TECHNICAL REPORT STANDARD PAGE

1. Report No. FHWA/LA.03/373	2. Government Accession No.	**3. Recipient's Catalog No.**
4. Title and Subtitle Evaluation of the Effect of Synthetic Fibers and Nonwoven Geotextile Reinforcement on the Stability of Heavy Clay Embankments	5. Report Date April 2003 6. Performing Organization Code	
7. Author(s) Zhongjie "Doc" Zhang, Khalid Farrag, and Mark Morvant	8. Performing Organization Report No. 373	
9. Performing Organization Name and Address Louisiana Transportation Research Center 4101 Gourrier Avenue Baton Rouge, LA 70808	10. Work Unit No. 11. Contract or Grant No. LTRC No. 95-1GT S.P. No. 736-99-0760	
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered Final Report, 01/01/1996 – 12/31/2001 14. Sponsoring Agency Code	
15. Supplementary Notes Conducted in Cooperation with the U.S. Department of Transportation, Federal Highway Administration		

16. Abstract

This study evaluates two methods for repairing slope surface failures of clayey soil embankments. One method involves reinforcing the cohesive soils with randomly oriented synthetic fibers; the other method incorporates non-woven geotextiles. The performance of soils reinforced using these two methods was studied in the laboratory and in the field. In the laboratory, a parametric study was conducted to compare the performances of soil and fiber-soil in terms of their shear strengths. Both a large direct shear and a standard triaxial apparatus were used to experimentally evaluate the shear strengths of the reinforced materials. The interface friction between the geotextile fabric and the soil was also evaluated using the large direct shear apparatus. The specimens of soil, fiber-soil, and fabric-soil materials were tested at various moisture contents and confining stresses. Various fiber contents were also used to evaluate their effect on shear strength. The laboratory results indicated that, in the short term, the fiber reinforcement will compensate the loss of soil shear strength caused by the increase in soil moisture content. The best results were achieved with a fiber content of 0.1% by weight.

Field evaluation included experimental repairs of failed slopes and monitoring their performance. Site investigations indicated that slope surface failures occurred when surface water trapped in fissures or cracks saturated the adjacent soils. To investigate the long-term stability, seven experimental slope sections with fiber and geotextile reinforcements were constructed at various compaction efforts and moisture contents. The performance of these slopes was monitored and the results indicated that repairing failed slopes with the non-woven geotextile was a good option to battle repetitive surface failures in slopes of high plastic soils. Accordingly, a simple procedure of repairing the slope with the low-cost material was recommended for use by maintenance crews in daily rehabilitation activities.

17. Key Words Non woven Geotextile, Synthetic Fibers, Geosynthetic Reinforcement, Slope Stability, roadway embankment.		18. Distribution Statement Unrestricted. This document is available through the National Technical Information Service, Springfield, VA 21161.	
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages 78	22. Price

EVALUATION OF THE EFFECT OF SYNTHETIC FIBERS AND NONWOVEN GEOTEXTILE REINFORCEMENT ON THE STABILITY OF HEAVY CLAY EMBANKMENTS

by

Zhongjie "Doc" Zhang, Ph.D., P.E.
Khalid Farrag, Ph. D., P.E.

and

Mark Morvant, P.E.

Louisiana Transportation Research Center
4101 Gourrier Ave.
Baton Rouge, LA 70808

LTRC PROJECT NO. 95-1GT
STATE PROJECT NO. 736-99-0760

Conducted for
LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT
LOUISIANA TRANSPORTATION RESEARCH CENTER

in cooperation with

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

April 2003

ABSTRACT

This study evaluates two methods for repairing slope surface failures of clayey soil embankments. One method involves reinforcing the cohesive soils with randomly oriented synthetic fibers; the other method incorporates non-woven geotextiles. The performance of soils reinforced using these two methods was studied in the laboratory and in the field. In the laboratory, a parametric study was conducted to compare the performances of soil and fiber-soil in terms of their shear strengths. Both a large direct shear and a standard triaxial apparatus were used to experimentally evaluate the shear strengths of the reinforced materials. The interface friction between the geotextile fabric and the soil was also evaluated using the large direct shear apparatus. The specimens of soil, fiber-soil, and fabric-soil materials were tested at various moisture contents and confining stresses. Various fiber contents were also used to evaluate their effect on shear strength. The laboratory results indicated that, in the short term, the fiber reinforcement will compensate the loss of soil shear strength caused by the increase in soil moisture content. The best results were achieved with a fiber content of 0.1% by weight.

Field evaluation included experimental repairs of failed slopes and monitoring their performance. Site investigations indicated that slope surface failures occurred when surface water trapped in fissures or cracks saturated the adjacent soils. To investigate the long-term stability, seven experimental slope sections with fiber and geotextile reinforcements were constructed at various compaction efforts and moisture contents. The performance of these slopes was monitored and the results indicated that repairing failed slopes with the non-woven geotextile was a good option to battle repetitive surface failures in slopes of high plastic soils. Accordingly, a simple procedure of repairing the slope with the low-cost material was recommended for use by maintenance crews in daily rehabilitation activities.

ACKNOWLEDGEMENTS

This study was funded by the Louisiana Department of Transportation and Development (LADOTD)/Louisiana Transportation Research Center (LTRC) under State Project Number 736-99-0760 and LTRC Research Project Number 95-1GT.

The authors acknowledge the valuable input from Kevin Gaspard and Hadi Shirazi when they worked in the geotechnical unit of LTRC. Appreciation is extended to our laboratory staff - Ken Johnston, Melba Bounds, Paul Brady, and Bill Tierney - for their assistance in this study.

Special thanks to Tommy Hale, District 58 Maintenance Engineer, and his staff for the cooperation provided in this study.

Dr. Barry Christopher provided design consultation assistance through the FHWA Demonstration No. 82 Project.

Acknowledgement is also given to Amoco Fabrics and Fiber Company for donating the geotextile that was used in the repaired embankment test sections.

IMPLEMENTATION STATEMENT

Historically, Louisiana allowed natural heavy clay (CH) to be used to construct embankments. Although this has been changed by current LADOTD specifications, this past practice has caused a major slope stability problem that exists today in many areas within the state. Highway maintenance engineers, therefore, have been seeking a cost-effective way to solve the problem of repetitive slope surface failures. Using non-woven geotextile to repair failed slopes of high plastic soils is a good option to solve the problem. The initial cost of the geotextile will be compensated for by the savings from the prevention of future failures. The construction process recommended by this study is similar to routine rehabilitation procedures; maintenance units in districts should be able to handle the majority of repairs. Therefore, the maintenance units in each district of the state should consider using this technique in their daily rehabilitation activities.

TABLE OF CONTENTS

Abstract iii

Acknowledgment v

Implementation Statement vii

Table of Contents ix

List of Tables xi

List of Figures xiii

Introduction 1

Objectives 3

Scope 5

Methodology 7
- Field Test Sites 7
  - Test Site 7
  - Soil Properties 7
  - Material Properties 9
- Laboratory Evaluation 9
  - Fiber-Soil Testing Program 10
  - Geotextile Testing Program 14
- Field Evaluation 14
  - Fiber-Reinforced Test Sections 14
  - Geotextile Test Sections 18

Discussion of Results 23
- Laboratory Evaluation 23
  - Fiber-Soil Behavior 23
  - Geotextile-Soil Behavior 29
- Field Evaluation 30
- Slope Failure Mechanism 30

Performance of Fiber-Reinforced Sections....................32
Performance of Non-Woven Fabric Sections....................36
Conclusions....................39
Recommendations....................41
References....................43
Bibliography....................45
Appendix A Fiber Reinforced Field Measurements....................47
Appendix B Fabric Field Measurements....................53
Appendix C Fiber Reinforced Inclinometer Readings....................57
Appendix D Fabric Inclinometer Readings....................72

LIST OF TABLES

Table 1. Fiber Reinforced Test Section Soil Properties..8
Table 2. Direct Shear Testing Program on Soil/Fiber-Soil Mix 13
Table 3. Consolidated-Undrained Triaxial Tests on Soil/Fiber-Soil 14
Table 4. List of the Fiber-Repaired Test Sections 18
Table 5. Summary of Soil Parameters Used in the Analysis 19
Table 6. Direct Shear Testing Results with Soil/Soil Mix Properties................................24
Table 7. Consolidated-Undrained Triaxial Testing Results...28
Table 8. Summary of Measured Deformations in the Test Sections 35

Table B-1. Moisture-Density Measurements in site1 55
Table B-2. Moisture-Density Measurements in site2 56

LIST OF FIGURES

Figure 1. Location of the Repair Sections on Highway LA-15 8

Figure 2. Moisture-Density Relationships of the Soils and Fiber-Soil Mix 10

Figure 3. View of the Large Direct Shear Box 12

Figure 4. Typical Section for Fiber-Reinforced Slope Repair..15

Figure 5. Fiber-Soil Mixing Process in the Field..17

Figure 6. Distribution of Fiber into Soil 17

Figure 7. View of Field Compaction 20

Figure 8. Placement of Fabric During Construction...21

Figure 9. Cross-Section of the Reinforced Slope at Location 1 21

Figure 10. Shear Strength from Direct Shear...25

Figure 11. Shear Strength Increment due to Fiber Reinforcement 25

Figure 12. Increase of Shear Strength due to Fiber Content
(at Moisture Content 18%)..26

Figure 13. Increase of Shear Strength due to Fiber Content
(at Moisture Content 28%)..26

Figure 14. Change of Strength due to Increase of Moisture Content 27

Figure 15. Change of Strength per unit increment of Moisture Content 27

Figure 16. Results of Unconsolidated-Undrained Triaxial Test on Fiber Soils.................28

Figure 17. Direct Shear Test Results in the Fabric-Soil Specimens..................................29

Figure 18. View of an Embankment Slope Failure in I-20..31

Figure 19. View of Failure in a Slope Section in LA 15 31

Figure 20. View of Slope Failure in Fiber Section, Station 27+05 32

Figure 21. Reading of Top Inclinometer in Section 224 [Soil-Fiber Mix]........................36

Figure 22. View of Slope Failure n Un-Reinforced Section Adjacent to
Fabric Site 2 33

Figure 23. Readings of Middle Inclinometer in Fabric Section 1......................................37

Figure A-1 Typical Cross-Section in Section 132 49

Figure A-2. Field Measurements of Moisture and Density in Section 132 49

Figure A-3. Typical Cross-Section of the Slope in Section 213......................................50

Figure A-4. Field Measurements of Moisture and Density in Section 213 50

Figure A-5. Typical Cross-Section of the Slope in Section 224......................................51
Figure A-6. Field Measurements of Moisture and Density in Section 224 51
Figure A-7. Typical Cross-Section of the Slope in Section 244......................................52
Figure A-8. Field Measurements of Moisture and Density in Section 244 52
Figure C-1: Top-Inclinometer Readings in Section 132 [Soil-Fiber Mix] 58
Figure C-2: Middle-Inclinometer Readings in Section 132 [Soil-Fiber Mix]...................59
Figure C-3: Time-Deformations of the Middle Inclinometer in Section 132....................59
Figure C-4: Top-Inclinometer Readings in Section 213 [Soil-Fiber Mix] 60
Figure C-5: Middle-Inclinometer Readings in Section 213 [Soil-Fiber Mix]...................61
Figure C-6: Time-Deformations of the Top Inclinometer in Section 213.........................62
Figure C-7: Time-Deformations of the Middle Inclinometer in Section 213....................62
Figure C-8: Top-Inclinometer Readings in Section 224 [Soil-Fiber Mix] 63
Figure C-9: Middle-Inclinometer Readings in Section 224 [Soil-Fiber Mix]...................64
Figure C-10: Time-Deformations of the Inclinometers in Section 224.............................65
Figure C-11: Top-Inclinometer Readings in Section 242 [Soil Only]...............................66
Figure C-12: Middle-Inclinometer Readings in Section 242 [Soil Only]..........................67
Figure C-13: Time-Deformations of the Inclinometers in Section 242.............................68
Figure C-14: Top-Inclinometer Readings in Section 244 [Soil Only]...............................69
Figure C-15: Middle-Inclinometer Readings in Section 244 [Soil Only]..........................70
Figure C-16: Time-Deformations of the Inclinometers in Section 244.............................71
Figure D-1: Top-Inclinometer Readings in Fabric Section 1 73
Figure D-2: Middle-Inclinometer Readings in Fabric Section 1 74
Figure D-3: Time-Deformations of the Inclinometers in Fabric Section 1 75
Figure D-4: Top-Inclinometer Readings in Fabric Section 2 76
Figure D-5: Middle-Inclinometer Readings in Fabric Section 2 77
Figure D-6: Time-Deformations of the Inclinometers in Fabric Section 2 78

INTRODUCTION

The seasonal variation of soil moisture content is a common phenomenon in poorly-drained embankment slopes of cohesive soils. An increase in moisture content, usually observed after rainfalls, causes a decrease in soil shear strength and results in a reduction of slope safety [*1,2*]. The long-term effect of these wet-and-dry cycles on slope stability depends on the type of soils used to build the embankments. In the past, natural heavy clay was used to construct embankments in Louisiana. Although this has been changed by current Louisiana Department of Transportation and Development (LADOTD) specifications, this past practice has been a factor in the slope stability problems that exists in some areas within the state. Highway maintenance crews spend many hours fighting this problem annually.

One good example of embankment slope constructed with natural heavy clay (CH) is the section of Highway LA 15 next to the Mississippi River levee in Concordia Parish. This roadway experiences a high frequency of slope failures each year. When this occurs, a maintenance crew is assigned to handle the problem and in most instances, the failed slopes are reshaped back to the original grade with minimal moisture control or compaction effort. When the failure threatens the road, additional materials will be hauled in to bring the slope back to grade. This is a common rehabilitation technique used by maintenance crews. Unfortunately, these slopes will usually fail again due to the material type, improper fix, and the typically wet Louisiana weather conditions.

This type of slope stability problem is quite common to areas with conditions similar to Louisiana's geography and weather. Many investigators have spent substantial time and research efforts to understand and discover solutions to the problem. Some work has been done on the effect of randomly oriented fibers on the shear strength of cohesive soils. Andersland and Khattak observed that the bond between organic fibers and clay particles led to an increase in the soil shear strength [3]. Chen also found that fibers improve the compressive strength and ductility of kaolinite clay, with the greatest increase observed at low water contents [4]. At the same fiber content level, an increase in fiber length reduced the contribution of fibers to the compressive strength. A more recent study by Puppala and

Musenda showed that fiber reinforcements enhanced the unconfined compressive strength and reduced the swelling potential of expansive clays [5]. Although the available studies indicate a positive contribution of fibers on the shear strength of clayey soils, they are very limited both in quantity and in quality as compared with the studies on sandy soils. The application of fiber treatment to improve the stability of clayey soil slopes required more extensive study of the behavior of fiber-soil with the variations in soil properties anticipated in the field. A lab-study program was therefore conducted to investigate the effect of fibers on the shear strength of cohesive soils at various moisture contents, soil densities, and confining pressures.

In this study, the Louisiana Transportation Research Center (LTRC) in conjunction with Louisiana Department of Transportation and Development (LA DOTD) evaluated two possible methods for the rehabilitation of embankment slope failures. The first method is to reinforce the cohesive soils with randomly oriented synthetic fibers. The second method is to reinforce the slope with non-woven geotextile fabric. When the geotextile is used, the tension forces mobilized in the fabric would enhance the overall stability of slopes. Moreover, the relatively high in-plane permeability of the fabric may reduce the development of pore water pressure in clayey soils and allow horizontal drainage through the fabric. The Federal Highway Administration (FHWA) "Geosynthetic Design and Construction Guidelines" manual also indicates the potential for using geotextiles as reinforcement and drainage elements to improve slope stability. Therefore, both methods have a potential to be used in the DOTD's daily maintenance repair activities. The evaluation of these methods for embankment slope stabilization is to evaluate how the geosynthetic reinforcement of clayey soils is affected by the variation of soil moisture content, confining stress, and construction method.

OBJECTIVES

The objectives of this research are:

i) Evaluation of the short-term effects:

- Investigate the effect of soil density, moisture content, fiber content, and confining pressure on shear strength of clayey soil and fiber-soil mixes;
- Investigate the effect of soil moisture content and confining pressure on the interface friction between non-woven fabric and clayey soil encountered in the field.

ii) Evaluation of the long-term effects:

- Understand the mechanism of shallow surface failures in slopes of heavy clay;
- Evaluate the effect of construction procedures on the performance of fiber-soil mixes and non-woven fabric-reinforced embankment slopes;
- Evaluate the effect of wet-and-dry cycles on the performance of clayey soil slopes reinforced by geosynthetic fibers and non-woven fabrics.

SCOPE

This study evaluates two methods for repairing slope surface failures of clayey soil embankments. One is reinforcing the cohesive soils of slopes with randomly oriented synthetic fibers; the other is using a non-woven fabric. Both their short- and long-term performances were investigated through a parametric study in the laboratory, in-situ slope failure investigations, computer software simulation, and a construction and monitoring program of seven experimental slopes. These experimental slopes were constructed with various moisture contents at compaction. Some of these slopes were constructed with fiber or fabric reinforcement, while others were not.

METHODOLOGY

Field Test Sites

Test Site

Five slope test sections were constructed in this study to evaluate the potential of using randomly oriented fibers to reinforce slopes of clayey soils and to monitor their long-term stability. These test sections were at various locations within a five-mile stretch along the roadway of LA 15 between Shaw and Slocum in Concordia Parish as shown in Figure 1. The roadway is constructed along the Mississippi River levee. The slopes are 12 to 18 ft high with horizontal-to-vertical slope ratios of 4:1 to 6:1.

Additionally, two slope failures were repaired with non-woven fabric to explore its potential as a reinforcement and drainage medium. The two test sites are located north of Deer Park on LA 15 as shown in Figure 1. They were designated as Fabric Location 1 at station 2+00 and Fabric Location 2 at station 10+00. The slope in Location 1 has a horizontal-to-vertical ratio of 3:1 with an average height of 12 ft and the slope in Location 2 is 4:1 with an average height of 17 ft.

Soil Properties

The soils in the slope test sections have relatively similar gradation and index properties. Table 1 summarizes the average soil properties in the various fiber reinforced test sections. The soil in the fabric-reinforced sections consisted of fat clay with high plasticity indexes ranging from 40 at Location 1 to 70 at Location 2.

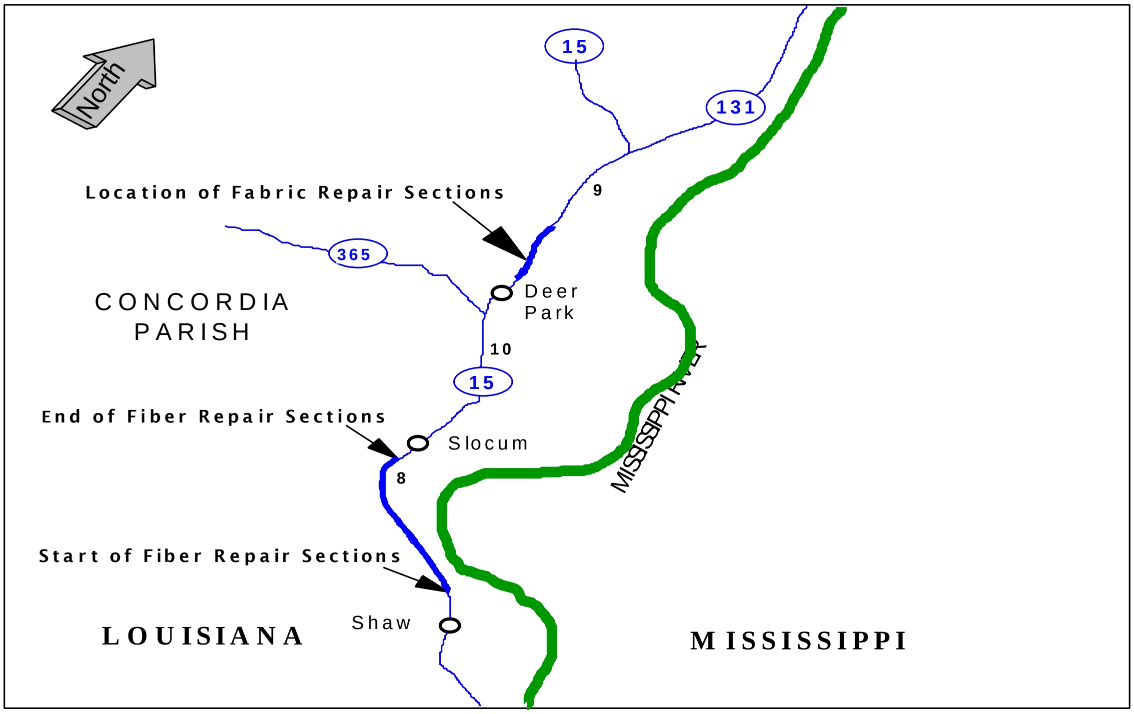


Figure 1

Location of the repair sections on highway LA-15

Table 1

Fiber-reinforced test section soil properties

Section	Station	% Passing				% silt	% clay	MC	LL	PI
		#4	#10	#40	#200					
132	130+55	91.7	89.1	82.8	77.2	27.2	50.0	24.8	68	47
213	214+43	99.3	99.1	98.5	97.3	23.0	74.2	48.3	94	69
242	242+58	96.6	95.8	93.8	88.9	24.1	64.7	46.8	83	58
244	244+92	99.8	99.8	99.7	96.3	18.6	77.6	56	100	78

MC= soil moisture content of the field samples (%)
LL = Liquid Limit of soils
PI = Plastic Index of soils

Material Properties

The fiber material used in this study was manufactured by Synthetic Industries. It is a discrete fibrillated polypropylene fiber of one-inch length. The fibrillated fibers open up when properly mixed with soil to form dispersed three-dimensional strands that reinforce the soil.

The non-woven geotextile used is an 8-oz/yd^3 needle-punched polypropylene non-woven fabric manufactured by Amoco Fabrics and Fibers Co. The average ultimate strength obtained from wide-width test specified by ASTM 4595 on this fabric is 1016 lb/ft.

Laboratory Evaluation

The laboratory evaluation was a parametric investigation that involved material property characterization, standard triaxial testing, and large direct-shear testing. The purpose of the laboratory program was to investigate the short-term behavior of compacted clayey soils with and without geosynthetic reinforcement under different moisture and confining stress environments. The soil samples used in the lab-study program were obtained from the slope failure sites at LA 15. The soil used in the fiber-reinforced tests, designated as lab soil type 1, was taken from station 132 with properties as shown in Table 1. The soil used for the fabric testing, designated as lab soil type 2, was obtained from Location 1 and is highly plastic clay with a PI of 40.

Figure 2 shows the typical moisture-density relationships of the soils used in the lab-testing program. Soil type 1 has optimum moisture content of 22% and a maximum dry density about 95 pcf. Soil type 2 has optimum moisture content of 25% and a maximum dry density about 92pcf. Compaction tests showed that the optimum moisture content is 17% and maximum dry density is 100 lb/ft^3 when fibers are added to the soil type 1.

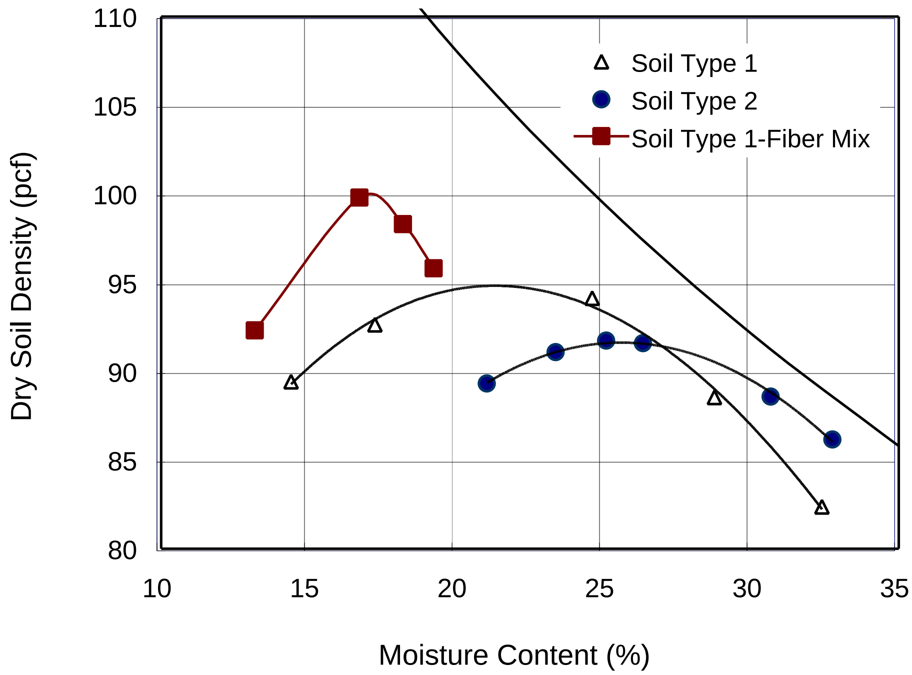


Figure 2

Moisture-density relationships of the soils and fiber-soil mix

Fiber-Soil Testing Program

Fiber-Soil Sample Preparation: The fibers used in the testing are one-inch long discrete polypropylene-strands of "GeoFibers" manufactured by Synthetic Industries. Specimens were prepared by using soil type 1 mixed with various fiber contents of 0%, 0.1 %, 0.2% and 0.4% by weight. During the specimen preparation process, the fibrillated fibers opened into a randomly oriented net that interlocked with the clayey soil. The proper mix of fiber with the clayey soil enhanced soil properties with an increase in dry density and a decrease in the optimum moisture content as shown in Figure 2. The results in the figure were achieved by using fiber-soil mixed at fiber content of 0.2% by soil weight.

The preparation of the fiber-soil specimens for the laboratory program required a special mixing procedure to ensure that the specimens were mixed evenly and that they represented a structure similar to the ones in the field. A summary of the laboratory mixing procedure is as follows:

- Process a bulk soil sample through No. 4 sieve. Thoroughly mix the soil and split it into appropriate batches equivalent to the required soil volume for a test in the direct shear box.
- Weigh out enough volume of soil to fill a mixing bowl to the bottom tip of a wire whip.
- Weigh out enough water to bring the soil to the desired moisture content.
- Add about one-fourth of the soil to the mixing bowl and uniformly spread one-fourth of the fiber over the soil layer.
- Continue the soil-fiber mix sequence for the rest of the soil and fiber.
- Start the mixer and mix the soil initially in its dry state. Add water slowly and gradually in intervals during the mix. Adding water too soon may result in fiber clumps or an uneven mix.
- Remove the fiber that clumps inside the wire whip or on the side of the mixing bowl and evenly re-distribute it on the mix. Continue mixing until the fibrillated fiber opens into a randomly oriented net that interlocks with the clayey soil.

<u>Strength Testing</u>: Two types of tests were performed on fiber-soil specimens. The first type is the direct shear test conducted by using a large direct shear box as shown in Figure 3. This test apparatus has an interface shear area of 12 inches by 12 inches and a specimen height of 4 inches. The shear load and the confining pressures were applied using a displacement-controlled hydraulic system with a constant shear rate about 0.01 inch/min.

The direct shear test specimens were all compacted at moisture content of 18%. The specimens with 28% moisture content were obtained by adding water to the compacted specimens so that a 10% increase in moisture was reached after the initial compaction. Specimens with fiber contents of 0%, 0.1%, 0.2%, and 0.4% were tested at various confining pressures. Direct shear tests were also performed on specimens mixed in the field. These field specimens were compacted at moisture very close to the optimum moisture content and had a fiber content of 0.2% by weight. Table 2 shows the direct shear tests performed on the fiber-soil mixes.

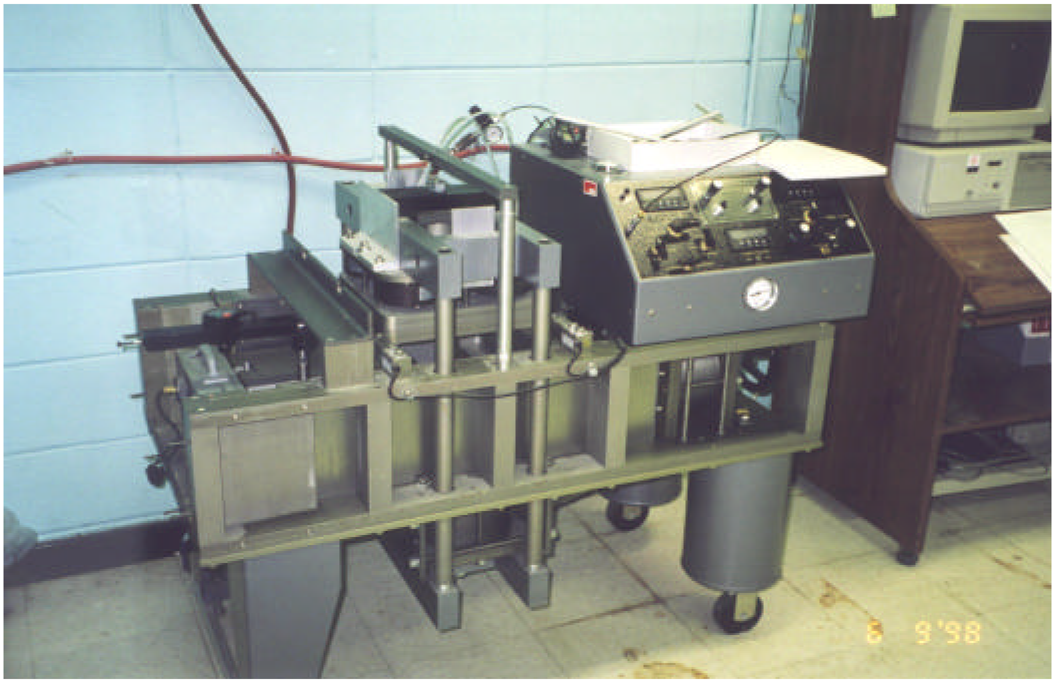


Figure 3
View of the large direct shear box

The second type of test is the consolidated undrained (CU) triaxial test. Table 3 shows a list of the triaxial tests conducted on the fiber-soil samples. The specimens used in the test were compacted at the moisture content of 18.0% in the lab to a soil density of 95 pcf. The test was conducted at various consolidation pressures with fiber content of 0.0%, 0.1%, and 0.2% by weight, respectively.

Table 2
Direct shear testing program on soil and fiber-soil mix

Soil mix-type	Fiber content (%)	Soil unit wt., γ (ton/ft^3)	Confining pressure, σ (psi)	Moisture content (%)
Field mix	0.2	95	3 4.75	18.8
		90	5 6.6 10	18.8
Lab mix	0 (Soil only)	95	3.85 5.75 9.6	18 18 18
			3.8 5.75 9.55	28.8 28.8 28.8
	0.1	95	3.96 5.95 9.6	18.5 18.5 18.5
			3.9 5.8 9.6	28 28 28
	0.2	95	3.85 5.78 5.75 10	18 18 18 18
			4 6 10	28 28 28
	0.4	95	3.85 5.75 9.6	18.6 18.8 18.8
			3.85 5.76 9.56	28.8 28.8 28.8

Table 3

Consolidated-undrained triaxial tests on soil/fiber-soil

Fiber content (%)	Soil unit wt., γ (ton/ft^3)	Consolidating pressure (psi)	Water content (%)
0	95	10 15	18.8
0.1	95	5 10	18.0
0.2	95	5 10 15	18.8

Geotextile-Soil Testing Program

The interface friction between heavy clay soil and non-woven fabric was studied in the lab by direct shear test under various moisture-content and confining-pressure conditions. The test was conducted in the large direct shear box at the moisture content of 18%, 28%, and the soaked condition (38%).

Field Evaluation

Fiber Reinforced Test Sections

A typical cross-section of the fiber reinforced slope repair test sections is as shown in figure 4.

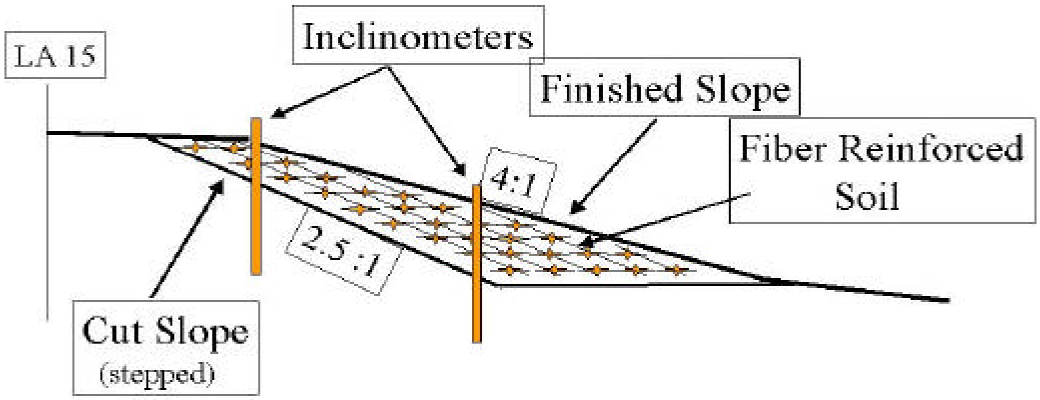


Figure 4

Typical section of the fiber-reinforced slope repair test sections

Construction of Test Sections: The fiber-reinforced slopes were constructed with a general contractor as part of a roadway rehabilitation project. Three failed slopes, namely test sections 132, 213 and 224, were repaired using fiber-soil mix with a fiber ratio of 0.2% by dry soil weight. The mix was calculated and installed in the field based on soil volume. The excavated soils from the failed sections were spread over working areas at a maximum lift thickness of 12 inches. The bags of fiber were manually spread over the embankment lifts and fiber-soil mixing was achieved using a rotary pulverizer mixer. Figure 5 shows the fiber-soil mixing process with the stabilizer in the field. Figure 6 shows the dispersion of the fibers after the field mixing process. The fiber-soil mix was then compacted in layers parallel to the roadbed. The field compaction control was based on the soil-only compaction curve, not the fiber-soil compaction curve. In an attempt to mimic common maintenance practices, the test sections were constructed with various construction procedures and specifications in order to evaluate the effect of embankment construction controls on the long-term stability of the slopes.

Test section 132 was constructed according to the Louisiana standard specifications of placement of embankment material. The compaction in this section was based on optimum moisture content of 22% and maximum soil dry density of 95 lb/ft^3.

Test section 213 was constructed at moisture contents as high as 8% wet of the optimum and at a low compaction effort. In order to achieve low compaction, the layers were compacted with tracked equipment for about six passes. Field measurements showed that the fiber-soil mix in this section was compacted at an average of 4% wet of optimum the optimum moisture and at an average soil dry density of 85 lb/ft^3.

Test section 224 was to be constructed at the optimum moisture content with a low compaction effort. The soil in this section was compacted using the same compaction effort as in section 213, producing the same field measured average dry density of 85 lb/ft^3. However, the average moisture content was about 8% dry of the optimum moisture of 22%.

Test Sections 242 and 244 are the two control sections that were reconstructed using excavated soils without fiber reinforcements or modifications. Section 242 was constructed with a low compaction effort at high moisture content. Field measurements showed that the average moisture content in this section was 35%, about 12% higher than the optimum moisture, with the average soil dry density of 86 lb/ft^3. Section 244 was constructed according to the Louisiana standard specifications of placement of embankment material. The compaction control was based on the optimum moisture content of 30% and a soil dry density of 85 lb/ft^3.

Table 4 summarizes the five slope test sections and their construction control methods. Their typical cross-sections and field measurements of moisture and density are shown in Appendix A.

Figure 5

Fiber-soil mixing process in the field

Figure 6

Distribution of fiber into soil

Table 4
List of the fiber-repaired test sections

Section	Station from	Station To	Repair method	Construction control	Length (ft)	Volume (yd^3)
132	129+65	135+47	Fiber Reinforcement	Standard Specifications	582	4196
213	211+80	214+90	Fiber Reinforcement	High Moisture – Minor Compaction	310	1975
224	223+00	231+00	Fiber Reinforcement	Optimum Moisture-Minor Compaction	599	4792
242	242+24	243+00	Control Section	High Moisture-Minor Compaction	76	1319
244	243+00	245+50	Control Section	Standard Specifications	250	2861

Performance Monitoring**:** Vertical inclinometers were installed in each of the five slope test sections to monitor their long-term deformation. One was placed at the top of the slope near the highway shoulder while the other was placed at the mid height of the slope. The data from the inclinometers enabled the determination of the horizontal movements along the depth of the slopes and the estimation of the locations of possible slip failure surfaces.

Geotextile Test Sections

Design of Test Sections: The stability analysis of the slope embankment was conducted using a Bishop circular failure surface with two effective stress analysis approaches. The first approach assumed c = 0 and iterated the analysis by lowering the true φ' value until a factor of safety of less than one was achieved to simulate the failed slope section. The reinforcement was then added until an acceptable factor of safety of 1.3 was achieved. The second analysis modeled the soil with c' = 100 psf and φ' = 24°. These values were based on lab testing of drained strength parameters. The analysis assumed that long-term drainage is provided by the geotextile. The variation of pore water pressure was iterated until a safety factor of less than one was achieved. The geotextile-reinforced section was then designed, using the same soil parameters, for the acceptable safety factor. Because of the relative high drain ability of the non-woven geotextile, pore pressure parameter was reduced to zero in the reinforced zone. The geotextile allowable strength used in both analysis was 200 lb/ft. This value was based on the appropriate reduction factors for long-term creep, installation damage, and durability. Table 5 shows a summary of the design parameters.

Table 5

Summary of soil parameters used in the analysis

Section	Analysis	Zone	Height (ft)	Slope	φ (°)	c (psf)	Pore pressure	No. of fabric layers	Layer thick. (in.)	Safety factor
1	A	Soil only	12	3:1	16	0	0	0		0.958
		Reinforced			16	0	0	13	10	1.28
2	A	Soil only	17	4:1	13	0	0	0		0.96
		Reinforced			13	0	0	13	12	1.14
1	B	Soil only	12	3:1	24	100	0.35	0		0.91
		Reinforced			24	100	0	13	10	1.32
2	B	Soil only	17	4:1	24	100	0.45	0		0.97
		Reinforced			24	100	0	13	12	1.36

Construction: The Maintenance unit at District 58 of LA DOTD repaired the failed slopes in the test sections. The repair process in both locations was similar except that the soil at location 2 was constructed at much higher moisture content (average 35%) than at location 1 (average 22%). The soil density averaged 90 pcf at location 1 compared to an average of 81 pcf at location 2. The layer thickness between fabric reinforcement layers was also larger. The repair process consisted of excavating the soil along the failed slopes to a depth below the failure plane. The back slope was benched approximately three to five ft to preserve the stability of the backfill under the roadway during construction. The embankment soil was then spread and allowed to dry before being placed in a lift with an average thickness of 10 inches in location 1 and 12 inches in location 2. The lifts were placed on a slight grade away from the roadway to allow gravity drainage through the fabric. Soil was compacted using a loaded dump truck as shown in Figure 7. The fabric was placed on the top of each lift in one continuous sheet and was extended about two to four inches outside the slope facing. Figures 8 and 9 show a view of the fabric placement during construction. The field measurements of moisture and density are shown in Appendix B.

Performance Monitoring: Similar to the fiber-soil sections, two vertical inclinometers were installed at each of the fabric sections with one within the top third of the slope and the other at the mid-height of the slope.

Figure 7 Field compaction with loaded dump truck

Figure 8

Placement of fabric during construction

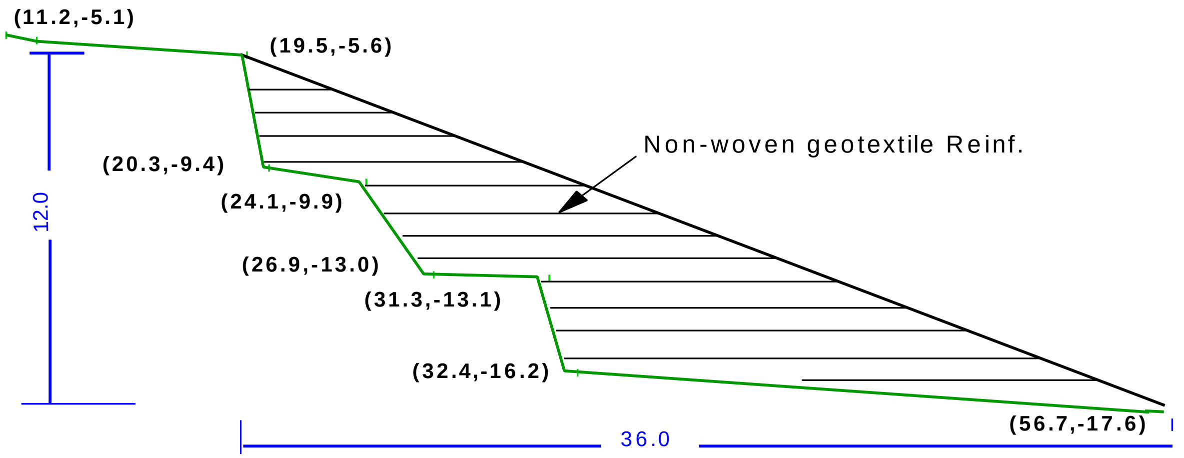


Figure 9

Cross-section of the reinforced slope at location 1

DISCUSSION OF RESULTS

Laboratory Evaluation

Fiber-Soil Behavior

The testing parameters and results of the direct-shear tests on the fiber-soil mixes are shown in table 6. The results at moisture contents of 18 % and 28.8 % are shown in figures 10 and 11, respectively. Two major conclusions can be drawn from the results. These conclusions are:

1. Fiber reinforcement increases the shear strength of heavy clay soils. The figures show that the biggest benefit of fiber reinforcement was achieved with a fiber content of 0.1% by weight. The increase in shear strength due to fiber content is illustrated in figures 12 and 13. The figures show the percentage change of soil shear strength for various fiber-soil mixes at moisture contents of 18 % and 28.8 %, respectively.
2. The increase in moisture content in clayey soils reduces the shear strength of soils and fiber-soil mixes. The percentage reduction of shear strength due to the increase of moisture content is shown in figure 14. The quantification of the decrease of shear strength is further illustrated in figure 15. The figure shows that for every unit increment of moisture content, the shear strength of soil is decreased by at least 3 %. This relationship can be used to estimate the short-term impact on shear strength due to a specific variation of soil moisture content from its optimum value.

The results of consolidated-undrained triaxial tests on various fiber-soil mixes are shown in figure 16 using the average confining stress (p) and maximum shear stress (q) parameters. Here, $p = (\sigma_1 + \sigma_3)/2$ and $q = (\sigma_1 - \sigma_3)/2$. The best-fit straight lines of these curves yield Kf enclosure lines characterized by slope ψ and cohesion intercept a.

The shear strength parameters can then be determined from the following:

$$\sin(\varphi') = \tan(\psi')$$

$$c' = a / \cos(\varphi')$$

Where φ' is the angle of soil friction and c' is soil cohesion. These calculated parameters are shown in Table 7.

Table 6

Direct shear test results on fiber-soil Mixes

Soil mix-type	Fiber content (%)	Soil unit wt., γ (ton/ft^3)	Confining pressure, σ (psi)	Water content (%)	Max. shear stress (kips/ft^2)
Field mix	0.2	95	3 4.75	18.8	0.89 1.311
		90	5 6.6 10	18.8	0.61 0.88 1.12
Lab mix	0 (Soil only)	95	3.85 5.75 9.6	18 18 18	0.75 0.91 1.1
			3.8 5.75 9.55	28.8 28.8 28.8	0.21 0.45 0.66
	0.1	95	3.96 5.95 9.6	18.5 18.5 18.5	1.11 1.5 2.16
			3.9 5.8 9.6	28 28 28	0.73 0.93 1.2
	0.2	95	3.85 5.78 5.75 10	18 18 18 18	0.92 1.0 1.1 1.38
			4 6 10	28 28 28	0.52 0.66 0.81
	0.4	95	3.85 5.75 9.6	18.6 18.8 18.8	0.95 1.13 1.7
			3.85 5.76 9.56	28.8 28.8 28.8	0.42 0.6 0.81

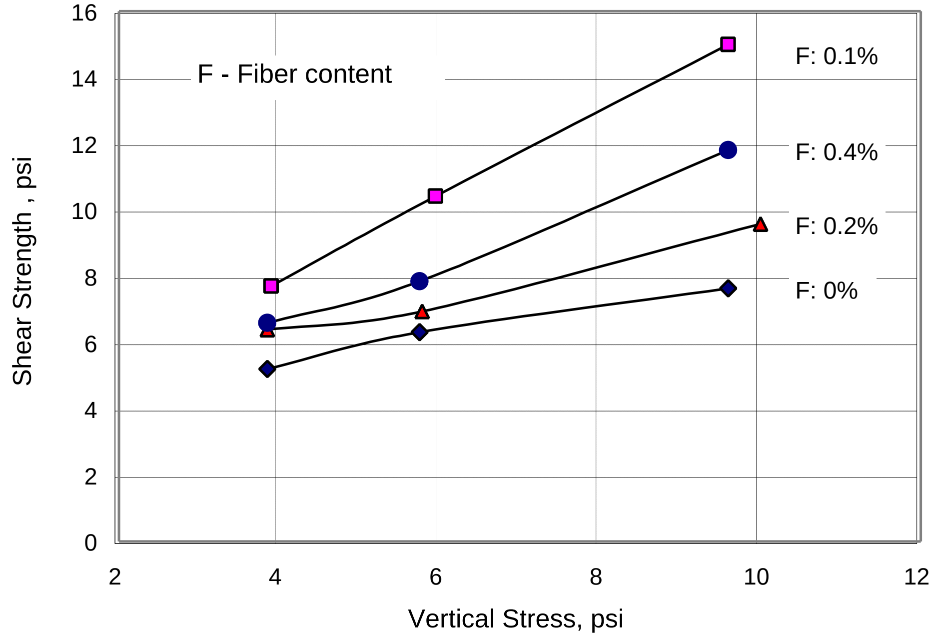


Figure 10

Direct shear test results at moisture content 18 %

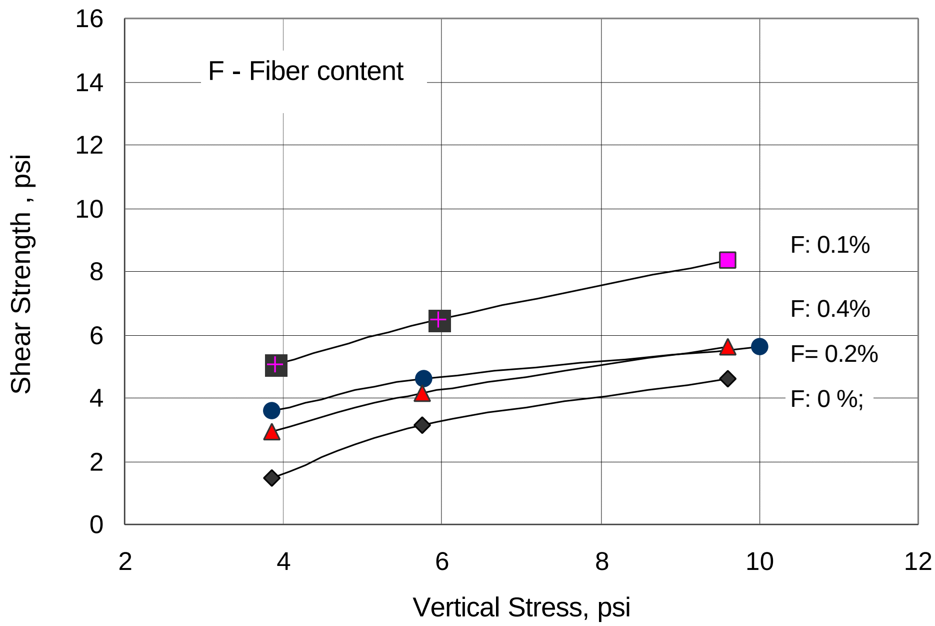


Figure 11

Direct shear test results at moisture content 28 %

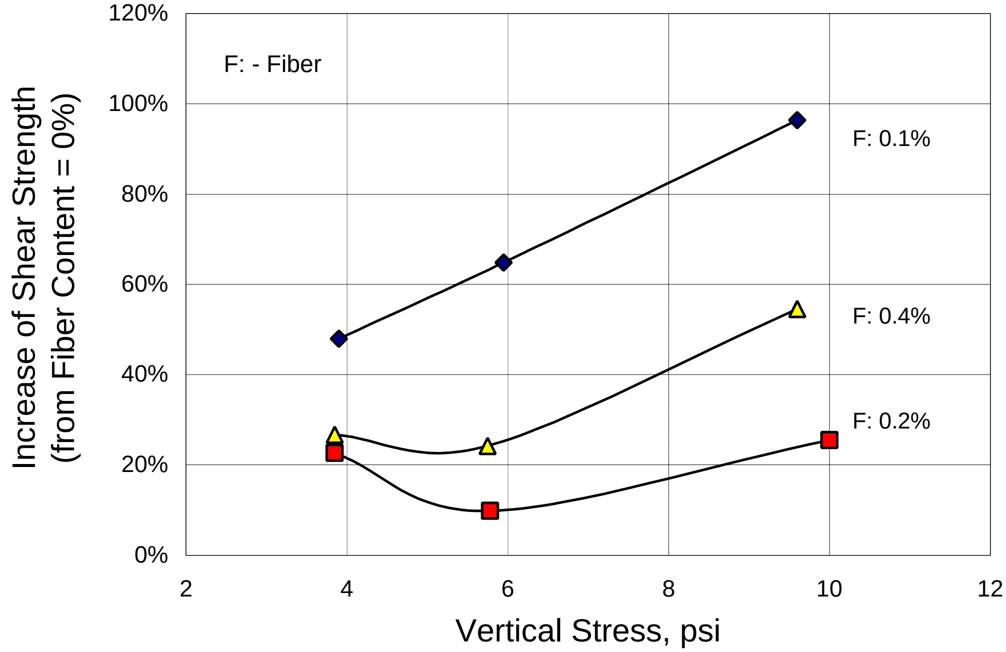


Figure 12

Increase of shear strength due to fiber content

(at moisture content 18 %)

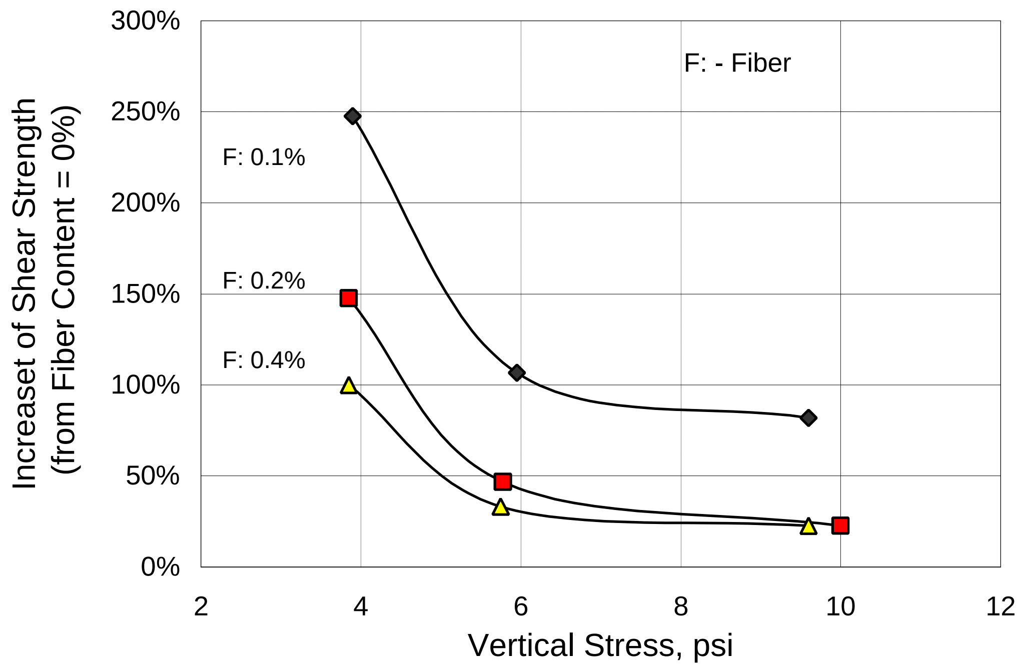


Figure 13

Increase of shear strength due to fiber content

(at moisture content 28.8 %)

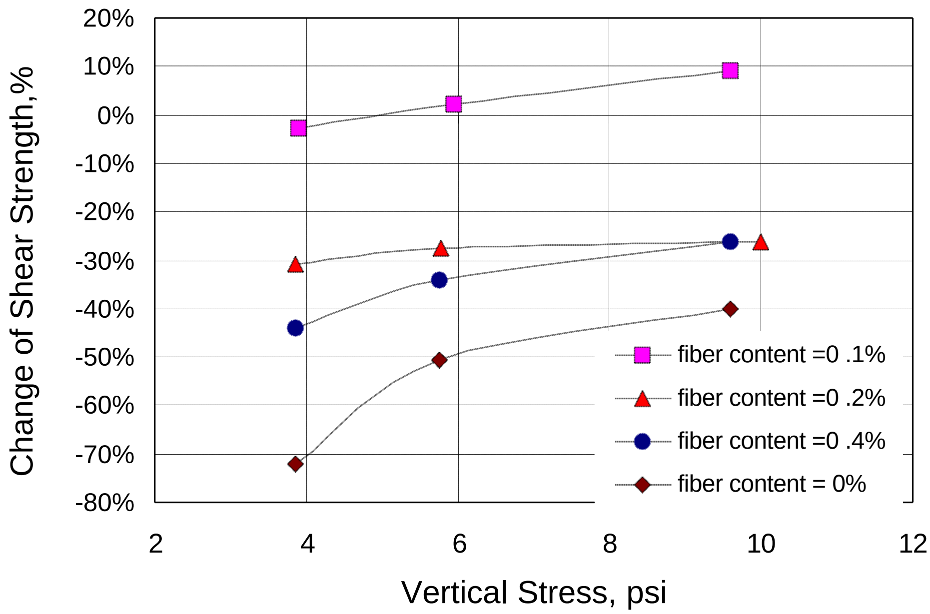


Figure 14

Change of strength due to increase in moisture content from 18% to 28%

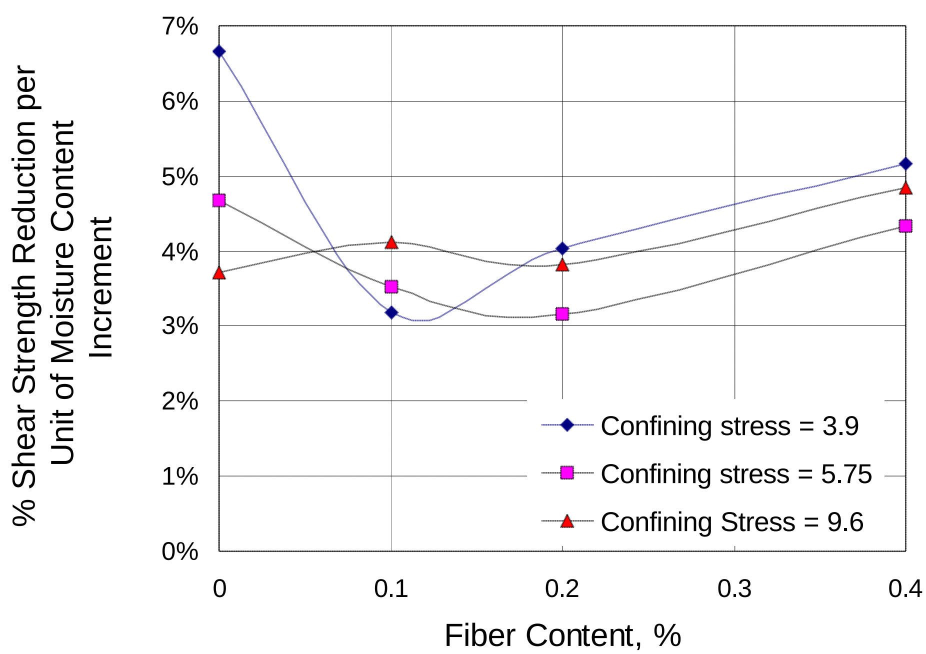


Figure 15

Change of shear strength per unit increment of moisture content

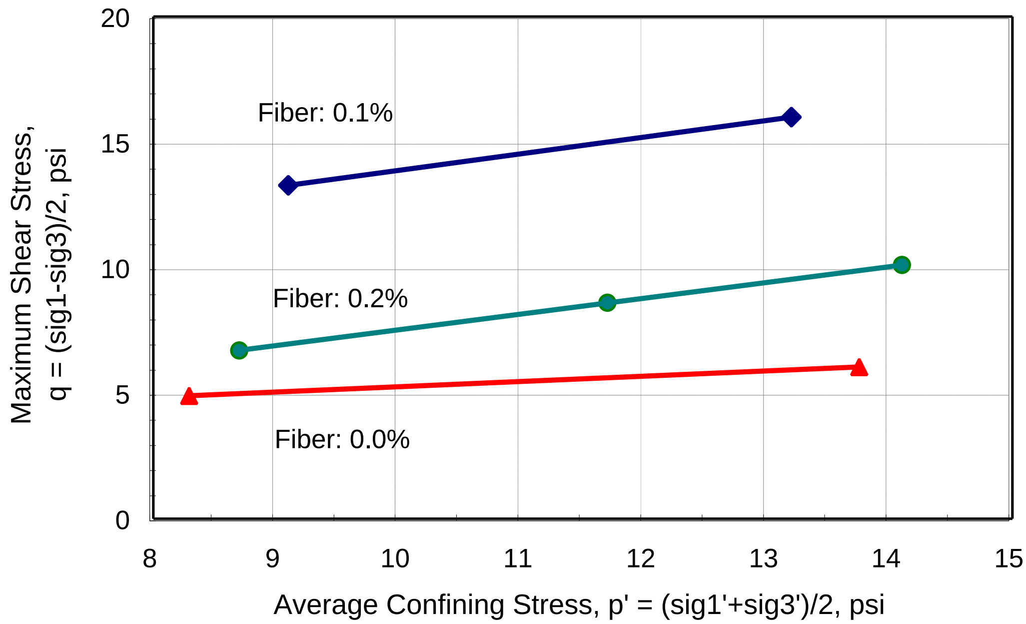


Figure 16

Results of consolidated-undrained triaxial test on fiber-soils (at moisture content of 18%)

Table 7

Consolidated-undrained triaxial test results on fiber-soil mixes

Fiber content (%)	Soil unit wt., γ (ton/ft^3)	Consolidating pressure (psi)	Water content (%)	Friction angle (φ)	Cohesion C (psi)
0	95	10 15	18.8	12.2	3.2
0.1	95	5 10	18.0	41.6	9.7
0.2	95	5 10 15	18.8	39	1.6

Geotextile-Soil Behavior

Figure 17 shows the results of direct shear tests in order to determine soil friction and the interface shear between the heavy clay soil and non-woven fabric at various confining pressures and three different moisture contents. The results show a reduction of the interface shear with the increase of moisture content. As a reference, the strength lines of friction angles tan 3°, tan 6°, and tan 9° are plotted in the graph.

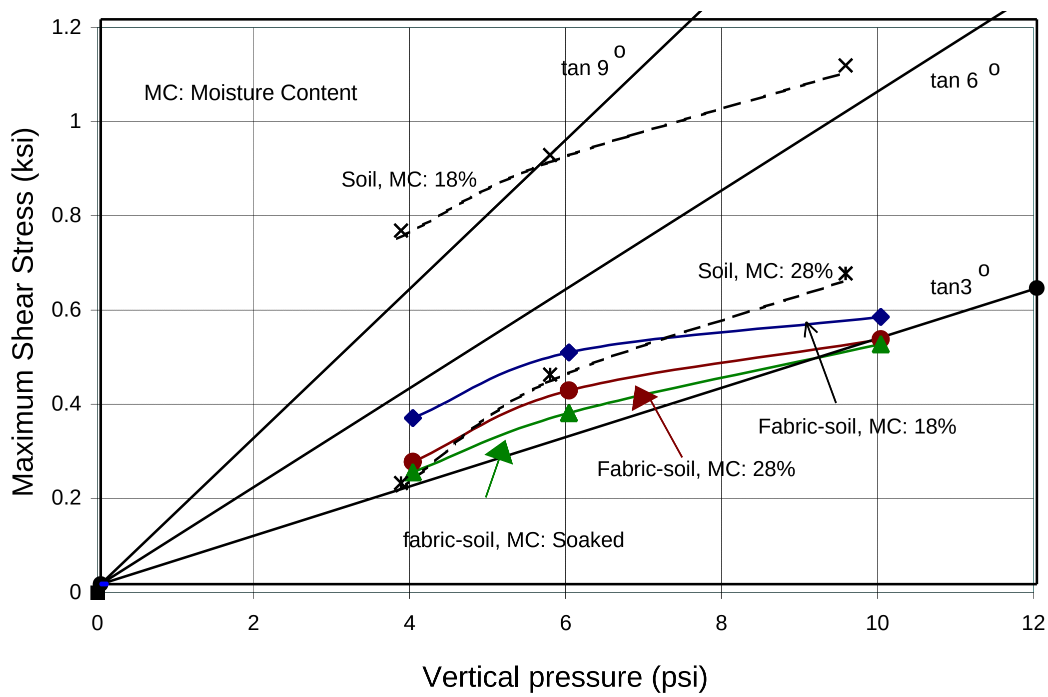


Figure 17

Direct shear test results on the fabric-soil specimens

Field Evaluation

Slope Failure Mechanism

The fiber-reinforced slopes in the field were constructed with heavy clay of plasticity index (PI) higher than 35. This means that the clay soil has a high potential to expand and shrink with the variation of moisture due to a high level of clay-water interaction among soil particles. Field monitoring of the sections indicated that slope failures occurred after a long period of rainy days, resulting in soil saturation under the slope surface. The mechanism through which water infiltrates the soil can be explained as follows:

When the heavy clay in a slope is exposed to a wet- and dry-weather cycle, it expands and shrinks accordingly. This cycle of expanding and shrinking causes fissures and cracks to develop in the slope surface, thus allowing surface water to infiltrate. As the cycle repeats, the fissures and cracks become deeper. During a long wet season, the ground water will not only be trapped in these fissures and cracks, but it will also have enough time to soak the clay adjacent to these fissures and cracks. As the soil saturation increases, the shear strength decreases due to the interaction between the water and clay particles. As such, the soil will lose some of the initial shear strength established during the process of soil compaction at the optimum moisture content. The water molecules will change the fabric structure of the soil, breaking the bonds between clay particles. Slope failures most often occur in slopes when the soil becomes totally saturated causing a reduction of soil strength. This process is supported by the observation of the test sections and by other investigators [*6,7*]. Figures 18 and 19 show typical failures at sections in slopes constructed with heavy clay soil.

Figure 18
View of an Embankment Slope Failure on I-20

Figure 19
View of a Failure in a Slope Section in LA-15

Performance of Fiber-Reinforced Test Sections

Several slope-sliding failures have been observed in the fiber-reinforced test sections since they were constructed in 1997. Most of these failures were visually observed. Only one slope failure in Section 132 (Fiber-Reinforcement–Standard Specifications) was detected by the vertical inclinometers. The results of the inclinometers in this section were used to estimate the location of the failure surface inside the slope. The location of the failure surface indicated that sliding developed in the wet clay soil below the repaired fiber-soil zone. Consequently, this section could not be used to evaluate the long-term performance of fiber soils. The other failures occurred in Test Section 224 (fiber reinforced at optimum moisture-minor compaction) in late fall of 2001. The cause of these failures was inconclusive since they occurred outside the instrumented zones and the sliding surfaces could not be identified with certainty. However, visual investigation showed that they appeared to be shallow failures passing through the fiber-reinforced zones. Figure 20 shows one of these failures.

Figure 20

View of Slope Failure in Fiber Section, Station 227+05

The results of the monitoring program in the remaining four sections can be summarized as follows:

- The sections constructed at higher moisture contents experienced more deformations than the ones compacted at the optimum. Most of these deformations occurred during the wet season of the years 2000 and 2001 after relatively lower deformations during the earlier dry seasons of 1998 and 1999.
- There was no significant difference in performance between soil sections and fiber-soil sections.
- Fiber-soil section 242 did not show improvement in performance over soil section 213 (both compacted at the high moisture content using a lower compaction effort).
- Similarly, fiber-soil section 224 and soil section 244 showed similar deformation values. Both sections were compacted at the optimum moisture content. Although fiber-soil section 224 had a lower compaction effort, field measurements showed that its average dry density of 86 pcf was close to the measured densities of section 244.

The results of the measurements of the vertical inclinometers are shown in Appendix C. A typical inclinometer plot is shown in figure 21. The measurements of the maximum deformations at each section are also compiled in table 8.

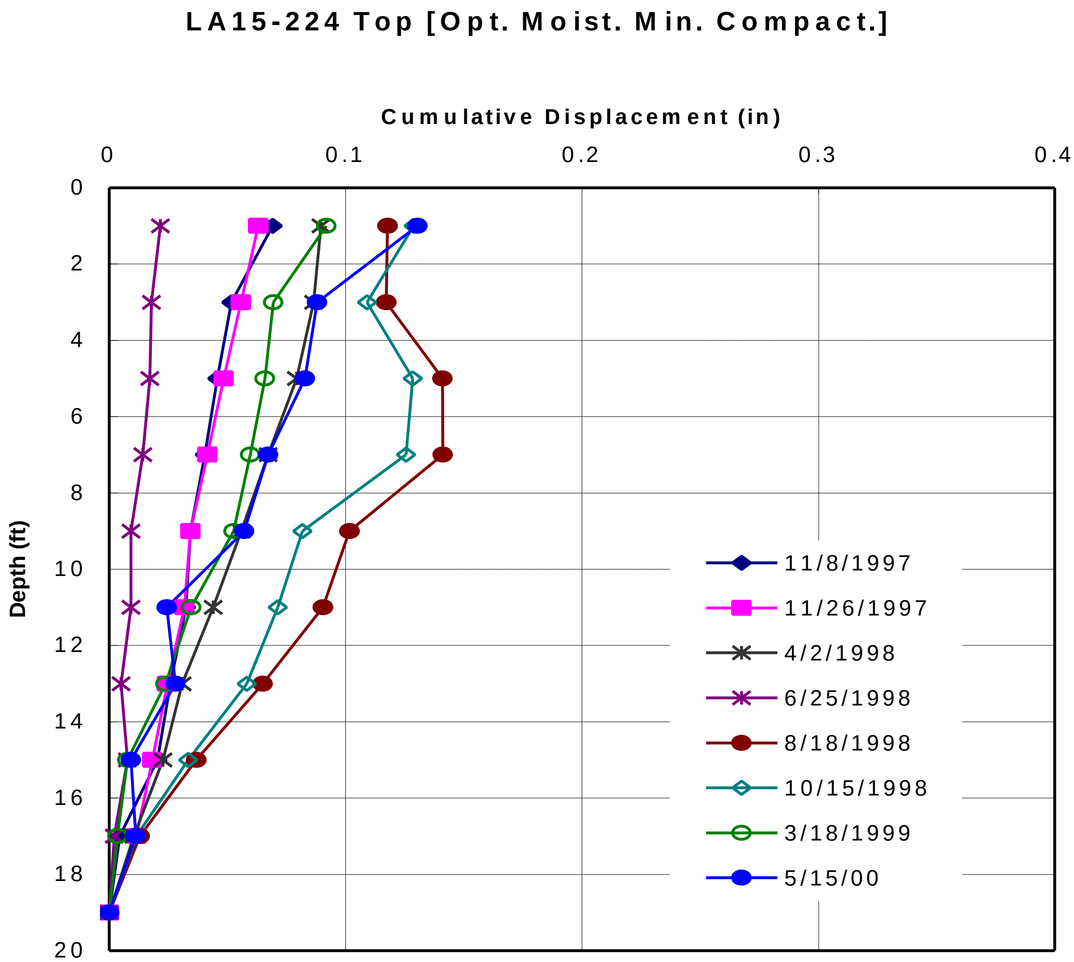


Figure 21

Readings of the top inclinometer in section 224 [soil-fiber mix]

Table 8

Summary of measured deformations in the test sections

Test Section	Repair method	Monitoring period (months)	Maximum deformation (inches)	Notes
132	Fiber reinforced (Standard Specification)	3	Top 0.4 Middle 1.5	Section had a premature failure below repaired part after 3 months
213	Fiber reinforced (High moisture, Minor compaction)	36	Top 0.25 Middle 0.46	Most deformations occurred in the last 6 months
224	Fiber reinforced (Optimum moisture, Minor compaction)	36	Top 0.14 Middle 0.12	Minor deformations in the last 12 months
242	Soil (High moisture, Minor compaction)	36	Top 0.17 Middle 0.35	Most deformations occurred in the last 12 months.
244	Soil (Standard specification)	36	Top 0.14 Middle 0.14	Minor deformations in the last 12 months
2 + 00	Fabric reinforced (Standard specification)	24	Top 0.65 Middle 0.75	High initial deformations, minor changes in last 12 months.
10 + 00	Fabric reinforced (Standard specification)	24	Top 0.82 Middle 0.82	Continuous increase in deformations.

Performance of Non-Woven Fabric Reinforced Test Sections

The two fabric-reinforced slopes, in general, showed higher deformations than the soil-only sections and the fiber-reinforced sections as shown in table 8. However, most of these deformations occurred in the first year after construction. Furthermore, deformation measurements at the top and bottom of the test sections were almost identical indicating minimum movement of the reinforced section between the two inclinometers.

No slope failures have occurred in the fabric-reinforced test sections. Slope failures only occurred in soil sections adjacent to the fabric-reinforced zones at both sites. These failures did not progress into the reinforced zones. Figure 22 shows the slope failure in un-reinforced section adjacent to Fabric Site 2. The adjacent failures were subsequently repaired with fabric reinforcements.

A typical inclinometer reading of the fabric sections is shown in figure 23. The measurements of the inclinometers in these sections are shown in Appendix D.

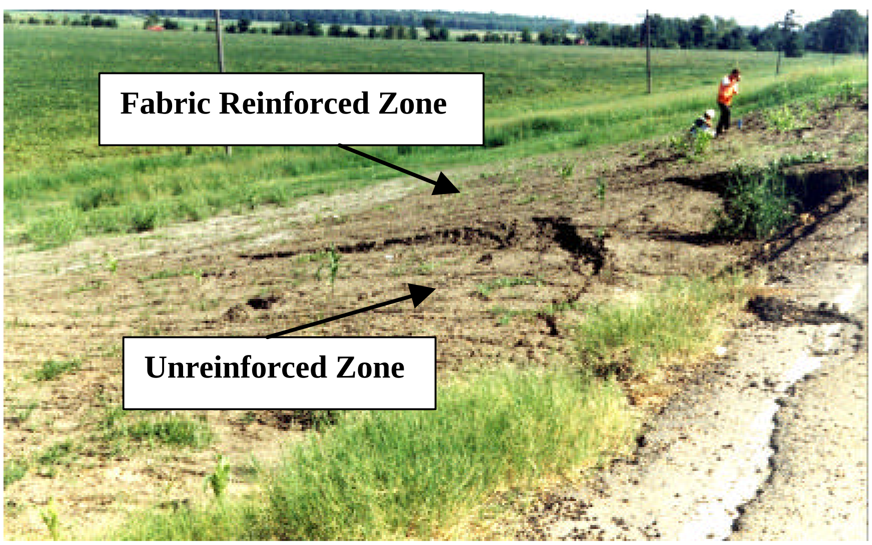


Figure 22
View of slope failure in un-reinforced section adjacent to fabric site 2

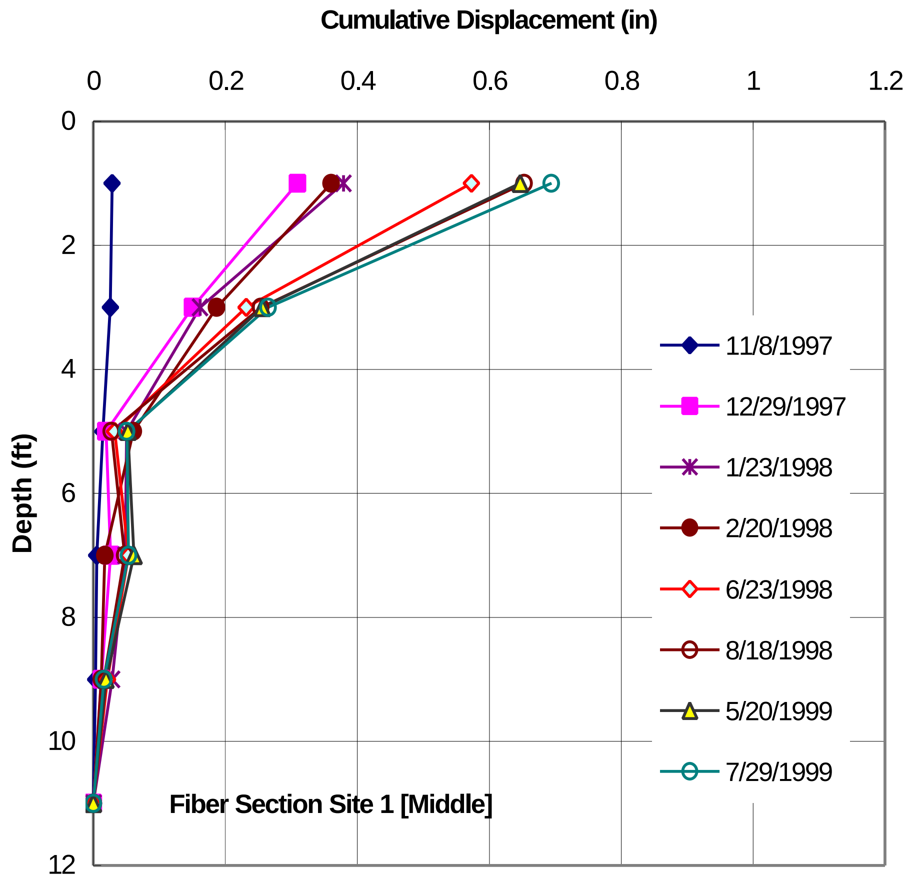


Figure 23

Readings of the middle inclinometer in fabric section 1

CONCLUSIONS

This study has evaluated two methods to repair slope failures of embankments constructed with cohesive soils. One is to reinforce the slope with randomly oriented synthetics fibers; the other is using non-woven geotextiles. The performance of the soils reinforced with these two materials was studied in the laboratory and the in field. A summary of research conclusions is as follows:

- Laboratory results showed that the increase of soil moisture content in the clayey soil has a detrimental effect on its shear strength. Such effect can be quantified be estimating 3% decrease in soil shear strength for every unit increase of soil moisture content. This relationship can only be used to estimate the short-term impact on shear strength due to increase of soil moisture content.
- Laboratory results showed that fiber-reinforced clayey soils would gain extra shear strength as the fibrillated fibers interlock with the soils in a randomly oriented manner. The largest increase in shear strength was achieved when fiber content was 0.1%. A minimum of 50% increase in soil shear strength was achieved with a fiber content of 0.1% by weight when the soil was compacted at its optimum moisture content.
- Field investigations showed that slope surface failures occur when the surface water trapped in fissures and cracks fully soaks the adjacent soils. The sections, which were constructed at moisture content higher than the optimum, experienced more deformations than the ones compacted at the optimum.
- Results were inconclusive regarding the long-term stability of fiber-reinforced slopes. Small failures have occurred in the fiber test sections placed at optimum moisture and minimum compaction. The test section placed at optimum moisture and 95% compaction could not be evaluated because of a slope failure occurring outside the reinforced zone.
- There was no significant difference in the inclinometer deformations among the soil control sections and fiber-soil sections with different construction controls.
- Although the readings of the vertical inclinometers in the fabric-reinforced sections

were initially higher than the fiber sections, no significant long-term movements were observed in these sections. The monitoring program indicated that the low-cost non-woven fabric is a good candidate to repair failed slopes, especially with maintenance forces.

RECOMMENDATIONS

The results from this study indicate that using the non-woven fabric to repair failed embankment slopes is a good option to prevent repetitive slope surface failures. When the non-woven fabric is used, it not only generates the tension forces to enhance the overall stability of slopes, but also prevents the development of pore water pressure trapped in clayey soils by providing horizontal drainage through the fabric. It also has an advantage of having a relatively low material cost of about $0.50 to $0.75 per square yard.

There is no complicated design procedure to follow when repairing man-made embankments of conventional 3:1 slopes or flatter slopes constructed of high PI soils. Twelve to fifteen inch vertical spacing can be used with the fabric reinforcement. The slope’s back cut will control the width and length of the fabric. District maintenance units should be able to handle the repair work depending upon the work volume. Large equipment may need to be rented in some cases. The repair process consists of excavating the soil along the failed slope to a depth below the failure plane. The back slope should be benched approximately three to five feet on an effective slope to insure the stability of embankments under roadways during construction. Wet embankment soils should be spread and allowed to dry before being placed in a lift with an average thickness of 12 inches. Each lift should be place on a gradient to allow gravity flow of moisture through the fabric to the slope surface. Soils should be compacted to about 95% of maximum dry density as close to the optimum moisture content as possible. The fabric is placed on the top of each lift in one continuous sheet and is extended about four inches outside the slope facing.

For repair projects outside the scope of this research, a geotechnical engineer should be consulted.

REFERENCES

1. Ignold, T.S., and Miller, K.S., "The Behavior of Geotextile Reinforced Clay Subjected to Undrained Loading," Proceeding, 2nd International Conference on Geotextiles, Las Vegas, pp. 593-597, 1982.
2. Mitchell, J.K., Seed, R.B., and Seed, H.B. "Kettleman Hills Waste Landfill Slope Failure. I: Linear-System Properties." *Journal of Geotechnical Engineering*, ASCE, Vol. 116, No. 4, 1990, pp. 647-668.
3. Andersland, O.B., and Khattak, A.S., "Shear Strength of Kaolinite/Fiber Soil Mixtures," Proceedings, International Conference on Soil Reinforcement, Paris, Vol. 1, pp. 11-16, 1979.
4. Chen, H.Y., "Behavior of Fiber-Reinforced Cemented Soils Under Static and Cyclic Loads," Thesis for Ph.D., The State University of New Jersey, Rutgers, 1992.
5. Puppala, A., and Musenda, C., "Effects of Fiber Reinforcement on Strength and Volume Change in Expansive Soils," *Transportation Research Record 1736*, 2000, pp. 134-140.
6. Gregory, G.H., and Chill, D.S., "Stabilization of Earth Slopes with Fiber Reinforcement," Sixth International Conference on Geosynthetics, 1998.
7. Gregory, G.H., "Mechanisms of Shallow Slope Failures in Clay," ASCE Texas Section Fall Meeting, Geotechnical Section, 1998.

BIBLIOGRAPHY

1. Farrag, K., "Effect of Moisture Content on the Interaction Properties of Geosynthetics," Proceedings, Geosynthetics '95 Conference, Nashville, 1995.
2. Gray, D.H., and Ohashi, H., "Mechanics of Fiber Reinforcements in Sand", *Journal of Geotechnical Engineering*, ASCE, Vol. 109, No. 3, 1983, pp. 335-353.
3. Gray, D.H., and Maher, M.H., "Admixture Stabilization with Randomly Oriented Discrete Fibers," Proceedings, XIIth International Conference on Soil Mechanics and Foundation Engineering, Rio De Janeiro, Brazil, pp. 1363-1366, 1989.
4. Hoare, D.J., "Laboratory Study of Granular Soil Reinforced with Randomly Oriented Discrete Fibers," Proceedings, International Conference on Soil Reinforcement, Paris, Vol. 1, pp. 47-52, 1979.

APPENDIX A

FIBER REINFORCED FIELD MEASUREMENTS

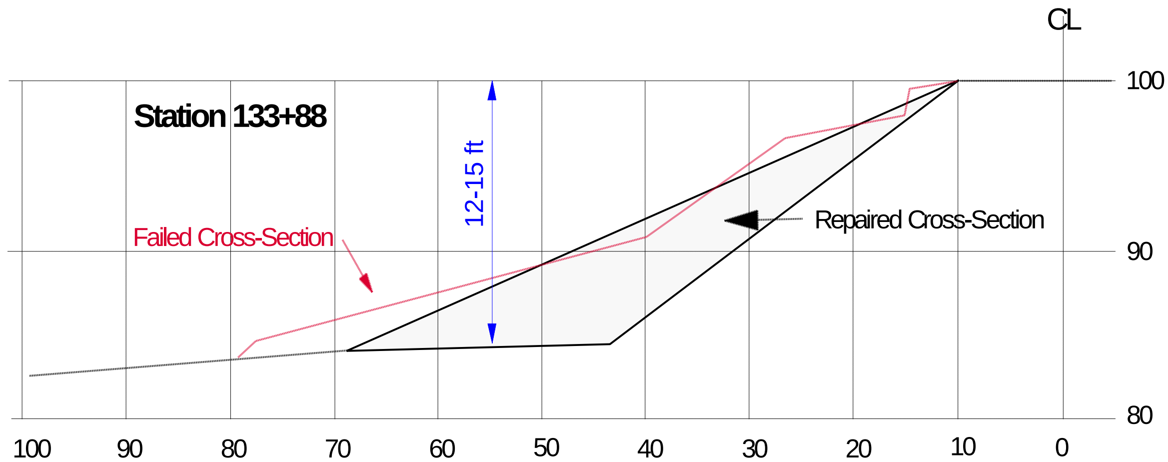


Figure A-1. Typical cross-section in section 132

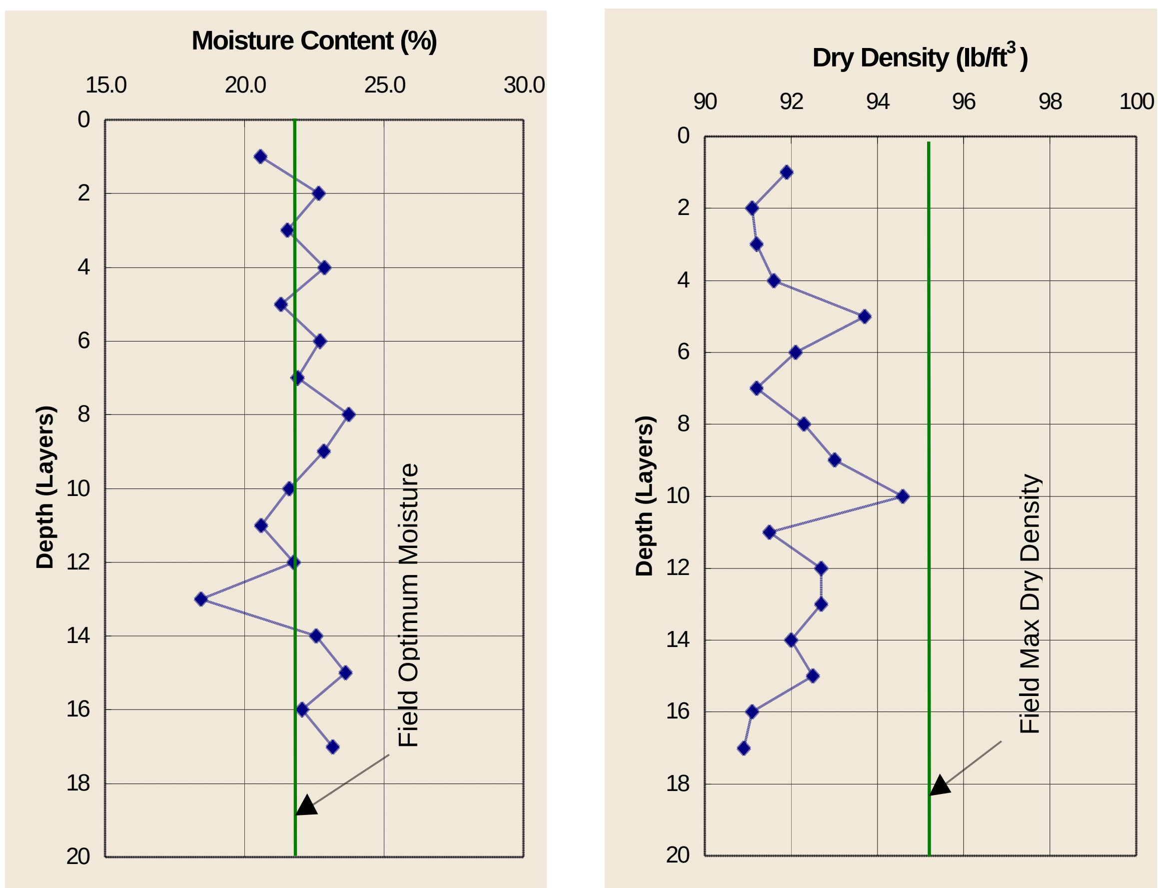


Figure A-2. Field measurement of moisture and density in section 132

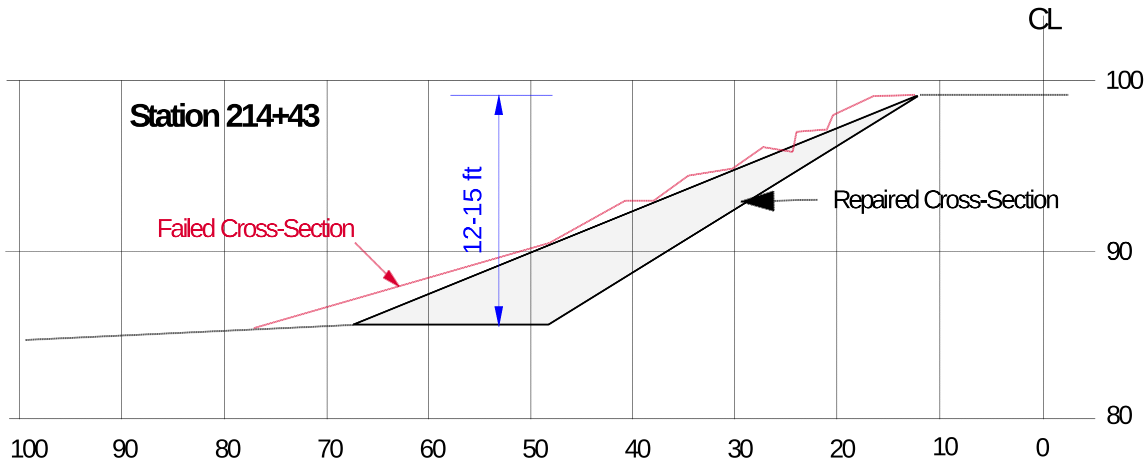


Figure A-3. Typical cross-section of the slope in section 213

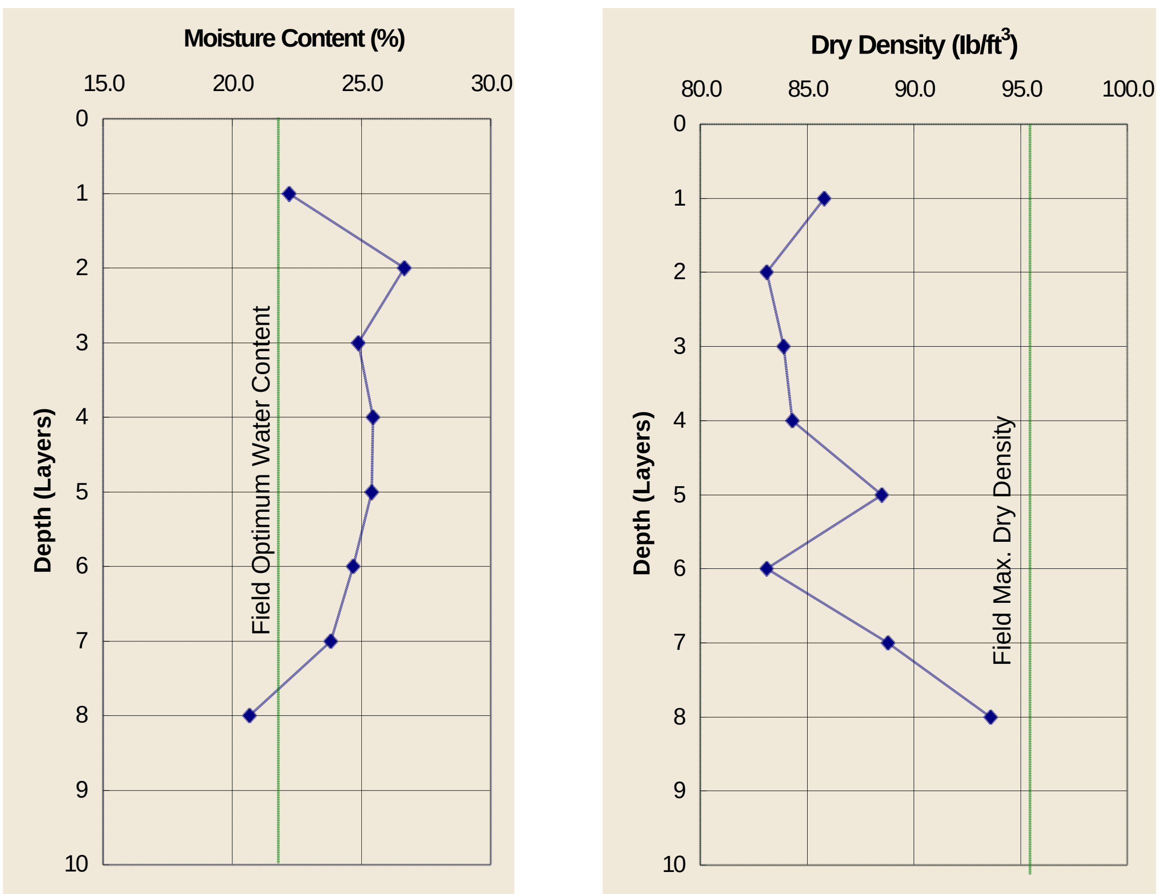


Figure A-4. Field measurements of moisture and density in section 213

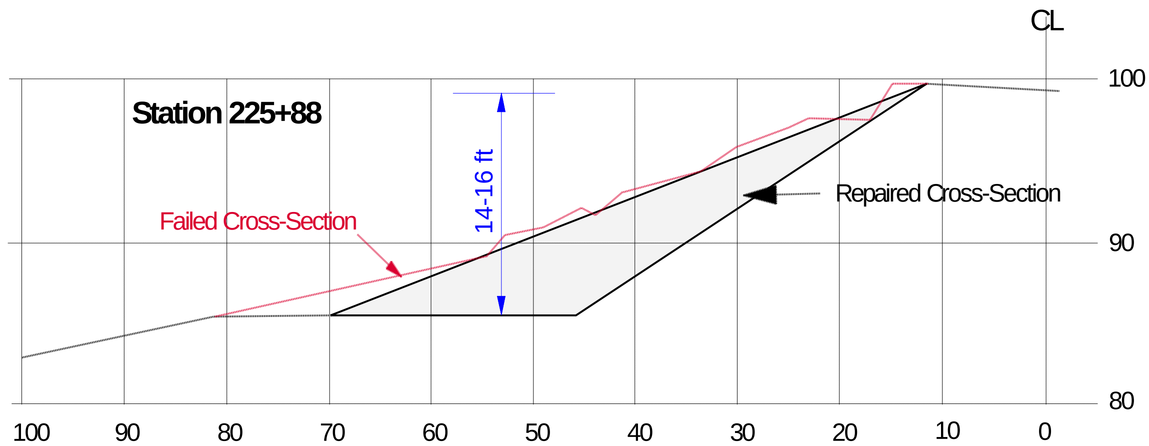
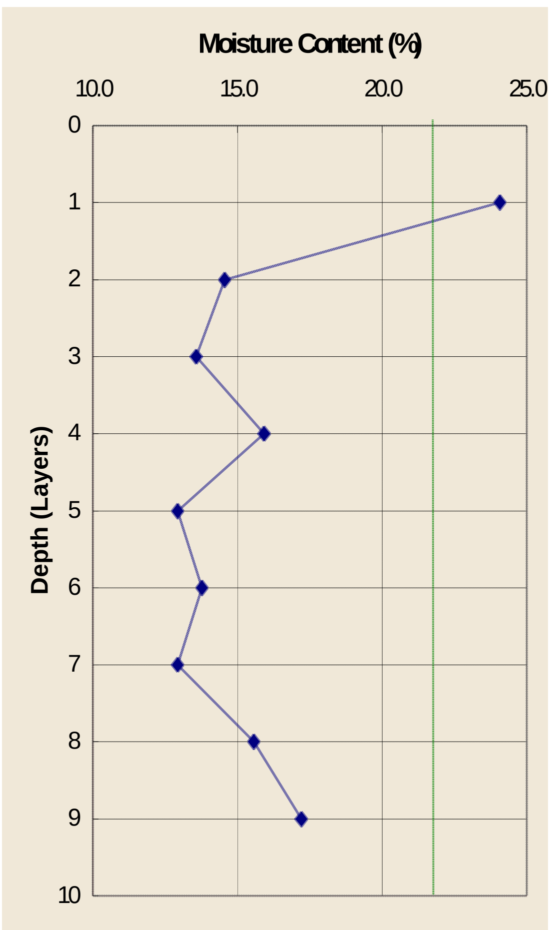


Figure A-5. Typical cross-section of the slope in section 224



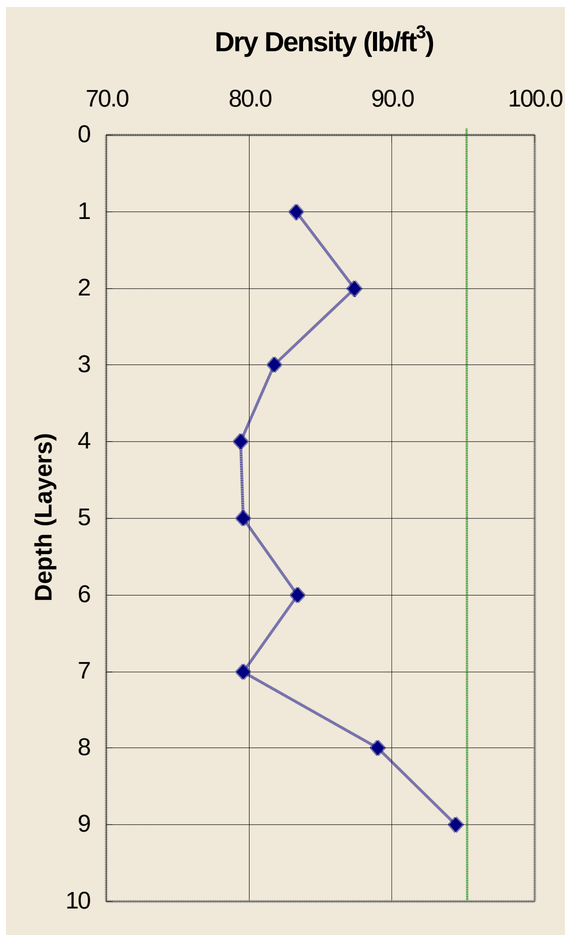


Figure A-6. Field measurements of moisture and density in section 224

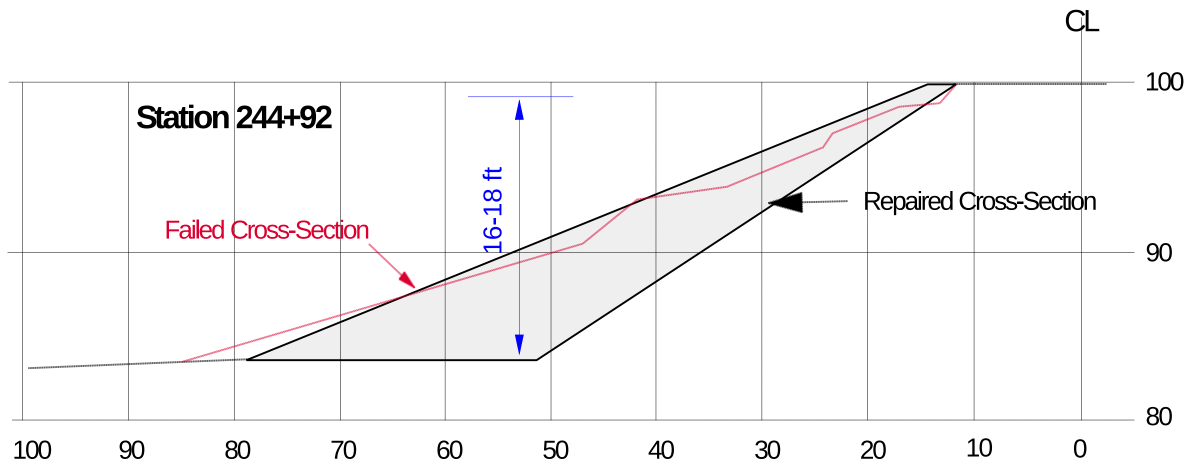


Figure A-7. Typical cross-section of the slope in section 244

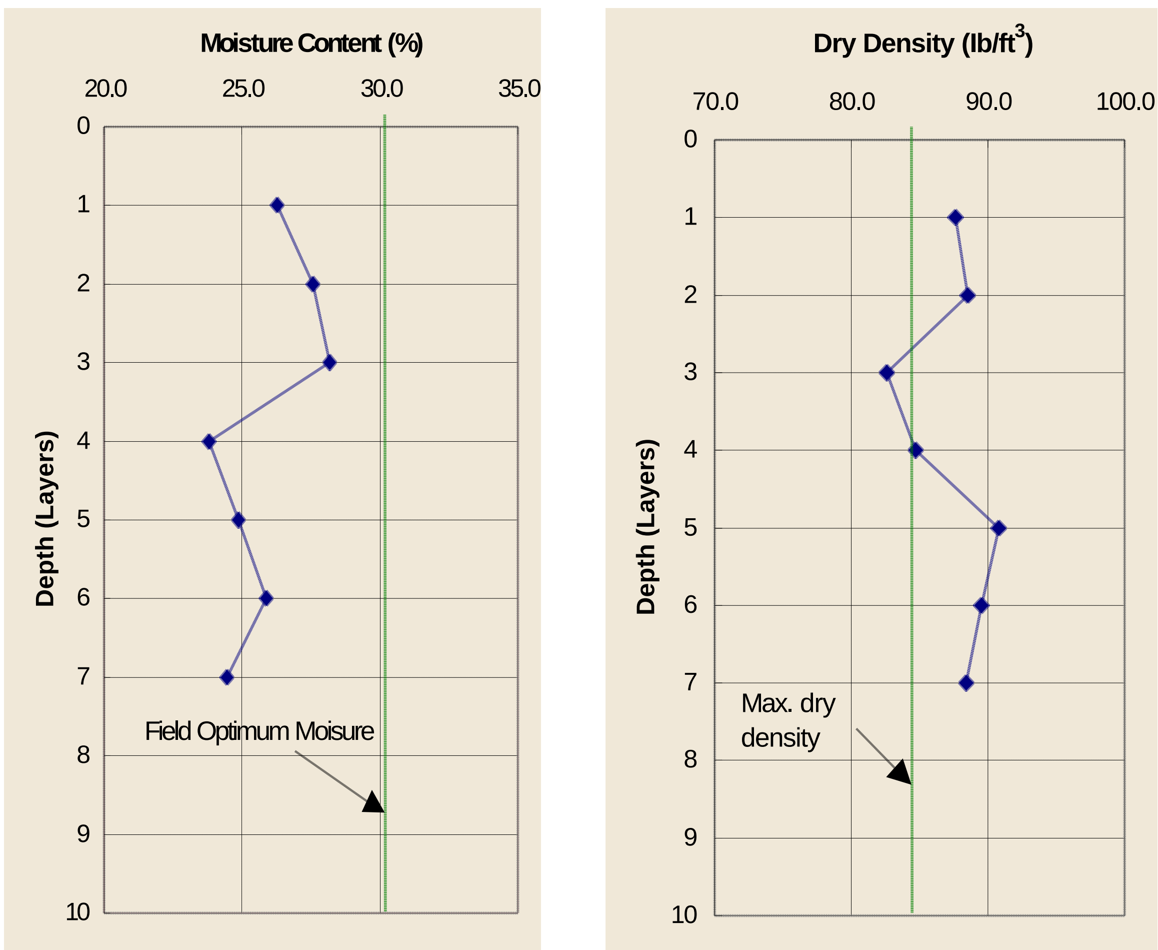


Figure A-8. Field measurements of moisture and density in section 244

APPENDIX B

FABRIC FIELD MEASUREMENTS

Table B-1
Moisture-density measurements in site 1

Layer	Top Elevation Feet	Moisture Content (%)	Dry Density (lbs/ft^{3})	Layer Thickness (Inches)
0	87.50	22.80	84.00	
1	88.30	23.80	93.20	9.6
2	89.10	22.90	92.90	9.6
3	90.00	23.80	91.20	10.8
4	90.80	20.40	89.80	9.6
5	91.70	23.00	92.40	10.8
6	92.50	23.80	91.40	9.6
7	93.30	21.80	89.50	9.6
8	94.10	17.90	89.50	9.6
9	95.00	20.20	90.00	10.8
10	95.80	21.70	90.80	9.6
11	96.70	22.00	90.30	10.8
12	97.50	21.20	88.30	9.6
13	98.30	21.10	86.80	9.6

Table B-2

Moisture-density measurements in site 2

Layer	Top Elevation (ft)	Moisture Content (%)	Dry Density (lbs/ft$^{3)}$	Layer Thickness (Inches)
0	82.67	42.00	74.00	
1	83.45	36.30	80.20	9.4
2	84.20	33.00	82.00	9.0
3	85.63	34.00	83.00	17.2
4	86.64	30.00	87.00	12.1
5	87.30	30.00	87.00	7.9
6	88.84	39.40	78.00	18.5
7	90.15	39.40	78.00	15.7
8	91.00	40.20	77.00	10.2
9	92.14	33.00	84.00	13.7
10	92.94	36.00	80.00	9.6
11	94.33	33.00	81.00	16.7
12	95.27	33.00	81.00	11.3
13	96.10	33.00	81.00	10.0

APPENDIX C

FIBER REINFORCED INCLINOMETER READINGS

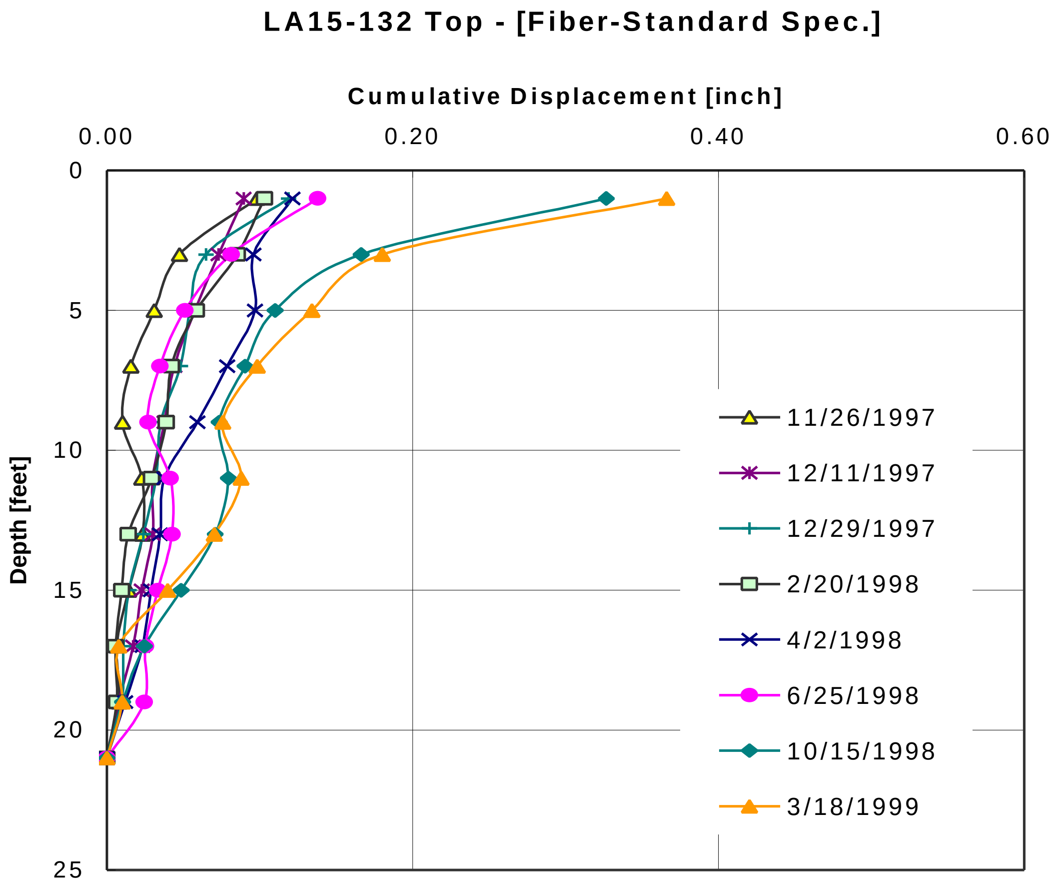


Figure C-1: Top-inclinometer readings in section 132
[soil-fiber mix]

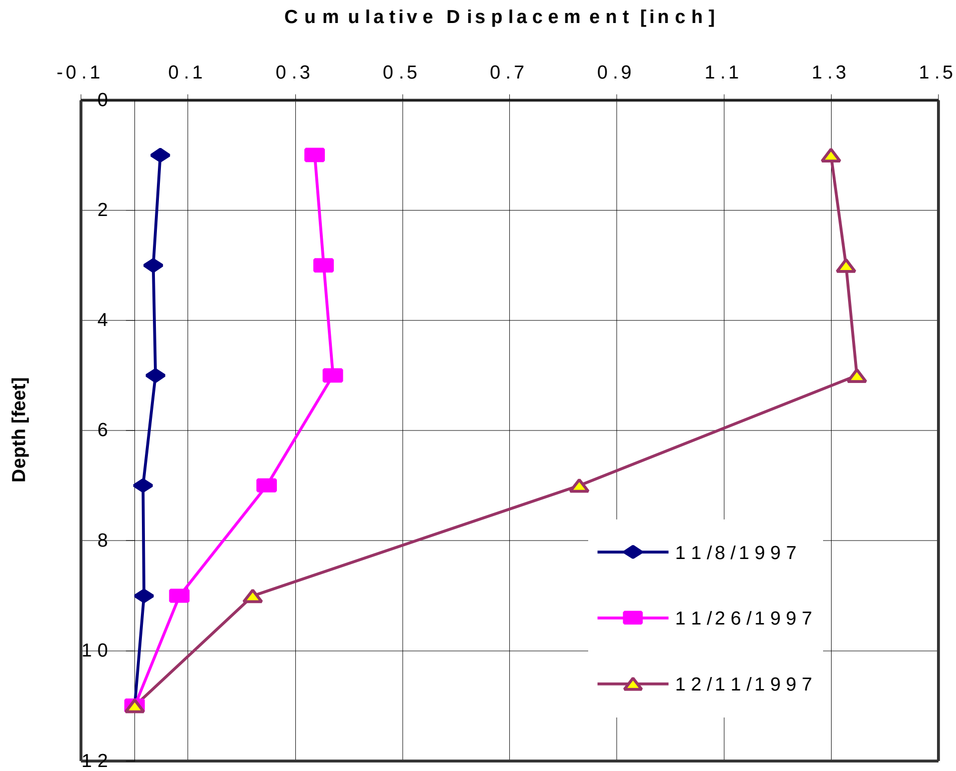


Figure C-2: Middle-inclinometer readings in section 132 [soil-fiber mix]

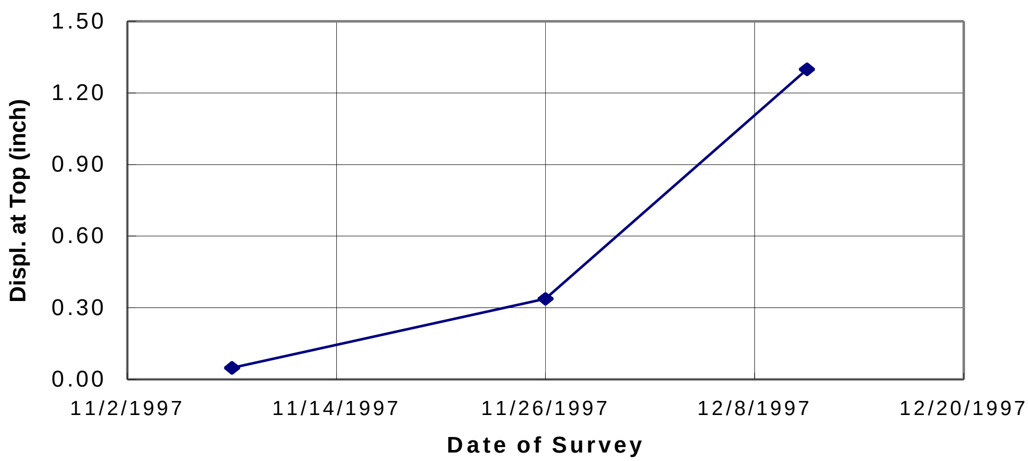


Figure C-3: Time-deformations of the middle-inclinometer in section 132

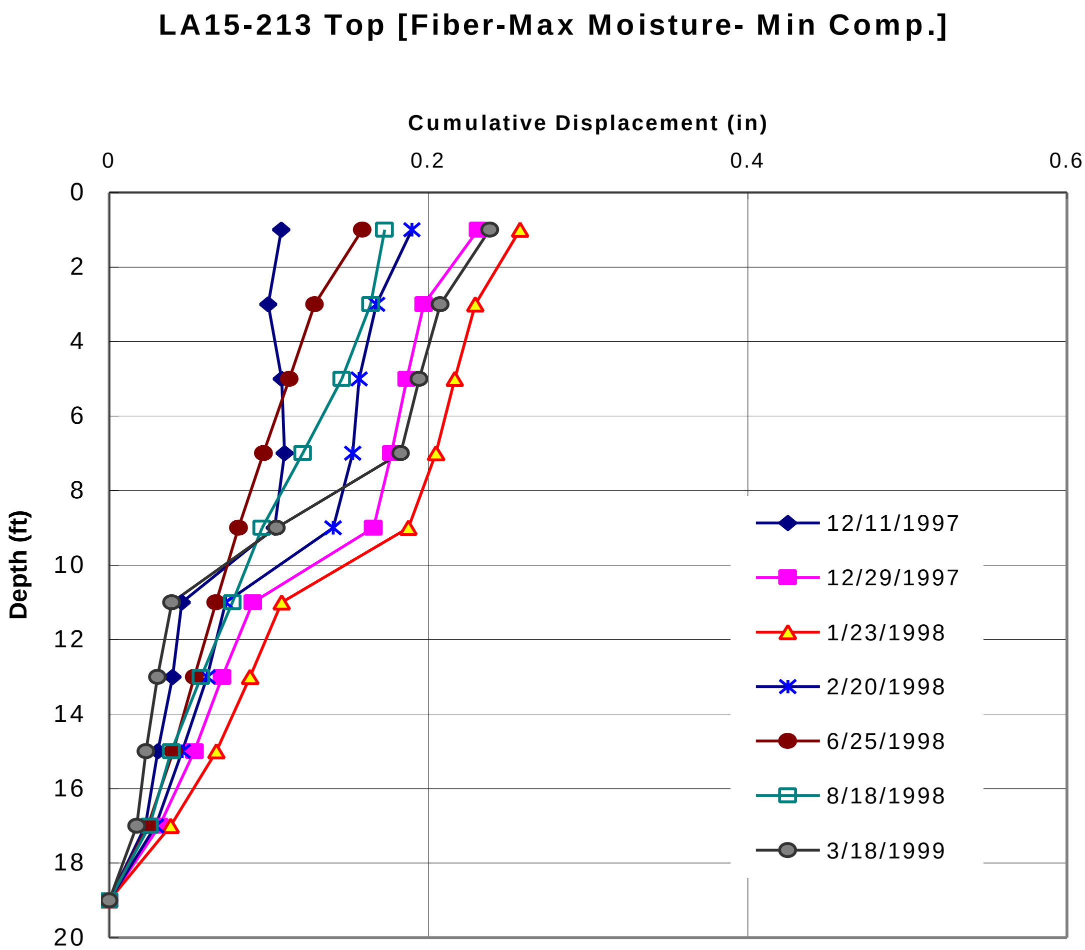


Figure C-4: Top inclinometer readings in section 213 [soil-fiber mix]

LA15-213 Middle [Fiber- max Moist. min Compact.]

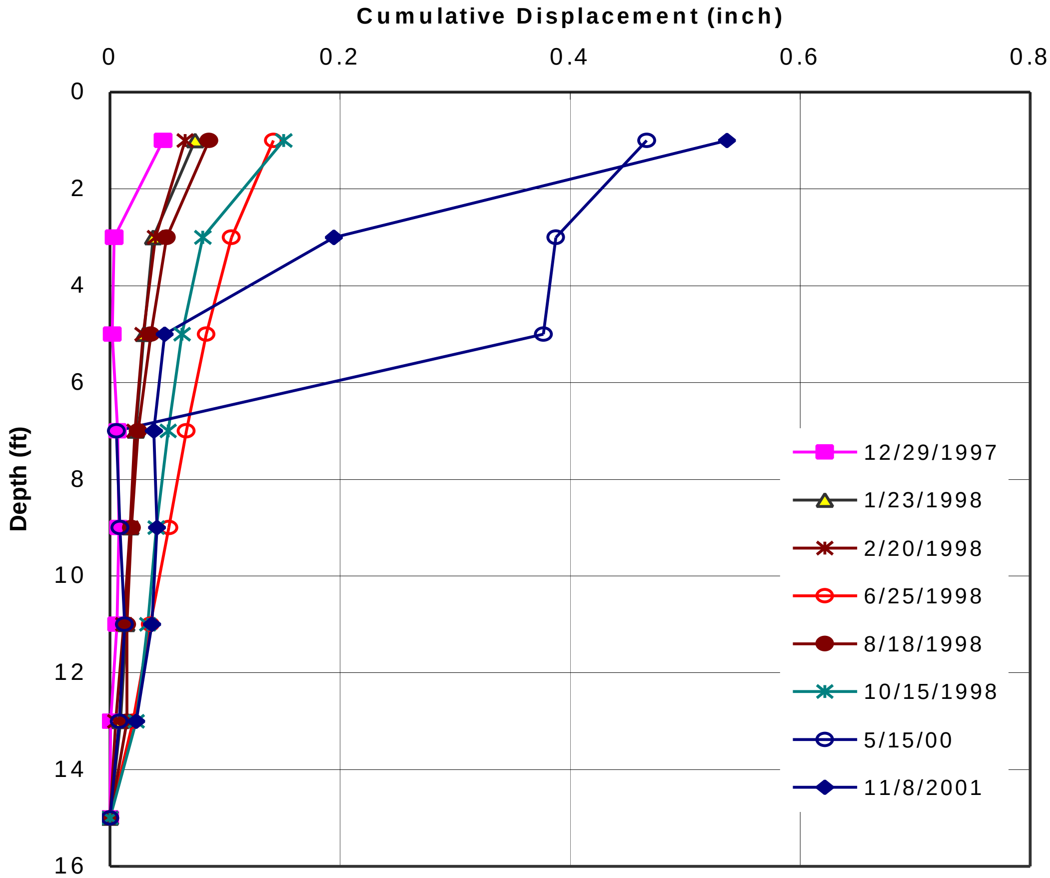


Figure C-5: Middle inclinometer readings in section 213 [soil-fiber mix]

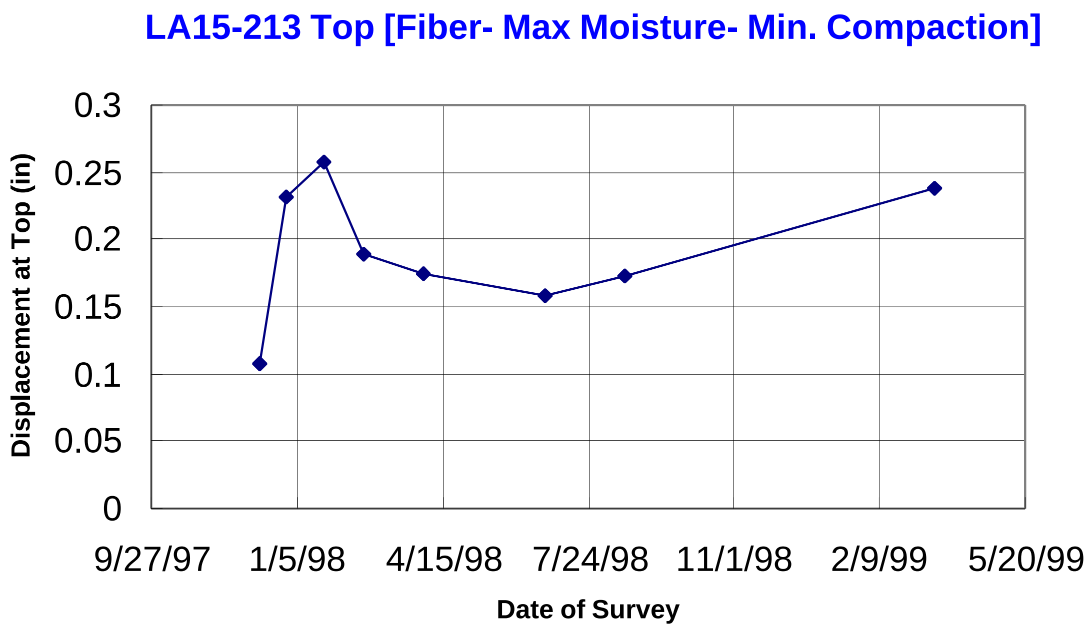


Figure C-6: Time deformation at top inclinometer, Section 213

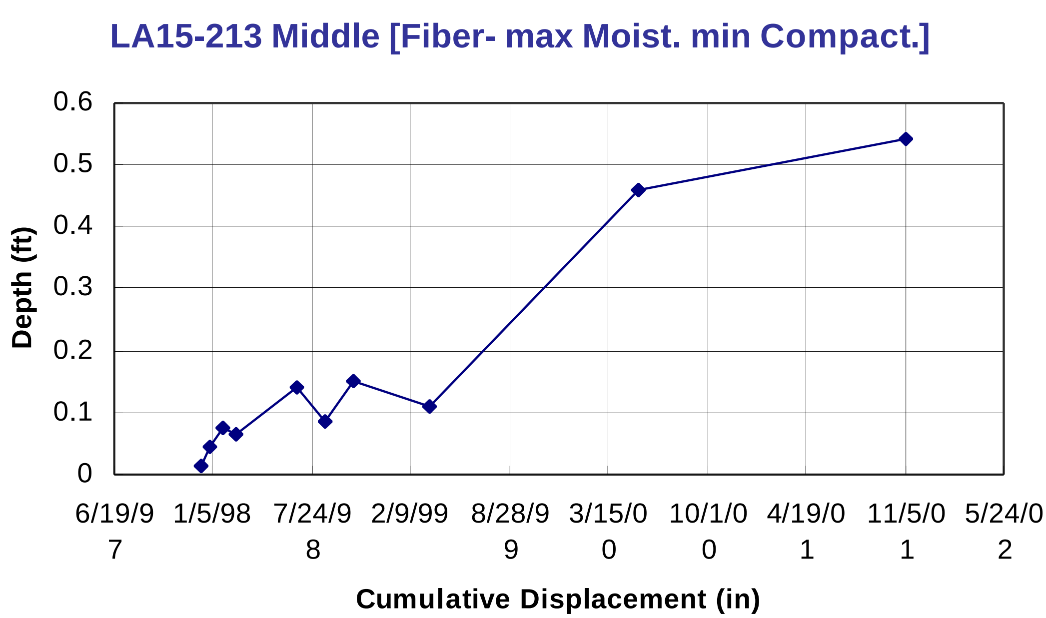


Figure C-7: Time deformation at middle inclinometer, section 213

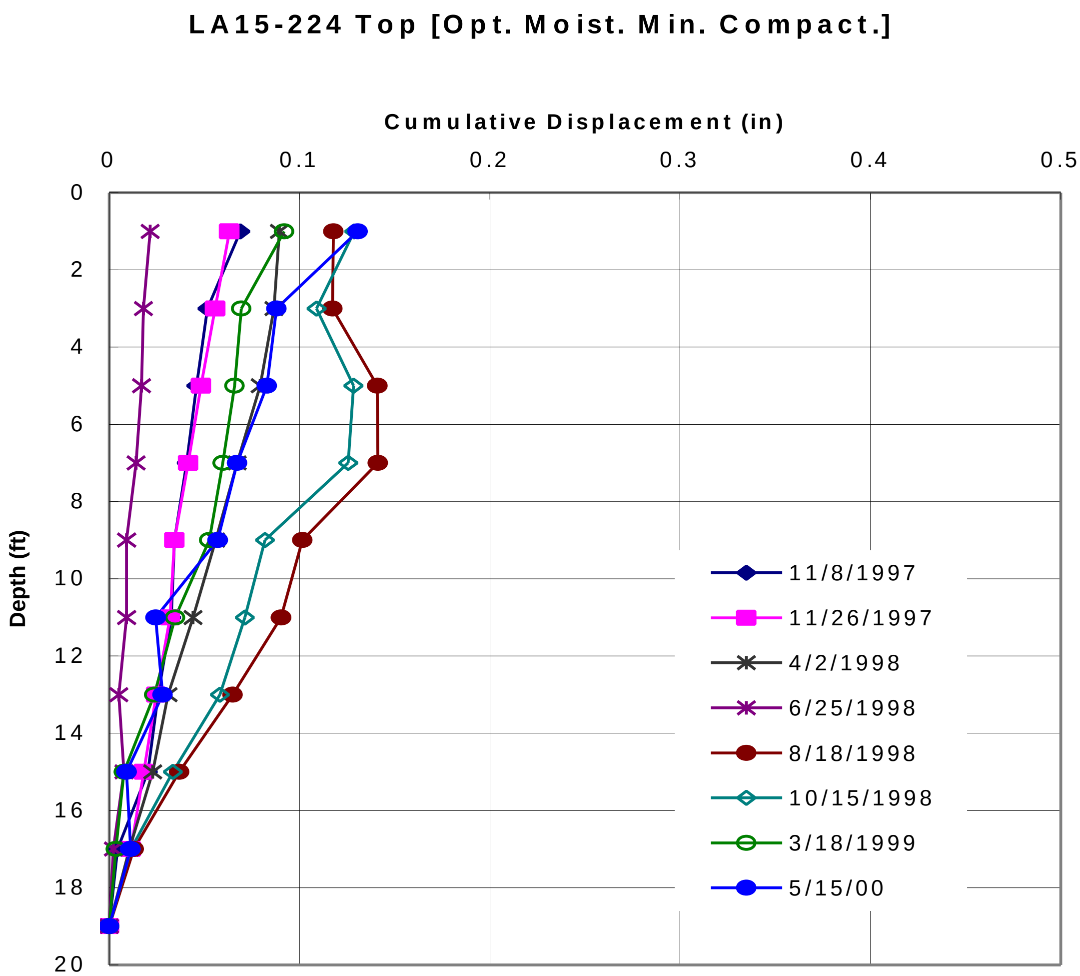


Figure C-8: Top inclinometer readings in section 224 [soil-fiber mix]

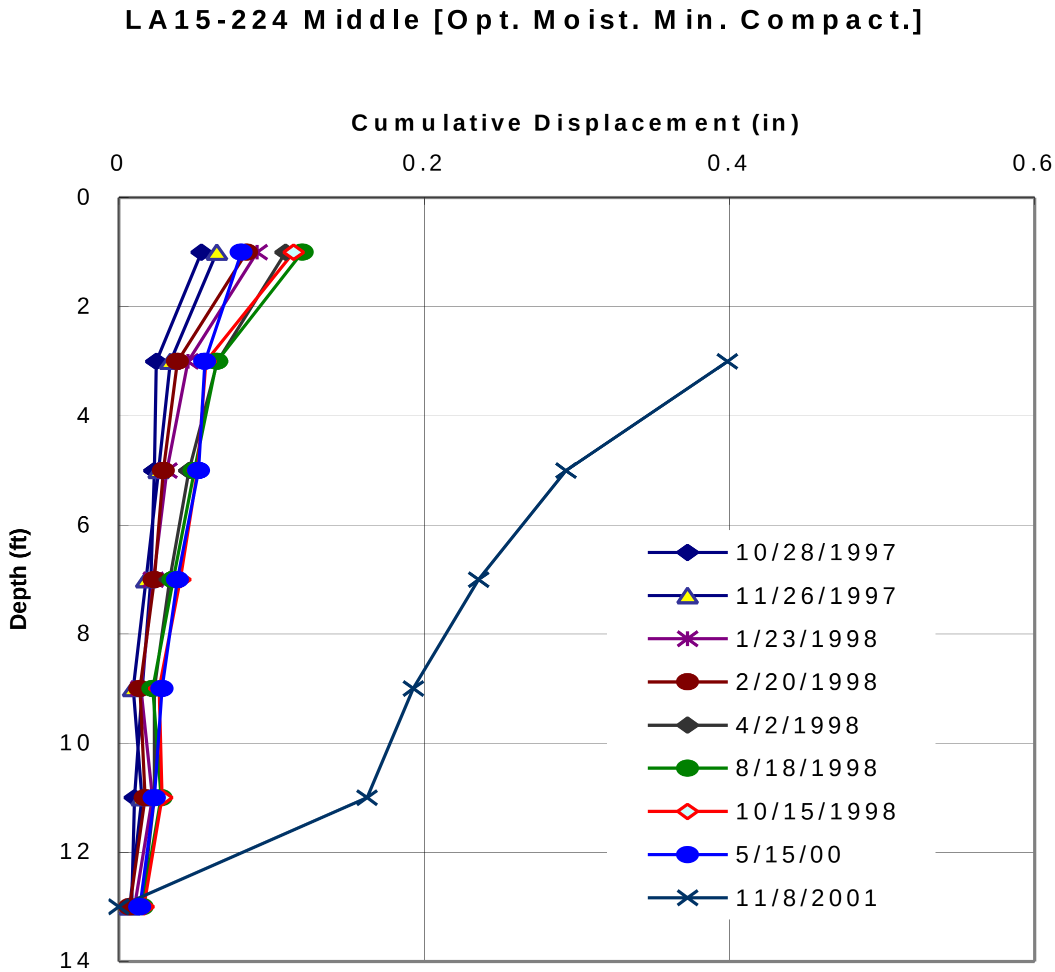


Figure C-9: Middle inclinometer readings in section 224 [soil-fiber mix]

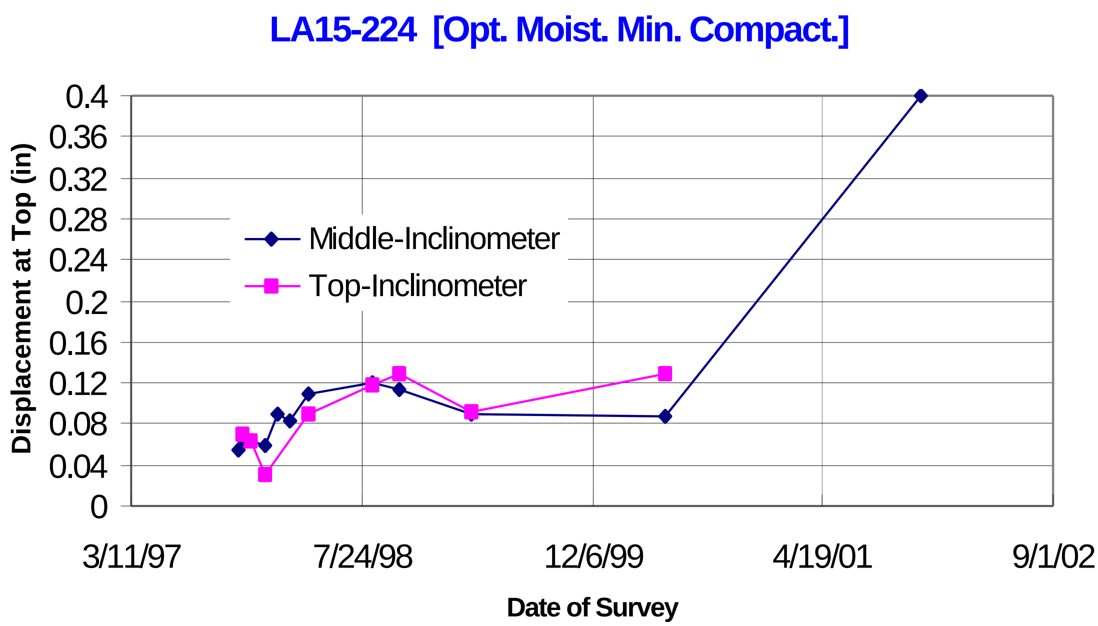


Figure C-10: Time deformation of the inclinometers, section 224

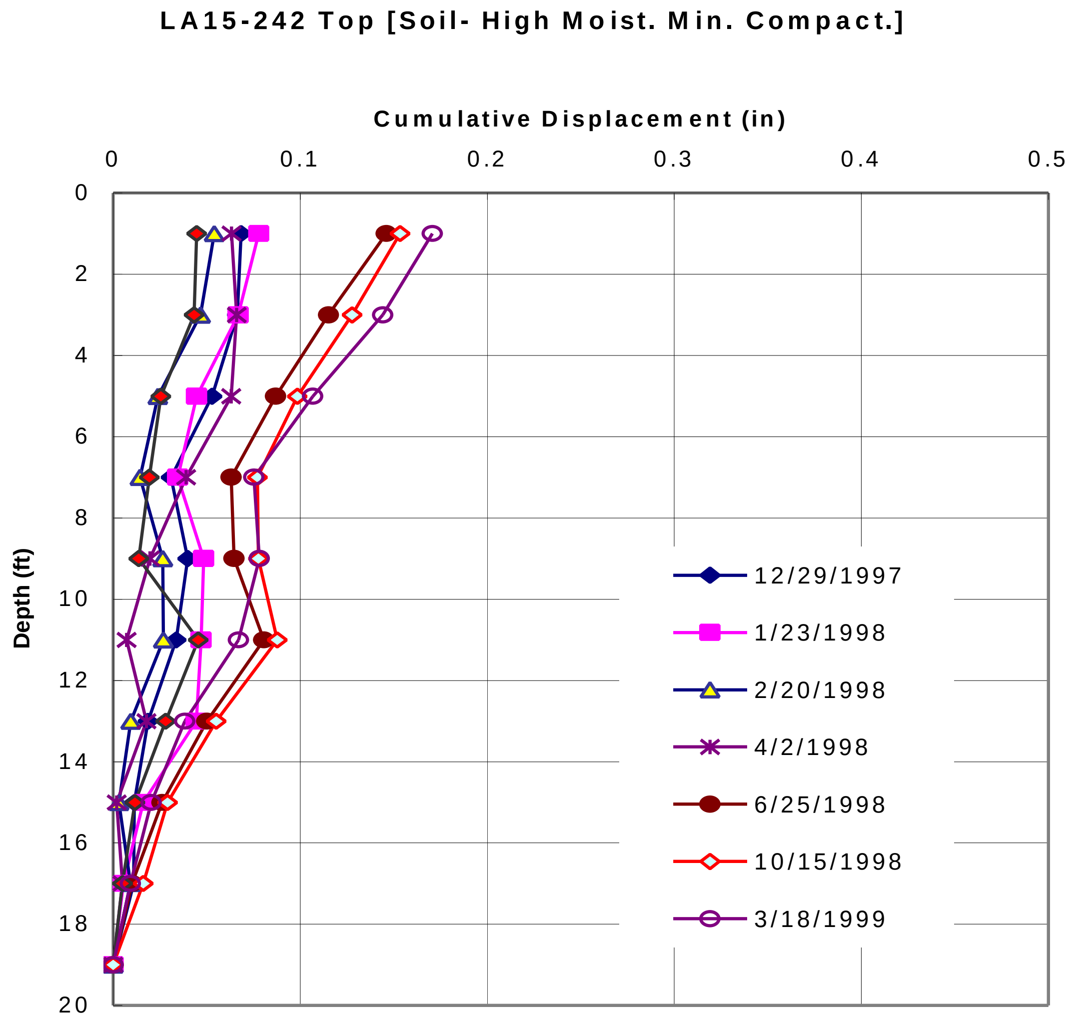


Figure C-11: Top inclinometer readings in section 242 [soil only]

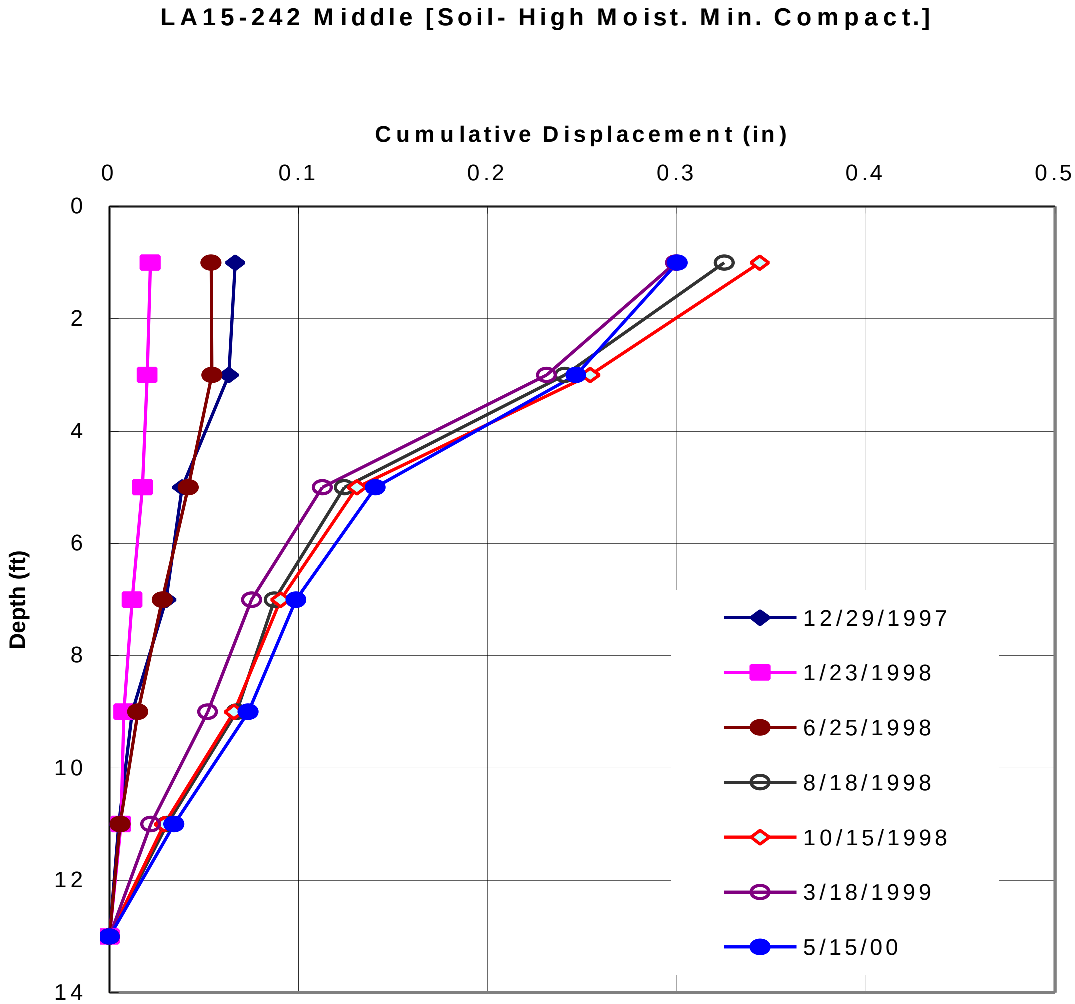


Figure C-12: Middle inclinometer readings in section 242 [soil only]

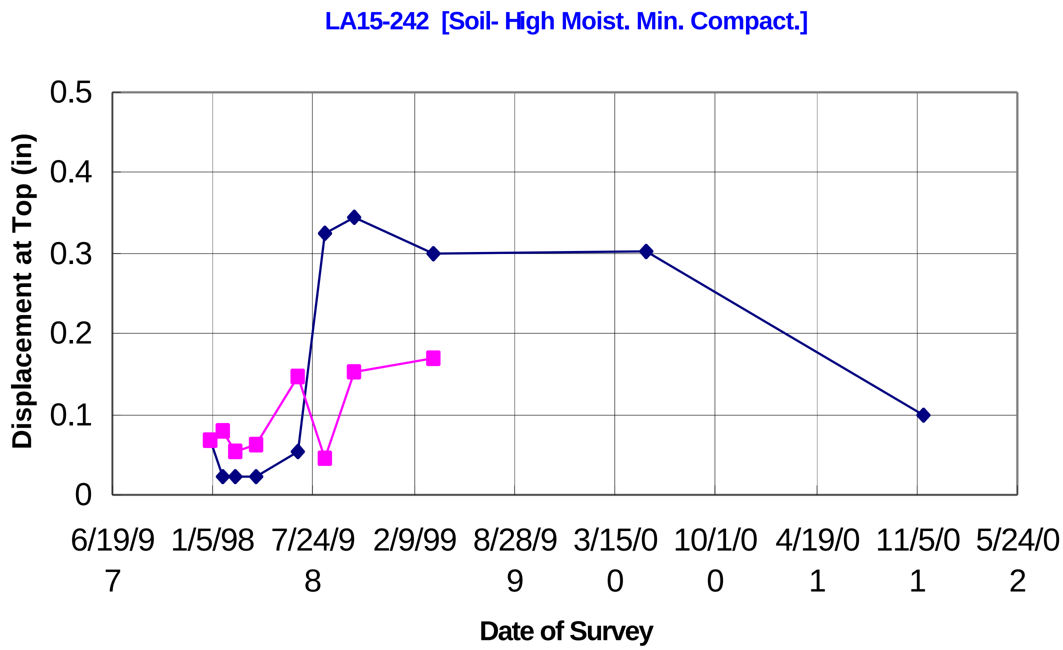


Figure C-13: Time deformation of the inclinometers, section 242

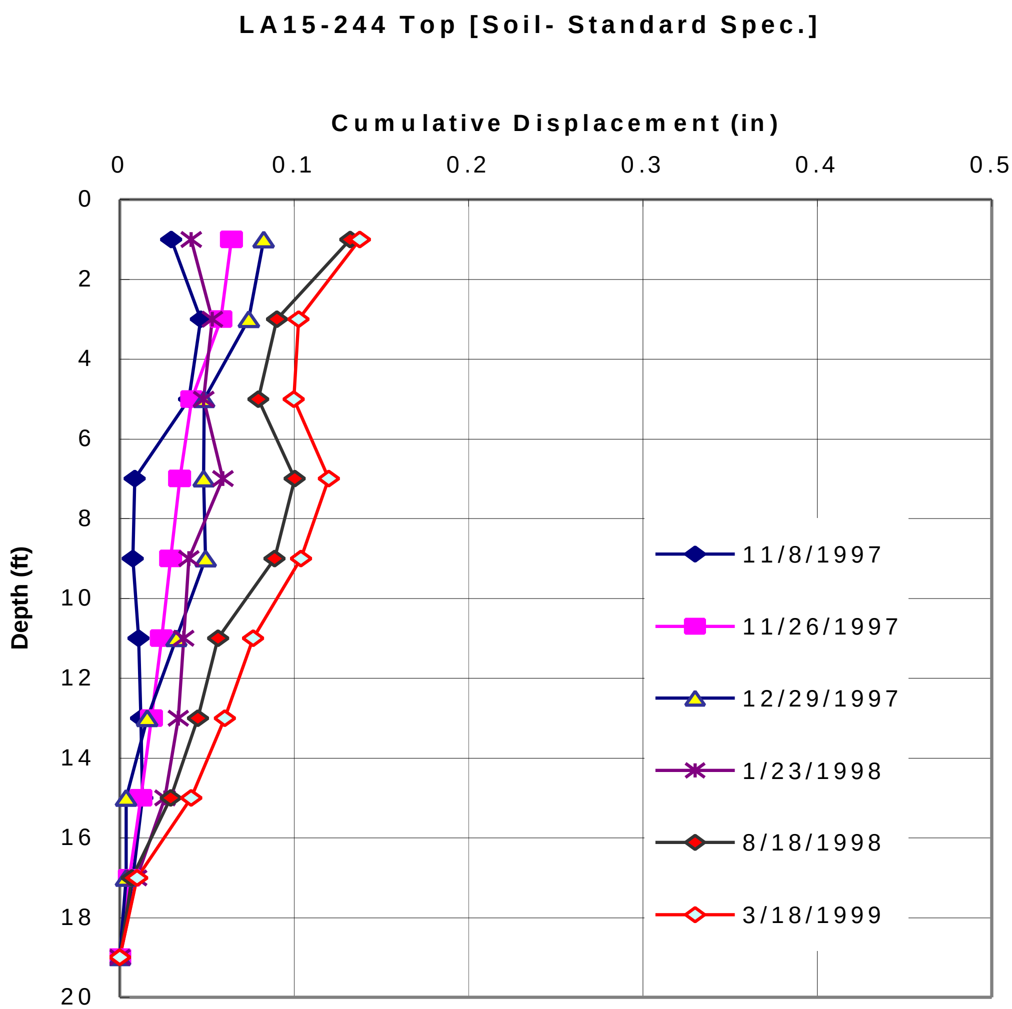


Figure C-14: Top inclinometer readings in section 244 [soil only]

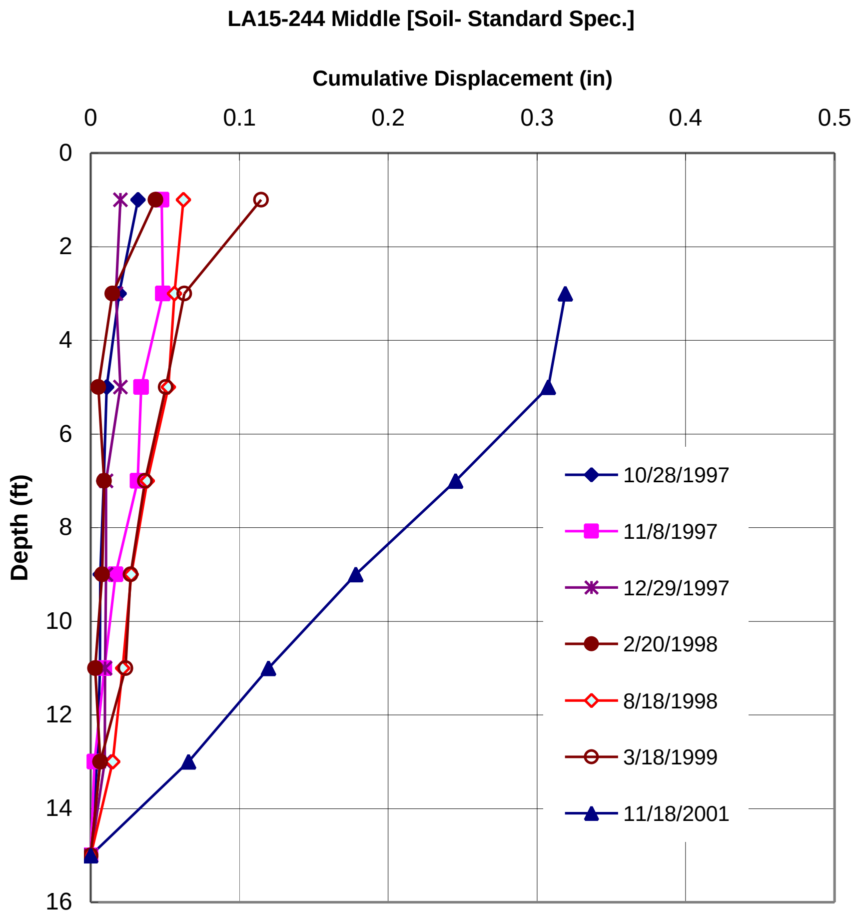


Figure C-15: Middle inclinometer readings in section 244 [soil only]

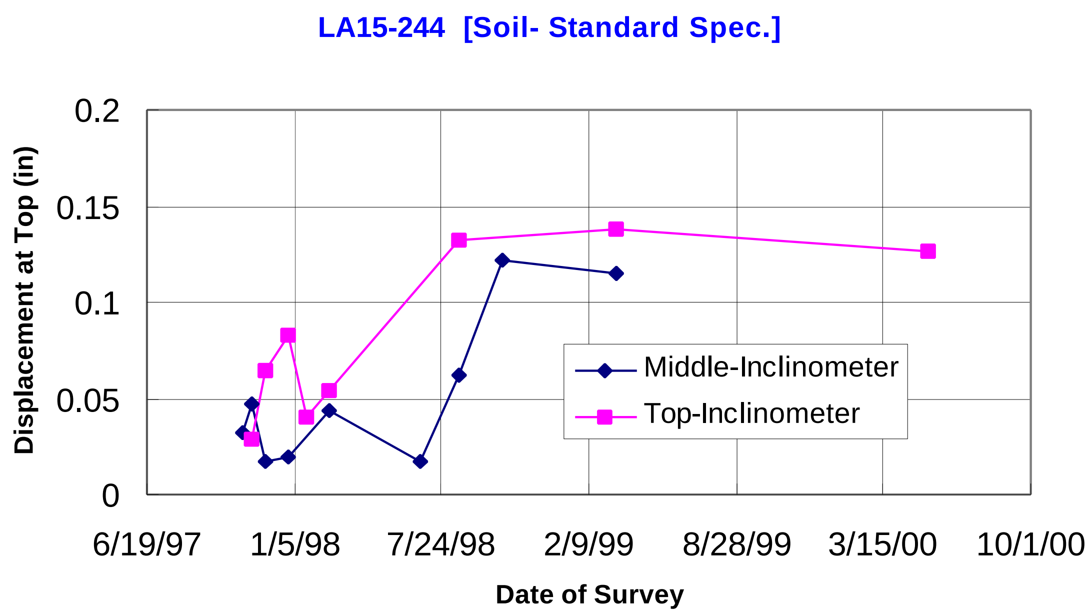


Figure C-16: Time deformation of the inclinometers, section 244

APPENDIX D

FABRIC INCLINOMETER READINGS

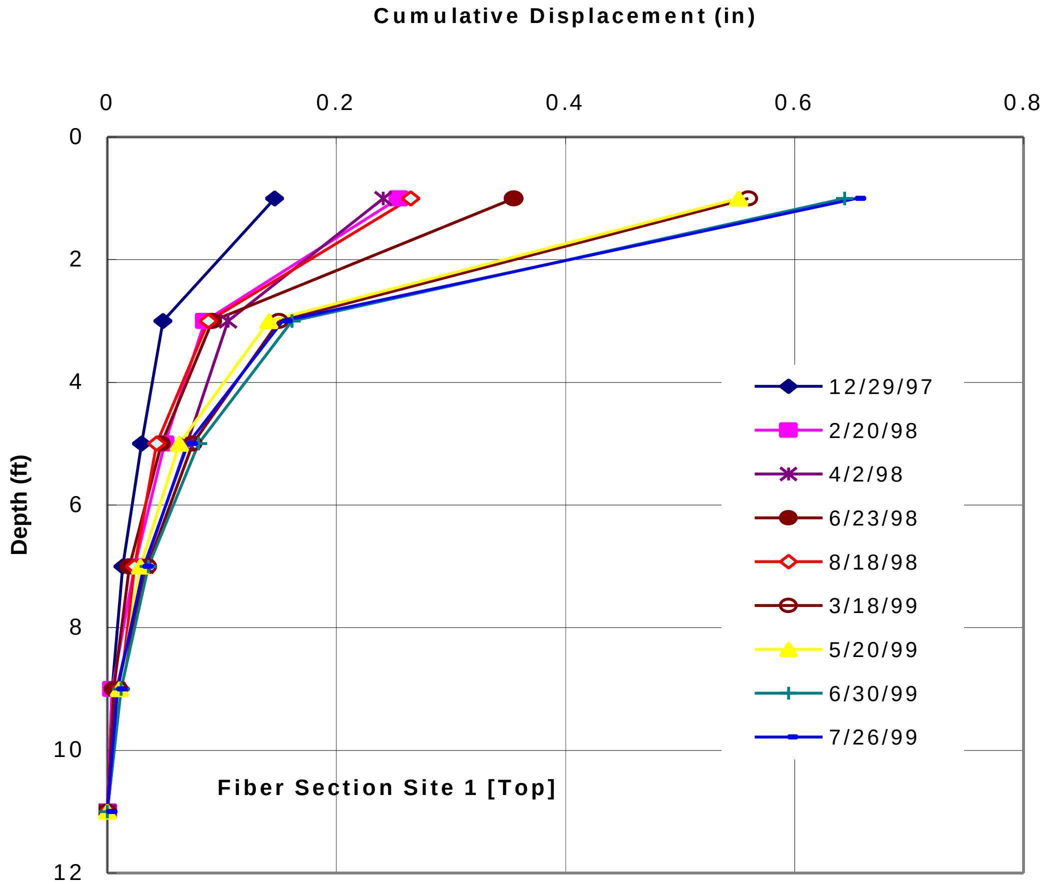


Figure D-1: Readings of the top inclinometer in fabric section 1

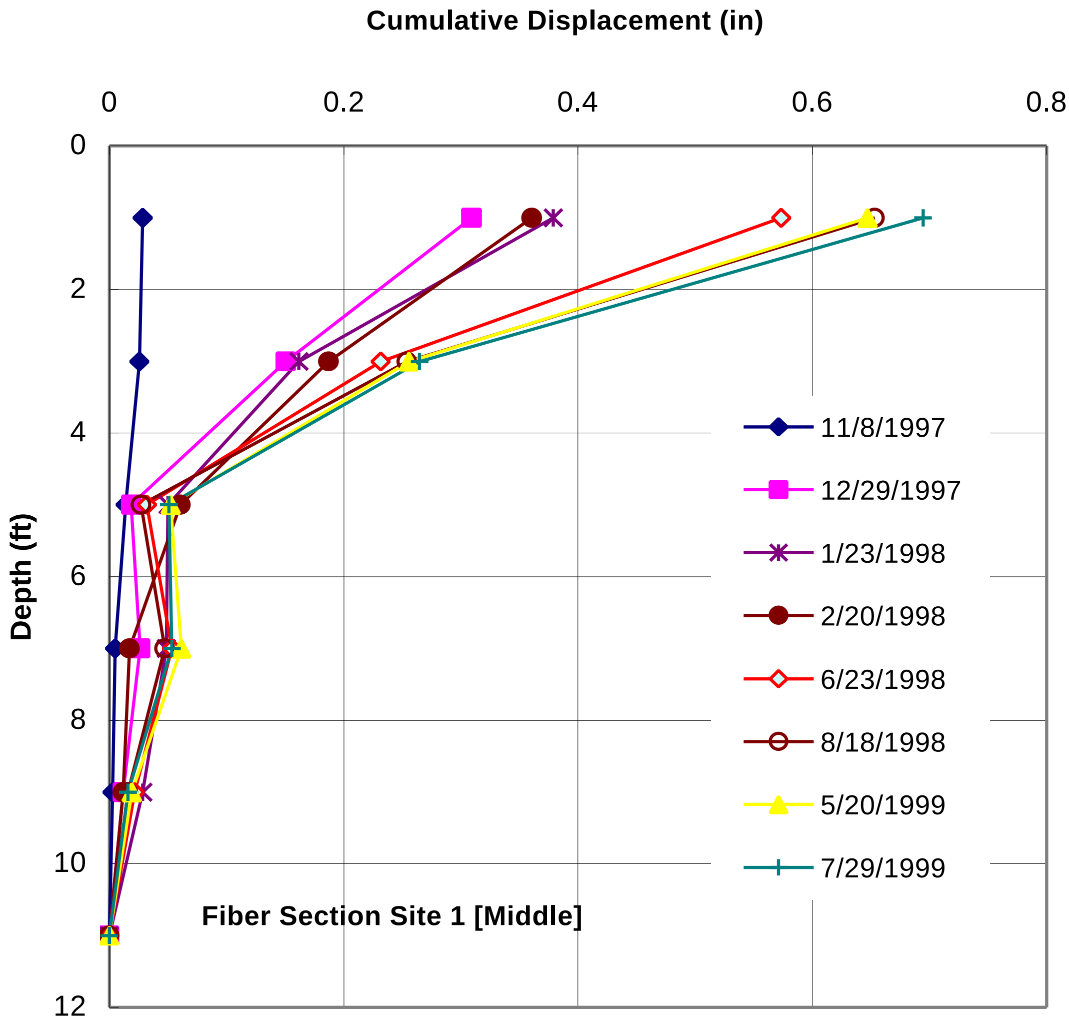


Figure D-2: Readings of the middle inclinometer in fabric section 1

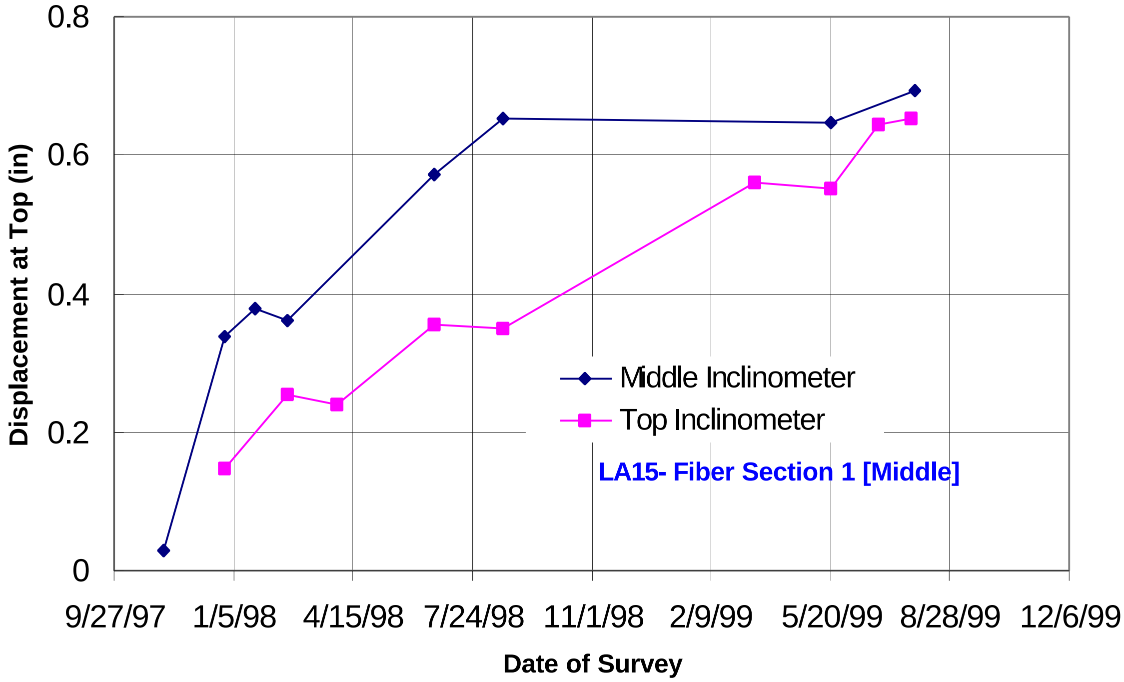


Figure D-3: Time-deformation readings in fabric section 1

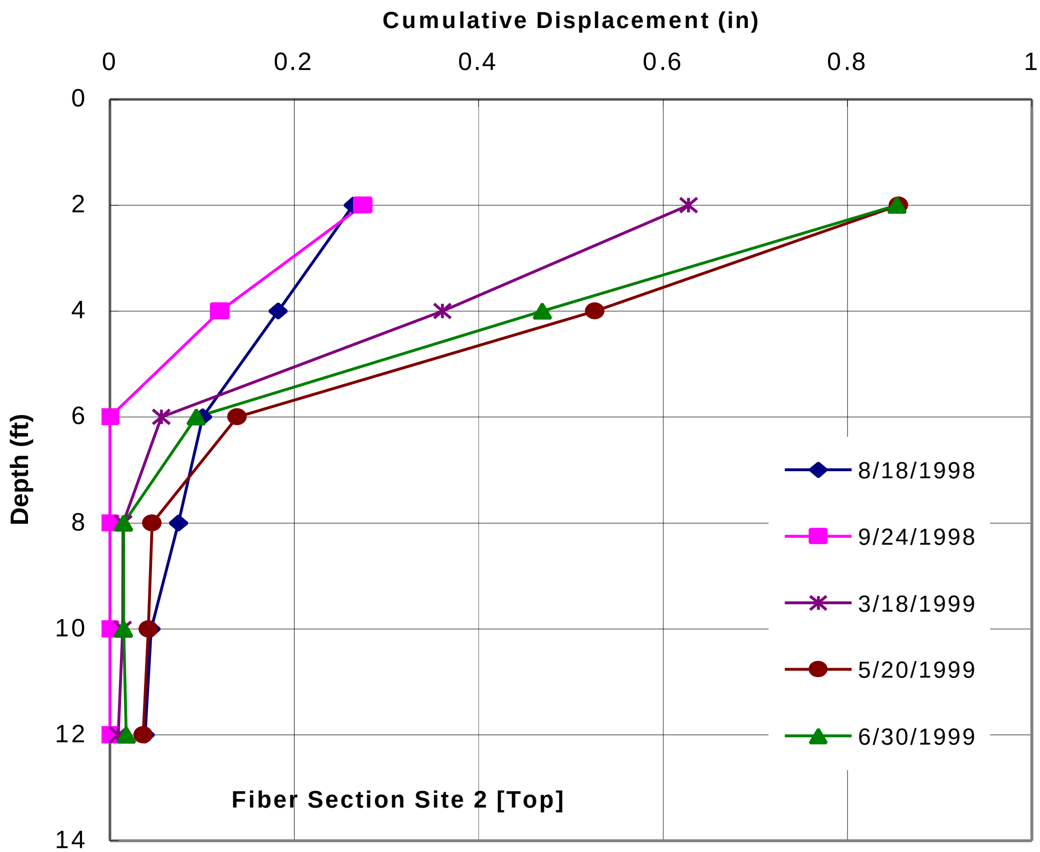


Figure D-4: Readings of the top inclinometer in fabric section 2

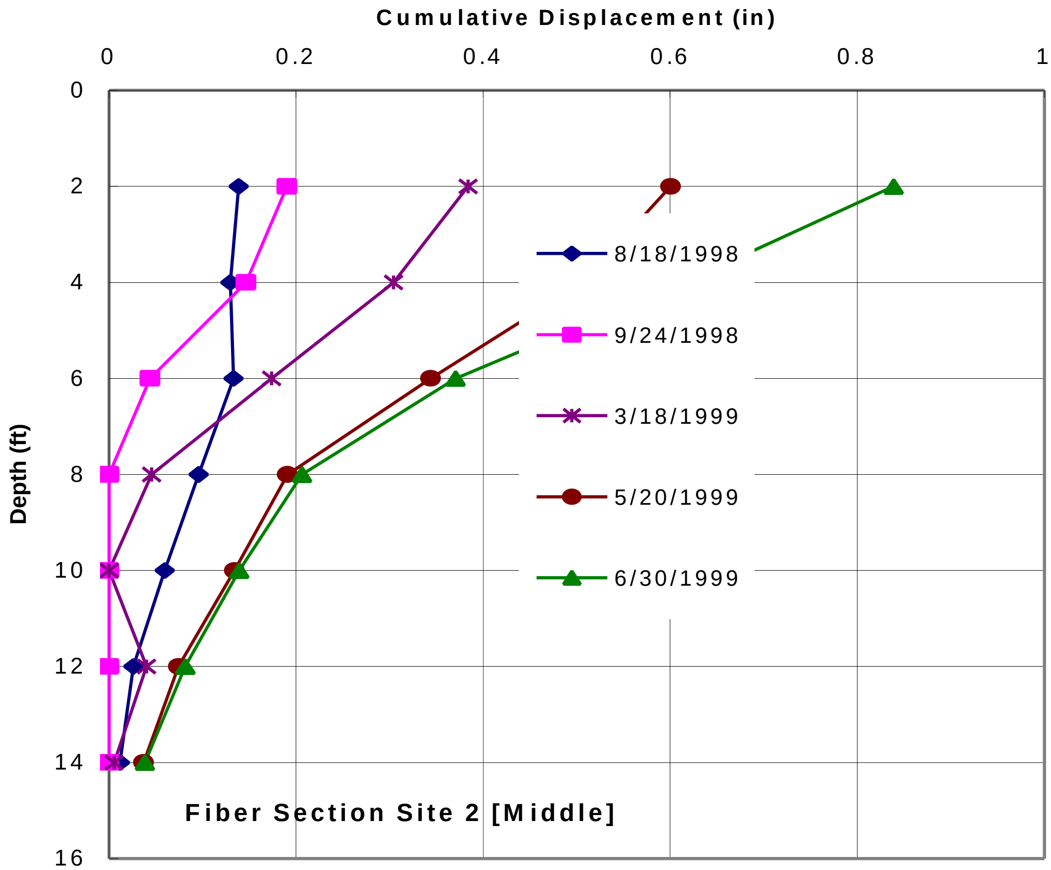


Figure D-5: Readings of the middle inclinometer in fabric section 2

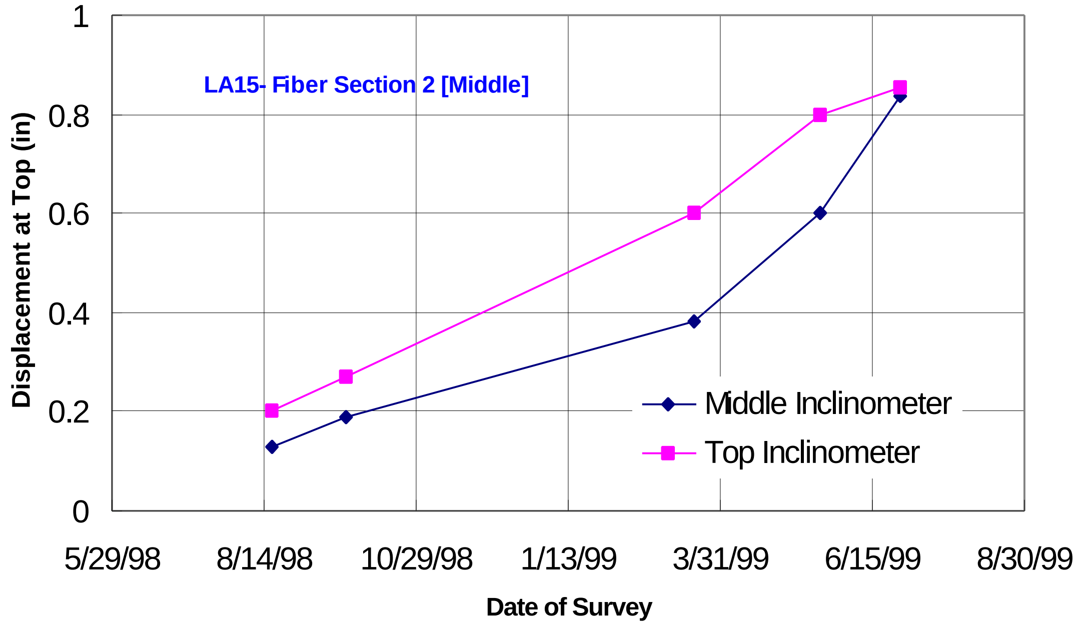


Figure D-6: Time deformation readings in fabric section 2