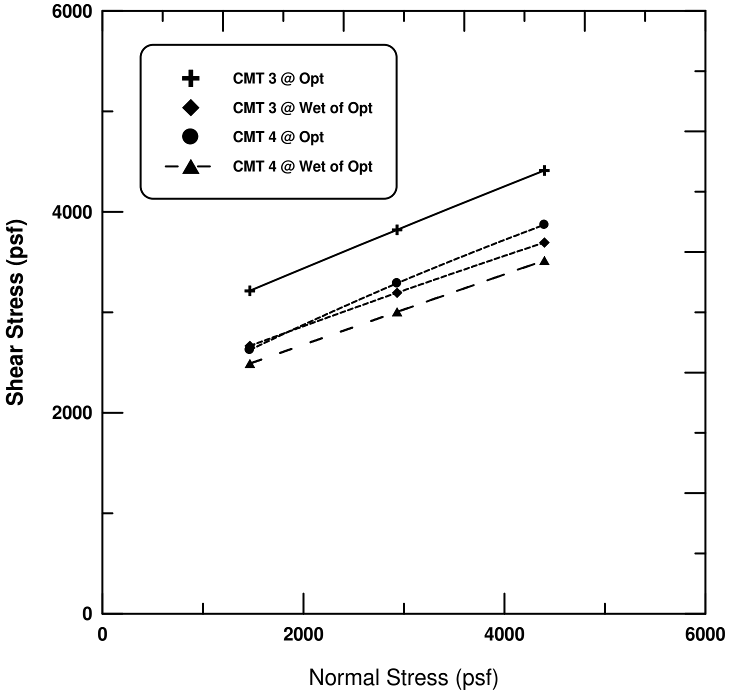


a)



b)

Figure 4.5 Direct Shear Test Results of a) Control Soil b) CMT 1 and CMT 2 c) CMT 3 and CMT 4



c)

Figure 4.5 Direct Shear Test Results of a) Control Soil b) CMT 1 and CMT 2 c) CMT 3 and CMT 4 (Continued).

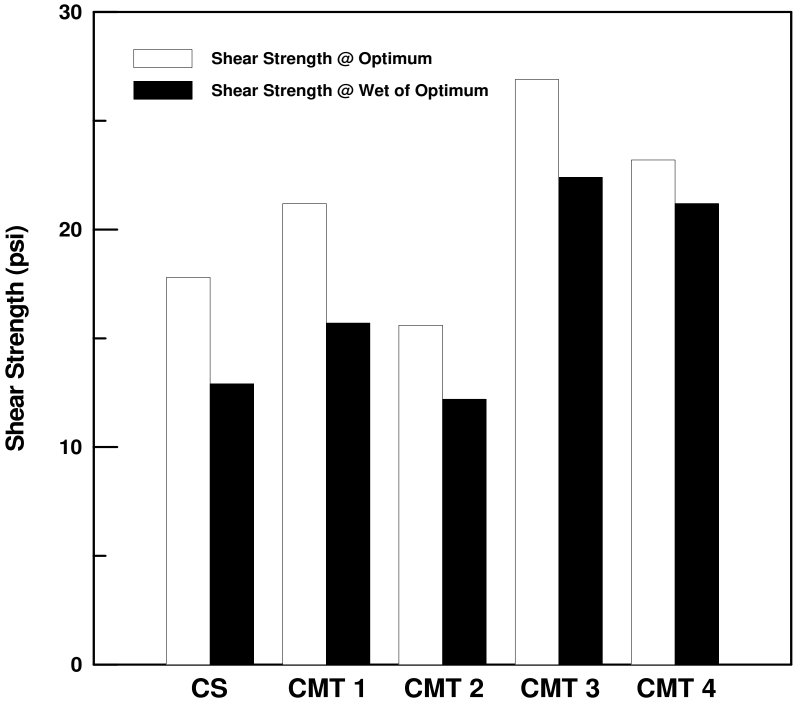


Figure 4.6 Shear Strength of Control Soil and CMTs at a Normal Confining Stress of 14 psi

4.3.2 One-Dimensional Free Swell Test

The one-dimensional free swell test was used to measure the amount of free swell strain in the vertical direction. The test was continued until there was no significant change in displacements for more than 24 hours.

Table 4.8 shows the free vertical swell strains in percent of the control and amended soils. Figure 4.7 presents swell strains of the control soil at different periods. Figure 4.8 shows a typical photograph of the biosolids compost amended soils (CMT 3) subjected to swell. Figure 4.9 shows the graphical representation of free vertical swell strains of control and amended soils.

From Table 4.8, the following observations are made:

- The maximum amount of swelling was recorded for CMT 4 after 5 days or 120 hours of soaking.
- The swell strain values of all soils varied from 5.6 to 31.2%.
- The free swell strain at optimum moisture content was higher than the same at wet of optimum moisture content due to differences in degree of saturation at these moisture contents.
- The biosolids compost amended soils exhibited high swell strain values of 27.9% for CMT 3 and 31.2% for CMT 4.
- Compost materials have more water holding capacity than the control soil. Because of this, when the soil sample was saturated, the compost amended soils exhibited more swelling. These numbers demonstrate that biosolids compost have more water holding capacity than dairy manure compost.

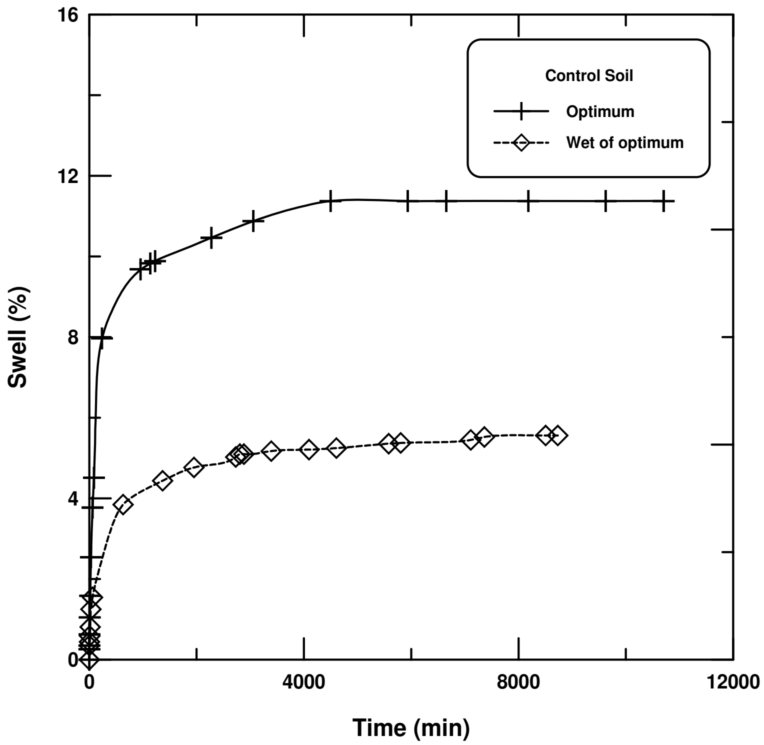
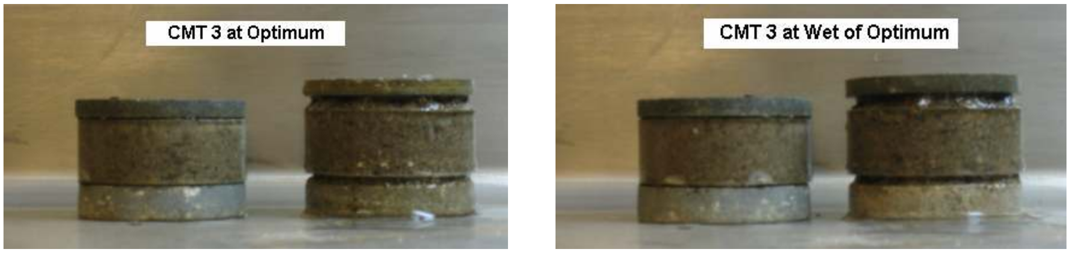


Figure 4.7 Average Free Vertical Swell Strain of Control Soil



A)

B)

Figure 4.8 CMT 3 Samples – Before and After Swell Tests A) Optimum Moisture Content and B) Wet of Optimum Moisture Content

Table 4.8 Free Vertical Swell Strains of Control and Compost Amended Soils

Soil Description	@ Optimum Moisture Content (%)	@ Wet of Optimum Moisture Content (%)
CS	11.4	5.6
CMT 1	24.6	22.8
CMT 2	23.8	22.5
CMT 3	27.9	23.2
CMT 4	31.2	28.4

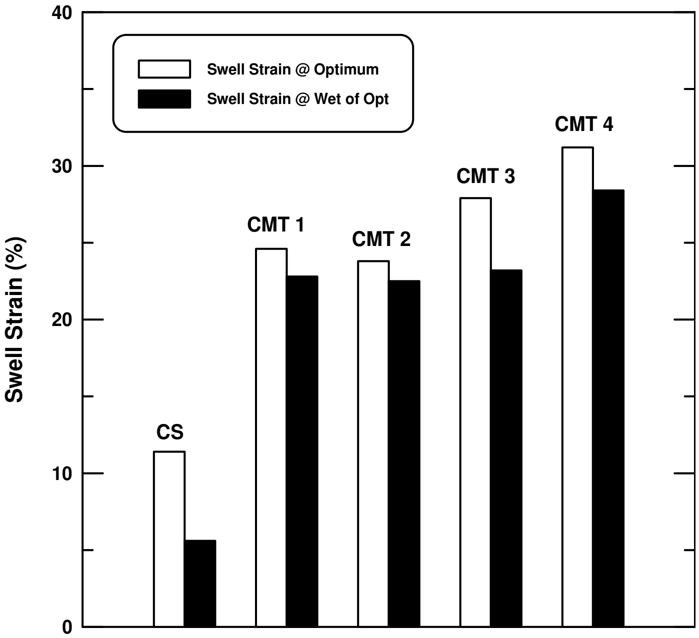


Figure 4.9 Swell Strains of Control and Amended Soils

4.3.3 Linear Shrinkage Test

Linear shrinkage was conducted on the control soil and compost amended soils at three different moisture contents; optimum moisture content, wet of optimum moisture content and liquid limit. Table 4.9 presents the linear shrinkage strain values for the control and amended soils at different moisture contents. Figure 4.10 presents the linear shrinkage strain values for the control and amended soils at two moisture content levels; optimum moisture content and wet of optimum moisture content.

From Table 4.9 and Figure 4.10, the following observations are made:

- Linear shrinkage strain values of all soils varied between 4.2% and 23.4%.
- Both CMT 1 and CMT 2 were observed to experience low shrinkage strain values. The decrease was attributed to changes in plasticity characteristics.
- Though both CMT 3 and CMT 4 had higher initial moisture content, the shrinkage strain values were low because of the presence of yard trimmings.

Table 4.9 Linear Shrinkage Strain Values for Control Soil, Compost Amended Soils, and Lime-Treated Biosolids

Soil Description	@ Optimum	@ Wet of Optimum	@ Liquid Limit
CS	14.0	17.0	23.4
CMT 1	6.0	8.0	10.0
CMT 2	4.2	4.8	5.7
CMT 3	5.8	6.5	14.3
CMT 4	10.7	12.2	18.1

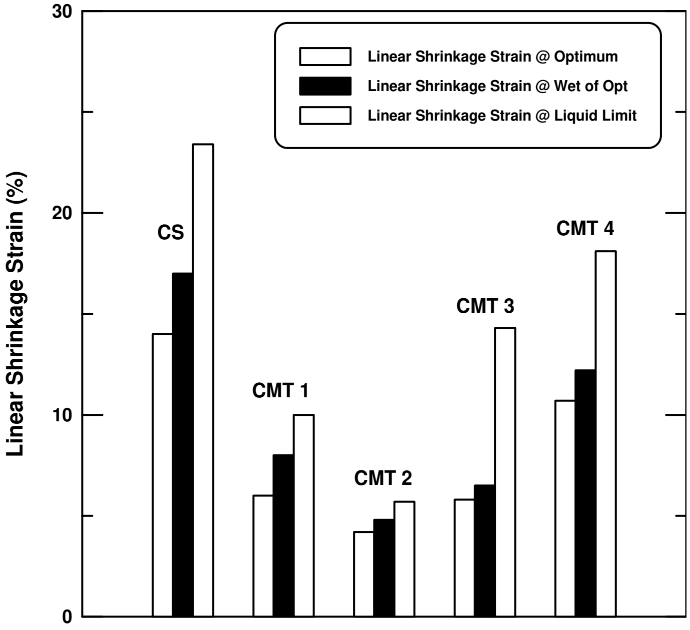


Figure 4.10 Linear Shrinkage Strains of Control and Compost Amended Soils

4.3.4 Permeability Test

The permeability test was conducted on all soils at two compaction moisture content levels; optimum moisture content and wet of optimum moisture content. The Constant Head Permeability test was followed in this research. Table 4.10 shows the permeability values of all soils at the two compaction moisture content levels.

From Table 4.10, the following conclusions can be made:

- All soils exhibited low permeability values. These values varied between 3.0×10^{-9} cm/sec and 1.2×10^{-7} cm/sec.
- Soils mixed with Biosolids compost exhibited low permeability values. This is because soils with high plasticity properties have a thicker double layer, possess greater dispersivity, and exhibit lower permeability. The reduced water absorption capacity indicates a decrease in the double layer thickness and therefore, an increase in soil permeability.
- All soils were observed to have higher permeability values at optimum moisture content than at wet of optimum moisture content. An increase in the compaction moisture content results in a decrease in the soil permeability. This decrease is attributed to the soil structure, which becomes dispersed at high moisture contents.
- The dairy manure compost amended soils exhibited slightly higher permeability values than the control soil. This is because D_{50} of the dairy manure compost is more than D_{50} of the control soil. Permeability property depends on soil size and hence high permeability properties were obtained for dairy manure compost.

Table 4.10 Coefficient of Permeability of Control and Amended Soils

Soil Description	@ Optimum (cm/sec)	@ Wet of Optimum (cm/sec)
CS	1.2×10^{-8}	3.0×10^{-9}
CMT 1	4.2×10^{-8}	4.3×10^{-9}
CMT 2	8.9×10^{-8}	8.7×10^{-9}
CMT 3	7.8×10^{-8}	9.7×10^{-9}
CMT 4	1.2×10^{-7}	7.8×10^{-8}

4.4 Ranking Analysis

The following scale system was used in which the transformation of each soil property from problematic levels to non-problematic levels is assigned a numeric ranking. The magnitude of ranking is based on the severity of the soil problem. The worst soil condition is given a rank of 1, and the best soil condition is given a rank of 5. In between conditions, ranks of 2 to 4 are assigned for different ranges of soil properties.

Table 4.11 shows the ranking for PI values used in this research (Nelson and Miller, 1992; Wattanasanticharoen, 2000). The ranking in this table is based on the literature information on the PI values. It should be mentioned here that a PI value of 15 is recommended for select subgrades. Hence, the PI ranging from 5 to 15 is given the second highest rank. Soils whose PI values are less than 5 are considered the best subgrade material, and hence they are given the highest ranking of 5. Soils with PI values above 25 and 50 are considered poor and weak subgrade soils, and they are given a rank of 2 and 1, respectively.

Table 4.11 Soil Characterization Based on the Plasticity Index of the Soils (Modified from Wattanasanticharoen, 2000)

Plasticity Index	Degree of Plasticity (Soil Characterization)	Rank
$0 \leq PI \leq 5$	Non-Plastic	5
$5 < PI \leq 15$	Low-Plastic	4
$15 < PI \leq 25$	Medium-Plastic	3
$PI > 25$	Highly Plastic	2
$PI > 50$	Very Highly Plastic or Soft	1

Table 4.12 shows the ranking based on free swell strain magnitudes expressed as a percent of the original soil height. This ranking is prepared by following the swell strain magnitudes and characterizations reported in Nelson and Miller (1992).

Table 4.12 Soil Characterization Based on the Free Vertical Swell Strain of the Soils

Vertical Swelling Strain (%)	Degree of Swelling of the Soils	Rank
0 - 0.5	Non - Critical	5
0.51 - 1.5	Marginal	4
1.51 - 4.0	Critical	3
> 4.0	Highly - Critical	2
> 8.0	Severe Damage to Infrastructure	1

Table 4.13 shows the ranking based on the linear shrinkage strain magnitudes, which are presented in terms of the degree of linear expansion of the soils. This ranking is based on the linear shrinkage strain magnitudes reported in Nelson and Miller (1992).

Table 4.13 Soil Characterization Based on the Linear Shrinkage Strain of the Soils

Linear Shrinkage Strain (%)	Degree of Shrinkage of the Soils	Rank
< 5.0	Non – Critical	5
5.0 – 8.0	Marginal	4
8.1 – 12.0	Critical	3
12.1 – 15.0	Highly - Critical	2
>15.0	Severe Damage to Infrastructure	1

Table 4.14 shows the ranking based on the shear strength of soils, which are presented in terms of the psi. The shear strength values used in this table are low due to the fact that the requirements of this material is for shoulder covers and hence do not support any traffic loads for long durations. The strength properties are selected such that the materials with these properties will be stable when they are encountered in slopes.

Table 4.14 Soil Characterization Based on the Shear Strength of the Soils

Shear Strength, psi (kPa)	Rank
> 28 (200)	5
21 – 28 (150 – 200)	4
14 – 21 (100 – 150)	3
7 – 14 (50 – 100)	2
0 – 7 (0 – 50)	1

Table 4.15 shows the ranking based on the permeability of soils. The main intent of shoulder covers is to provide encapsulation (i.e., to act as a moisture barrier). Hence, low permeability characteristics are assigned with high ranks, and high permeability characteristics are assigned with low ranks. The above ranking system is used on all the soils, and then each soil is assigned a rank between 1 and 5 for all soil property characterizations. An average rank termed as an index value is calculated. This index value is then used to assess the soils with respect to their overall performance in laboratory conditions.

Table 4.15 Soil Characterization Based on the Coefficient of Permeability of the Soils

Coefficient of Permeability (cm/sec)	Rank
$<10^{-8}$	5
10^{-7} - 10^{-8}	4
10^{-6} - 10^{-7}	3
10^{-5} - 10^{-6}	2
10^{-4} - 10^{-5}	1

Table 4.16 presents the ranking of the control and amended soils based on both physical and engineering test results. From the table it can be observed that all the soils have a better ranking at optimum moisture content level than wet of optimum moisture content level. CMT 2 has a reasonably good ranking (3.3) when compared to other amended soils. Dairy manure compost has enhanced the control soil ranking from a poor (2.6) to good (3.6) ranking. On the other hand, BSC (at 20% dosage level) has enhanced the control soil ranking from 2.6 to 3.2.

Table 4.16 Ranking of Control and Amended Soils Based on Test Results

Soil Type	w%	PI	FS	LS	τ	k	IV^1	IV^2	IV^3
CS	O	2	1	2	3	5	2.6	2.1	2.3
	W	2	2	1	2	5	2.4	2	2
CMT 1	O	3	1	4	3	5	3.2	2.9	2.9
	W	3	1	4	3	5	3.2	2.9	2.9
CMT 2	O	4	1	5	3	5	3.6	3.3	3.3
	W	4	1	5	2	5	3.4	3.2	3.1
CMT 3	O	2	1	4	4	5	3.2	2.9	3
	W	2	1	4	4	5	3.2	2.9	3
CMT 4	O	2	1	3	4	4	2.8	2.5	2.7
	W	2	1	2	3	5	2.6	2.1	2.3

Where, k - Coefficient of permeability (cm/sec); τ- Shear Strength (kPa);

$I.V^1$ - 0.2 (PI) + 0.2 (FS) + 0.2 (LS) + 0.2 (τ) + 0.2 (k) - Equal Weight Factor;

$I.V^2$ - 0.15 (PI) + 0.3 (FS) + 0.3 (LS) + 0.15 (τ) + 0.1 (k); and

$I.V^3$ - 0.15 (PI) + 0.25 (FS) + 0.25 (LS) + 0.25 (τ) + 0.1 (k).

Compaction moisture content for each compost amended soil was selected from the above table. The moisture content at which the index value is high for a given compost material is recommended for field compactions. These recommended moisture contents and their corresponding dry unit weights are presented in Table 4.17.

Table 4.17 Recommended Moisture Contents and Their Corresponding Dry Unit Weights for Field Compaction Specifications

Soil Description	Recommended Values	
	Moisture Content (%)	Dry Unit Weight (pcf)
CS	22.2	99.7
CMT 1	24.8	92.8
CMT 2	25.9	88.7
CMT 3	32.2	77.6
CMT 4	41.5	68.9

4.5 Field Compaction Specifications

Field compaction specifications for the compaction of composted soils in field sections are developed and presented in this section. These specifications are preliminary specifications and are revised after the construction of test plots in the field. The revised specifications are submitted as another set of deliverables in the first year study.

4.5.1 Compost Dosages and Compaction Moisture Content

Four types of CMTs (Compost Manufactured Topsoil) are used. All percents correspond to dry weight of the material. All the specimens are recommended to be compacted at optimum moisture content.

DMC_75 (CMT 1)	-	75% Dairy Manure Compost: 25% Control Soil
DMC_100 (CMT 2)	-	100% Dairy Manure Compost
BSC_20 (CMT 3)	-	20% Dillo Dirt: 80% Control Soil
BSC_30 (CMT 4)	-	30% Dillo Dirt: 70% Control Soil

4.5.2 Equipment Needed

1. Maintainer
2. Rotary Tiller
3. Smooth Drum Roller

4.5.3 Construction Steps

1. Remove topsoil and vegetation from the area to be treated. The shoulder subgrade soil shall be bladed to the required grade and cross-section in accordance with the plans and specifications.
2. Scarify the shoulder to full depth and width of the shoulder using a rotary tiller. After the subgrade has been scarified, any lumps in the subgrade shall be broken to ensure that no large size particles are present during compaction. More passes of the rotary tiller may be needed if this condition is not met.
3. Distribute the compost material evenly over the scarified subgrade with a maintainer. The quantities of compost material and water needed to achieve the targeted moisture contents and dry unit weights of CMTs should be thoroughly checked based on in situ densities of the shoulder soils and compost materials from stockpiles.
4. Add the required water in gallons by spraying it uniformly over the compost material. Mix all three materials, compost, topsoil, and water using the rotary tiller. Mixing should be performed within an hour after placement of the materials.
5. Compact the mixed soil with a smooth drum roller for at least 8 passes. The compaction time of each plot should not exceed more than one hour after mixing.
6. Measure both moisture content and dry unit weight of the compacted material in the field by using either a nuclear gauge or a sand cone test method. Testing

should be performed at least in two locations, at every 25 foot interval. The relative compaction (R) of the compacted CMT is calculated as follows:

$R\ (\%) = \{\gamma_{d\ (field)}/\gamma_{d\ (lab\_max)}\}\times 100 = 0.95$ to 0.99 (close)

Moisture content in field = $w_{field} = w_{opt} + 1$ to 2%

7. If the relative compaction criterion is not met (i.e., when the R value is less than 0.95 or the moisture content is not within the allowable values), then compact the soil with the roller for another two or more passes until the above criterion is satisfied. In the case of high moisture contents in the field, compact the CMTs after drying them in the natural condition for 6 to 8 hours.
8. The pneumatic roller is recommended only if the smooth wheel roller is not available. However, care should be taken to ensure that this mode of compaction does not result in layering problems at the surface.
9. Additional care is needed when Biosolids are used in the CMT construction because of high initial moisture contents. Any inaccurate estimation of initial moistures of Biosolids may result in extremely wet subgrade conditions, which are not appropriate for field compaction. This is due to poor workability of the material at high moisture content levels and high settlements of the maintainer or roller into the subgrade.

4.6 Summary

A summary of test results for the control and amended soils were presented and analyzed in this chapter. Based on the ranking analysis, all the soils have been ranked. All amended soils showed significant improvement in soil properties. Field compaction specifications are prepared and presented in Chapter 5.

CHAPTER 5

DESIGN METHOD AND CONSTRUCTION OF TEST PLOTS FOR FIELD STUDIES

5.1 Introduction

This chapter covers the construction steps of the 17 test sections built with different compost manufactured topsoils including a control soil as shoulder covers. It also describes different design steps to estimate the quantity of composts and provides site instrumentation details used in the field construction.

5.2 Design Method

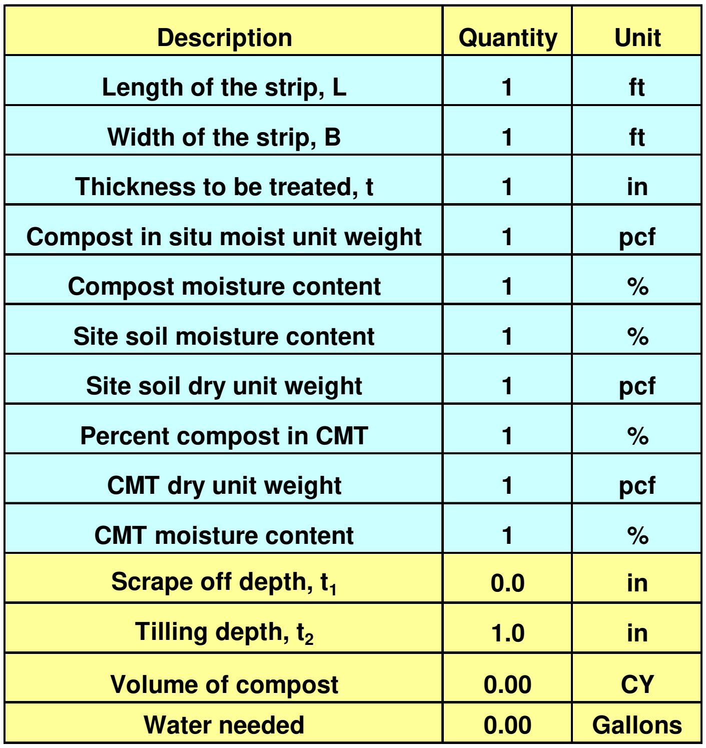
The test site was located on State Highway 108 near Stephenville, Texas. The field test plot construction began March 27, 2003, and was completed March 28, 2003. Prior to construction, soil from the test plots was collected and evaluated in the laboratory. Two composts, Dairy Manure compost and Biosolids compost, were acquired from local sources and mixed with the control soil to form four types of Compost Manufactured Topsoils or CMTs. These CMTs were intended to be used as shoulder cover materials by studying their soil characteristics and evaluating their performance in field conditions.

Both physical and engineering properties of CMTs and the control soil were first determined in the laboratory, which were presented in the earlier chapters. These properties were analyzed by the ranking scale system, which were developed from the existing literature. Based on these engineering property evaluations, various proportions of CMTs and their compaction properties were established for field treatments.

Table 5.1 presents the CMTs and their proportions considered in this research. In the field, two variables were studied and these were the width and thickness of the CMT sections. Two widths (5 ft and 10 ft) and two thicknesses (2 in. and 4 in.) were considered. These two variables along with the four CMTs resulted in 16 test sections. One Control with no CMT section was included for comparison studies and this section was established as the untreated test section. Table 5.2 provides details of these test sections along with variables considered in their construction.

A spreadsheet-based program (Figure 5.1) was developed, and the program used input parameters, which included moisture content and dry unit weight properties of composts and subsoils as well as targeted or design compaction characteristics of CMTs. The output parameters of the program are the amounts of compost needed, amount of topsoil that needs to be tilled, and the amount of water in gallons to be added in order to mix the compost with the soils.

Table 5.3 presents approximate percent amounts of composts, amounts of water in gallons, thickness of topsoil to be removed, and thickness of topsoil for tilling in the preparation of present CMT sections. This table was prepared using the properties determined in the laboratory investigations in the spreadsheet software.



Description	Quantity	Unit
Length of the strip, L	1	ft
Width of the strip, B	1	ft
Thickness to be treated, t	1	in
Compost in situ moist unit weight	1	pcf
Compost moisture content	1	%
Site soil moisture content	1	%
Site soil dry unit weight	1	pcf
Percent compost in CMT	1	%
CMT dry unit weight	1	pcf
CMT moisture content	1	%
Scrape off depth, t_1	0.0	in
Tilling depth, t_2	1.0	in
Volume of compost	0.00	CY
Water needed	0.00	Gallons

Figure 5.1 A Spreadsheet-Based Program to Compute Compost and Water Quantities

Prior to site construction, both moisture content and dry unit weights of the compost materials transferred to the test site were again determined and compared with those used in the preparation of Table 5.3. The compost and water quantities were adjusted by using the values from the spreadsheet program.

5.3 Construction of Test Plots

The field construction was started first by removing the top layer (thickness is t_1 in.) of the soil, which was composed of vegetation and other organic matter. The 'maintainer' was then used to blade the remaining shoulder subgrade section to the required grade and cross-section in accordance with the variables noted in Table 5.3. Figure 5.2 shows a photograph of this step in the field.

Figure 5.2 Maintainer to Blade the Subgrade Shoulder

The shoulder was then scarified to full length (which is 50 ft of test section and 25 ft of transition), width (variable) and thickness (t_2 in.) of Table 5.3 using a rotary tiller. Any lumps in the subgrades were broken up such that no large sized particles (2 in. or above) were present in the tilled soil (Figure 5.3).

Figure 5.3 Rotary Tiller for Tilling Operations

Compost materials were transferred to the test sections as shown in Figure 5.4, and the material was then distributed evenly over the test section with a maintainer. The compost materials were mixed with the tilled topsoil using the same tiller. At least eight passes of the rotary tiller were applied for the initial soil mixing. At this juncture, the required water in gallons was uniformly distributed over the compost and topsoil mixture (Figure 5.5). These three materials, compost, soil and water, were again mixed with the tiller for another 8 passes. This mixing was completed within an hour after placement and mixing of all three materials.

Figure 5.4 Distributing Composts on the Tilled Subgrade

Figure 5.5 Application of Water over the CMT Loose Mixture

The mixed CMT was then compacted with a smooth drum roller (Figure 5.6) for at least 8 passes within an hour after mixing. Both moisture content and dry unit weights of the compacted material in the field were measured using a nuclear gauge at different locations.

The average values of these measurements were used in the following Equations 5.1 and 5.2 to calculate the relative compaction (R) and water content of the compacted CMT.

$$R\,(\%) = \{\gamma_{d\,(field)}/\gamma_{d\,(lab\_max)}\}\times 100 \geq 0.95 \quad (5.1)$$

$$\text{Field moisture content of CMT} = w_{field} = w_{opt} + 1 \text{ to } 2\% \quad (5.2)$$

Where $\gamma_{d\,(field)}$ is the dry unit weight of compacted CMT cover; $\gamma_{d\,(lab\_max)}$ is the maximum dry unit weight of compacted CMT from the TEX-113/114-E compaction test method used in the laboratory; w_{field} is the field moisture content of the compacted CMT in %; and w_{opt} is the optimum moisture content of the CMT from the laboratory TEX-113/114-E compaction test.

Figure 5.6 Smooth Drum Roller Used for Soil Compaction

The shoulder subgrade section was re-compacted with two more passes using the same roller when the compaction criterion was not met (i.e., when the R value is less than 0.95 or moisture content is not within the allowable values or both). Compaction moisture content and dry unit weights were measured again to recalculate and assess the targeted R and moisture content values in the field. When the criterion was met, then the construction of the test section was completed. If not, the same steps were repeated using additionally two more passes of the same roller. In the case of high moisture contents in the field, compact the CMTs after drying the subgrade in natural conditions for 6 to 8 hours.

During construction, care was taken to prevent spillage of composts on roadways over which the hauling was done. Any spilled material was cleaned up immediately. All compost materials shall be removed, and the general condition of the test site shall be as good as or better than before construction. Final approval of the cleanup shall be given by the Department of Transportation Inspector.

5.4 Installation of Sensors

After construction of the test sections, moisture and temperature probes were installed. These sensors were selected for field instrumentation since the objective of the research is to assess the subgrade moisture and volume change conditions due to construction of a CMT cover system over the shoulder section. Both moisture and temperature probes were selected since they can provide real-time moisture and temperature data. Site surveys and digital image studies were considered since they provide volume changes in underlying soils.

Sensors were placed after the construction of the test sections rather than during the construction due to the sensitivity of the equipment against the weight of the construction equipment.

Several moisture and temperature probes were acquired and used in the field site installation. Three square-shaped holes were carefully excavated up to 6 in., 12 in., and 18 in. Three moisture sensors were placed at the bottom of each hole, and one temperature sensor was placed at the 6 in. hole. Figure 5.7 shows a picture depicting these sensors. Prior to placement of the sensor, a small 0.5 in. depression was made at the bottom of the hole, in which the sensor was carefully placed such that there were no air gaps between the sensor and soil. The excavated soil was then placed in the hole and compacted in short lifts (4 in.). Extreme care was taken to ensure the compaction was similar to the adjoining subsoils.

Figure 5.7 Placement of Sensors in a Test Section

Table 5.1 CMT Materials

Designation	**Percents of Constituents**
CMT 1	75% Dairy Manure Compost and 25% Control Soil
CMT 2	100% Dairy Manure Compost
CMT 3	20% Biosolids Compost and 80% Control Soil
CMT 4	30% Biosolids Compost and 70% Control Soil

Table 5.2 Details of Test Sections

Section	Plot name	Soil	Shoulder width (ft)	Thickness (in.)
1	CMT4-10-4	CBS_30	10	4
2	CMT3-10-4	CBS_20	10	4
3	CMT2-10-4	DM_100	10	4
4	CMT1-10-4	DM_75	10	4
5	CMT4-10-2	CBS_30	10	2
6	CMT3-10-2	CBS_20	10	2
7	CMT2-10-2	DM_100	10	2
8	CMT1-10-2	DM_75	10	2
9	CMT4-5-2	CBS_30	5	2
10	CMT3-5-2	CBS_20	5	2
11	CMT2-5-2	DM_100	5	2
12	CMT1-5-2	DM_75	5	2
13	CMT4-5-4	CBS_30	5	4
14	CMT3-5-4	CBS_20	5	4
15	CMT2-5-4	DM_100	5	4
16	CMT1-5-4	DM_75	5	4
17	CS-10-4	CS	10	4

Table 5.3 Details of Construction

Section	Thickness of topsoil to be removed (in.)	Scarifying depth (in.)	Amount of water (gallons)	Volume of compost (CY)
1	2	2	180	10.35
2	1.4	2.6	210	7.77
3	4	0	0	21.47
4	3	1	36	16.84
5	1	1	90	5.17
6	0.7	1.3	105	3.88
7	2	0	0	10.73
8	1.5	0.5	18	8.42
9	1	1	45	2.59
10	0.7	1.3	52.5	1.94
11	2	0	0	5.37
12	1.5	0.5	9	4.21
13	2	2	90	5.17
14	1.4	2.6	105	3.88
15	4	0	0	10.73
16	3	1	18	8.42
17	0	4	0	543.57

Note: The above calculations are approximate and are based on dry unit weight of 95 pcf and moisture content of 4%

5.5 Data Collection

Site visits have been performed once in every two weeks or depending on the climatic conditions at the site. Rainfall data is collected from a rain gauge installed at the site. The rain gauge will collect readings once in every 20 minutes. Moisture and temperature data are collected from data loggers buried at each section. These loggers will store readings of moisture and temperature probes. A typical moisture and temperature data collected during May is presented in Figure 5.8.

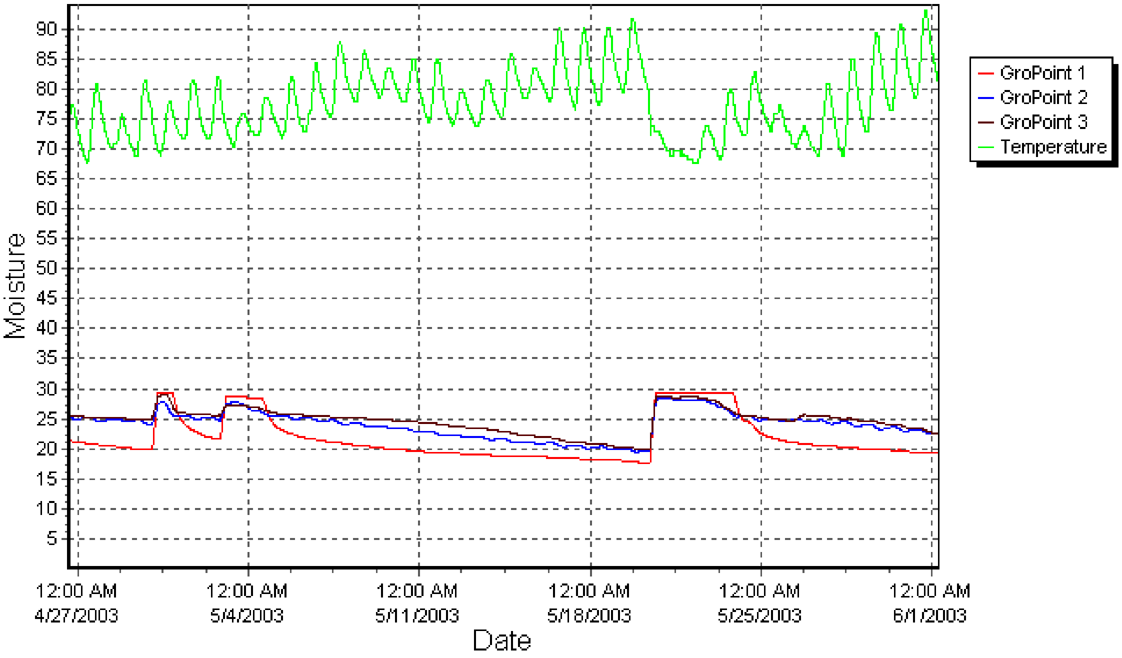


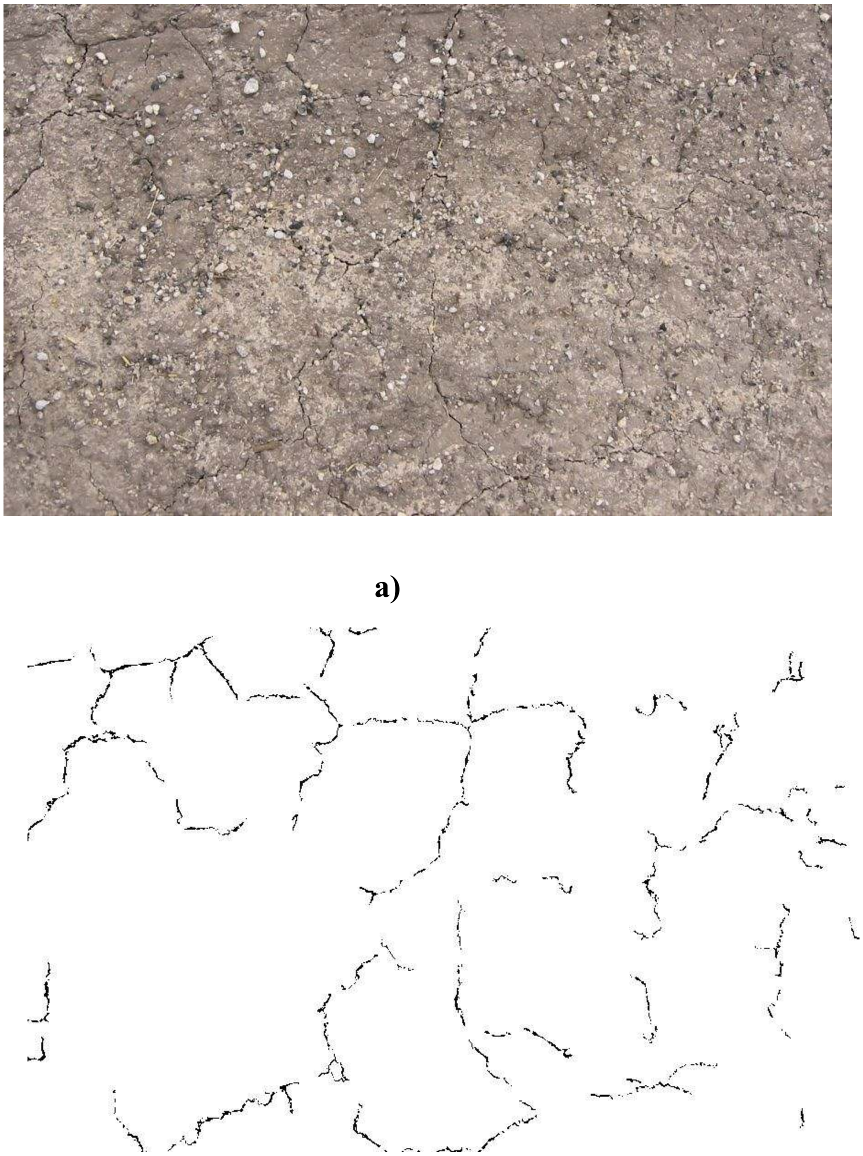
Figure 5.8 Moisture and Temperature Data from Control Section during the First 36 Days

Topographic surveys are also conducted during data collection, and this will be used to evaluate erosion conditions and grading changes in both longitudinal and transverse directions. A typical surveying data collected from 'Total Station' is presented in Table 5.4.

Table 5.4 Typical Surveying Data from Test Section 1

Date	Reference point 1	Reference point 2	Station 1				
			Spike 1	Spike 2	Spike 3	Spike 4	Spike 5
Apr 03	2.96	3.01	-9.65	-9.74	-9.75	-9.18	-10.42
Apr 15	2.99	3.04	-9.54	-9.69	-9.68	-9.12	-10.35
Apr 24	2.96	3	-9.59	-9.7	-9.73	-9.2	-10.39
Jun 01	2.89	2.92	-9.65	-9.82	-9.79	-9.23	-10.44
Jun 17	2.99	2.55	-9.63	-9.76	-9.77	-9.22	-10.51

Digital images of each test section were taken during each site visit. These images were analyzed to study the shrinkage cracks in surficial soils. A typical digital image is presented in Figure 5.9. The data collection of all test sections will be continued for a total of 18 months.



a)

b)

Figure 5.9 Digital Images (a) before (b) after the analysis

5.6 Summary

This chapter provides a complete description of various steps involved in the construction of test sections in field conditions. Sensor systems and other measurement methods attempted in the field are also described. This field-testing phase will be continued for 18 months, and these results will be statistically analyzed to evaluate the potentials of compost materials for better treatment of expansive shoulder subgrades with minimal desiccation cracking.

CHAPTER 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

6.1 Summary and Conclusions

The main objective of the present research was to investigate the effectiveness of using two types of composts as shoulder cover material in order to mitigate shoulder cracking. Two phases of investigations, laboratory studies (Phase I) and field monitoring studies (Phase II) were planned. This report summarizes the finding from the laboratory studies conducted in the first year of the research as well as construction details of the test plots prepared for field monitoring studies.

Four types of compost manufactured topsoils amended with Dairy Manure compost and Biosolids compost were investigated in the present experimental phase. Several tests including physical, engineering, and chemical tests were performed on these materials to understand the effectiveness of the compost materials in soils to enhance physical and engineering properties. Test results were also analyzed to assess and rank each amended soil in providing enhancements to soil properties. Ranking analysis was used in this analysis by establishing ranks to various soil properties. This analysis also provided compaction moisture content and dry unit weight conditions for constructing field test plots.

The following lists a few salient conclusions obtained from the laboratory studies performed in this research:

1. The mean diameter (D_{50}) of all soils varied between 0.06 and 0.55 mm with large sized average particles measured for pure Biosolids compost.
2. The Plasticity Index (PI) values of Dairy Manure compost amended soils were decreased when compared to the PI of the control soil. On the other hand, the PI values of Biosolids compost amended soils were increased when compared to the PI of the control soil. The decrease in the plasticity

index values in the DMC amended soils is attributed to the presence of coarse sized particles present in the Dairy Manure compost. The increase in the plasticity indices of Biosolids compost amended soils is attributed to the presence of hydrophilic-natured soil particles in the biosolids, which tend to absorb more moisture when available to them. Also, high PI values in BSC soils are attributed to high amounts of organic matter present in these soils. It should be noted that DSC soils contain relatively low amounts of organic matter when compared to BSC soils.

3. Based on Proctor compaction results, the DMC amended soils exhibited lower optimum moisture content and higher optimum dry unit weight properties when compared to those of the BSC amended soils.
4. Based on direct shear strength test results, the CMTs with the DMC exhibited high friction angles and the CMTs with the BSC exhibited high cohesion values. Based on swell test results, soils blended with both Dairy Manure compost and Biosolids composts exhibited high swelling, with BSC materials yielding higher swells than DMC materials. Again, this increase was attributed to the presence of hydrophilic characteristics of materials and high organic content.
5. Based on linear shrinkage tests, soils blended with DMC exhibited low shrinkage strains when compared to soils blended with BSC. It is interesting to note that the shrinkage strains of DMC amended soils are lower than those of the control soils. Low shrinkage in the DMC amended soils are attributed to relatively low amounts of moisture that these materials are capable of holding, low organic content presence, and moderate strength of these materials at the compaction moisture contents.
6. All the amended soils exhibited low permeability values ranging between 3.0×10^{-9} to 1.2×10^{-7} cm/sec. This indicates that all these materials have the

potential to serve as an encapsulation material surrounding the underlying subgrades.

7. A ranking system from literature on expansive soils was used to analyze the improvements in properties of control soils to those of amended soils. This analysis confirmed that the Dairy Manure compost has enhanced the control soil ranking from a poor (2.6) to good (3.6) ranking. On the other hand, BSC (at 20% dosage level) has enhanced the control soil ranking from 2.6 to 3.2. Based on the ranking analyses, all four CMTs (CMT 1, CMT 2, CMT 3 and CMT 4) were recommended for field testing at compaction moisture content equal to optimum moisture content.

6.2 Ongoing Studies

Continuing research on the compost-amended soils that have shown promising results in laboratory studies will further enhance the understanding of the effectiveness of compost materials in field conditions. Field studies on 17 test plots constructed with various variable conditions are currently being conducted. Extensive amounts of field monitoring and field testing including elevation surveys and digital image studies are planned, and these results will be statistically analyzed to evaluate the effectiveness of CMTs in the field conditions. These results will be documented in the final report.

REFERENCES

1. Alexander, R. and Tyler, R. (1992). "Using Compost Successfully," Lawn and Landscape Maintenance, November, pp. 23-34.
2. Alexander, M. (1961). "Introduction to Soil Microbiology," Wiley Publishing Co., New York, NY.
3. Benedict, A.H., Epstein, E., and Alpert, J. (1998). "Composting Municipal Sludge: A Technology Evaluation," Noyes Data Corporation, Park Ridge, NJ.
4. Black, R.J., Kidder, G., Graetz, D.A., Miller, G.L., and Dehgan, B. (1999). "Evaluation of Composted Materials To Be Utilised in Florida Roadside and , Median Plantings," WPI- 0510743, Final Report. Department of Environmental Horticulture, Soil and Water Science Department, University of Florida.
5. Black, R.J. and Miller, G.L. (1998). "Benefits of Using Compost and Mulch in Florida Roadside Plantings," Institute of Food and Agricultural Sciences, University of Florida.
6. Boyd, R.F. (1988). "General Microbiology," Mosby College Publishing, Times Mirror/Mosby College Publishing, St. Louis.
7. Bruce, A.M., Colin, F., and Newman, P.J. (1989). "Treatment of Sewage Sludge," Elsevier Science Publishers Ltd., England.
8. Cawthon, D.L. and Freeman, T.M. (date?) "Benefits of Using Compost Dairy Manure." Source:
www7.tamu-commerce.edu/agscience/res-dlc/reports/broch-use.doc
9. Chen, F.H. (1988). "Foundations on Expansive Soils," Developments in Geotechnical Engineering, Vol.12, Elsevier Publications, Netherlands.
10. Collins, J. (1991) "Road Waste Issues and Options," Oregon Department of Transportation, Salem, OR, Report No. FHWA-OR-RD-98-21. December 1998.

11. Collins, R.J. and Ciesielski, S.K. (1994). Synthesis of Highway Practice 199: “Recycling and Use of Waste Materials and By-Products in Highway Construction,” National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C.
12. Dawson, A.R. and Nunes, M.C.M. (1993). “Some British Experience of the Behavior of Furnace Bottom Ash and Slate Waste for Pavement Foundations,” Proceedings, Symposium on Recovery and Effective Reuse of Discarded Materials and By-Products for Construction of Highway Facilities. Denver, CO, October 19-22, 1993.
13. Degroot, D. (1996). “Workshop on Use of Compost and Recycled Content Products in Highway Construction,” Final Report, University of Massachusetts, Transportation Center, Amherst, MA, 83 pages.
14. Diaz, L.F., Savage, G.M., Eggerth, L.L., and Golueke, C.G. (1993). “Composting and Recycling Municipal Solid Waste,” Lewis Publishers, FL.
15. Example of a Pavement in Good Condition and a Pavement in Poor Condition. Source: www.roads.act.gov.au
16. Fang, H.Y. (1997). “Introduction to Environmental Geotechnology,” CRC Press LLC, New York, NY.
17. Finstein, M.S., Miller, F.C., and Strom, P.F. (1986). “Waste Treatment Composting as a Controlled System,” Weihem, Germany.
18. Ghezzi, M.N., Moore, J.T., Collins, J., Bretsch, K., and Hunt, L. (2001). “Road Waste Management: Field Trials,” FHWA-OR-RD-01-12., Final Report, pp. 116. Oregon Department of Transportation.
19. Girovich, M.J. (1996). “Biosolids Treatment and Management,’’ Marcel Dekker, Inc., NY.
20. Gray, K.R., Sherman, K., and Biddlestone, A.J. (1971a). “A Review of Composting: Part 1 – Process,” Biochemistry, 6(6):32-36.

21. Gray, K.R., Sherman, K., and Biddlestone, A.J. (1971b). "A Review of Composting: Part 2 – The Practical Process," Biochemistry, 6(10):22-28.

22. Grebus, M.E., Watson, M.E., and Hoitink, H.A.J. (1994). "Biological, Chemical and Physical Properties of Composted Yard Trimmings as Indicators of Maturity and Plant Disease Suppression," Compost Science and Utilization, Vol. 2, No. 1, pp. 57-71.

23. Haug, R.T. (1980). "Compost Engineering: Principles and Practice," Ann Arbor Science, MI.

24. Hausmann, M.R. (1990). "Engineering Principle of Ground Modification," McGraw Hill, New York, NY.

25. He, X., Logan, T.J., and Traina, S.J. (1995). "Physical and Chemical Characteristics of Selected U.S. Municipal Solid Waste Composts," Journal of Environment Quality, Vol. 23, No. 3, May-June, pp. 543-552.

26. Katha, B. (2002). "Shrinkage Strain Characteristics of Expansive Soils Using Digital Imaging Technology," Masters Thesis, The University of Texas at Arlington, Arlington, Texas.

27. Kirchoff, C. J. (2002). Composted Animal Manures and Biosolids: A Study to Assess the Chemical and Physical Properties of Compost and Compost Amended Soils for Use along Highway Rights-of-ways." MS Thesis, The University of Texas at Austin, Austin, Texas.

28. Kota, P.B.V.S., Hazlett, D., and Perrin, L. (1996). "Sulfate Bearing Soils: Problems with Calcium Based Stabilizers," TRR 1546, Transportation Research Board, Washington, D.C.

29. Lewis, L., Hagen, S., and Salisbury, S. (2001). "Soil Bioengineering for Upland Slope Stabilization," WA-RD 491.1., Research Report, pp. 96. USDA Forest Service.

30. Schmitt, M. and Rehm, G. (1998). "Fertilizing Cropland with Dairy Manure." Source : www.extension.unm.edu/distribution/cropsystems/DC5880.html

31. Mitchell, D. (1997). "Compost Utilization by Departments of Transportation in the United States," Department of Environmental Horticulture, Soil and Water Science Department, University of Florida.

32. Mitchell, D. (1997). "Trends in Utilization: State Highway Departments Find It Pays to Use Compost," Biocycle, August 1997.

33. Mitchell, J.K. (1993). "Fundamentals of Soil Behavior," John Wiley and Sons, Inc., New York, NY.

34. Nelson D.J. and Miller, J.D. (1992). "Expansive Soils: Problems and Practice in Foundation and Pavement Engineering," John Wiley & Sons, New York, NY.

35. Oweis, I.S. and Khera, R.P. (1998). "Geotechnology of Waste Management," PWS Publishing Company, Boston, MA.

36. Perrin, L. (1992). "Expansion of Lime Treated Clays Containing Sulfates," Proceedings, 7th International Conference on Expansive Soils, Dallas, TX, Vol. 1, pp. 409-414.

37. Polprasert, C. (1989). "Organic Waste Recycling," Anchor Press Ltd., Great Britain.

38. Puppala A.J. and Punthutaecha, K. (2000). "Effects of Polymeric Fibers on Shrinkage Cracking Behavior of Expansive Plastic Clays," Seventh Annual International Conference on Composites Engineering, ICCE/7, Denver, CO, USA, pp. 713-714.

39. Qasim, S.R. (1999). "Wastewater Treatment Plants," Technomic Publishing Co., Inc., PA.

40. Richard, T.L. (1992a). "Municipal Solid Waste Composting: Physical and Biological Processing. Biomass and Bioenergy," Tarrytown, NY: Paragon Press. 3(3-4):163-180.

41. Rynk, R. – Editor (1992). "On-farm Composting Handbook," Ithaca, NY: Cooperative Extension, Northeast Regional Agricultural Engineering Service.

42. Schroeder, R.L. (1994). "The Use of Recycled Materials in Highway Construction," Public Roads, Autumn, 1994.

43. Shelburne, W.M. and DeGroot, D.J. (1998). "The Use of Waste and Recycled Materials in Highway Construction," Journal of Civil Engineering Practice, Vol. 13, Issue 1, pp. 5-16.

44. Storey, B.B., McFalls, J.A., and Godfrey, S.H. (1996). "The Use of Compost Shredded Brush on Right-of-Way for Erosion Control: Final Report," FHWA/TX-97/1352-2F, pp. 240.

45. Strom, P.F. (1985). "Effect of Temperature on Bacterial Species Diversity in Thermophilic Solid Waste Composting," Applied Environmental Microbiology. 50(4):899-905. Tarrytown, NY: Pergamon Press. 3(3-4):163-180.

46. Tester, C.F. and Parr, J.F. (1983). "Decomposition of Sewage Sludge in Soil: IV. Effect of Indigenous Salinity," Journal of Environmental Quality, 12: 123-126.

47. Tchobanoglous, G. and Bourton, F.L. (1991). Metcalf and Eddy, "Wastewater Engineering," 3rd Edition, McGraw-Hill, Inc., New York, NY.

48. Tchobanoglous, G., Theisen, H., and Vigil, S. (1993). "Integrated Solid Waste Management: Engineering Principles and Management," McGraw Hill, Inc., NY

49. United States Environmental Protection Agency. (1997). "Innovative Uses of Compost: Bioremediation and Pollution Prevention," EPA530-F-97-042, October.

50. United States Environmental Protection Agency. (1997). "Innovative Uses of Compost: Erosion Control, Turf Remediation, and Landscaping," EPA530-F-97-043, October.

51. Wiley, J.S. (1956). Proceedings of the 11th Industrial Waste Conference. Purdue University, Series 91, p. 334.

52. Viyanant, C. (2000). “Laboratory Evaluation of Sulfate Heaving Mechanisms Using Artificial Kaolinite Soil,” Masters Thesis, The University of Texas at Arlington, Arlington, TX.

53. Wattanasanticharoen, E. (2000) “Investigations to Evaluate the Performance of Four Selected Stabilization Methods on Soft Subgrade Soils of Southeast Arlington,” MS Thesis, The University of Texas at Arlington, Arlington, Texas, 2000, 190 pages.

54. Texas Environmental Almanac, 1995 - Web site address: http://www.texascenter.org/almanac/TXENVALMANAC.HTML

55. http://www.reeusda.gov/success/impact02/htm02/waste.htm

APPENDIX A

DIRECT SHEAR TEST FIGURES

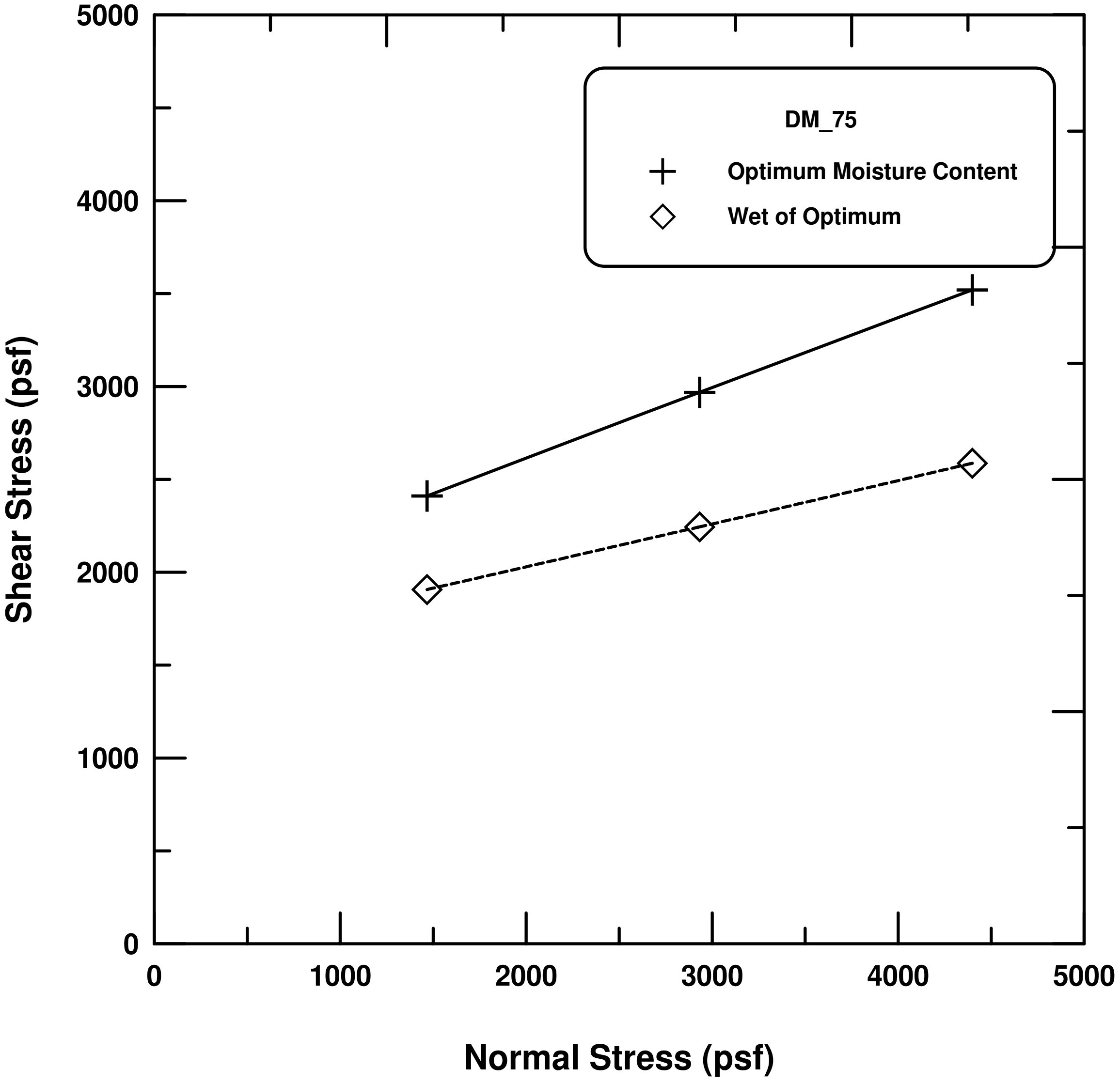


Figure A.1 Direct Shear Test Results of DM_75

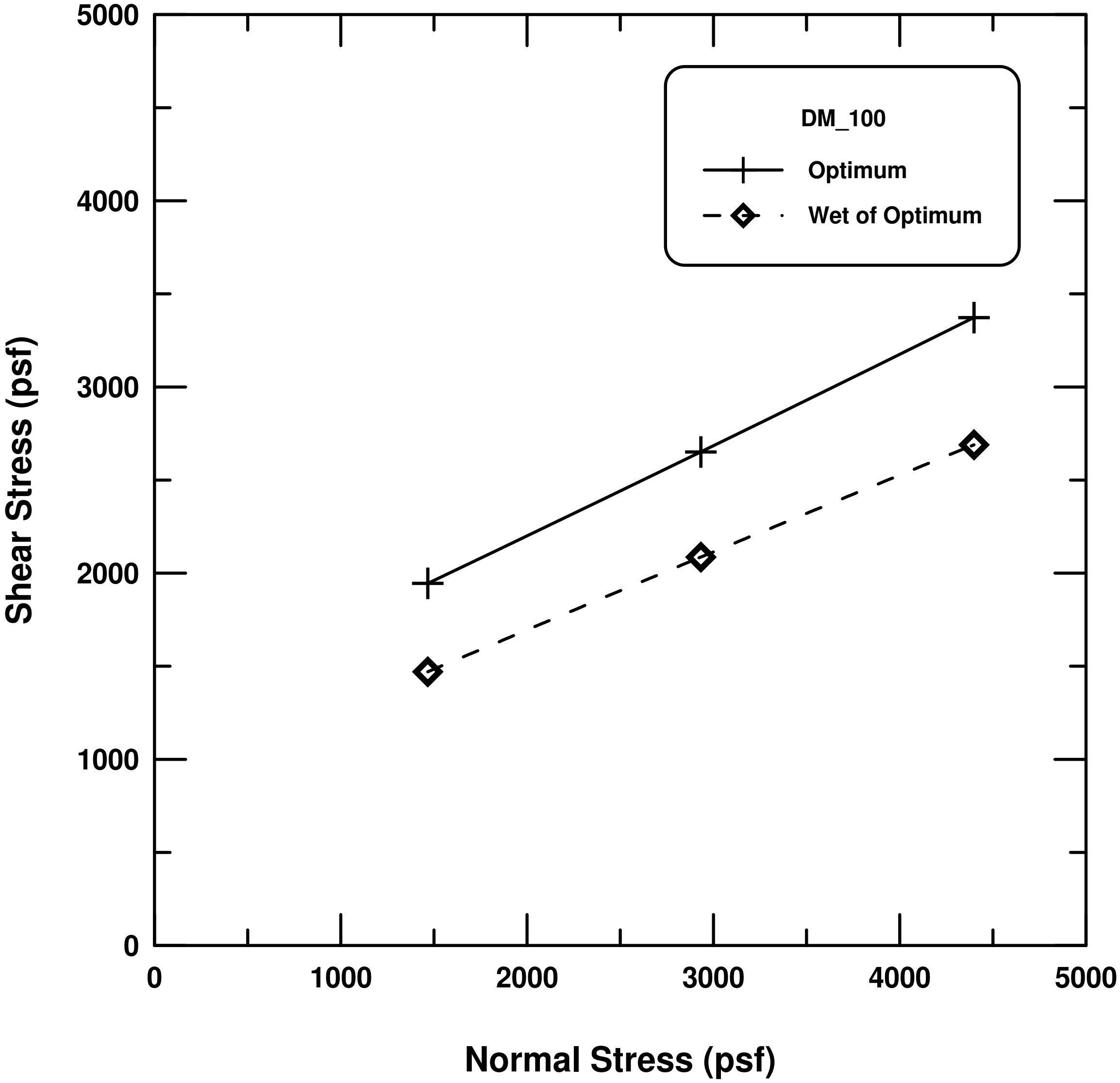


Figure A.2 Direct Shear Test Results of DM_100

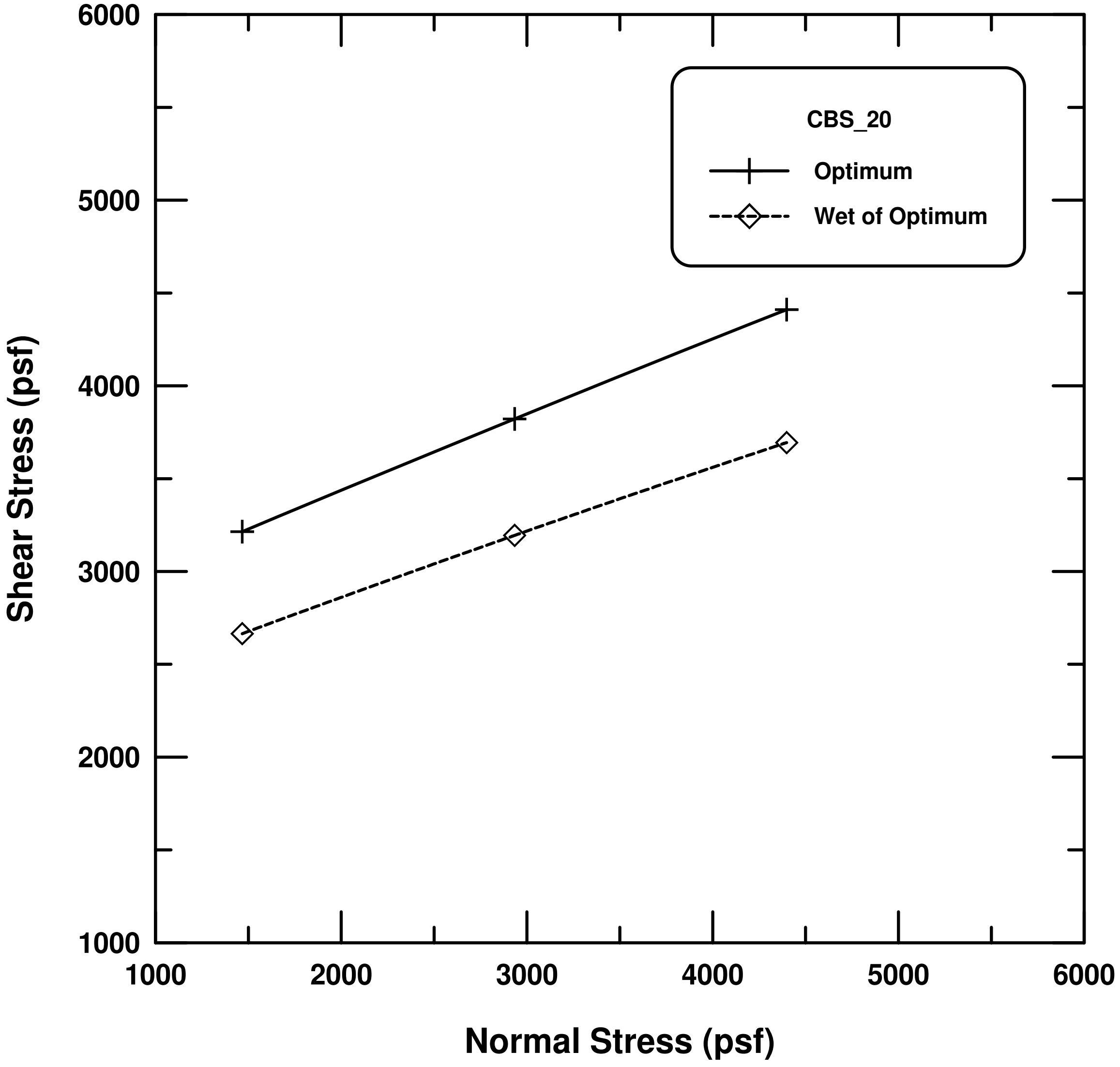


Figure A.3 Direct Shear Test Results of CBS_20

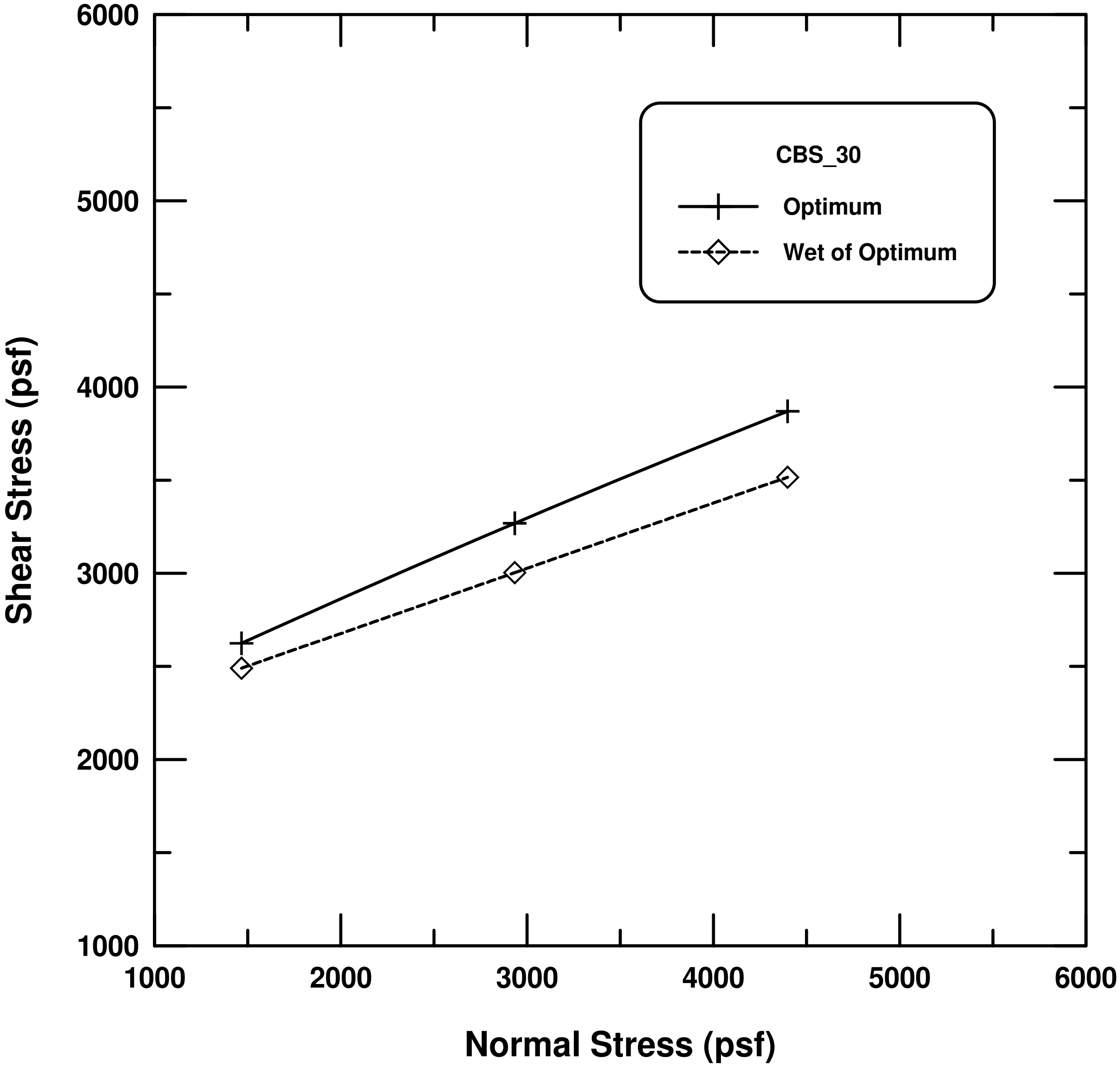


Figure A.4 Direct Shear Test Results of CBS_30

APPENDIX B

ONE-DIMENSIONAL FREE SWELL TEST FIGURES AND TEST SAMPLES

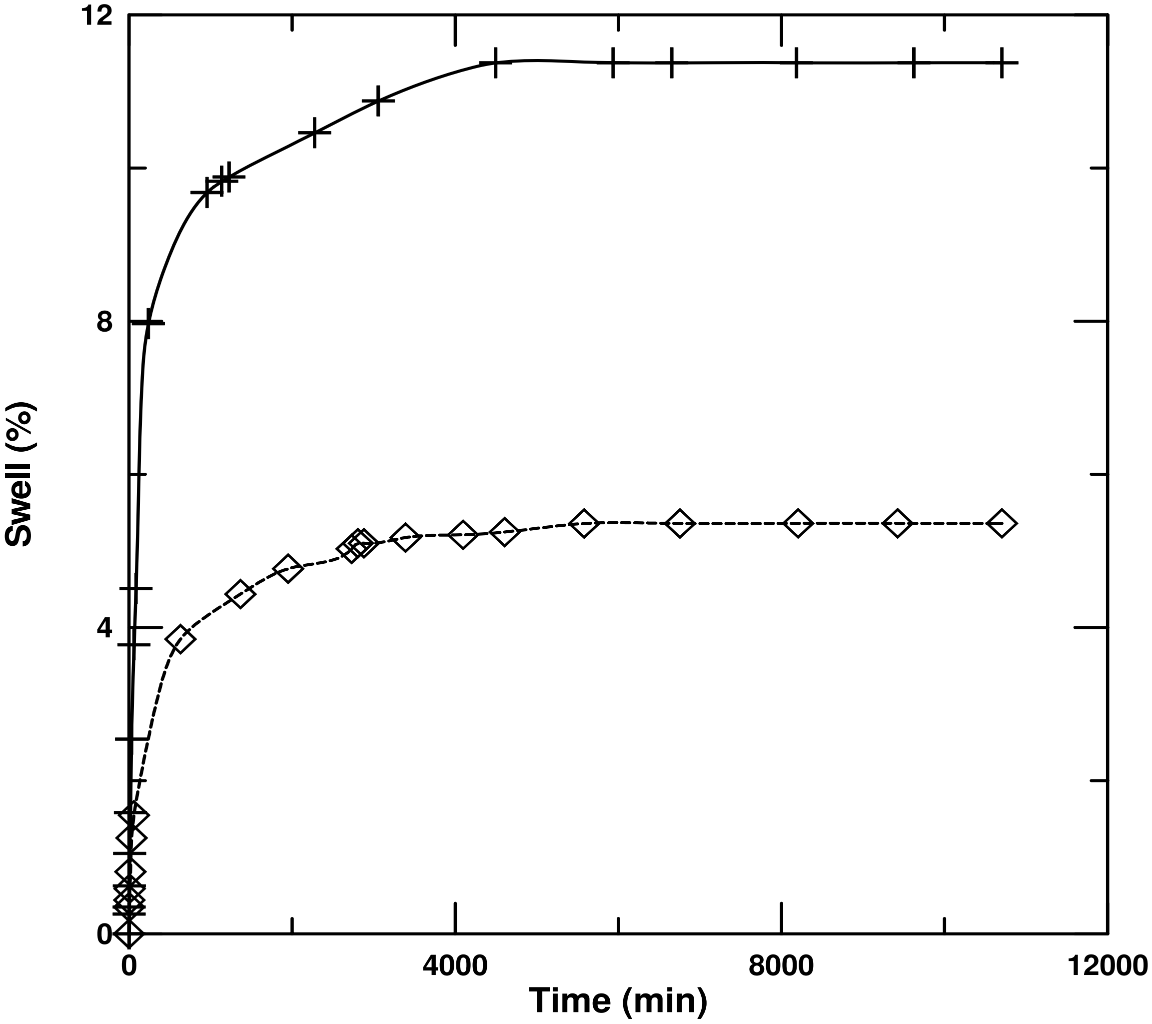


Figure B.1 Free Vertical Swell Strain of CS

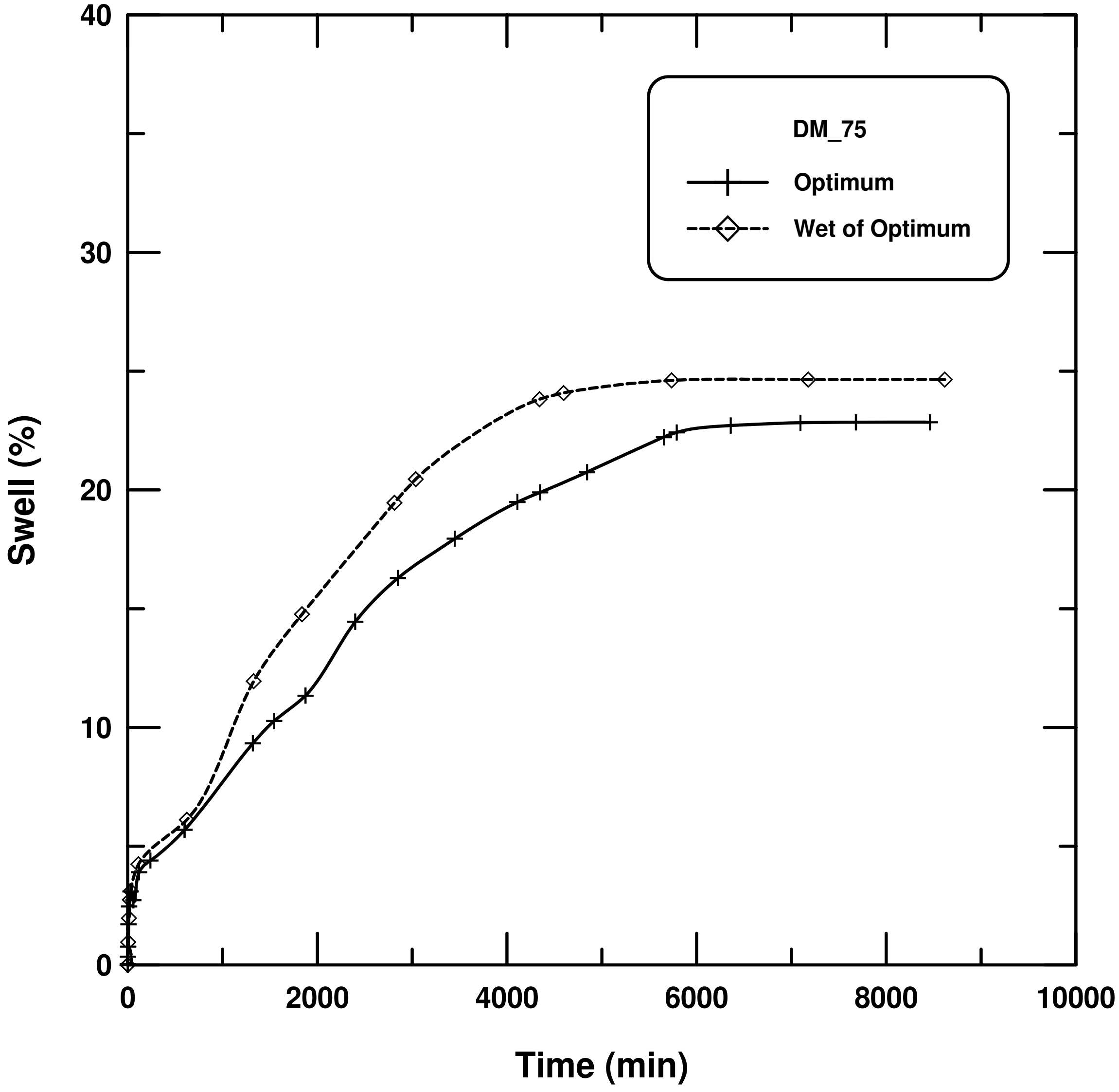


Figure B.2 Free Vertical Swell Strain of DM_75

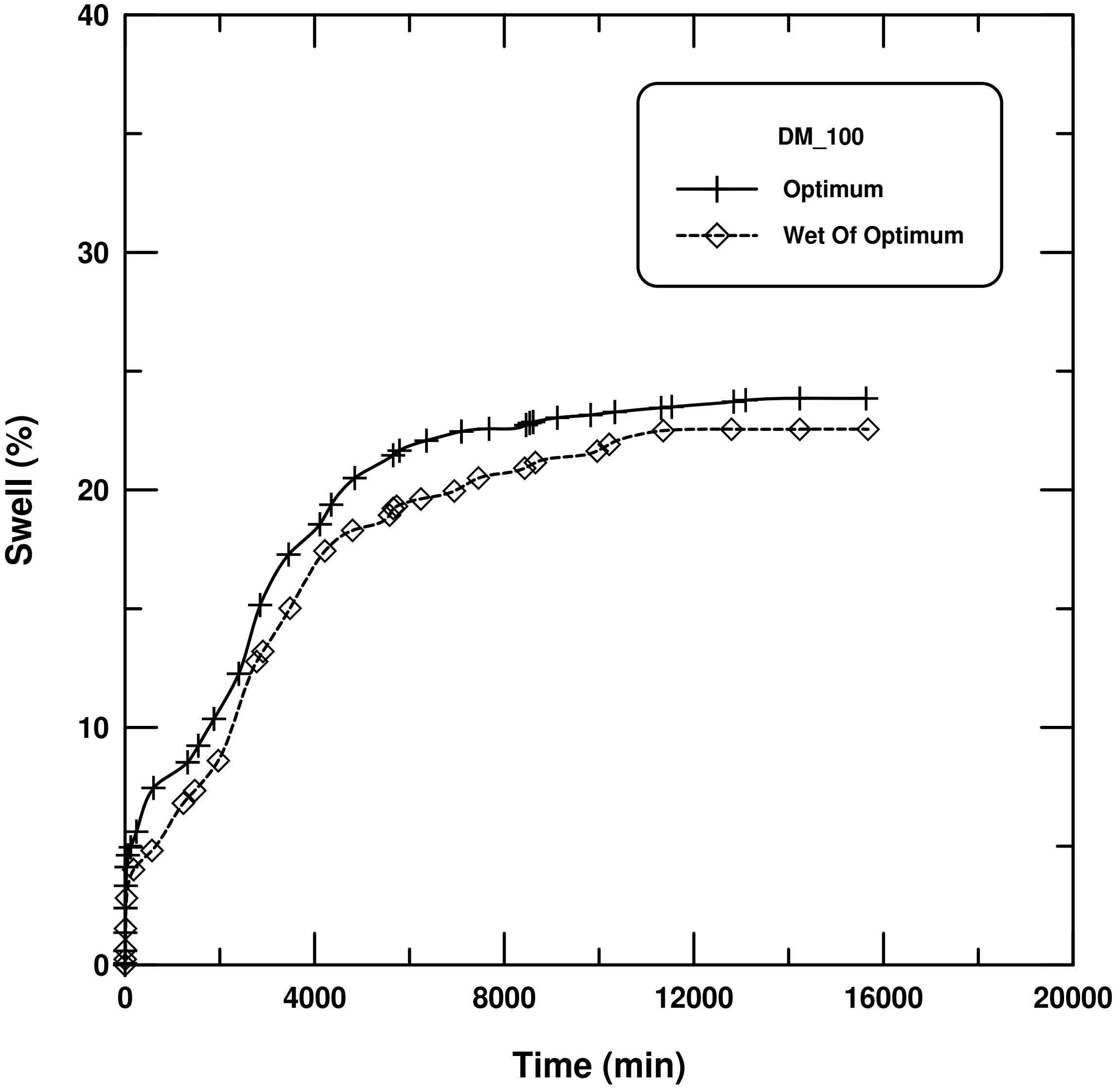


Figure B.3 Free Vertical Swell Strain of DM_100

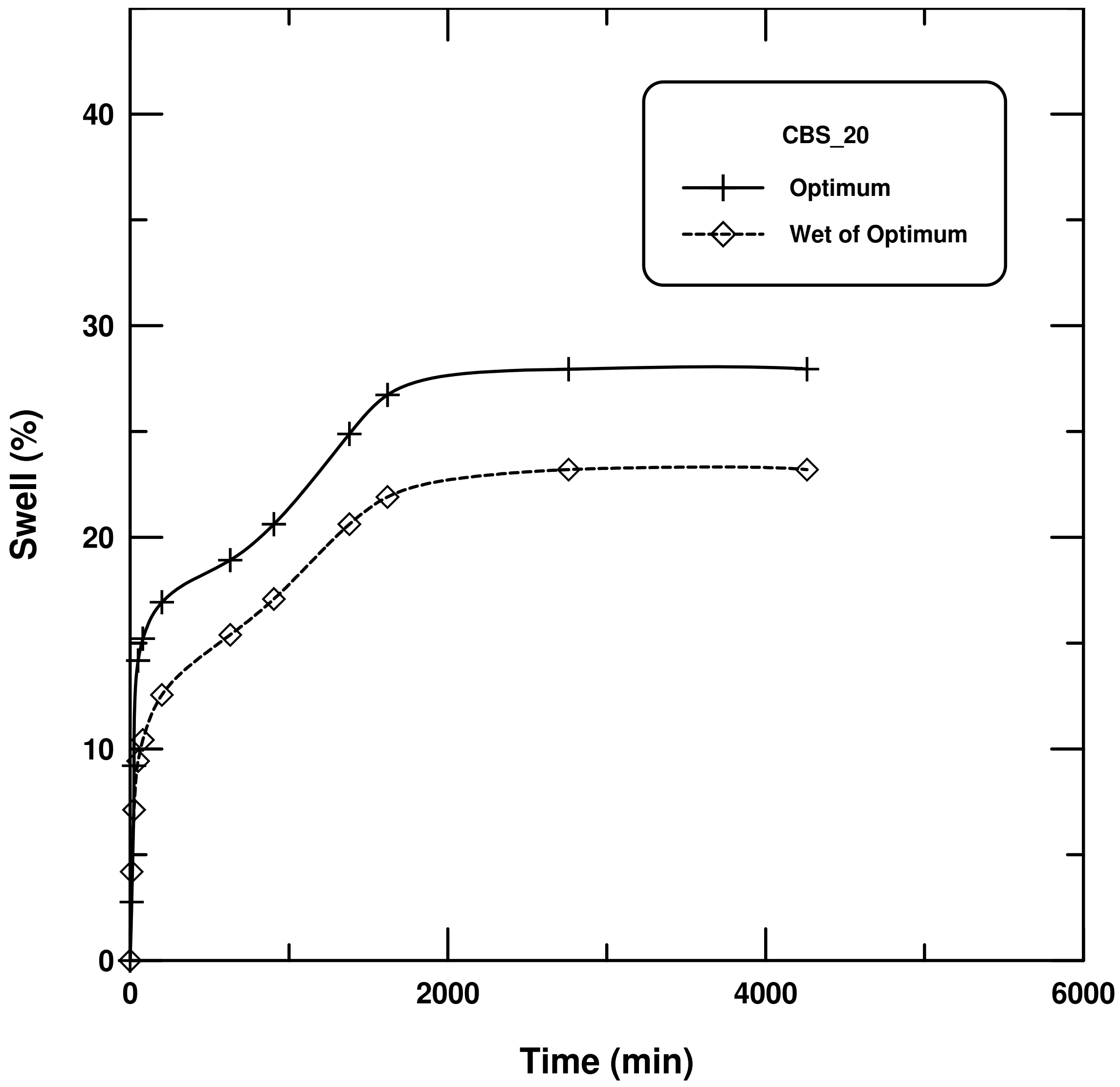


Figure B.4 Free Vertical Swell Strain of CBS_20

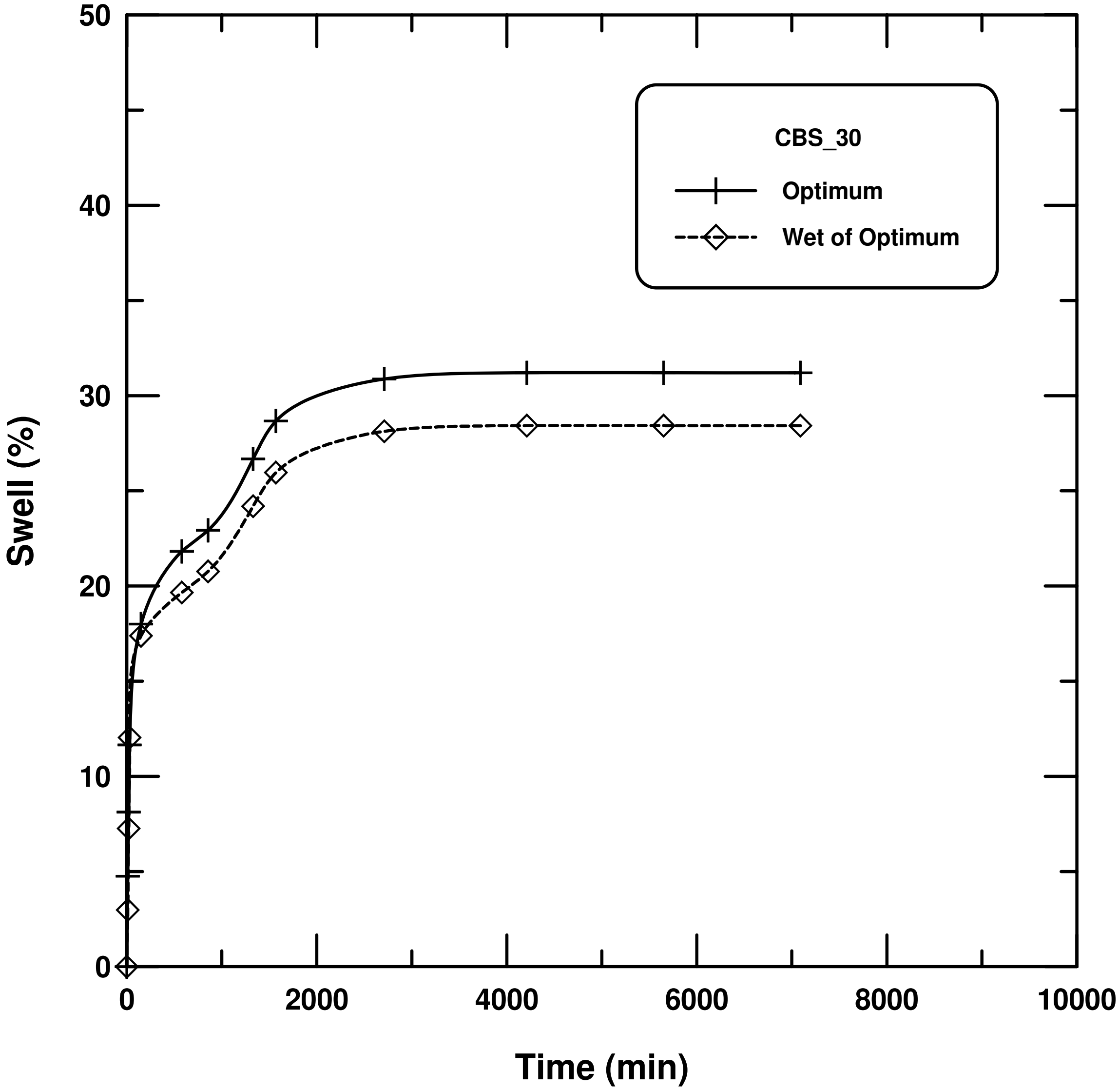


Figure B.5 Free Vertical Swell Strain of CBS_30

APPENDIX C

BAR LINEAR SHRINKAGE TEST SAMPLES

Figure C.1 Linear Shrinkage Mold of Control Soil at Optimum Moisture Content

Figure C.2 Linear Shrinkage Mold of Control Soil at Liquid Limit

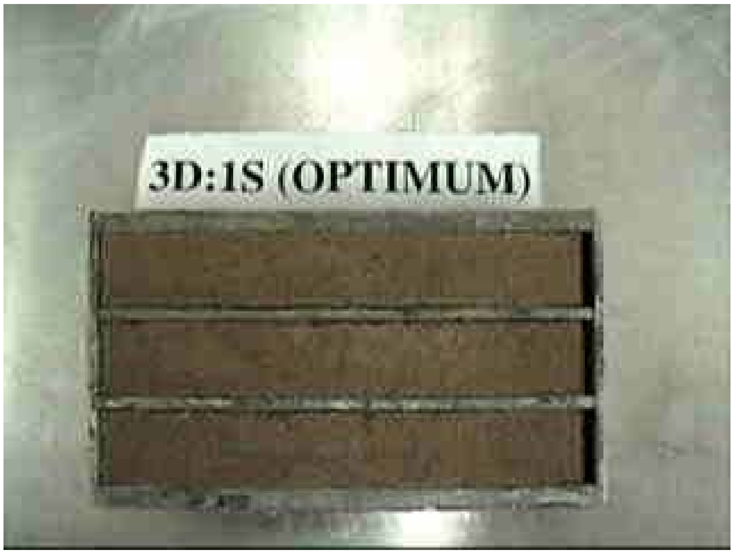


Figure C.3 Linear Shrinkage of CMT 1 (DM_75) at

Optimum Moisture Content

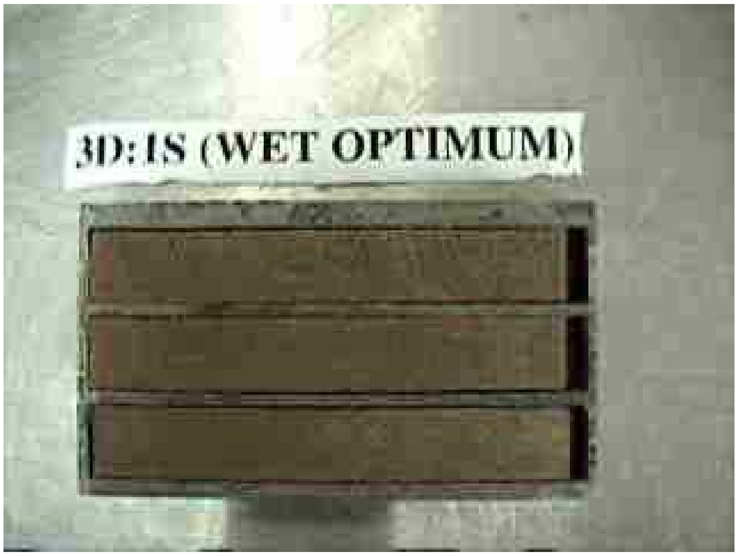


Figure C.4 Linear Shrinkage Mold of CMT 1 (DM_75) at

Wet of Optimum Moisture Content

Figure C.5 Linear Shrinkage Mold of CMT 1 (DM_75) at Liquid Limit

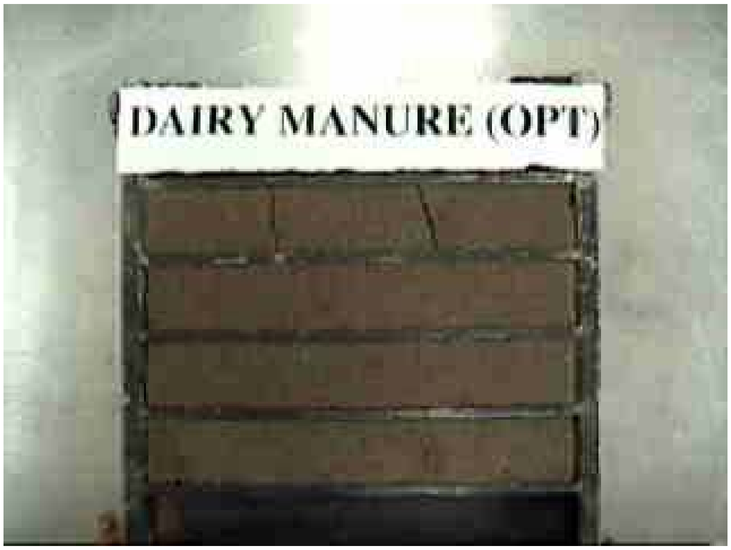


Figure C.6 Linear Shrinkage Mold of CMT 2 (DM_100) at Optimum Moisture Content

Figure C.7 Linear Shrinkage Mold of CMT 2 (DM_100) at Wet of optimum Moisture Content Level

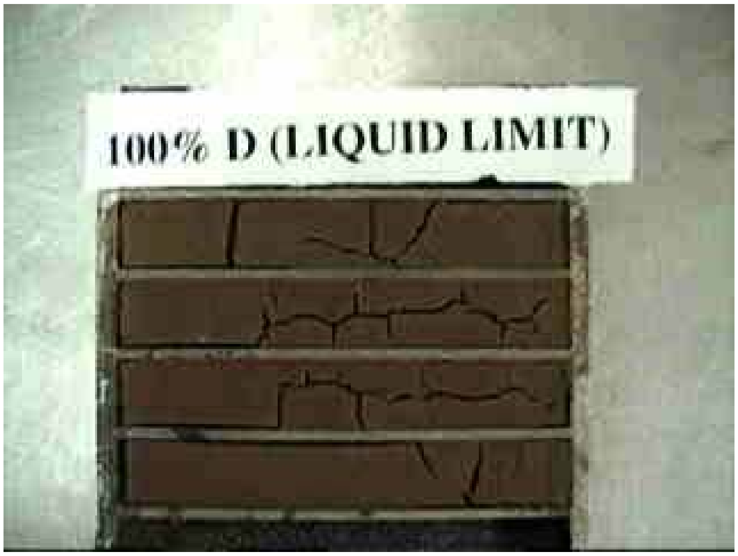


Figure C.8 Linear Shrinkage Mold of CMT 2 (DM_100) at Liquid Limit