

FINAL REPORT

For the Florida Department of Transportation

**Constructability of Stabilized Subgrade Layer
Under High Groundwater Table**

FDOT Research Contract No.: BC-352-7

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by

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METRIC CONVERSIONS

inches = 25.4 millimeters

feet = 0.305 meters

square inches = 645.1 millimeters squared

square feet = 0.093 meters squared

cubic feet = 0.028 meters cubed

pounds = 0.454 kilograms

poundforce = 4.45 newtons

poundforce per square inch = 6.89 kilopascals

pound per cubic inch = 16.02 kilograms per meters cubed

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| 16. Abstract <p>This research consists of a laboratory experimental program and a field experimental program to determine the minimum separation required between the bottom of subgrade and the groundwater table for adequate compaction of the subgrade layer. Two full-scale test pits and two field sites were used to simulate the field conditions in highway construction. Various soil types (both the embankment and subgrade materials) were investigated and both static and dynamic compacting methods were studied in the research. Water levels in the test pits were set to different levels to simulate various groundwater table levels. At the field sites, subgrade elevations were varied in relation to existing groundwater table to achieve targeted water levels. The experimental programs were conducted to evaluate whether or not the subgrade layers could be constructed according to specifications under various levels of groundwater table.</p> <p>The experimental results indicated that constructability of the subgrade soils used by this study was not a problem by either static or dynamic compaction where the groundwater table was about 18 to 24 inches below the subgrade-embankment interface. Static compaction would be preferred for compacting subgrade layers in this study.</p> | | |
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EXECUTIVE SUMMARY

In highway construction, loose embankment and subgrade soils must be compacted to increase their density. Compaction increases the strength characteristics of soils, thereby increasing the bearing capacity of the pavement constructed above them.

However, due to various reasons, road grades sometimes do not allow for much clearance between the pavement section and the groundwater table. When an adequate separation is not provided between the stabilized subgrade and the groundwater table, difficulties in compacting the stabilized subgrade are often encountered. Research is needed to determine the minimum separation required between the bottom of the stabilized subgrade and the groundwater table so that construction can proceed without delay.

This research consists of a laboratory experimental program and a field experimental program. Two full-scale test pits and two field sites were used to simulate the field conditions in highway construction. Various soil types (both the embankment and subgrade materials) were investigated and both static and dynamic compacting methods

were studied in the research. Water levels in the test pits were set to different levels to simulate various groundwater table levels. At the field sites, subgrade elevations were varied in relation to existing groundwater table to achieve targeted water levels. The experimental programs were conducted to evaluate whether or not the subgrade layers could be constructed according to specifications under various levels of groundwater table.

The experimental results indicated that constructability of the subgrade soils used by this study was not a problem by either static or dynamic compaction where the groundwater table was about 18 to 24 inches below the subgrade-embankment interface. Static compaction would be preferred for compacting subgrade layers in this study.

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CHAPTER 1 INTRODUCTION

1.1 Background

In highway construction, loose embankment and subgrade soils must be compacted to increase their density. Compaction increases the strength characteristics of soils, thereby increasing the bearing capacity of the pavement constructed above them. Compaction also decreases the undesirable settlement of pavement structures and increases the stability of embankment slopes.

However, due to various reasons, road grades sometimes do not allow for much clearance between the pavement section and the groundwater table. When an adequate separation is not provided between the stabilized subgrade and the groundwater table, difficulties in compacting the stabilized subgrade are often encountered. Underdrains have not been found to be an adequate solution to this type of problems because to be effective across the entire width of the roadway, they would have to be placed at extremely impractical depths. These constructability problems are

sometimes so severe, work must be stopped and the project redesigned during construction.

1.2 Statement of Problem

A case history is presented in Appendix A to demonstrate the problem during construction due to a high groundwater table level. The constructability problem resulted in large claims and delays. The project was forced to be redesigned using an asphalt base in place of the limerock base. A 90-day time extension and an extra \$500,000 for walls and fill were required to resolve the problem for almost 0.5 miles of the roadway construction (see Appendix A for details).

Most past research studies have focused on the needed separation (base clearance) between the base and the groundwater table to ensure long-term performance of the pavement section. However, the most critical condition in designing base clearance, which needs to be taken into consideration, is the period during construction when the contractor is trying to compact the stabilized subgrade. Research is needed to determine the minimum separation required between the bottom of the stabilized subgrade and the groundwater table so that construction can proceed

without delay and to ensure the stabilized subgrade can be compacted to the desired density.

1.3 Study Objective

The primary objective of this research was to study the constructability of pavement subgrade layers under various levels of high groundwater table in the underlying layer so that a minimum required clearance above the water table could be determined in order for the subgrade layers to achieve an adequate compaction as required by construction specifications. The research goal was to evaluate whether or not the subgrade layers could be constructed according to construction specifications for different types of soil materials under varying groundwater tables.

1.4 Scope of Study

To achieve the objective, a full-scale laboratory experimental program and a field experimental program were conducted to evaluate the constructability of the subgrade layers. Two large test pits were set up in the laboratory to simulate the field conditions of compacting subgrade layers under various levels of high groundwater table. Two field test sites were also selected to evaluate the

constructability problems under actual field compaction. An A-3 soil with 5% fines and an A-2-4 soil with 12% fines were selected for the embankment materials. The selected embankment materials were typical Florida soils and believed to be representative of the most commonly used pavement materials in Florida.

1.5 Report Organization

This report summarizes the study to evaluate the constructability of pavement subgrade layers under various levels of high groundwater in both the test pit and actual field conditions. As in the first chapter, the background, problem statement, and study objectives are introduced. The full-scale laboratory experimental program is discussed in chapter 2. Laboratory experimental results are presented in two separate parts. The first part, which is the capillary rise behavior, is presented and analyzed in Chapter 3. The second part of laboratory experimental results focuses on the constructability study of the subgrade soils, and is presented and analyzed in Chapter 4. The field experimental program is described and discussed in Chapter 5. A comparison of laboratory and field experimental constructability results is summarized in Chapter 6. Finally, conclusions and recommendations are presented in

Chapter 7. A case history concerning the type of constructability problems encountered in Florida is presented in Appendix A. A literature review related to the capillary rise in soils is presented in Appendix B.

CHAPTER 2 LABORATORY EXPERIMENTAL PROGRAM

2.1 General

The primary objective of this research was to study the constructability of subgrade layers under various levels of high groundwater table in the underlying layer so that a minimum required clearance above the water table could be determined for achieving desired compaction of the constructed subgrade layers. To achieve the objective, a full-scale laboratory experimental program was initiated to evaluate the constructability of subgrade layers in a large test pit. Two test pits were set up for the experimental program at the FDOT State Materials Office in Gainesville, Florida. The purpose of the test-pit program was to simulate the field conditions of compacting pavement subgrade layers under high groundwater tables. The subgrade and embankment materials were selected and believed to represent the most commonly used pavement materials in Florida. The testing programs are described in the following sections.

2.2 Test Material

The materials under evaluation in this research study were:

- Embankment Soils:
 - A-2-4 soil (12% passing No. 200 sieve)
 - A-3 soil (5% passing No. 200 sieve)
- Stabilized Subgrade Soils:
 - A-2-4 soil (12% passing No. 200 sieve) (denoted as Subgrade A)
 - A-2-4 soil (12% passing No. 200 sieve) mixed with 25% (by weight) of limerock (denoted as Subgrade B)

The tested soils are easily available and typically used in Florida as embankment and stabilized subgrade. Tests were conducted to measure the basic properties of the subgrade soils. The compaction characteristics of the subgrade materials for A-2-4 soil (12% passing No. 200 sieve), denoted as Subgrade A, and A-2-4 soil (12% passing No. 200 sieve mixed with 25% of limerock), denoted as Subgrade B, are presented in Table 2.1.

Two other subgrade materials, an A-2-4 soil stabilized with 40% of limerock and a clay stabilized soil, were planned to be evaluated in the test pits as subgrade soils at the project planning stage. However, after the A-2-4(12%) and the A-2-4(12%) with 25% of limerock were

completed in the test pit program as stabilized subgrade soils, two actual full-scale field tests were implemented to evaluate the targeted goal. Therefore, only two types of soil were used as stabilized subgrade soils in the test pit simulation.

2.3 Test Pit Program

The Florida DOT test-pit program was adopted for this research study. A new state of the art facility including two test pits was constructed and completed in September 2002, and was used for this study. The test pit is a controlled environment structure where soil or recycled materials can be constructed as a model pavement and evaluated. The test pit is a 24 ft x 9 ft x 7 ft deep structure that is surrounded by a sump with an interconnecting channel system for controlling the water table. Soils or other materials to be tested are placed, usually in six inch lifts, and compacted to a specific density. After all the materials are in place, the water level is adjusted to the desired height. The testing is usually done under different water levels to simulate the various situations in the field.

The test pit evaluation of subgrade soils provides the following advantages:

- (a) The test pit can be used to simulate different material components of a pavement system on a full-scale basis
- (b) The test pit can be used to simulate various water content in a pavement system
- (c) The test pit can be used to evaluate the constructability of subgrade layer by static and dynamic compactors

After the water level has been set to the desired height, a Time Domain Reflectometry (TDR) probe can be deployed in the test pit to observe the capillary action. During the testing, the TDR probe can provide the moisture profile of tested materials. A brief description of the test pit program is presented as follows.

2.3.1 Test Pit Setup

As shown in Figure 2.1, the Florida DOT test pit set for the constructability study is shaped like a rectangular reinforced concrete vessel that is 24 feet long, nine feet wide, and seven feet deep (Figure 2.2). There are three inter-connecting channels on the bottom of the test pit joined with a sump to allow the water to flow through (Figure 2.3). The materials in the test pit consist of four layers. The bottom layer is composed of a bed of 9-inch river gravel layer. A builder's sand layer with a depth of

nine inches is set upon the river gravel and separated by a permeable filter fabric. Both layers are composed of well absorbent materials and located on the interconnecting water channel system to facilitate the upward percolation of groundwater. For this study, a 36-inch embankment layer was placed in 12-inch lifts on the builder's sand layer and compacted to 100% of the maximum standard Proctor density. On top of the embankment soil was the 12-inch stabilized subgrade layer for evaluation (Figure 2.4).

A Kotron Model 801 transmitter presented in Figure 2.5 is connected to a sump around the test pit. The transmitter can monitor the water level in the sump through the probes connected with the sump. The sump, with an interconnecting channel system, can be used to adjust the water table in the test pits. By using this digital transmitter the water table level in the test pits can be set and monitored easily and precisely.

2.3.2 Testing Program

Five different water level conditions were used for the research study:

- 24-inches below the interface of the subgrade layer and the embankment layer, referred to as "at water level -24 inches" and thereafter

- 12-inches below the interface (at water level -12 inches)
- 6-inches below the interface (at water level -6 inches)
- 6-inches below the interface (at water level -6 inches (drained))
- 12-inch below the interface (at water level -12 in. (drained))

The five water table conditions are illustrated in Figure 2.4.

Since two embankment soils (A-3 (5%) and A-2-4 (12%)) and two subgrade soils (A-2-4 (12%) and A-2-4 (12%) mixed with 25% of limerock) were studied in the research, the two embankment soils were arranged in two separate test pits. In order to make the test program more efficient, the two subgrade soils were placed on top of the embankment soil and divided by a wood board in each of the two test pits as shown in Figures 2.6 and 2.7. A cross sectional view of the test pit experimental program is illustrated in Figure 2.8. A summary of the test pit experimental program is presented in Table 2.2. The compaction data of the embankment soils are presented in Table 2.3.

2.3.3 Compaction Techniques

The tested subgrade soils were compacted by two types of compactors, i.e., static compactors and dynamic compactors, to simulate field compactive efforts. Four compactors were employed in the research study, and the main characteristics are summarized in Table 2.4. The pictures of the compactors are shown in Figures 2.9, 2.10, 2.11, and 2.12.

The compactive energy was represented by "cover", which meant the compactor was moved back and forth on the subgrade soil for a complete cover. The dry unit weight (density) of the compacted subgrade soil was measured by the nuclear gauge method (AASHTO T310). The desired dry densities for both subgrade soils were 98% of the maximum modified Proctor density.

2.4 Moisture Content Measurements

To obtain the dry density of the subgrade soils, the moisture content was needed. Meanwhile, the moisture content in the embankment soils was required to monitor the capillary behavior and water movement in the soils. The subgrade soil moisture content was measured by the nuclear gauge and the oven moisture method while a set of TDR

probes were deployed to take measurements of the embankment soil moisture.

2.4.1 Moisture Measurement on Subgrade Soil

Several methods can be used to estimate the soil moisture content. The moisture content obtained by the oven method (AASHTO T265) is commonly believed to be the most accurate. In this laboratory simulation experiment, two methods were adopted to estimate the moisture. To measure the dry density of the 12-inch subgrade layer, the oven moisture was used for better accuracy. To obtain the dry density of the top 6-inch subgrade layer, which was just for comparison, the nuclear gauge moisture was used for Water Conditions 1 and 2, and the oven moisture for Water Conditions 3, 4 and 5 (refer to section 2.5). Using the nuclear gauge moisture measurement was convenient since the nuclear gauge was used to read the wet density also.

A separate calibration test was conducted to determine the nuclear gauge moisture to the oven moisture. A strong container with approximate dimensions of 24 in. x 24 in. x 16 in. was used for the calibration test as shown in Figure 2.13. The calibration procedures can be described as follows:

- 1) Warm up the nuclear gauge and take the standard count

- 2) Fill the container in 3-inch layers and compact each layer uniformly
- 3) Prepare a horizontal area, sufficient in size to accommodate the gauge, by leveling to a smooth surface to obtain the maximum contact between the gauge and the material being tested. The maximum depressions beneath the gauge shall not exceed 3 mm (1/8 in.). Use fine sand to fill the voids and level the excess with a rigid plate or other suitable tool
- 4) Take nuclear moisture readings at depths of 6 and 12 inches, but not less than 6 inches
- 5) Obtain 500 to 1000 grams of material throughout the depth of the test for two separate oven-dried samples. One sample is throughout the 6 inches and the other is throughout the 12 inches
- 6) Determine the moisture of two samples by the oven method
- 7) Unload the tested material, add moisture and mix it thoroughly with cement mixer. Add extra soils to replace the oven samples
- 8) Repeat the above procedure for at least 10 times for different moisture content

The calibration test data sheets for the A-2-4 (12%) and A-2-4 (12%) mixed with 25% limerock are shown in Tables 2.5 and 2.6. The calibration curves for those two soils are shown in Figures 2.14 and 2.15.

According to the figures, the following two equations were used to convert the easily obtained nuclear gauge moisture content to a more accurate oven moisture:

- For A-2-4 (12%) soil (subgrade A)

$$\text{Oven moisture (\%)} = \text{gauge moisture (\%)} \times 0.9697 + 1.4777$$

- For A-2-4 (12%) + 25% limerock (subgrade B)

$$\text{Oven moisture (\%)} = \text{gauge moisture (\%)} \times 0.8874 + 2.1665$$

2.4.2 Moisture Measurement on Embankment Soil

Originally developed to measure the dielectric constant of homogeneous materials, conventional Time Domain Reflectometry (TDR) techniques have been usefully applied to soil measurement for many years. TDR has many advantages over other methods of soil moisture measurement. It offers excellent spatial resolution and definition, the ability to measure close to the soil surface, and its signals can be multiplexed and directly post processed using computers. In addition, measurements of volumetric water content are substantially independent of soil type and salinity for most soil types.

One of the properties of TDR is that the round trip time of a pulse through a transmission line embedded in the soil is directly related to the moisture content of the soil (i.e., the more moisture in the soil, the longer the round trip time). By measuring the time it takes for the pulse to travel across a small portion, or segment of the probe, the moisture content of that segment can be determined.

A new state of the art TDR device was employed to observe the moisture variation during the capillary rise in embankment soils. A brief description of the new TDR device follows.

2.4.2.1 TDR Equipment. A new piece of TDR based apparatus was used in the test pit to monitor the moisture profile of pavement material. This system is called "Moisture·Point" manufactured by Environmental Sensors Inc. (ESI) for measuring the volumetric moisture content in soils.

As shown in Figure 2.16, the Moisture·Point system is composed of two main parts: MP-917 data viewing/logging instrument (Figure 2.17) and the profiling probes (Figure 2.18).

(A) MP-917 data viewing/logging instrument

The MP-917 instrument is specifically designed to interpret data from Moisture Point probes, display data retrieved, and/or export the data received to a datalogger. The entire process is automatic once the MP-917 "MEASURE" activation button is pressed. Digital data displayed is an average "Volumetric Water Content" measured over the length of each probe segment. Moisture Point readings achieve the stated accuracy without soil calibration. The MP-917 is pre-loaded with factory calibration coefficients for the standard probes offered by ESI.

(B) System Probes

The system probe delivers contiguous vertical profiles of soil moisture content. The standard probe resembles a long, rectangular black and silver spear. It consists of two flat stainless steel side bars with black epoxy filler sandwiched between. Encased in the epoxy filler is the electronic circuitry that defines each segment length.

The probe is 0.50 x 0.75 inches or approximately 1.4 x 2.0 cm. through a cross section. As indicated in Figure 2.18, the profiling probe comprises five measuring segments. Moisture measurement for each segment is the average moisture content over the length of the segment.

2.4.2.2 Gravimetric and Volumetric Moisture. Only the volumetric moisture content can be measured from the

TDR device. To obtain gravimetric moisture from the volumetric moisture, the relationship between gravimetric and volumetric moisture needs to be established.

The volumetric moisture indicates the relationship between the volume of water of a sample and the total volume of the sample.

$$\omega_{vol} = \frac{V_{water}}{V_{total}} \times 100\%$$

Where,

ω_{vol} = volumetric moisture of sample in percentage by volume

V_{water} = volume of water inside the sample (ft³)

V_{total} = total volume of the sample (ft³)

The gravimetric moisture indicates the relationship between the weight of water of a sample and the dry weight of the sample in percentage.

$$\omega_{grav(d)} = \frac{W_{water}}{W_d} \times 100\%$$

Where,

$\omega_{grav(d)}$ = gravimetric moisture on a dry weight basis in percentage by weight

W_{water} = weight of water present in the sample (lb)

W_d = dry weight of the sample (lb)

To obtain the gravimetric moisture from the volumetric moisture, the following conversion can be made:

$$\omega_{grav(d)} = \frac{W_{water}}{W_d} \times 100\% = \frac{W_{water}}{V_{water}} \times \frac{V_{water}}{V_{total}} \times \frac{V_{total}}{W_d} \times 100\% = \frac{\gamma_{water}}{\gamma_d} \times \omega_{vol} = \frac{\omega_{vol}}{0.016 \times \gamma_d}$$

Where,

γ_d = dry density of the sample (lb/ft³)

2.5 Experimental Procedure

The test pit experimental program for the research study was initiated in April 2001 at the Florida DOT State Materials Office. The first stage of the experimental program began with the preparation of the test materials. This stage was completed approximately August 2001 and involved the following tasks:

(A) Embankment Soil

Two embankment soils, an A-3 soil (5% passing No. 200 sieve) and an A-2-4 soil (12% passing No. 200 sieve), were separately placed and compacted at three 12-in lifts in the two test pits. Each lift was compacted to the desired dry density, i.e., 100% of the maximum density determined by the standard Proctor test. The compaction data are presented in Table 2.3. Basically,

the embankment soils were compacted and met the density requirements.

(B) Subgrade Soil

Two subgrade soils, an A-2-4 soil (12%) and an A-2-4 (12%) mixed with 25% limerock, were prepared and stored in bulk at a shed near the test pits.

The second stage of the experimental program involved the water table adjustment and monitoring of the capillary action taking place in the embankment soils. After the water table in the test pits was set to one of the five desired levels, the capillary rise was monitored in the embankment soils. To ensure simulation of the field condition, the subgrade soils were placed and compacted after the capillary rise action in the embankment soils had been stabilized. TDR probes were employed to monitor the capillary behavior in the embankment soils. For measuring the moisture content variation with time, the TDR monitoring was continuously taken during the capillary rise prior to raising the water table to the next level in the test pit.

The third stage of the test involved the mobilization and compaction of the subgrade soils. Two stabilized subgrade soils, an A-2-4 (12%) and an A-2-4 (12%) plus 25% limerock were stored at a shed near the test pits. After a

careful estimation, a certain amount of the A-2-4(12%) soil was weighed and placed in the south part of two test pits, while the A-2-4 soil (12%) plus 25% limerock was placed in the north part. Then compaction was initiated on the subgrade soils. The compactive energy was measured simply by the "covers". After the subgrade soils were compacted for a certain number of covers, the wet density and moisture content of the subgrade soils were measured to check the results. The compaction would come to a halt when the desired density was achieved. Depending on the test results, a decision could be made when the required density could not be achieved under the circumstance. Upon completion, the compacted subgrade layers were then excavated and replaced with new materials for the next water level condition.

The first stage of the experimental program was completed by August 2001. Then, the second stage began with adjusting the water table to five different levels. The test pit evaluation for compacting the subgrade soils under five different water levels were:

- Condition 1: Water level at -24 inches below the interface
- Condition 2: Water level at -12 inches below the interface

- Condition 3: Water level at -6 inches below the interface
- Condition 4: Water level at -6 inches (drained) below the interface
- Condition 5: Water level at -12 inches (drained) below the interface

A description of the test procedure for each of the five test conditions follows.

2.5.1 Condition 1: Water level at -24 inches

The water table for the two test pits was set to 24 inches below the top of the embankment layer on August 13, 2001. Subsequently, four TDR probes were deployed in both test pits to continuously monitor the capillary action for the following 15 days. Based on the measured data, the capillary rises in both test pits were stabilized after 15 days of observation. Compaction of the subgrade soils began after the stabilization of capillary rise.

The subgrade soils were placed in the test pits and divided by a wood board (Figure 2.19). The compaction of the subgrade soils was conducted on October 2, 2001. A plate compactor, shown in Figure 2.9 was employed to conduct the compaction. The desired density was achieved in this case.

A chronicle description of the test procedure for this condition is summarized in Table 2.7. Experimental test results are presented in the subsequent chapters.

2.5.2 Condition 2: Water Level at -12 inches

The water table for both test pits was set to 12 inches below the top of the embankment layers on October 11, 2001. Subsequently, four TDR probes were deployed in both test pits to monitor the capillary action for the following 27 days.

The capillary rises in both test pits monitored by TDR were stabilized after 27 days according to the moisture content measurements.

Compaction of subgrade soils was initiated after the stabilization of capillary action. Two types of subgrade soils were placed in the test pits and divided by a wood board (Figure 2.19). The compaction of the subgrade soils for both test pits was performed on November 8, 2001. A plate compactor, shown in Figure 2.9, was employed to conduct the compaction. The desired density was achieved in this case.

A chronicle description of the test procedure for this condition is summarized in Table 2.8. Test results of the compaction activities are presented in the subsequent chapters.

2.5.3 Condition 3: Water level at -6 inches

The water table for both test pits was set to 6 inches below the top of the embankment layers on December 11, 2001. Subsequently, four TDR probes were deployed in both test pits to monitor the capillary rise for the following 29 days. Based on the monitored data, the capillary rises in both test pits were stabilized after 29 days.

Compaction of subgrade soils began after the stabilization of capillary action. Two types of subgrade soils were placed in the test pits and divided by a wood board (Figure 2.19). The compaction of the subgrade soils for both test pits was performed on January 9, 2002. A plate compactor, shown in Figure 2.9 was employed to conduct the compaction. At first, based on the oven moisture content, the compacted dry density was below the desired dry density for both test pits. The compaction was resumed on January 14, after six additional covers of compaction, the desired dry density of 98% of the maximum modified Proctor density was achieved.

A chronicle description of the activities for this condition is summarized in Table 2.9. Test results of the compaction activities are presented in the subsequent chapters.

2.5.4 Condition 4: Water level at -6 inches (drained)

After the compaction for Condition 3 was completed on January 14, 2002, the water table for the west test pit was raised to two inches above the top of the embankment layer. The water table was maintained at this level until March 20, 2002, when the water table was lowered down to six inches below the top of the embankment layer. The embankment layer was allowed seven hours for the water to drain down from the surface (interface). This test condition was only performed on the west test pit with the A-3 soil as embankment layer.

Two types of subgrade soils were placed in the west test pit and divided by a wood board (Figure 2.19) for compaction. A smooth-wheeled roller compactor, shown in Figure 2.12, was employed to conduct the compaction on March 20, 2002. After 32 covers of compaction, the compacted density was inclined to drop. A dynamic (vibratory) compactor, shown in Figure 2.11, was then adopted to resume the compaction. After additional 30 covers of compaction, the desired dry density was still not achieved. The test was terminated due the problem with constructability.

A chronicle description of the activities for this condition is summarized in Table 2.10. Test results of the compaction activities are presented in the subsequent chapters.

2.5.5 Condition 5: Water level at -12 inches (drained)

After the compaction for Condition 4 was completed on March 21, 2002, the water table for the west test pit was again raised to two inches above the top of the embankment layer. The water table was maintained at this level until June 3, 2002, when the water table was lowered down to 12 inches below the top of the embankment layer. The embankment layer was allowed 15 hours for the water to drain down from the surface level (or interface).

Two types of subgrade soils were placed in the west test pit and divided by a wood board. One set of earth pressure cells with instrumentation was embedded under the subgrade soil layer to evaluate the compactive energy. The plate compactor was employed to conduct the compaction on June 4, 2002 for the first two covers. A vibratory sheepsfoot compactor, shown in Figure 2.10, was then employed to compact the subgrade soil of both the north and south parts for additional four covers. In addition, six more covers of compaction by the vibratory sheepsfoot compactor were only performed on the north part (A-2-4 soil

+ 25% limerock as the subgrade soil) due to the operational difficulty of the compactor. The last four covers were compacted by the plate compactor for both the south and north parts. Finally, the desired dry density was achieved. The pressure cells showed that the vibratory sheepsfoot compactor delivered lower compactive energy than that of the plate compactor.

A chronicle description of the activities for this condition is summarized in Table 2.11. Test results of the compaction activities are presented in the subsequent chapters.

Table 2.1 Basic Properties of Stabilized Subgrade Materials

| Material | Sample No. | Modified Proctor Optimum Moisture Content (%) | Modified Proctor Maximum Dry Density (lb/ft ³) | LBR* |
|---|------------|---|--|------|
| A-2-4 (12%) (Subgrade A) | 1 | 12.5 | 110.8 | 42 |
| | 2 | 12.7 | 110.1 | 45 |
| | 3 | 12.8 | 110.1 | 45 |
| | Average | 12.7 | 110.2 | 44 |
| A-2-4 (12%) + 25% limerock (Subgrade B) | 1 | 12.9 | 111.0 | 37 |
| | 2 | 12.0 | 110.9 | 44 |
| | 3 | 12.6 | 110.6 | 35 |
| | Average | 12.5 | 110.8 | 39 |

* LBR= Limerock Bearing Ratio = 1.25 x (California Bearing Ratio)

Table 2.2 Test Pit Experimental Program

| Test Condition | Water Level (below the interface), inch | Embankment Soils | Subgrade Soils |
|----------------|---|-------------------------|----------------------------------|
| 1 | -24 | A-3 (5%) West Pit | A-2-4 (12%) South Part |
| | | | A-2-4 (12%) +25%LR North Part |
| | | A-2-4 (12%) East Pit | A-2-4 (12%) South Part |
| | | | A-2-4 (12%) +25%LR North Part |
| 2 | -12 | A-3 (5%) West Pit | A-2-4 (12%) South Part |
| | | | A-2-4 (12%) +25%LR North Part |
| | | A-2-4 (12%) East Pit | A-2-4 (12%) South Part |
| | | | A-2-4 (12%) +25%LR North Part |
| 3 | -6 | A-3 (5%) West Pit | A-2-4 (12%) South Part |
| | | | A-2-4 (12%) +25%LR North Part |
| | | A-2-4 (12%) East Pit | A-2-4 (12%) South Part |
| | | | A-2-4 (12%) +25%LR North Part |
| 4 | -6 (drained) | A-3 (5%) West Pit | A-2-4 (12%) South Part |
| | | | A-2-4 (12%) +25%LR North Part |
| 5 | -12 (drained) | A-3 (5%) West Pit | A-2-4 (12%) South Part |
| | | | A-2-4 (12%) +25%LR North Part |

Table 2.3 Compaction Data of Embankment Soils

| Soil Type | Lift NO. | Depth from the interface (inches) | Desired Density (lb/ft ³) | Optimum water content (%) | Actual Density (lb/ft ³) | Actual water Content (%) | Percent age of desired density (%) |
|----------------|----------|-----------------------------------|---------------------------------------|---------------------------|--------------------------------------|--------------------------|------------------------------------|
| A-3 (5%) | 1 | 24-36 | 110.8 | 10.9 | 109.9 | 10.1 | 99.2 |
| | 2 | 12-24 | | | 109.0 | 8.1 | 98.4 |
| | 3 | 0-12 | | | 110.1 | 10.1 | 99.4 |
| A-2-4 (12%) | 1 | 24-36 | 108.8 | 12.2 | 109.4 | 11 | 100.6 |
| | 2 | 12-24 | | | 108.0 | 7 | 99.3 |
| | 3 | 0-12 | | | 108.9 | 6.8 | 100.1 |

Table 2.4 Compactors Used in the Test Pit Program

| Brand (Type) | Model | Used for Water Level (in) | Comp. Depth (in) | Oper. Size (in) | Oper. Weight (lbs) | Center Force (lbs) | Comments |
|-------------------------------|-----------|---------------------------------|------------------|---------------------|--------------------|--------------------|-----------------|
| Wacker (Vibratory Plate) | BPU 3345A | -24 -12 -6 - 12 (D) | -28 | 35 x 23.6 | 636 | 7,550 | See Figure 2.9 |
| Rammer (Vibratory Sheepsfoot) | P33 HMR | - 12 (D) | N/A | 33 (Drum) | 3,175 | 15,975 | See Figure 2.10 |
| Gardener (Vibratory) | Plus 716 | -6 (D) | -8 | 4.0 x 8.0 (tire) | 139 | N/A | See Figure 2.11 |
| Wacker (Static Smooth Drum) | RD880 | -6 (D) | N/A | 36 (Drum) | 2,430 | 3,000 | See Figure 2.12 |

Table 2.5 Moisture Calibration Data Sheet (A-2-4(12%) Soil)

| Test No. | Nuclear Gauge Moisture (%) | | | Oven Moisture (%) | | |
|----------|----------------------------|------|---------|-------------------|------|---------|
| | 6" | 12" | Average | 6" | 12" | Average |
| 1 | 4.7 | 4.4 | 4.55 | 6.2 | 6.2 | 6.2 |
| 2 | 5.3 | 5.4 | 5.35 | 6.9 | 7.1 | 7 |
| 3 | 7.6 | 7.2 | 7.4 | 8.4 | 8.5 | 8.45 |
| 4 | 8.6 | 9.3 | 8.95 | 9.8 | 10 | 9.9 |
| 5 | 10.7 | 10.6 | 10.65 | 11.3 | 11.5 | 11.4 |
| 6 | 12.7 | 12.8 | 12.75 | 13 | 13.1 | 13.05 |
| 7 | 15.7 | 15.4 | 15.55 | 16.4 | 16.9 | 16.65 |
| 8 | 17 | 16.9 | 16.95 | 17.5 | 18.2 | 17.85 |
| 9 | 6.1 | 5.6 | 5.85 | 6.5 | 6.2 | 6.35 |
| 10 | 5.2 | 4.7 | 4.95 | 6.8 | 6.9 | 6.85 |
| 11 | 9.8 | 9.9 | 9.85 | 11.4 | 11.4 | 11.4 |
| 12 | 15.4 | 15.2 | 15.3 | 17 | 17.3 | 17.15 |

Table 2.6 Moisture Calibration Data Sheet (A-2-4(12%
+25%LR Soil)

| Test No. | Nuclear Gauge Moisture (%) | | | Oven Moisture (%) | | |
|----------|----------------------------|------|---------|-------------------|------|---------|
| | 6" | 12" | Average | 6" | 12" | Average |
| 1 | 3.3 | 3.3 | 3.3 | 5 | 5.2 | 5.1 |
| 2 | 4.2 | 3.9 | 4.05 | 5.3 | 5.9 | 5.6 |
| 3 | 6.4 | 6.4 | 6.4 | 7.7 | 7.3 | 7.5 |
| 4 | 7.7 | 7.4 | 7.55 | 9.1 | 9 | 9.05 |
| 5 | 9.5 | 10.1 | 9.8 | 10.5 | 10.8 | 10.65 |
| 6 | 10.9 | 11.1 | 11 | 12.1 | 12 | 12.05 |
| 7 | 12.7 | 12.3 | 12.5 | 13.6 | 13.6 | 13.6 |
| 8 | 14.6 | 15 | 14.8 | 15.4 | 15.6 | 15.5 |
| 9 | 16.7 | 15.9 | 16.3 | 17.4 | 17.5 | 17.45 |
| 10 | 20.4 | 19.6 | 20 | 19.1 | 19.5 | 19.3 |
| 11 | 17.8 | 18.2 | 18 | 17.2 | 18.4 | 17.8 |

Table 2.7 Test Pit Procedures for Condition 1

| Date | Embankment Materials | Description of Test Procedures |
|---------------------------|---|--|
| 08/13/01 | A-3 (5%) A-2-4 (12%) (Both Test Pits) | Water table set to -24" |
| 08/13/01 - 08/27/01 | A-3 (5%) A-2-4 (12%) (Both Test Pits) | TDR probes deployed in the test pit. Moisture contents were measured. The capillary rise was stabilized. |
| 10/01/01 | A-3 (5%) (West Test Pit) | Two types of subgrade soils were placed in the test pit and divided by a wood board. |
| 10/02/01 | A-3 (5%) West Test Pit | Subgrade soils were compacted by a plate compactor. After 1,3,5,7,11,15 covers, for each part of the test pit, a nuclear gauge was deployed on 3 different spots to measure the average wet density of the subgrade soils. (Sketch is shown in Figure 2.21). On each spot, soil sample was taken and instant speedy moisture was obtained to determine the dry density. More accurate oven moisture would be found later. The instant results showed the desired dry density was not achieved. |
| 10/03/01 | A-3 (5%) West Test Pit | Subgrade soils were continuously compacted by a plate compactor. After 19,25,31,41,51 covers, the same procedures used on 10/02/01 was followed and the desired dry density, 98% of maximum modified Proctor density, was obtained from the nuclear gauge results. |
| 10/03/01 | A-2-4 (12%) East Test Pit | Two types of subgrade soils were placed in the test pit and divided by a wood board. |
| 10/04/01 | A-2-4 (12%) East Test Pit | Subgrade soils were compacted by a plate compactor. The procedures were simplified comparing with west test pit. After 4,8,16,24,32 covers, for each part of the test pit, a nuclear gauge was deployed on 1 spot to measure the wet density of the subgrade soils. (Sketch is shown in Figure 2.22). On each spot, a soil sample was taken and instant speedy moisture was obtained to determine the dry density. More accurate oven moisture would be found later. The instant results showed the desired dry density, 98% of maximum Proctor density, was achieved. |

Table 2.8 Test Pit Procedures for Condition 2

| Date | Embankment Materials | Description of Test Procedures |
|-----------------------|---|---|
| 10/11/01 | A-3 (5%) A-2-4 (12%) (Both Test Pits) | Water table set to -12" |
| 10/11/01- 11/07/01 | A-3 (5%) A-2-4 (12%) (Both Test Pits) | TDR probes deployed in the test pits. Moisture contents were measured. The capillary rise was stabilized. |
| 11/07/01 | A-3 (5%) A-2-4 (12%) (Both Test Pits) | Two types of subgrade soils were placed in the test pits and divided by a wood board. |
| 11/08/01 | A-3 (5%) A-2-4 (12%) (Both Test Pits) | For both east and west test pits, the compaction was conducted at the same time and with the same procedures. Subgrade soils were compacted by a plate compactor. After 2,4,8,13,17 covers, for each part of the test pit, a nuclear gauge was deployed on 1 spot to measure the wet density of the subgrade soils. (Sketch is shown in Figure 2.22). On each spot, soil sample was taken and instant speedy moisture was obtained to determine the dry density. More accurate oven moisture would be found later. The instant results showed the desired dry density, 98% of maximum modified Proctor density, was achieved. |

Table 2.9 Test Pit Procedures for Condition 3

| Date | Embankment Materials | Description of Test Procedures |
|----------------------|---|---|
| 12/11/01 | A-3 (5%) A-2-4 (12%) (Both Test Pits) | Water table set to -6" |
| 12/11/01- 1/08/02 | A-3 (5%) A-2-4 (12%) (Both Test Pits) | TDR probes deployed in the test pits. Moisture contents were measured. The capillary rise was stabilized. |
| 1/8/02 | A-3 (5%) A-2-4 (12%) (Both Test Pits) | Two types of subgrade soils were placed in the test pits and divided by a wood board. |
| 1/9/02 | A-3 (5%) A-2-4 (12%) (Both Test Pits) | For both east and west test pits, the compaction was conducted at the same time and with the same procedure. Subgrade soils were compacted by a plate compactor. After 2,8,14 covers, for each part of the test pit, a nuclear gauge was deployed on 1 spot to measure the wet density of the subgrade soils. (Sketch is shown in Figure 2.22). On each spot, a soil sample was taken and instant speedy moisture was obtained to determine the dry density. More accurate oven moisture would be found later. The instant results showed the desired dry density, 98% of maximum modified Proctor density, was achieved. |
| 1/14/02 | A-3 (5%) A-2-4 (12%) (Both Test Pits) | From oven moisture, the dry density was below the desired dry density for both test pits. Compaction continued and after 6 more covers of compaction, the required dry density, 98% of maximum modified Proctor density, was achieved. |

Table 2.10 Test Pit Procedures for Condition 4

| Date | Embankment Materials | Description of Test Procedures |
|---------|----------------------|---|
| 1/14/02 | A-3 (5%) | Water table set to 2" above the embankment layer |
| 3/20/02 | A-3 (5%) | Water table drained down to -6" |
| 3/20/02 | A-3 (5%) | Two types of subgrade soils were placed in the test pit and divided by a wood board. |
| 3/20/02 | A-3 (5%) | Roller compactor was employed to conduct the compaction. After 2, 6,10,16 covers, for each part of the test pit, a nuclear meter was deployed on 1 spot to measure the wet density of the subgrade soils. (Sketch is shown in Figure 2.22). On each spot, soil sample was taken and instant speedy moisture was obtained to determine the dry density. More accurate oven moisture would be found thereafter. The desired dry density was not achieved. |
| 3/21/02 | A-3 (5%) | Compaction resumed (same procedure as yesterday). After 20,24,32 (total) covers, the dry density was inclined to drop. |
| 3/21/02 | A-3 (5%) | Vibratory compactor was employed. After 34,38,44,50,56,62 (total) covers, for each part of the test pit, a nuclear gauge was deployed on 1 spot to measure the wet density of the subgrade soils. (Sketch is shown in Figure 2.22). On each spot, soil sample was taken and instant speedy moisture was obtained to determine the dry density. More accurate oven moisture would be found later. The desired dry density, 98% of maximum modified Proctor density, was not achieved. The test was terminated. |

Table 2.11 Test Pit Procedures for Condition 5

| Date | Embankment Materials | Description of Test Procedures |
|---------|----------------------|---|
| 3/21/02 | A-3 (5%) | Water table set to 2" above the embankment layer |
| 6/3/02 | A-3 (5%) | Water table drained down to -12" |
| 6/4/02 | A-3 (5%) | Two types of subgrade soils were placed in the test pit and divided by a wood board. One set of earth pressure cell was embedded under the subgrade soil layer to evaluate the compactive energy. |
| 6/04/02 | A-3 (5%) | Plate compactor was employed to conduct the compaction. After 2 covers, for each part of the test pit, a nuclear gauge was deployed on 1 spot to measure the wet density of the subgrade soils. (Sketch is shown in Figure 2.22). On each spot, a soil sample was taken and instant speedy moisture was obtained to determine the dry density. More accurate oven moisture would be found later. The desired dry density was not achieved. Vibratory sheepsfoot compactor shown in Figure 2.10 was used to conduct the compaction. After 4 covers, for each part of the test pit, a nuclear gauge was deployed on 1 spot to measure the wet density of the subgrade soils. Instant results showed the desired dry density was not achieved. For the north part of the subgrade soil only, another 6 covers by vibratory sheepsfoot compactor was applied. The moisture and density measurements were taken. For both parts, 4 covers by plate compactor were applied. The measurements were taken and desired dry density, 98% of maximum modified Proctor density, was achieved. |



Figure 2.1 Overview of FDOT Test Pit

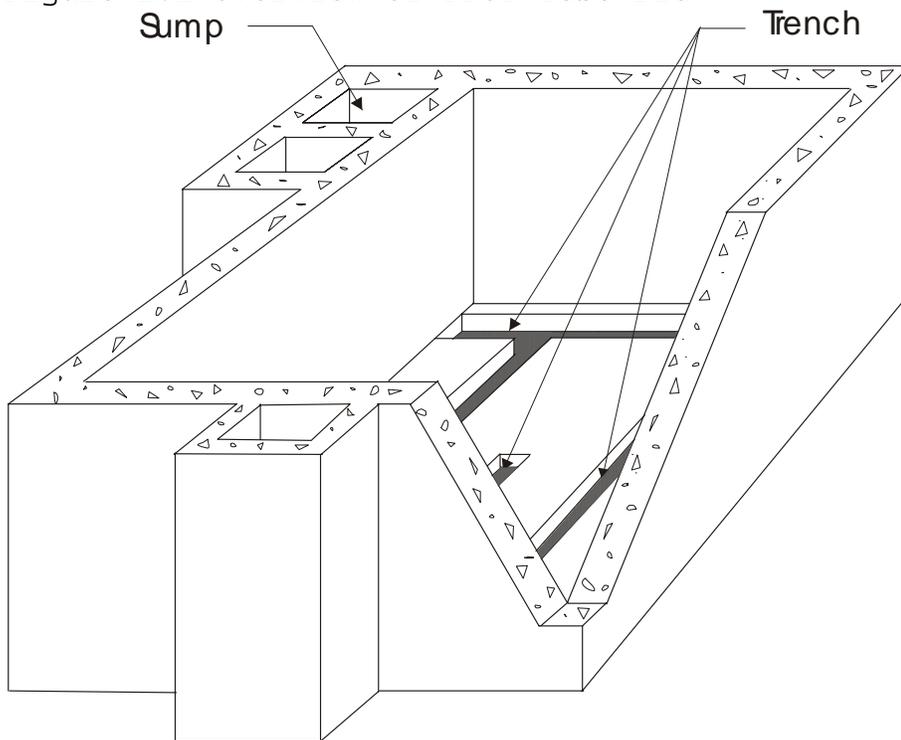


Figure 2.2 Schematic Sketch of Test Pit

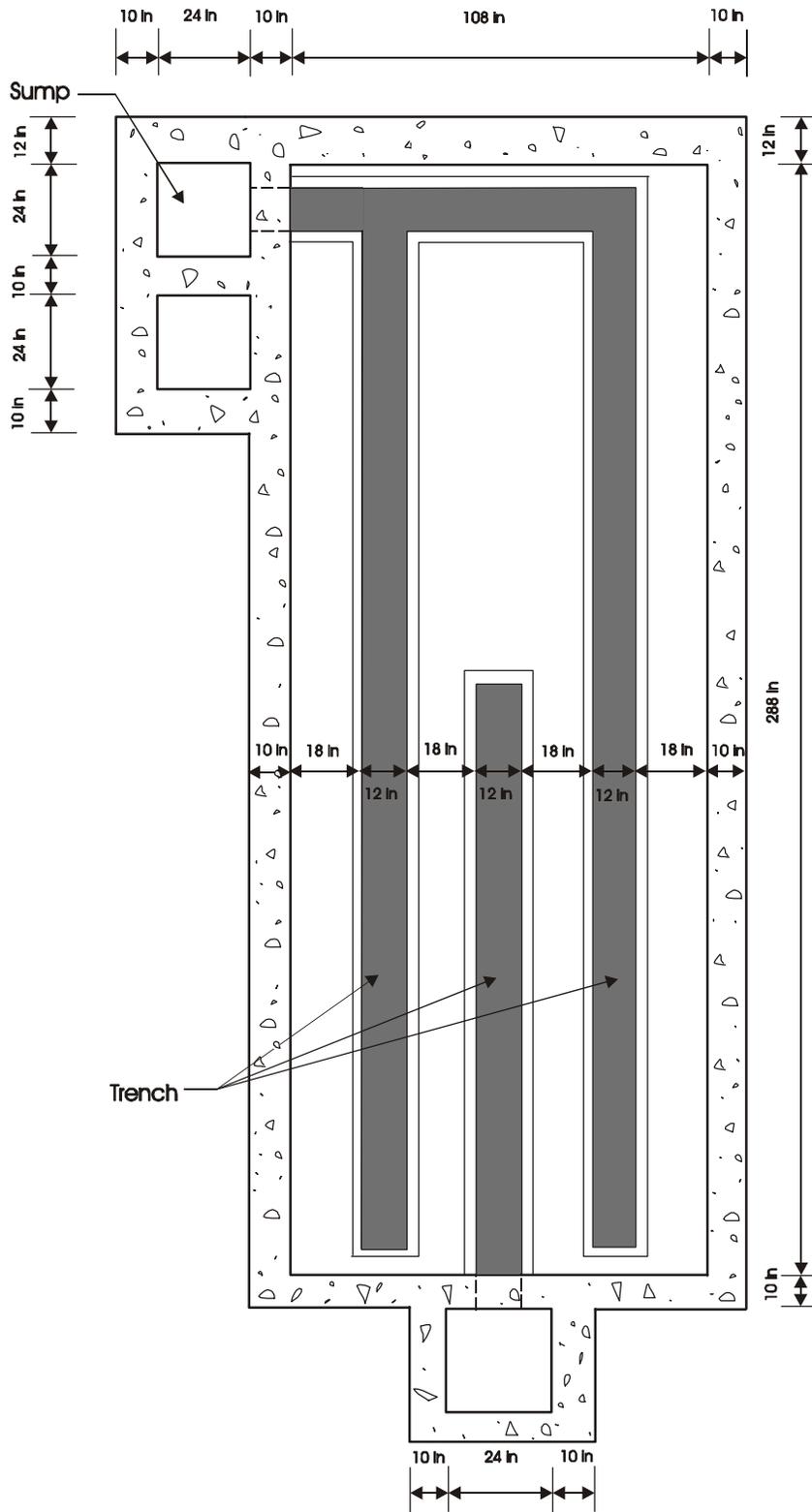
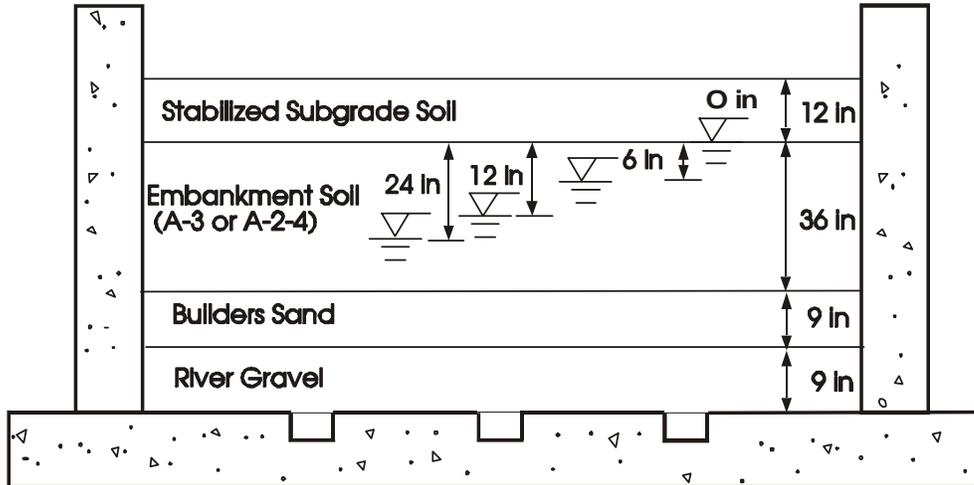


Figure 2.3 Plan View of Test Pit



Water Level Condition:

Condition 1: 24 in. below the interface

Condition 2: 12 in. below the interface

Condition 3: 6 in. below the interface

Condition 4: 6 in. below the interface (drained)

Condition 5: 12 in. below the interface (drained)

Figure 2.4 Cross Sectional View of Test Pit Program



Figure 2.5 Instruments for Water Table Monitoring



Figure 2.6 Two test pits used in the Study

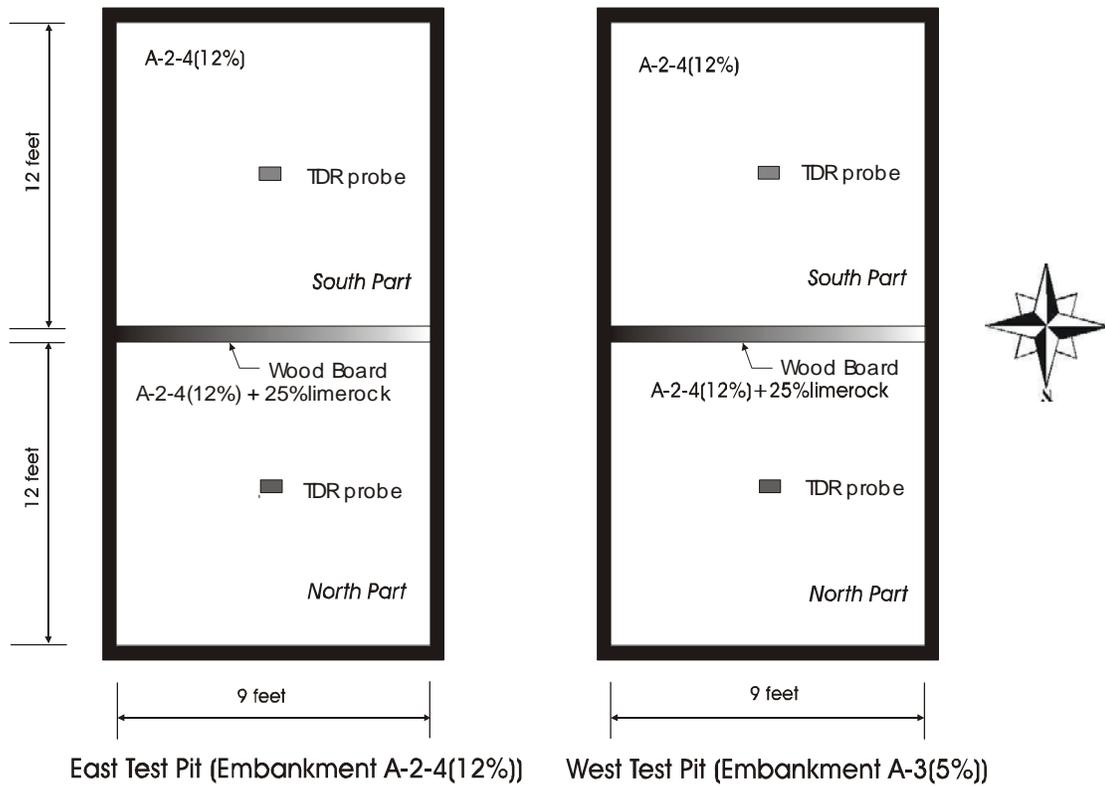
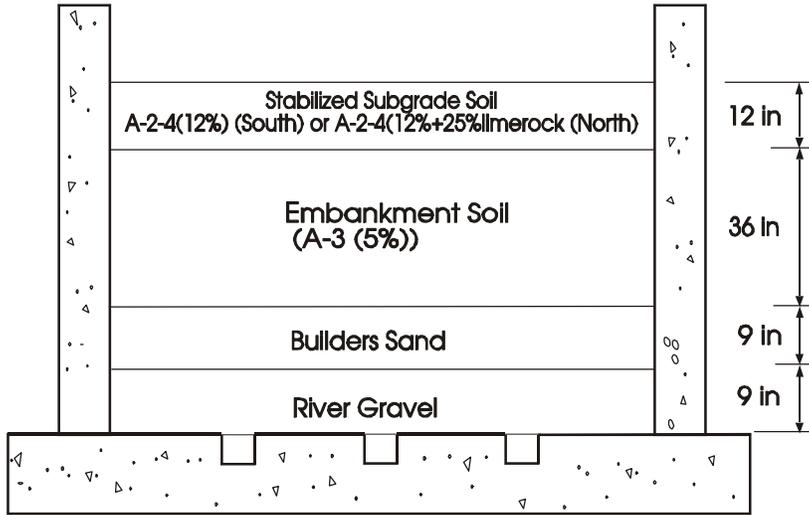
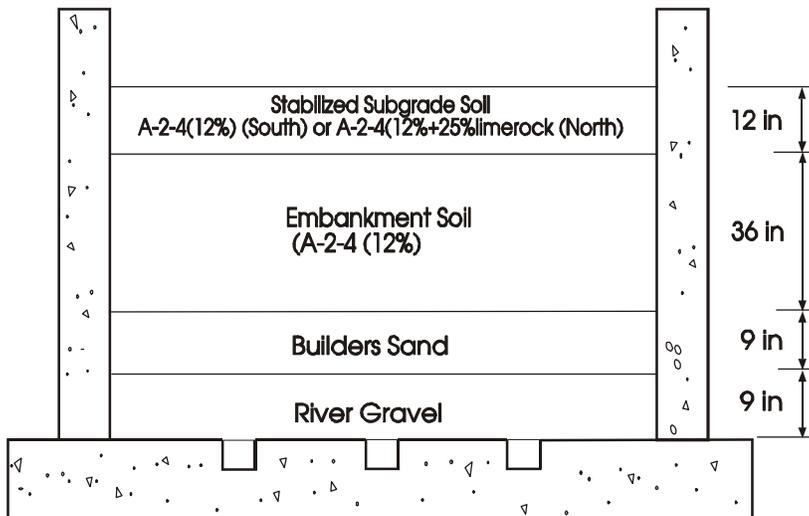


Figure 2.7 Layouts of Test Pit Experimental Program



West Test Pit



East Test Pit

Figure 2.8 Cross Sectional View of Test Pit Experimental Program



Figure 2.9 Plate Compactor (dynamic) used at Water Conditions 1, 2, 3, and 5



Figure 2.10 Sheepfoot Compactor (Vibratory) used at Water Condition 5

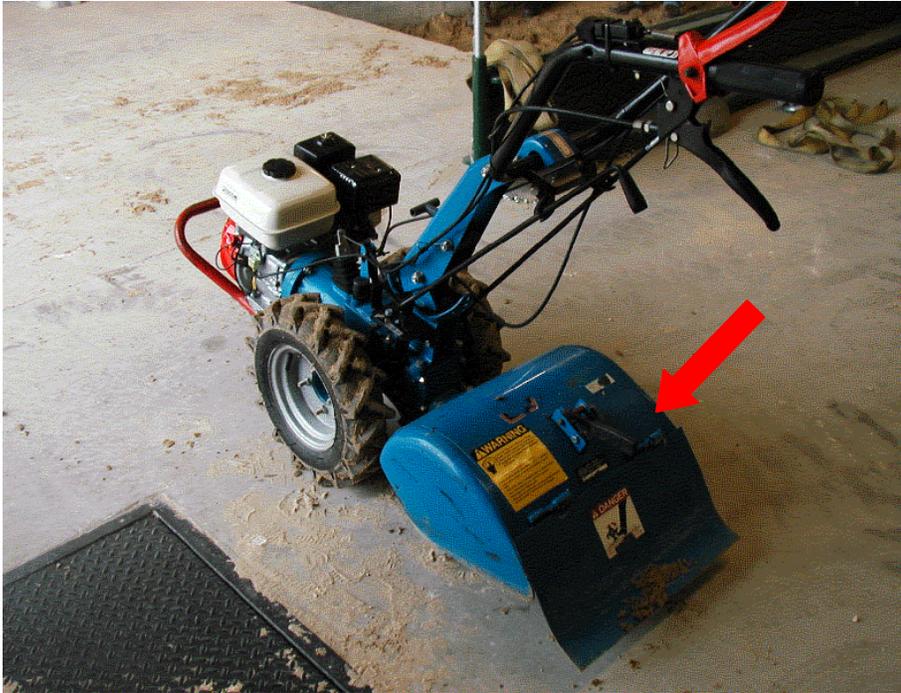


Figure 2.11 Dynamic Compactor (Vibratory) used at Water Condition 4



Figure 2.12 Roller Compactor (Static) used at Water Condition 4

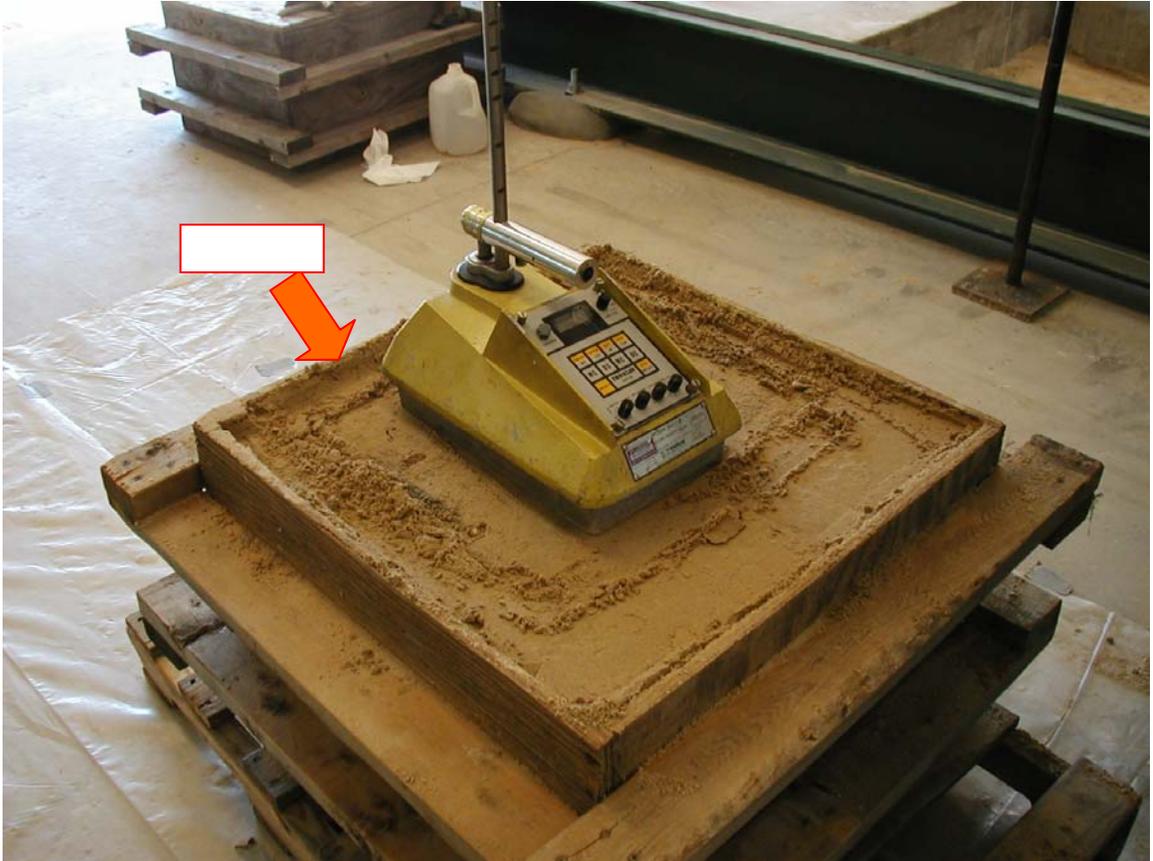


Figure 2.13 Soil Moisture Calibration Test

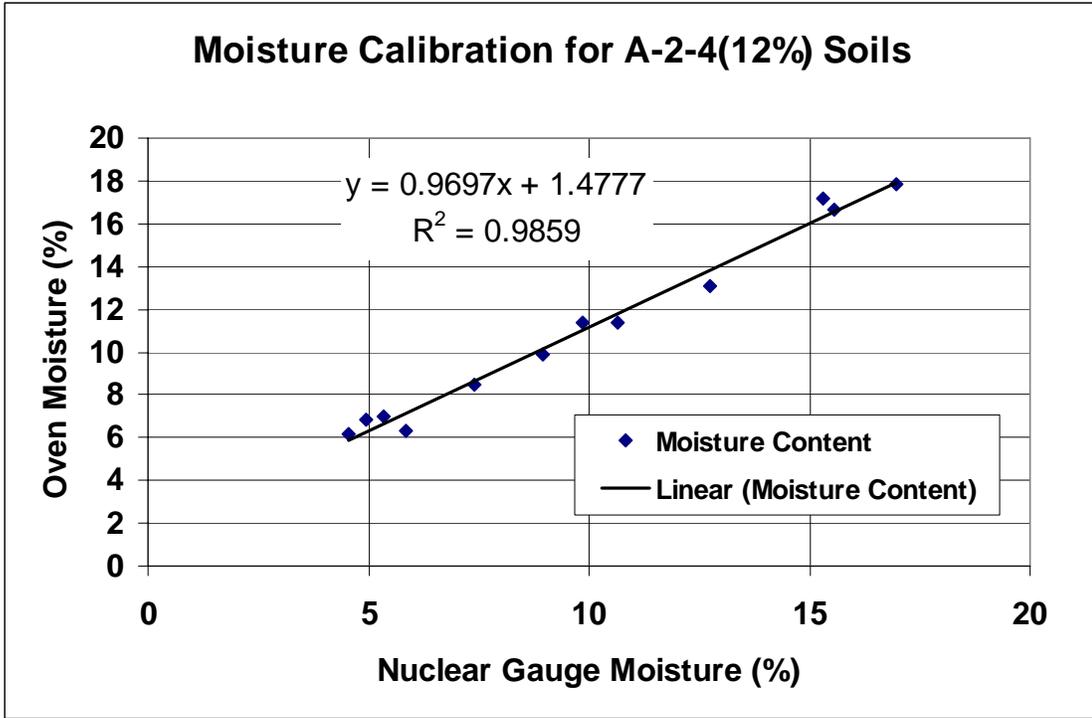


Figure 2.14 Moisture Calibration Curve for A-2-4(12%) Soils

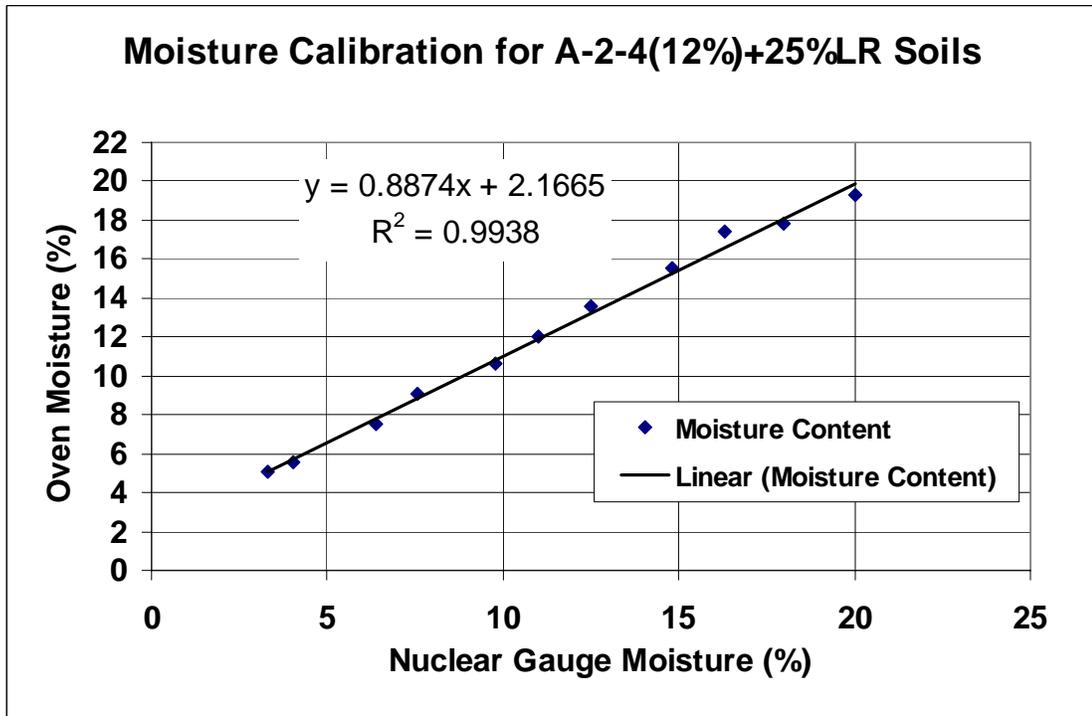


Figure 2.15 Moisture Calibration Curve for A-2-4(12%) +25% LR Soils

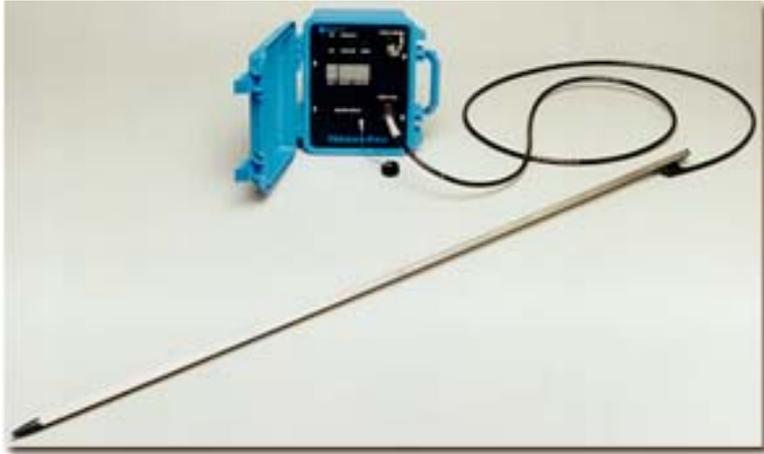


Figure 2.16 TDR Device used in the test



Figure 2.17 MP-917 data viewing/logging instrument

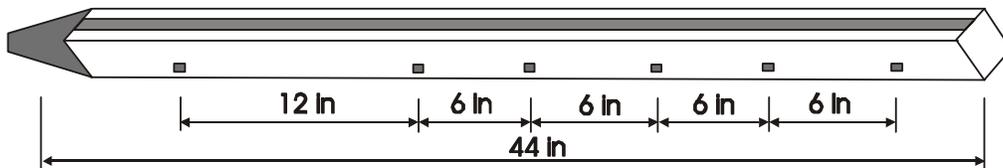


Figure 2.18 Profiling Probe

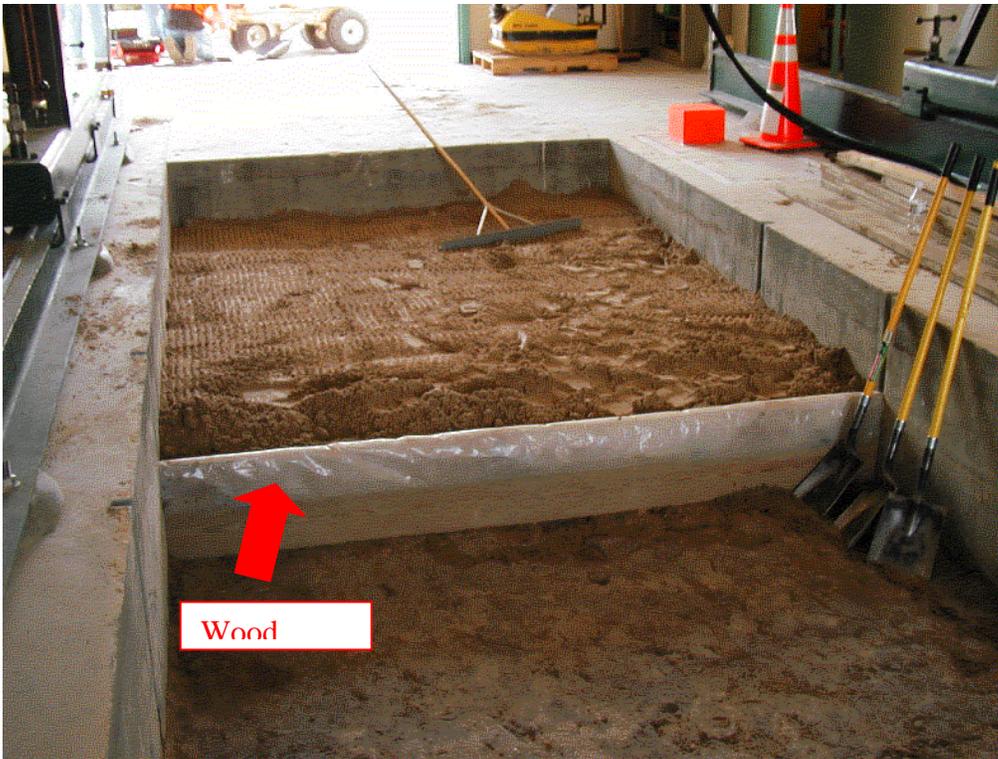


Figure 2.19 Two Subgrade Soils Separated by a Board

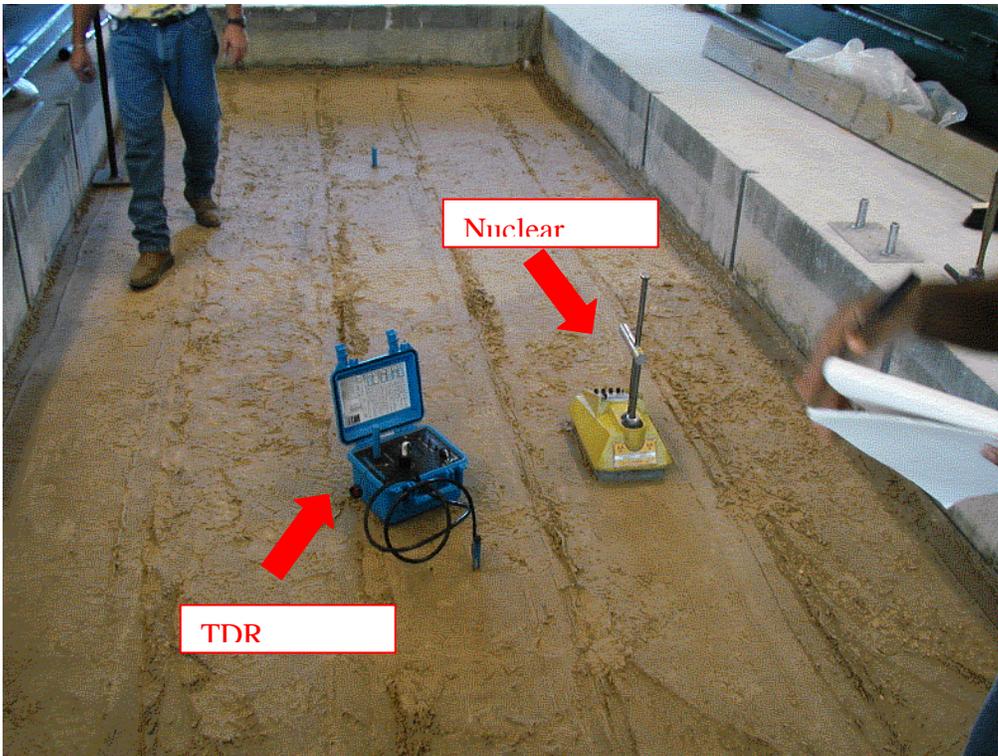


Figure 2.20 TDR Instrument and Nuclear Gauge in Measurement

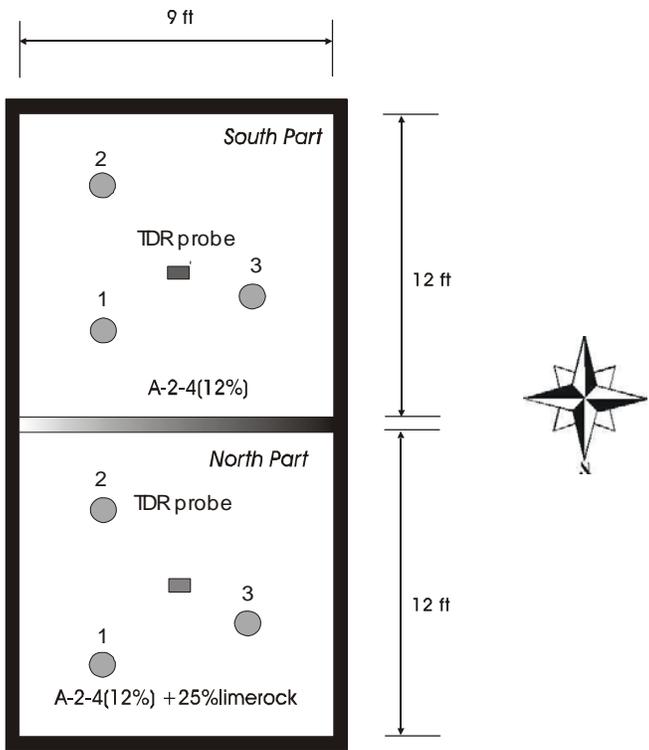


Figure 2.21 Relative Positions of TDR Probes and Nuclear Gauge Tests in the Test Pit for Condition 1

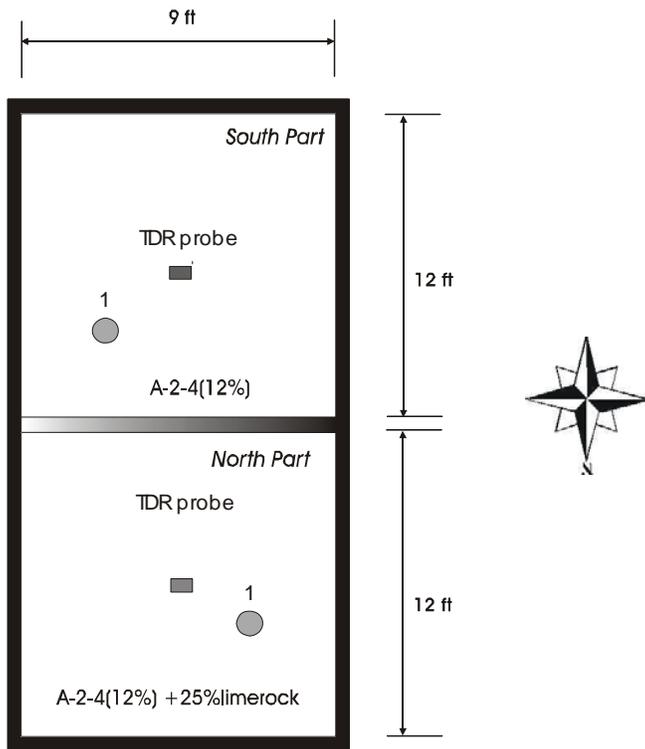


Figure 2.22 Relative Positions of TDR Probes and Nuclear Gauge Tests in the Test Pit for Conditions 1, 2, 3, 4, and 5

CHAPTER 3 CAPILLARY RISE STUDY

3.1 General

The laboratory experimental results can be presented in two separate parts: the capillary rise behavior as a result of adjustment of water levels, and the constructability study of the compacted subgrade soils as a result of the water table adjustments and capillary rises. The capillary rise behavior is evaluated in this chapter.

At the water-air interface, a surface tension exists, and the continuous voids in soil can act as capillary tubes. Because of this surface tension force and the continuous voids in soils that act as capillary tubes, water may move in soils by capillary rise. A brief review of capillary rise in soils is presented in Appendix B. The capillary rise experimental results are presented as follows.

3.2 Capillary Rise Experimental Results

To study the behavior of capillary rise in the embankment soils under a high ground water table, the

moisture content variations in the test pits were monitored on a daily basis. Four TDR probes were installed in the test pits to measure the moisture content of the embankment soils in both the south and north parts of the two test pits. The moisture monitoring was initiated once the water table was set to the desired water levels and the monitoring was continued every day thereafter until the soil moisture was stabilized. Three water levels were under the evaluation:

- 24 inches below the top (interface) of the embankment soils (-24 inches)
- 12 inches below the top (interface) of the embankment soils (-12 inches)
- 6 inches below the top (interface) of the embankment soils (-6 inches)

The other two water levels with drained conditions were not included in the evaluation.

The daily moisture variations are summarized in Tables 3.1, 3.2, 3.3, and 3.4 under the water level at 24 inches below the top of embankments for the south and north parts of west test pit with A-3 embankment soil and the south and north parts of east test pit with A-2-4 embankment soil, respectively. The moisture variations are plotted versus

elapsed time in Figures 3.1 and 3.2 for the west and east test pits, respectively.

The daily moisture variations are presented in Tables 3.5, 3.6, 3.7, and 3.8 under the water table level at 12 inches below the top of embankment for the south and north parts of west test pit with A-3 embankment soil and the south and north parts of east test pit with A-2-4 embankment soil, respectively. The moisture variations are illustrated with elapsed time in Figures 3.3 and 3.4 for the west and east test pits, respectively.

Under the water level at six inches below the interface, the daily moisture variations are presented in Tables 3.9, 3.10, 3.11, and 3.12 for the south and north parts of west pit with A-3 embankment soil and the south and north parts of east test pit with A-2-4 embankment soil, respectively. The results are shown in Figures 3.5 and 3.6 for the west and east test pits, respectively.

3.3 Analysis and Discussion of Capillary Rise Results

The daily moisture variations versus elapsed time are presented in Figures 3.1 and 3.2 for the water table level at 24 inches below the interface of embankment and subgrade soils. The two figures show that the average moisture levels over the length of Segment 5 have increased

significantly with time for both the A-3 and A-2-4 embankment soils. In the west pit where the embankment soil is A-3 (5%) (Figure 3.1), the average moisture levels over the length of Segment 4 have increased a little with time while those of Segment 3 have not made noticeable changes. From these observations, it appears that the capillary rise of the A-3 (5%) soil reached a height of about 24 inches. In the east test pit, the average moisture levels over the length of Segments 3 and 4 in the A-2-4 (12%) soil displayed significant increases over time (Figure 3.2). It appears that the capillary rise of the A-2-4 (12%) soil had a height of higher than or at least 24 inches. Clearly, the A-2-4 (12%) soil showed a greater capability than the A-3 (5%) soil.

In Figures 3.3 and 3.4, the daily moisture variations versus elapsed time are presented for the water table level at 12 inches below the interface of embankment and subgrade soils. For the A-3 (5%) soil (Figure 3.3), the average moisture content over the length of Segments 4 and 5 were about the same without any significant increase. However, the average moisture levels over Segment 3 showed significant increases over time but never reached a level as high as that of Segments 4 and 5. Segment 5 represented the depth of 12 inches under the water table level, and

Segments 3 and 4 represented the height of 6 inches to 12 inches and 0 to 6 in. above the water table level, respectively. Therefore, for the A-3 (5%) soil, the capillary rise caused the soil at 6 in. above the water table level to reach a saturation stage, but the soil from the 6 in. to 12 in. above the water table level was not able to reach a fully saturated level of moisture content. Moisture evaporation near the surface may cause a reduction in the degree of saturation for the A-3 soil.

For the A-2-4 (12%) soil (Figure 3.4), the average moisture content levels over the length of Segments 3, 4 and 5 were all about the same or very close to each other. Thus, the capillary rise caused the A-2-4 soil at 12 inches above the water table level to reach a saturation stage.

In Figures 3.5 and 3.6, the daily moisture variations versus elapsed time are presented for the water table level at 6 inches below the interface of embankment and subgrade soils. For the two soils, the average moisture levels in Segments 3, 4, and 5 were about the same after a certain period of time, which is very close to the saturation stage.

The moisture content variations due to capillary action are summarized in Table 3.13 to illustrate a height of capillary rise about 24 inches for the A-3 soil, whereas

the A-2-4(12%) soil is capable of reaching at least 24 inches or higher of capillary rise.

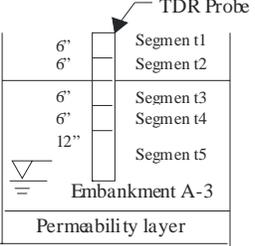
In terms of the time rate of capillary rise, the height of capillary rise and moisture levels in the soil are highly time dependent. Soils with an ultimately higher capillary rise may not necessarily reach a higher level of capillary rise and moisture content than those with a lower level of ultimate capillary rise in a short period of time. In addition, climatic factors may influence and play a crucial role prior to reaching the ultimate capillary rise. Thus, the time rate effect must be taken into consideration for capillary rise analysis.

To study the rate of capillary performance, the average rate of moisture variations for the two soils at 0 to 6 inches above the water level surface were compared, and are summarized in Tables 3.14 and 3.15. The results are shown in Figure 3.7. Both soils showed very similar rates of capillary rise. Both soils had a significant moisture rise during the first day and then were stabilized after about additional seven days. It appeared that the two embankment soils had a similar rate of capillary rise.

In summary, it appeared that the A-2-4 soil had a height of capillary rise of more than 24 inches, whereas the A-3 soil had a height of capillary rise of about 24

inches. The capillary rise results were consistent with what had been expected in the literature (see Table B.1, Appendix B). The A-2-4 soil with 12% fines is a silty sand, which has smaller pore size and effective D_{10} size than the fine sand (A-3 soil). Thus, the A-2-4 soil has a higher capillary potential than the A-3 soil. In terms of the time rate of capillary rise, it appears that both the A-2-4 and A-3 soils have a similar rate of capillary rise, reaching the maximum height in about eight days.

Table 3.1 Moisture Profile under Water Level at -24 inches
(A-3 soil, South)

| Date | Segment No. | Vol. Moist. (%) | Dry Density (pcf) | Moisture (%) | Notes |
|---------|-------------|-----------------|-------------------|--------------|--|
| 8/13/01 | 3 | 4.2 | 109.0 | 2.4 |  <p>The diagram shows a vertical soil profile divided into five segments: Segment t1 (6"), Segment t2 (6"), Segment t3 (6"), Segment t4 (6"), and Segment t5 (12"). A TDR probe is shown inserted into the soil. Below the soil profile is a horizontal line representing the 'Embankment A-3' and a hatched area below that representing the 'Permeability layer'.</p> |
| | 4 | 9.2 | 110.6 | 5.2 | |
| | 5 | 13.0 | 109.9 | 7.4 | |
| 8/14/01 | 3 | 4.2 | 109.0 | 2.4 | |
| | 4 | 9.7 | 110.6 | 5.5 | |
| | 5 | 19.7 | 109.9 | 11.2 | |
| 8/15/01 | 3 | 3.2 | 109.0 | 1.8 | |
| | 4 | 10.3 | 110.6 | 5.8 | |
| | 5 | 20.5 | 109.9 | 11.7 | |
| 8/16/01 | 3 | 3.9 | 109.0 | 2.2 | |
| | 4 | 11.1 | 110.6 | 6.3 | |
| | 5 | 20.8 | 109.9 | 11.8 | |
| 8/17/01 | 3 | 4.2 | 109.0 | 2.4 | |
| | 4 | 10.9 | 110.6 | 6.2 | |
| | 5 | 20.9 | 109.9 | 11.9 | |
| 8/20/01 | 3 | 5.1 | 109.0 | 2.9 | |
| | 4 | 11.7 | 110.6 | 6.6 | |
| | 5 | 21.1 | 109.9 | 12.0 | |
| 8/21/01 | 3 | 5.4 | 109.0 | 3.1 | |
| | 4 | 12.3 | 110.6 | 7.0 | |
| | 5 | 21.1 | 109.9 | 12.0 | |
| 8/22/01 | 3 | 5.2 | 109.0 | 3.0 | |
| | 4 | 11.9 | 110.6 | 6.7 | |
| | 5 | 21.0 | 109.9 | 11.9 | |
| 8/23/01 | 3 | 4.8 | 109.0 | 2.8 | |
| | 4 | 11.4 | 110.6 | 6.4 | |
| | 5 | 20.9 | 109.9 | 11.9 | |
| 8/24/01 | 3 | 4.8 | 109.0 | 2.8 | |
| | 4 | 11.1 | 110.6 | 6.3 | |
| | 5 | 21.1 | 109.9 | 12.0 | |
| 8/27/01 | 3 | 5.1 | 109.0 | 2.9 | |
| | 4 | 11.1 | 110.6 | 6.3 | |
| | 5 | 21.2 | 109.9 | 12.1 | |

- 1) Segments 1& 2 are not in use.
- 2) Embankment soil is A-3(5%).
- 3) Data are for the south part of test pit.

Table 3.2 Moisture Profile under Water Level at -24 inches
(A-3 soil, North)

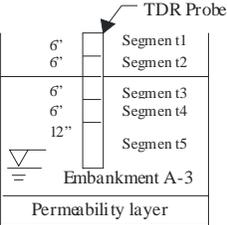
| Date | Segment No. | Vol. Moist. (%) | Dry Density (pcf) | Moisture (%) | Notes |
|---------|-------------|-----------------|-------------------|--------------|---|
| 8/13/01 | 3 | 5.4 | 109 | 3.1 |  <p>The diagram shows a vertical soil profile with five segments. Segment 1 is 6 inches high, Segment 2 is 6 inches high, Segment 3 is 6 inches high, Segment 4 is 6 inches high, and Segment 5 is 12 inches high. A TDR probe is shown inserted into the soil, with its tip at the top of Segment 1. Below Segment 5 is a permeability layer. The entire profile is labeled as Embankment A-3.</p> <p>1) Segments 1 & 2 are not in use. 2) Embankment soil is A-3(5%). 3) Data are for the north part of test pit.</p> |
| | 4 | 8.9 | 110.6 | 5.0 | |
| | 5 | 13.9 | 109.9 | 7.9 | |
| 8/14/01 | 3 | 5.1 | 109.0 | 2.9 | |
| | 4 | 10.9 | 110.6 | 6.2 | |
| | 5 | 21.7 | 109.9 | 12.3 | |
| 8/15/01 | 3 | 4.8 | 109.0 | 2.8 | |
| | 4 | 11.7 | 110.6 | 6.6 | |
| | 5 | 21.5 | 109.9 | 12.2 | |
| 8/16/01 | 3 | 5.1 | 109.0 | 2.9 | |
| | 4 | 11.7 | 110.6 | 6.6 | |
| | 5 | 21.9 | 109.9 | 12.5 | |
| 8/17/01 | 3 | 4.8 | 109.0 | 2.8 | |
| | 4 | 11.1 | 110.6 | 6.3 | |
| | 5 | 21.9 | 109.9 | 12.5 | |
| 8/20/01 | 3 | 6.0 | 109.0 | 3.4 | |
| | 4 | 11.1 | 110.6 | 6.3 | |
| | 5 | 22.2 | 109.9 | 12.6 | |
| 8/21/01 | 3 | 5.7 | 109.0 | 3.3 | |
| | 4 | 11.4 | 110.6 | 6.4 | |
| | 5 | 22.5 | 109.9 | 12.8 | |
| 8/22/01 | 3 | 5.4 | 109.0 | 3.1 | |
| | 4 | 11.5 | 110.6 | 6.5 | |
| | 5 | 22.6 | 109.9 | 12.9 | |
| 8/23/01 | 3 | 5.1 | 109.0 | 2.9 | |
| | 4 | 11.7 | 110.6 | 6.6 | |
| | 5 | 22.5 | 109.9 | 12.8 | |
| 8/24/01 | 3 | 4.8 | 109.0 | 2.8 | |
| | 4 | 11.7 | 110.6 | 6.6 | |
| | 5 | 22.7 | 109.9 | 12.9 | |
| 8/27/01 | 3 | 5.1 | 109.0 | 2.9 | |
| | 4 | 11.4 | 110.6 | 6.4 | |
| | 5 | 22.8 | 109.9 | 13.0 | |

Table 3.3 Moisture Profile under Water Level at -24 inches
(A-2-4 soil, South)

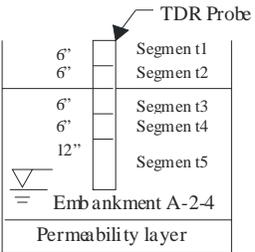
| Date | Segment No. | Vol. Moist. (%) | Dry Density (pcf) | Moisture (%) | Notes |
|---------|-------------|-----------------|-------------------|--------------|---|
| 8/13/01 | 3 | 4.2 | 108 | 2.4 |  <p> TDR Probe 6" Segment t1 6" Segment t2 6" Segment t3 6" Segment t4 12" Segment t5 ▽ = Embankment A-2-4 Permeability layer </p> <p> 1) Segments 1 & 2 are not in use. 2) Embankment soil is A-2-4(12%). 3) Data are for the south part of test pit. </p> |
| | 4 | 8.4 | 109.1 | 4.8 | |
| | 5 | 18.4 | 109.6 | 10.5 | |
| 8/14/01 | 3 | 7.0 | 108.0 | 4.1 | |
| | 4 | 13.9 | 109.1 | 8.0 | |
| | 5 | 23.7 | 109.6 | 13.5 | |
| 8/15/01 | 3 | 7.6 | 108.0 | 4.4 | |
| | 4 | 13.9 | 109.1 | 8.0 | |
| | 5 | 23.9 | 109.6 | 13.6 | |
| 8/16/01 | 3 | 7.6 | 108.0 | 4.4 | |
| | 4 | 14.2 | 109.1 | 8.1 | |
| | 5 | 24.0 | 109.6 | 13.7 | |
| 8/17/01 | 3 | 8.8 | 108.0 | 5.1 | |
| | 4 | 13.7 | 109.1 | 7.8 | |
| | 5 | 24.0 | 109.6 | 13.7 | |
| 8/20/01 | 3 | 8.2 | 108.0 | 4.7 | |
| | 4 | 14.5 | 109.1 | 8.3 | |
| | 5 | 24.3 | 109.6 | 13.9 | |
| 8/21/01 | 3 | 8.2 | 108.0 | 4.7 | |
| | 4 | 13.7 | 109.1 | 7.8 | |
| | 5 | 24.4 | 109.6 | 13.9 | |
| 8/22/01 | 3 | 8.3 | 108.0 | 4.8 | |
| | 4 | 13.8 | 109.1 | 7.9 | |
| | 5 | 24.3 | 109.6 | 13.9 | |
| 8/23/01 | 3 | 8.5 | 108.0 | 4.9 | |
| | 4 | 13.9 | 109.1 | 8.0 | |
| | 5 | 24.4 | 109.6 | 13.9 | |
| 8/24/01 | 3 | 8.2 | 108.0 | 4.7 | |
| | 4 | 14.2 | 109.1 | 8.1 | |
| | 5 | 24.4 | 109.6 | 13.9 | |
| 8/27/01 | 3 | 8.2 | 108.0 | 4.7 | |
| | 4 | 13.7 | 109.1 | 7.8 | |
| | 5 | 24.4 | 109.6 | 13.9 | |

Table 3.4 Moisture Profile under Water Level at -24 inches
(A-2-4 soil, North)

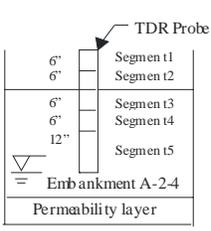
| Date | Segment No. | Vol. Moist. (%) | Dry Density (pcf) | Moisture (%) | Notes |
|---------|-------------|-----------------|-------------------|--------------|---|
| 8/13/01 | 3 | 6.6 | 108 | 3.8 |  <p>TDR Probe</p> <p>6" Segmen 1</p> <p>6" Segmen 2</p> <p>6" Segmen 3</p> <p>6" Segmen 4</p> <p>12" Segmen 5</p> <p>Embankment A-2-4</p> <p>Permeability layer</p> <p>1) Segments 1& 2 are not in use. 2) Embankment soil is A-2-4(12%). 3) Data are for the north part of test pit.</p> |
| | 4 | 8.9 | 109.1 | 5.1 | |
| | 5 | 18.0 | 109.6 | 10.3 | |
| 8/14/01 | 3 | 10.1 | 108 | 5.8 | |
| | 4 | 14.2 | 109.1 | 8.1 | |
| | 5 | 23.1 | 109.6 | 13.2 | |
| 8/15/01 | 3 | 11.3 | 108.0 | 6.5 | |
| | 4 | 14.5 | 109.1 | 8.3 | |
| | 5 | 23.3 | 109.6 | 13.3 | |
| 8/16/01 | 3 | 11.3 | 108.0 | 6.5 | |
| | 4 | 15.3 | 109.1 | 8.8 | |
| | 5 | 23.6 | 109.6 | 13.5 | |
| 8/17/01 | 3 | 10.7 | 108.0 | 6.2 | |
| | 4 | 14.8 | 109.1 | 8.5 | |
| | 5 | 23.4 | 109.6 | 13.3 | |
| 8/20/01 | 3 | 10.7 | 108.0 | 6.2 | |
| | 4 | 15.0 | 109.1 | 8.6 | |
| | 5 | 23.9 | 109.6 | 13.6 | |
| 8/21/01 | 3 | 10.7 | 108.0 | 6.2 | |
| | 4 | 14.8 | 109.1 | 8.5 | |
| | 5 | 23.9 | 109.6 | 13.6 | |
| 8/22/01 | 3 | 10.8 | 108.0 | 6.3 | |
| | 4 | 14.7 | 109.1 | 8.4 | |
| | 5 | 24.0 | 109.6 | 13.7 | |
| 8/23/01 | 3 | 11.0 | 108.0 | 6.4 | |
| | 4 | 14.8 | 109.1 | 8.5 | |
| | 5 | 24.1 | 109.6 | 13.7 | |
| 8/24/01 | 3 | 10.7 | 108.0 | 6.2 | |
| | 4 | 15.6 | 109.1 | 8.9 | |
| | 5 | 24.0 | 109.6 | 13.7 | |
| 8/27/01 | 3 | 10.7 | 108.0 | 6.2 | |
| | 4 | 14.8 | 109.1 | 8.5 | |
| | 5 | 24.3 | 109.6 | 13.9 | |

Table 3.5 Moisture Profile under Water Level at -12 inches
(A-3 soil, South)

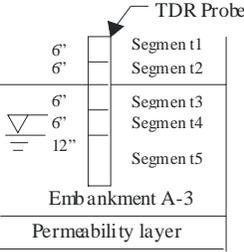
| Date | Segment No. | Vol. Moist. (%) | Dry Density (pcf) | Moisture (%) | Notes |
|----------|-------------|-----------------|-------------------|--------------|--|
| 10/11/01 | 3 | 7.6 | 109 | 4.4 |  <p>TDR Probe</p> <p>6" 6" 6" 6" 12"</p> <p>Segmen t1 Segmen t2 Segmen t3 Segmen t4 Segmen t5</p> <p>Embankment A-3</p> <p>Permeability layer</p> <p>1) Segments 1& 2 are not in use. 2) Embankment soil is A-3(5%). 3) Data are for the south part of test pit.</p> |
| | 4 | 11.7 | 110.6 | 6.6 | |
| | 5 | 23.9 | 109.9 | 13.6 | |
| 10/12/01 | 3 | 8.2 | 109.0 | 4.7 | |
| | 4 | 19.0 | 110.6 | 10.7 | |
| | 5 | 26.5 | 109.9 | 15.1 | |
| 10/15/01 | 3 | 7.6 | 109.0 | 4.4 | |
| | 4 | 19.8 | 110.6 | 11.2 | |
| | 5 | 26.9 | 109.9 | 15.3 | |
| 10/16/01 | 3 | 8.5 | 109.0 | 4.9 | |
| | 4 | 19.7 | 110.6 | 11.1 | |
| | 5 | 26.8 | 109.9 | 15.2 | |
| 10/17/01 | 3 | 15.3 | 109.0 | 8.8 | |
| | 4 | 21.5 | 110.6 | 12.1 | |
| | 5 | 30.8 | 109.9 | 17.5 | |
| 10/18/01 | 3 | 17.8 | 109.0 | 10.2 | |
| | 4 | 26.2 | 110.6 | 14.8 | |
| | 5 | 28.1 | 109.9 | 16.0 | |
| 10/19/01 | 3 | 17.8 | 109.0 | 10.2 | |
| | 4 | 26.5 | 110.6 | 15.0 | |
| | 5 | 26.1 | 109.9 | 14.8 | |
| 10/22/01 | 3 | 17.2 | 109.0 | 9.9 | |
| | 4 | 26.2 | 110.6 | 14.8 | |
| | 5 | 26.3 | 109.9 | 15.0 | |
| 10/23/01 | 3 | 18.7 | 109.0 | 10.7 | |
| | 4 | 27.0 | 110.6 | 15.3 | |
| | 5 | 26.3 | 109.9 | 15.0 | |
| 10/24/01 | 3 | 18.4 | 109.0 | 10.6 | |
| | 4 | 27.0 | 110.6 | 15.3 | |
| | 5 | 26.2 | 109.9 | 14.9 | |
| 10/25/01 | 3 | 19.7 | 109.0 | 11.3 | |
| | 4 | 26.2 | 110.6 | 14.8 | |
| | 5 | 26.5 | 109.9 | 15.1 | |
| 10/26/01 | 3 | 19.4 | 109.0 | 11.1 | |
| | 4 | 26.5 | 110.6 | 15.0 | |
| | 5 | 26.5 | 109.9 | 15.1 | |
| 10/29/01 | 3 | 17.8 | 109.0 | 10.2 | |
| | 4 | 27.3 | 110.6 | 15.4 | |
| | 5 | 26.8 | 109.9 | 15.2 | |

Table 3.5 Moisture Profile under Water Level at -12 inches
(A-3 soil, South) (Continued)

| | | | | |
|-----------------|----------|------|-------|------|
| 10/30/01 | 3 | 17.5 | 109.0 | 10.0 |
| | 4 | 27.3 | 110.6 | 15.4 |
| | 5 | 26.9 | 109.9 | 15.3 |
| 10/31/01 | 3 | 18.1 | 109.0 | 10.4 |
| | 4 | 26.8 | 110.6 | 15.1 |
| | 5 | 26.6 | 109.9 | 15.1 |
| 11/2/01 | 3 | 18.1 | 109.0 | 10.4 |
| | 4 | 26.5 | 110.6 | 15.0 |
| | 5 | 26.3 | 109.9 | 15.0 |
| 11/5/01 | 3 | 18.4 | 109.0 | 10.6 |
| | 4 | 26.8 | 110.6 | 15.1 |
| | 5 | 26.2 | 109.9 | 14.9 |
| 11/6/01 | 3 | 18.2 | 109.0 | 10.4 |
| | 4 | 26.6 | 110.6 | 15.0 |
| | 5 | 26.4 | 109.9 | 15.0 |
| 11/7/01 | 3 | 19.0 | 109.0 | 10.9 |
| | 4 | 23.7 | 110.6 | 13.4 |
| | 5 | 29.3 | 109.9 | 16.7 |
| 11/9/01 | 3 | 22.1 | 109.0 | 12.7 |
| | 4 | 24.8 | 110.6 | 14.0 |
| | 5 | 23.6 | 109.9 | 13.4 |
| 11/12/01 | 3 | 22.5 | 109.0 | 12.9 |
| | 4 | 25.9 | 110.6 | 14.6 |
| | 5 | 24.6 | 109.9 | 14.0 |

Table 3.6 Moisture Profile under Water Level at -12 inches
(A-3 soil, North)

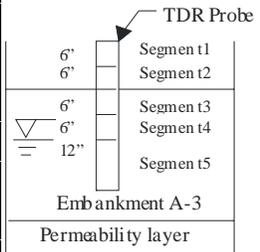
| Date | Segment No. | Vol. Moist. (%) | Dry Density (pcf) | Moisture (%) | Notes |
|----------|-------------|-----------------|-------------------|--------------|---|
| 10/11/01 | 3 | 7.9 | 109 | 4.5 |  <p>TDR Probe</p> <p>6" Segment 1 6" Segment 2 6" Segment 3 6" Segment 4 12" Segment 5 Embankment A-3 Permeability layer</p> <p>1) Segments 1& 2 are not in use. 2) Embankment soil is A-3(5%). 3) Data are for the north part of test pit.</p> |
| | 4 | 13.6 | 110.6 | 7.7 | |
| | 5 | 24.6 | 109.9 | 14.0 | |
| 10/12/01 | 3 | 10.7 | 109.0 | 6.1 | |
| | 4 | 21.5 | 110.6 | 12.1 | |
| | 5 | 27.1 | 109.9 | 15.4 | |
| 10/15/01 | 3 | 10.7 | 109.0 | 6.1 | |
| | 4 | 22.3 | 110.6 | 12.6 | |
| | 5 | 27.5 | 109.9 | 15.6 | |
| 10/16/01 | 3 | 10.7 | 109.0 | 6.1 | |
| | 4 | 22.3 | 110.6 | 12.6 | |
| | 5 | 27.4 | 109.9 | 15.6 | |
| 10/17/01 | 3 | 16.9 | 109.0 | 9.7 | |
| | 4 | 25.9 | 110.6 | 14.6 | |
| | 5 | 27.5 | 109.9 | 15.6 | |
| 10/18/01 | 3 | 16.3 | 109.0 | 9.3 | |
| | 4 | 25.9 | 110.6 | 14.6 | |
| | 5 | 27.5 | 109.9 | 15.6 | |
| 10/19/01 | 3 | 16.6 | 109.0 | 9.5 | |
| | 4 | 26.8 | 110.6 | 15.1 | |
| | 5 | 27.1 | 109.9 | 15.4 | |
| 10/22/01 | 3 | 15.9 | 109.0 | 9.1 | |
| | 4 | 25.9 | 110.6 | 14.6 | |
| | 5 | 27.1 | 109.9 | 15.4 | |
| 10/23/01 | 3 | 18.7 | 109.0 | 10.7 | |
| | 4 | 27.0 | 110.6 | 15.3 | |
| | 5 | 26.3 | 109.9 | 15.0 | |
| 10/24/01 | 3 | 18.4 | 109.0 | 10.6 | |
| | 4 | 27.6 | 110.6 | 15.6 | |
| | 5 | 27.4 | 109.9 | 15.6 | |
| 10/25/01 | 3 | 18.7 | 109.0 | 10.7 | |
| | 4 | 26.5 | 110.6 | 15.0 | |
| | 5 | 27.4 | 109.9 | 15.6 | |
| 10/26/01 | 3 | 19.7 | 109.0 | 11.3 | |
| | 4 | 26.5 | 110.6 | 15.0 | |
| | 5 | 27.4 | 109.9 | 15.6 | |
| 10/29/01 | 3 | 19.0 | 109.0 | 10.9 | |
| | 4 | 27.6 | 110.6 | 15.6 | |
| | 5 | 27.8 | 109.9 | 15.8 | |

Table 3.6 Moisture Profile under Water Level at -12 inches
(A-3 soil, North) (Continued)

| | | | | |
|-----------------|----------|------|-------|------|
| 10/30/01 | 3 | 19.0 | 109.0 | 10.9 |
| | 4 | 26.5 | 110.6 | 15.0 |
| | 5 | 27.7 | 109.9 | 15.8 |
| 10/31/01 | 3 | 20.3 | 109.0 | 11.6 |
| | 4 | 26.8 | 110.6 | 15.1 |
| | 5 | 27.2 | 109.9 | 15.5 |
| 11/2/01 | 3 | 19.7 | 109.0 | 11.3 |
| | 4 | 27.9 | 110.6 | 15.8 |
| | 5 | 27.5 | 109.9 | 15.6 |
| 11/5/01 | 3 | 19.7 | 109.0 | 11.3 |
| | 4 | 26.8 | 110.6 | 15.1 |
| | 5 | 27.4 | 109.9 | 15.6 |
| 11/6/01 | 3 | 20.1 | 109.0 | 11.5 |
| | 4 | 27.5 | 110.6 | 15.5 |
| | 5 | 27.3 | 109.9 | 15.5 |
| 11/7/01 | 3 | 26.2 | 109.0 | 15.0 |
| | 4 | 28.7 | 110.6 | 16.2 |
| | 5 | 29.6 | 109.9 | 16.8 |
| 11/9/01 | 3 | 20.3 | 109.0 | 11.6 |
| | 4 | 24.3 | 110.6 | 13.7 |
| | 5 | 25.2 | 109.9 | 14.3 |
| 11/12/01 | 3 | 20.6 | 109.0 | 11.8 |
| | 4 | 25.1 | 110.6 | 14.2 |
| | 5 | 25.5 | 109.9 | 14.5 |

Table 3.7 Moisture Profile under Water Level at -12 inches
(A-2-4 soil, South)

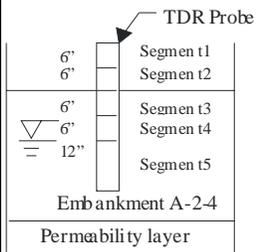
| Date | Segment No. | Vol. Moist. (%) | Dry Density (pcf) | Moisture (%) | Notes |
|----------|-------------|-----------------|-------------------|--------------|---|
| 10/11/01 | 3 | 7.9 | 108 | 4.6 |  <p>TDR Probe</p> <p>6" Segment t1 6" Segment t2 6" Segment t3 6" Segment t4 12" Segment t5 Embankment A-2-4 Permeability layer</p> <p>1) Segments 1& 2 are not in use. 2) Embankment soil is A-2-4(12%). 3) Data are for the south part of test pit.</p> |
| | 4 | 13.3 | 109.1 | 7.6 | |
| | 5 | 27.5 | 109.6 | 15.7 | |
| 10/12/01 | 3 | 11.5 | 108.0 | 6.7 | |
| | 4 | 19.5 | 109.1 | 11.2 | |
| | 5 | 29.6 | 109.6 | 16.9 | |
| 10/15/01 | 3 | 12.2 | 108.0 | 7.1 | |
| | 4 | 19.2 | 109.1 | 11.0 | |
| | 5 | 30.8 | 109.6 | 17.6 | |
| 10/16/01 | 3 | 9.7 | 108.0 | 5.6 | |
| | 4 | 19.8 | 109.1 | 11.3 | |
| | 5 | 30.6 | 109.6 | 17.4 | |
| 10/17/01 | 3 | 20.6 | 108.0 | 11.9 | |
| | 4 | 24.0 | 109.1 | 13.7 | |
| | 5 | 29.4 | 109.6 | 16.8 | |
| 10/18/01 | 3 | 20.3 | 108.0 | 11.7 | |
| | 4 | 24.3 | 109.1 | 13.9 | |
| | 5 | 29.7 | 109.6 | 16.9 | |
| 10/19/01 | 3 | 20.9 | 108.0 | 12.1 | |
| | 4 | 24.0 | 109.1 | 13.7 | |
| | 5 | 29.6 | 109.6 | 16.9 | |
| 10/22/01 | 3 | 16.9 | 108.0 | 9.8 | |
| | 4 | 23.7 | 109.1 | 13.6 | |
| | 5 | 28.7 | 109.6 | 16.4 | |
| 10/23/01 | 3 | 20.6 | 108.0 | 11.9 | |
| | 4 | 24.0 | 109.1 | 13.7 | |
| | 5 | 29.1 | 109.6 | 16.6 | |
| 10/24/01 | 3 | 19.4 | 108.0 | 11.2 | |
| | 4 | 24.0 | 109.1 | 13.7 | |
| | 5 | 28.7 | 109.6 | 16.4 | |
| 10/25/01 | 3 | 17.8 | 108.0 | 10.3 | |
| | 4 | 23.4 | 109.1 | 13.4 | |
| | 5 | 29.3 | 109.6 | 16.7 | |
| 10/26/01 | 3 | 19.7 | 108.0 | 11.4 | |
| | 4 | 24.0 | 109.1 | 13.7 | |
| | 5 | 29.0 | 109.6 | 16.5 | |
| 10/29/01 | 3 | 19.7 | 108.0 | 11.4 | |
| | 4 | 24.0 | 109.1 | 13.7 | |
| | 5 | 29.7 | 109.6 | 16.9 | |

Table 3.7 Moisture Profile under Water Level at -12 inches
(A-2-4 soil, South) (Continued)

| | | | | |
|-----------------|----------|------|-------|------|
| 10/30/01 | 3 | 18.7 | 108.0 | 10.8 |
| | 4 | 23.7 | 109.1 | 13.6 |
| | 5 | 29.9 | 109.6 | 17.1 |
| 10/31/01 | 3 | 19.7 | 108.0 | 11.4 |
| | 4 | 24.0 | 109.1 | 13.7 |
| | 5 | 29.6 | 109.6 | 16.9 |
| 11/2/01 | 3 | 18.7 | 108.0 | 10.8 |
| | 4 | 23.1 | 109.1 | 13.2 |
| | 5 | 29.6 | 109.6 | 16.9 |
| 11/5/01 | 3 | 18.4 | 108.0 | 10.6 |
| | 4 | 22.6 | 109.1 | 12.9 |
| | 5 | 29.1 | 109.6 | 16.6 |
| 11/6/01 | 3 | 18.8 | 108.0 | 10.9 |
| | 4 | 23.5 | 109.1 | 13.5 |
| | 5 | 29.6 | 109.6 | 16.9 |
| 11/7/01 | 3 | 17.8 | 108.0 | 10.3 |
| | 4 | 27.0 | 109.1 | 15.5 |
| | 5 | 26.6 | 109.6 | 15.2 |
| 11/9/01 | 3 | 26.8 | 108.0 | 15.5 |
| | 4 | 26.2 | 109.1 | 15.0 |
| | 5 | 27.8 | 109.6 | 15.9 |
| 11/12/01 | 3 | 20.3 | 108.0 | 11.7 |
| | 4 | 24.3 | 109.1 | 13.9 |
| | 5 | 27.2 | 109.6 | 15.5 |

Table 3.8 Moisture Profile under Water Level at -12 inches
(A-2-4 soil, North)

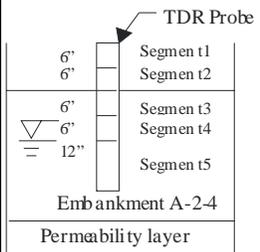
| Date | Segment No. | Vol. Moist. (%) | Dry Density (pcf) | Moisture (%) | Notes |
|----------|-------------|-----------------|-------------------|--------------|---|
| 10/11/01 | 3 | 11.1 | 108.0 | 6.4 |  <p>TDR Probe</p> <p>6" Segmen t1 6" Segmen t2 6" Segmen t3 6" Segmen t4 12" Segmen t5</p> <p>Embankment A-2-4 Permeability layer</p> <p>1) Segments 1& 2 are not in use. 2) Embankment soil is A-2-4(12%). 3) Data are for the north part of test pit.</p> |
| | 4 | 13.6 | 109.1 | 7.8 | |
| | 5 | 25.5 | 109.6 | 14.5 | |
| 10/12/01 | 3 | 14.7 | 108.0 | 8.5 | |
| | 4 | 19.2 | 109.1 | 11.0 | |
| | 5 | 29.7 | 109.6 | 16.9 | |
| 10/15/01 | 3 | 15.6 | 108.0 | 9.0 | |
| | 4 | 20.3 | 109.1 | 11.6 | |
| | 5 | 30.0 | 109.6 | 17.1 | |
| 10/16/01 | 3 | 15.0 | 108.0 | 8.7 | |
| | 4 | 20.3 | 109.1 | 11.6 | |
| | 5 | 30.2 | 109.6 | 17.2 | |
| 10/17/01 | 3 | 25.9 | 108.0 | 15.0 | |
| | 4 | 27.9 | 109.1 | 16.0 | |
| | 5 | 29.3 | 109.6 | 16.7 | |
| 10/18/01 | 3 | 23.4 | 108.0 | 13.5 | |
| | 4 | 27.6 | 109.1 | 15.8 | |
| | 5 | 29.0 | 109.6 | 16.5 | |
| 10/19/01 | 3 | 23.4 | 108.0 | 13.5 | |
| | 4 | 29.0 | 109.1 | 16.6 | |
| | 5 | 29.3 | 109.6 | 16.7 | |
| 10/22/01 | 3 | 22.1 | 108.0 | 12.8 | |
| | 4 | 27.6 | 109.1 | 15.8 | |
| | 5 | 29.4 | 109.6 | 16.8 | |
| 10/23/01 | 3 | 24.6 | 108.0 | 14.2 | |
| | 4 | 27.0 | 109.1 | 15.5 | |
| | 5 | 29.0 | 109.6 | 16.5 | |
| 10/24/01 | 3 | 26.2 | 108.0 | 15.2 | |
| | 4 | 28.2 | 109.1 | 16.2 | |
| | 5 | 29.3 | 109.6 | 16.7 | |
| 10/25/01 | 3 | 26.5 | 108.0 | 15.3 | |
| | 4 | 27.3 | 109.1 | 15.6 | |
| | 5 | 29.0 | 109.6 | 16.5 | |
| 10/26/01 | 3 | 26.5 | 108.0 | 15.3 | |
| | 4 | 27.0 | 109.1 | 15.5 | |
| | 5 | 29.3 | 109.6 | 16.7 | |
| 10/29/01 | 3 | 26.8 | 108.0 | 15.5 | |
| | 4 | 28.7 | 109.1 | 16.4 | |
| | 5 | 29.7 | 109.6 | 16.9 | |

Table 3.8 Moisture Profile under Water Level at -12 inches
(A-2-4 soil, North) (Continued)

| | | | | |
|-----------------|----------|------|-------|------|
| 10/30/01 | 3 | 25.6 | 108.0 | 14.8 |
| | 4 | 27.6 | 109.1 | 15.8 |
| | 5 | 29.6 | 109.6 | 16.9 |
| 10/31/01 | 3 | 26.5 | 108.0 | 15.3 |
| | 4 | 27.9 | 109.1 | 16.0 |
| | 5 | 29.4 | 109.6 | 16.8 |
| 11/2/01 | 3 | 25.9 | 108.0 | 15.0 |
| | 4 | 28.2 | 109.1 | 16.2 |
| | 5 | 29.6 | 109.6 | 16.9 |
| 11/5/01 | 3 | 26.2 | 108.0 | 15.2 |
| | 4 | 28.2 | 109.1 | 16.2 |
| | 5 | 29.3 | 109.6 | 16.7 |
| 11/6/01 | 3 | 25.8 | 108.0 | 14.9 |
| | 4 | 28.0 | 109.1 | 16.0 |
| | 5 | 29.4 | 109.6 | 16.8 |
| 11/7/01 | 3 | 20.3 | 108.0 | 11.7 |
| | 4 | 28.2 | 109.1 | 16.2 |
| | 5 | 27.4 | 109.6 | 15.6 |
| 11/9/01 | 3 | 26.8 | 108.0 | 15.5 |
| | 4 | 26.2 | 109.1 | 15.0 |
| | 5 | 27.8 | 109.6 | 15.9 |
| 11/12/01 | 3 | 26.2 | 108.0 | 15.2 |
| | 4 | 27.0 | 109.1 | 15.5 |
| | 5 | 28.4 | 109.6 | 16.2 |

Table 3.9 Moisture Profile under Water Level at -6 inches
(A-3 soil, South)

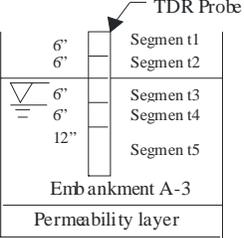
| Date | Segment No. | Vol. Moist. (%) | Dry Density (pcf) | Moisture (%) | Notes |
|----------|-------------|-----------------|-------------------|--------------|--|
| 12/11/01 | 3 | 5.7 | 110.8 | 3.2 |  <p>TDR Probe</p> <p>6" 6" 6" 6" 12"</p> <p>Segment t1 Segment t2 Segment t3 Segment t4 Segment t5</p> <p>Embankment A-3 Permeability layer</p> <p>1) Segments 1& 2 are not in use. 2) Embankment soil is A-3(5%). 3) Data are for the south part of test pit.</p> |
| | 4 | 10.6 | 111.9 | 5.9 | |
| | 5 | 23.5 | 109.9 | 13.4 | |
| 12/12/01 | 3 | 17.5 | 110.8 | 9.9 | |
| | 4 | 23.7 | 111.9 | 13.2 | |
| | 5 | 28.0 | 109.9 | 15.9 | |
| 12/13/01 | 3 | 19.0 | 110.8 | 10.7 | |
| | 4 | 22.9 | 111.9 | 12.8 | |
| | 5 | 28.0 | 109.9 | 15.9 | |
| 12/14/01 | 3 | 21.5 | 110.8 | 12.1 | |
| | 4 | 23.4 | 111.9 | 13.1 | |
| | 5 | 27.4 | 109.9 | 15.6 | |
| 12/17/01 | 3 | 21.8 | 110.8 | 12.3 | |
| | 4 | 23.1 | 111.9 | 12.9 | |
| | 5 | 27.5 | 109.9 | 15.6 | |
| 12/18/01 | 3 | 21.5 | 110.8 | 12.1 | |
| | 4 | 23.1 | 111.9 | 12.9 | |
| | 5 | 27.4 | 109.9 | 15.6 | |
| 12/19/01 | 3 | 21.5 | 110.8 | 12.1 | |
| | 4 | 23.1 | 111.9 | 12.9 | |
| | 5 | 27.5 | 109.9 | 15.6 | |
| 12/20/01 | 3 | 21.2 | 110.8 | 12.0 | |
| | 4 | 23.1 | 111.9 | 12.9 | |
| | 5 | 27.5 | 109.9 | 15.6 | |
| 12/21/01 | 3 | 19.4 | 110.8 | 10.9 | |
| | 4 | 22.9 | 111.9 | 12.8 | |
| | 5 | 27.4 | 109.9 | 15.6 | |
| 12/24/01 | 3 | 20.9 | 110.8 | 11.8 | |
| | 4 | 22.3 | 111.9 | 12.5 | |
| | 5 | 26.8 | 109.9 | 15.2 | |
| 12/26/01 | 3 | 19.0 | 110.8 | 10.7 | |
| | 4 | 22.6 | 111.9 | 12.6 | |
| | 5 | 27.4 | 109.9 | 15.6 | |
| 12/27/01 | 3 | 18.1 | 110.8 | 10.2 | |
| | 4 | 22.6 | 111.9 | 12.6 | |
| | 5 | 26.9 | 109.9 | 15.3 | |
| 12/28/01 | 3 | 18.7 | 110.8 | 10.5 | |
| | 4 | 22.6 | 111.9 | 12.6 | |
| | 5 | 26.9 | 109.9 | 15.3 | |

Table 3.9 Moisture Profile under Water Level at -6 inches
(A-3 soil, South) (Continued)

| | | | | |
|-----------------|----------|------|-------|------|
| 12/31/01 | 3 | 18.1 | 110.8 | 10.2 |
| | 4 | 22.3 | 111.9 | 12.5 |
| | 5 | 27.1 | 109.9 | 15.4 |
| 1/2/02 | 3 | 15.9 | 110.8 | 9.0 |
| | 4 | 23.1 | 111.9 | 12.9 |
| | 5 | 27.1 | 109.9 | 15.4 |
| 1/3/02 | 3 | 17.2 | 110.8 | 9.7 |
| | 4 | 23.4 | 111.9 | 13.1 |
| | 5 | 26.9 | 109.9 | 15.3 |
| 1/7/02 | 3 | 16.6 | 110.8 | 9.4 |
| | 4 | 23.4 | 111.9 | 13.1 |
| | 5 | 26.8 | 109.9 | 15.2 |
| 1/8/01 | 3 | 16.9 | 110.8 | 9.5 |
| | 4 | 24.9 | 111.9 | 13.9 |
| | 5 | 27.1 | 109.9 | 15.4 |

Table 3.10 Moisture Profile under Water Level at -6 inches
(A-3 soil, North)

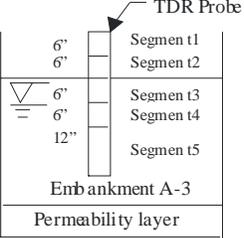
| Date | Segment No. | Vol. Moist. (%) | Dry Density (pcf) | Moisture (%) | Notes |
|----------|-------------|-----------------|-------------------|--------------|--|
| 12/11/01 | 3 | 6.3 | 111.1 | 3.5 |  <p>TDR Probe</p> <p>6" 6" 6" 6" 12"</p> <p>Segmen t1 Segmen t2 Segmen t3 Segmen t4 Segmen t5</p> <p>Embankment A-3</p> <p>Permeability layer</p> <p>1) Segments 1& 2 are not in use. 2) Embankment soil is A-3(5%). 3) Data are for the north part of test pit.</p> |
| | 4 | 17.3 | 111.8 | 9.7 | |
| | 5 | 24.9 | 109.9 | 14.2 | |
| 12/12/01 | 3 | 18.7 | 111.1 | 10.5 | |
| | 4 | 27.6 | 111.8 | 15.4 | |
| | 5 | 26.6 | 109.9 | 15.1 | |
| 12/13/01 | 3 | 20.9 | 111.1 | 11.8 | |
| | 4 | 27.3 | 111.8 | 15.3 | |
| | 5 | 26.5 | 109.9 | 15.1 | |
| 12/14/01 | 3 | 24.0 | 111.1 | 13.5 | |
| | 4 | 26.8 | 111.8 | 15.0 | |
| | 5 | 26.5 | 109.9 | 15.1 | |
| 12/17/01 | 3 | 24.6 | 111.1 | 13.8 | |
| | 4 | 27.3 | 111.8 | 15.3 | |
| | 5 | 26.3 | 109.9 | 15.0 | |
| 12/18/01 | 3 | 24.6 | 111.1 | 13.8 | |
| | 4 | 27.6 | 111.8 | 15.4 | |
| | 5 | 26.3 | 109.9 | 15.0 | |
| 12/19/01 | 3 | 24.3 | 111.1 | 13.7 | |
| | 4 | 27.9 | 111.8 | 15.6 | |
| | 5 | 26.5 | 109.9 | 15.1 | |
| 12/20/01 | 3 | 24.6 | 111.1 | 13.8 | |
| | 4 | 28.4 | 111.8 | 15.9 | |
| | 5 | 26.5 | 109.9 | 15.1 | |
| 12/21/01 | 3 | 24.9 | 111.1 | 14.0 | |
| | 4 | 28.2 | 111.8 | 15.8 | |
| | 5 | 26.6 | 109.9 | 15.1 | |
| 12/24/01 | 3 | 24.3 | 111.1 | 13.7 | |
| | 4 | 27.6 | 111.8 | 15.4 | |
| | 5 | 26.2 | 109.9 | 14.9 | |
| 12/26/01 | 3 | 24.0 | 111.1 | 13.5 | |
| | 4 | 27.3 | 111.8 | 15.3 | |
| | 5 | 26.2 | 109.9 | 14.9 | |
| 12/27/01 | 3 | 22.5 | 111.1 | 12.7 | |
| | 4 | 27.6 | 111.8 | 15.4 | |
| | 5 | 26.6 | 109.9 | 15.1 | |
| 12/28/01 | 3 | 21.8 | 111.1 | 12.3 | |
| | 4 | 29.5 | 111.8 | 16.5 | |
| | 5 | 26.2 | 109.9 | 14.9 | |

Table 3.10 Moisture Profile under Water Level at -6 inches
(A-3 soil, North) (Continued)

| | | | | |
|-----------------|----------|------|-------|------|
| 12/31/01 | 3 | 20.3 | 111.1 | 11.4 |
| | 4 | 27.9 | 111.8 | 15.6 |
| | 5 | 26.8 | 109.9 | 15.2 |
| 1/2/02 | 3 | 20.6 | 111.1 | 11.6 |
| | 4 | 28.4 | 111.8 | 15.9 |
| | 5 | 26.6 | 109.9 | 15.1 |
| 1/3/02 | 3 | 20.3 | 111.1 | 11.4 |
| | 4 | 28.2 | 111.8 | 15.8 |
| | 5 | 26.6 | 109.9 | 15.1 |
| 1/7/02 | 3 | 18.1 | 111.1 | 10.2 |
| | 4 | 27.9 | 111.8 | 15.6 |
| | 5 | 26.5 | 109.9 | 15.1 |
| 1/8/01 | 3 | 19.4 | 111.1 | 10.9 |
| | 4 | 27.6 | 111.8 | 15.4 |
| | 5 | 26.8 | 109.9 | 15.2 |

Table 3.11 Moisture Profile under Water Level at -6 inches
(A-2-4 soil, South)

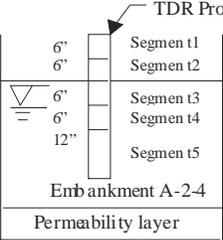
| Date | Segment No. | Vol. Moist. (%) | Dry Density (pcf) | Moisture (%) | Notes |
|----------|-------------|-----------------|-------------------|--------------|--|
| 12/11/01 | 3 | 11.6 | 110.4 | 6.6 |  <p>TDR Probe</p> <p>6" Segmen t1 6" Segmen t2 6" Segmen t3 6" Segmen t4 12" Segmen t5</p> <p>Embankment A-2-4</p> <p>Permeability layer</p> <p>1) Segments 1& 2 are not in use. 2) Embankment soil is A-2-4(12%). 3) Data are for the south part of test pit.</p> |
| | 4 | 20.1 | 111.3 | 11.3 | |
| | 5 | 24.7 | 109.6 | 14.1 | |
| 12/12/01 | 3 | 27.7 | 110.4 | 15.7 | |
| | 4 | 27.9 | 111.3 | 15.7 | |
| | 5 | 29.0 | 109.6 | 16.5 | |
| 12/13/01 | 3 | 26.2 | 110.4 | 14.8 | |
| | 4 | 27.0 | 111.3 | 15.2 | |
| | 5 | 29.1 | 109.6 | 16.6 | |
| 12/14/01 | 3 | 29.0 | 110.4 | 16.4 | |
| | 4 | 27.0 | 111.3 | 15.2 | |
| | 5 | 29.0 | 109.6 | 16.5 | |
| 12/17/01 | 3 | 28.7 | 110.4 | 16.2 | |
| | 4 | 26.8 | 111.3 | 15.0 | |
| | 5 | 29.0 | 109.6 | 16.5 | |
| 12/18/01 | 3 | 29.3 | 110.4 | 16.6 | |
| | 4 | 27.0 | 111.3 | 15.2 | |
| | 5 | 28.6 | 109.6 | 16.3 | |
| 12/19/01 | 3 | 29.3 | 110.4 | 16.6 | |
| | 4 | 27.3 | 111.3 | 15.3 | |
| | 5 | 28.7 | 109.6 | 16.4 | |
| 12/20/01 | 3 | 29.6 | 110.4 | 16.8 | |
| | 4 | 27.9 | 111.3 | 15.7 | |
| | 5 | 28.8 | 109.6 | 16.4 | |
| 12/21/01 | 3 | 29.0 | 110.4 | 16.4 | |
| | 4 | 27.3 | 111.3 | 15.3 | |
| | 5 | 28.8 | 109.6 | 16.4 | |
| 12/24/01 | 3 | 29.0 | 110.4 | 16.4 | |
| | 4 | 27.3 | 111.3 | 15.3 | |
| | 5 | 28.7 | 109.6 | 16.4 | |
| 12/26/01 | 3 | 28.3 | 110.4 | 16.0 | |
| | 4 | 28.4 | 111.3 | 15.9 | |
| | 5 | 28.6 | 109.6 | 16.3 | |
| 12/27/01 | 3 | 28.7 | 110.4 | 16.2 | |
| | 4 | 27.9 | 111.3 | 15.7 | |
| | 5 | 28.7 | 109.6 | 16.4 | |
| 12/28/01 | 3 | 28.3 | 110.4 | 16.0 | |
| | 4 | 27.0 | 111.3 | 15.2 | |
| | 5 | 28.7 | 109.6 | 16.4 | |

Table 3.11 Moisture Profile under Water Level at -6 inches
(A-2-4 soil, South) (Continued)

| | | | | |
|-----------------|----------|------|-------|------|
| 12/31/01 | 3 | 29.3 | 110.4 | 16.6 |
| | 4 | 27.3 | 111.3 | 15.3 |
| | 5 | 28.6 | 109.6 | 16.3 |
| 1/2/02 | 3 | 29.3 | 110.4 | 16.6 |
| | 4 | 27.3 | 111.3 | 15.3 |
| | 5 | 28.8 | 109.6 | 16.4 |
| 1/3/02 | 3 | 29.3 | 110.4 | 16.6 |
| | 4 | 27.6 | 111.3 | 15.5 |
| | 5 | 28.6 | 109.6 | 16.3 |
| 1/7/02 | 3 | 31.1 | 110.4 | 17.6 |
| | 4 | 27.9 | 111.3 | 15.7 |
| | 5 | 28.4 | 109.6 | 16.2 |
| 1/8/01 | 3 | 28.0 | 110.4 | 15.9 |
| | 4 | 27.3 | 111.3 | 15.3 |
| | 5 | 28.7 | 109.6 | 16.4 |

Table 3.12 Moisture Profile under Water Level at -6 inches
(A-2-4 soil, North)

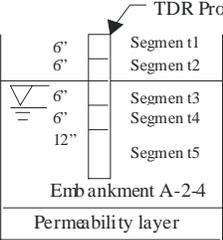
| Date | Segment No. | Vol. Moist. (%) | Dry Density (pcf) | Moisture (%) | Notes |
|----------|-------------|-----------------|-------------------|--------------|---|
| 12/11/01 | 3 | 15.3 | 108.6 | 8.8 |  <p>TDR Probe</p> <p>6" Segmen t1 6" Segmen t2 6" Segmen t3 6" Segmen t4 12" Segmen t5</p> <p>Embankment A-2-4</p> <p>Permeability layer</p> <p>1) Segments 1& 2 are not in use. 2) Embankment soil is A-2-4(12%). 3) Data are for the north part of test pit.</p> |
| | 4 | 22.4 | 109.4 | 12.8 | |
| | 5 | 26.6 | 109.6 | 15.2 | |
| 12/12/01 | 3 | 30.8 | 108.6 | 17.7 | |
| | 4 | 27.6 | 109.4 | 15.8 | |
| | 5 | 28.1 | 109.6 | 16.0 | |
| 12/13/01 | 3 | 31.8 | 108.6 | 18.3 | |
| | 4 | 28.4 | 109.4 | 16.2 | |
| | 5 | 28.4 | 109.6 | 16.2 | |
| 12/14/01 | 3 | 33.6 | 108.6 | 19.3 | |
| | 4 | 27.3 | 109.4 | 15.6 | |
| | 5 | 28.4 | 109.6 | 16.2 | |
| 12/17/01 | 3 | 33.0 | 108.6 | 19.0 | |
| | 4 | 27.6 | 109.4 | 15.8 | |
| | 5 | 28.3 | 109.6 | 16.1 | |
| 12/18/01 | 3 | 33.5 | 108.6 | 19.3 | |
| | 4 | 27.5 | 109.4 | 15.7 | |
| | 5 | 28.3 | 109.6 | 16.1 | |
| 12/19/01 | 3 | 33.3 | 108.6 | 19.2 | |
| | 4 | 28.7 | 109.4 | 16.4 | |
| | 5 | 28.3 | 109.6 | 16.1 | |
| 12/20/01 | 3 | 32.7 | 108.6 | 18.8 | |
| | 4 | 27.3 | 109.4 | 15.6 | |
| | 5 | 28.3 | 109.6 | 16.1 | |
| 12/21/01 | 3 | 33.3 | 108.6 | 19.2 | |
| | 4 | 28.2 | 109.4 | 16.1 | |
| | 5 | 28.4 | 109.6 | 16.2 | |
| 12/24/01 | 3 | 32.1 | 108.6 | 18.5 | |
| | 4 | 27.9 | 109.4 | 15.9 | |
| | 5 | 28.4 | 109.6 | 16.2 | |
| 12/26/01 | 3 | 32.7 | 108.6 | 18.8 | |
| | 4 | 28.4 | 109.4 | 16.2 | |
| | 5 | 28.3 | 109.6 | 16.1 | |
| 12/27/01 | 3 | 33.9 | 108.6 | 19.5 | |
| | 4 | 26.2 | 109.4 | 15.0 | |
| | 5 | 28.8 | 109.6 | 16.4 | |
| 12/28/01 | 3 | 32.1 | 108.6 | 18.5 | |
| | 4 | 27.9 | 109.4 | 15.9 | |
| | 5 | 28.6 | 109.6 | 16.3 | |

Table 3.12 Moisture Profile under Water Level at -6 inches
(A-2-4 soil, North) (Continued)

| | | | | |
|-----------------|----------|------|-------|------|
| 12/31/01 | 3 | 32.4 | 108.6 | 18.6 |
| | 4 | 27.6 | 109.4 | 15.8 |
| | 5 | 29.0 | 109.6 | 16.5 |
| 1/2/02 | 3 | 32.1 | 108.6 | 18.5 |
| | 4 | 28.4 | 109.4 | 16.2 |
| | 5 | 28.4 | 109.6 | 16.2 |
| 1/3/02 | 3 | 32.7 | 108.6 | 18.8 |
| | 4 | 28.7 | 109.4 | 16.4 |
| | 5 | 28.6 | 109.6 | 16.3 |
| 1/7/02 | 3 | 31.4 | 108.6 | 18.1 |
| | 4 | 28.4 | 109.4 | 16.2 |
| | 5 | 28.7 | 109.6 | 16.4 |
| 1/8/01 | 3 | 31.1 | 108.6 | 17.9 |
| | 4 | 28.7 | 109.4 | 16.4 |
| | 5 | 28.7 | 109.6 | 16.4 |

Table 3.13 Moisture Content Variation in the Test Pits

| Soil Type | Water Level, in | TDR Seg No. | Segment Range (in) | Test Pit | MC Before (%) | MC After (%) | MC Increase (%) | Average Increase (%) | Capillary Rise (?) | Capillary Rise Height (in) |
|----------------|-----------------|-------------|--------------------|----------|---------------|--------------|-----------------|----------------------|--------------------|----------------------------|
| A-3 (5%) | -24 | 3 | -6 to 0 | South | 2.4 | 3.1 | 0.7 | 0.5 | N/Y | ≅ 24 |
| | | | | North | 3.1 | 3.4 | 0.3 | | | |
| | | 4 | -12 to -6 | South | 5.2 | 7.0 | 1.8 | 1.7 | Y | |
| | | | | North | 5.0 | 6.6 | 1.6 | | | |
| | | 5 | -24 to -12 | South | 7.4 | 12.1 | 4.7 | 4.9 | Y | |
| | | | | North | 7.9 | 13.0 | 5.1 | | | |
| | -12 | 3 | -6 to 0 | South | 4.4 | 11.3 | 6.9 | 7.0 | Y | |
| | | | | North | 4.5 | 11.6 | 7.1 | | | |
| | | 4 | -12 to -6 | South | 6.6 | 15.4 | 8.8 | 8.5 | Y | |
| | | | | North | 7.7 | 15.8 | 8.1 | | | |
| | -6 | 3 | -6 to 0 | South | 3.2 | 12.3 | 9.0 | 9.8 | Y | |
| | | | | North | 3.5 | 14.0 | 10.5 | | | |
| A-2-4 (12%) | -24 | 3 | -6 to 0 | South | 2.4 | 5.1 | 2.7 | 2.7 | Y | >24 |
| | | | | North | 3.8 | 6.5 | 2.7 | | | |
| | | 4 | -12 to -6 | South | 4.8 | 8.3 | 3.5 | 3.6 | Y | |
| | | | | North | 5.1 | 8.8 | 3.7 | | | |
| | | 5 | -24 to -12 | South | 10.5 | 13.9 | 3.4 | 3.5 | Y | |
| | | | | North | 10.3 | 13.9 | 3.6 | | | |
| | -12 | 3 | -6 to 0 | South | 4.6 | 12.1 | 7.5 | 8.3 | Y | |
| | | | | North | 6.4 | 15.5 | 9.1 | | | |
| | | 4 | -12 to -6 | South | 7.6 | 13.9 | 6.3 | 7.6 | Y | |
| | | | | North | 7.8 | 16.6 | 8.8 | | | |
| | -6 | 3 | -6 to 0 | South | 6.6 | 17.6 | 11 | 10.9 | Y | |
| | | | | North | 8.8 | 19.5 | 10.7 | | | |

Table 3.14 Capillary Rise Rate Comparison at Water Level -12 inches

| Soil Type | Water Level | Capillary Rise (in) | Segment No./ Range | Moisture Content (%) | | | | | | | | | | | | |
|----------------|-------------|---------------------|--------------------|----------------------|-------|-------|-------|-------|-------|-------|-------|--------|--------|--------|--------|--------|
| | | | | | Day 1 | Day 2 | Day 5 | Day 6 | Day 7 | Day 8 | Day 9 | Day 12 | Day 13 | Day 14 | Day 15 | Day 16 |
| A-3 (5%) | -12" | ≈24 | 4/ -6"to -12" | South | 6.6 | 10.7 | 11.2 | 11.1 | 12.1 | 14.8 | 15.0 | 14.8 | 15.3 | 15.3 | 14.8 | 15.0 |
| | | | | North | 7.7 | 12.1 | 12.6 | 12.6 | 14.6 | 14.6 | 15.1 | 14.6 | 15.3 | 15.6 | 15.0 | 15.0 |
| | | | | Avg. | 7.2 | 11.4 | 11.9 | 11.9 | 13.4 | 14.7 | 15.1 | 14.7 | 15.3 | 15.5 | 14.9 | 15.0 |
| | | | | Change | | 4.2 | 0.5 | 0 | 1.5 | 1.3 | 0.4 | -0.4 | 0.6 | 0.2 | -0.5 | 0.1 |
| A-2-4 (12%) | -12" | >24 | 4/-6" to -12 | South | 7.6 | 11.2 | 11.0 | 11.3 | 13.7 | 13.9 | 13.7 | 13.6 | 13.7 | 13.7 | 13.4 | 13.7 |
| | | | | North | 7.8 | 11.0 | 11.6 | 11.6 | 16.0 | 15.8 | 16.6 | 15.8 | 15.5 | 16.2 | 15.6 | 15.5 |
| | | | | Avg. | 7.7 | 11.1 | 11.4 | 11.5 | 14.9 | 14.9 | 15.2 | 14.7 | 14.6 | 15.0 | 14.5 | 14.6 |
| | | | | Change | | 3.4 | 0.3 | 0.1 | 3.4 | 0 | 0.3 | -0.5 | -0.1 | 0.4 | -0.5 | 0.1 |

Table 3.15 Capillary Rise Rate Comparison at Water Level -6 inches

| Soil Type | Water Level | Capillary Rise (in) | Segment No./ Range | Moisture Content (%) | | | | | | | | | | | | |
|----------------|-------------|---------------------|--------------------|----------------------|-------|-------|-------|-------|-------|-------|--------|--------|--------|--------|--------|------|
| | | | | Day 1 | Day 2 | Day 3 | Day 4 | Day 7 | Day 8 | Day 9 | Day 10 | Day 11 | Day 14 | Day 16 | Day 17 | |
| A-3 (5%) | -6" | ≈24 | 3/ 0 to -6" | South | 3.2 | 9.9 | 10.7 | 12.1 | 12.3 | 12.1 | 12.1 | 12.0 | 10.9 | 11.8 | 10.7 | 10.2 |
| | | | | North | 3.5 | 10.5 | 11.8 | 13.5 | 13.8 | 13.8 | 13.7 | 13.8 | 14.0 | 13.7 | 13.5 | 12.7 |
| | | | | Avg. | 3.4 | 10.2 | 11.3 | 12.8 | 13.1 | 13.0 | 12.9 | 12.9 | 12.5 | 12.8 | 12.1 | 11.5 |
| | | | | Change | | 6.8 | 1.1 | 1.5 | 0.3 | -0.1 | -0.1 | 0.0 | -0.4 | 0.3 | -0.7 | -0.6 |
| A-2-4 (12%) | -6" | >24 | 3/ 0 to -6" | South | 6.6 | 15.7 | 14.8 | 16.4 | 16.2 | 16.6 | 16.6 | 16.8 | 16.4 | 16.4 | 16.0 | 16.2 |
| | | | | North | 8.8 | 17.7 | 18.3 | 19.3 | 19.0 | 19.3 | 19.2 | 18.8 | 19.2 | 18.5 | 18.8 | 19.5 |
| | | | | Avg. | 7.7 | 16.7 | 16.6 | 17.9 | 17.6 | 18.0 | 17.9 | 17.8 | 17.8 | 17.5 | 17.4 | 17.9 |
| | | | | Change | | 9.0 | -0.1 | 1.3 | -0.3 | 0.4 | -0.1 | -0.1 | 0.0 | -0.3 | -0.1 | 0.5 |

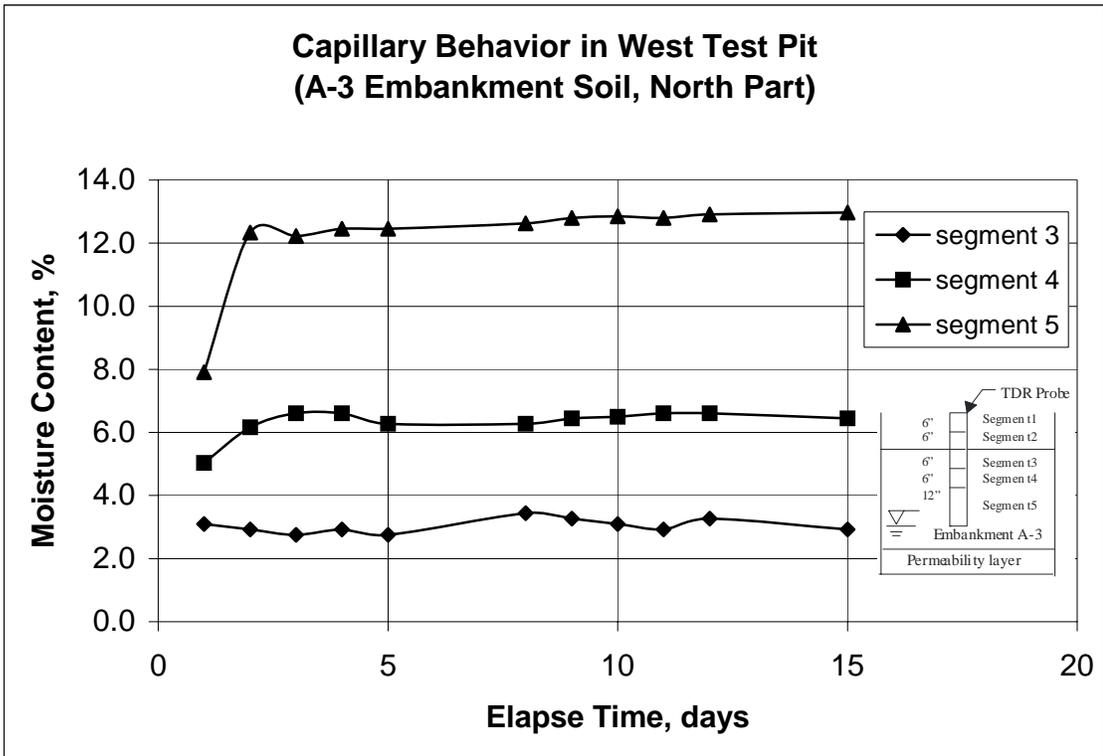
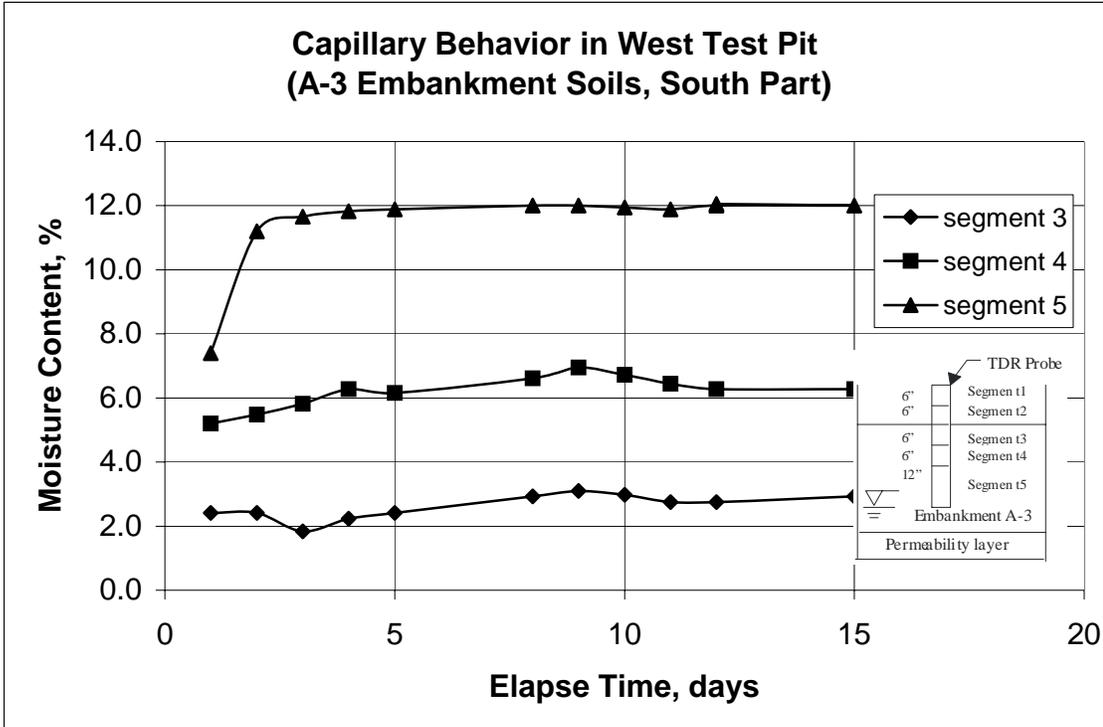


Figure 3.1 Capillary Rise Behavior at Water Level -24 inches (West Pit)

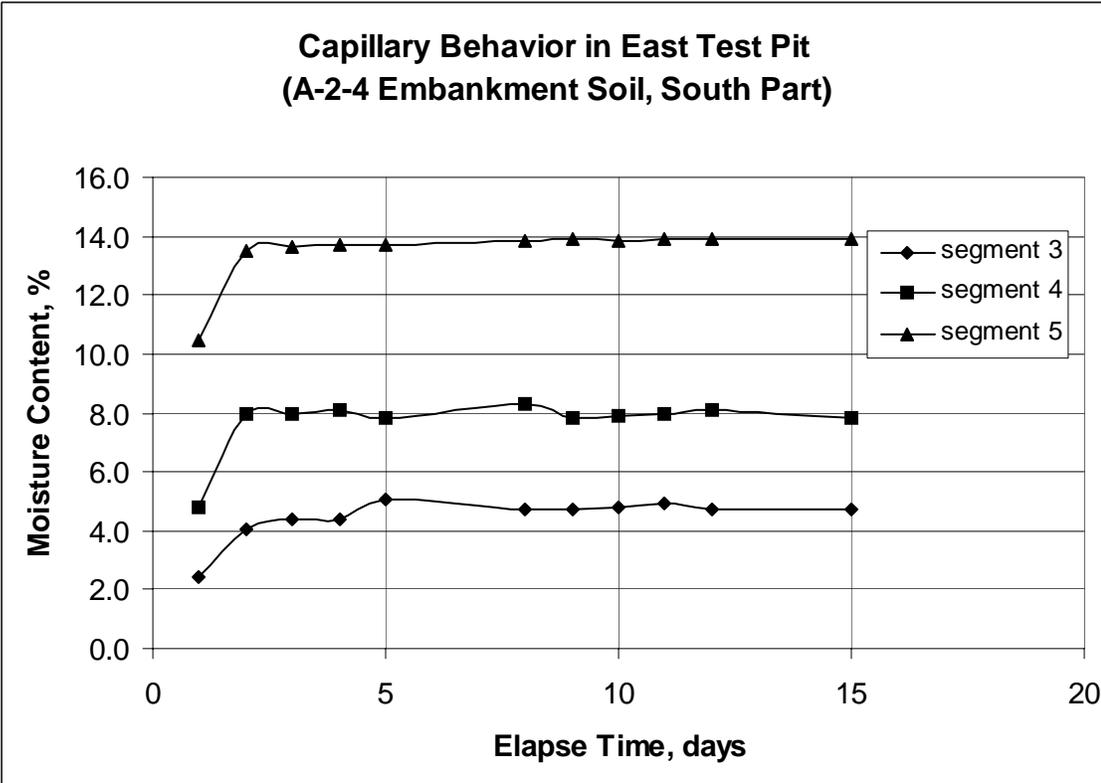
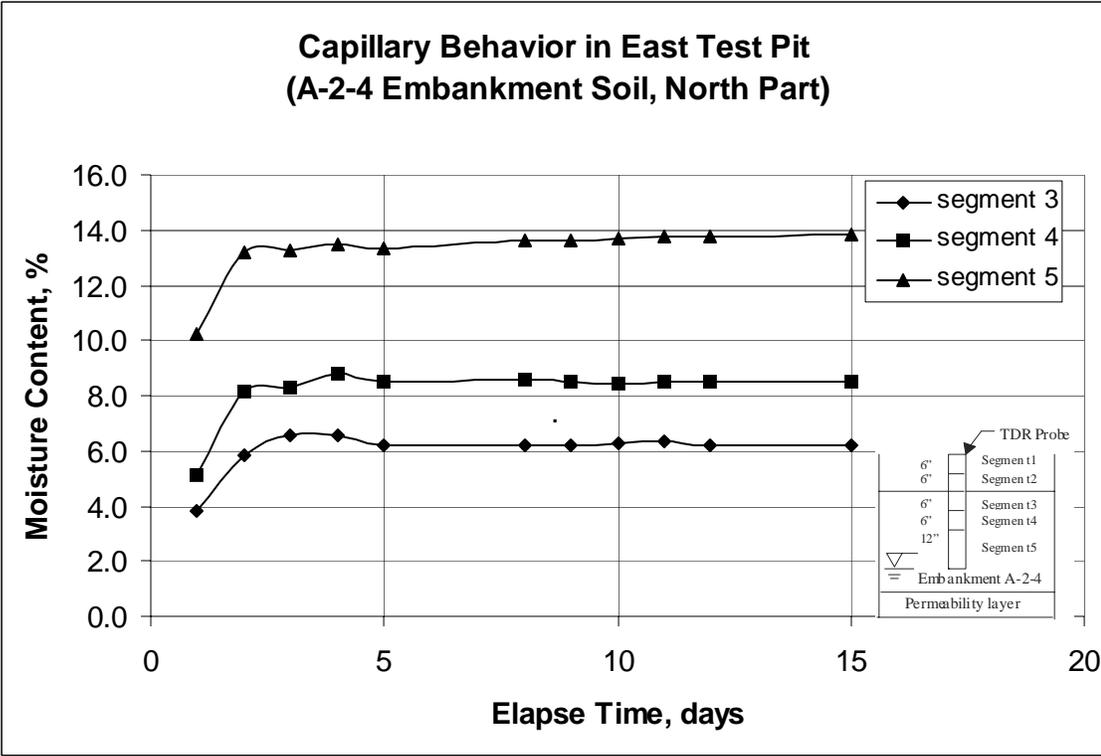


Figure 3.2 Capillary Rise Behavior at Water Level -24 inches (East Pit)

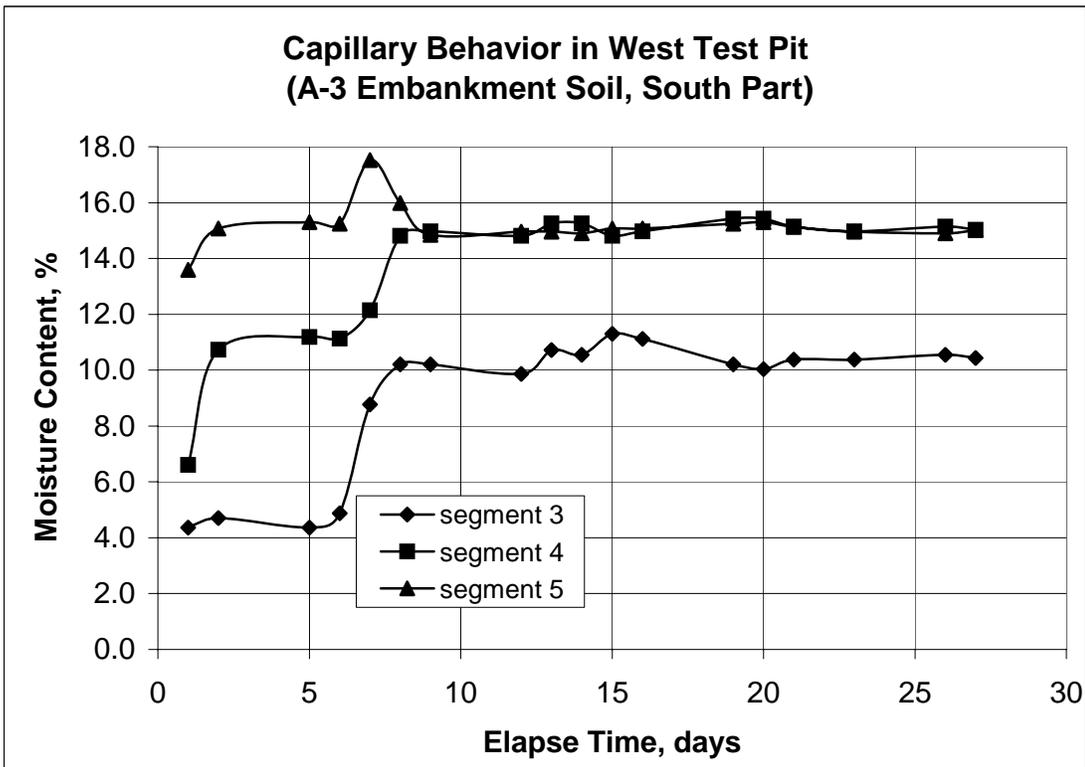
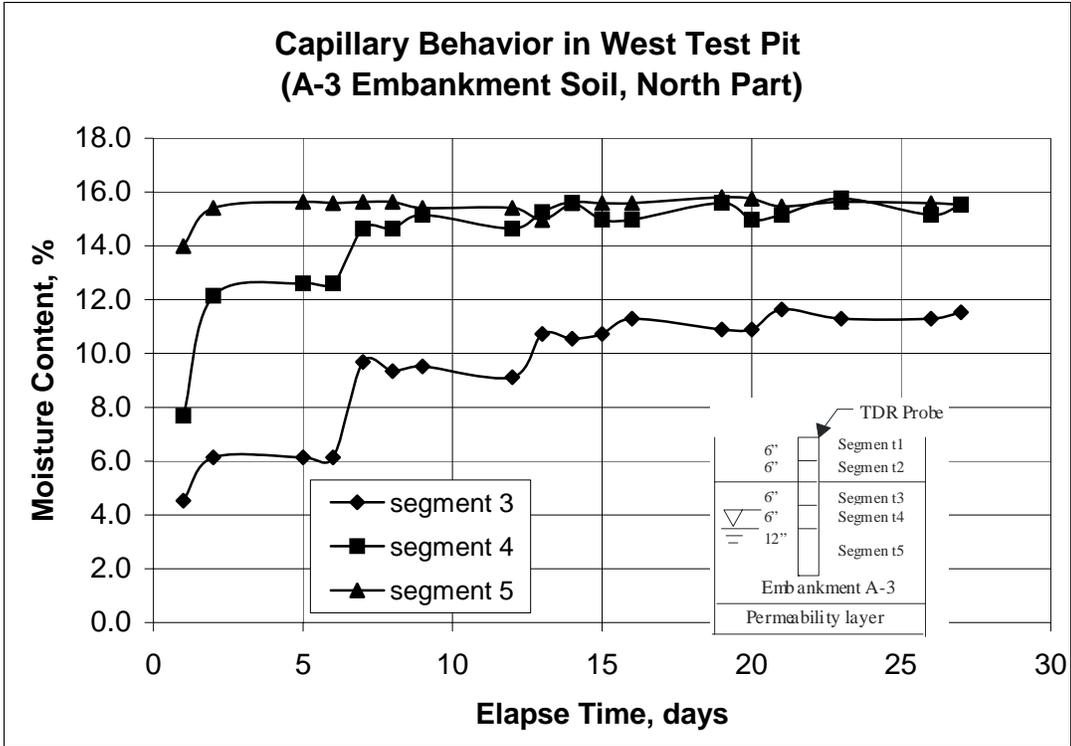


Figure 3.3 Capillary Rise Behavior at Water Level -12 inches (West Pit)

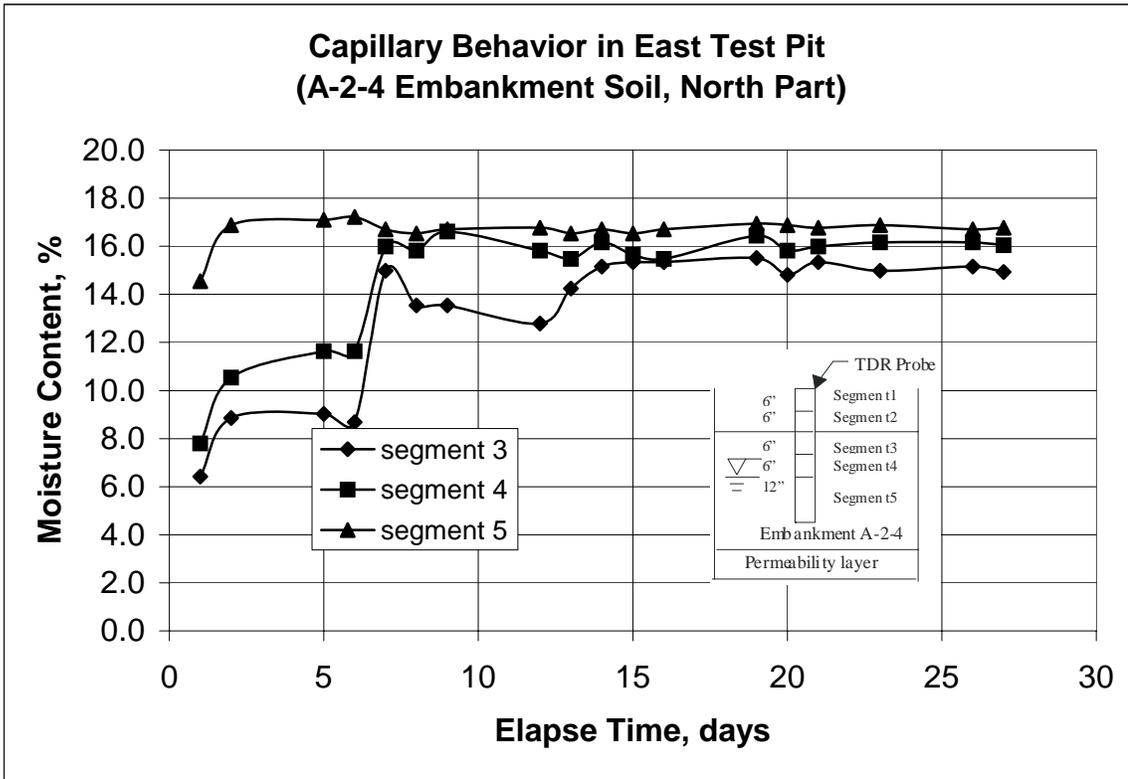
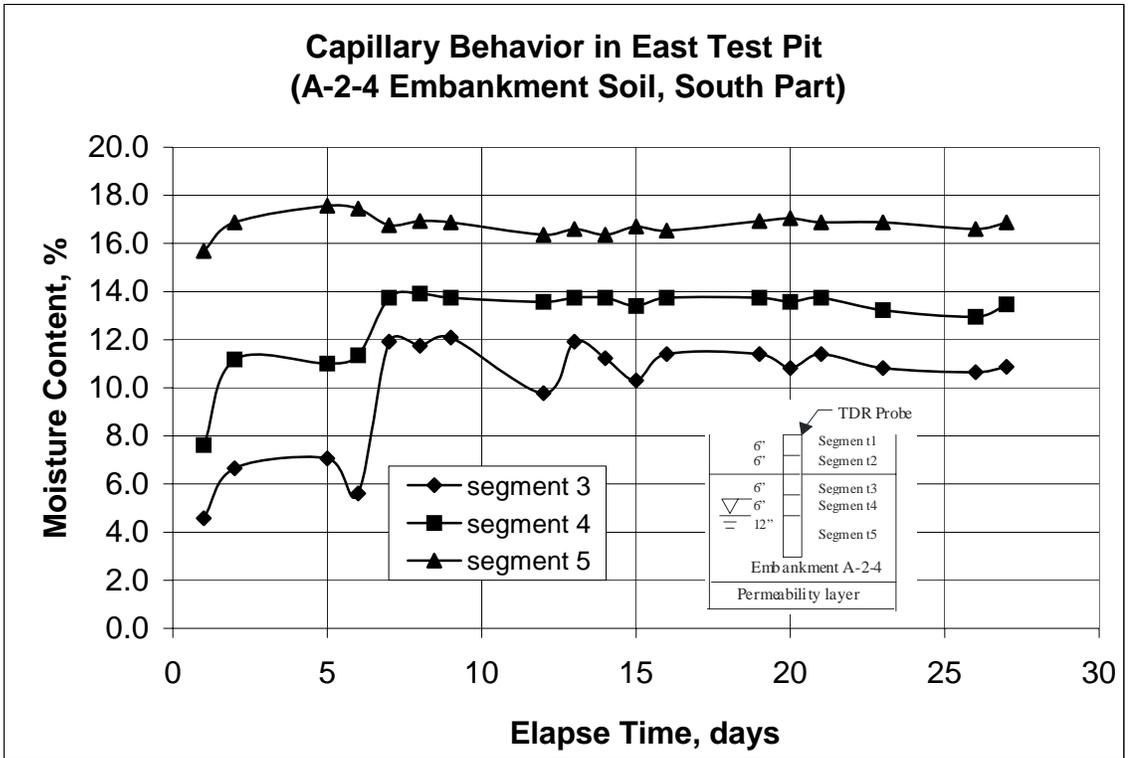


Figure 3.4 Capillary Rise Behavior at Water Level -12 inches (East Pit)

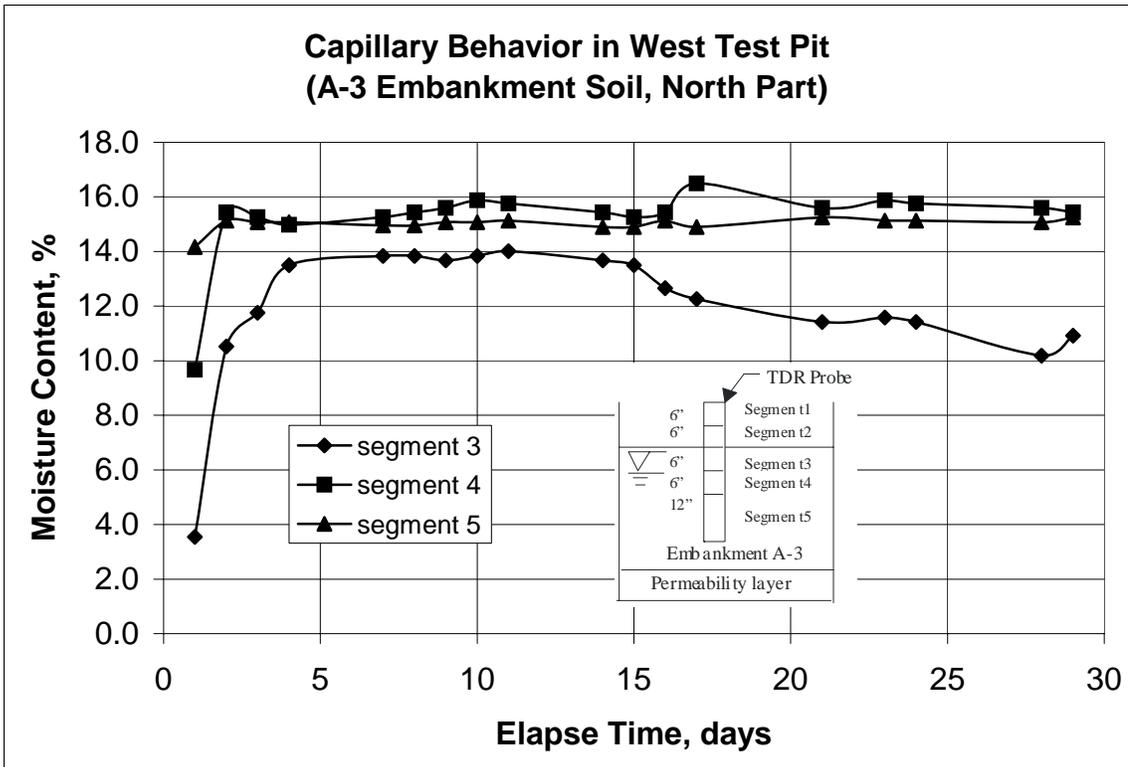
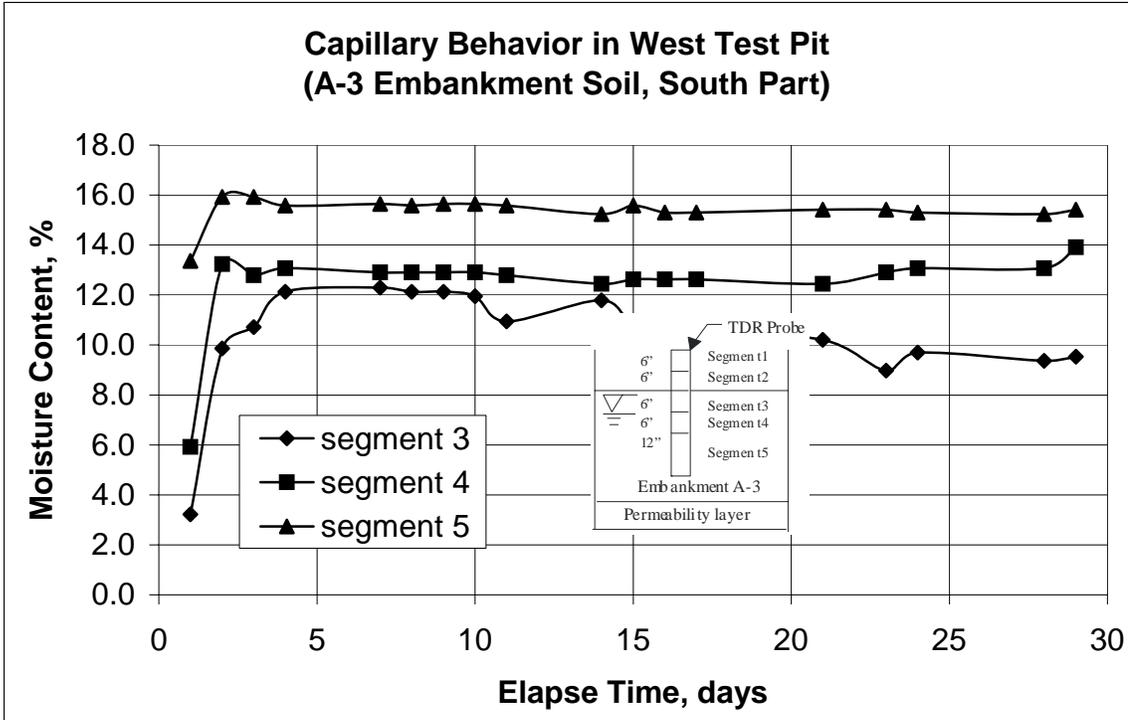


Figure 3.5 Capillary Rise Behavior at Water Level -6 inches (West Pit)

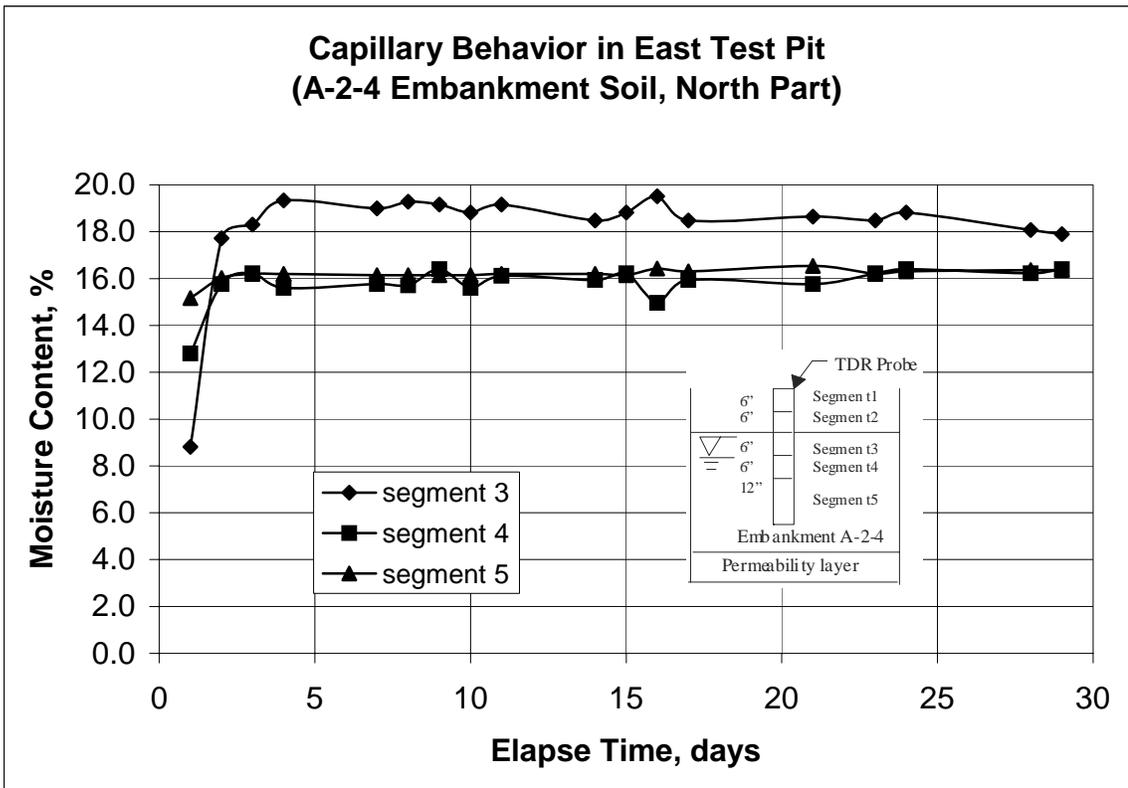
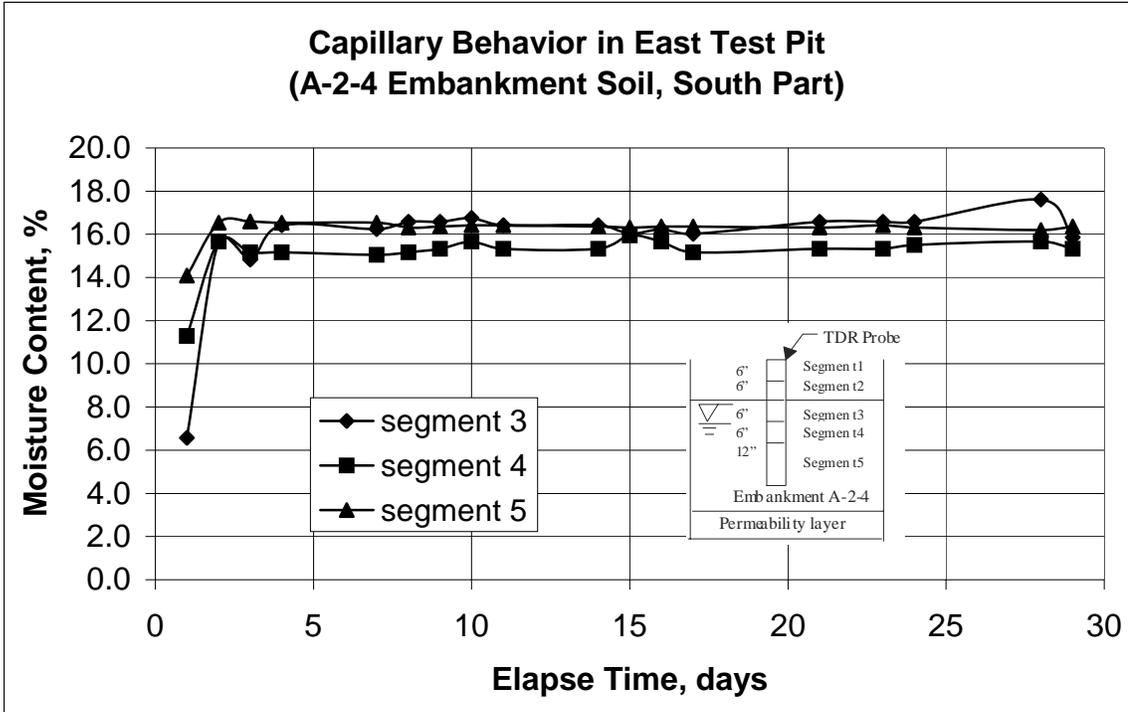


Figure 3.6 Capillary Rise Behavior at Water Level -6 inches (East Pit)

Capillary Rise Comparison at water level -12"

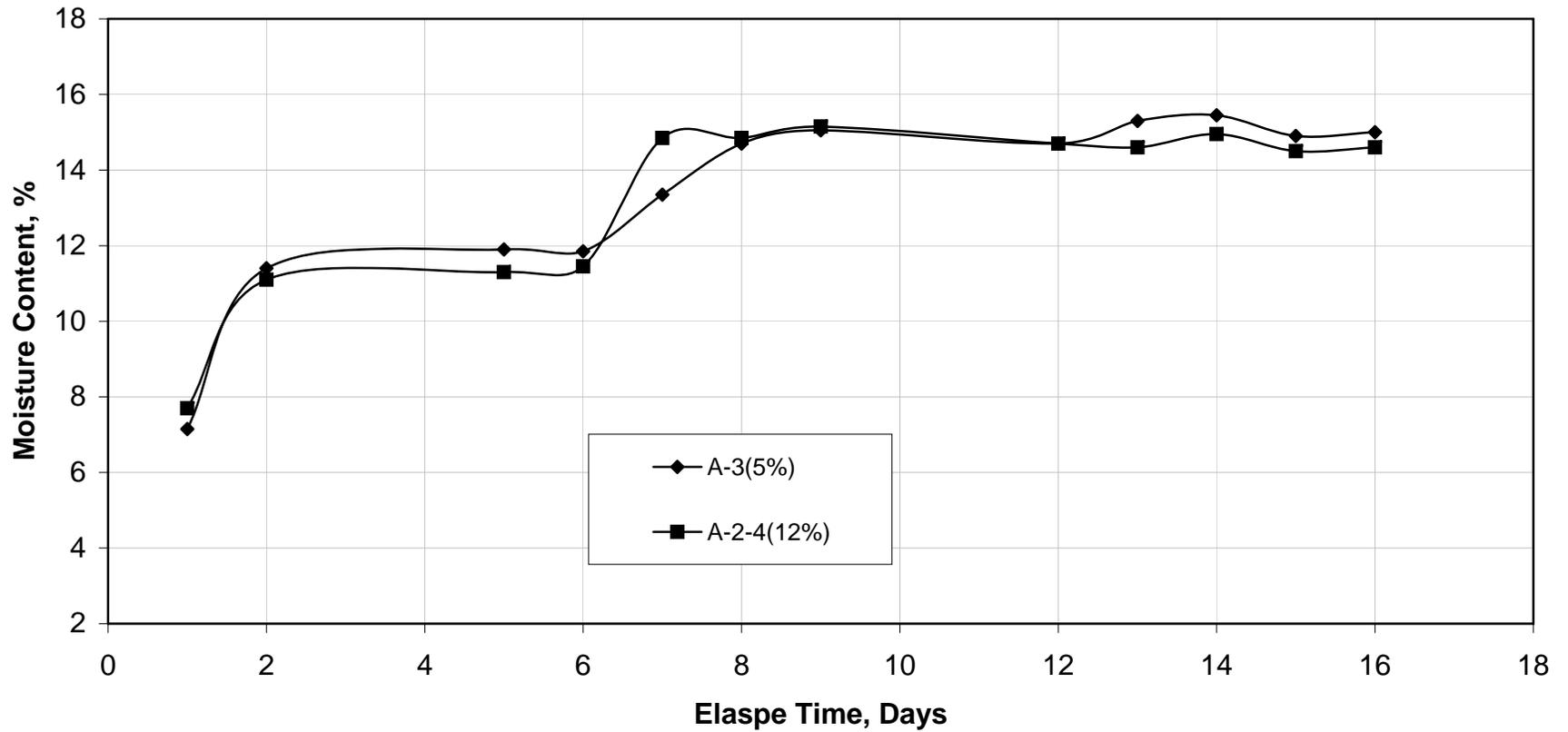


Figure 3.7 Comparison of Capillary Rise Rate at Water Level -12 inches

CHAPTER 4 LABORATORY CONSTRUCTABILITY STUDY

4.1 General

The laboratory experimental results are presented and analyzed in this chapter to evaluate the constructability of stabilized subgrade layers under high water levels in the test pit. The primary objective was to evaluate whether or not the stabilized subgrade layer could be constructed according to construction specifications. A 98% degree of compaction of the maximum dry density, which was determined by the modified Proctor test (AASHTO T180), was set to be the desired dry density as required by most field compaction specifications. The constructability experimental results are presented as follows.

4.2 Constructability Experimental Results

To study the constructability of the stabilized subgrade layers under the influence of different levels of high water table, the water level was first raised to the desired elevation. A period of time, usually about a month,

was needed until the moisture of the capillary rise had become stable. After the stabilization of capillarity, subgrade soils were placed in the test pit, and then compaction was initiated. The dry density (unit weight) of the compacted subgrade soils was measured after a certain number of compaction "covers", which were defined as the number of times the compactor was moved forward and back in compacting the subgrade soils. The relationship between the degree of compaction, i.e., the measured dry density divided by the maximum dry density determined from the modified Proctor test, and the number of compaction covers could be interpreted to evaluate whether the desired 98% degree of compaction had been achieved after a sufficient number of compaction covers. Upon completion of the constructability test for each water level, the compacted subgrade layer were excavated and replaced with new materials.

The experimental test results are summarized and presented according to the five different levels of high water table in this section. In addition, the dry densities (unit weights) of the top 6 inches measurements are presented versus those of the top 12 inches measurements to study the effect of compaction on the constructability.

- **Condition 1: Water level at -24 inches**

The compaction test results are summarized in Tables 4.1 and 4.2 for the south and north part of the west test pit (with A-3 embankment soil), respectively. For the east test pit with an A-2-4 embankment soil, the compaction test results are summarized in Tables 4.3 and 4.4 for the south and north part, respectively. For Condition 1, the results are also illustrated in Figure 4.1 in terms of degree of compaction versus number of compaction covers on the stabilized subgrade. Comparisons between the 6 in. and 12 in. measurements in terms of degree of compaction are shown in Figures 4.2 and 4.3 for the west and east test pit, respectively.

- **Condition 2: Water level at -12 inches**

The compaction test results are summarized in Tables 4.5 and 4.6 for the south and north part of the west test pit (with an A-3 embankment soil), respectively. For the east test pit, with an A-2-4 embankment soil, the compaction test results are summarized in Tables 4.7 and 4.8 for the south and north part, respectively. For Condition 2, the compaction results are also illustrated in Figure 4.4 in terms of degree of compaction versus number

of compaction covers on the stabilized subgrade. Comparisons between the 6 inch and 12 inch measurements in terms of degree of compaction are shown in Figures 4.5 and 4.6 for the west and east test pit, respectively.

- **Condition 3: Water level at -6 inches**

The compaction test results are summarized in Tables 4.9 and 4.10 for the south and north part of the west test pit (with an A-3 embankment soil), respectively. For the east test pit, with an A-2-4 embankment soil, the compaction test results are summarized in Tables 4.11 and 4.12 for the south and north part, respectively. For Condition 3, the compaction results are also illustrated in Figure 4.7 in terms of degree of compaction versus number of compaction covers on the stabilized subgrade. Comparisons between the 6 inch and 12 inch measurements in terms of degree of compaction are shown in Figures 4.8 and 4.9 for the west and east test pit, respectively.

- **Condition 4: Water level at -6 inches (drained)**

The compaction test results are summarized in Tables 4.13 and 4.14 for the south and north part of the west test pit with an A-3 embankment soil,

respectively. The east test pit was not evaluated for constructability under this condition. For Condition 4, the compaction results are also illustrated in Figure 4.10 in terms of degree of compaction versus number of compaction covers on the stabilized subgrade. A comparison is shown in Figure 4.11 between the 6 inch and 12 inch measurements in terms of degree of compaction.

- **Condition 5: Water level at -12 inches (drained)**

The compaction test results are summarized in Tables 4.15 and 4.16 for the south and north part of the west test pit with an A-3 embankment soil, respectively. The east test pit was not evaluated for constructability under this condition. For Condition 5, the compaction results are also illustrated in Figure 4.12 in terms of degree of compaction versus number of compaction covers on the stabilized subgrade. A comparison is shown in Figure 4.13 between the 6 inch and 12 inch measurements in terms of degree of compaction.

It should be noted that new subgrade materials were used for each water level condition. Upon completion of a water level condition, the compacted subgrade layers were excavated and replaced with new loose materials for the

next level of water condition. Analysis and discussion of the test results are presented in the following sections.

4.3 Analysis and Discussion of Test Results

The main focus of the laboratory experimental program was to evaluate whether or not the stabilized subgrade layer could be constructed under the conditions of high water table according to specifications. A 98% degree of compaction of the maximum dry density determined by AASHTO T180 (modified Proctor test) was the desired dry density as required by most field compaction specifications. The experimental results are analyzed and discussed according to the five test conditions in this section.

4.3.1 Condition 1: Water Level at -24 inches

At water level -24 inches from the interface, the degree of compaction increases with an increase in the number of compaction covers as shown in Figure 4.1. However, the degree of compaction did not reach the desired 98% in three out of the four cases. Only in the case of compacting the stabilized subgrade layer (Subgrade B) on top of the A-3 embankment soil, the degree of compaction reached 98.8% after 51 compaction covers.

Several factors should be taken into consideration during the compaction operations in the test pit. One factor was that the moisture and density measurements were taken at six different locations in each of the two test pits, and the testing and sampling operations took a long period of time to conduct. The moisture in the openly exposed subgrade soils was evaporating over time, and the as-compacted optimum moisture content was difficult to maintain. Another factor was that the dry density (unit weight) was calculated by using nuclear gauge moisture which was available immediately during the test, but the value tended to be lower than the oven moisture. So the actual dry density was lower than the on-site calculated dry density which was based on a lower moisture content from nuclear gauge. As a result, the compaction effort was terminated prematurely because of the false data which led the researchers to believe that the desired dry density was achieved while actually it was not.

Nevertheless, from Figure 4.1, the trend of the increasing degree of compaction with an increase in the number of compaction covers is apparent even after over 50 compaction covers. An interpretation of the trend has led to believe that the desired dry density of 98% of the maximum dry density could have been achieved with

additional compaction covers. A compaction study conducted later at water level -12 inches below the interface has confirmed the interpretation. The two subgrade soils can be constructed to achieve the desired dry density over the underlying embankment layers. Thus, the condition 1 at water level -24 inches below the interface is not considered a critical high groundwater level for constructability concerns.

As shown in Figure 4.2(a), the degree of compaction of the top 6 inches was initially higher than that of the full 12 inches for compacting the A-2-4 subgrade (Subgrade A) on top of the underlying A-3 embankment at water level -24 inches below the interface. However, the 6 inch and 12 inch measurements were eventually reaching the same level of degree of compaction after over 50 compaction covers. For compacting the Subgrade B (A-2-4 subgrade soil mixed with 25% limerock), comparison of the degree of compaction for the 6 inch and 12 inch measurements does not show a significant difference as demonstrated in Figure 4.2(b). The test results indicated that the A-3 embankment layer provided a good underlying foundation to support the compaction of the stabilized subgrade soils. The results also indicated that the Subgrade B was easier to compact

and to achieve the desired dry density than the Subgrade A (A-2-4(12%) soil).

Using the A-2-4 soil as an embankment layer, the measured density results of the top 6 inches are lower than that of the full 12 inch measurements for compacting the stabilized A-2-4 subgrade on top, as shown in Figure 4.3(a). For compacting the Subgrade B (A-2-4 soil mixed with 25% limerock) over the underlying A-2-4 embankment layer, the 6 inch and 12 inch measurements were eventually reaching the same level of degree of compaction after over 30 compaction covers (Figure 4.3(b)). Both the A-2-4 and A-3 embankment layers provided very satisfactory support for constructing the stabilized subgrade layers.

4.3.2 Condition 2: Water level at -12 inches

As shown in Figure 4.4 for Condition 2, the degree of compaction increases with the increasing number of compaction covers. Eventually, all of the four soil conditions reached the desired 98% of the maximum dry density after 17 compaction covers by a plate compactor. The two subgrade soils can be constructed according to the specifications under the water level at -12 inches below the top of embankment layer. Thus, the condition 2 at water

level -12 inches below the interface is not considered a critical level for constructability concerns.

When the A-3 soil was used as an embankment layer, the measured density results of the top 6 inches and the full 12 inches were very close to each other, as shown in Figure 4.5(a) and (b). While the A-2-4 soil was used as the embankment layer, the degrees of compaction of the top 6 inches were generally lower than those of the full 12 inches for compacting both the Subgrade A and B, as shown in Figure 4.6(a)&(b). However, all of the soil conditions reached the same level of degree of compaction after 17 compaction covers regardless of the depth of measurements.

4.3.3 Condition 3: Water Level at -6 inches

According to Figure 4.7 for the condition 3, the degree of compaction increases with the increasing number of compaction covers. All of the four soil conditions eventually reached the desired 98% of the maximum dry density after 20 compaction covers by a plate compactor. The subgrade soils could be constructed according to the specifications under the water level at -6 inches below the top of embankment.

Comparisons of degree of compaction for the 6 inch and 12 inch measurements are shown in Figures 4.8(a), 4.8(b),

4.9(a), and 4.9(b). The measured density results of the top 6 inch and the full 12 inch were very close to each other for the four soil conditions. However, the degrees of compaction of the top 6 inch were generally lower than those of the full 12 inch, although all of the soil conditions reached the same level of degree of compaction in the end. One of the reasons for the initial discrepancy between the measured density results of the 6 inch and 12 inch was that it took a long period of time to conduct the moisture and density measurements. The moisture in the openly exposed subgrade soils was evaporating over time and the as-compacted optimum moisture content was difficult to maintain near the surface. Another reason might be that because of capillarity and drainage, the moisture from the embankment layer at -6 inches below the interface might become elevated to a higher level due to vibrations and dynamic stress as caused by compaction.

Using the Subgrade B (A-2-4 soil mixed with 25% limerock) as an example for illustration, the following oven moisture data are taken from Tables 4.10 and 4.12 for the north part of the west and the east test pits:

| Oven Moisture, % | | | |
|-----------------------------------|----------------------------------|-----------------------------------|-----------------------------------|
| 0-6 in. Measurement | | 0-12 in. Measurement | |
| A-3 Embankment | A-2-4 Embankment | A-3 Embankment | A-2-4 Embankment |
| 9.9 | 8.9 | 11.2 | 11.5 |
| 10.9 | 8.4 | 11.4 | 10.7 |
| 9.7 | 9.5 | 11.2 | 11.6 |
| 9.6 | 9.2 | 9.6 | 11.4 |
| 10.5 | 10.5 | 11.5 | 10.6 |
| 11.0 | 10.5 | 11.9 | 12.0 |
| 10.4 | 10.7 | 11.9 | 12.1 |
| 11.0 | 11.4 | 11.8 | 12.0 |
| Avg. 10.4 (less than OMC*) | Avg. 9.9 (less than OMC*) | Avg. 11.3 (less than OMC*) | Avg. 11.5 (less than OMC*) |

***OMC = 12.3%**

From the results presented above, the average oven moisture of the 6 inch measurements are about 2% lower than the OMC (12.3%) and the average oven moisture of the 12 inch measurements are about 1% lower than the OMC. In essence, the average oven moisture content of the 6 inch measurements is about 1% lower than that of the 12 inch measurements. Because of the lower moisture content, the top 6 inch was drier and harder to compact than the full 12 inch layer. Thus, the degrees of compaction of the top 6 inch were generally lower than those of the full 12 inch layer.

4.3.4 Condition 4: Water level at -6 inches (drained)

For this condition, the water level for the west test pit was raised to two inches above the top of the

embankment layer, and then the water level was maintained at this level for about two months prior to a rapid drawdown to a level of six inches below the top of the embankment layer. The compaction of the stabilized subgrade soils was initiated at about seven hours after the rapid drawdown of the water level to simulate the field drained conditions. This test condition was only performed on the west test pit with the A-3 soil as an embankment layer.

This test condition turned out to be the critical water level for constructing a stabilized layer on the top of the embankment layer with a rapid drawdown condition. The experimental results are shown in Figures 4.10, 4.11(a), and 4.11(b). As shown in Figure 4.10, the degree of compaction tends to drop after 32 covers of static roller compaction. A vibratory compactor was used to resume the compaction after the static roller compactor. However, after an additional 30 covers of vibratory compaction, the desired dry density was still not achieved.

As shown in Figure 4.11(a) and (b), the degrees of compaction of the top 6 inches and the full 12 inches are very much different. In fact, the top 6 inch soils reached the desired 98% of the maximum dry density under the vibratory compaction while the full 12 inch soils were

inclined to drop or did not reach the desired 98% degree of compaction. The oven moisture data were shown to cause the discrepancy between the 6 inch and 12 inch measurements. The following oven moisture data are taken from Tables 4.13 and 4.14 for the south and north part of the west test pit:

- Embankment soil: A-3 (5%)

| Total Covers | Oven Moisture, % | | | |
|------------------|---------------------|--------------|----------------------|--------------|
| | 0-6 in. Measurement | | 0-12 in. Measurement | |
| | Subgrade A* | Subgrade B** | Subgrade A* | Subgrade B** |
| Static | | | | |
| 2 | 11.7 | 11.2 | 8.6 | 11.4 |
| 6 | 9.4 | 10.9 | 8.8 | 11.9 |
| 10 | 8.4 | 9.9 | 10.2 | 10.8 |
| 16 | 8.9 | 10.5 | 10.1 | 12.3 |
| 20 | 8.0 | 9.0 | 10.5 | 11.8 |
| 24 | 8.4 | 10.0 | 10.7 | 11.7 |
| 32 | 8.1 | 10.0 | 11.1 | 11.7 |
| Vibratory | | | | |
| 34 | 8.2 | 9.8 | 15.5*** | 12.6 |
| 38 | 8.4 | 9.7 | 13.5*** | 12.2 |
| 44 | 8.4 | 9.2 | 18.7*** | 12.6 |
| 50 | 8.4 | 9.9 | 16.7*** | 12.9 |
| 56 | 8.4 | 9.5 | 17.6*** | 12.6 |
| 62 | 8.2 | 9.5 | 18.2*** | 12.9 |

*OMC = 12.4%

**OMC = 12.3%

***Oven Moisture higher than OMC

Based on the results presented above, some observations might be made. First, the moisture content of

the 6 inch measurements tended to be lower than the optimum moisture content and were kept at a constant level throughout the static and vibratory compaction stages. The top 6 inch soils were shown not to be affected by the high water level at -6 inches below the interface. Secondly, moisture content of the 12 inch measurements was much higher than the optimum moisture content for the A-2-4 subgrade under the vibratory compaction. The moisture from the embankment layer had become elevated to a higher level due to vibrations and dynamic stresses caused by the vibratory compaction. This was the primary cause for the drop in degree of compaction for the A-2-4 subgrade. The Subgrade B was a stronger material than the A-2-4 subgrade and was shown to achieve a higher degree of compaction under the vibratory compaction. The moisture content of the 12 inch measurements are not much influenced by the high groundwater level for Subgrade B (A-2-4 soil mixed with 25% limerock) even under the vibratory compaction.

4.3.5 Condition 5: Water Level at -12 inches (drained)

For this condition, the water level for the west test pit was again raised to two inches above the top of the embankment layer upon completion of testing for the condition 4. The water level was maintained at this level for over two months prior to a rapid drawdown to a level of

12 inches below the top of the interface. New loose subgrade soils were brought in and placed in the pit. Compaction of the subgrade soils was started at about 15 hours after the rapid drawdown of the water level to simulate the field drained condition. This test condition was only performed on the west test pit with the A-3 soil as embankment layer.

The experimental results are shown in Figures 4.12, 4.13(a), and 4.13(b). As shown in Figure 4.12, the A-2-4 subgrade has reached the desired 98% degree of compaction after 10 compaction covers, while the stabilized subgrade has started to level off after 16 compaction covers. For the stabilized subgrade, the degrees of compaction of the top 6 inch soils are generally higher than those of the full 12 inch soils, as shown in Figure 4.13(b), and again demonstrate that the mixed subgrade can be constructed to reach the desired 98% degree of compaction under this condition of high water level. For the A-2-4 subgrade, the measured density results of the top 6 inch and the full 12 inch soils are similar and all reach the 98% degree of compaction after 10 compaction covers (Figure 4.13(a)). The two subgrade soils could be constructed to reach the desired 98% degree of compaction according to the

specifications under this condition of high water level at -12 inches drawdown below the top of embankment.

4.4 Summary of Test Results

Based on the analysis and discussion presented above, for the A-3 embankment soil, the two subgrade soils could be constructed according to the specifications under the conditions of water level at least 12 inches below the top of embankment layer. When the drained or drawdown condition occurred as in Condition 4 (water level at -6 inches, drained condition), proper compaction could not be achieved mainly because of the higher moisture content in the embankment and subgrade layers.

For the A-2-4 embankment soil, the drained or drawdown conditions were not simulated in the test pit. But based on the constructability study under the water conditions 1, 2, and 3, both the A-3 and A-2-4 embankment soils were shown to have very similar performance. Therefore, the performance of the A-2-4 embankment soil under drained conditions should be expected to be very similar to the A-3 embankment soil.

In summary, based on the test pit experimental results, the groundwater level should not be less than 12

inches below the top of embankment layer to ensure a proper compaction of subgrade layers. In case of a drained or drawdown condition under construction, the groundwater table should be lowered to a level of at least 12 inches below the top of the interface for facilitating the compaction of subgrade layers.

Table 4.1 Summary of Compaction Test Results for Water Level at -24 inches (Condition 1)
(West Test Pit, South Part)

Embankment Soil: A-3 (5%)

Stabilized Subgrade Soil: A-2-4 (12%)

Modified Proctor Max DD (pcf): 110.3

OMC : 12.4%

| Test Date (m/d/y) | Covers | Location | 0-6" Gauge Measurement | | | | | | 0-12" Gauge Measurement | | | | | |
|----------------------|--------|----------|------------------------|---------------------|-----------------------------------|------------------------|------------------|----------------------|-------------------------|------------------------|-----------------------------------|------------------------|------------------|----------------------|
| | | | Wet Density (pcf) | Gauge Moist. (%) | Corrected Gauge Moist. (%)* | Dry Density (pcf)** | DD/Max DD (%) | Avg DD/Max DD (%) | Wet Density (pcf) | Gauge Moist. (%) | Corrected Gauge Moist. (%)* | Dry Density (pcf)** | DD/Max DD (%) | Avg DD/Max DD (%) |
| 10/02/01 | 1 | south | | | | | | | 105.8 | 7.2 | 8.5 | 97.5 | 88.4 | 87.7 |
| | | middle | | | | | | 105.8 | 8.8 | 10.0 | 96.2 | 87.2 | | |
| | | north | | | | | | 107.1 | 10.0 | 11.2 | 96.3 | 87.3 | | |
| | 3 | south | 112.7 | 9.0 | 10.2 | 102.3 | 92.7 | 93.3 | 108.8 | 9.3 | 10.5 | 98.5 | 89.3 | 90.1 |
| | | middle | 115.7 | 9.7 | 10.9 | 104.3 | 94.6 | | 110.1 | 10.3 | 11.5 | 98.8 | 89.6 | |
| | | north | 109.6 | 6.0 | 7.3 | 102.1 | 92.6 | | 108.1 | 6.0 | 7.3 | 100.7 | 91.3 | |
| | 5 | south | 113.5 | 10.3 | 11.5 | 101.8 | 92.3 | 93.1 | 110.7 | 11.2 | 12.3 | 98.5 | 89.3 | 89.9 |
| | | middle | 115.1 | 10.1 | 11.3 | 103.4 | 93.8 | | 111.0 | 10.3 | 11.5 | 99.6 | 90.3 | |
| | | north | 113.1 | 8.9 | 10.1 | 102.7 | 93.1 | | 110.1 | 9.5 | 10.7 | 99.5 | 90.2 | |
| | 7 | south | 116.2 | 11.6 | 12.7 | 103.1 | 93.5 | 94.3 | 113.9 | 11.5 | 12.6 | 101.1 | 91.7 | 91.7 |
| | | middle | 116.8 | 11.2 | 12.3 | 104.0 | 94.3 | | 113.7 | 11.3 | 12.4 | 101.1 | 91.7 | |
| | | north | 118.5 | 11.8 | 12.9 | 104.9 | 95.1 | | 114.7 | 12.1 | 13.2 | 101.3 | 91.9 | |
| | 11 | south | 116.5 | 10.8 | 12.0 | 104.1 | 94.3 | 94.1 | 115.3 | 10.6 | 11.8 | 103.2 | 93.5 | 92.6 |
| | | middle | 115.1 | 10.2 | 11.4 | 103.4 | 93.7 | | 112.8 | 11.0 | 12.1 | 100.6 | 91.2 | |
| | | north | 116.5 | 10.8 | 12.0 | 104.1 | 94.3 | | 115.0 | 10.8 | 12.0 | 102.7 | 93.1 | |
| | 15 | south | 117.5 | 9.2 | 10.4 | 106.4 | 96.5 | 95.6 | 115.9 | 9.8 | 11.0 | 104.4 | 94.7 | 94.0 |
| | | middle | 116.7 | 10.8 | 12.0 | 104.2 | 94.5 | | 114.9 | 10.8 | 12.0 | 102.6 | 93.1 | |
| | | north | 116.0 | 8.7 | 9.9 | 105.5 | 95.7 | | 114.6 | 8.9 | 10.1 | 104.1 | 94.4 | |
| | 19 | south | 119.1 | 11.0 | 12.1 | 106.2 | 96.3 | 95.9 | 117.1 | 11.5 | 12.6 | 104.0 | 94.3 | 93.3 |
| | | middle | 119.0 | 11.3 | 12.4 | 105.8 | 96.0 | | 116.6 | 12.5 | 13.6 | 102.6 | 93.1 | |
| | | north | 117.7 | 10.7 | 11.9 | 105.2 | 95.4 | | 114.7 | 11.0 | 12.1 | 102.3 | 92.7 | |
| | 25 | south | 117.8 | 11.5 | 12.6 | 104.6 | 94.8 | 95.8 | 117.7 | 10.9 | 12.0 | 105.0 | 95.2 | 94.6 |
| | | middle | 118.0 | 10.2 | 11.4 | 106.0 | 96.1 | | 115.5 | 10.3 | 11.5 | 103.6 | 93.9 | |
| | | north | 117.7 | 9.5 | 10.7 | 106.3 | 96.4 | | 116.2 | 10.0 | 11.2 | 104.5 | 94.8 | |
| 10/03/01 | 31 | south | 119.1 | 11.7 | 12.8 | 105.6 | 95.7 | 95.6 | 117.3 | 12.6 | 13.7 | 103.2 | 93.5 | 94.3 |
| | | middle | 117.5 | 11.6 | 12.7 | 104.2 | 94.5 | | 117.4 | 11.9 | 13.0 | 103.9 | 94.2 | |
| | | north | 119.5 | 11.0 | 12.1 | 106.6 | 96.6 | | 118.5 | 11.6 | 12.7 | 105.1 | 95.3 | |
| | 41 | south | 120.1 | 11.8 | 12.9 | 106.4 | 96.4 | 96.3 | 120.0 | 11.7 | 12.8 | 106.4 | 96.4 | 96.3 |
| | | middle | 118.7 | 12.1 | 13.2 | 104.8 | 95.1 | | 116.7 | 11.2 | 12.3 | 103.9 | 94.2 | |
| | | north | 120.5 | 11.1 | 12.2 | 107.4 | 97.3 | | 121.1 | 10.7 | 11.9 | 108.3 | 98.2 | |
| | 51 | south | 120.0 | 12.5 | 13.6 | 105.6 | 95.8 | 96.0 | 121.4 | 12.1 | 13.2 | 107.2 | 97.2 | 96.8 |
| | | middle | 119.4 | 13.0 | 14.1 | 104.7 | 94.9 | | 120.1 | 12.8 | 13.9 | 105.5 | 95.6 | |
| | | north | 121.2 | 11.8 | 12.9 | 107.3 | 97.3 | | 121.7 | 11.9 | 13.0 | 107.7 | 97.6 | |

*Corrected gauge moisture (%)=0.9697 x gauge moisture (%) + 1.4777

**Dry Density calculation uses the corrected gauge moisture for the 6" and 12" depths.

Table 4.2 Summary of Compaction Test Results for Water Level at -24 inches (Condition 1)
(West Test Pit, North Part)

Embankment Soil: A-3 (5%)

Stabilized Subgrade Soil: A-2-4 (12%)+25%LR

Modified Proctor Max DD (pcf): 111.3

OMC : 12.3%

| Test Date (m/d/y) | Covers | Location | 0-6" Gauge Measurement | | | | | | 0-12" Gauge Measurement | | | | |
|----------------------|--------|----------|-------------------------|---------------------|------------------------------------|----------------------------|------------------|----------------------|-------------------------|-------------------------|-----------------------------|---------------|----------------------|
| | | | Wet Density (pcf) | Gauge Moist. (%) | Corrected Gauge Moist. (%) * | Dry Density (pcf) ** | DD/Max DD (%) | Avg DD/Max DD (%) | Wet Density (pcf) | Oven Moisture (%) | Dry Density (pcf) *** | DD/Max DD (%) | Avg DD/Max DD (%) |
| 10/02/01 | 1 | south | | | | | | 106.8 | 9.6 | 97.4 | 87.6 | 91.2 | |
| | | middle | | | | | | 113.0 | 9.3 | 103.4 | 92.9 | | |
| | | north | | | | | | 112.8 | 8.9 | 103.6 | 93.1 | | |
| | 3 | south | 113.3 | 9.8 | 10.9 | 102.2 | 112.0 | 99.0 | 112.4 | 10.0 | 102.2 | 91.8 | 92.3 |
| | | middle | 114.4 | 8.2 | 9.4 | 104.5 | 93.9 | 113.8 | 9.1 | 104.3 | 93.7 | | |
| | | north | 111.2 | 8.4 | 9.6 | 101.4 | 91.1 | 110.9 | 8.9 | 101.8 | 91.5 | | |
| | 5 | south | 114.0 | 9.5 | 10.6 | 103.1 | 92.6 | 93.3 | 113.2 | 11.5 | 101.5 | 91.2 | 93.1 |
| | | middle | 116.2 | 10.1 | 11.1 | 104.6 | 93.9 | 115.4 | 9.7 | 105.2 | 94.5 | | |
| | | north | 114.9 | 9.5 | 10.6 | 103.9 | 93.3 | 114.1 | 9.6 | 104.1 | 93.5 | | |
| | 7 | south | 117.4 | 11.9 | 12.7 | 104.1 | 93.6 | 94.4 | 116.3 | 11.1 | 104.7 | 94.1 | 94.8 |
| | | middle | 118.9 | 11.5 | 12.4 | 105.8 | 95.1 | 117.8 | 10.6 | 106.5 | 95.7 | | |
| | | north | 118.3 | 11.7 | 12.5 | 105.1 | 94.4 | 116.9 | 10.9 | 105.4 | 94.7 | | |
| | 11 | south | 117.6 | 12.2 | 13.0 | 104.1 | 93.5 | 94.7 | 117.3 | 11.9 | 104.8 | 94.2 | 94.0 |
| | | middle | 118.8 | 11.3 | 12.2 | 105.9 | 95.1 | 112.2 | 11.0 | 101.1 | 90.8 | | |
| | | north | 119.4 | 11.6 | 12.5 | 106.2 | 95.4 | 120.1 | 11.1 | 108.1 | 97.1 | | |
| | 15 | south | 118.6 | 12.0 | 12.8 | 105.1 | 94.5 | 94.8 | 119.2 | 11.0 | 107.4 | 96.5 | 96.2 |
| | | middle | 118.9 | 10.9 | 11.8 | 106.3 | 95.5 | 116.9 | 10.1 | 106.2 | 95.4 | | |
| | | north | 117.9 | 11.4 | 12.3 | 105.0 | 94.3 | 118.6 | 10.3 | 107.5 | 96.6 | | |
| | 19 | south | 120.4 | 12.9 | 13.6 | 106.0 | 95.2 | 95.4 | 118.4 | 11.5 | 106.2 | 95.4 | 95.6 |
| | | middle | 119.4 | 12.1 | 12.9 | 105.8 | 95.0 | 118.5 | 11.1 | 106.7 | 95.8 | | |
| | | north | 121.1 | 12.5 | 13.3 | 106.9 | 96.1 | 119.7 | 12.7 | 106.2 | 95.4 | | |
| | 25 | south | 120.3 | 11.8 | 12.6 | 106.8 | 96.0 | 95.8 | 119.5 | 11.6 | 107.1 | 96.2 | 96.4 |
| | | middle | 119.0 | 12.0 | 12.8 | 105.5 | 94.8 | 119.4 | 11.3 | 107.3 | 96.4 | | |
| | | north | 121.0 | 11.6 | 12.5 | 107.6 | 96.7 | 119.2 | 10.9 | 107.5 | 96.6 | | |
| 10/03/01 | 31 | south | 121.9 | 13.2 | 13.9 | 107.0 | 96.2 | 96.0 | 120.5 | 13.3 | 106.4 | 95.6 | 96.3 |
| | | middle | 121.1 | 13.2 | 13.9 | 106.3 | 95.5 | 121.2 | 12.4 | 107.8 | 96.9 | | |
| | | north | 122.6 | 13.9 | 14.5 | 107.1 | 96.2 | 121.1 | 12.8 | 107.4 | 96.5 | | |
| | 41 | south | 123.1 | 12.8 | 13.5 | 108.4 | 97.4 | 97.2 | 121.2 | 12.2 | 108.0 | 97.1 | 96.8 |
| | | middle | 122.1 | 14.1 | 14.7 | 106.5 | 95.7 | 120.8 | 12.6 | 107.3 | 96.4 | | |
| | | north | 124.6 | 13.1 | 13.8 | 109.5 | 98.4 | 122.9 | 13.8 | 108.0 | 97.0 | | |
| | 51 | south | 122.6 | 13.3 | 14.0 | 107.6 | 96.7 | 97.3 | 122.0 | 10.2 | 110.7 | 99.5 | 98.8 |
| | | middle | 124.0 | 13.8 | 14.4 | 108.4 | 97.4 | 122.8 | 12.5 | 109.2 | 98.1 | | |
| | | north | 124.3 | 13.3 | 14.0 | 109.1 | 98.0 | 122.8 | 11.5 | 110.1 | 99.0 | | |

*Corrected gauge moisture (%)=0.8874*gauge moisture(%) +2.1665

**Dry Density calculation uses the corrected gauge moisture for the 6" depth

***Dry Density calculation uses the oven moisture for the 12" depth.

Table 4.3 Summary of Compaction Test Results for Water Level at -24 inches (Condition 1)
(East Test Pit, South Part)

Embankment Soil: A-2-4(12%)

Stabilized Subgrade Soil: A-2-4 (12%)

Modified Proctor Max DD (pcf): 110.3

OMC : 12.4%

| Test Date (m/d/y) | Covers | Location | 0-6" Gauge Measurement | | | | | | 0-12" Gauge Measurement | | | | | | |
|----------------------|--------|----------|-------------------------|------------------------|------------------------------------|----------------------------|------------------|----------------------|--------------------------|---------------------|------------------------------------|----------------------|-----------------------------|---------------|----------------------|
| | | | Wet Density (pcf) | Gauge Moist. (%) | Corrected Gauge Moist. (%) * | Dry Density (pcf) ** | DD/Max DD (%) | Avg DD/Max DD (%) | Wet Density. (pcf) | Gauge Moist. (%) | Corrected Gauge Moist. (%) * | Oven Moisture (%) | Dry Density (pcf) *** | DD/Max DD (%) | Avg DD/Max DD (%) |
| 10/04/01 | 4 | Middle | 118.1 | 13.7 | 14.8 | 102.9 | 93.3 | 93.3 | 113.6 | 14.4 | 15.4 | 10.0 | 103.3 | 93.6 | 93.6 |
| | 8 | Middle | 117.9 | 11.5 | 12.6 | 104.7 | 94.9 | 94.9 | 114.9 | 12.2 | 13.3 | 8.0 | 106.4 | 96.5 | 96.5 |
| | #1 16 | Middle | 118.8 | 11.2 | 12.3 | 105.8 | 95.9 | 95.4 | 122.1 | 10.2 | 11.4 | 9.8 | 111.2 | 100.8 | 95.9 |
| | #2R 16 | Middle | 118.5 | 12.0 | 13.1 | 104.8 | 95.0 | | 117.1 | 12.4 | 13.5 | | 103.2 | 93.5 | |
| | #3R 16 | Middle | 118.3 | 11.3 | 12.4 | 105.2 | 95.4 | | 115.5 | 11.0 | 12.1 | | 103.0 | 93.4 | |
| | 24 | Middle | 117.1 | 12.1 | 13.2 | 103.4 | 93.8 | 93.8 | 118.7 | 12.4 | 13.5 | 10.9 | 107.0 | 97.0 | 97.0 |
| | 32 | Middle | 120.0 | 10.5 | 11.7 | 107.5 | 97.4 | 96.9 | 119.0 | 10.8 | 12.0 | | 106.3 | 96.4 | 97.6 |
| | | South | 118.8 | 10.3 | 11.5 | 106.6 | 96.6 | | 119.5 | 9.8 | 11.0 | 9.4 | 109.2 | 99.0 | |
| | | North | 118.5 | 10.1 | 11.3 | 106.5 | 96.6 | | 117.9 | 9.5 | 10.7 | 9.6 | 107.6 | 97.5 | |

*Corrected gauge moisture(%) = 0.9697 x gauge moisture(%) + 1.4777

**Dry Density calculation uses the corrected gauge moisture for the 6" depth.

***Dry Density calculation uses the corrected gauge moistures and oven moisture for the 12" depth.

Table 4.4 Summary of Compaction Test Results for Water Level at -24 inches (Condition 1)
(East Test Pit, North Part)

Embankment Soil: A-2-4 (12%)

Stabilized Subgrade Soil: A-2-4 (12%)+25% LR

Modified Proctor Max DD (pcf): 111.3

OMC : 12.3%

| Test Date (m/d/y) | Covers | Location | 0-6" Gauge Measurement | | | | | | 0-12" Gauge Measurement | | | | |
|----------------------|--------|----------|------------------------|---------------------|------------------------------------|----------------------------|------------------|----------------------|-------------------------|-------------------------|--------------------------|------------------|----------------------|
| | | | Wet Density (pcf) | Gauge Moist. (%) | Corrected Gauge Moist. (%) * | Dry Density (pcf) ** | DD/Max DD (%) | Avg DD/Max DD (%) | Wet Density (pcf) | Oven Moisture (%) | Dry Density (pcf) *** | DD/Max DD (%) | Avg DD/Max DD (%) |
| 10/04/01 | 4 | Middle | 118.9 | 14.6 | 15.1 | 103.3 | 92.8 | 92.8 | 115.9 | 12.4 | 103.1 | 92.6 | 92.6 |
| | 8 | Middle | 119.7 | 16.1 | 16.5 | 102.8 | 92.4 | 92.4 | 117.7 | 13.1 | 104.1 | 93.5 | 93.5 |
| | 16 | Middle | 121.0 | 14.1 | 14.7 | 105.5 | 94.8 | 94.8 | 120.9 | 12.7 | 107.3 | 96.4 | 96.4 |
| | 24 | Middle | 121.0 | 13.1 | 13.8 | 106.3 | 95.5 | 95.5 | 121.0 | 12.6 | 107.5 | 96.5 | 96.5 |
| | 32 | Middle | 121.9 | 12.7 | 13.4 | 107.5 | 96.6 | 96.9 | 121.3 | 12.1 | 108.2 | 97.2 | 97.5 |
| | | South | 122.5 | 12.0 | 12.8 | 108.6 | 97.6 | | 121.9 | 12.2 | 108.6 | 97.6 | |
| | | North | 122.1 | 12.8 | 13.5 | 107.6 | 96.6 | | 122.1 | 12.4 | 108.6 | 97.6 | |

*Corrected gauge moisture (%)=0.8874*gauge moisture(%) +2.1665

**Dry Density calculation uses the corrected gauge moisture for 6" depth.

***Dry Density calculation uses the oven moisture for 12" depth.

Table 4.5 Summary of Compaction Test Results for Water Level at -12 inches (Condition 2)
(West Test Pit, South Part)

Embankment Soil: A-3 (5%)

Stabilized Subgrade Soil: A-2-4 (12%)

Modified Proctor Max DD (pcf): 110.3

OMC : 12.4%

| Test Date (m/d/y) | Covers | Location | 0-6" Gauge Measurement | | | | | | | 0-12" Gauge Measurement | | | | |
|----------------------|--------|----------|------------------------|---------------------|------------------------------------|-------------------------|-------------------------|------------------|----------------------|-------------------------|----------------------|--------------------------|------------------|----------------------|
| | | | Wet Density (pcf) | Gauge Moist. (%) | Corrected Gauge Moist. (%) * | Oven Moisture (%) | Dry Density (pcf) ** | DD/Max DD (%) | Avg DD/Max DD (%) | Wet Density (pcf) | Oven Moisture (%) | Dry Density (pcf) *** | DD/Max DD (%) | Avg DD/Max DD (%) |
| 11/08/01 | 2 | middle | 116.7 | 12.1 | 13.2 | | 103.1 | 93.5 | 93.5 | 111.3 | 8.7 | 102.4 | 92.8 | 92.8 |
| | 4 | middle | 118.8 | 12.2 | 13.3 | | 104.8 | 95.1 | 95.1 | 115.7 | 10.2 | 105.0 | 95.2 | 95.2 |
| | 8 | middle | 119.9 | 11.3 | 12.4 | | 106.6 | 96.7 | 96.7 | 117.7 | 9.7 | 107.3 | 97.3 | 97.3 |
| | 13 | middle | 119.8 | 10.9 | 12.0 | | 106.9 | 96.9 | 96.9 | 118.7 | 10.4 | 107.5 | 97.5 | 97.5 |
| | 17 | south | 119.8 | 11.6 | 12.7 | 10.0 | 108.9 | 98.7 | 98.7 | 118.7 | 10.2 | 107.7 | 97.7 | 97.7 |
| | | middle | 120.1 | 12.1 | 13.2 | 10.2 | 109.0 | 98.8 | | 118.6 | 10.3 | 107.5 | 97.5 | |
| | | north | 120.5 | 11.9 | 13.0 | 10.7 | 108.9 | 98.7 | | 119.6 | 10.7 | 108.0 | 98.0 | |

*Corrected gauge moisture(%) = 0.9697 x gauge moisture (%) + 1.4777

**Dry Density calculations for the 6" use the Corrected Gauge Moisture, except for Cover 17 use Oven Moisture.

***Dry Density calculations for the 12" use the Oven Moisture.

Table 4.6 Summary of Compaction Test Results for Water Level at -12 inches (Condition 2)
(West Test Pit, North Part)

Embankment Soil: A-3 (5%)

Stabilized Subgrade Soil: A-2-4 (12%)+25%LR

Modified Proctor Max DD (pcf): 111.3

OMC : 12.3%

| Test Date (m/d/y) | Covers | Location | 0-6" Gauge Measurement | | | | | | 0-12" Gauge Measurement | | | | | |
|----------------------|--------|----------|-------------------------|---------------------|------------------------------------|-------------------------|-------------------------|------------------|-------------------------|----------------------|-------------------------|-----------------------------|---------------|----------------------|
| | | | Wet Density (pcf) | Gauge Moist. (%) | Corrected Gauge Moist. (%) * | Oven Moisture (%) | Dry Density (pcf) ** | DD/Max DD (%) | Avg DD/Max DD (%) | Wet Density (pcf) | Oven Moisture (%) | Dry Density (pcf) *** | DD/Max DD (%) | Avg DD/Max DD (%) |
| 11/08/01 | 2 | middle | 119.3 | 12.7 | 13.4 | | 105.2 | 94.5 | 94.5 | 113.6 | 10.2 | 103.1 | 92.6 | 92.6 |
| | 4 | middle | 120.8 | 14.0 | 14.6 | | 105.4 | 94.7 | 94.7 | 117.1 | 10.6 | 105.9 | 95.1 | 95.1 |
| | 8 | middle | 121.1 | 12.2 | 13.0 | | 107.2 | 96.3 | 96.3 | 117.8 | 10.6 | 106.5 | 95.7 | 95.7 |
| | 13 | middle | 122.3 | 12.7 | 13.4 | | 107.8 | 96.9 | 96.9 | 119.2 | 11.0 | 107.4 | 96.5 | 96.5 |
| | 17 | south | 121.5 | 12.6 | 13.3 | 11.1 | 109.4 | 98.3 | 98.6 | 120.2 | 11.3 | 108.0 | 97.0 | 97.4 |
| | 17 | middle | 121.8 | 13.1 | 13.8 | 10.9 | 109.8 | 98.7 | | 120.8 | 11.0 | 108.8 | 97.8 | |
| | 17 | north | 122.3 | 12.7 | 13.4 | 11.3 | 109.9 | 98.7 | | 120.9 | 11.4 | 108.5 | 97.5 | |

*Corrected gauge moisture(%) = 0.8874 x gauge moisture(%) + 2.1665

**Dry Density calculations for the 6" use the Corrected Gauge Moisture, except for Cover 17 use Oven Moisture.

***Dry Density calculations for the 12" use the Oven Moisture.

Table 4.7 Summary of Compaction Test Results for Water Level at -12 inches (Condition 2)
(East Test Pit, South Part)

Embankment Soil: A-2-4(12%)

Stabilized Subgrade Soil: A-2-4 (12%)

Modified Proctor Max DD (pcf):

110.3

OMC : 12.4%

| Test Date (m/d/y) | Covers | Location | 0-6" Gauge Measurement | | | | | | | 0-12" Gauge Measurement | | | | | |
|----------------------|--------|----------|-------------------------|---------------------|-----------------------------------|----------------------|------------------------|------------------|----------------------|-------------------------|-------------------------|-------------------------|------------------|----------------------|------|
| | | | Wet Density (pcf) | Gauge Moist. (%) | Corrected Gauge Moist. (%)* | Oven Moisture (%) | Dry Density (pcf)** | DD/Max DD (%) | Avg DD/Max DD (%) | Wet Density. (pcf) | Oven Moisture (%) | Dry Density (pcf)*** | DD/Max DD (%) | Avg DD/Max DD (%) | |
| 11/08/01 | 2 | middle | 111.1 | 6.6 | 7.9 | | 103.0 | 93.4 | 93.4 | 109.1 | 6.6 | 102.3 | 92.8 | 92.8 | |
| | 4 | middle | 113.0 | 9.0 | 10.2 | | 102.5 | 93.0 | 93.0 | 111.7 | 8.1 | 103.3 | 93.7 | 93.7 | |
| | 8 | middle | 114.8 | 9.7 | 10.9 | | 103.5 | 93.9 | 93.9 | 114.4 | 8.1 | 105.8 | 95.9 | 95.9 | |
| | 13 | middle | 115.9 | 10.3 | 11.5 | | 104.0 | 94.3 | 94.3 | 116.3 | 9.1 | 106.6 | 96.6 | 96.6 | |
| | 17 | south | | 118.5 | 11.0 | 12.1 | 9.8 | 107.9 | 97.8 | 97.5 | 118.1 | 9.2 | 108.2 | 98.1 | 97.8 |
| | | middle | | 119.0 | 10.9 | 12.0 | 9.4 | 108.8 | 98.6 | | 117.9 | 9.3 | 107.9 | 97.8 | |
| | | north | | 116.7 | 11.3 | 12.4 | 10.1 | 106.0 | 96.1 | | 117.7 | 9.5 | 107.5 | 97.5 | |

*Corrected gauge moisture(%) = 0.9697x gauge moisture(%) + 1.4777

**Dry Density calculations for the 6" use the Corrected Gauge Moisture, except for Cover 17 use Oven Moisture.

***Dry Density calculations for the 12" use the Oven Moisture.

Table 4.8 Summary of Compaction Test Results for Water Level at -12 inches (Condition 2)
(East Test Pit, North Part)

Embankment Soil: A-2-4 (12%)

Stabilized Subgrade Soil: A-2-4 (12%)+25% LR

Modified Proctor Max DD (pcf):

111.3

OMC :

12.3%

| Test Date (m/d/y) | Covers | Location | 0-6" Gauge Measurement | | | | | | | 0-12" Gauge Measurement | | | | |
|----------------------|--------|----------|-------------------------|---------------------|---------------------------------|-------------------------|-------------------------|------------------|----------------------|-------------------------|-------------------------|--------------------------|---------------|----------------------|
| | | | Wet Density (pcf) | Gauge Moist. (%) | Corrected Gauge Moist. (%) * | Oven Moisture (%) | Dry Density (pcf) ** | DD/Max DD (%) | Avg DD/Max DD (%) | Wet Density (pcf) | Oven Moisture (%) | Dry Density (pcf) *** | DD/Max DD (%) | Avg DD/Max DD (%) |
| 11/08/01 | 2 | middle | 114.8 | 10.0 | 11.0 | | 103.4 | 92.9 | 92.9 | 112.3 | 8.9 | 103.1 | 92.7 | 92.7 |
| | 4 | middle | 115.4 | 11.8 | 12.6 | | 102.5 | 92.1 | 92.1 | 113.9 | 9.5 | 104.0 | 93.5 | 93.5 |
| | 8 | middle | 119.6 | 12.1 | 12.9 | | 105.9 | 95.2 | 95.2 | 116.8 | 10.7 | 105.5 | 94.8 | 94.8 |
| | 13 | middle | 119.0 | 11.5 | 12.4 | | 105.9 | 95.1 | 95.1 | 118.6 | 10.2 | 107.6 | 96.7 | 96.7 |
| | 17 | south | 121.3 | 12.3 | 13.1 | 10.7 | 109.6 | 98.5 | 99.1 | 121.0 | 11.1 | 108.9 | 97.9 | 97.7 |
| | | middle | 122.2 | 12.0 | 12.8 | 10.5 | 110.6 | 99.4 | | 121.8 | 12.0 | 108.8 | 97.7 | |
| | | north | 123.0 | 12.1 | 12.9 | 11.2 | 110.6 | 99.4 | | 121.7 | 12.0 | 108.7 | 97.6 | |

*Corrected gauge moisture(%) = 0.8874 x gauge moisture(%) + 2.1665

**Dry Density calculations for the 6" use the Corrected Gauge Moisture, except for Cover 17 use Oven Moisture.

***Dry Density calculations for the 12" use the Oven Moisture.

Table 4.9 Summary of Compaction Test Results for Water Level at -6 inches (Condition 3)
(West Test Pit, South Part)

Embankment Soil: A-3 (5%)

Stabilized Subgrade Soil: A-2-4 (12%)

Modified Proctor Max DD (pcf): 110.3

OMC : 12.4%

| Test Date (m/d/y) | covers | Location | 0-6" Gauge Measurement | | | | | 0-12" Gauge Measurement | | | | |
|----------------------|--------|----------|------------------------|----------------------|------------------------|---------------|----------------------|-------------------------|----------------------|-------------------------|------------------|-------------------|
| | | | Wet Density (pcf) | Oven Moisture (%) | Dry Density (pcf) * | DD/Max DD (%) | Avg DD/Max DD (%) | Wet Density (pcf) | Oven Moisture (%) | Dry Density (pcf) ** | DD/Max DD (%) | Avg DD/Max DD (%) |
| 01/09/02 | 4 | Middle | 114.4 | 10.1 | 103.9 | 94.2 | 94.2 | 115.4 | 10.8 | 104.2 | 94.4 | 94.4 |
| | 8 | Middle | 116.1 | 11.0 | 104.6 | 94.8 | 94.8 | 117.4 | 10.9 | 105.9 | 96.0 | 96.0 |
| | 14 | South | 118.3 | 10.1 | 107.4 | 97.4 | 97.6 | 120.1 | 11.2 | 108.0 | 97.9 | 97.6 |
| | | Middle | 118.3 | 10.1 | 107.4 | 97.4 | | 119.7 | 11.1 | 107.7 | 97.7 | |
| | | North | 118.7 | 9.8 | 108.1 | 98.0 | | 119.5 | 11.4 | 107.3 | 97.3 | |
| 01/14/02 | 20 | Middle | 120.5 | 10.7 | 108.9 | 98.7 | 98.0 | 121.9 | 11.6 | 109.2 | 99.0 | 98.4 |
| | | South | 119.3 | 10.6 | 107.9 | 97.8 | | 120.5 | 11.5 | 108.1 | 98.0 | |
| | | North | 119.3 | 10.9 | 107.6 | 97.5 | | 120.9 | 11.7 | 108.2 | 98.1 | |
| | | | | | | | | | | | | |

*Dry Density calculations for the 6" use the Oven Moisture.

**Dry Density calculations for the 12" use the Oven Moisture.

Table 4.10 Summary of Compaction Test Results for Water Level at -6 inches (Condition 3)
(West Test Pit, North Part)

Embankment Soil: A-3 (5%)

Stabilized Subgrade Soil: A-2-4 (12%)+25%LR Modified Proctor Max DD (pcf): 111.3 OMC : 12.3%

| Test Date (m/d/y) | Covers | Location | 0-6" Gauge Measurement | | | | | 0-12" Gauge Measurement | | | | |
|----------------------|--------|----------|------------------------|-------------------------|------------------------|------------------|----------------------|-------------------------|----------------------|-------------------------|---------------|----------------------|
| | | | Wet Density (pcf) | Oven Moisture (%) | Dry Density (pcf) * | DD/Max DD (%) | Avg DD/Max DD (%) | Wet Density (pcf) | Oven Moisture (%) | Dry Density (pcf) ** | DD/Max DD (%) | Avg DD/Max DD (%) |
| 01/09/02 | 4 | Middle | 115.5 | 9.9 | 105.1 | 94.4 | 94.4 | 116.9 | 11.2 | 105.1 | 94.5 | 94.5 |
| | 8 | Middle | 117.7 | 10.9 | 106.1 | 95.4 | 95.4 | 120.0 | 11.4 | 107.7 | 96.8 | 96.8 |
| | 14 | North | 117.8 | 9.7 | 107.4 | 96.5 | 96.4 | 120.2 | 11.2 | 108.1 | 97.1 | 97.2 |
| | | Middle | 117.8 | 9.6 | 107.5 | 96.6 | | 119.6 | 9.6 | 109.1 | 98.0 | |
| | | South | 118.3 | 10.5 | 107.1 | 96.2 | | 119.7 | 11.5 | 107.4 | 96.5 | |
| 01/14/02 | 20 | North | 121.8 | 11.0 | 109.7 | 98.6 | 97.9 | 123.3 | 11.9 | 110.2 | 99.0 | 98.4 |
| | | Middle | 120.3 | 10.4 | 109.0 | 97.9 | | 122.3 | 11.9 | 109.3 | 98.2 | |
| | | South | 120.0 | 11.0 | 108.1 | 97.1 | | 122.0 | 11.8 | 109.1 | 98.0 | |

*Dry Density calculations for the 6" use the Oven Moisture.

**Dry Density calculations for the 12" use the Oven Moisture.

Table 4.11 Summary of Compaction Test Results for Water Level at -6 inches (Condition 3)
(East Test Pit, South Part)

Embankment Soil: A-2-4(12%)

Stabilized Subgrade Soil: A-2-4 (12%) Modified Proctor Max DD (pcf): 110.3 OMC : 12.4%

| Test Date (m/d/y) | Covers | Location | 0-6" Gauge Measurement | | | | | 0-12" Gauge Measurement | | | | |
|----------------------|--------|----------|------------------------|----------------------|------------------------|---------------|----------------------|-------------------------|----------------------|-------------------------|------------------|----------------------|
| | | | Wet Density (pcf) | Oven Moisture (%) | Dry Density (pcf) * | DD/Max DD (%) | Avg DD/Max DD (%) | Wet Density. (pcf) | Oven Moisture (%) | Dry Density (pcf) ** | DD/Max DD (%) | Avg DD/Max DD (%) |
| 01/09/02 | 4 | Middle | 112.8 | 8.5 | 104.0 | 94.3 | 94.3 | 116.2 | 8.6 | 107.0 | 97.0 | 97.0 |
| | 8 | Middle | 117.6 | 10.2 | 106.7 | 96.7 | 96.7 | 118.6 | 11.6 | 106.3 | 96.3 | 96.3 |
| | 14 | South | 119.8 | 11.3 | 107.6 | 97.6 | 96.8 | 121.3 | 11.7 | 108.6 | 98.5 | 98.0 |
| | | North | 117.1 | 10.2 | 106.3 | 96.3 | | 120.0 | 11.2 | 107.9 | 97.8 | |
| 01/14/02 | 20 | Middle | 117.5 | 10.4 | 106.4 | 96.5 | 97.8 | 120.1 | 11.6 | 107.6 | 97.6 | 98.6 |
| | | North | 118.5 | 10.6 | 107.1 | 97.1 | | 121.0 | 11.5 | 108.5 | 98.4 | |
| | | Middle | 120.2 | 11.0 | 108.3 | 98.2 | | 121.6 | 11.8 | 108.8 | 98.6 | |
| | | South | 120.0 | 11.0 | 108.1 | 98.0 | | 121.7 | 11.6 | 109.1 | 98.9 | |

*Dry Density calculations for the 6" use the Oven Moisture.

**Dry Density calculations for the 12" use the Oven Moisture.

Table 4.12 Summary of Compaction Test Results for Water Level at -6 inches (Condition 3)
(West Test Pit, North Part)

Embankment Soil: A-2-4 (12%)

Stabilized Subgrade Soil: A-2-4 (12%)+25% LR Modified Proctor Max DD (pcf): 111.3 OMC : 12.3%

| Test Date (m/d/y) | Covers | Location | 0-6" Gauge Measurement | | | | | 0-12" Gauge Measurement | | | | |
|----------------------|--------|----------|------------------------|----------------------|------------------------|---------------|----------------------|-------------------------|----------------------|-------------------------|---------------|-------------------|
| | | | Wet Density (pcf) | Oven Moisture (%) | Dry Density (pcf) * | DD/Max DD (%) | Avg DD/Max DD (%) | Wet Density (pcf) | Oven Moisture (%) | Dry Density (pcf) ** | DD/Max DD (%) | Avg DD/Max DD (%) |
| 01/09/02 | 4 | Middle | 111.2 | 8.9 | 102.1 | 91.7 | 91.7 | 115.5 | 11.5 | 103.6 | 93.1 | 93.1 |
| | 8 | Middle | 113.6 | 8.4 | 104.8 | 94.2 | 94.2 | 116.5 | 10.7 | 105.2 | 94.6 | 94.6 |
| | 14 | North | 115.3 | 9.5 | 105.3 | 94.6 | 94.9 | 117.9 | 11.6 | 105.6 | 94.9 | 95.6 |
| | | South | 115.9 | 9.2 | 106.1 | 95.4 | | 118.0 | 11.4 | 105.9 | 95.2 | |
| | | Middle | 116.4 | 10.5 | 105.3 | 94.6 | | 119.0 | 10.6 | 107.6 | 96.7 | |
| 01/14/02 | 20 | South | 118.8 | 10.5 | 107.5 | 96.6 | 96.7 | 121.9 | 12.0 | 108.8 | 97.8 | 97.7 |
| | | North | 118.9 | 10.7 | 107.4 | 96.5 | | 121.7 | 12.1 | 108.6 | 97.5 | |
| | | Middle | 120.4 | 11.4 | 108.1 | 97.1 | | 121.7 | 12.0 | 108.7 | 97.6 | |

*Dry Density calculations for the 6" use the Oven Moisture.

**Dry Density calculations for the 12" use the Oven Moisture.

Table 4.13 Summary of Compaction Test Results for Water Level at -6 inches drained
(Condition 4) (West Test Pit, South Part)

Embankment Soil: A-3 (5%)

Stabilized Subgrade Soil: A-2-4 (12%)

Modified Proctor Max DD (pcf): 110.3

OMC : 12.4%

| Test Date (m/d/y) | Covers | Location | 0-6" Gauge Measurement | | | | 0-12" Gauge Measurement | | | |
|----------------------|--------|----------|------------------------|-------------------|---------------------|---------------|-------------------------|-------------------|----------------------|---------------|
| | | | Wet Density (pcf) | Oven Moisture (%) | Dry Density (pcf) * | DD/Max DD (%) | Wet Density (pcf) | Oven Moisture (%) | Dry Density (pcf) ** | DD/Max DD (%) |
| Static | | | | | | | | | | |
| 03/20/02 | 2 | middle | 112.9 | 11.7 | 101.1 | 91.6 | 109.6 | 8.6 | 100.9 | 91.5 |
| | 6 | middle | 118.2 | 9.4 | 108.0 | 98.0 | 113.1 | 8.8 | 104.0 | 94.2 |
| | 10 | middle | 115.8 | 8.4 | 106.8 | 96.9 | 113.5 | 10.2 | 103.0 | 93.4 |
| | 16 | middle | 117.0 | 8.9 | 107.4 | 97.4 | 113.6 | 10.1 | 103.2 | 93.5 |
| 3/21/2002 | 20 | middle | 116.9 | 8.0 | 108.2 | 98.1 | 114.7 | 10.5 | 103.8 | 94.1 |
| | 24 | middle | 117.1 | 8.4 | 108.0 | 97.9 | 115.0 | 10.7 | 103.9 | 94.2 |
| | 32 | middle | 116.2 | 8.1 | 107.5 | 97.5 | 114.8 | 11.1 | 103.3 | 93.7 |
| Vibratory | | | | | | | | | | |
| 03/21/02 | 2 | middle | 116.3 | 8.2 | 107.5 | 97.4 | 115.4 | 15.5 | 99.9 | 90.6 |
| | 6 | middle | 118.0 | 8.4 | 108.9 | 98.7 | 117.0 | 13.5 | 103.1 | 93.5 |
| | 12 | middle | 117.3 | 8.4 | 108.2 | 98.1 | 118.2 | 18.7 | 99.6 | 90.3 |
| | 18 | middle | 118.1 | 8.4 | 108.9 | 98.8 | 118.3 | 16.7 | 101.4 | 91.9 |
| | 24 | middle | 118.0 | 8.4 | 108.9 | 98.7 | 118.1 | 17.6 | 100.4 | 91.0 |
| | 30 | middle | 119.2 | 8.2 | 110.2 | 99.9 | 118.2 | 18.2 | 100.0 | 90.7 |

*Dry Density was calculated using the oven moisture for the 6"

**Dry Density was calculated using the oven moisture for the 12"

Table 4.14 Summary of Compaction Test Results for Water Level at -6 inches drained
(Condition 4) (West Test Pit, North Part)

Embankment Soil: A-3 (5%)

Stabilized Subgrade Soil: A-2-4 (12%)+25% LR Modified Proctor Max DD (pcf): 111.3 OMC : 12.3%

| Test Date (m/d/y) | Covers | Location | 0-6" Gauge Measurement | | | | 0-12" Gauge Measurement | | | |
|----------------------|--------|----------|------------------------|-------------------------|------------------------|---------------|-------------------------|-------------------|-------------------------|---------------|
| | | | Wet Density (pcf) | Oven Moisture (%) | Dry Density (pcf) * | DD/Max DD (%) | Wet Density (pcf) | Oven Moisture (%) | Dry Density (pcf) ** | DD/Max DD (%) |
| Static | | | | | | | | | | |
| 03/20/02 | 2 | middle | 118.5 | 11.2 | 106.6 | 95.7 | 114.9 | 11.4 | 103.1 | 92.7 |
| | 6 | middle | 114.3 | 10.9 | 103.1 | 92.6 | 112.7 | 11.9 | 100.7 | 90.5 |
| | 10 | middle | 119.5 | 9.9 | 108.7 | 97.7 | 115.9 | 10.8 | 104.6 | 94.0 |
| | 16 | middle | 119.9 | 10.5 | 108.5 | 97.5 | 116.9 | 12.3 | 104.1 | 93.5 |
| 3/21/2002 | 20 | middle | 118.7 | 9.0 | 108.9 | 97.8 | 116.8 | 11.8 | 104.5 | 93.9 |
| | 24 | middle | 120.5 | 10.0 | 109.5 | 98.4 | 117.4 | 11.7 | 105.1 | 94.4 |
| | 32 | middle | 119.3 | 10.0 | 108.5 | 97.4 | 115.8 | 11.7 | 103.7 | 93.1 |
| Vibratory | | | | | | | | | | |
| 03/21/02 | 2 | middle | 117.2 | 9.8 | 106.7 | 95.9 | 116.3 | 12.6 | 103.3 | 92.8 |
| | 6 | middle | 121.3 | 9.7 | 110.6 | 99.3 | 118.8 | 12.2 | 105.9 | 95.1 |
| | 12 | middle | 119.1 | 9.2 | 109.1 | 98.0 | 119.1 | 12.6 | 105.8 | 95.0 |
| | 18 | middle | 120.4 | 9.9 | 109.6 | 98.4 | 121.0 | 12.9 | 107.2 | 96.3 |
| | 24 | middle | 120.2 | 9.5 | 109.8 | 98.6 | 120.8 | 12.6 | 107.3 | 96.4 |
| | 30 | middle | 121.1 | 9.5 | 110.6 | 99.4 | 121.2 | 12.9 | 107.4 | 96.5 |

*Dry Density was calculated using the oven moisture for the 6"

**Dry Density was calculated using the oven moisture for the 12"

Table 4.15 Summary of Compaction Test Results for Water Level at -12 inches drained
(Condition 5) (West Test Pit, South Part)

Embankment Soil: A-3 (5%)

Stabilized Subgrade Soil: A-2-4 (12%)

Modified Proctor Max DD (pcf): 110.3

OMC : 12.4%

| Test Date (m/d/y) | Covers | Location | 0-6" Gauge Measurement | | | | | 0-12" Gauge Measurement | | | | | Type of Compaction |
|----------------------|--------|----------|------------------------|-----------------------|----------------------|------------------------|------------------|-------------------------|-----------------------|----------------------|-------------------------|------------------|----------------------|
| | | | Wet Density (pcf) | Gauge Moisture (%) | Oven Moisture (%) | Dry Density (pcf) * | DD/Max DD (%) | Wet Density (pcf) | Gauge Moisture (%) | Oven Moisture (%) | Dry Density (pcf) ** | DD/Max DD (%) | |
| 06/04/02 | 2 | Middle | 114.0 | 9.6 | 8.0 | 105.6 | 95.7 | 110.7 | 9.3 | 6.8 | 103.7 | 94.0 | Plate Compactor |
| | 6 | Middle | 114.6 | 9.9 | | 104.3 | 94.5 | 116.0 | 9.5 | | 105.9 | 96.0 | Vibratory Sheepsfoot |
| | 10 | Middle | 116.1 | 8.5 | 7.7 | 107.8 | 97.7 | 118.6 | 8.2 | 9.0 | 108.8 | 98.6 | Plate Compactor |

*Dry Density was calculated using the oven moisture for the 6"(when available)

**Dry Density was calculated using the oven moisture for the 12" (when available)

Table 4.15 Summary of Compaction Test Results for Water Level at -12 inches drained
(Condition 5) (West Test Pit, North Part)

Embankment Soil: A-3 (5%)

Stabilized Subgrade Soil: A-2-4 (12%)+25% LR Modified Proctor Max DD (pcf): 111.3 OMC: 12.3%

| Test Date (m/d/y) | Covers | Location | 0-6" Gauge Measurement | | | | | 0-12" Gauge Measurement | | | | | Type of Compaction |
|----------------------|--------|----------|------------------------|-----------------------|----------------------|------------------------|------------------|-------------------------|-----------------------|----------------------|-------------------------|------------------|----------------------|
| | | | Wet Density (pcf) | Gauge Moisture (%) | Oven Moisture (%) | Dry Density (pcf) * | DD/Max DD (%) | Wet Density (pcf) | Gauge Moisture (%) | Oven Moisture (%) | Dry Density (pcf) ** | DD/Max DD (%) | |
| 06/04/02 | 2 | Middle | 113.8 | 9.9 | 8.7 | 104.7 | 94.1 | 109.3 | 9.3 | 6.9 | 102.2 | 91.9 | Plate Compactor |
| | 6 | Middle | 118.3 | 11.4 | | 106.2 | 95.4 | 116.1 | 9.5 | | 106.0 | 95.3 | Vibratory Sheepsfoot |
| | 12 | Middle | 119.9 | 12.0 | 8.9 | 110.1 | 98.9 | 118.1 | 8.2 | 8.9 | 108.4 | 97.4 | Vibratory Sheepsfoot |
| | 16 | Middle | 119.0 | 9.1 | 8.3 | 109.9 | 98.7 | 116.9 | 8.2 | 8.4 | 107.8 | 96.9 | Plate Compactor |

*Dry Density was calculated using the oven moisture for the 6" (when available)

**Dry Density was calculated using the oven moisture for the 12" (when available)

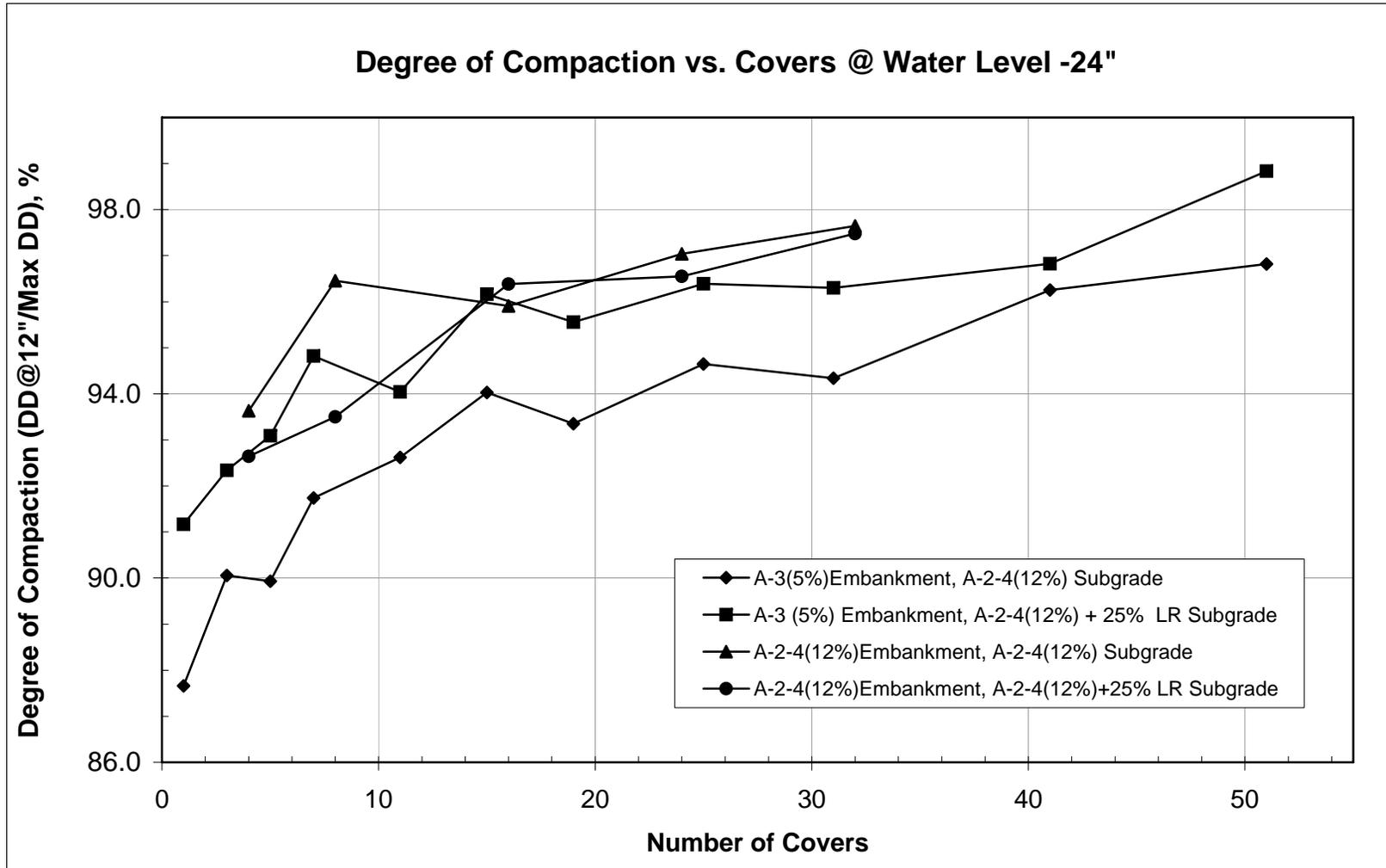


Figure 4.1 Degree of Compaction versus Number of Compaction Covers on Stabilized Subgrade for Water Level at -24 in. (Condition 1)

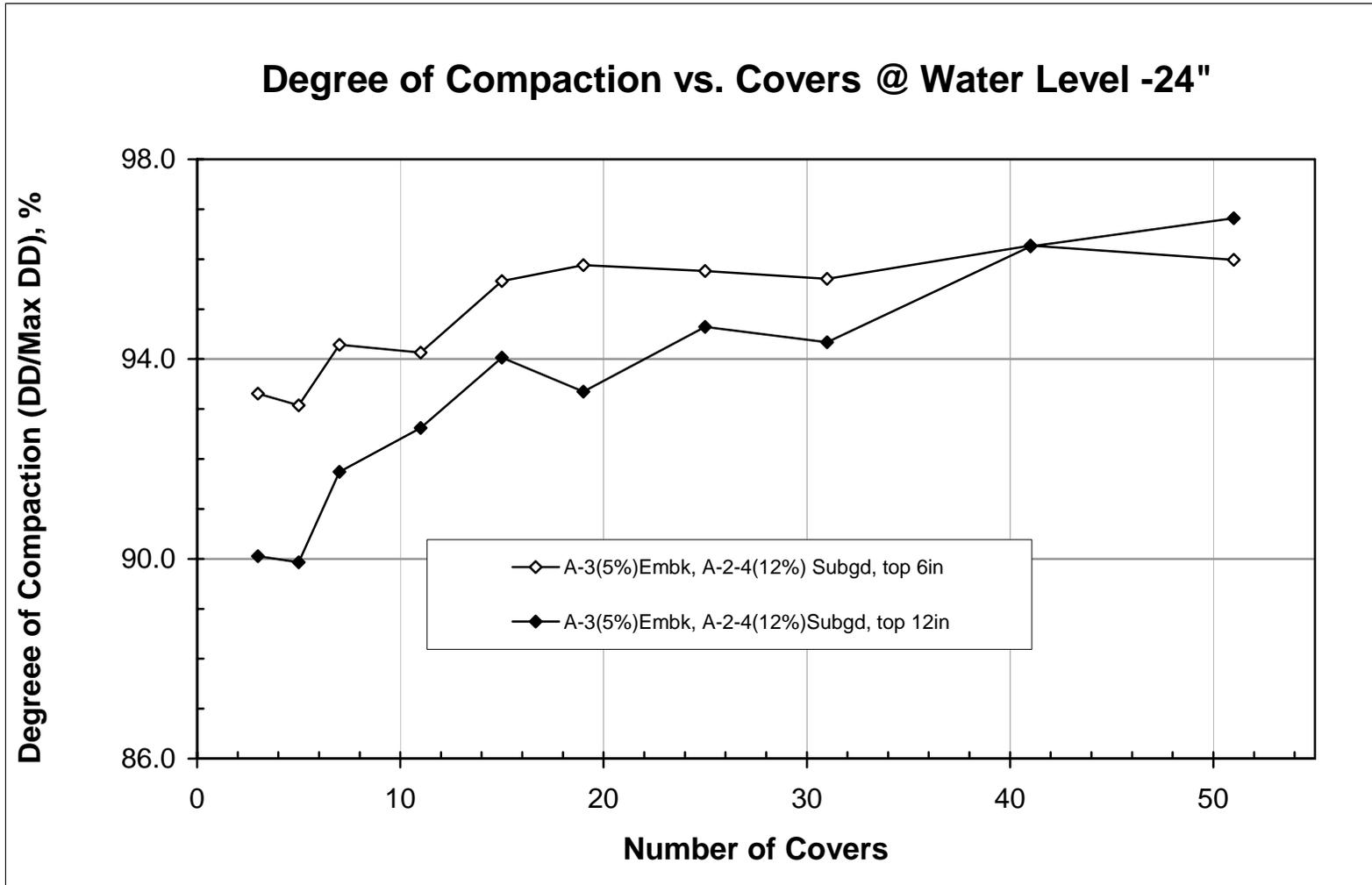


Figure 4.2(a) Comparison of Degree of Compaction for 6 in. and 12 in. Measurements (Condition 1, A-3 (5%) Embankment, A-2-4 (12%) Subgrade)

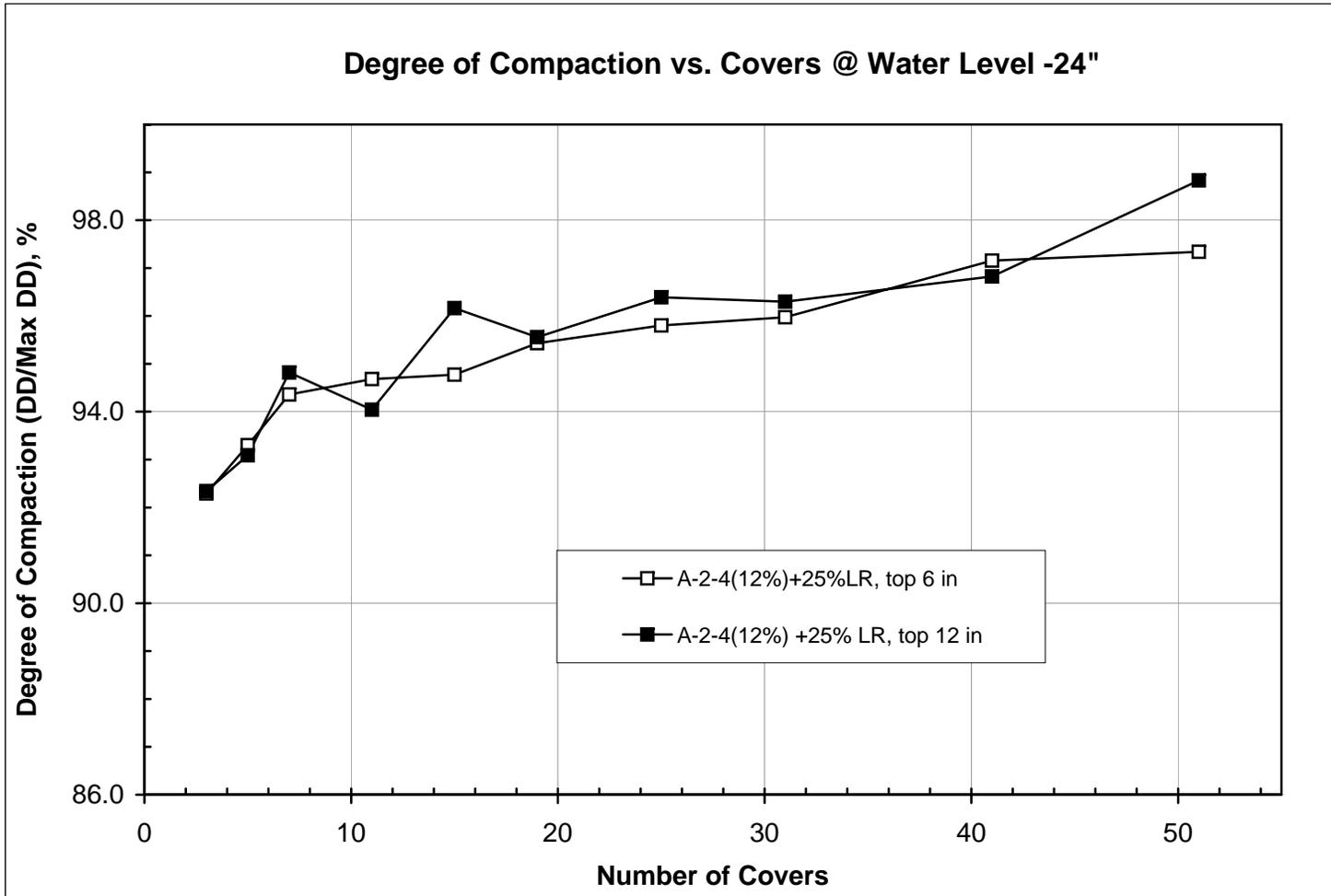


Figure 4.2(b) Comparison of Degree of Compaction for 6 inch and 12 inch Measurements (Condition 1, A-3 (5%) Embankment, A-2-4 (12%) +25% limerock Subgrade)

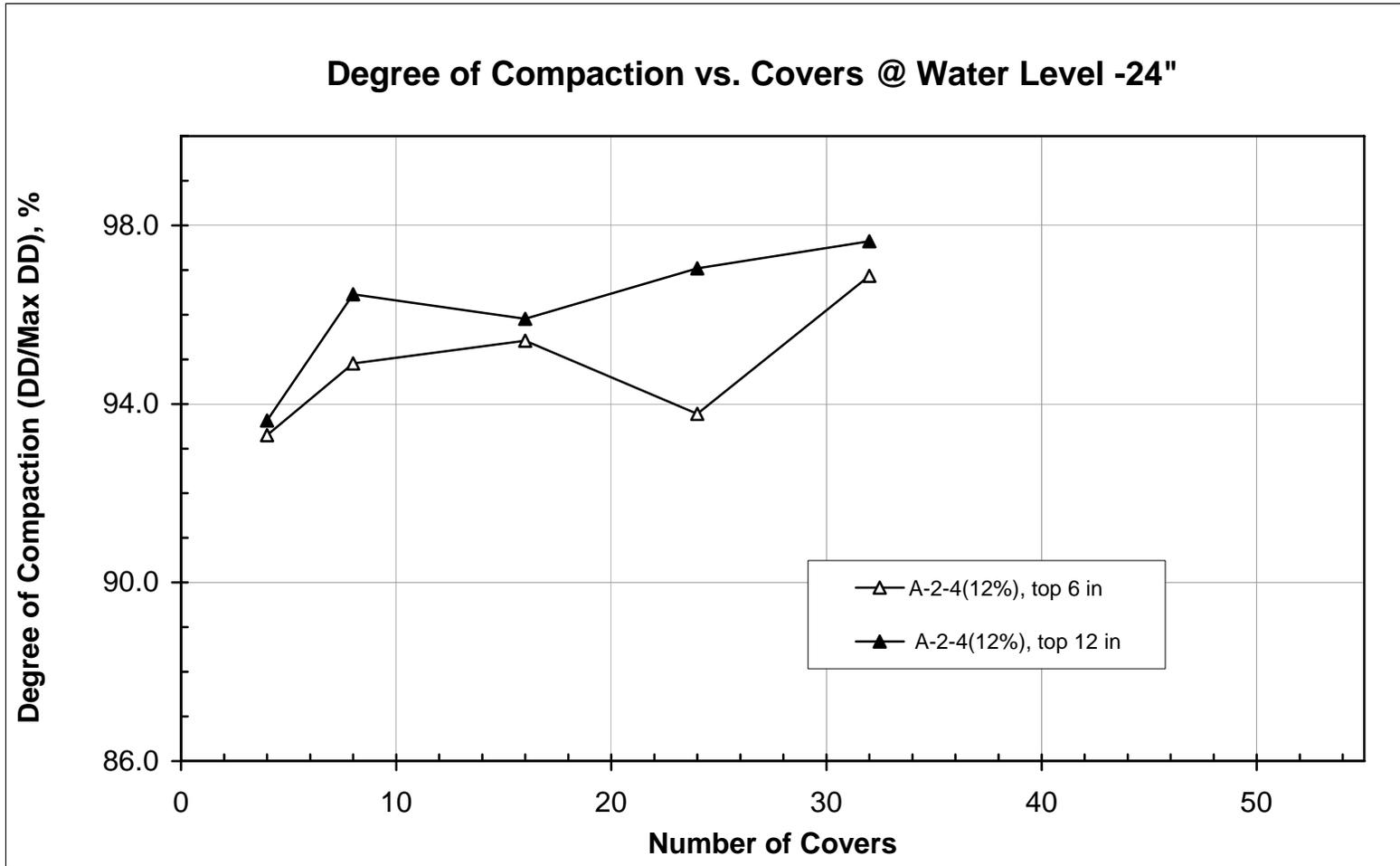


Figure 4.3(a) Comparison of Degree of Compaction for 6 in. and 12 in. Measurements (Condition 1, A-2-4 (12%) Embankment, A-2-4 (12%) Subgrade)

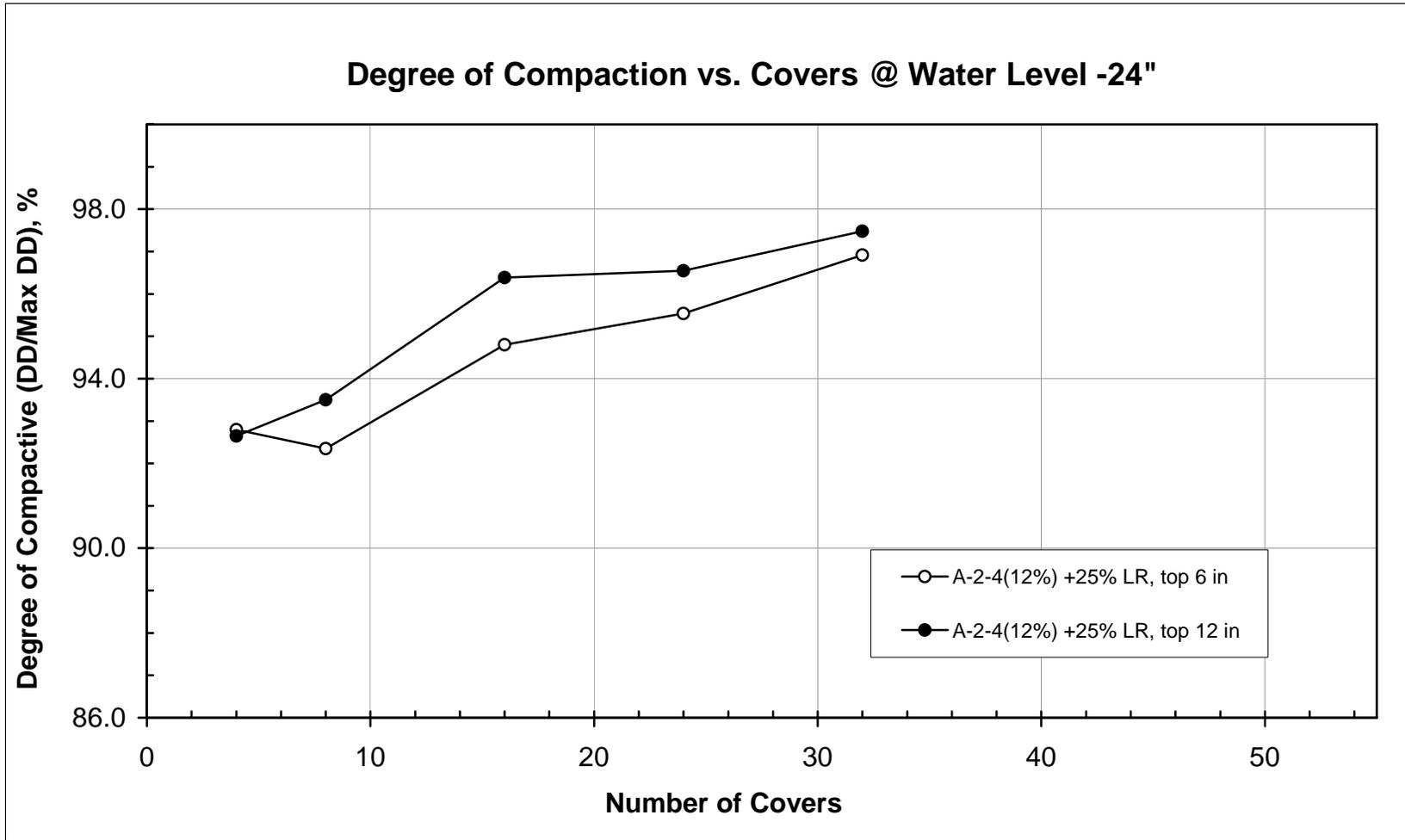


Figure 4.3(b) Comparison of Degree of Compaction for 6 inch and 12 inch Measurements (Condition 1, A-2-4 (12%) Embankment, A-2-4 (12%) + 25% limerock Subgrade)

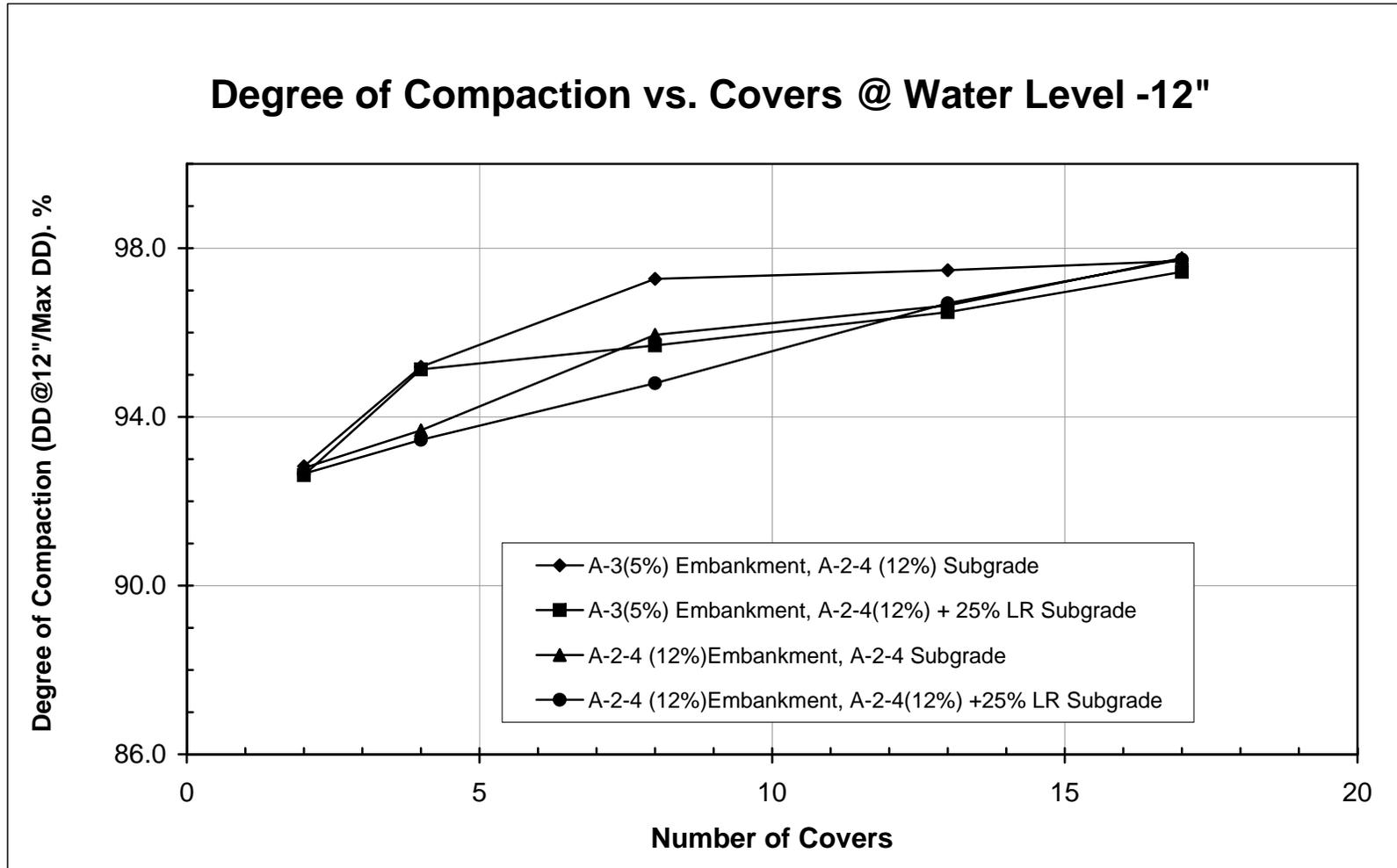


Figure 4.4 Degree of Compaction versus Number of Compaction Covers on Stabilized Subgrade for Water Level at -12 in. (Condition 2)

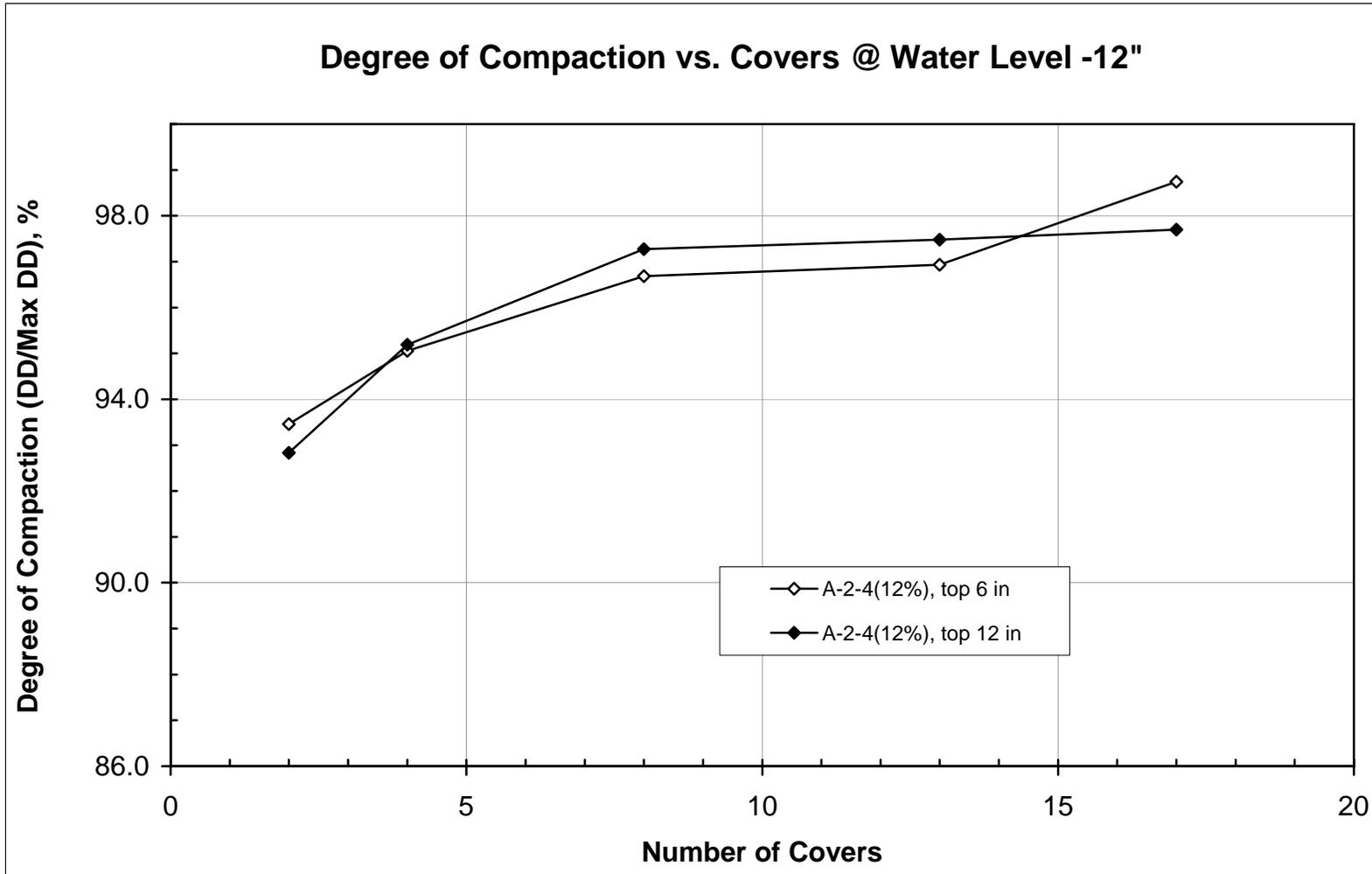


Figure 4.5(a) Comparison of Degree of Compaction for 6 in. and 12 in. Measurements (Condition 2, A-3 (5%) Embankment, A-2-4 (12%) Subgrade)

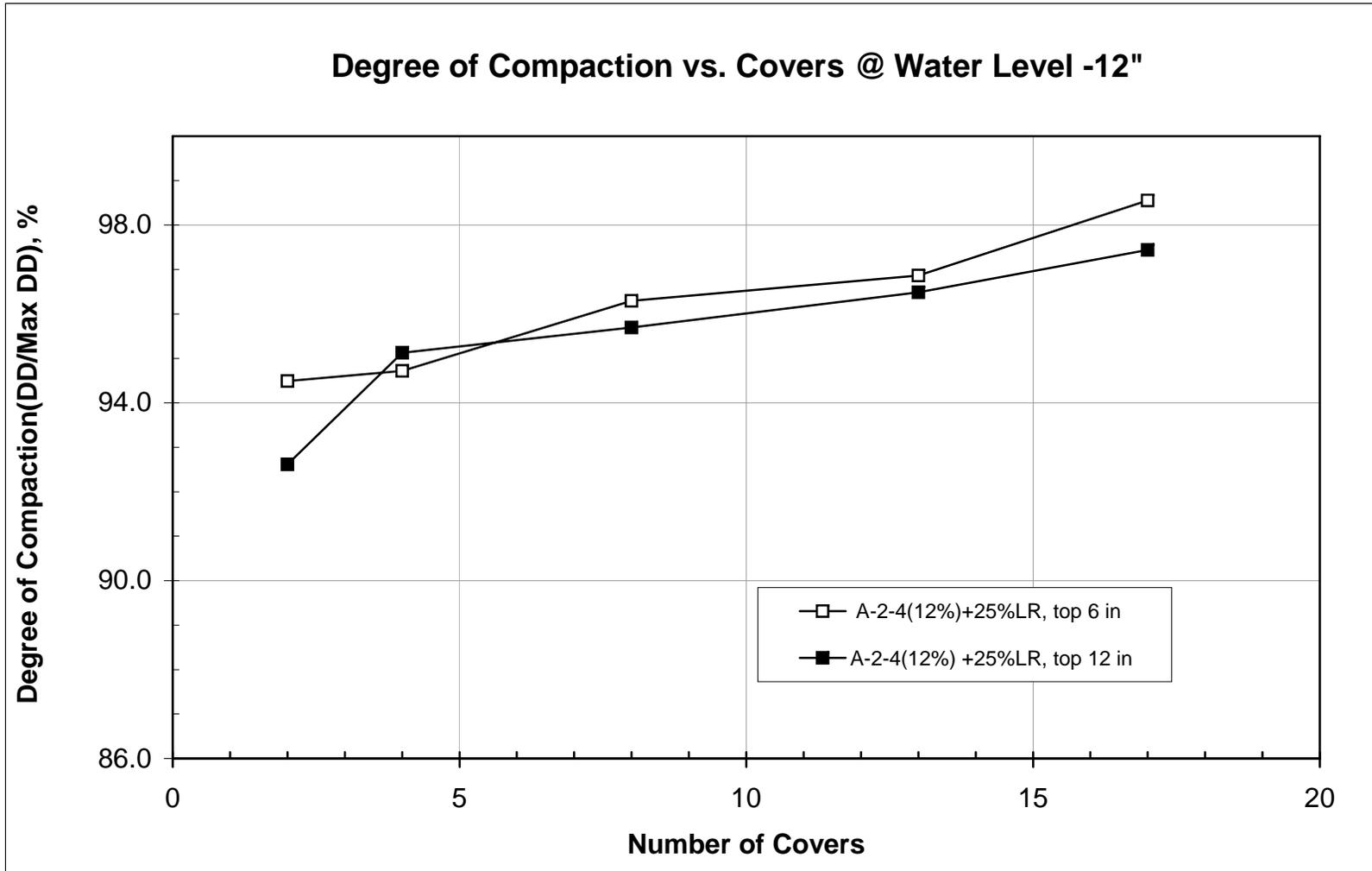


Figure 4.5(b) Comparison of Degree of Compaction for 6 inch and 12 inch Measurements (Condition 2, A-3 (5%) Embankment, A-2-4 (12%) + 25% limerock Subgrade)

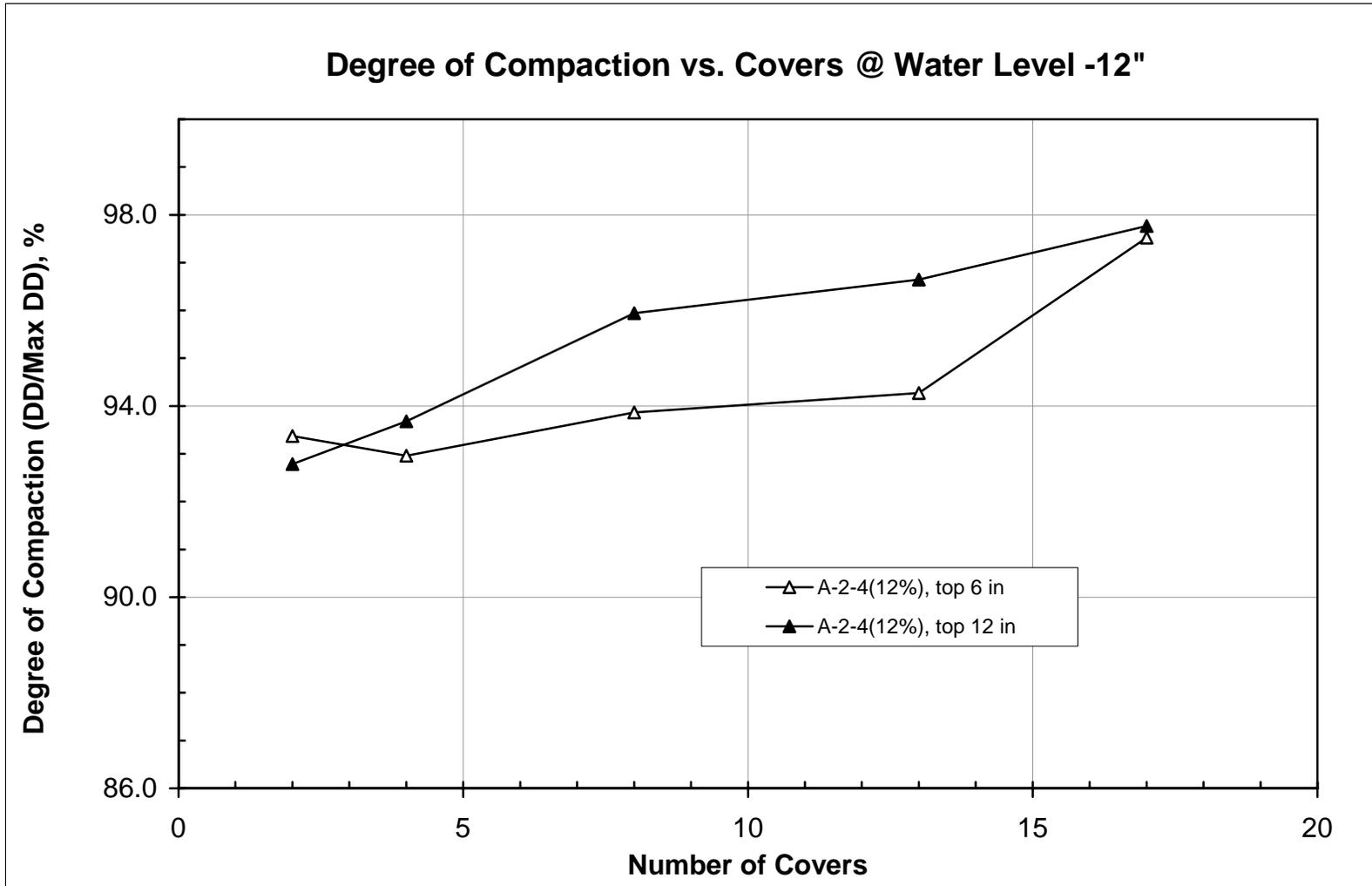


Figure 4.6(a) Comparison of Degree of Compaction for 6 in. and 12 in. Measurements (Condition 2, A-2-4 (12%) Embankment, A-2-4 (12%) Subgrade)

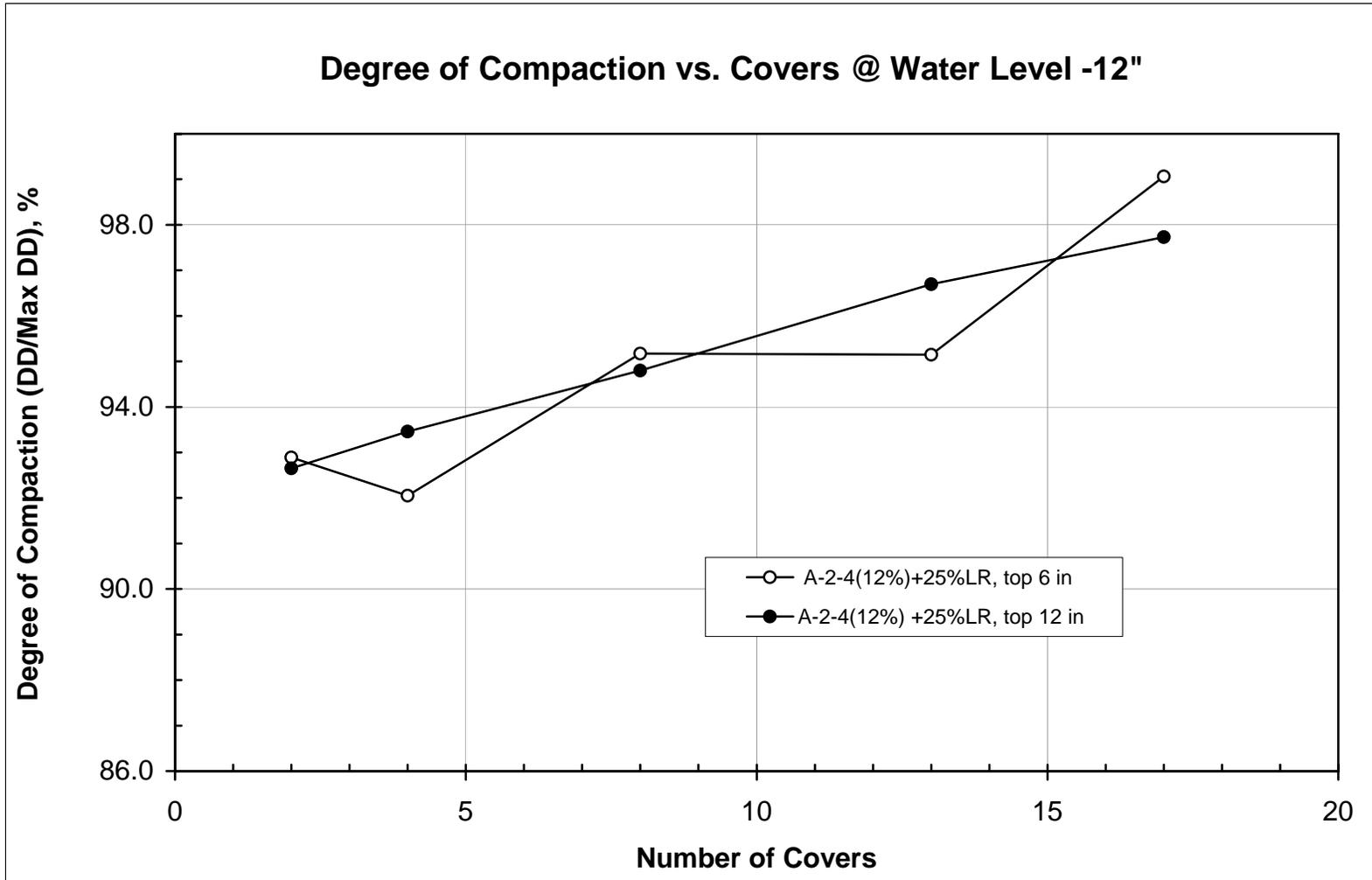


Figure 4.6(b) Comparison of Degree of Compaction for 6 inch and 12 inch Measurements (Condition 2, A-2-4 (12%) Embankment, A-2-4 (12%) + 25% limerock Subgrade)

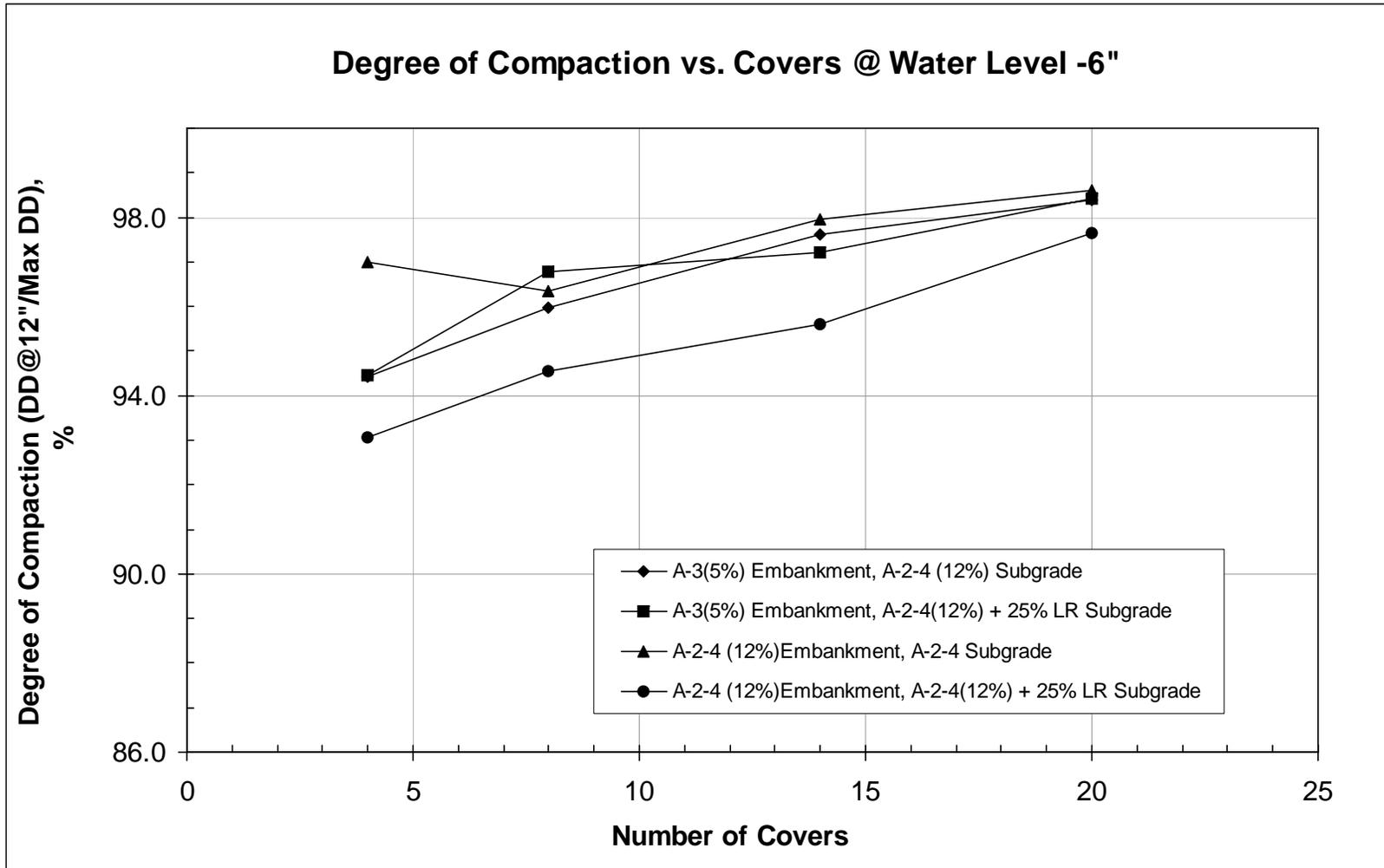


Figure 4.7 Degree of Compaction versus Number of Compaction Covers on Stabilized Subgrade for Water Level at -6 in. (Condition 3)

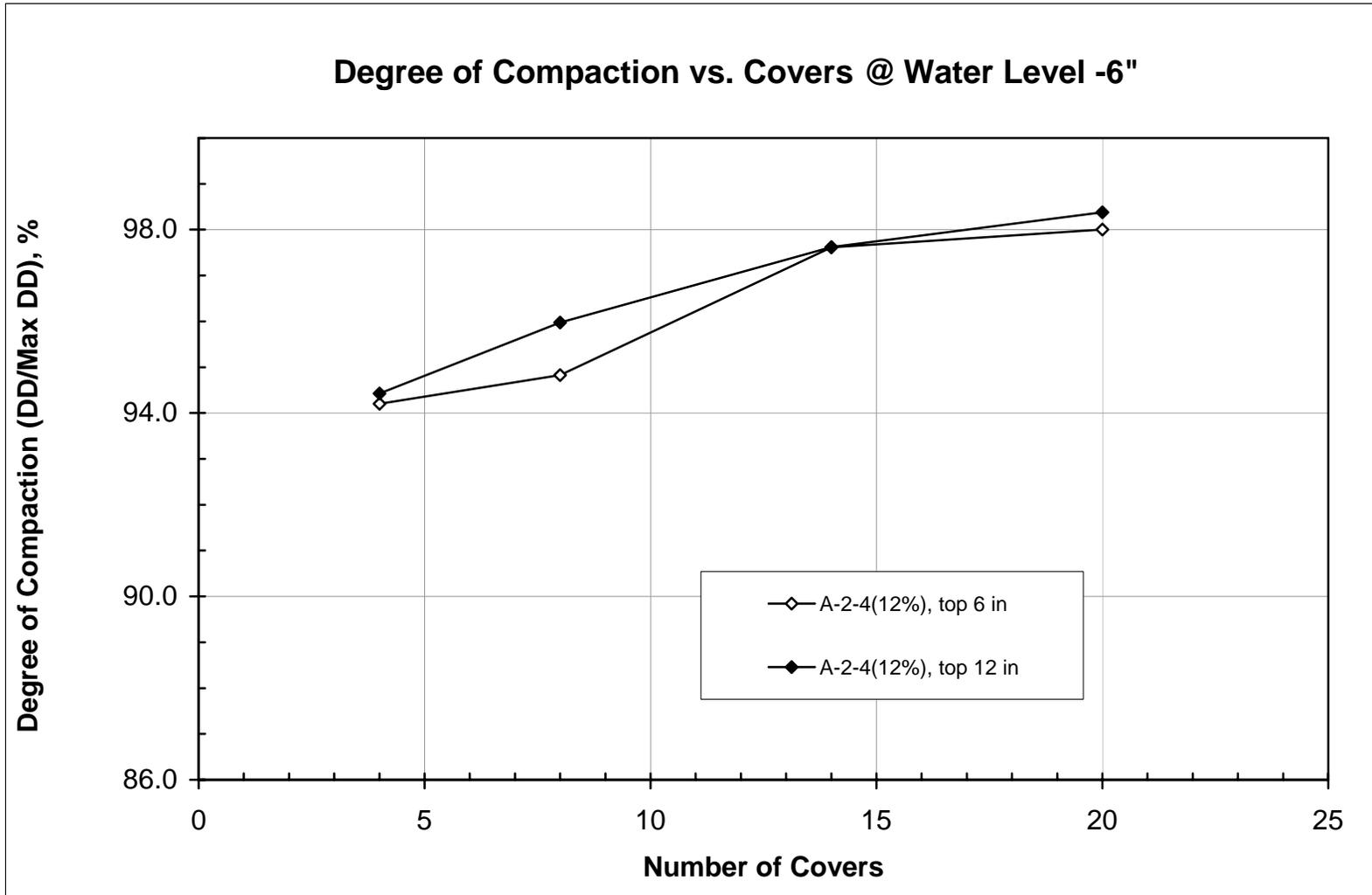


Figure 4.8(a) Comparison of Degree of Compaction for 6 in. and 12 in. Measurements (Condition 3, A-2-4 (12%) Embankment, A-2-4 (12%) Subgrade)

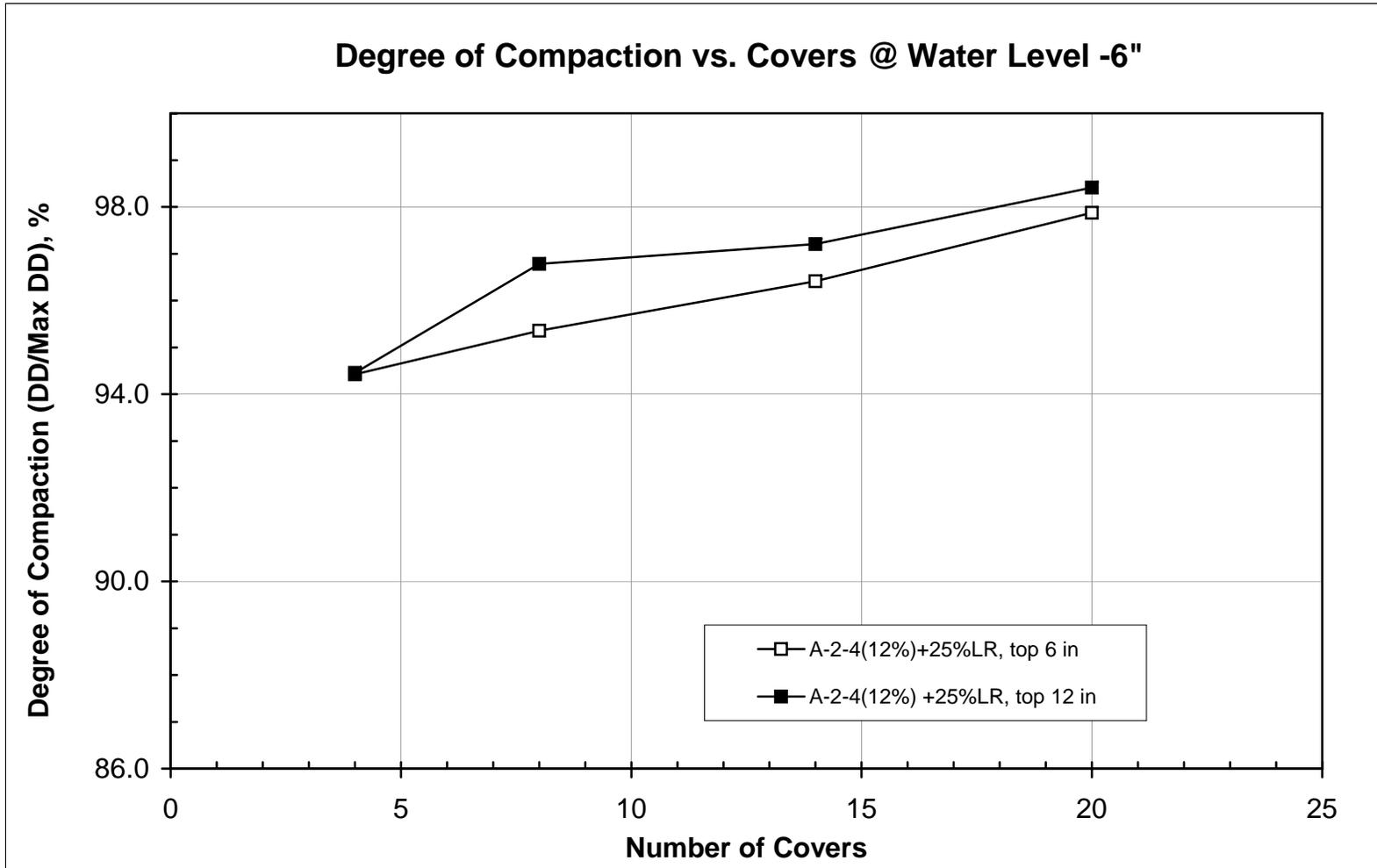


Figure 4.8(b) Comparison of Degree of Compaction for 6 inch and 12 inch Measurements (Condition 3, A-2-4 (12%) Embankment, A-2-4 (12%) + 25% limerock Subgrade)

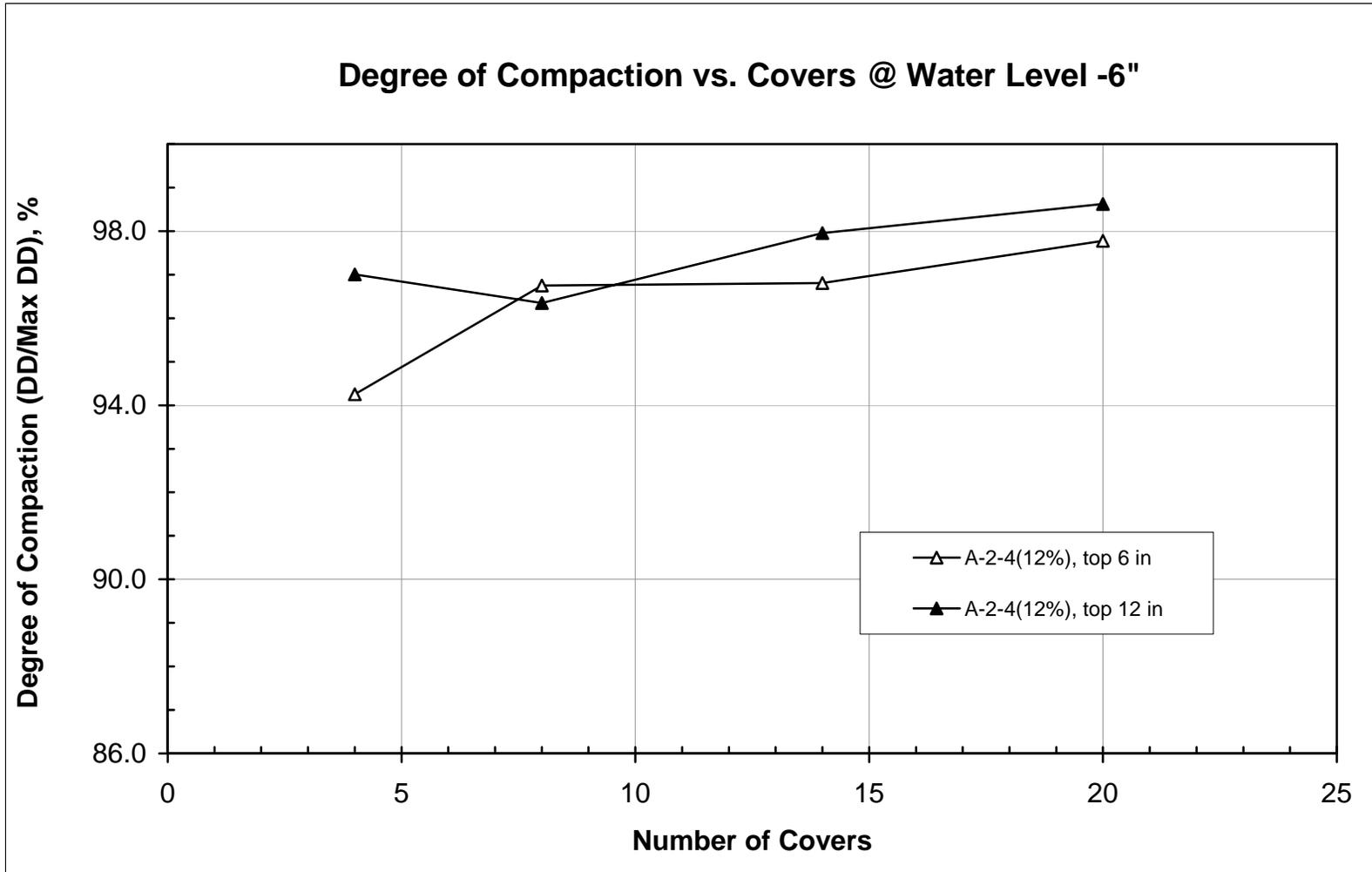


Figure 4.9(a) Comparison of Degree of Compaction for 6 in. and 12 in. Measurements (Condition 3, A-2-4 (12%) Embankment, A-2-4 (12%) Subgrade)

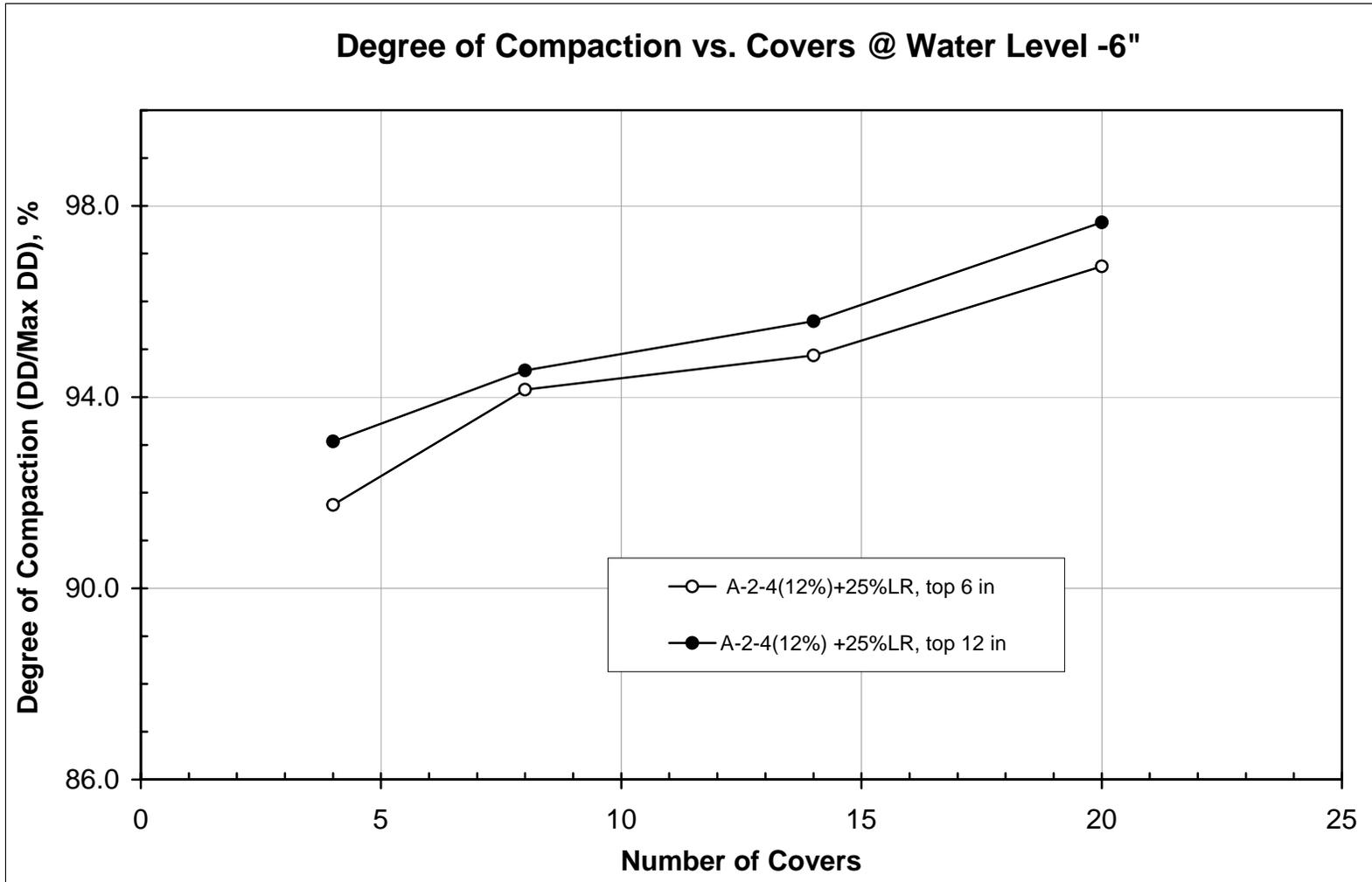


Figure 4.9(b) Comparison of Degree of Compaction for 6 inch and 12 inch Measurements (Condition 3, A-2-4 (12%) Embankment, A-2-4 (12%) + 25% limerock Subgrade)

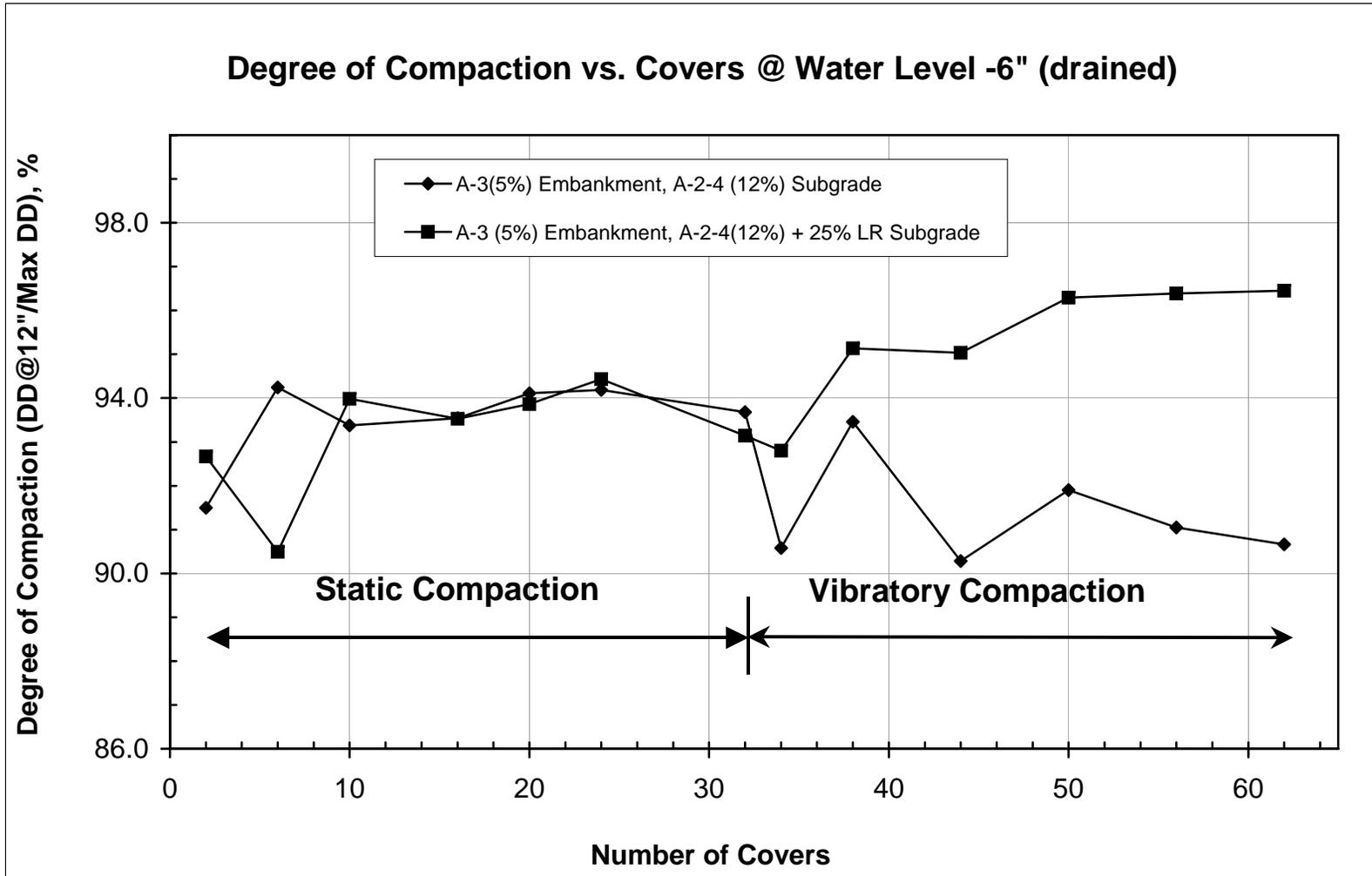


Figure 4.10 Degree of Compaction versus Number of Compaction Covers on Stabilized Subgrade for Water Level at -6 in. (drained) (Condition 4)

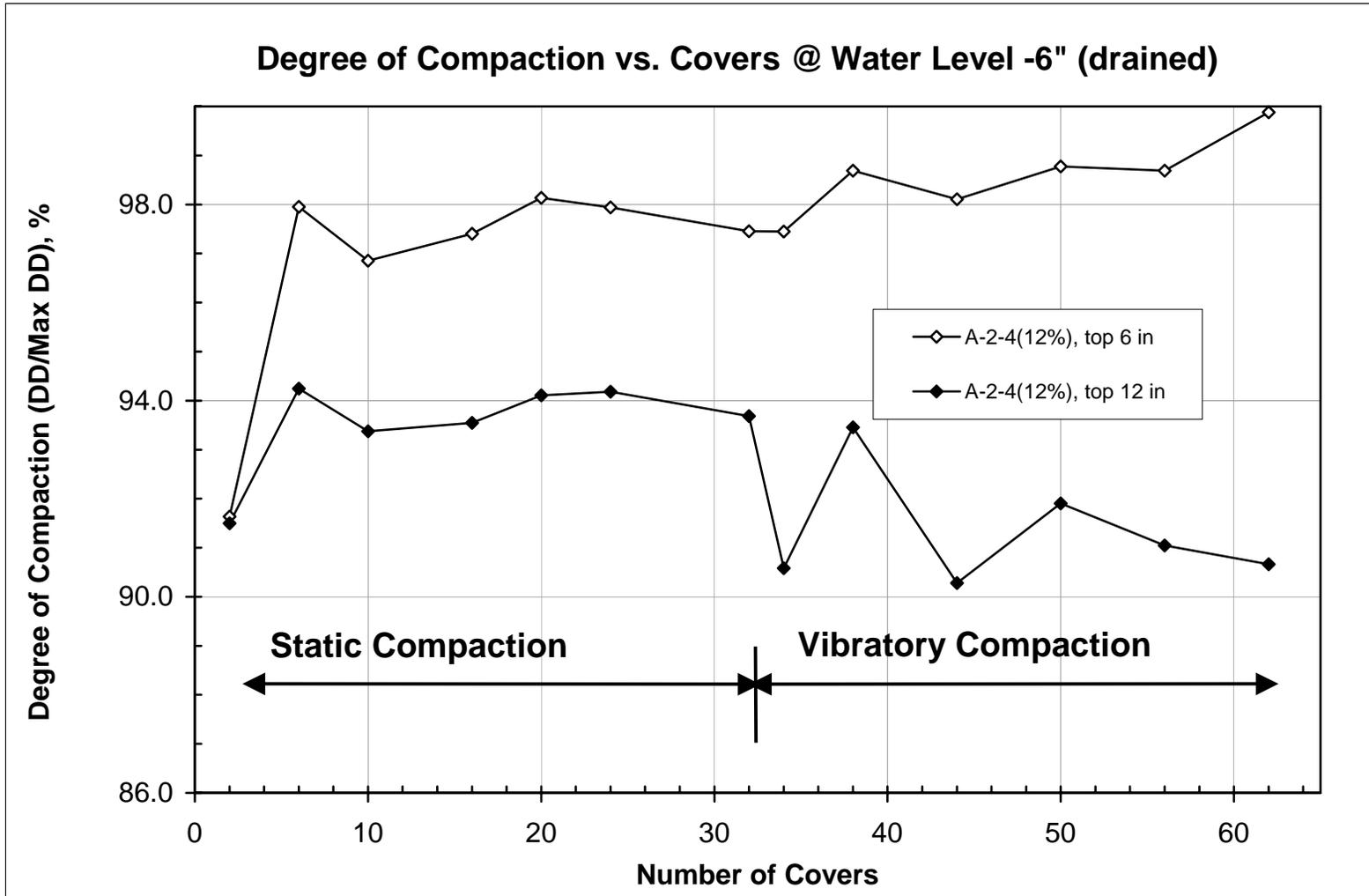


Figure 4.11(a) Comparison of Degree of Compaction for 6 in. and 12 in. Measurements (Condition 4, A-3 (5%) Embankment, A-2-4 (12%) Subgrade)

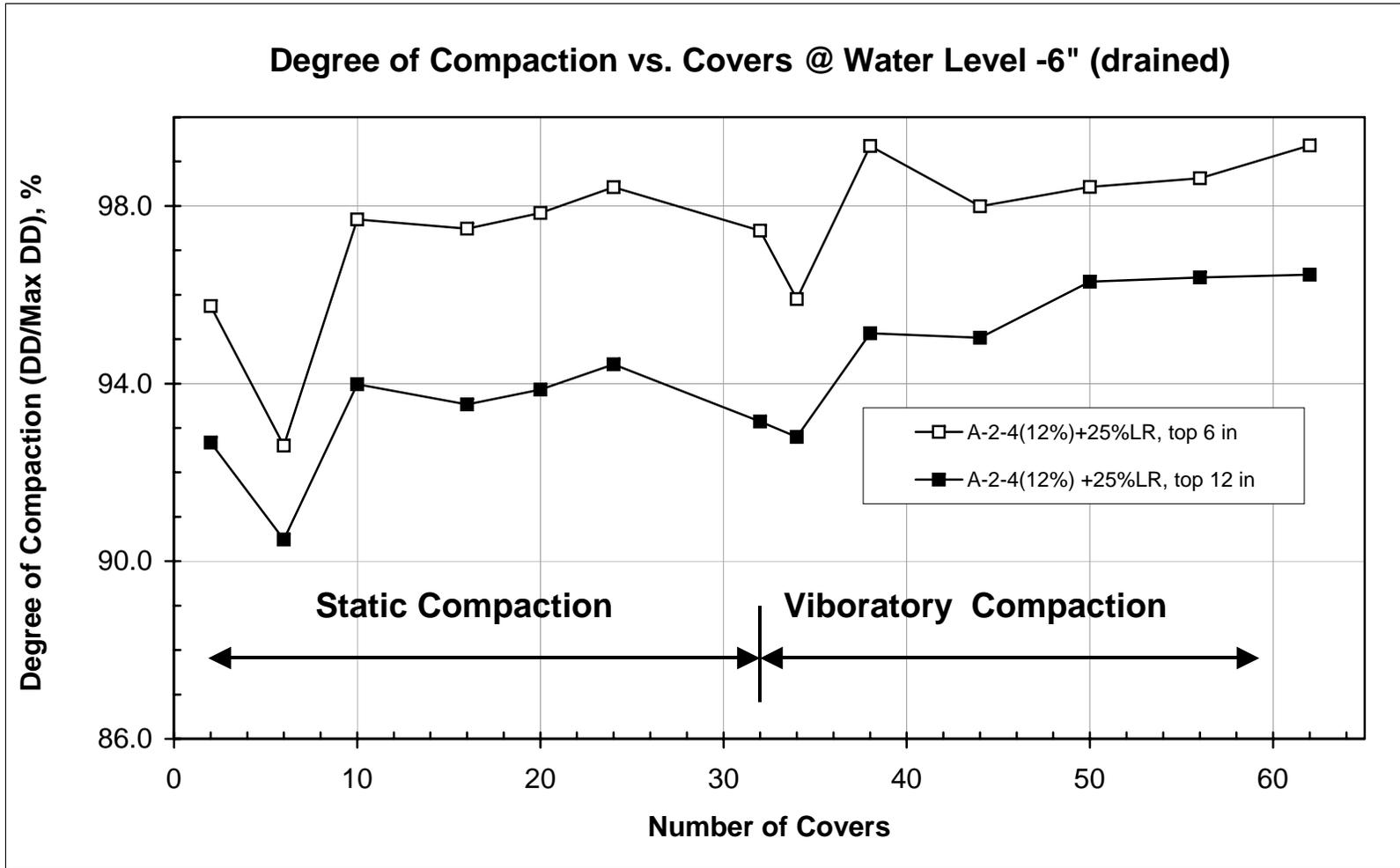


Figure 4.11(b) Comparison of Degree of Compaction for 6 inch and 12 inch Measurements (Condition 4, A-3 (5%) Embankment, A-2-4 (12%) + 25% limerock Subgrade)

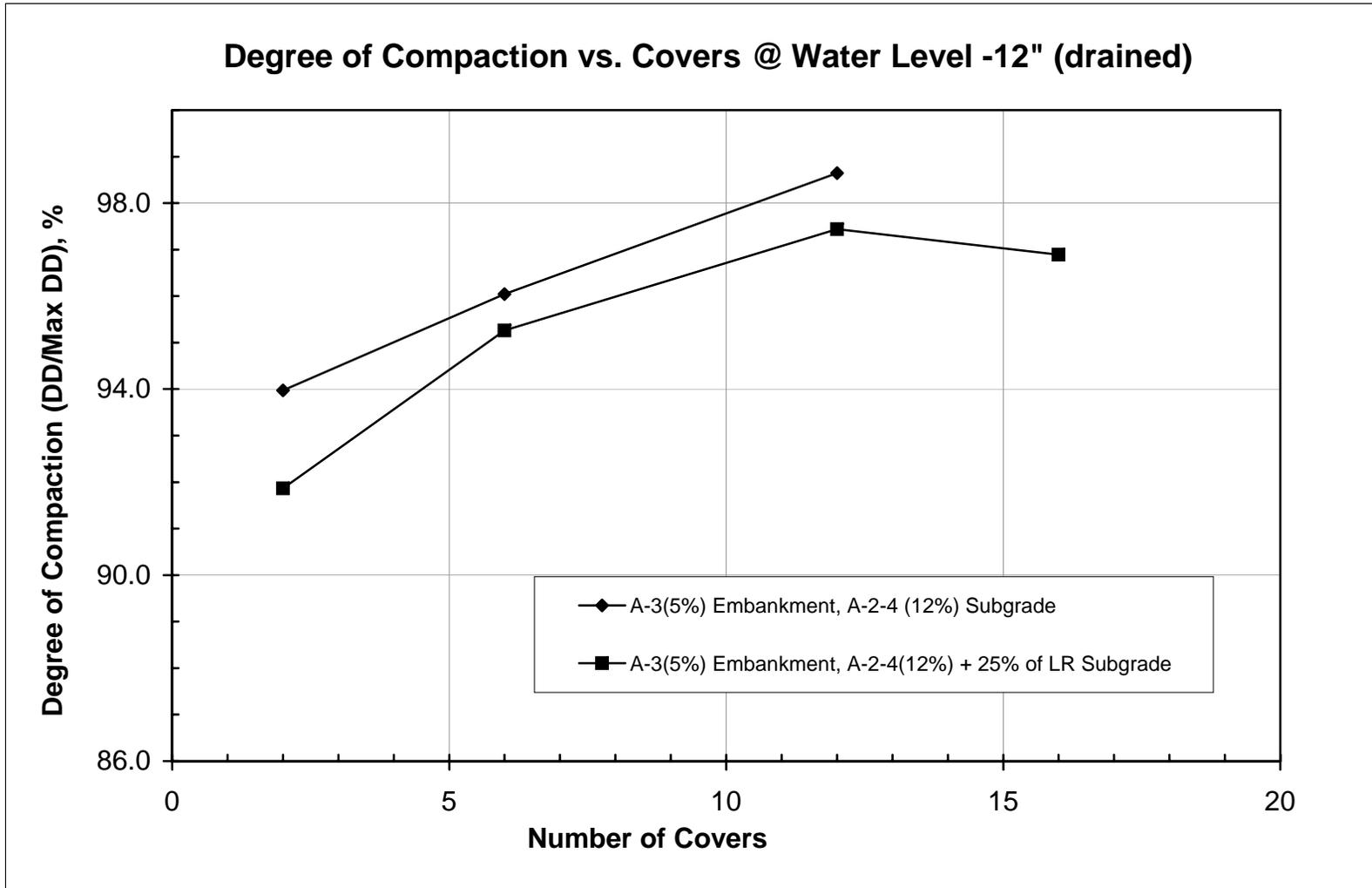


Figure 4.12 Degree of Compaction versus Number of Compaction Covers on Stabilized Subgrade for Water Level at -12 in. (drained) (Condition 5)

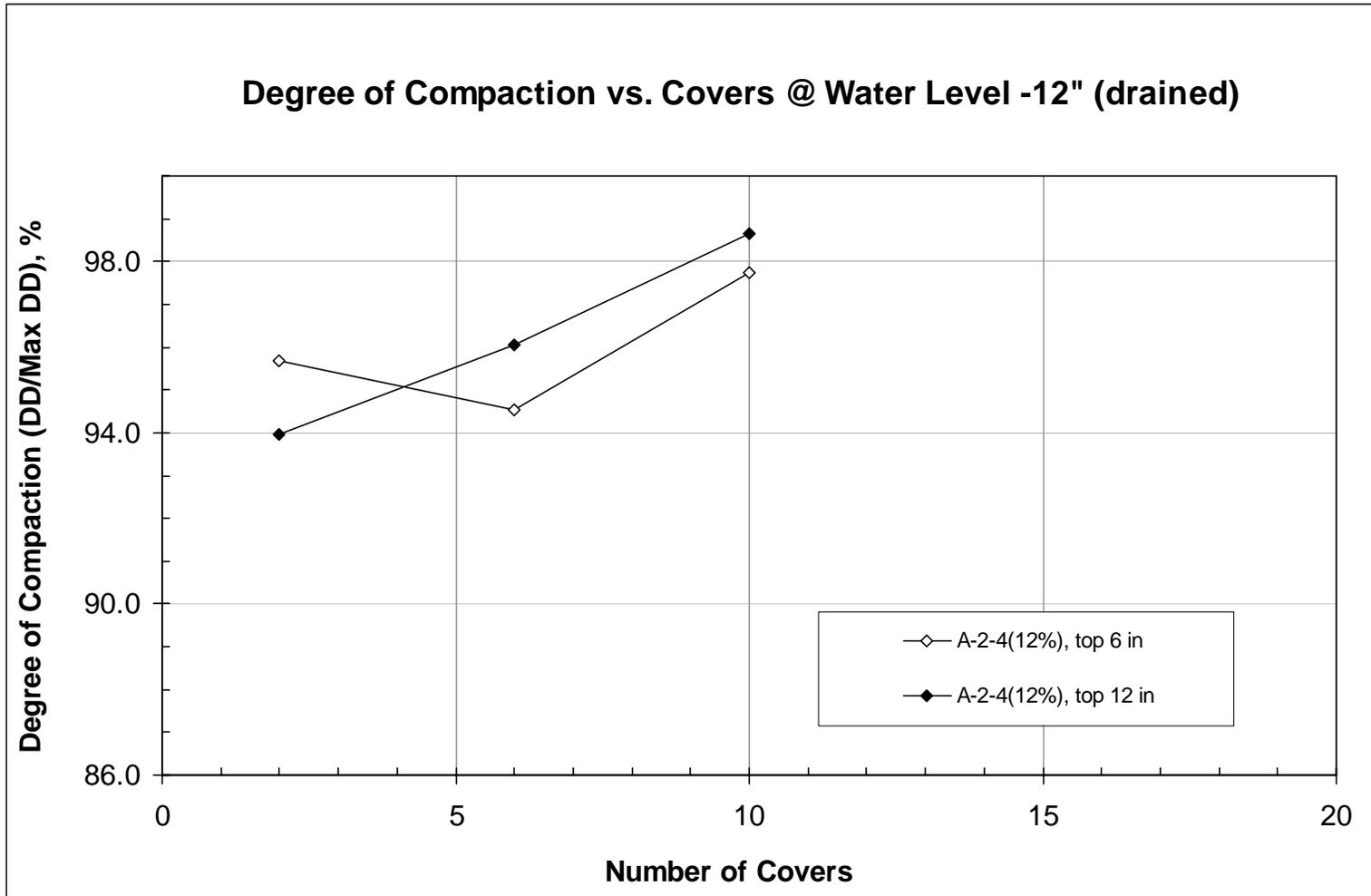


Figure 4.13(a) Comparison of Degree of Compaction for 6 in. and 12 in. Measurements (Condition 5, A-3 (5%) Embankment, A-2-4 (12%) Subgrade)

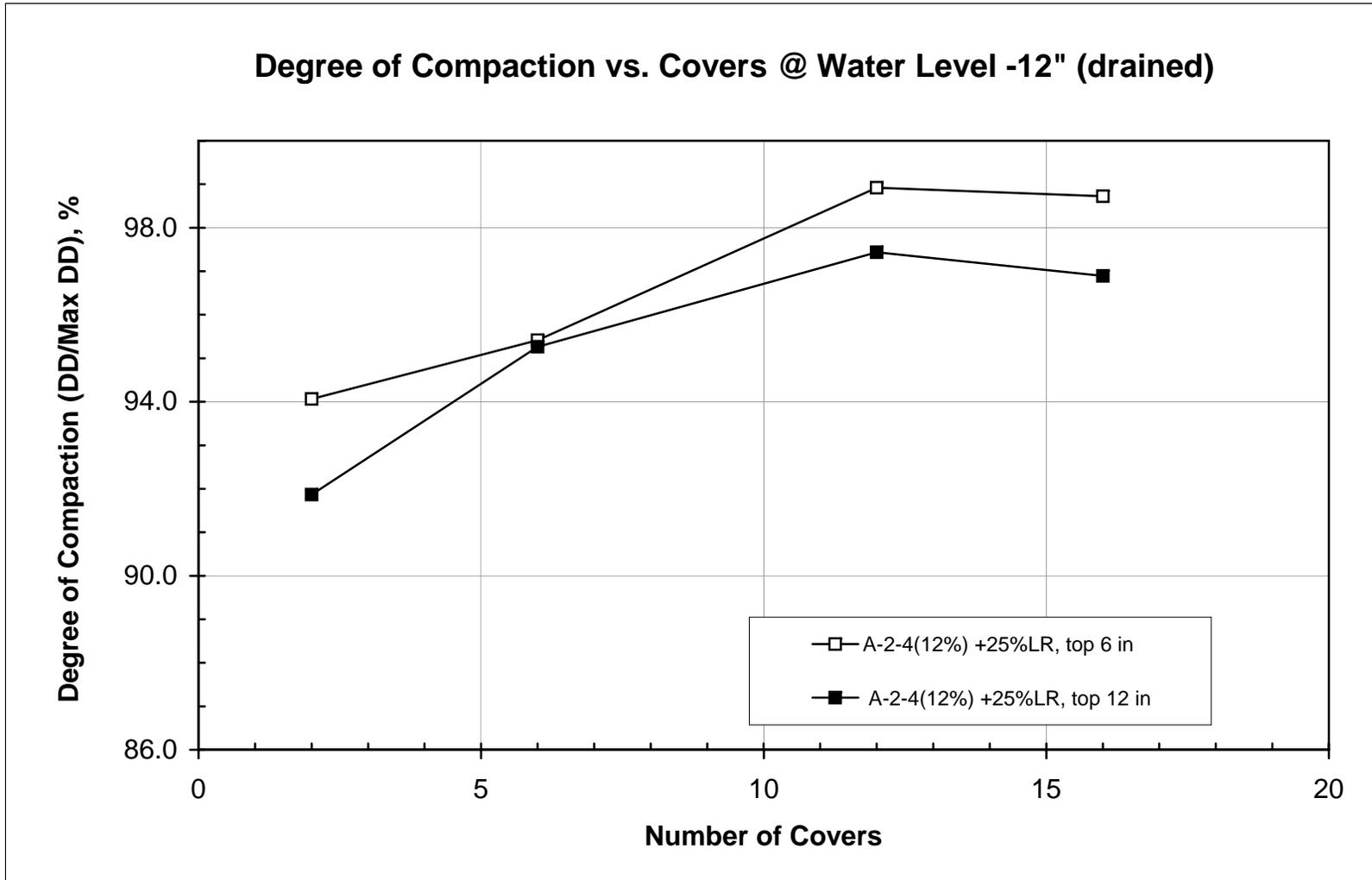


Figure 4.13(b) Comparison of Degree of Compaction for 6 inch and 12 inch Measurements (Condition 5, A-3 (5%) Embankment, A-2-4 (12%) + 25% limerock Subgrade)

CHAPTER 5 FIELD EXPERIMENTAL PROGRAM

5.1 General

Field sites were needed to simulate full size compaction as a result of lower stress levels achieved in the test pits. The primary objective of the field experimental program was to study whether or not the subgrade layer can be constructed under various levels of high groundwater table in field conditions. To achieve the objective, two field sites were selected and tests were carried out to validate and verify the laboratory constructability experimental results under actual field conditions. The selection of the field test sites took into consideration the availability of a high groundwater table, the type of embankment and subgrade materials, and the accessibility of field operations. General site characteristics are summarized in Table 5.1 for the two sites. The field test programs were carried out by a field test team from the geotechnical materials section of the FDOT State Materials Office in conjunction with the research team.

5.2 Lake Worth Test Program

The first field test took place from October 21 to 24, 2002, at the Lake Worth site in West Palm Beach, Florida (Figure 5.1). A test site with a groundwater level at five feet below ground surface was excavated and prepared for the field investigation (Figures 5.2, 5.3, and 5.4). The groundwater level was at -12 inches below excavated surface. The embankment material was an A-3 soil with a wet unit weight of 124.9 pcf and in-situ moisture content 14.5% (based on the speedy moisture) prior to the testing. An A-3 material was also used for the subgrade layer. The basic properties of the A-3 subgrade material are:

Maximum dry unit weight = 117 pcf

(based on the modified Proctor test)

Optimum moisture content = 8.7%

Limerock Bearing Ratio = 53

The field test program was conducted in the following sequence:

- Case A1: groundwater level at -12 inches below the top of the embankment
- Case A2: groundwater level at -18 inches below the top of the embankment

- Case A3: groundwater level at - 6 inches below the top of the embankment
- Case A4: groundwater level at - 12 inches below the top of the embankment
- Case A5: groundwater level at 0 inch below the top of the embankment

A BOMAG BM-213D-3 vibratory compactor was used for the field compaction. The compactor characteristics are summarized in the following:

Basic weight of BOMAG single drum vibratory roller is 26,020 lbs. With ROPS, it has an operating weight of 26,850 lbs. The dimensions of the compactor are 83.0 inches in width and 137.6 inches in track radius. Axle load under the drum is 114,945 lbs and axle load under both wheels is 11,905 lbs. Under the vibratory system, the roller allows a low frequency of 1,800 vpm and high frequency of 2,160 vpm. The amplitude can vary from a high amplitude of 0.071 inches and a low amplitude of 0.036 inches.

A description of the field activities follows.

5.2.1 Case A1: Groundwater Level at -12 inches

Prior to placing the loose subgrade material onto the top of the embankment layer, the groundwater table (GWT) was measured to be at about 12 inches below the embankment (Figure 5.4). The site plan for Case A1 is illustrated in

Figure 5.5. Two earth pressure cells were placed on the test bed at about 15 feet apart for monitoring the compactor stress (Figure 5.6). A front end loader was used for placing the loose A-3 soil from a nearby stockpile to the test bed (Figure 5.7). Approximately 16 inches of loose fill was added on top of the test bed prior to compaction. Survey instruments were used to measure the water level clearance and the height of the fill materials (Figure 5.8). Then two TDR moisture probes were installed near the two sides of the test bed (Figure 5.9). Water was added to the loose fill layer to meet the optimum moisture condition (Figure 5.10). A couple of hours after adding moisture, the compaction began (Figures 5.11, 5.12 and 5.13). The compaction began with two vibratory forward passes and two static backward passes (i.e., two complete forward and backward covers, with one cover being static and another being vibratory). The vibratory frequency was set at 1,800 rpm with the high amplitude of vibration. After two complete covers of compaction, the layer became saturated and the moisture level was observed gradually rising upward to about two inches below the surface (Figure 5.14). The desired 98% degree of compaction was not achieved.

The next morning, the moisture level was drained down, and the moisture and wet density were measured to be 10.6%

(speedy) and 120.7 pcf, respectively. A nuclear density gauge was used for measuring the unit weight (Figure 5.15). Moisture samples were taken for speedy moisture and oven moisture tests (Figure 5.16).

An additional three static covers was applied to compact the layer. The measurements were retaken to measure the moisture and density of the compacted layer. The measured values were: wet density = 124.9 pcf, speedy moisture content = 11.7%.

The compaction test results are summarized in Table 5.2. For Case A1, the compaction test results are also illustrated in Figure 5.17 in terms of degree of compaction versus number of compaction covers on the stabilized subgrade. It appeared that the desired 98% degree of compaction was within reach using the static compaction technique. The differences are not very significant between the 6 inch and 12 inch measurements in terms of the degree of compaction presented in Table 5.2.

5.2.2 Case A2: Groundwater Level at -18 inches

Following the compaction of case A1, the top 6 inches of the stabilized subgrade soil was removed. Additional 16 inches of loose A-3 material was placed on the top of the remaining 6 inch stabilized subgrade which was at a level of 12 inches above the groundwater table (Figure 5.18). The

loose subgrade layer was at 18 inches above the groundwater level prior to compaction.

The compaction began with one dynamic cover (one forward vibratory pass and one backward vibratory pass) and one static cover (one forward static pass and one backward static pass) (Figure 5.19). The desired density was not achieved according to the test results.

Three additional covers of dynamic compaction were applied to make the total compactive effort of four dynamic covers and one static cover. The desired density was increased gradually to close to 98% of the maximum Proctor dry density. Thirteen additional covers of dynamic compaction were again applied to make the total compactive effort of 17 dynamic covers and one static cover. However, despite the additional dynamic compaction, the density decreased.

The compaction test results are summarized in Table 5.3. For this case, the compaction test results are also illustrated in Figure 5.20 in terms of degree of compaction versus number of compaction covers on the stabilized subgrade. As shown in Figure 5.20, the desired 98% degree of compaction was not achieved using the dynamic compaction for the Case A2 (groundwater level at -18 inches). However, the desired density could have been achieved if the static

compaction was used for this case based on the results from Case A1.

5.2.3 Case A3: Groundwater at -6 inches

The compacted layer was excavated and the material was removed to a level at about 6 inches above the groundwater table. Additional 16 inches of loose A-3 soil was placed on top of the embankment layer (Figure 5.21). The compaction was started with three initial covers of static compaction. An additional 10 covers of static compaction was applied to make the total compactive effort of 13 static covers of compaction. The moisture and density values were obtained. The results indicated that the density was gradually increased to a level close to only 96% of the modified Proctor dry density.

Three more dynamic covers were applied in addition to the 13 static covers. However, the layer was losing density due to the additional effort of the three dynamic covers. The moisture content increased due to pumping as a result of the vibratory compaction.

The compaction test results are summarized in Table 5.4. For this case, the compaction test results are also illustrated in Figure 5.22 in terms of degree of compaction versus number of compaction covers on the subgrade. It

appears that the desired density was not achieved using either the static or the dynamic compaction techniques.

5.2.4 Case A4: Groundwater Level at -12 inches

Following the compaction of Case A3, an additional 6 inches of loose material was placed on the top. Five dynamic covers were applied to begin the compaction. The groundwater level was considered at -12 inches for this case (Case A4) since the dynamic compaction could impact a 12 inch layer of material (Figure 5.23). The desired density was not achieved. Five additional dynamic covers were applied to make the total compactive effort of 10 dynamic covers. The desired density was again not reached. Finally, an additional 10 dynamic covers were applied (total of 20 dynamic covers). The desired density was still not obtained.

The compaction test results are summarized in Table 5.2 with the Case A1. The test results are also illustrated in Figure 5.17 together with the Case A1. It appears that the desired 98% degree of compaction could not be achieved using the dynamic compaction for this case.

5.2.5 Case A5: Groundwater Level at 0 inch

The compacted layer was further excavated to the groundwater table level (Figure 5.24). An additional 15 inches of loose A-3 material was placed on top of the test

bed (Figure 5.25). The site plan for Case A5 is illustrated in Figure 5.26.

The compaction was started with five static covers. The desired density was not reached. Ten additional static covers were applied (total of 15 static covers). However, the density was far short of the desired value.

The compaction test results are summarized in Table 5.5. The test results are also illustrated in Figure 5.27 in terms of degree of compaction versus number of compaction covers on the subgrade. As shown in Figure 5.27, the desired 98% degree of compaction was not achieved using the static compaction. For this case, the dynamic compaction was not even tried because of the previously unsuccessful experience.

5.3 UCF Field Test Program

The second field test was conducted from April 7 to April 8, 2003 at the University of Central Florida (UCF) field site shown in Figure 5.28. The field test location was about 50 ft long and 10 ft wide (Figure 5.29). The embankment soil was an A-3 material and the stabilized subgrade soil was an A-2-4 soil with 12% fines passing No. 200 sieve (Figure 5.30). The basic properties of the tested stabilized subgrade materials are summarized in Table 5.6.

The groundwater table was lowered by dewatering equipment to a level at 30 inches below the ground level (Figure 5.31). As illustrated in Figure 5.30, the dewatering pipe was 47 inches deep and exposed at 17 inches above the ground level. At the initial condition, the surface of the subgrade soil was 6 inches under the ground level, and so the initial groundwater level was 12 inches under the bottom of the subgrade soil (Figure 5.30).

Compaction of the stabilized subgrade layers was conducted at the following sequence:

- Case B1: Groundwater Level at -12 inches below
- Case B2: Groundwater Level at -18 inches below
- Case B3: Groundwater Level at -6 inches below

A BOMAG BM-213D-3 vibratory compactor was used for the field compaction. The compactor was the same model as used for the Lake Worth field test.

A description of the field activities follows.

5.3.1 Case B1: Groundwater Level at -12 inches

Under the dynamic conditions, the compactor was set to use a level of high amplitude and low frequency in order to achieve higher compactive effort. After initial two dynamic compaction covers, a nuclear density meter was deployed to measure the soil wet density (Figure 5.33). In addition, soil samples were taken from the same spot where the

nuclear density was measured and speedy moisture was obtained (Figure 5.34). More accurate oven moisture was measured from the soil samples in the laboratory. The field test results showed that the desired 98% of the maximum dry density by the modified Proctor method was not achieved. An additional five covers and 10 covers (total of 17 covers) were applied to the subgrade layer. The same measurements showed that after an additional 15 covers of dynamic compaction, the desired density was still not achieved. The compaction test results are summarized in Table 5.7 and illustrated in Figure 5.35.

After 10 and 20 covers of static compaction, the moisture and density measurements were taken again. The dry density calculated based on the speedy moisture showed that the desired density was achieved, and the test was stopped then. Although, based on the more accurate oven moisture performed at a later date, the field dry density was slightly lower than the desired dry density. However, the desired dry density could be achieved according to the trend of increase over the static compaction covers as shown in Figure 3.35. The compaction test results are summarized in Table 5.7 and illustrated in Figure 5.35. The field moisture condition (~15%) was much higher than the optimum moisture content (9.4%). This type of A-2-4 soil

was very difficult to dry out in the field. Although the attempt was made to dry the soil during the field test, the effort proved to be unsuccessful.

Based on the data shown in Figure 5.35, it seems that the desired density of 98% degree of compaction could be obtained by static compaction when the groundwater table was 12 inches below the bottom of the stabilized subgrade layer. Further tests were taken to evaluate the effect of dynamic compaction under shallower groundwater levels.

5.3.2 Case B2: Groundwater Level at -18 in.

Following the compaction of Case B1, the top 6 inches of the stabilized subgrade soil was removed, and an additional 12 inches of loose A-2-4 material was placed on the top of the remaining 6 inches of stabilized subgrade which was at a level of 12 inches above the groundwater level. The operation was done with a Gradall excavator (Figure 5.36) and controlled by the theodolite equipment (Figure 5.37). In this case, the loose A-2-4 subgrade layer was at 18 inches above the desired 98% degree of compaction.

Prior to the dynamic compaction, the speedy moisture content of the A-2-4 material was measured to be 15.6%,

which was higher than the optimum moisture content. The initial 10 covers of dynamic compaction were applied to the loose subgrade layer. Subsequently, the moisture and density were measured to indicate that the desired density was not achieved and the moisture condition was much higher than the optimum moisture content (9.4%).

The semi-compacted A-2-4 material was partially removed to the side and replaced by some subgrade soil with a drier condition. The speedy moisture content was again measured and it turned out to be 12.2% which was slightly lower than the initial field moisture but still higher than the optimum content (9.4%). An additional five covers were applied (total of 15 covers) and the desired density was measured to be at about 93.7% degree of compaction. The dynamic compaction was continued and density measurements were taken after 37, 42, and 50 total covers. The results indicated an increasing trend of the degree of compaction. The compaction test results are summarized in Table 5.8. The test results are also illustrated in Figure 5.38 in terms of degree of compaction versus number of dynamic compaction covers on the stabilized (A-2-4) subgrade. As shown in Figure 5.38, it appears that the desired 98% degree of compaction was within reach using dynamic compaction. However, the field moisture content (14%) was

still higher than the optimum moisture content (9.4%) at the end of the dynamic compaction.

5.3.3 Case B3: Groundwater Level at -6 inches

The compacted layer was excavated and the material was removed to a level at about 6 inches above the groundwater table. An additional 12 inches of loose A-2-4 was placed on top of the A-3 embankment layer. The compaction was started with five, 10, and 15 total static covers.

After the initial five static covers, the speedy moisture was measured to be (15.2%) much higher than the optimum moisture content. The nuclear density was not measured due to the higher field moisture condition. After a total of 15 static covers, the nuclear density and speedy moisture were measured and the results showed that the dry density was much lower than the desired 98% degree of compaction (only achieving 93.6%). The desired density was not achieved by the static compaction for the Case B3 at groundwater level -6 inches below the top of the A-3 embankment layer. The compaction test results are summarized in Table 5.9.

Table 5.1 General Characteristics of Field Test Sites

| Site No. | Location | Test Date | Embankment Soil | Subgrade Soil | Groundwater Table (below surface) |
|----------|---|---------------------------|------------------|---------------------|-----------------------------------|
| A | Lake Worth Site, West Palm Beach, Florida | October 21-24, 2002 | A-3 Fine Sand | A-3 Fine Sand | -60 in |
| B | UCF Site, Orlando, Florida | April 7-8, 2003 | A-3 Fine Sand | A-2-4 Silty Sand | -30 in |

Table 5.2 Summary of Compaction Test Results for Water Level at -12 inches (Lake Worth Field Test)

Embankment Soil: A-3

Stabilized Subgrade Soil: A-3

Modified Proctor Max DD (pcf): 117 OMC: 8.70%

| Test Date | Total Covers | Location | 0-6" Gauge Measurement | | | | | | 0-12" Gauge Measurement | | | | | |
|-----------------------|-------------------------|----------|------------------------|---------------------|-------------------|--------------------|---------------|-----------------------|-------------------------|---------------------|-------------------|--------------------|---------------|-----------------------|
| | | | Wet Density (pcf) | Speedy Moisture (%) | Oven Moisture (%) | Dry Density (pcf)* | DD/Max DD (%) | Average DD/Max DD (%) | Wet Density (pcf) | Speedy Moisture (%) | Oven Moisture (%) | Dry Density (pcf)* | DD/Max DD (%) | Average DD/Max DD (%) |
| 10/22/2002 | 2(1 static + 1 dynamic) | 1 | 118.9 | 13.1 | 11.6 | 106.5 | 91.1 | 91.1 | 120.3 | 107.1 | 11.6 | 107.8 | 92.1 | 92.3 |
| | | 2 | 118.9 | 13.1 | 11.6 | 106.5 | 91.1 | | 120.7 | 13.1 | 11.6 | 108.2 | 92.4 | |
| Case A1 10/23/2002 | 5(3 Static) | 1 | 120.9 | 11.7 | 10.1 | 109.8 | 93.9 | 95.8 | 124.9 | 11.7 | 10.1 | 113.4 | 97.0 | 97.0 |
| | | 2 | 125.5 | 11.7 | 10.1 | 114.0 | 97.4 | | 126.8 | 11.7 | 10.1 | 115.2 | 98.4 | |
| | | 3 | 123.7 | 11.7 | 10.1 | 112.4 | 96.0 | | 123.3 | 11.7 | 10.1 | 112.0 | 95.7 | |
| Dynamic | | | | | | | | | | | | | | |
| Case A4 10/24/2002 | 5 | middle | 110.8 | 6.4 | 6 | 104.5 | 89.3 | 89.3 | 114.2 | 6.9 | 6.8 | 106.9 | 91.4 | 91.4 |
| | 10 | middle | 112.2 | 6.7 | 5.9 | 105.9 | 90.6 | 90.6 | 115.2 | 7.7 | 6.9 | 107.8 | 92.1 | 92.1 |
| | 20 | middle | 118.3 | 8.8 | 6.9 | 110.7 | 94.6 | 94.6 | 120.4 | 11 | 8.5 | 111.0 | 94.8 | 94.8 |

*Dry density was obtained by using oven moisture.

Table 5.3 Summary of Compaction Test Results for Water Level at -18 inches (Lake Worth Field Test)

Embankment Soil: A-3
 Stabilized Subgrade Soil: A-3 Modified Proctor Max DD (pcf): 117 OMC: 8.70%

| Test Date | Total Covers | Location | 0-6" Gauge Measurement | | | | | | 0-12" Gauge Measurement | | | | | |
|----------------|-------------------------|----------|------------------------|---------------------|-------------------|--------------------|---------------|-----------------------|-------------------------|---------------------|-------------------|--------------------|---------------|-----------------------|
| | | | Wet Density (pcf) | Speedy Moisture (%) | Oven Moisture (%) | Dry Density (pcf)* | DD/Max DD (%) | Average DD/Max DD (%) | Wet Density (pcf) | Speedy Moisture (%) | Oven Moisture (%) | Dry Density (pcf)* | DD/Max DD (%) | Average DD/Max DD (%) |
| 10/23/2002 | 2(1 static + 1 dynamic) | middle | 115.1 | 6.4 | 5.8 | 108.8 | 93.0 | 93.0 | 115.9 | 6.4 | 5.8 | 109.5 | 93.6 | 93.6 |
| | 5(3 Dynamic) | 1 | 119.8 | 7.3 | 5.7 | 113.3 | 96.9 | 97.3 | 118.6 | 7.3 | 5.7 | 112.2 | 95.9 | 96.3 |
| | | 2 | 123.2 | 7.3 | 5.7 | 116.6 | 99.6 | | 121.2 | 7.3 | 5.7 | 114.7 | 98.0 | |
| | | 3 | 117.9 | 7.3 | 5.7 | 111.5 | 95.3 | | 117.3 | 7.3 | 5.7 | 111.0 | 94.8 | |
| 18(13 Dynamic) | middle | 111.4 | 7.3 | 5.7 | 105.4 | 90.1 | 90.1 | 116 | 7.3 | 5.7 | 109.7 | 93.8 | 93.8 | |

*Dry density was obtained by using oven moisture.

Table 5.4 Summary of Compaction Test Results for Water Level at -6 inches (Lake Worth Field Test)

Embankment Soil: A-3
 Stabilized Subgrade Soil: A-3 Modified Proctor Max DD (pcf): 117 OMC: 8.70%

| Test Date | Total Covers | Location | 0-6" Gauge Measurement | | | | | | 0-12" Gauge Measurement | | | | | |
|---------------|---------------|----------|------------------------|---------------------|-------------------|--------------------|---------------|-----------------------|-------------------------|---------------------|-------------------|--------------------|---------------|-----------------------|
| | | | Wet Density (pcf) | Speedy Moisture (%) | Oven Moisture (%) | Dry Density (pcf)* | DD/Max DD (%) | Average DD/Max DD (%) | Wet Density (pcf) | Speedy Moisture (%) | Oven Moisture (%) | Dry Density (pcf)* | DD/Max DD (%) | Average DD/Max DD (%) |
| 10/24/2002 | 3(Static) | middle | 119.8 | 9 | 9.6 | 109.3 | 93.4 | 93.4 | 116.4 | 9 | 9.6 | 106.2 | 90.8 | 90.8 |
| | 13(10 Static) | 1 | 123.7 | 9.4 | 7.8 | 114.7 | 98.1 | 96.8 | 120.9 | 9.4 | 7.8 | 112.2 | 95.9 | 96.2 |
| | | 2 | 118.3 | 9.4 | 7.8 | 109.7 | 93.8 | | 119.6 | 9.4 | 7.8 | 110.9 | 94.8 | |
| | | 3 | 124.4 | 9.4 | 7.8 | 115.4 | 98.6 | | 123.5 | 9.4 | 7.8 | 114.6 | 97.9 | |
| 16(3 Dynamic) | middle | 111.8 | | 7.8 | 103.7 | 88.6 | 88.6 | 113.2 | | 9.4 | 103.5 | 88.4 | 88.4 | |

*Dry density was obtained by using oven moisture.

Table 5.5 Summary of Compaction Test Results for Water Level at inch (Lake Worth Field Test)

Embankment Soil: A-3
 Stabilized Subgrade Soil: A-3 Modified Proctor Max DD (pcf): 117 OMC: 8.70%

| Test Date | Total Covers | Location | 0-6" Gauge Measurement | | | | | | 0-12" Gauge Measurement | | | | | |
|------------|--------------|----------|------------------------|---------------------|-------------------|--------------------|---------------|-----------------------|-------------------------|---------------------|-------------------|--------------------|---------------|-----------------------|
| | | | Wet Density (pcf) | Speedy Moisture (%) | Oven Moisture (%) | Dry Density (pcf)* | DD/Max DD (%) | Average DD/Max DD (%) | Wet Density (pcf) | Speedy Moisture (%) | Oven Moisture (%) | Dry Density (pcf)* | DD/Max DD (%) | Average DD/Max DD (%) |
| Static | | | | | | | | | | | | | | |
| 10/24/2002 | 5 | middle | 119.7 | 11.4 | 10.4 | 108.4 | 92.7 | 92.7 | 118.7 | 10.9 | 8.6 | 109.3 | 93.4 | 93.4 |
| | 15 | middle | 117.5 | 8.3 | 7.6 | 109.2 | 93.3 | 93.3 | 118.2 | 10.5 | 9.2 | 108.2 | 92.5 | 92.5 |

*Dry density was obtained by using oven moisture.

Table 5.6 Basic Properties of Tested Subgrade Materials
(UCF Site)

| Material | Sample No. | Modified Proctor Optimum Moisture Content (%) | Modified Proctor Maximum Dry Density (lb/ft ³) | LBR |
|-------------|------------|---|--|-----|
| A-2-4 (12%) | 1 | 8.8 | 109 | 72 |
| | 2 | 11.2 | 109 | 75 |
| | 3 | 8.8 | 110 | 65 |
| | 4 | 8.9 | 109 | 75 |
| | 5 | 9.1 | 110 | 74 |
| | Average | 9.4 | 109 | 72 |

Table 5.7 Summary of Compaction Test Results for Water Level at -12 inches (UCF Field Test)

Embankment Soil: A-3

Stabilized Subgrade Soil: A-2-4

Modified Proctor Max DD (pcf): 109

OMC: 9.40%

| Test Date | Total Covers | Location | 0-6" Gauge Measurement | | | | | | 0-12" Gauge Measurement | | | | | |
|-----------|--------------|----------|------------------------|---------------------|-------------------|--------------------|---------------|-----------------------|-------------------------|---------------------|-------------------|--------------------|---------------|-----------------------|
| | | | Wet Density (pcf) | Speedy Moisture (%) | Oven Moisture (%) | Dry Density (pcf)* | DD/Max DD (%) | Average DD/Max DD (%) | Wet Density (pcf) | Speedy Moisture (%) | Oven Moisture (%) | Dry Density (pcf)* | DD/Max DD (%) | Average DD/Max DD (%) |
| Dynamic | | | | | | | | | | | | | | |
| 4/7/2003 | 2 | 1 | 113.5 | 14.7 | 13.6 | 99.9 | 91.7 | 91.6 | 114.6 | 14.1 | 15.5 | 99.2 | 91.0 | 91.1 |
| | | 2 | 114.1 | | 14.4 | 99.7 | 91.5 | | 114.4 | | 15.1 | 99.4 | 91.2 | |
| | 7 | 1 | 115.5 | | 14.3 | 101.0 | 92.7 | 94.2 | 117.2 | | 14.3 | 102.5 | 94.1 | 94.1 |
| | | 2 | 119.2 | | 14.3 | 104.3 | 95.7 | | 119 | | 15.9 | 102.7 | 94.2 | |
| | 17 | 1 | 116.6 | 13.9 | 13.6 | 102.6 | 94.2 | 94.4 | 117.8 | 16 | 15 | 102.4 | 94.0 | 94.4 |
| | | 2 | 118.1 | | 14.5 | 103.1 | 94.6 | | 119.1 | | 15.2 | 103.4 | 94.8 | |
| Static | | | | | | | | | | | | | | |
| 4/8/2003 | 10 | middle | 115.3 | | | | | | 118 | 15.3 | 15 | 102.6 | 94.1 | 94.1 |
| | 20 | 1 | 119.1 | | | 119.1 | 109.3 | 109.4 | 121.1 | 13.9 | 14.9 | 105.4 | 96.7 | 96.0 |
| | | 2 | 119.4 | | | 119.4 | 109.5 | | 119.4 | 14.5 | 15 | 103.8 | 95.3 | |

*Dry density was obtained by using oven moisture.

Table 5.8 Summary of Compaction Test Results for Water Level at -18 inches (UCF Field Test)

Embankment Soil: A-3

Stabilized Subgrade Soil: A-2-4

Modified Proctor Max DD (pcf): 109

OMC: 9.40%

| Test Date | Total Covers | Location | 0-6" Gauge Measurement | | | | | | 0-12" Gauge Measurement | | | | | |
|-----------|--------------|----------|------------------------|---------------------|-------------------|--------------------|---------------|-----------------------|-------------------------|---------------------|-------------------|--------------------|---------------|-----------------------|
| | | | Wet Density (pcf) | Speedy Moisture (%) | Oven Moisture (%) | Dry Density (pcf)* | DD/Max DD (%) | Average DD/Max DD (%) | Wet Density (pcf) | Speedy Moisture (%) | Oven Moisture (%) | Dry Density (pcf)* | DD/Max DD (%) | Average DD/Max DD (%) |
| Dynamic | | | | | | | | | | | | | | |
| 4/8/2003 | 10 | 1 | 114 | 15.2 | 14.5 | 99.6 | 91.3 | 91.7 | 113.2 | 16 | 14.9 | 98.5 | 90.4 | 91.3 |
| | | 2 | 116.6 | 14.9 | 16.1 | 100.4 | 92.1 | | 115.9 | 15.3 | 15.4 | 100.4 | 92.1 | |
| | 15 | 1 | 115.6 | 14.9 | 14.6 | 100.9 | 92.5 | 92.9 | 116.7 | 14 | 14.3 | 102.1 | 93.7 | 93.7 |
| | | 2 | 117 | 14.9 | 15.2 | 101.6 | 93.2 | | 117.6 | 14.8 | 15 | 102.3 | 93.8 | |
| | 25 | middle | 114.2 | | | | | | 116.5 | | | | | |
| | 30 | middle | | | | | | | 115.2 | | | | | |
| | 37 | middle | 116.3 | 13.9 | 13.8 | 102.2 | 93.8 | 93.8 | 116.7 | 14 | 14.3 | 102.1 | 93.7 | 93.7 |
| | 42 | middle | 117.7 | 14 | 14.2 | 103.1 | 94.6 | 94.6 | 118.7 | 14.3 | 13.9 | 104.2 | 95.6 | 95.6 |
| | 50 | middle | 120.3 | 14.9 | 14.9 | 104.7 | 96.1 | 96.1 | 120.5 | 14.1 | 14 | 105.7 | 97.0 | 97.0 |

*Dry density was obtained by using oven moisture.

Table 5.9 Summary of Compaction Test Results for Water Level at -6 inches (UCF Field Test)

Embankment Soil: A-3

Stabilized Subgrade Soil: A-2-4

Modified Proctor Max DD (pcf): 109

OMC: 9.40%

| Test Date | Total Covers | Location | 0-6" Gauge Measurement | | | | | | 0-12" Gauge Measurement | | | | | |
|-----------|--------------|----------|------------------------|---------------------|-------------------|-------------------|---------------|-----------------------|-------------------------|---------------------|-------------------|--------------------|---------------|-----------------------|
| | | | Wet Density (pcf) | Speedy Moisture (%) | Oven Moisture (%) | Dry Density (pcf) | DD/Max DD (%) | Average DD/Max DD (%) | Wet Density (pcf) | Speedy Moisture (%) | Oven Moisture (%) | Dry Density (pcf)* | DD/Max DD (%) | Average DD/Max DD (%) |
| Static | | | | | | | | | | | | | | |
| 4/8/2003 | 5 | middle | | | | | | | | | | | | |
| | 10 | middle | | | | | | | 116.7 | 15.2 | | | | |
| | 15 | middle | 119.3 | | | | | | 118.4 | 16.1 | | 102.0 | 93.6 | 93.6 |

*Oven moisture was not available, dry density was obtained by using speedy moisture.

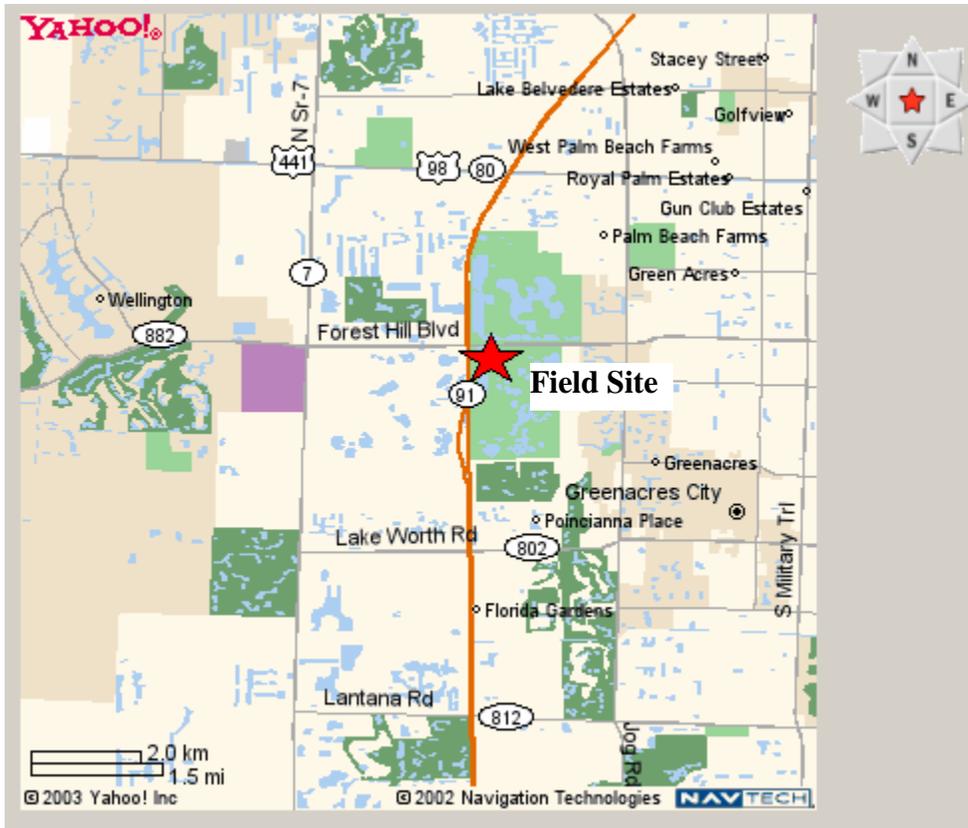


Figure 5.1 Lake Worth Field Test Site Location (Site A) in West Palm Beach, Florida



Figure 5.2 Test Site with One-Foot Water Clearance before Placing the Testing Subgrade Material (Lake Worth Site)

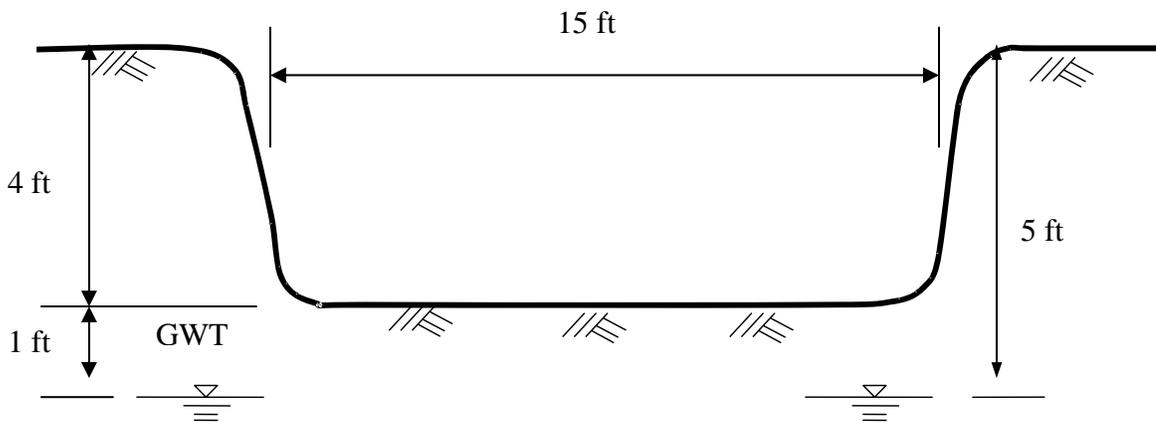
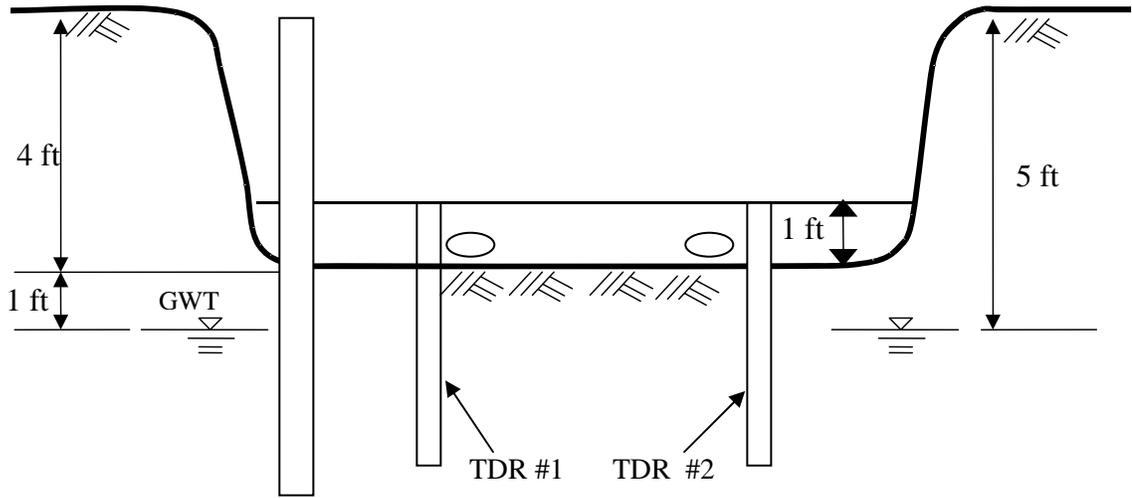


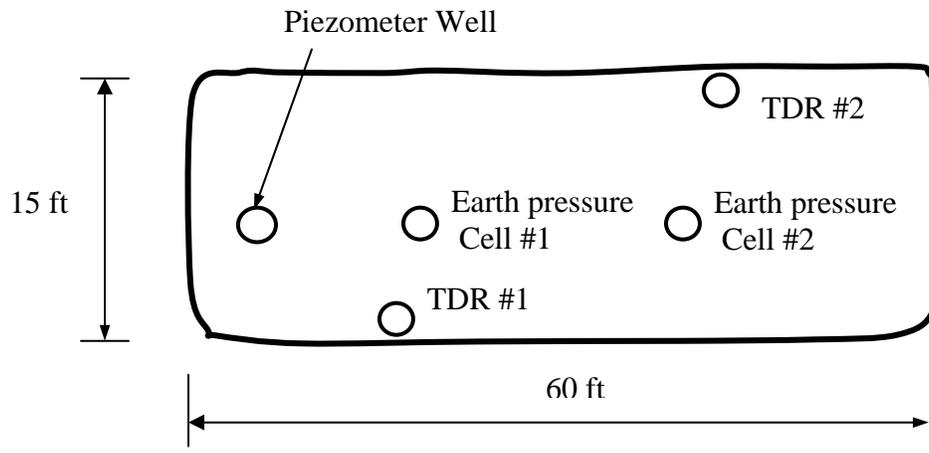
Figure 5.3 Schematic Sketch of Field Test Site Profile, Lake Worth Site



Figure 5.4 Measuring Ground Water Level at -12 in. below surface (Lake Worth Site)



Cross-sectional View



Plan View

Figure 5.5 Site Plan for Case A1 (Lake Worth Site)



Figure 5.6 Earth Pressure Load Cell (Lake Worth Site)



Figure 5.7 Placing the Testing Subgrade Material to the Test Site (-12" Ground Water Level) (Lake Worth Site)



Figure 5.8 Survey Instrument Used to Measure the Water Clearance and Testing Material Thickness (Lake Worth Site)



Figure 5.9(a) Installing the TDR Moisture Sensor (Lake Worth Site)



Figure 5.9 (b) TDR Moisture Measurement (Lake Worth Site)



Figure 5.10 Adding Water to the Testing Soil Layer to Meet the Optimum Moisture Content (Lake Worth Site)



Figure 5.11 Starting Compaction with BOMAG Compactor (Lake Worth Site)



Figure 5.12 Recording the Compaction Energy through Earth Pressure Cell (Lake Worth Site)



Figure 5.13 Vibration Frequency Recording (Lake Worth Site)



Figure 5.14 Water in the Soil after Vibratory Compaction (Lake Worth Site)



Figure 5.15 Nuclear Density Meter to Measure the Soil Density (Lake Worth Site)



Figure 5.16 Sampling the Soil Moisture Content (Lake Worth Site)

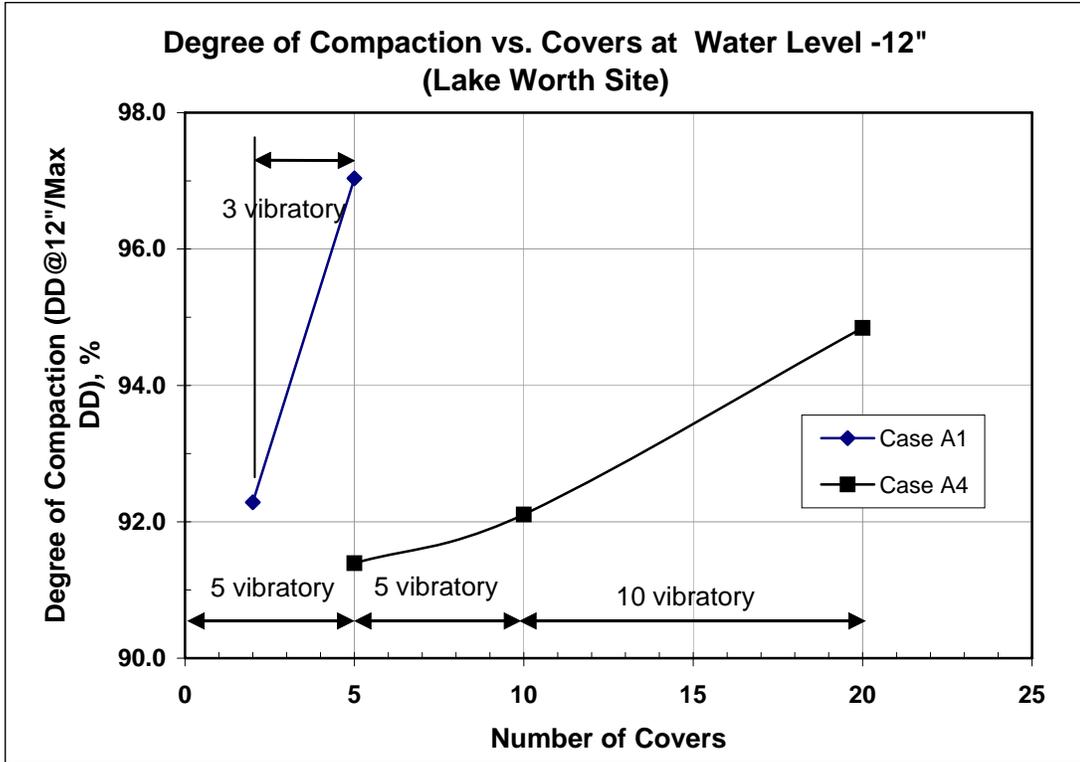


Figure 5.17 Degree of Compaction versus Number of Covers on Stabilized Subgrade for Water Level at -12 inches (Lake Worth Site)

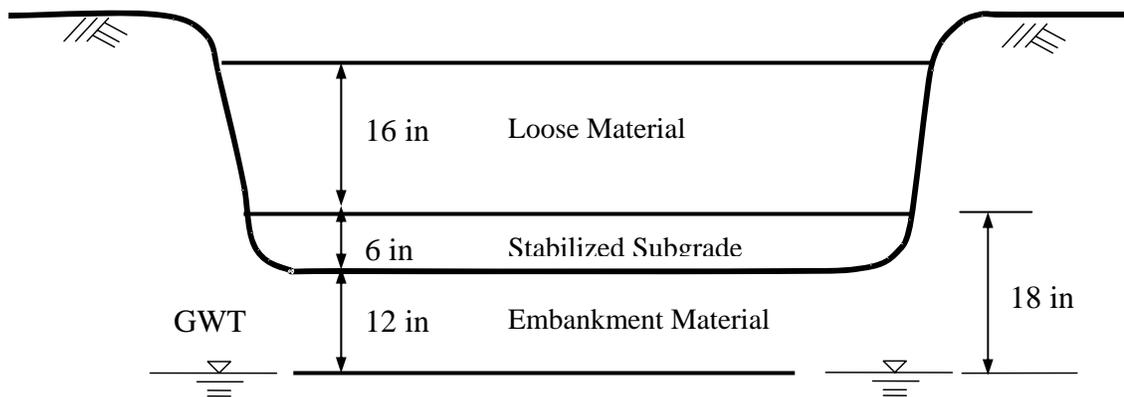


Figure 5.18 Schematic Site Plan for Compaction of Case A2 (Lake Worth Site)



Figure 5.19 Compaction in Static Mode for Case A2 (Lake Worth Site)

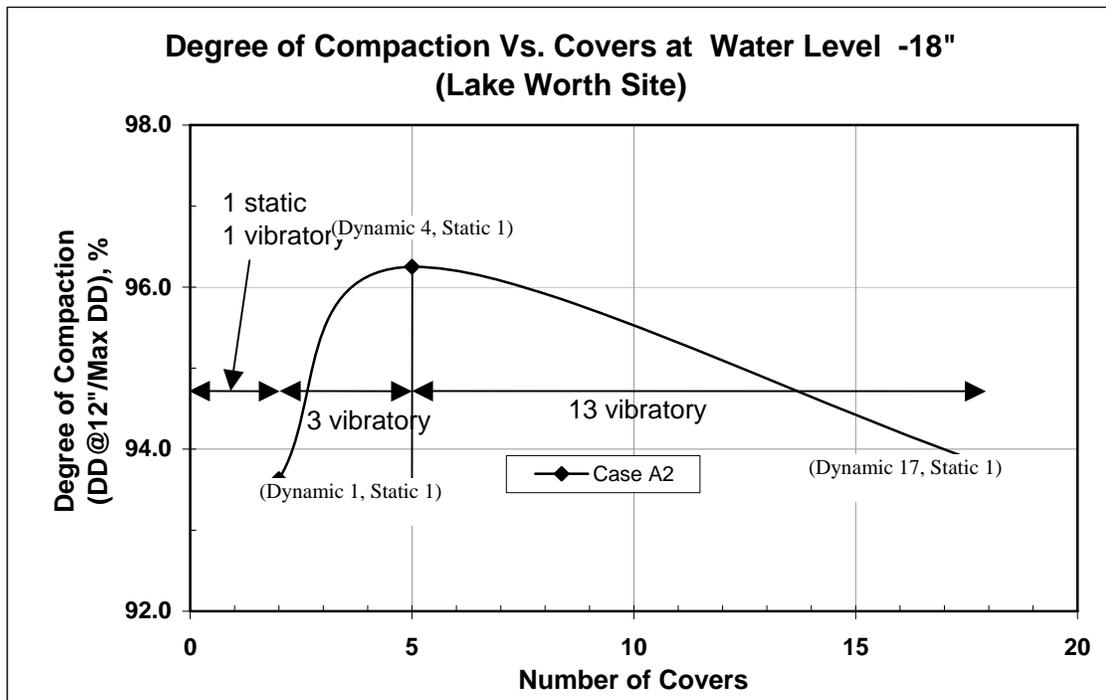


Figure 5.20 Degree of Compaction versus Number of Covers on Stabilized Subgrade for Water Level at -18 inches (Lake Worth Site)

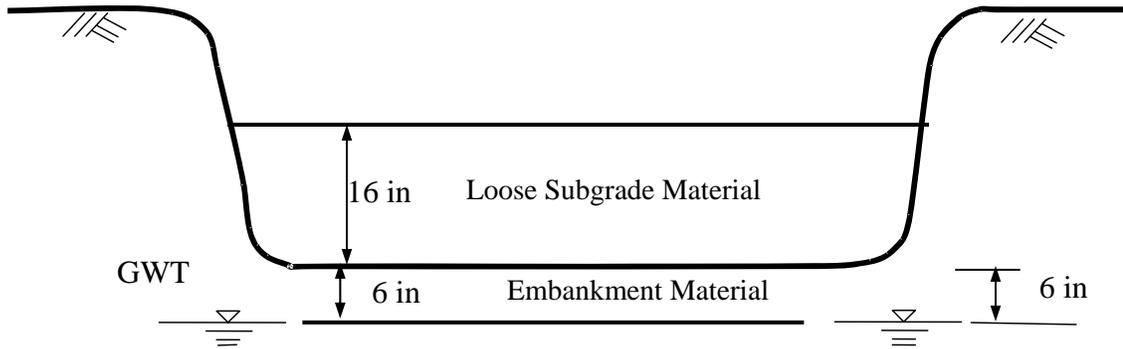


Figure 5.21 Schematic Site Plan for Compaction of Case A3 (Lake Worth Site)

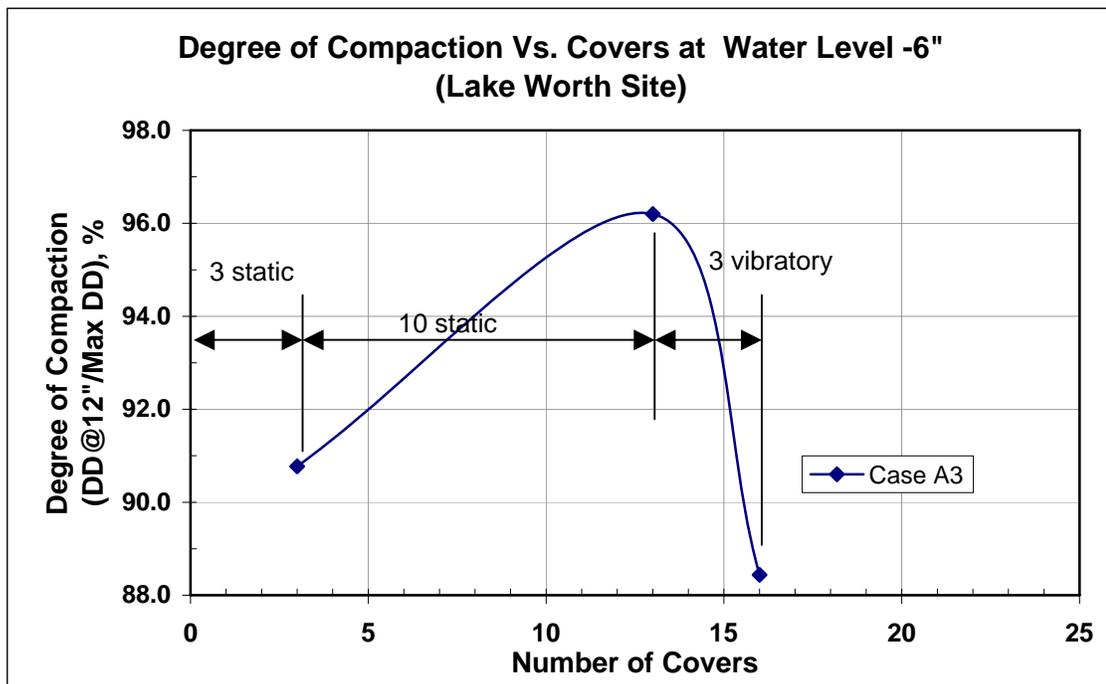


Figure 5.22 Degree of Compaction versus Number of Covers on Stabilized Subgrade for Water Level at -6 inches (Lake Worth Site)

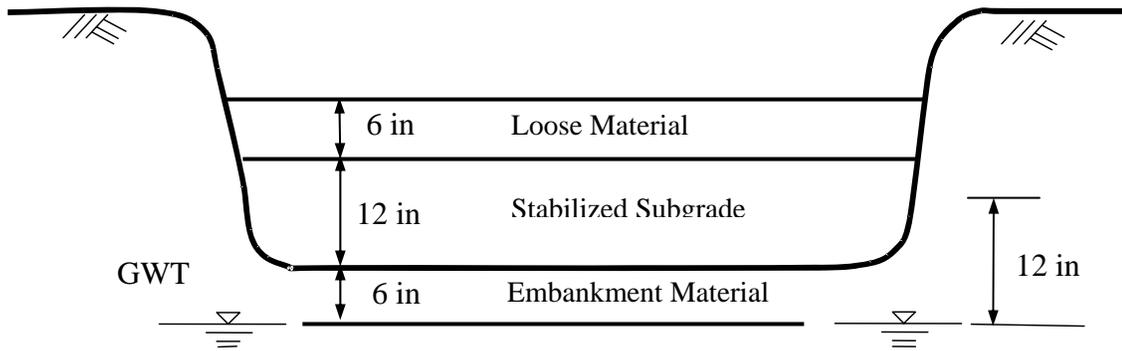


Figure 5.23 Schematic Site Plan for Compaction of Case A4 (Lake Worth Site)



Figure 5.24 Digging to the Groundwater Level (Lake Worth Site)



Figure 5.25 Placing Loose Material at 0" Groundwater Level (Lake Worth Site)

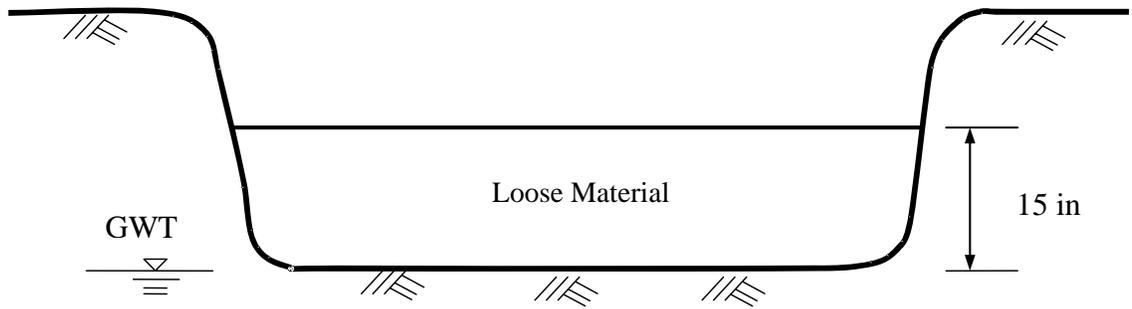


Figure 5.26 Schematic Site Plan for Compaction of Case A5 (Lake Worth Site)

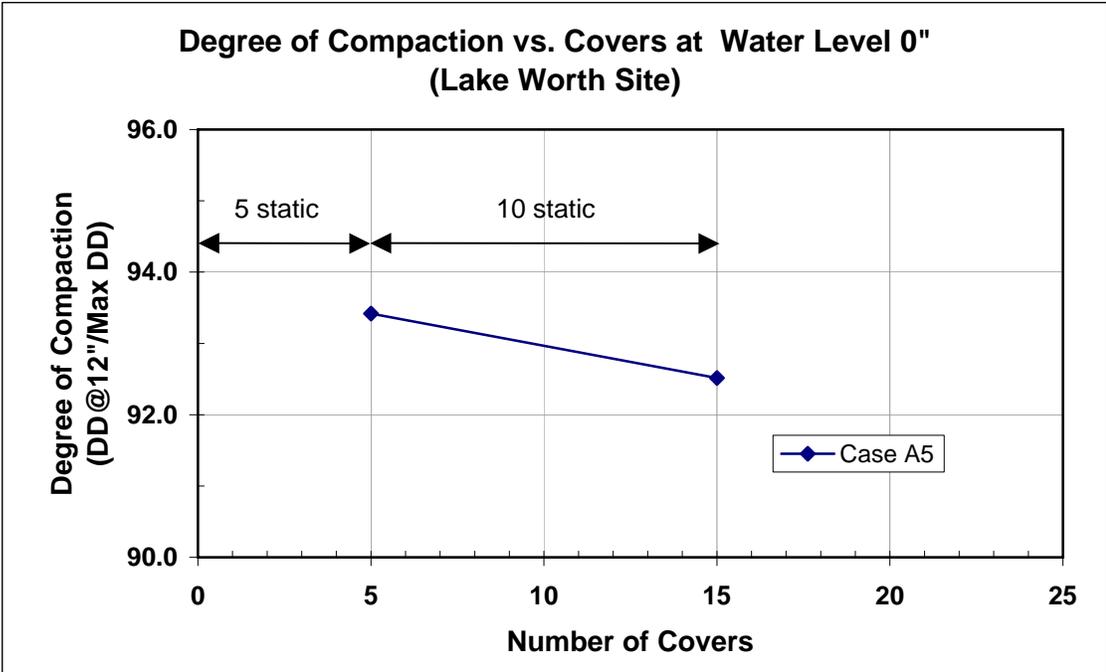


Figure 5.27 Degree of Compaction versus Number of Covers on Stabilized Subgrade for Water Level at 0 in. (Lake Worth Site)



Figure 5.28 UCF Field Test Site Location (Site B) in Orlando, Florida



Figure 5.29 UCF Field Test Site (about 50 ft x 10 ft)

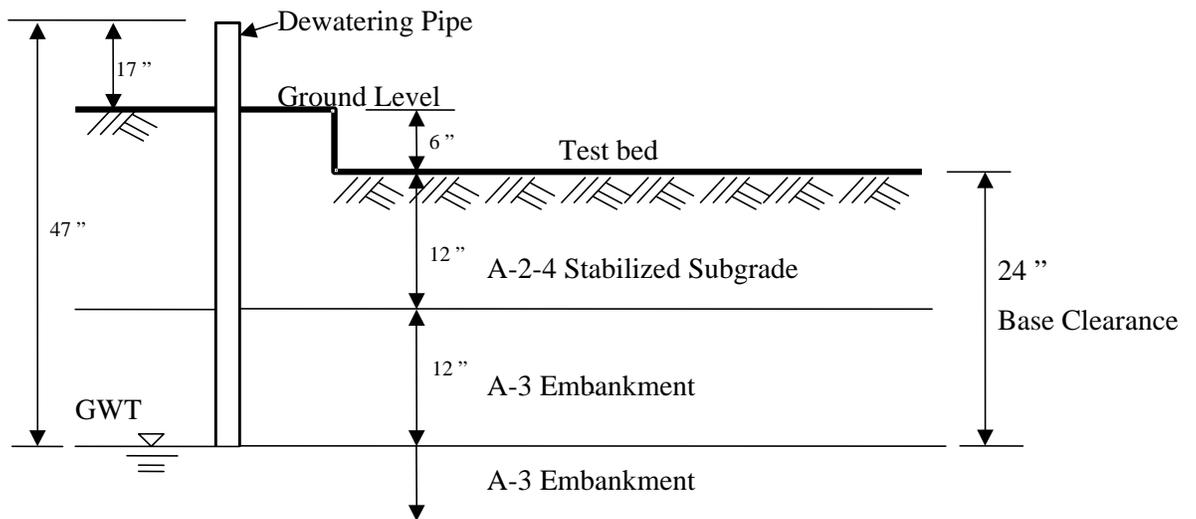


Figure 5.30 Schematic Sketch of UCF Field Test Site Profile



Figure 5.31 Dewatering Pipe to Control the Water Table Level (UCF Site)



Figure 5.32 Static/Dynamic Drum Compactor (UCF Site)



Figure 5.33 Nuclear Density Meter to Measure Soil Wet Density (UCF Site)



Figure 5.34 Taking Soil Sample for Measuring Speedy and Oven Moisture Content (UCF Site)

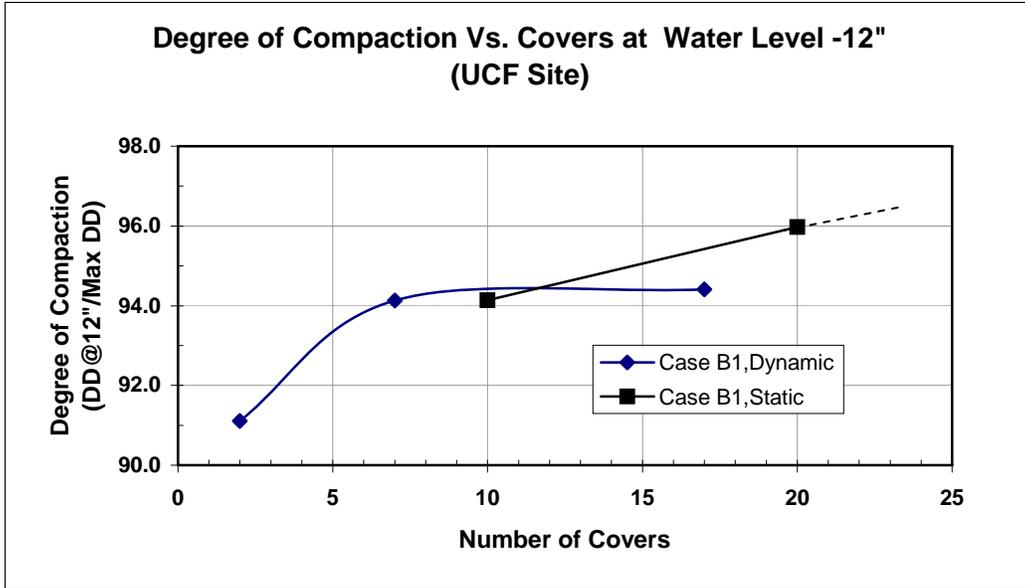


Figure 5.35 Degree of Compaction versus Number of Covers on Stabilized Subgrade for Water Level at -12 inches (UCF Site)



Figure 5.36 Equipment Used to Dig Out and Dump Soil (UCF Site)



Figure 5.37 Theodolite with Scale to Control the Subgrade Soil Depth (UCF Site)

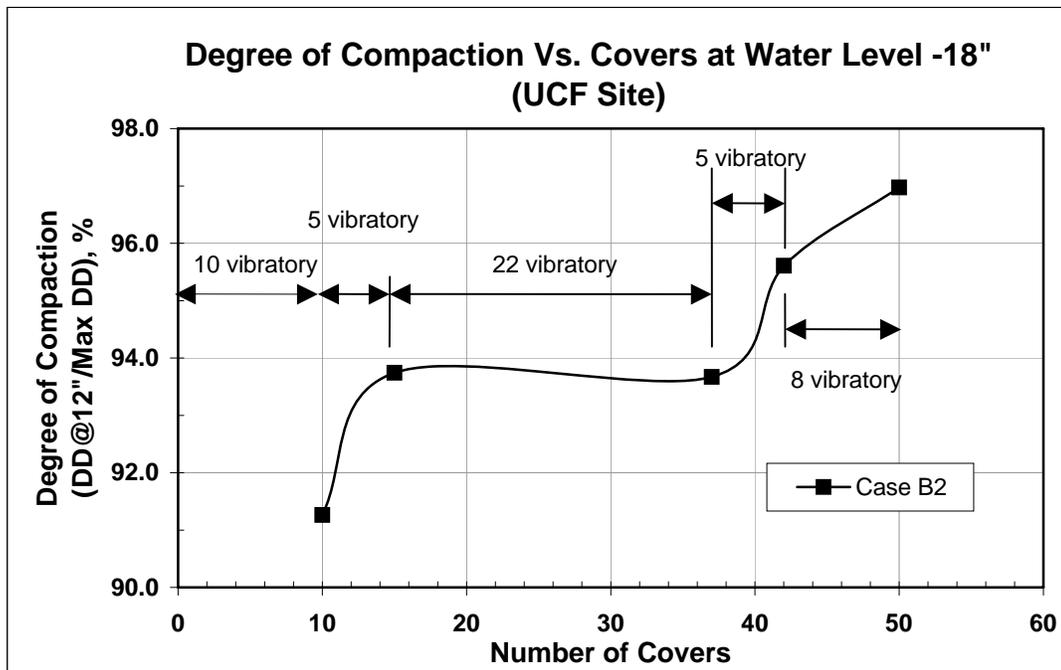


Figure 5.38 Degree of Compaction versus Number of Covers on Stabilized Subgrade for Water Level at -18 inches (UCF Site)

CHAPTER 6 DISCUSSION OF CONSTRUCTABILITY RESULTS

6.1 General

The constructability research consisted of a laboratory test-pit experimental program and field test program. The research was conducted over a span of almost two years from August 2001 to April 2003. The test-pit experimental program and the field test were discussed separately in previous chapters. Table 6.1 presents a summary of the test-pit experimental program and field tests. Due to lower stress levels achieved, the test-pit results were used to show trends. The field test results could be used to validate the test-pit experimental results. The following is a summary and discussion of constructability results on both the test-pit experimental program and the field test based on specific water table levels.

6.2 Water Table 24 inches below the Interface

The compaction of subgrade soils under this water level condition was only observed in the test-pit program since it is a commonly used clearance by designers. The test-pit experimental program started at this water level using both the A-3 and A-2-4 embankment soils. According to the results, proper compaction could be achieved under this water condition for both subgrade soils (A-2-4 and A-2-4 mixed with 25% of limerock) and on both embankment soils.

6.3 Water Table 18 inches below the Interface

The compaction of subgrade soils under this water condition was observed in the field tests only. Both field sites had A-3 embankment soils, but the Lake Worth site had A-3 soil for the subgrade layer and the UCF site had A-2-4 soil for the subgrade layer. The A-2-4 subgrade layer at the UCF site had an in-situ moisture content much higher than the optimum moisture content, and was proved to be difficult to work. It appeared that the desired 98% degree of compaction was within reach using the dynamic compaction technique at the UCF site.

For the Lake Worth field test, the desired compaction was not achieved using the dynamic compaction at this water condition. However, the desired density could be achieved

if the static compaction was used for this case. A summary of experimental results is presented in Table 6.2 under this water level condition.

6.4 Water Table 12 inches below the Interface

This condition was proved to be the critical water table level. The compaction of subgrade soils under this water condition was observed in both the test pits and in the field. The test pit simulations were conducted under two water conditions:

1. An undrained condition is one in which the water level was raised from the bottom of the test pit to 12 inches below the interface. Under this condition, for both A-3 and A-2-4 embankment soils, the A-2-4 and A-2-4 stabilized with 25% limerock subgrade soils were both evaluated. Results showed that adequate compaction was obtained for each condition.
2. A drained condition is one in which the water level was lowered down from two inches above the subgrade-embankment interface to 12 inches below the interface. Under this condition, only the A-3 embankment soils were used for evaluation. Results showed that adequate compaction was obtained for both subgrade soils (A-2-4 and A-2-4 mixed with 25% limerock).

The field simulations under this water level were performed at both sites. At both the Lake Worth site (A-3 embankment soil and A-3 subgrade soil) and the UCF site (A-3 embankment soil and A-2-4 subgrade soil), the compaction results were consistent. Both subgrade soils indicated good compaction by static compaction and poor compaction by dynamic vibratory compaction. Table 6.3 presents the results for both the test-pit and field site programs.

6.5 Water Table 6 inches below the Interface

This water level was also proved to be critical. The compaction of subgrade soils under this water condition were observed in both the test pits and in the field. The test pit simulations were conducted under two water conditions:

1. An undrained condition is one in which the water level was raised from the bottom of the test pit to six inches below the subgrade-embankment interface. Under this condition, for both A-3 and A-2-4 embankment soils, the A-2-4 and A-2-4 stabilized with 25% limerock subgrade soils were both evaluated. Results showed that adequate compaction was obtained for each condition although lower stress levels were achieved in the test pit than in the field.

2. A drained condition is one in which the water level was lowered down from two inches above the interface to 12 inches below the interface. Under this condition, only the A-3 embankment soil was used for the evaluation. Results showed that adequate compaction could not be obtained by either static or dynamic (vibratory) compaction efforts for both subgrade soils (A-2-4 and A-2-4 mixed with 25% limerock).

The field simulations under this water level condition were performed at both sites. At both the Lake Worth site (A-3 embankment soil and A-3 subgrade soil) and the UCF site (A-3 embankment soil and A-2-4 subgrade soil), the compaction results were consistent. Adequate compaction was not obtained by static methods. Based on the results from the water level condition at -12 inches below the interface, adequate compaction could not be obtained either by dynamic compactive efforts under this water level condition. Table 6.4 presents the results for both the test pit and field site programs under this water level condition.

6.6 Water Table 0 inch below the Interface

The compaction of subgrade soil under this water level condition was only performed at the Lake Worth field site. Adequate compaction was not achieved at all using the static compaction. For this case, the dynamic compaction was not even tried because of the experience from the water level condition at -12 inches below the interface. The results at this water level condition validated the unsuccessful compaction test at the water level six inches below the interface. Table 6.5 presents the results for the Lake Worth field site under this water level condition.

6.7 Summary of Constructability Results

The field tests were used to calibrate or check the test pit compaction results. Various water level conditions were simulated under the field compaction including the groundwater levels at 18 inches, 12 inches, 6 inches, and 0 inch below the subgrade-embankment interface. Although the drawdown (drained) condition was simulated at the test pit, the drawdown condition was not evaluated in the field due to physical site limitations.

Based on the test results of the Lake Worth field site, the A-3 subgrade soil could be constructed according to specifications under the water level conditions at least

18 inches below the subgrade-embankment interface. Under this condition, adequate compaction was achieved using either the static or dynamic (vibratory) compaction. When the groundwater level was raised to 12 inches below the interface, adequate compaction could not be achieved using the dynamic (vibratory) compaction, although using the static compaction was feasible to achieve the desired compaction. When the groundwater level was further raised to 6 inches below the interface, using the static compaction was even questionable to achieve the desired compaction. Adequate compaction was not possible for the groundwater level right at surface of the embankment.

In summary, the groundwater level should be at least 18 inches or deeper below the subgrade-embankment interface to ensure a good constructability of overlying subgrade layers. In case of a drawdown condition in the field, the groundwater table should be lowered to a level of at least 24 inches below the interface to facilitate an adequate compaction of subgrade layers. Static compaction techniques would be preferred under those groundwater conditions.

Table 6.1 Summary of Test Pit Experimental Program and Field Tests

| Test Location | Water Level (inches, from the interface) | Embankment Soil | Subgrade Soil | Test Designation |
|--------------------|--|------------------|------------------|------------------|
| Test Pit | -24 | A-3 (5%) | A-2-4(12%) | Condition 1 |
| | | | A-2-4(12%)+25%LR | |
| | | A-2-4 (12%) | A-2-4(12%) | |
| | | | A-2-4(12%)+25%LR | |
| | -12 | A-3 (5%) | A-2-4(12%) | Condition 2 |
| | | | A-2-4(12%)+25%LR | |
| | | A-2-4 (12%) | A-2-4(12%) | |
| | | | A-2-4(12%)+25%LR | |
| | -6 | A-3 (5%) | A-2-4(12%) | Condition 3 |
| | | | A-2-4(12%)+25%LR | |
| | | A-2-4 (12%) | A-2-4(12%) | |
| | | | A-2-4(12%)+25%LR | |
| -6(draind) | A-3 (5%) | A-2-4(12%) | Condition 4 | |
| | | A-2-4(12%)+25%LR | | |
| -12(draind) | A-3 (5%) | A-2-4(12%) | Condition 5 | |
| | | A-2-4(12%)+25%LR | | |
| Field (Lake Worth) | -12 | A-3 | A-3 | Case A1 & A4 |
| | -18 | A-3 | A-3 | Case A2 |
| | -6 | A-3 | A-3 | Case A3 |
| | 0 | A-3 | A-3 | Case A5 |
| Field (UCF) | -12 | A-3 | A-2-4 | Case B1 |
| | -18 | A-3 | A-2-4 | Case B2 |
| | -6 | A-3 | A-2-4 | Case B3 |

Table 6.2 Summary of Constructability Results at Water Level 18 inches Below the Interface

| Test Location | Test Designation | Constructability Results |
|--------------------|------------------|--|
| Field (Lake Worth) | Case A2 | <ul style="list-style-type: none"> • Dynamic compaction: The desired 98% degree of compaction was not achieved. • Static compaction: The desired 98% degree of compaction could be achieved. |
| Field (UCF) | Case B2 | <ul style="list-style-type: none"> • The field moisture content was much higher than the optimum moisture content. • The A-2-4 subgrade layer was difficult to work. |

Table 6.3 Summary of Constructability Results at Water Level 12 inches Below the Interface

| Test Location | Test Designation | Constructability Results |
|--------------------|-----------------------|---|
| Test Pit | Condition 2 | Adequate compaction was obtained. |
| | Condition 5 (Drained) | Adequate compaction was obtained. |
| Field (Lake Worth) | Case A1 | Adequate compaction was within reach using the static compaction. |
| | Case A4 | Adequate compaction could not be achieved using the dynamic compaction. |
| Field (UCF) | Case B1 | <ul style="list-style-type: none"> • The field moisture content was much higher than the optimum moisture content. Adequate compaction was within reach using the static compaction. • Adequate compaction was not possible using the dynamic compaction. |

Table 6.4 Summary of Constructability Results at Water Level 6 inches Below the Interface

| Test Location | Test Designation | Constructability Results |
|--------------------|-----------------------|---|
| Test Pit | Condition 3 | Adequate compaction was obtained. |
| | Condition 4 (Drained) | Adequate compaction could not be obtained. |
| Field (Lake Worth) | Case A3 | Adequate compaction could not be obtained using either the static or the dynamic compaction techniques. |
| Field (UCF) | Case B3 | <ul style="list-style-type: none"> • The field moisture content was much higher than the optimum moisture content. • Adequate compaction could not be obtained using the static compaction. |

Table 6.5 Summary of Constructability Results at Water Level 0 inch Below the Interface

| Test Location | Test Designation | Constructability Results |
|--------------------|------------------|--|
| Field (Lake Worth) | Case A5 | Adequate compaction could not be obtained using the static compaction. |

CHAPTER 7 CONCLUSION AND RECOMMENDATION

7.1 Conclusion

Based on the discussions on the test pit program and field the test, the following conclusions may be drawn:

Capillary Rise Study

1. The A-2-4 (12%) soil displayed a greater capillary rise than did the A-3 (5%) soil. The A-2-4 (12%) soil had a capillary height of more than 24 inches, while the A-3 (5%) soil had a capillary height of about 18 inches. The capillary rise results confirm previous work in the literature.
2. Both the A-2-4 and A-3 soils have a similar rate of capillary rise, reaching the maximum height in about eight days.

Test Pit Constructability Study

3. The A-3(5%) and A-2-4(12%) soils showed similar performances as an embankment in this study. As a result, conclusions drawn from this study on the A-3 (5%) embankment soils may also be inferred to the A-2-

4 (12%) embankment soils. However, A-2-4 soils with higher percent of fines could prove differently.

4. The A-2-4 (12%) soil and A-2-4(12%) mixed with 25% limerock had similar compaction and LBR results, and showed similar performance as a stabilized subgrade layer in this study.
5. Due to lower stress levels achieved, the test-pit constructability results were used to show trends and should be validated by field compaction tests.

Field Constructability Study

6. The in-situ moisture content of subgrade soil was critical to successful compaction and to achieve the specified density (unit weight).
7. The static compaction technique was more effective for compacting A-3 and A-2-4 subgrade layers under high groundwater conditions.
8. For both A-3 and A-2-4 embankment soils, the A-3 and A-2-4 subgrade soils could be constructed according to specifications by either the static or dynamic compaction when the groundwater level was at least 18 inches or deeper below the subgrade-embankment interface. When the groundwater level was raised to 12 inches below the interface, adequate compaction could only be achieved using the static compaction.

9. In case of a drawdown condition in the field, the groundwater level should be lowered to a level of at least 24 inches below the interface to facilitate an adequate compaction of subgrade layers.
10. When the groundwater level was raised to six inches below the subgrade-embankment interface, the top six inches of compacted subgrade soils showed greater dry density than the bottom six inches of subgrade soils due to capillary effects and pumping caused by compaction. Under this groundwater condition, the field test results showed that adequate compaction could not be obtained by either static or dynamic compaction efforts.

7.2 Recommendation

The following recommendations are made based on the findings of this study:

1. It appeared that the minimum required groundwater level clearance below the subgrade-embankment interface was approximately 18 to 24 inches or deeper in order to achieve an adequate compaction of subgrade layers according to construction specifications. In case of a drawdown condition, the minimum required groundwater level clearance

below the interface was approximately 24 inches or deeper for achieving an adequate compaction of the overlying subgrade layer. However, the pavement materials were limited to A-3 silty sands and A-2-4 silty soils with lower percent of fines for the subgrade and embankment layers in this field study. Additional field verification tests should be required for other types of Florida pavement materials.

2. Full-scale tests using outdoor pits or field sites are recommended for additional A-2-4 subgrade and embankment soils, particularly with higher percent of fines.
3. The findings of this study should be incorporated into developing statewide guidelines to ensure design base clearances that will not affect construction.
4. Additional studies are recommended for evaluating critical groundwater clearance levels such as less than 18 inches below the subgrade-embankment interface when the static compaction is required for achieving adequate compaction.

APPENDIX A CONSTRUCTABILITY CASE HISTORY

This case history involved an FDOT roadway project during construction in April 1996. The project was on State Road (SR) 551, Goldenrod Road (Project No. 75200-3519), in Orange County, Florida. Upon inspection during the construction stage, the District 5 geotechnical staff noticed that the inspected stabilized subgrade layer did not meet the density requirement and was yielding to the construction traffic immediately after construction.

Upon review of the project design, a significant increase was noticed in the level of the groundwater elevation during construction. The water table measured during design on May 2, 1989 and the water table measured during construction on April 15, 1996 were quite different (shown in Figure A.1). The water level raised up about five feet as the time changed. The main cause for this variation in the water table was believed to be the increase in precipitation, which is shown in Table A.1. As shown in the table, the average rainfall was 9.9 inches in March 1996 and 0.7 inches in April 1996, while the average rainfall

was 2.3 inches in April 1989 and 2.4 inches in May 1989. The extremely high precipitation rate in March 1996 caused the groundwater table to rise during the construction period.

This constructability problem resulted in large claims and delays. The project was forced to be redesigned using an asphalt base in place of the limerock base. A 90-day time extension and an extra \$500,000 for walls and fill were required to resolve the problem for about 0.5 mile of the project.

From this case history, engineers and others involved in the project learned that there could be wide variation in water table as time changed. The rainfall information should have been considered when the designer and contractor looked at the soil boring information. Under these circumstances, the designer must keep in mind that a minimum clearance is needed between the water table and the bottom of the subgrade layer to facilitate proper construction.

Table A.1 Rainfall Data (Orlando International Airport)

| Month | 1989 | 1996 |
|-----------|------|------|
| January | 3.8 | 5.4 |
| February | 0.2 | 1.5 |
| March | 1.4 | 9.9 |
| April | 2.3 | 0.7 |
| May | 2.4 | 5.1 |
| June | 6.8 | 6.5 |
| July | 4.7 | 4.1 |
| August | 6.2 | 11.3 |
| September | 10.3 | 6.0 |
| October | 1.8 | 3.3 |
| November | 1.4 | 0.7 |
| December | 4.5 | 2.1 |
| Total | 45.7 | 56.7 |

S.R. 551 (Goldenrod Road)

State Proj. No. 75200-3519
 WPI No. 5114576
 Orange County
 Sta. 1+00

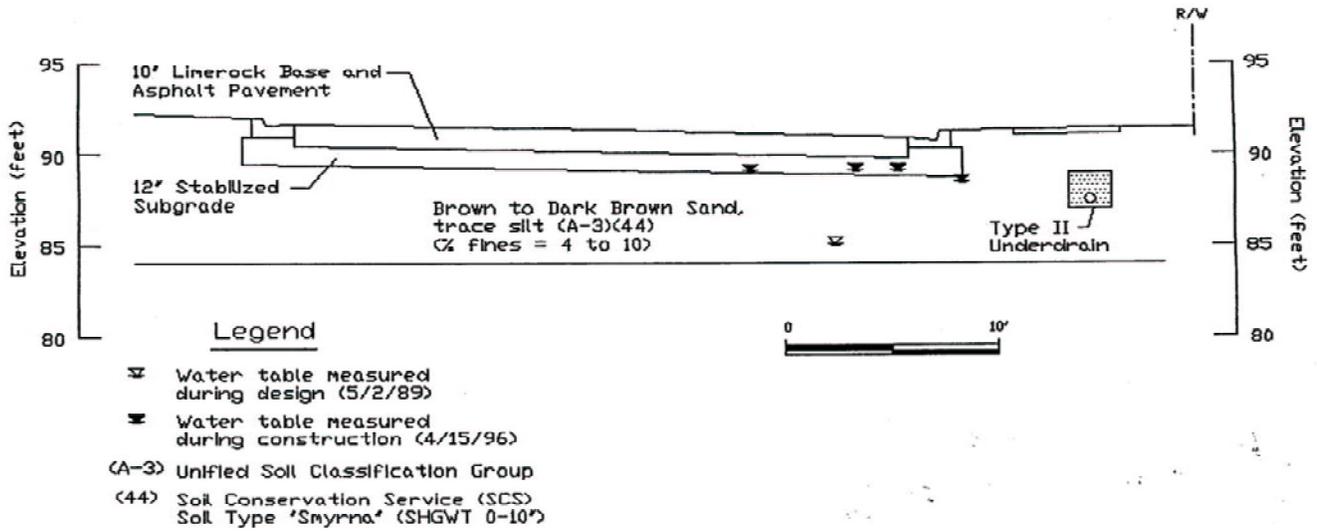


Figure A.1 Ground Water Table Variations

APPENDIX B LITERATURE REVIEW: CAPILLARY RISE IN SOILS

B.1 Water in Capillary Tubes

The basic principles of capillary rise in soils can be related to the rise of water in glass capillary tubes under laboratory conditions. When the end of a capillary tube is put in contact with a source of water, the water rises up in the tube and remains there. Figure B.1 shows the capillary rise in a capillary tube. The height of the rise of water in the capillary tube can be obtained from:

$$h_c = \frac{4T \cos \alpha}{d \cdot \gamma_w}$$

Where

T = surface tension

α = angle of contact

d = diameter of the capillary tube

γ_w = unit weight of water

The surface tension T for water varies according to temperature. Generally, as temperature increases, the value of T_s decreases.

B.2 Capillary Rise in Soils

In soils, the shapes of void spaces between solid particles are unlike those in capillary tubes. The voids are of irregular and varying shape and size, and interconnect in all directions. Those properties make the accurate prediction of the height of a capillary rise in soil almost impossible. However, Hazen (1930) gave the following formula to approximate the maximum capillary rise in soils:

$$h_c(mm) = \frac{C}{eD_{10}}$$

Where

D_{10} = Hazen's effective size (mm)

e = void ratio

C = a constant that varies from 10 to 50 mm^2

From the formula, the maximum capillary rise is reciprocal to the effective size, D_{10} . When the effective size, D_{10} , of a certain soil decreases, the pore size decreases, causing a higher capillary rise height.

Table B.1 shows the range of capillary rise for different soils.

B.3 Time Rate of Capillary Rise

The time required for the expected maximum height of the capillary rise has to be considered in some practical applications. On the basis of typical void sizes, clay and fine silt soils will have significant heights of capillary rise. However, the time period required for the rise to occur may be so great that other influences, such as evaporation and change in groundwater level, also have to be considered.

The term indicating the time rate of capillary rise is capillary conductivity or capillary permeability, k_{cap} . Factors affecting the K_{cap} of a soil are void sizes, moisture content, and temperature of the soil. Generally, K_{cap} is greater at a higher moisture content and lower temperature.

Absolute K_{cap} values are not available, but the relative rates of capillary conductivity can be thought of in terms of the comparative values for permeability - that is, rapid for coarse-grained soils, low for silts and clays.

Table B.1 Approximate Range of Capillary Rise in Soils

| Soil Type | Range of capillary rise | |
|-------------|-------------------------|----------|
| | (in.) | (cm) |
| Coarse sand | 4-20 | 10-50 |
| Fine sand | 12-47 | 30-120 |
| Silt | 30-300 | 75-750 |
| Clay | 300-800 | 750-2000 |

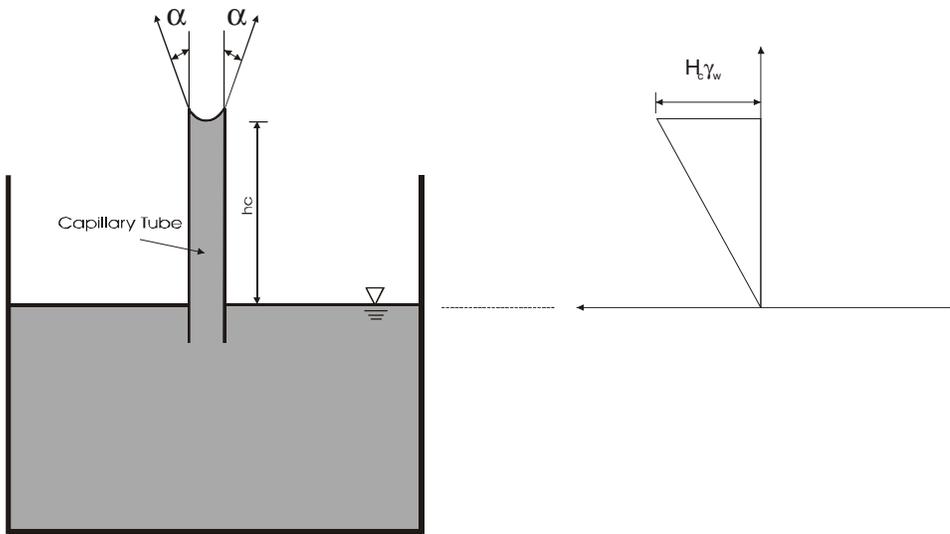


Figure B.1 Water Rise in the Capillary Tube

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