EVALUATION AND GUIDELINES FOR DRAINABLE BASES

by

Vivek Tandon, Ph.D.

Miguel Picornell, Ph.D., P.E.

and

Soheil Nazarian, Ph.D., P.E.

Research Project 0-1456

Conducted for

Texas Department of Transportation
in cooperation with
Federal Highway Administration

The Center for Highway Materials Research
The University of Texas at El Paso
El Paso, TX 79968-0516
Research Report 1456-1F
December 1996

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
TX-96 1456-1F		

4. Title and Subtitle	5. Report Date
EVALUATION AND GUIDELINES FOR DRAINABLE BASES	June, 1997
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Tandon, V., Picornell, M., and Nazarian, S.	Research Report 1456-1
9. Performing Organization Name and Address	10. Work Unit No.
Center for Highway Materials Research The University of Texas at El Paso El Paso, Texas 79968-0516	11. Contract or Grant No. Study No. 0-1456
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered Final Report
Texas Department of Transportation P.O. Box 5051 Austin, Texas 78763	14. Sponsoring Agency Code

15. Supplementary Notes

Research Performed in Cooperation with TxDOT and FHWA
Research Study Title: EVALUATION AND GUIDELINES FOR DRAINABLE BASES

16. Abstract

Base materials are normally selected to achieve maximum density, and to possess enough stiffness and strength to carry the traffic loads. The poor drainability of these materials has been of concern. This report describes the characterization of base materials being commonly used throughout the State of Texas. This includes the characterization of stiffness and strength based on the resilient modulus and the static strength of compacted specimens. The drainability is evaluated based on the permeability coefficient and the water retention capacity. The water retention test was found to be easier to perform and it is believed to be more directly related to the drainability of the compacted base than the permeability test. Alternative materials evaluated consisted of open-graded bases and cement- stabilized gravel. The results of the present study indicate that cement stabilized gravel is the best alternative to achieve high stiffness and strength and at the same time minimize water retention capacity of the compacted base. Guidelines for design and construction of base layers are proposed based on properties of cement-stabilized gravel.

17. Key Words	18. Distribution Statement
Permeability, Stiffness, Resilient Modulus, Soil Water Retention, Drainable Base	No restrictions. This document is available to the public through the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	190	

Form DOT F 1700.7 (8-69)

NOT INTENDED FOR CONSTRUCTION, BIDDING, OR PERMIT PURPOSES

Vivek Tandon, Ph.D.
Miguel Picornell, Ph.D., P.E. (82058)
Soheil Nazarian, Ph.D., P.E. (69263)

ACKNOWLEDGEMENTS

The authors would like to express their sincere appreciation to Mr. Mark Schluter, Area Engineer in the Fort Worth District of the Texas Department of Transportation for his ever-present support. Thanks are also due to the personnel of the nine districts that supplied the material for testing.

The authors would also like to thank both the graduate and undergraduate students that worked in this project. Specifically, the recognition is extended to Jaime Rojas, Raymond Guerra, Victor Saenz, Jorge Gomar, Christopher Villa, Gilbert Saldana, and Siradol Siridhara for their enthusiasm in performing all the necessary tests for this project and their help in the preparation of this report.

ABSTRACT

Base materials are normally selected to achieve maximum density, and to possess enough stiffness and strength to carry the traffic loads. The poor drainability of these materials has been of concern. This report describes the characterization of base materials being commonly used throughout the State of Texas. This includes the characterization of stiffness and strength based on the resilient modulus and the static strength of compacted specimens. The drainability is evaluated based on the permeability coefficient and the water retention capacity. The water retention test was found to be easier to perform and it is believed to be more directly related to the drainability of the compacted base than the permeability test. Alternative materials evaluated consisted of open-graded bases and cement- stabilized gravel. The results of the present study indicate that cement stabilized gravel is the best alternative to achieve high stiffness and strength and at the same time minimize water retention capacity of the compacted base. Guidelines for design and construction of base layers are proposed based on properties of cement-stabilized gravel.

EXECUTIVE SUMMARY

Base materials for pavements have been traditionally selected on their ability to distribute the traffic loads to a weaker underlying subbase layer or subgrade. Little or no emphasis has been focused towards drainability of base materials. The base materials commonly used in Texas have poor drainability. This has resulted in premature failure of pavements. The concern of poor drainability, a lack of guidelines for the design, and construction of drainable bases lead to the sponsoring of the presently reported project.

The objective of developing guidelines for design and construction of permeable bases was achieved in three phases. In the first phase, a literature search was performed to identify test procedures for the evaluation of stability and drainability of base materials. In the second phase, the existing base materials were evaluated for stability and drainability. In the third phase, new or alternative materials were developed and tested for stability and drainability. The goal for the new or alternative materials was to achieve higher drainability while maintaining stabilities similar to those of existing bases.

The existing base materials showed high water retention capacities and small coefficients of permeability, in general less than 100 m/day. The FHWA suggests permeability coefficients of more than 300 m/day. These results confirmed that the existing base materials have poor drainability.

To improve the drainability of base materials, it was decided to eliminate fines and fine, medium, and coarse sand. The tested materials showed improved drainability; however, these materials also exhibited drastic reductions of stability.

The gravel fraction of the existing base materials was used for the stabilized materials to retain a high level of drainability. Two cement contents 5 percent and 7 percent and two water-cement ratios 0.45 and 0.475 were used. Three sources of gravel were used: 1) limestone, 2) caliche, and 3) gravel and sand. The results of the laboratory program showed that gravels stabilized with Portland cement can provide highly drainable materials with also very high strength and stiffness.

IMPLEMENTATION STATEMENT

The results of the present study clearly illustrate the need to incorporate permeable bases in the construction of new pavements. The major concern is the poor drainability of bases constructed with the commonly used base materials throughout the State of Texas. The present report includes proposed guidelines for the design of permeable bases that improve drainability without adversely affecting strength and stiffness of the base. It is recommended that the Texas Department of Transportation considers the construction of pilot projects to evaluate field performance of these materials. The identified problem areas can then be used to modify the proposed guidelines. It is recommended that the Texas Department of Transportation considers these guidelines for implementation at the earliest possible time.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

PROBLEM STATEMENT

In Texas, the primary factor that determines the use of a base material is its availability. Base materials have been traditionally specified for construction using mainly strength, gradation, resistance to abrasion, and plasticity requirements. Almost all the base layers are constructed by compacting to maximum density with little or no emphasis placed on drainage characteristics.

The assumption behind this approach is that a base layer compacted to maximum density prevents water from entering and, at the same time, provides strength to the pavement. However, experience has shown that it is impossible to prevent water from entering pavement layers through cracks and joints. Nearly saturated base layers are not uncommon (due to poor drainability). The base material retains water like a sponge that cannot drain by gravitational forces alone. Under wheel loads the fines are pumped out through joints and cracks causing the formation of voids and loss of support at the edge of the pavement. Therefore, to increase the longevity of pavements, it is desirable to construct base layers that can allow the drainage of water by gravity.

Drainage specifications have not been required by the Texas Department of Transportation (TxDOT). The American Association of State Highway and Transportation Officials (AASHTO) guide for the design of pavement structures provides inadequate guidance towards designing drainable bases. This guide provides criteria for assessing the quality of drainage of the pavement as a function of its exposure time to moisture levels approaching saturation. The AASHTO guide presents only definitions of drainage quality and leaves the engineer with the task of estimating what quality of drainage is achieved in the field. Accordingly, the design engineer needs to assess the contribution of the drainage facilities (e.g., pipes, filters, etc.) as well as the contribution of the pavement layers, namely the base and subbase courses, in order to estimate the overall quality of drainage of the pavement. Presently, this is a difficult task since very limited guidelines are available.

According to the Federal Highway Administration (FHWA) guidelines (Baumgardner, 1992), a permeable base must provide both permeability and stability. Aggregate materials for permeable bases must be hard, durable, angular with good aggregate interlock. The guidelines also suggest that permeable bases should have a minimum coefficient of permeability of 300 m/day (1,000 ft/day).

However, the guidelines do not suggest test methods to measure the permeability coefficients or suggest a test method to measure the stability of permeable base materials.

Various researchers have suggested that the use of drainable bases increases the life of pavements substantially by improving pavement performance. The economic advantages that the use of drainable bases may generate have not been quantified. Also, little is known about the drainage properties of the different base materials commonly used in Texas.

Consequently, it is essential to evaluate the base materials used in Texas, to assess their drainage and strength properties. This information can then be used to modify/stabilize the base materials such that optimum drainage could be achieved without loosing strength. As a result, it would be possible to propose guidelines for the design and construction of base layers possessing adequate strength and stability while the drainage of water infiltrated would also be ensured.

OBJECTIVES

The primary objective of this report is to propose guidelines for the design and construction of drainable base layers. This objective was approached by first identifying the drainage and stiffness properties of base materials currently being used in Texas. New materials could then be proposed having strength and stability properties similar to those currently being used in Texas and at the same time improving the drainage properties; or if not possible, a compromise would have to be achieved between strength/stability and drainage properties. The steps taken to achieve this goal were the following:

1. perform resilient modulus and unconfined compressive strength tests on specimens of base materials currently used in Texas compacted at optimum conditions,

2. perform soil water retention and permeability tests on specimens of the same base materials,

3. perform resilient modulus and unconfined compressive strength tests on the modified/stabilized base materials and compare with those of existing base materials,

4. perform soil water retention and permeability tests on the modified/ stabilized base materials and compare these results to the properties of existing base materials,

5. select the base materials that can give optimum performance i.e., maximum drainage without loosing strength, and finally

6. propose guidelines for the design and construction of drainable bases.

ORGANIZATION

The report contains eight chapters. Chapter 2 discusses, the literature search, the proposed design parameters, and the research approach. Chapter 3 presents the laboratory test procedures followed and the data reduction. The selection of material and test results on the existing base materials are presented and discussed in Chapter 4. Chapters 5 and 6 contain the test results and the discussions for open-graded base materials (OGBM) and cement-stabilized base materials (CSBM), respectively. The Guidelines for Design and Construction of Base materials are proposed in Chapter 7. The final chapter consists of a summary, conclusions and recommended future directions. Several appendices are included which contain detailed descriptions of methodologies and the data collection and reduction procedures, as well as a complete set of the data recorded in the laboratory program.

CHAPTER 2

BACKGROUND

LITERATURE SEARCH

The presence of water, free and capillary held, in pavement layers has been documented by a number of investigators. The sources of this water are numerous, some sources are site specific (such as artesian groundwater) and others are common to any pavement structure. Among the latter ones is the infiltration of rainfall through unsealed cracks and through the matrix of the upper pavement layers. The measurements reported by Grogan (1992), on a newly constructed asphalt concrete pavement, indicate that this source of water can be very important. This study reported infiltration rates of up to 23% of the recorded rainfall. Similar findings have been documented in field and laboratory studies (Ridgeway, 1976) and in the field observations reported by Dempsey and Robnet (1979). These concerns are not only for asphalt concrete pavements, but are also applicable for Portland cement concrete pavements as described by Ridgeway (1976) and studied by Barksdale and Hicks (1977).

The presence of this water within the pavement layers accelerates the deterioration of the pavement structure by causing premature distress of the pavement. The mechanisms by which the pavement layers deteriorate has been attributed to loss of support, freeze-thaw effects, weakening of the subgrade, pumping of the subbase and/or subgrade, etc.

There is ample agreement in the existing literature about the need to remove the water in the pavement layers in the most expedient way possible. The new Federal Highway Administration (FHWA) guide for design of drainable pavement systems incorporates drainage as a key input (Baumgardner, 1992). The Corps of Engineers has incorporated drainage considerations to design pavements in military installations (Grogan, 1992).

The most common approach to provide drainability has been to include a layer within the pavement structure with a coefficient of permeability, or a hydraulic conductivity, adequate to permit the speedy removal of water percolating into the pavement layers. A large number of studies have been performed to analyze the minimum coefficient of permeability required in a drainable base, to permit the removal of excess water from the base layer (Randolph et al, 1996; Highlands and Hoffman, 1987; Zhou et al., 1993; Jones and Jones, 1989). A typical requirement laid down is a minimum coefficient of permeability of 300 m/day (1000 ft/day). Grogan (1992) has also found requirements of this order of magnitude to ensure 85% drainage in one day. Nevertheless, the field test sections monitored by Highlands and Hoffman (1987) built using different drainable base layers show little effect of the coefficient of permeability of the drainable base (over several orders of magnitude) on the Present Serviceability Index (PSI) of the pavement surface over a period of more than seven years. These results seem to indicate that perhaps the permeability coefficient is not such an influential parameter as indicated by the technical literature.

The coefficient of permeability indicates the ability of the material to conduct water; however, it does not indicate the total volume of water that can be drained from a material (Grogan, 1992). In this sense, water is held by the solid particles as films and meniscii and filling the smaller capillaries. Therefore, not all water in the pores can drain by gravity flow. This fact has been recognized by most of the investigators (Grogan, 1992; Jones & Jones, 1989; and McEnroe, 1994) who have worked with this problem. However, most of the consideration given to this aspect deals with the "effective porosity" (or drainable porosity) and analyzes the time required to empty the effective porosity as a measure of how drainable a base might be.

The approach adopted by McEnroe (1994) is somewhat different. He attempted to define a minimum degree of saturation as a function of the material and the position of the layer within the pavement structure. He postulated that the best measure of the drainability of a granular base was the minimum degree of saturation that can be achieved through gravity drainage in the field.

The saturated coefficient of permeability is a parameter extremely sensitive to features that might not be representative of the average conditions of the matrix of the materials under question. In other words, a single macro pore can be responsible for the conduction of water that would indicate a high coefficient of permeability. Thus one macro pore can provide a high permeability coefficient, while the rest of the matrix has small pores with large capillary rises. This would imply high coefficient of permeability concurrent with a high water retention capacity of the material.

By way of contrast, the water retention properties of a soil matrix are influenced by the whole spectrum of pore sizes present in the base material. The presence of macro pores would be indicated by desaturation of the matrix at very low soil suctions. These considerations lead us to believe that the water retention properties of the base materials could be a more reliable approach to evaluate drainability of a base material than the saturated permeability coefficient of the same materials. These considerations have been used in the present study to perform water retention tests together with permeability tests to evaluate base materials commonly used in Texas.

Various researchers have made unsuccessful attempts to measure the permeability of both open-graded materials and stabilized open-graded materials. Zhou et al. (1993) reports coefficients of permeability of asphalt treated open-graded material anywhere from 150 to 1,260 m/day (500 to 4,130 ft/day). A study conducted by Randolph et al. (1996) showed less variations in permeability measurements from 1,500 to 2,400 m/day (5,000 to 8,000 ft/day). A study conducted by Jones and Jones (1989) suggested that laboratory permeability measurements are not accurate enough to obtain reasonable estimates.

To increase the permeability of base materials, researchers have usually suggested the use of AASHTO No. 57 or 67 grade aggregates. The gradations of both of these aggregates have 0-5% material passing No. 8 sieve. Aggregates of this gradation have lower strength as well as stiffness because of poor mechanical interlock between the aggregates due to the lack of finer aggregates. A study conducted by Wisconsin DOT (Hall, 1994a) established that if an open-graded material is used in a base layer, it is necessary to build a haul road to prevent the base layer from being damaged by the construction traffic. The same study also indicated that in some cases, even stabilized open-graded materials show signs of damage due to construction traffic.

The FHWA has recently proposed new guidelines (Drainable Pavement Systems, 1992) to design and construct permeable bases. However, the design guidelines do not suggest test methods or procedures to measure the stability i.e. strength and stiffness of the base materials. Hall (1994b) has performed stability tests on cement-stabilized open-graded materials. These included laboratory-cured compressive and bending, field-cured compressive and split tensile, and core split tensile tests. However, these tests were performed only for static loads. Zhou et al. (1993) have measured resilient modulus of asphalt-treated open-graded materials in accordance with ASTM D4123 standard procedure.

It can be concluded from the above discussion that most of the research has been focused towards achieving higher permeability coefficients and less effort has been placed on measuring stability in the laboratory or the water retention capacity of bases. Existing guidelines have not suggested reliable tests to measure the saturated coefficient of permeability.

PROPOSED DESIGN PARAMETERS

The stiffness and strength evaluation of base materials is proposed to be implemented using the resilient modulus and unconfined compression tests. The main aspect to consider for the evaluation of drainability is how much and how fast the pore water that has accumulated into a base layer can be expected to drain out of the matrix by gravity alone.

In the movement of water through the base, there are two distinctive phases with quite different controlling parameters. In the first phase, the water percolates into the base and accumulates until it reaches a nearly saturated condition. At this moment, the water moves through the base under positive pressures. The saturated coefficient of permeability would then be the parameter that determines how fast the seepage moves towards the side drainage facilities.

As soon as the supply of water stops, the water in the pores of the base layer is under negative pore pressures. The water that is held by capillary action within the base will not drain under the influence of gravity alone no matter how high the saturated permeability coefficient might be. For this condition, the more relevant and direct parameter would be the water retention capacity of the compacted base material.

In this sense, it is important to realize that a base layer with only an adequate coefficient of permeability will act as a drain as long as the pore pressures are positive (above atmospheric pressure). However, as soon as the infiltration stops the water accumulated in the base layer and held by capillarity will remain in the base layer indefinitely unless some force other than gravity comes into play. Under these conditions, the base layer would act as a reservoir remaining nearly saturated after each rainy episode and supplying water to the subbase that can soak it depending on the soil suction of the subgrade soils.

These considerations indicate that the water retention capacity of the base would be a much more direct parameter to assess the capability of a base layer to empty the pore water after each episode of infiltration. Furthermore, as discussed in subsequent sections of this report, the determination of the water retention capacity of the base layer is much easier to implement in the laboratory and it is subjected to fewer uncertainties for laboratory measurement. As such, the water retention is included as one of the parameters to assess drainability. These tests were complemented with measurements of permeability coefficient when feasible.

RESEARCH APPROACH

As a part of a study, Nazarian et al. (1996) conducted a survey to identify the base materials commonly used throughout the State of Texas. The ten most commonly used base materials were identified through the survey. Nine out of the ten base materials were used in the present study.

Common index tests were performed on the selected base materials. After characterization, compacted specimens were tested to evaluate the coefficient of permeability, water retention capacity, and strength and stiffness. The permeability and soil water retention tests were developed in the present study while stiffness and strength tests were performed using test procedures suggested by Nazarian et al. (1996). These properties were then compared with the properties of alternative materials. These materials were evaluated in such a way that the increase in permeability coefficient and the decrease in water retention capacity should not adversely affect strength and stiffness. In other words, the selected alternative material should have a balance of stiffness and drainability.

Two alternative materials were evaluated in the present study; open-graded base material (OGBM) and cement-stabilized base material (CSBM). The OGBM is an unbound material with reduced or negligible percentage of fines. The CSBM consist of gravel stabilized with three different cement contents using two water cement ratios.

CHAPTER 3

TEST METHODOLOGIES

STIFFNESS AND STRENGTH

In the resilient modulus test (Nazarian et al., 1996), the specimen is subjected to several confining pressures and, for each pressure, several deviatoric stress cycles are applied. Upon completion of the resilient modulus test, the confining pressure is reduced to atmospheric pressure (zero effective confining pressure) and a quasi-static compression test is performed until failure of the specimen. The strength of some specimens of CSBM exceeded the capacity of the testing facility. These specimens were dismounted from the testing facility and placed in a concrete cylinder tester to measure the unconfined compressive strength.

The resilient modulus and the unconfined compression tests were performed on compacted specimens 150 mm (6 inches) in diameter and 300 mm (12 inches) in height. The specimen were prepared in a cylindrical split mold in six lifts. Each lift was compacted with 25 blows of a Proctor hammer. Small steel angles were placed on certain lifts to serve as supports for the targets of the non-contact probes used to measure axial as well as radial displacements during testing.

The resilient modulus of base materials is typically determined in a triaxial test set-up. The specimen is confined in a triaxial cell under a cell pressure and, then, repeated axial load pulses are applied on the specimen. The variables measured during the test are the axial deformation and the applied intensity of the load pulse. The resilient modulus is calculated from the following expression:

$$M_R = \frac{\sigma_d}{\epsilon_{ax}} \tag{3.1}$$

where:
M_R is the resilient modulus,
σ_d is the peak axial deviatoric stress, and
ϵ_{ax} is the resilient axial strain.

The axial deviatoric stress is calculated from the following expression:

$$\sigma_d = \frac{P}{A_i} \tag{3.2}$$

where P is the applied peak load and A_i is the original cross-sectional area of the specimen. The resilient axial strain, is calculated from the following expression:

$$\epsilon_{ax} = \frac{\Delta L}{L_i} \tag{3.3}$$

where ΔL is the recovered axial deformation along a gage length, L_i, after each load pulse.

A sketch showing the test setup is presented in Figure 3.1. The axial deformations are measured with six proximeters placed in pairs at 120 degrees around the specimen. In this fashion, three independent measurements of axial deformation are recorded. The targets for these proximeters are placed to measure the deformation of the middle third of the specimen. Two additional proximeters are placed on opposite ends of a diameter at the mid point of the specimen. These two proximeters are used to measure transversal deformations of the specimen. A detailed description of the testing sequence has been presented by Nazarian et al. (1996).

WATER RETENTION CAPACITY

The water retention capacity was determined on compacted specimens of base material. These specimens were first saturated and then were allowed to equilibrate at specified soil suction levels. These soil suction levels were selected to be representative of the conditions expected to occur in the field. For each level, equilibration was determined by making certain that the specimen had reached constant weight.

The water retention capacity set-up was specifically designed and constructed for the present application. The device is modelled after the pressure plate extractors used by soil scientist. A sketch of the device is shown in Figure 3.2. The mold consists of a section of schedule 40 PVC pipe of 150 mm (6 inches) inner diameter. The main purpose of using PVC pipe and fixtures was to reduce the total weight of the mold. This was intended to facilitate the weighing process. The mold that contains the specimen is closed by a high air entry porous stone on one end and a cap at the other end. The top cap has a connection to allow vacuum during saturation and air pressure for the equilibration phase. Furthermore, the cap incorporates a window of transparent plexiglass to allow the visual inspection of water levels during the saturation process.

The specimen is compacted inside the mold fixed in a specially designed mold holder. Compaction is performed in three lifts. Each lift is compacted with 25 blows of a standard Proctor hammer.

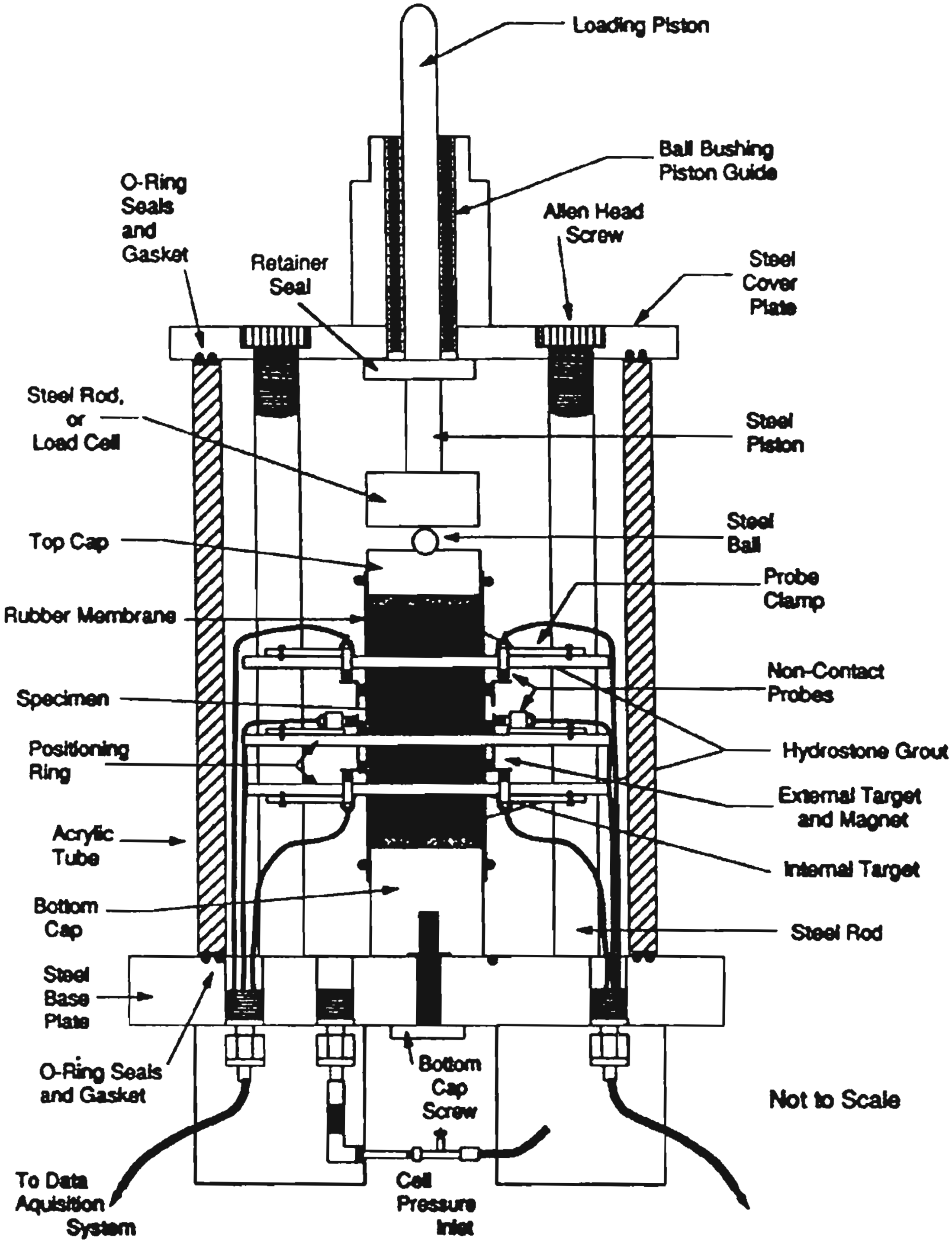

Figure 3.1 Resilient Modulus Test Setup

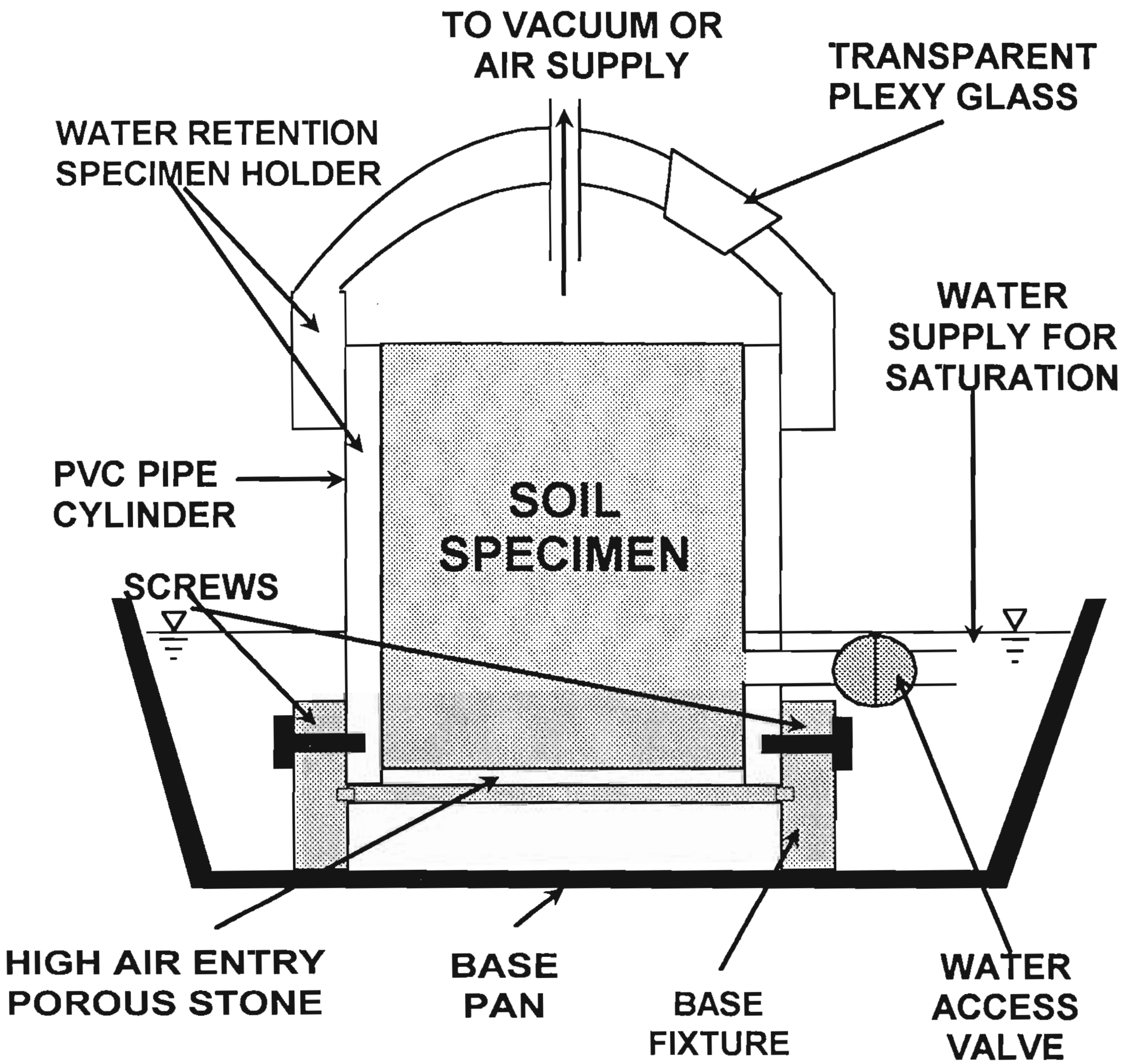

Figure 3.2 Water Retention Test Setup

Upon compaction, the mold with the specimen is removed from the mold holder. The high air entry porous stone (of 1 bar air entry value) is placed in a recess machined in the bottom of the mold. A special support for the porous stone (base fixture) is then attached to the bottom of the mold. To ensure proper hydraulic contact between the specimen and the porous stone, silica flour is sprinkled on the stone at the time of assembling the device. The pipe cap is placed on the mold, and sealed with silicone rubber. The assembled mold with the specimen is weighed and the mass is recorded. The mold with the specimen is then placed in a pan with a water level maintained above the high air entry porous stone. The specimen is saturated by applying a vacuum equivalent to a few centimeters of mercury to the top cap while the water access valve is opened. The vacuum is maintained until about 10 mm of water had been pulled above the surface of the specimen. At this time, the water access valve is closed and remains closed for the duration of the test. The low vacuum levels during the saturation process minimize the movement of fines within the specimen.

The next step is to release the vacuum from the top of the specimen. The specimen is allowed to drain under gravitational forces for a day. At the end of 24 hrs, the specimen and mold assembly is weighed and the mass recorded as the mass of the saturated specimen.

In the next phase of the test, air pressure is applied on top of the specimen. The water in the base pores is in contact with water in the pan under atmospheric pressure. The excess air pressure causes the pore water to recede in the pores and form meniscii. The difference between air and water pressure is the soil suction applied on the base specimen. The mass of the mold/specimen assembly is measured and recorded on a daily basis. The air pressure is maintained constant until the mold/specimen assembly reaches constant mass. At this time, the air pressure is increased to the next level.

The major goal of this test is to subject the pore water in the specimen to soil suctions similar to those that can reasonably be expected to occur in the field. Assuming that a continuous water column exists from the top of the base layer to the water in the pipe of the side drainage collection system, the soil suctions applied to the water within the base layer would be equivalent to the pressure of a column of water of height equal to the difference in elevation from the top of the base layer to the water level within the side drainage system. In most cases, this difference in elevation is only a few feet. In many cases, the water column would not be continuous and thus the soil suction imposed on the base would be even lower.

At the beginning of the test program the air pressure applied was 7 KPa (1 psi or equivalent to an 28 inch column of water). Upon equilibration, the air pressure was increased to 21 KPa (3 psi or equivalent to an 83 inch column of water). In the final step the air pressure was increased to 35 KPa (5 psi or equivalent to a column of water of 138 inches tall). As the test program progressed, it was clear that the major water losses were obtained with 7 KPa (1 psi) and, thus, further increases of the air pressure were deemed not necessary. In this fashion, the parameter that is proposed to evaluate drainability is the water retention capacity of the compacted base layer under 7 KPa (1 psi) of soil suction or capillary pressure.

The amount of water retained by the specimen under 7 KPa of soil suction is used to estimate the degree of saturation at the end of the test. The calculations are based on the following relationship:

$$Saturation\ (\%) = \frac{V_W}{V_v} \qquad \textbf{(3.4)}$$

where V_W is the volume of water retained, and V_v is the volume of voids in the specimen. This volume of voids is calculated as follows:

$$V_v = V_T - V_S \qquad \textbf{(3.5)}$$

where V_T is the total volume of the specimen and V_S is the volume of the solids. The degree of saturation obtained by this method for an applied soil suction of 7 KPa (1 psi) has been used to characterize the water retention capacity. Detailed protocols proposed for this test are presented in Appendices A and B. Appendix A includes the protocol for the test of dense-graded base materials. Appendix B includes the protocol for the test of cement-stabilized gravel.

PERMEABILITY CHARACTERISTICS

The determination of the saturated coefficient of permeability of base materials is difficult because almost each material requires an specific set-up to ascertain that the measurements of head loss and flow rates can be performed under reasonable conditions. Due to the large coefficient of permeability of base materials and the large diameter of the specimens (150 mm; 6 inches), one of the main logistics problems is the supply of the de-aired water needed to perform the test.

Sketches of the permeability setups assembled are shown in Figures 3.3 and 3.4. The de-airing system consists of a 50 gallon steel drum with a line of misters. The de-aired water is prepared by misting water within the de-airing tank under a vacuum of 250 mm (10 inches) column of mercury. The production of 20 gallons of de-aired water requires from four to six hours. Upon preparation of the 20 gallons of de-aired water the de-airing tank is kept under vacuum continuously. The water is removed from the drum to a water pumping system by alternatively applying vacuum and compressed air into a cell-bladder system. In this fashion, the de-aired water is pumped to storage tanks. From these storage tanks, the water moves by gravity to the constant head tank that supplies the inflow to the permeability cell. The de-aired water is prevented from coming in contact with atmospheric air until it reached the constant head tank.

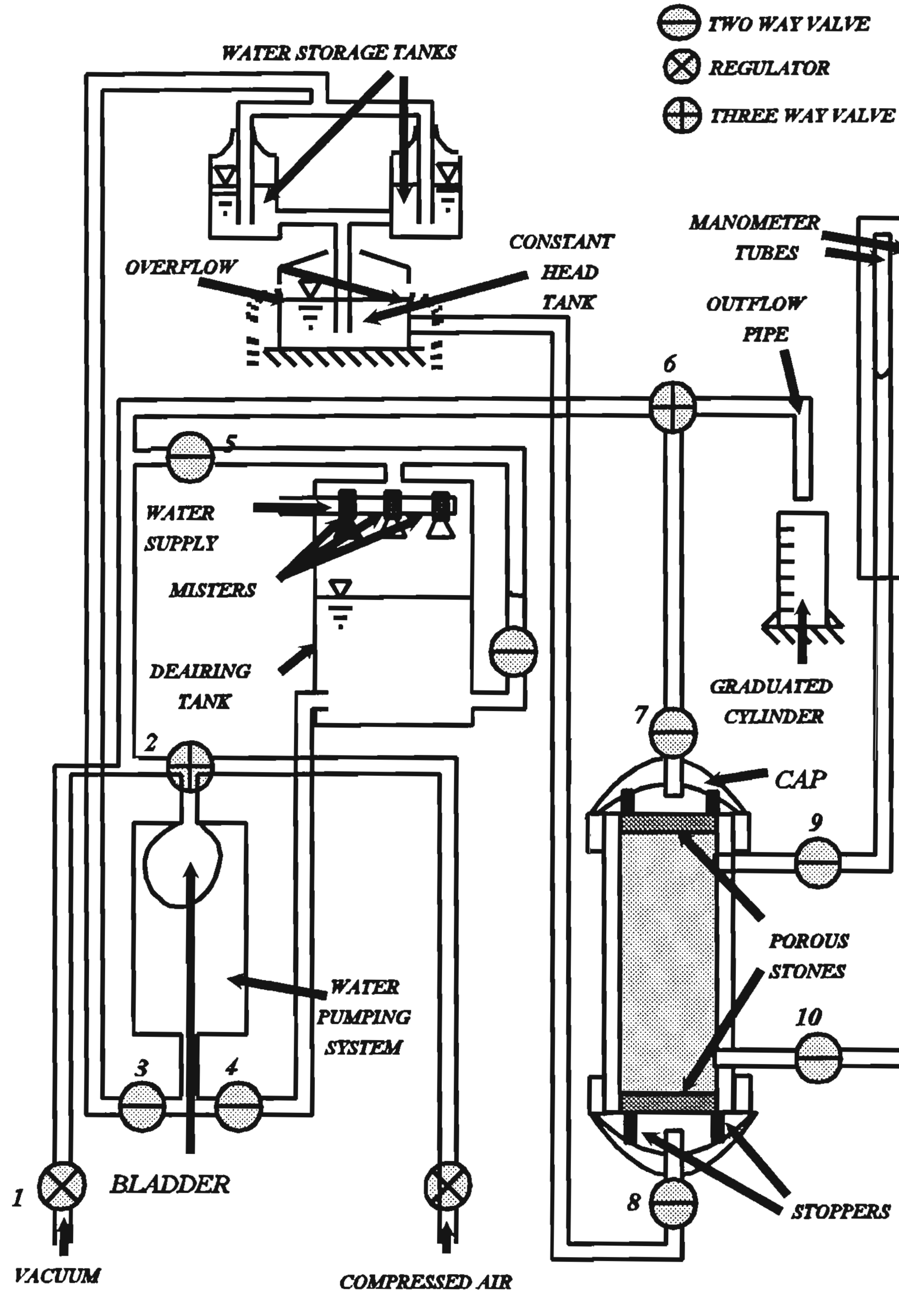

Figure 3.3 Permeability Test Setup for Dense-Graded Base Materials

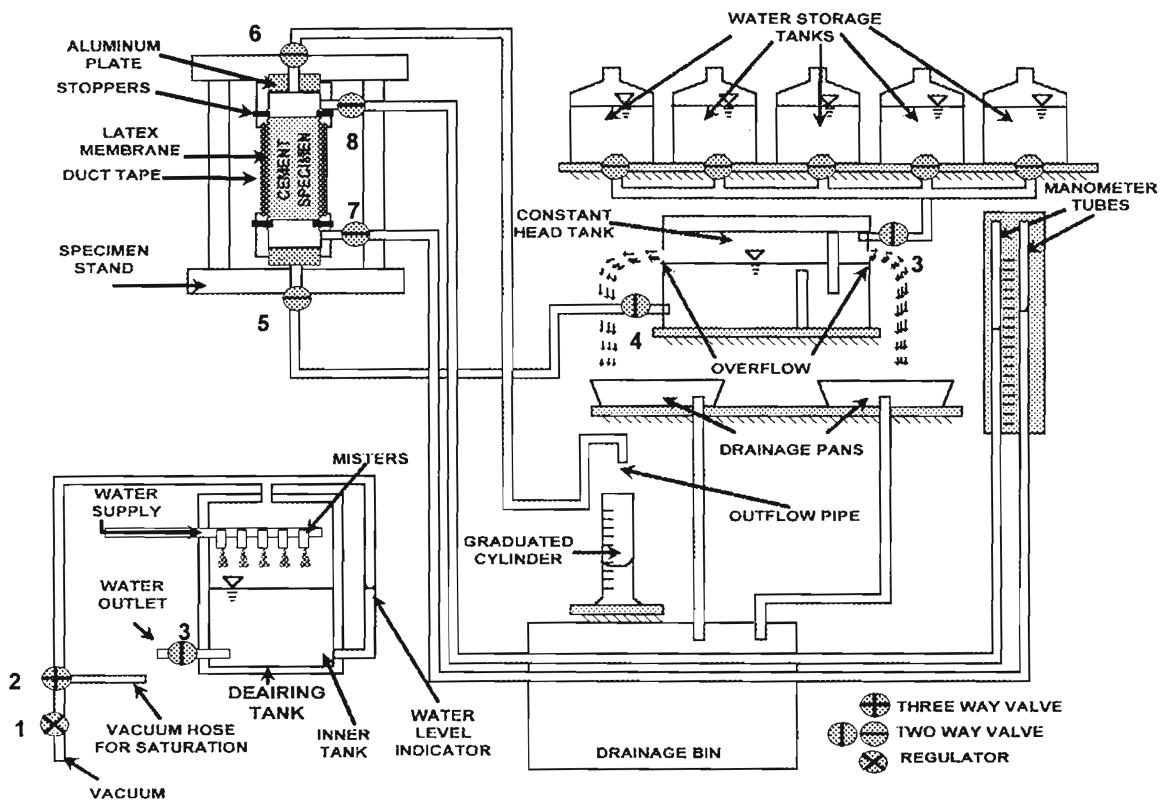

Figure 3.4 Permeability Test Setup for Cement Stabilized Base Materials

Different permeability cells are used for the different materials. For the dense-graded base materials, the cell consists of a 300 mm (12 inches) long section of schedule 40 PVC pipe of 150 mm (6 inches) inside diameter. The specimen is compacted in this mold in lifts similar to the specimen for the resilient modulus test. At the ends of the specimen, two manometer tubes are installed to measure piezometric head losses. The distance between centers of the manometer tubes is 220 mm (8.5 inches). At each manometer location, a mesh was embedded around the inside of the permeameter. The openings for the manometer tubes are further covered by a geotextile patch. The specimen is confined at the top and bottom with porous stones. The permeability cell is closed with pipe caps that are sealed with silicone rubber.

For the specimens of open-graded base materials, this set-up is insufficient to produce any measurable head loss between the two manometer tubes. The specimens of cement-stabilized gravel could not be compacted in the mold since the cement paste clogs the porous mesh and geotextile connections for the manometer tubes. For these specimens, the compaction, setting, and curing are performed in an auxiliary mold. The cured specimen is then wrapped with a rubber membrane that is confined on the specimen by producing negative pore water pressures (below atmospheric pressure) within the specimen. This effect is achieved by raising the specimen above the water level in the constant head tank as indicated in Figure 3.4.

Each specimen is first saturated and then subjected to the constant head permeability test. The saturation of each specimen is accomplished by applying vacuum to the top of the specimen while a minute flow of water is allowed by a valve on the bottom cap of the permeameter. Upon the water filling the top of the permeability cell, the vacuum is stopped, and the flow of water is started and maintained for some time. At the end of an hour or so, the outflow pipe is moved above the storage tanks to prevent any further flow and the specimen is left overnight under a column of water of about 2 m (6 ft).

The next morning, the water flow is initiated again and the manometer tubes are connected. Upon reaching an stable condition, the top and bottom valves are closed; thus, the specimen is isolated. The degree of saturation achieved in the specimen is checked by raising the specimen about 300 mm (1 ft) and measuring the associated rise of the water levels within the manometer tubes. Any rise of the water levels within the manometer tubes is attributed to expansion of air bubbles present within the system. The degree of saturation is calculated based on the ideal gas laws. It was systematically required that a 98% degree of saturation be achieved before proceeding with the constant head permeability test.

The constant head permeability test is initiated by allowing water into the bottom of the specimens and measuring the outflow on the top of the specimen. For the test on the dense graded bases the specimen is always kept under positive pore water pressure to ensure saturation at all times. The flow rates are measured for very small drops in head on the order of millimeters to produce hydraulic gradients of the same order of magnitude than those expected to occur in the base layers in service. The coefficient of permeability is calculated using Darcy's law:

$$k = \frac{Q}{A * t * i} \tag{3.6}$$

where "k" is the coefficient of permeability, "Q" is the volumetric flow, "A" is the bulk cross section area of the specimen, "t" is the time for the volumetric flow, and "i" is the hydraulic gradient. The hydraulic gradient is obtained by dividing the head loss between the manometer tubes by the distance travelled by the water between the centers of the two tubes at the connecting point on the permeameter wall. This equation (3.6) is valid only if the water flow occurs under laminar flow conditions.

The fluid flow through a porous medium can be characterized in terms of the dimensionless Reynolds Number, R_e and a friction factor, λ given by the following relationships (Jones and Jones, 1989):

$$R_e = \frac{\rho q d}{\mu} \tag{3.7}$$

and

$$\lambda = \frac{(\frac{\Delta p}{\Delta L})d}{2\rho q^2} \tag{3.8}$$

where ρ	=	density of fluid	μ	=	absolute viscosity
q	=	discharge velocity	Δp	=	pressure loss over length ΔL
d	=	characteristic diameter			

For laminar flow, log λ varies linearly with log R_e. The linear relation breaks down for R_e greater than 10 but for some materials this threshold may be lower than 1. At higher velocities, a transitional flow occurs which can be characterized by the following equation:

$$i = aq + bq^2 \tag{3.9}$$

where "i" is the hydraulic gradient, "q" is the discharge velocity, and "a" and "b" are constants.

A fundamental difficulty in applying Reynolds Number to soils is the choice of the characteristic diameter "d". Thus the validity of Darcy's law for a particular compacted material is best examined from experiment. It has been shown (Jones and Jones, 1989) that Darcy's Law is valid only for hydraulic gradients less than about 0.05 for base materials. To identify the laminar flow region in the present study, it was decided to plot the hydraulic gradient "i" versus the discharge velocity "q" data and fit a curve of the type of equation 3.9 to identify the parameters "a" and "b".

The inverse of constant "a" is the saturated coefficient of permeability. Evidence of turbulent flow, even in dense-graded base materials, was manifested from the very early stages of the permeability test. This fact further imposed the need to measure flow rates under very minute head losses.

Proposed new protocols including detailed testing procedures to perform the permeability test are presented in Appendices C and D. Appendix C consist of the detailed test procedure to determine the saturated coefficient of permeability of dense-graded base materials. Appendix D includes the detailed test procedure for cement-stabilized gravel.

CHAPTER 4

DENSE-GRADED MATERIALS

INTRODUCTION

This chapter describes the selection process followed to determine the base materials commonly used throughout the State of Texas. The results of the stability and drainability tests performed on the selected base materials are also reported in this chapter. Finally, a discussion of test results and selection of alternative materials are also included in this chapter.

MATERIAL SELECTION

This section describes the process followed to select the representative base materials used in the present study. *The selection process has been transcribed from Nazarian et al. (1996). This material was included for the sake of completeness.*

The first step in the selection process was to identify the base materials most commonly used in the state. Based on this information, the type, source and quantity of materials needed were identified.

A questionnaire was first prepared and distributed to all district laboratory engineers. The results from the 23 responses was organized in a database and analyzed. The findings were as follows: out of approximately 80,000 miles of highway included in the survey, about 92 percent are flexible pavements and 8 percent are rigid pavements. As shown in Figure 4.1, approximately 74 percent of the bases are constructed using granular materials (i.e. limestone, iron-ore, gravel, caliche). The rest are either treated with lime (about 12 percent) or cement (about 8 percent) or asphalt (about 5 percent). Figure 4.2 shows the distribution of the granular base materials used in the state. Approximately one-half of the base materials are limestone. The other materials are iron-ore (about 15 percent), caliche (about 11 percent), and gravel (about 7 percent).

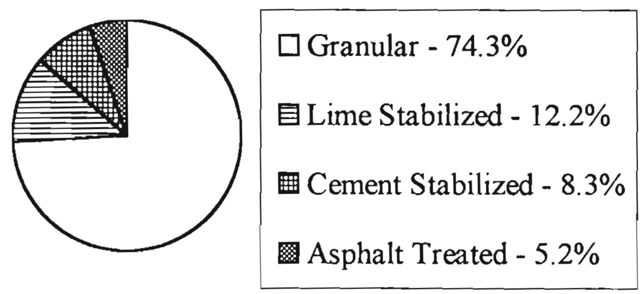

Figure 4.1 Distribution of Base Material Types Used in Texas Highways

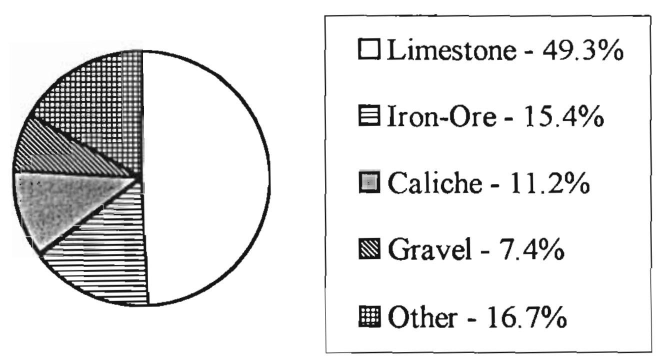

Figure 4.2 Distribution of Granular Base Material Types Used in Texas Highways

The primary consideration in selecting a material for a base course is the availability of such material in the district. Other factors, such as the traffic volume, pavement type and subgrade type are also considered, especially when the base is destined to be treated or stabilized.

Based upon the information gathered, ten base samples were requested from ten different districts and nine of the ten districts graciously provided the materials. The index properties of these materials are described in the next section. The materials provided consisted of limestone in five cases, caliche in two cases, one iron-ore, and one sand and gravel.

CHARACTERIZATION OF BASE MATERIALS

For identification purposes, the nine base materials were subjected to the following index tests:

1) Sieve Analysis (Tex-110-E),
2) Liquid limit test (Tex-104-E),
3) Plasticity index (Tex-106-E), and
4) Moisture-Density Relationship (Tex-113-E).

The classification of these nine base materials along with index properties, such as Atterberg limits and gradation, maximum dry density, and optimum moisture content are presented in Table 4.1. The gradations of the selected nine base materials are shown in Figure 4.3. As per the AASHTO soil classification system, all the base materials can be classified as A-2-4. The USCS classification system classifies base materials as gravel (except Odessa which is classified as sand). Out of the five limestones, two (Paris and San Angelo Districts) were well-graded gravel, one (Brownwood District) was well-graded silty gravel, one (El Paso District) was well-graded clayey gravel, and the other one (San Antonio District) was clayey gravel. One caliche (Corpus Christi District) was classified as well-graded gravel and the other caliche (Odessa District) as a silty clayey sand. The other two materials (iron-ore and sand and gravel) were classified as silty gravel (Tyler District) and the other one as well-graded silty gravel.

The optimum moisture content for limestones ranged from 3.8 percent to 7.9 percent. The material from Brownwood District had the lowest optimum moisture content and the materials from Paris and San Antonio Districts had the highest values. The maximum dry unit weight of these materials ranged from 20.4 KN/m^3 to 23.9 KN/m^3. The material from the Paris District had the lowest dry unit weight and the one from San Antonio District had the highest dry unit weight.

For the caliche base materials, the material from Odessa District had an optimum moisture content of 4.3 percent and the one from Corpus Christi District 17.8 percent. The maximum dry unit weight of the former was 21.0 KN/m^3 and the latter was 16.6 KN/m^3. The iron-ore material from the Tyler District had a maximum dry unit weight of 22.9 KN/m^3 at an optimum moisture content of 7.8 percent. The sand and gravel base (Childress District) had a maximum dry unit weight of 21.6 KN/m^3 and an optimum moisture content of 5.5 percent.

The liquid limits for the limestone materials varied from 16 percent to 24 percent. The plasticity index for the limestone materials varied from 3 to 10 percent. The liquid limit and plasticity index for caliche material varied from 24 to 35 percent and 1 to 6 percent, respectively.

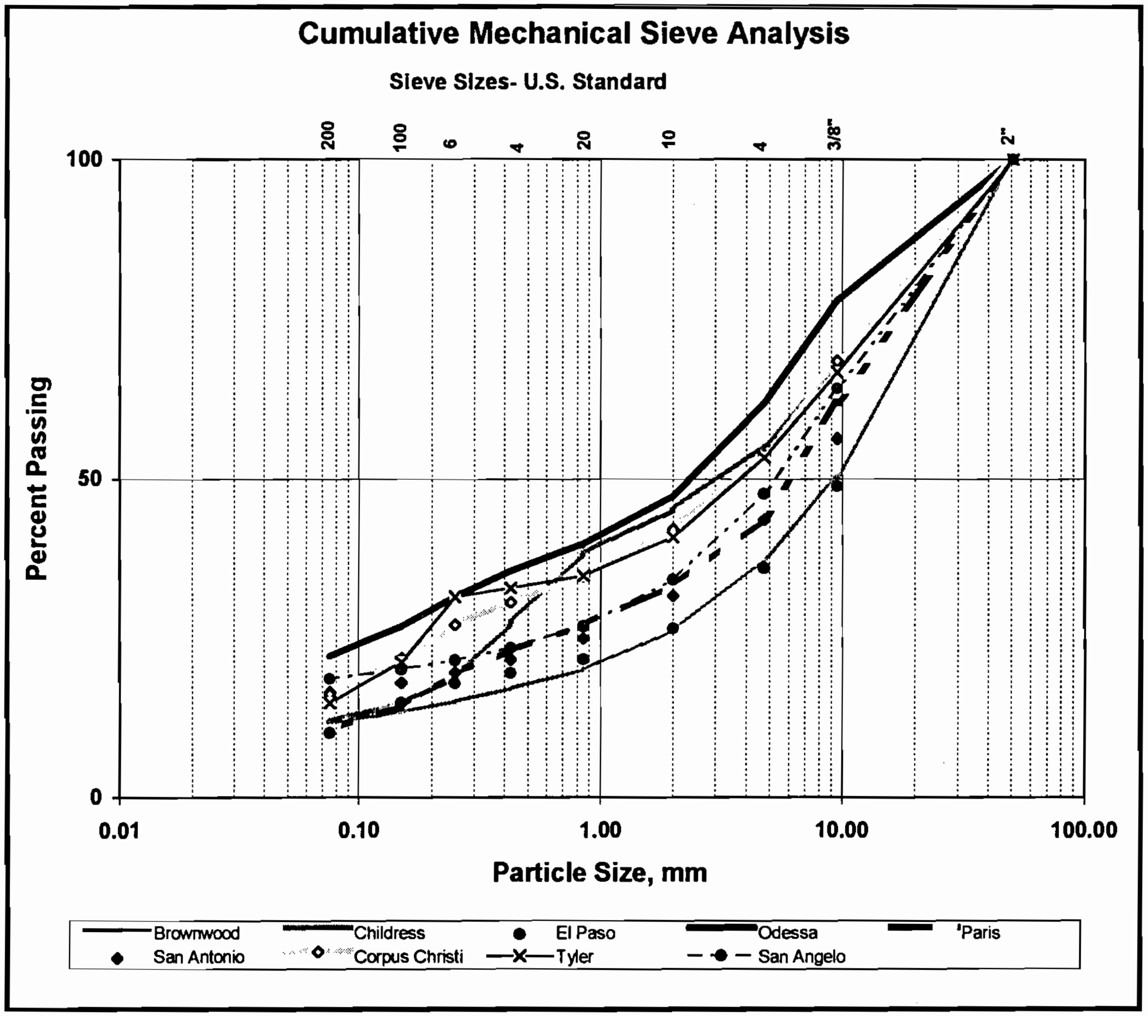

Figure 4.3 Gradation of the Nine Selected Texas Base Materials

Table 4.1 Index Properties of the Selected Nine Base Materials

District	Type	LL	PL	PI	Gradation (Percent Passing) Sieve #4	Sieve #40	Sieve #200	Optimum Moisture Content (%)	Maximum Dry Unit Weight, KN/m^3
Brownwood	Limestone	21	14	7	37	17	12	3.8	23.3
Childress	Sand and Gravel	14	12	2	55	27	12	5.5	21.6
Corpus Christi	Caliche	35	34	1	54	31	16	17.8	16.6
El Paso	Limestone	24	16	8	36	19	10	5.4	22.9
Odessa	Caliche	24	18	6	62	36	22	4.3	21
Paris	Limestone	21	18	3	44	23	11	7.9	20.4
San Angelo	Limestone	16	13	3	48	23	19	6.5	22.9
San Antonio	Limestone	24	14	10	43	22	17	7.5	23.9
Tyler	Iron-Ore	19	17	2	53	33	15	7.8	22.9

The maximum liquid limit (35%) was obtained for the caliche from Corpus Christi District. The minimum liquid limit (14%) was obtained for the sand and gravel material from the Childress District.

EVALUATION OF DENSE-GRADED BASE MATERIAL

Compacted specimens of the selected nine base materials were subjected to stability and drainability tests. The specimens were compacted at optimum water contents to simulate the dense-graded base layers built in the State of Texas.

The specimens prepared with base material from El Paso District were the first specimens subjected to all the evaluation tests. This material was more readily available and, thus, allowed to build numerous specimens needed to identify problems with test set-ups and/or procedures.

Water Retention Test Results

The partial results of the water retention tests performed on El Paso material are shown in Figure 4.4. This figure shows the changes in the amount of water retained in the specimen with time. The specimen lost approximately 500 grams of water under 7 KPa (1 psi) air pressure. However, the losses of water due to increasing air pressures to 21 KPa (3 psi) or 35 KPa (5 psi) amount to less than 25 grams. These results indicate that the specimens of El Paso material remained nearly saturated at all three air pressures. It is worth noticing that equilibration under 7 KPa took approximately 500 hours. This anomaly was attributed to migration of fines forming a layer on the high air entry porous stone. Nevertheless, this fact imposed the need to prolong equilibration times to make sure that constant mass had been reached.

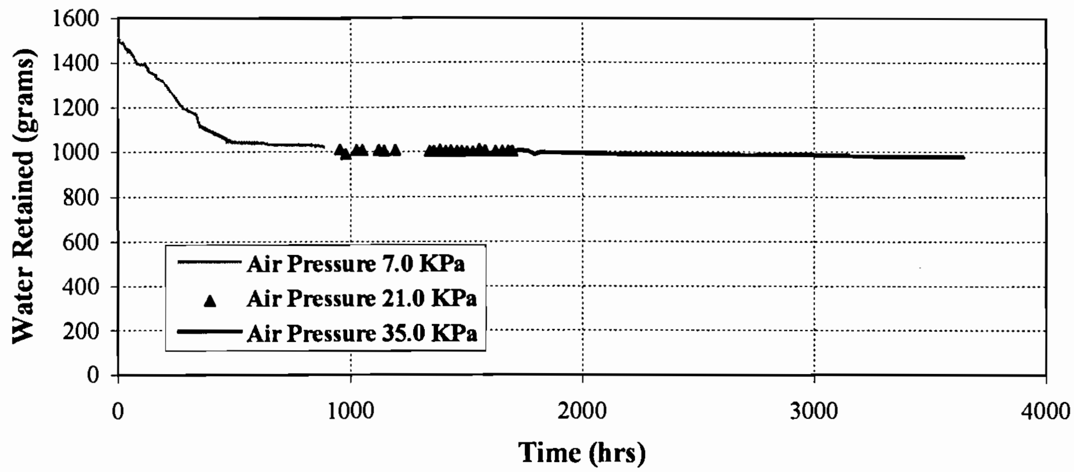

Figure 4.4 Water Retention Test Results of El Paso Base Material

The complete set of results is presented in Appendix E. The degree of saturation, after equilibration to 7 KPa, of duplicate specimens of all the base materials are summarized in Table 4.2. All the specimens remained more than 50% saturated. On the average three materials showed 100% saturation, four materials showed more than 70 % saturation, and the rest showed more than 60% saturation.

The results obtained on repeated specimens shown in Table 4.2 indicate significant variability in some cases. In an attempt to identify potential sources of this variability, all the base material was recovered from the water retention test set-up after performing the test. Grain size distribution analyses were performed on all the material of each specimen. The comparison of the gradation charts for the duplicate specimens indicated some variability in the gradation that could explain the differences in water retention capacities reported in Table 4.2. The differences in gradation observed in the duplicate specimens can be indicative of the type of variability to be expected under field construction conditions. Thus, it is reasonable to expect that the water retention capacities of dense-graded base layers compacted with these materials will have zones of very high water retention capacities and other areas with moderate to high water retention capacities.

These results indicate that the suction of a 71 cm (28 inches) column of water cannot remove significant amounts of the pore water held in the specimens. The height of the water column inducing the emptying of the pores in the field is with a reasonable certainty not going to exceed the 71 cm (28 inches) used in the present laboratory tests. Thus the results shown in Table 4.2 indicate that the majority of the water retained by the base specimens is held in small capillaries that will not empty by gravitational forces alone.

Table 4.2 Water Retention Capacity of the Selected Nine Base Materials

District	Type	Degree of Saturation (%)		
		Specimen No.		Average
		1	2	
Brownwood	Limestone	74	63	69
Childress	Sand and Gravel	100	100	100
Corpus Christi	Caliche	100	100	100
El Paso	Limestone	100	100	100
Odessa	Caliche	86	100	93
Paris	Limestone	52	68	60
San Angelo	Limestone	85	55	70
San Antonio	Limestone	73	86	80
Tyler	Iron-Ore	100	65	83

Permeability Test Results

The complete set of all the tests performed on the nine selected base materials are included in Appendix F. The results obtained on compacted specimens of El Paso base material are also shown in Figure 4.5. These results show that the coefficient of permeability decreases for increasing hydraulic gradient. According to AASHTO T 215-70, the hydraulic gradient should be between 0.2 and 0.5 to obtain a laminar flow. Jones and Jones (1989) have suggested that the hydraulic gradient should be lower than 0.05 to have a laminar flow when testing base materials. The results shown in Figure 4.5 suggest that the flow is turbulent even for hydraulic gradients well below 0.05.

To dwell more into this aspect, a plot of hydraulic gradient (i) versus discharge velocity (q) for El Paso base material was also generated and is shown in Figure 4.6. The data is for the same test illustrated in Figure 4.5. The discharge velocity (q) exhibits laminar flow (linear relationship) conditions at low hydraulic gradients and shows transitional flow (nonlinear relationship) at high hydraulic gradients. The results shown in Figure 4.6 suggest that the threshold is a discharge velocity of 0.01 cm/sec. The saturated coefficient of permeability is the inverse of constant "a" in equation (3.9). This equation (3.9) was fitted by regression to all the experimental data points obtained on each specimen.

The saturated coefficients of permeability obtained on replicate specimens of the nine selected base materials, are summarized in Table 4.3. The coefficient of permeability ranged from 0.07 to 1080 m/day (0.3 to 3543 ft/day). Except for one specimen of the San Antonio base material, the rest of materials had coefficients of permeability lower than recommended by FHWA (A minimum of 300 m/day [1,000 ft/day] is required for drainable bases). The specimens of Paris, San Angelo, and San Antonio materials showed coefficients of permeability higher than 100 m/day (328 ft/day). The rest of the base materials had very low permeabilities. On the average Corpus Christi, Odessa, and Tyler materials had coefficients of permeability lower than 5 m/day (16 ft/day). Corpus Christi and Tyler materials have also showed (Table 4.2) very high water retention capacities.

It is important to notice the amount of variability indicated by the coefficient of permeability (Table 4.3) as it compares to the variability observed for the water retention capacity test. The water retention capacities shown in Table 4.2 increased by 30 to 50 percent from one specimen to the replicate specimen. The same materials sampled and compacted in similar fashion yield coefficients of permeability that increase by factors of 3, 4, even 10 in some cases. This comparison is indicating that the coefficient of permeability is much more variable or sensitive to features such as one or few macro pores than the water retention capacity. These features can conduct a lot of water through the specimen while on a volume bases only represent a small fraction of the total pore volume of the compacted base specimen. These observations also support the recommendation of the present study that the use of water retention capacity provides a more reliable measure of the drainability of a base layer.

The coefficient of permeability reported in Table 4.3 indicate that none of the nine selected base materials yield consistently a base layer that could be considered a drainable base by FHWA standards. Thus based on the results of this experimental program, it can be concluded that all base materials currently used in Texas should be modified to increase drainability.

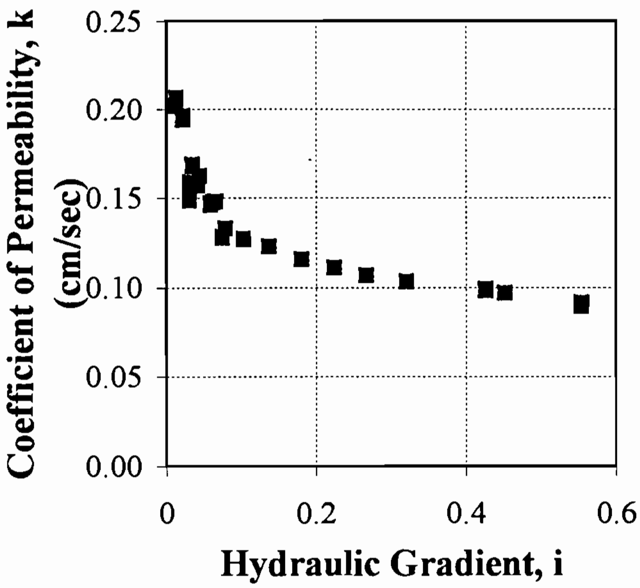

Figure 4.5 Variation in Coefficient of Permeability with the Hydraulic Gradient for El Paso Base Material

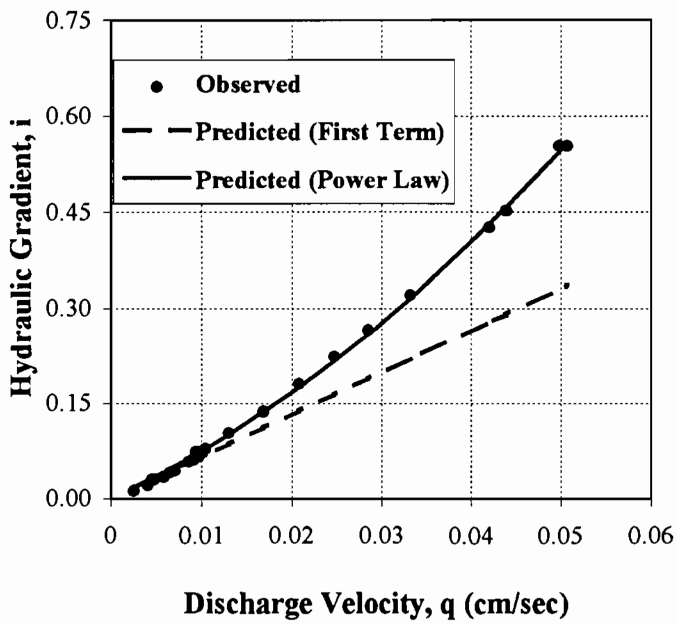

Figure 4.6 Discharge Velocity and Hydraulic Gradient Relationship for El Paso Base Material

Table 4.3 Coefficient of Permeability of the Selected Nine Base Materials

District	Type	Coefficient of Permeability, m/day (ft/day)		
		Specimen No.		Average
		1	2	
Brownwood	Limestone	59 (194)	21 (69)	40 (131)
Childress	Sand and Gravel	0.3 (1)	75 (246)	37.7 (124)
Corpus Christi	Caliche	0.1 (.3)	0.1 (.3)	0.1 (.3)
El Paso	Limestone	1.1 (3.6)	130 (426)	66 (217)
Odessa	Caliche	5 (16)	2 (7)	3.5 (12)
Paris	Limestone	796 (2,611)	26 (85)	411 (1,348)
San Angelo	Limestone	176 (577)	123 (403)	149.5 (1,608)
San Antonio	Limestone	1,080 (3,543)	213 (699)	646.5 (2,119)
Tyler	Iron-Ore	0.3 (1)	6 (20)	3.2 (10)

Stiffness and Strength Test Results

Specimens were compacted and tested for stiffness and strength following the procedure described in the previous chapter. Specifically, the specimens were compacted at optimum water contents. The specimens were tested under dynamic loads to obtain resilient modulus of the material, and under static loads to obtain elastic modulus and ultimate strength of the material.

The constitutive used to describe the results of resilient modulus test is the following:

$$M_R = k_1 \sigma_d^{k2} \sigma_c^{k3} \quad \textbf{(4.1)}$$

where σ_d and σ_c are the deviatoric stress and confining pressure, respectively. The parameters K_1, K_2, K_3 are statistically determined by fitting the experimental data.

Test parameters obtained for all the materials are summarized in Table 4.4. A more complete set of data can be found in Nazarian et al. (1996). A testing sequence for different deviatoric stresses and confining stresses was used to develop the constitutive model. The R^2 for the regression analyses were high indicating good correlations. The parameter k_2 of the model shows very low positive or negative values, indicating that the resilient modulus is essentially independent of confining pressure "σ_c" in the range of confining pressures tested.

The results of the unconfined compressive strength on a specimen of El Paso material are shown in Figure 4.7. The initial tangent modulus was calculated from the stress strain relationship and the strength was recorded when the material failed. The base materials had been compacted at field moisture contents, which are significantly different than the optimum moisture contents listed in Table 4.1. The unconfined compressive strength data is summarized in Table 4.5. The numbers in parenthesis indicate the moisture content at which the specimens had been compacted.

The results presented in Tables 4.4 and 4.5 are thus not directly comparable. This is because the specimens of Table 4.4 had been compacted at the optimum water contents listed in Table 4.1. While the specimens used for the test listed in Table 4.5 had been compacted at field moisture contents.

It is interesting to notice the variability of the resilient modulus as judged by the variability of the K_1 parameter. The changes observed for replicate specimens range from almost identical values to increases of 30 to 50 %. These specimens had been sampled, moistened, and compacted in very similar fashion than the water retention and permeability test specimens. The variability described above is quite similar to the variability observed and described previously for the water retention test; but is in stark contrast to the variability described previously for the coefficient of permeability. This is attributed to the fact that the resilient modulus, as well as the water retention capacity, depend on average conditions of the specimen unlike the coefficient of permeability that is influenced by small features such as the presence of a few macro pores.

Table 4.4 Constitutive Parameters from Resilient Modulus Tests on the Nine Selected Base Materials

Material Type	District	Specimen	k_1	k_2	k_3	R^2
Lime-stone	Brown-wood	1	12548	0.022	0.711	0.999
		2	12548	0.20	0.710	0.999
		Average	12548	0.021	0.711	
	El Paso	1	58047	-0.010	0.420	0.999
		2	44670	0.000	0.460	0.999
		Average	51359	-0.005	0.440	
	Paris	1	67205	-0.010	0.330	0.996
		2	39312	-0.010	0.430	0.999
		Average	53259	-0.010	0.380	
	San Angelo	1	77417	0.000	0.340	0.996
		2	51330	-0.010	0.470	0.998
		Average	64374	-0.005	0.405	
	San Antonio	1	67845	-0.010	0.400	0.999
		2	59695	-0.010	0.430	0.999
		Average	63770	-0.010	0.415	
Caliche	Corpus Christi	1	155258	-0.040	0.020	0.999
		2	149874	-0.030	0.030	0.999
		Average	152566	-0.035	0.025	
	Odessa	1	231694	-0.040	0.000	0.999
		2	230308	-0.040	0.000	0.999
		Average	231001	-0.040	0.000	
Iron-Ore	Tyler	1	128396	-0.030	0.080	0.999
		2	129040	-0.020	0.070	0.999
		Average	128718	-0.025	0.075	
Sand & Gravel	Childress	1	39348	0.020	0.340	0.967
		2	42748	0.010	0.350	0.946
		Average	41048	0.015	0.345	

Notes:

1)

$$M_R = k_1 \sigma_d^{k2} \sigma_c^{k3}$$

2) M_R in MPa and σ_d and σ_c in KPa.

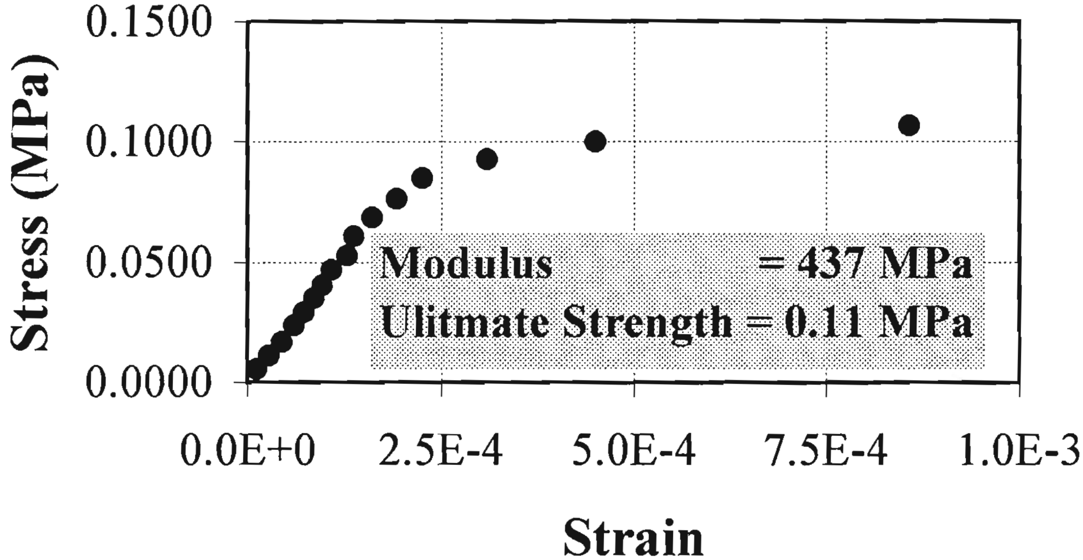

Figure 4.7 Results of Unconfined Compressive Strength Test on El Paso Base Material

Table 4.5 Unconfined Compressive Strength Test Results on the Nine Selected Base Materials

District	Type	Unconfined Compressive Strength, MPa	Elastic Modulus (Compression), MPa
Brownwood	Limestone	Not Tested	Not Tested
Childress	Sand and Gravel	0.16 (3.2%)*	578 (3.2%)
Corpus Christi	Caliche	0.19 (19.1%)	391 (19.1%)
El Paso	Limestone	0.11 (3.1%)	437 (3.1%)
Odessa	Caliche	0.215 (6.8%)	1119 (6.8%)
Paris	Limestone	0.17 (10.5%)	154 (10.5%)
San Angelo	Limestone	0.20 (7.8%)	148 (7.8%)
San Antonio	Limestone	0.19 (7.0%)	145 (7.0%)
Tyler	Iron-Ore	0.12 (10.2%)	76 (10.2%)

* Numbers in parenthesis indicate the compaction moisture content

CHAPTER 5

OPEN-GRADED BASE MATERIALS

INTRODUCTION

The results of the tests performed on OGBM are presented in this chapter. The tests were performed only on OGBM from El Paso base material. The stiffness and strength of these materials are too low to be a feasible alternative for permeable base.

MATERIAL SELECTION

To improve drainability, it was decided to remove fines from the existing base material. Four different types of OGBM were selected: 1) Type I (no fines i.e., no material passing sieve no. 200), 2) Type II (no fines and no fine sand i.e., no material passing no. 40 sieve), 3) Type III (no fines and no fine and medium sand i.e., no material passing no. 10 sieve), and 4) Type IV (no fines and no sand i.e., no material passing no. 4 sieve).

The El Paso base material was dry sieved and then the material retained on each sieve was washed on sieve number 200 to remove fines. The washed material retained on each sieve were kept in separate bins. This process was continued until sufficient material had been stocked. This washed materials were then used for preparation of specimens, by mixing the corresponding percentages of the materials retained on the appropriate sieves. Nevertheless, at the beginning of the test program some specimens were prepared with components that had not been washed but exclusively dry sieved.

SOIL WATER RETENTION CAPACITY

The results of water retention capacity tests are summarized in Table 5.1. These results show a larger variability than the test performed on DGBM. To explain this variation, after completing the water retention test the specimen was recovered and subjected to a wet sieve analysis. The grain size distributions obtained from these analyses indicated that the specimens with higher content of the fraction passing number 200 sieve showed higher retention capacities. For example, specimen no.1 (Type I) had approximately 16% passing number 200 sieve, while it was only 3% for specimen number 2.

Table 5.1 Water Retention Capacity of OGBM (El Paso)

Type	OGBM Description	Degree of Saturation (%)		
		Specimen No.		Average
		1	2	
I	No Fines	56	37	47
II	No Fines and No Fine Sand	82	41	62
III	No Fines and No Medium and Fine Sand	9	22	16
IV	No fines and No Sand	10	19	15

Similarly, specimen number 1 (Type II) had 5% passing number 200 as compared to 1.6% for specimen number 2. The same reasoning is valid for the other two combinations as well. The results shown in Table 5.1 indicate higher water retention capacities for Type II materials than for the Type I; when it would be expected that the water retention capacities would be higher for Type I rather than Type II. The grain size distributions of Type I, II, III, and IV material for both specimens are shown in Figure 5.1. The gradation chart clearly shows that the Type I is more open-graded than the Type II material. This indicates that poor sampling had caused the problem of higher water retention capacity for the Type II material.

The results shown in Table 5.1, in combination with the gradation data of Figure 5.1, indicate that if the fines have been removed (by washing the base material); it is possible to reduce the water retention capacity to degrees of saturation of 10 to 15 percent for the OGBM of Types III and IV. This implies the removal of all particles passing sieves number 10 or number 4.

STIFFNESS AND STRENGTH CHARACTERISTICS

Specimens of open-graded materials were compacted and tested to identify the stiffness and strength characteristics. First the resilient modulus test was performed on specimens of Type I material. The specimen failed during the testing sequence. The dense-graded material for El Paso had showed resilient moduli of up to 400 MPa at a confining pressure of 140 KPa and for deviatoric stresses of 210 KPa. The Type I material specimen failed under a confining pressure of 70 KPa and for a deviatoric stress of 42 KPa. The resilient moduli had reduced to 30 MPa.

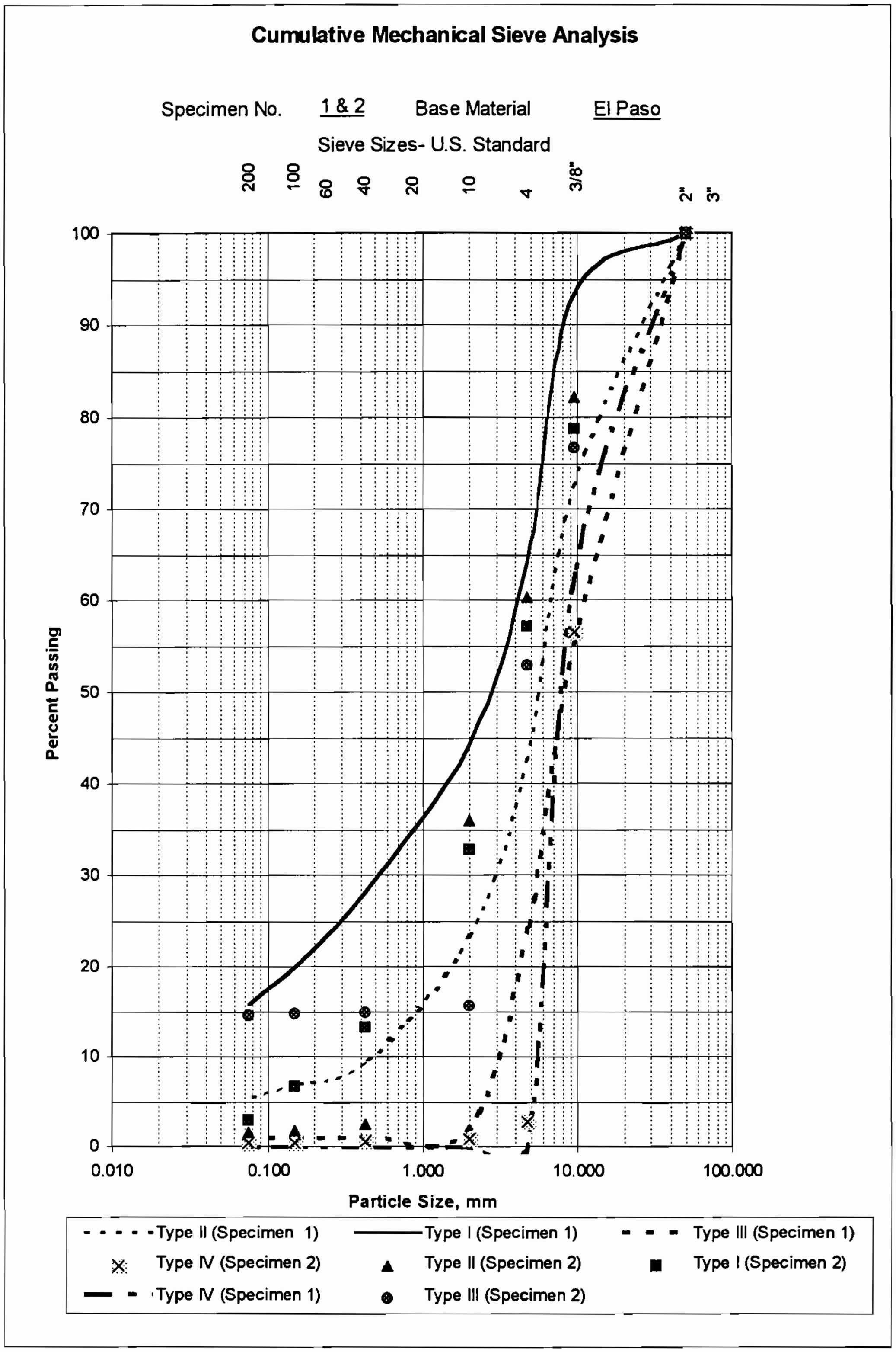

Figure 5.1 Gradations of Recovered Specimens of El Paso OGBM

This loss of stiffness can be attributed to the removal of fines. To justify this line of reasoning, it was decided to prepare specimens using stock material dry sieved. Because, the soil water retention test results had indicated that this stock contained some fines. The specimens prepared with dry sieved material showed higher stiffness, a resilient modulus of 100 MPa, but still failed upon the application of 60 KPa deviatoric stress under a confining pressure of 105 KPa. Since both specimens of OGBM failed, no unconfined compressive strength tests were performed. Specimens of Type II, III, and IV materials were not prepared, because the removal of sand would have created an even less stable material.

These stiffness tests show an extensive reduction in the stability of the OGBM even with only the removal of fines i.e. the fraction passing number 200. This lead to the believe that OGBM without stabilization will fail during construction or prematurely under traffic.

PERMEABILITY CHARACTERISTICS

The setup used to measure the coefficient of permeability of the dense-graded specimens was not appropriate for the open-graded materials. The main problem was that no measurable head loss was occurring between piezometric tubes and, thus, no hydraulic gradient could be measured. Various researchers have tried different test setups for OGBM but repeatability of these tests has been extremely poor. The development of a new setup was prohibitive in view of the project time frame. Nevertheless, the results would have not been beneficial to this project due to poor stiffness and strength of these materials. Hence, it was decided not to pursue any further the measurement of permeability characteristics of the open graded materials.

DISCUSSION

Four types of open-graded materials were selected to be used as potential permeable base materials. Only material from El Paso District was used as a source for this analysis. The test results indicated that the Type IV material (i.e., no material passing number 4 sieve) had a minimum water retention capacity and from the drainage point of view could be used as a permeable base material. However, the stiffness test results indicated that the removal of the fraction passing number 200 sieve (TYPE I material) results in an extreme reduction of the stiffness of compacted specimens. The loss of stiffness would be larger for a Type IV material than for Type I material. Thus, even though the Type IV material could be appropriate from a drainage point of view, the low stiffness and strength of this material precludes it from being used as a base material. These considerations lead to believe that the improved drainability and sufficient stiffness can only be achieved by stabilizing the OGBM.

CHAPTER 6

CEMENT-STABILIZED BASE MATERIALS

INTRODUCTION

The results of the tests performed on cement stabilized base material (CSBM) are presented in this chapter. The tests were performed on three different materials. The main reason being that since only the gravel fraction was used, there are only three different sources of material in the present study: 1) limestone, 2) caliche, and 3) sand and gravel.

MATERIAL SELECTION

The test results described previously on open-graded materials showed that the removal of fines and sand from the DGBM will improve drainability. However, the resilient modulus tests indicated that the removal of fines also reduces the stiffness. This led to believe in the need for stabilization of the OGBM to retain drainability and increase stiffness.

The base material could be stabilized either with portland or asphalt cements. The portland cement was selected as the stabilizing agent due to the following reasons:

1) Stabilization with portland cement was cheaper than using asphalt cement. The cost of cement stabilized material was roughly about \$39 per m^3 (\$30 per yd^3) while the asphalt stabilized material cost was roughly about \$47 per m^3 (\$36 per yd^3). This cost analyses is based on information provided by Jobe Concrete of El Paso, Texas.
2) Another factor to consider was the potential stripping of asphalt from the asphalt concrete mixture. The asphalt stabilized material may not have been a problem for a rigid pavement, because the strength of the base material is of more importance during the construction rather then after the concrete layer has been poured. However, for asphalt concrete pavements, the base layer is designed to carry the traffic loads and stripping of the asphalt stabilized base layer could result in failure under the traffic loads.

After selection of stabilizing agent, it was necessary to identify the amount needed for a permeable base. A literature survey of existing practices (Hall, 1994b) indicated that most of the agencies have used 90-180 Kg/m^3 (or 150-300 lb/yd^3) of cement for the stabilization of permeable base materials. To prepare specimens in the laboratory, it was more convenient to identify the cement requirement as a percent by weight of the base material. The Kg/m^3 information was converted to percent by weight of the OGBM material. Cement contents of 3%, 5%, and 7% were selected for the evaluation of the cement-stabilized open-graded materials. The 5% cement by weight translates to 95 Kg/m^3 (165 lb/yd^3) and the 7% cement in the specimen translates to 130 Kg/m^3 (230 lb/yd^3). Both of these combinations are well within the range suggested by the existing literature. The 3% cement content was selected to identify the possibility of lowering the construction cost of the permeable base. Water-cement ratios of 0.45 and 0.475 were used in the present study. The selection of these ratios was also based on the ranges suggested by previous researchers (Hall, 1994b).

The OGBM results indicated that a Type IV material (no fines and no sand) can be used to improve drainability. However, the loss of stability made it necessary to stabilize the OGBM. The stabilization of the base material could reduce the drainability as compared to the open-graded base material alone. Hence it was decided to eliminate all the material passing sieve number 3/8. The selection of this sieve as the cut off point was also based on the review of existing literature (Hall, 1994b).

The removal of material passing sieve number 3/8 resulted in just the gravel fraction. The nine selected DGBM had only four types of gravel: 1) Limestone, 2) Caliche, 3) Sand and Gravel, and 4) Iron-ore. Further investigation revealed that the usage of Iron-ore base material is declining because Iron-ore is not available any more. Hence only three materials were used in the present test program. Three gravel, three cement percentages, and two water cement ratios were selected. Specimens were prepared and cured. Then the specimens were subjected to similar tests as implemented on the nine selected base materials. The procedures followed for specimen preparation are provided in Appendix B (for water retention test) and Appendix D (for permeability test). The specimens for stiffness tests were prepared as the permeability test specimens but had three sets of steel targets inserted into them during compaction. Also, the strength and stiffness specimens were cured for 28 days as compared to 24 hrs for permeability or water retention specimens.

While performing stiffness and strength tests on limestone gravel, it was observed that the specimens with 3% cement were producing a lean stabilized material and the aggregate coating was poor (Even though the strength and stiffness were higher than for DGBM). This lead to the decision of not using 3% cement as an alternative material. Hence, soil water retention tests and permeability tests were not performed on specimens with 3% cement.

STIFFNESS AND STRENGTH CHARACTERISTICS

The complete set of all the tests performed on the selected cement stabilized materials are presented in Appendix H. The results obtained on the compacted specimens of stabilized base materials are summarized in Table 6.1. The parameters K_2 and K_3 indicate the influence of the deviatoric stress "σ_d" and the confining pressure "σ_c" on the resilient modulus. The values obtained from the regression analyses (Table 6.1) appear to have almost a random variability; some are positive, others are negative, and in general the absolute values are small. The correlation coefficients "R^2" are also listed in Table 6.1. They indicate quite a good fit of the regression line to the data points. All these considerations point to the fact that the variability of the results in the resilient modulus test cannot be explained by the dependence on deviatoric stress and/or confining pressure. From a phenomenological point of view, it can be expected that the resilient moduli of the CSBM should not be affected by confining pressure or deviatoric stress unless these can brake down the cement bonds. The stress levels applied during the test cannot break down the interparticle bonds and, thus, the variability observed can in all certainty be attributed to random testing errors.

Table 6.1 Constitutive Parameters from Resilient Modulus Tests of Cement Stabilized Gravels

Gravel Type	Cement (%)	Water-Cement Ratio	k_1	k_2	k_3	R^2
Limestone	5	0.45	96666938	-0.62554	-0.06235	0.96
		0.475	3622047	-0.107519	0.165294	0.73
	7	0.45	17873987	-0.046394	-0.110703	0.90
		0.475	1429804	-0.144798	0.427068	0.90
Caliche	5	0.45	10501146	-0.084457	-0.274227	0.95
		0.475	*	*	*	*
	7	0.45	67673323	0.144533	-0.302058	0.99
		0.475	1256652	-0.125351	0.308351	0.85
Sand and Gravel	5	0.45	8470931	0.019657	-0.07405	0.96
		0.475	34104605	-0.167408	-0.029829	0.79
	7	0.45	298543	0.276238	0.369332	0.71
		0.475	1273436	0.002577	0.07207	0.98

* Specimen failed during testing

Notes:

1) $$M_R = K_1 \sigma_d^{K_2} \sigma_c^{K_3}$$

2) M_R in MPa
σ_d in KPa
σ_c in KPa

3) All specimens were cured for 28 days.

These considerations suggested the need to fit a linear regression model to the stress versus induced strains data points irrespective of the confining or deviatoric stresses applied. The slope of the linear model is then an "average" resilient modulus for the material in Table 6.2. It is worth to point that the correlation coefficients for these linear regressions are very similar to those that had been obtained with the nonlinear regression model of Table 6.1.

The "average" resilient moduli of the dense-graded bases are shown in Table 6.2 in correspondence to the type of the material. These results clearly illustrate that the cement-stabilized gravel has resilient moduli 10 to 20 times larger than the dense-graded base. Thus according to these data, the cement stabilization has increased the stiffness of the base to levels more than adequate for the base to carry construction or traffic loads.

The elastic moduli (in compression) measured in unconfined compression tests are listed in Table 6.3. It is revealing to notice that the elastic moduli of CSBM are almost identical to the average resilient moduli of CSBM listed in Table 6.2. This observation further confirms the fact that the variability in the resilient modulus test results was the result of random testing errors; rather then the effect of changes in confining or deviatoric stresses. In summary, these considerations allow to consider the CSBM with 5% or 7% of cement as a linearly elastic material.

The average elastic moduli measured in unconfined compression tests of DGBM are also listed in Table 6.3. The elastic moduli of the CSBM are from 10 to 20 times larger than the elastic moduli measured on the specimens of DGBM of corresponding base material type.

The unconfined compressive strength of CSBM are presented in Table 6.4 in correspondence with the ultimate strengths about 5 to 10 times lower than the other two types of base, i.e., limestone or sand and gravel. For the caliche type base, the strength of CSBM is only about three times larger than the DGBM specimens while for limestone or sand and gravel the CSBM is from 20 to 30 times stronger than the specimens of DGBM of the corresponding type.

The results of strength and stiffness tests discussed have clearly shown that the cement-stabilized gravel can perform as a base layer and carry construction and the traffic loads at even higher levels than the specimens of DGBM.

Table 6.2 Comparison of Average Resilient Modulus of CSBM and DGBM

Gravel Type	Cement (%)	Water-Cement Ratio	Average Resilient Modulus of CSBM (MPa)	Average Resilient Modulus of DGBM (MPa)
Limestone	5	0.45	7000 (0.95)+	315
		0.475	6000 (0.91)	
	7	0.45	7000 (0.97)	
		0.475	10000 (0.82)	
Caliche	5	0.45	1000 (0.90)	151
		0.475	*	
	7	0.45	2000 (0.96)	
		0.475	4000 (0.78)	
Sand and Gravel	5	0.45	6000 (0.98)	184
		0.475	10000 (0.68)	
	7	0.45	10000 (0.82)	
		0.475	2000 (0.97)	

* Specimen failed before testing.
+ Number in parenthesis indicate the R^2 obtained from linear regression.

Table 6.3 Comparison of Elastic Moduli of CSBM and DGBM

Gravel Type	Cement (%)	Water-Cement Ratio	Average Elastic Modulus (Compression) of CSBM (MPa)	Average Elastic Modulus of DGBM (MPa)
Limestone	5	0.45	6000	154 (7.0%)+
		0.475	8000	
	7	0.45	9000	
		0.475	8000	
Caliche	5	0.45	6000	391 (19.1%)
		0.475	*	
	7	0.45	6000	
		0.475	6000	
Sand and Gravel	5	0.45	6000	578 (3.2%)
		0.475	10000	
	7	0.45	10000	
		0.475	10000	

* Specimen failed before testing

+ Number in parenthesis indicate the compaction moisture content

Table 6.4 Comparison of Unconfined Compressive Strengths of CSBM and DGBM

Gravel Type	Cement (%)	Water-Cement Ratio	Average Ultimate Strength of CSBM (MPa)	Average Ultimate Strength of DGBM (MPa)
Limestone	5	0.45	4.4	0.19 (7.0%)⁺
		0.475	4.3	
	7	0.45	4.6	
		0.475	6.2	
Caliche	5	0.45	0.6	0.19 (19.1%)
		0.475	*	
	7	0.45	0.6	
		0.475	2.5	
Sand and Gravel	5	0.45	4.0	0.16 (3.2%)
		0.475	5.7	
	7	0.45	3.3	
		0.475	4.3	

* Specimen failed during testing
⁺ Number in parenthesis indicate the compaction moisture content

SOIL WATER RETENTION CHARACTERISTICS

The complete set of water retention test performed on the selected cement stabilized materials is presented in Appendix I. The water retention capacities are summarized in Table 6.5. The table shows a maximum degree of saturation of 18% for limestone gravel with 7% cement and 0.45 water cement ratio. The minimum water retention capacity of 3% was observed for Caliche gravel with 7% cement and a 0.45 water-cement ratio. On the average the water retention capacities were around degrees of saturations of 12%. In general caliche gravel showed lower retention capacities than limestone or sand and gravel. It is worth noticing that the water retention capacities for CSBM are lower than those reported earlier for OGBM. To a certain extent the cement paste seams to occupy the grain-to-grain contacts such that they are not available for retention of capillary water.

It can be concluded that the water retention capacities of all the specimens are good and that the cement-stabilized material is an acceptable alternative for permeable bases.

PERMEABILITY CHARACTERISTICS

The complete set of permeability test on CSBM, is presented in Appendix J. A summary of test results is shown in Table 6.6. The minimum permeability coefficient measured was 20,000 m/day (Caliche 7% cement .45 water-cement ratio) and the maximum permeability coefficient of 89,500 m/day (Limestone 5% cement and 0.45 water-cement ratio). All the permeability coefficients measured were higher than the minimum suggested by FHWA of 300 m/day. However, caliche gravel showed lower permeability coefficients than limestone or sand and gravel. In general, the cement-stabilized materials with 7% cement had lower permeability coefficients than the specimens of cement-stabilized with 5% cement.

DISCUSSION

The results of the evaluation of the cement-stabilized gravels indicate that cement contents of 5% and 7% cement and water-cement ratios of 0.45 and 0.475 could be used for any of the three gravels to produce a permeable base material. The recommended materials are the following:

1)	Limestone	5% cement	0.475 water-cement ratio,
2)	Caliche	7% cement	0.475 water-cement ratio,
3)	Sand and Gravel	5% cement	0.475 water-cement ratio.

The caliche gravel stabilized with 5% cement showed poor handling during testing. Even though the stability numbers were higher with 5% cement than of those for the DGBM, the use of 7% cement is recommended to provide the strength expected from a base layer.

For the limestone or the sand and gravel base materials, the stability and drainability considerations suggests that 5% cement can provide a base material superior to the DGBM from every point of view. The results of the present study suggest that the stability of specimens of CSBM with water-cement ratio of 0.475 exhibit somewhat higher stability.

Table 6.5 Water Retention Capacities of Cement-Stabilized Base Material

Gravel Type	Cement (%)	Water-Cement Ratio	Saturation (%)
Limestone	5	0.45	11
		0.475	11
	7	0.45	18
		0.475	12
Caliche	5	0.45	9
		0.475	12
	7	0.45	3
		0.475	14
Sand and Gravel	5	0.45	11
		0.475	12
	7	0.45	12
		0.475	13

Table 6.5 Permeability Coefficients of Cement Stabilized Base Material

Gravel Type	Cement (%)	Water-Cement Ratio	Permeability Coefficient (m/day)
Limestone	5	0.45	89,500
		0.475	59,710
	7	0.45	46,273
		0.475	47,485
Caliche	5	0.45	*
		0.475	*
	7	0.45	20,727
		0.475	22,360
Sand and Gravel	5	0.45	49,751
		0.475	48,948
	7	0.45	40,023
		0.475	34,424

* Specimen broke before testing

CHAPTER 7

DESIGN AND CONSTRUCTION OF DRAINABLE BASES

INTRODUCTION

The design of a permeable base consists of the design of three components: 1) base course material, 2) separator layer, and 3) drainage system. The base course material includes aggregates and cement stabilization. The design and construction of a separator layer is necessary to prevent the contamination of the base layer by the fines in the subgrade or sub-base layers. The drainage system is necessary to drain the water out of the permeable base. The guidelines presented in this chapter are the result of a literature survey, and the laboratory program described in the previous sections of the present report.

BASE COURSE MATERIAL

Aggregate

Aggregate gradations used for permeable bases by different highway agencies are summarized in Table 7.1. The gradation of the gravels used in the present study are also summarized in this table. It is recommended to use this gradation band when selecting base material with no percent passing sieve number 3/8. The gradation used should be based on wet sieve analysis to prevent the inclusion of fines with the gravel.

Other aggregate properties also specified by various highway agencies include to require 90 to 100 percent crushed aggregate with a maximum loss of 40 percent in the LA Abrasion Wear test. Furthermore, the crushed aggregates should have at least two mechanically fractured faces, as determined on the material retained on sieve No. 4. When the permeable base will be subjected to freeze-thaw cycles, the durability of the aggregates should be tested by a soundness test. Typical specifications require that the soundness percent loss not to exceed 12 or 18 percent as determined by the sodium sulfate or magnesium sulfate tests, respectively.

Table 7.1 **Typical Aggregate Gradations for Cement-Treated Permeable Bases**

Sieve Size	Percent Passing				
	AASHTO No. 57 Stone	AASHTO No. 67 Stone	Virginia	Army Corps of Engineers	UTEP
37.5 mm (1.5 in.)	100				100
25.0 mm (1.0 in.)	95-100	100	100	100	75-60
19.0 mm (3/4 in.)		90-100		90-100	25-40
12.7 mm. (0.5 in.)	25-60		25-50	40-80	10-15
9.5 mm. (3/8 in.)		20-55		30-50	0
4.75 mm. (No. 4)	0-10	0-10	0-10	0-5	
2.36 mm. (No. 8)	0-5	0-5	0-5	0-2	

Cement

The recommended 5% cement content by weight in the laboratory specimen translates to 95 Kg/ m^3 (or 165 lb/yd^3) and the 7% cement in the specimen translates to 130 Kg/m^3 (or 230 lb/yd^3). The water-cement ratios of 0.45 and 0.475 yields 40 kg of water / m^3 (or 70 lb/yd^3) to mix with the cement and blend with the aggregate.

Curing

Curing is an important aspect of constructing cement stabilized bases. A possible method is to cover the permeable base with polyethylene sheeting for 3 to 5 days. Another method is to apply fine water mist several times of the day after the base has been poured.

Capillary Breaks

It is important to realize that if a perfect permeable base is placed in a pavement structure, care has to be exercised to ensure that the base layer is opened to the atmosphere whether in the drainage ditch or in special registers placed to achieve this goal. It is necessary to prevent that the base layer is in contact with the atmosphere only through crack and joints. In such case, the size of the cracks or joints will control, or could control, the drainability of an otherwise perfect permeable base. The concern is that if the base layer and the cracks or joints are saturated, the meniscii formed within the cracks will prevent the drainage of the pore water from the base, if the base does not have any other access to the atmosphere than minute fissures and cracks.

The solution is to not cover all the base with somewhat impermeable surface layers. An alternative is to have frequent breaks in the impermeable layer of a few inches in size, perhaps by leaving pipe sections embedded in the surface layers that expose the base layer to the atmosphere.

Base Thickness

A minimum base thickness of 100 mm (4 inches) is suggested for the permeable base. This thickness is adequate to overcome any construction variances and provide adequate hydraulic conduit to transmit the water to the edge drain. The material properties reported in Chapter 6 can also be used to estimate the minimum thickness necessary for the base layer.

SEPARATOR LAYER

A separator layer must be provided between the permeable base and the subbase/subgrade to keep soil particles from contaminating the permeable base. Either an aggregate separator layer or geomembrane can be used. The aggregate separator layer should consist of durable, crushed, angular aggregate material. The aggregate should at least meet the requirements for a Class C Aggregate in accordance with AASHTO M 283-83 Coarse Aggregate for Highway and Airport Construction. This means that the LA Abrasion Wear should not exceed 50 percent as determined by AASHTO T 96-87. The FHWA recommends that the soundness percent loss should not exceed 12 or 18 percent as determined by the sodium sulfate or magnesium sulfate tests, respectively. The material should be compacted at a 95 percent of the maximum density as determined by AASHTO T 180-90, Moisture Density Relationship Using a 4.5 Kg (10-lb) hammer and 45.7 cm (18 in.) drop.

The gradation of the aggregate separator layer must meet the requirements for the aggregate separator layer/subgrade interface as listed below:

$$D_{15} \text{ (Separator Layer)} \leq 5\, D_{85} \text{ (Subgrade)}$$

$$D_{50} \text{ (Separator Layer)} \leq 25\, D_{50} \text{ (Subgrade)}$$

where the D_x is the size that corresponds to "X" percent finer on the gradation curve of the corresponding material. These equations must also be applied to the base/separator layer interface:

$$D_{15} \text{ (Base)} \leq 5\, D_{85} \text{ (Separator Layer)}$$

$$D_{50} \text{ (Base)} \leq 25\, D_{50} \text{ (Separator Layer)}$$

The aggregate separator layer should contain a maximum percent of fines passing No. 200 sieve of 12 percent or less. A minimum thickness of 100 mm (4 inches) is recommended for the aggregate separator layer. This requirement is based on construction considerations. The aggregate separator layer is as important as the permeable base and the subgrade in developing a strong pavement section. A separator layer is not a substitute for a strong, uniform subgrade.

The presence of a granular separator layer under the drainable base layer has some disadvantages. The most obvious is that the separator layer will now be the trap of moisture. Thus it will act as a reservoir supplying moisture to the subgrade or subbase layer. Furthermore, this water reservoir will also be providing a source of water vapor within the pavement structure. This vapor phase will provide a bridge for the water in the separator layer to evaporate/condensate (associated with daily temperature variations) in other pavement layers. Thus the ideal separator layer should not only prevent soil contamination but at the same time not cause water retention within the pavement.

An obvious alternative is to use a geomembrane as the separator layer. The initial cost of a geomembrane could be outweighed by the long term savings. Other alternatives seems possible but their feasibility has to be investigated. One of these alternatives, could be to form a solid Portland cement concrete separator layer at the time of pouring the base layer.

DRAINAGE SYSTEM

It is necessary to design the drainage system to be able to handle all the surface run-off plus all the contribution from the permeable base. If the capacity of the drainage system is not enough, backflooding will be caused in the base layer and the time to drain will be correspondingly increased.

Some State highway agencies have used 150 mm (6 inches) diameter flexible corrugated polyethylene tubing for longitudinal edge drain pipe. Other highway agencies have used rigid PVC slotted pipes. In general the initial cost of rigid pipe is higher, however, rigid PVC pipes are a long term solution. One of the main advantages is that the rigid PVC pipes provide more protection against crushing during construction or maintenance operations.

DESIGN AND CONSTRUCTION CONSIDERATIONS

Subsurface drainage design must be coordinated with surface drainage. The lateral outlet pipes should be placed on a minimum slope of 3 percent. The invert of the outlet pipe should be located 150 mm (6 inches) above the 10-year design flow of the ditch. This is needed to help prevent flooding of the permeable base by water from the ditch backing up into the edge drain system. Although outlet spacings between 90 to 150 m (300 to 500 ft) have been used, FHWA recommends a maximum of 75 m (250 ft) to ensure rapid drainage. The edge drain should be segmented so that each section drains independently.

MAINTENANCE

With all permeable base systems, a definite commitment of agency resources is required to maintain edge drains and outlet in good conditions. Otherwise the system becomes clogged and the advantage of drainage is lost. Fines and sediment collecting in the edge drains may reduce flow and eventually clog the outlet pipe. On the outside, debris mower clippings accumulating at the rodent screens may block the flow. Outlets and the edge drains should be inspected regularly. Clearing the outlets and flushing the edge drains should be performed as necessary. Paint marks on the shoulder can help maintenance personals to locate the outlets.

CHAPTER 8

CLOSURE

SUMMARY

Base materials for pavements have been traditionally selected on their ability to distribute the traffic loads to the weaker underlying subbase layer or subgrade. Little or no emphasis has been focused towards drainability of the base materials. The base materials commonly used in Texas have poor drainability. This has resulted in premature failure of pavements. The concern of poor drainability, a lack of guidelines for the design, and construction of drainable bases lead to the sponsoring of the presently reported project.

The objective of developing guidelines for design and construction of permeable bases was achieved in three phases. In the first phase, a literature search was performed to identify test procedures for the evaluation of stability and drainability of base materials. In the second phase, the existing base materials were evaluated for stability and drainability. In the third phase, new or alternative materials were developed and tested for stability and drainability. The goal for the new or alternative materials was to have higher drainability and similar stability as of existing bases.

The existing base materials showed high water retention capacities and small coefficients of permeability, in general less than 100 m/day. The FHWA suggests permeability coefficient of more than 300 m/day. These results indicate that the existing base materials have poor drainability.

To improve the drainability of base materials, it was decided to eliminate fines and fine, medium, and coarse sand. The tested material showed improved drainability, but associated with a drastic reduction of stability indicating that the base material with no fines or sands needs to be stabilized.

The gravel fraction of the existing base materials was used for the stabilized materials to retain a high level of drainability. Two cement contents 5 percent and 7 percent and two water-cement ratios 0.45 and 0.475 were used. Three sources of gravel were used: 1) limestone, 2) caliche, and 3) gravel and sand. The results of the laboratory program showed that gravels stabilized with Portland cement can provide highly drainable materials with also very high strength and stiffness.

CONCLUSIONS

The following conclusions can be drawn from this study:

- Base materials currently used in Texas have poor drainability.
- Base materials with no fines are not stable enough to be used as an alternative material.
- Cement stabilized material can be used for improving the drainability without loosing the stability of the base layer.
- Limestone or sand and gravel should be stabilized with 5% cement and a 0.475 water-cement ratio. The caliche should be stabilized with 7% cement and a 0.475 water-cement ratio.

RECOMMENDATIONS FOR FUTURE RESEARCH

The results of the present study indicate that the cement stabilized materials can be used to improve drainability of base layers without compromising the stability. It is recommended that the Texas Department of Transportation considers the implementation of a pilot project using the presently proposed guidelines. This step will help in identifying problems with the proposed guidelines. These problems can then be used to modify/improve the guidelines. The pilot project can also be monitored on a long term basis to document the benefits of using permeable base layers in pavements.

An additional aspect that needs further study is the feasibility of providing alternative separator layers to the granular separator layer being considered in the present study.

REFERENCES

1. Barksdale, R.D. and Hicks, R.G. (1977), "Drainage Considerations to Minimize Distress at the Pavement-Shoulder Joint," Proceedings of International Conference on Concrete Pavement Design, Purdue University, West Lafayette, Indiana.

2. Baumgardner, R. H. (1992), "Overview of Permeable Bases," Materials: Performance and Prevention of Deficiencies and Failure, New York, NY, pp. 275-287.

3. Dempsey, B.J. and Robnett, Q.L. (1979), "Influence of Precipitation, Joints, and Sealing on Pavement Drainage," Transportation Research Record 705, Transportation Research Board, Washington, D.C.

4. Drainable Pavement Systems , Federal Highway Administration, Publication No. FHWA-SA-92-008, March 1992.

5. Grogan, W.P. (1992), "Performance of Free Draining Base Course at Fort Campbell," Materials: Performance and Prevention of Deficiencies and Failure, New York, NY, pp. 434-448.

6. Hall, M.(1994a), "Cement Stabilized Permeable Bases Drain Water, and Life to Pavements," Roads and Bridges, September, pp. 32-33.

7. Hall, M. (1994b), "Cement Stabilized Open-Graded Base Strength Testing and Field Performance Versus Cement Content," Transportation Research Record No. 1440, Transportation Research Board, Washington, D.C., January, pp. 22-31.

8. Highlands, K.L. and Hoffman, G.L. (1987), "Subbase Permeability and Pavement Performance," Research Report No. FHWA-PA-87-008+79-03, Pennsylvania Department of Transportation, Harrisburg, PA.

9. Jones H.A. and Jones R.H. (1989), "Granular Drainage Layers in Pavement Foundations," Unbound Aggregates in Roads, Proceeding UNBAR3, pp. 55-69.

10. McEnroe, B. M., (1994), "Drainability of Granular Bases for Highway Pavements," Report No. KU-93-4, Kansas Department of Transportation, Kansas, June.

11. Nazarian, S., R. Pezo, and M. Picornell (1996), "Testing Methodology for Resilient Modulus of Base Materials," Research Report 1336-1, Center for Geotechnical and Highway Materials Research, The University of Texas at El Paso, El Paso, Tx.

12. Randolph, B.W., Jiangeng, C., A.G. Heydinger, and J. D. Gupta (1996),"A Laboratory Study of Hydraulic Conductivity of Coarse Aggregate Bases," Presented at 75th Annual Meeting of Transportation Research Board, Paper No. 960408, Washington, D.C., January.

13. Ridgeway, H.H. (1976), "Infiltration of Water Through the Pavement Surface," Transportation Research Record 616, Transportation Research Board, Washington, D.C.

14. Zhou, H., L. Moore, Huddleston, J., and J. Gower (1993), "Determination of Free Draining Base Material Properties," Presented at 72nd Annual Meeting of Transportation Research Board, Washington, D.C., January.

APPENDIX A

DRAFT PROTOCOL FOR SOIL WATER RETENTION TESTING OF DENSE-GRADED BASE MATERIAL

WATER RETENTION CAPACITY OF DENSE-GRADED BASE MATERIALS

This method covers a test procedure for determining water retention capacity of dense-graded base material.

Test Conditions

The following ideal test conditions are prerequisite for the water retention capacity of dense-graded base material:

- Continuous saturation of high air entry porous stone during a test.
- Continuous supply of air pressure for maintaining constant pressure.
- Removal of all the air bubbles inside the dense-graded base material voids.
- Slow saturation of dense-graded base material specimen to avoid any movement of fines within the specimen.

Apparatus

- Water retention specimen holder, as shown in Figure A.1, shall consist of a cylinder (preferably PVC) with an average diameter of 150 mm (6 inches) and a height of approximately 160 mm (6.25 inches). The cylinder shall have groves at the bottom for proper fitting of high air entry porous stone and threads on the outer side of the cylinder (top only). A cap with matching threads shall be used to properly seal the top of the cylinder. The caps shall also have a viewing window (Figure A.1) to see the level of water above the specimen. A base fixture, as shown in Figure A.2, for preventing the movement of high air entry porous stone due to air pressure and continuous exposure of high air entry porous stone to the water.
- In general, tap water has salts and may alter the dense-graded base material composition. Hence, it is necessary to remove salts from the tap water and can be easily eliminated by de-ionizing water.
- A one bar high air entry porous stone.
- Specimen shall be compacted inside the cylinder using standard compaction equipment i.e. standard Proctor hammer and the compaction unit as shown in Figure A.3.
- Vacuum pump or water faucet aspirator, for evacuating and for saturating dense-graded base material specimens under full vacuum.
- Air compressor (or laboratory compressed air faucet), for applying constant air pressure on the specimen.
- Miscellaneous Apparatus, including, vernier calliper, pan, mixing pan, scoop, drying oven, balance, hydraulic press, moisture content cans, simple microscope, silicone gun and Teflon tape, pH and conductivity meter, valves, gages, tubes, fittings, and data sheets.

Specimen Preparation

Step	Action
1.	A representative sample of oven dried dense-graded base material shall be selected. Approximately, 7.5 Kg (16 lb) of base material is needed for 150 by 150 mm (6 by 6 inch) specimen. Add the amount of water necessary for achieving the 5% moisture content and mix the dense-graded base material and water thoroughly until a homogenous mixture is obtained.
2.	A small portion of the sample shall be taken for moisture content determination (Tex-103-E). Also, perform specific gravity tests on fine aggregates (Tex-108-E) and coarse aggregate (Tex-403-E) portions of the dense-graded base materials. The average of the coarse and fine aggregate shall be used as the specific gravity of dense-graded base material. Record moisture content, specific gravity of coarse and fine aggregate, and average specific gravity of dense-graded base material on test data sheet (Figure A.4).
3.	Get the desired cylinder and make the following measurements using vernier calliper and record on the test data sheet (Figure A.4): the inside diameter, D, of the cylinder at three different locations; the height, H, measured at three different locations above the groove for the high air entry porous stone. Calculate the average height, diameter and cross sectional area of the cylinder. These numbers will correspond to the specimen sizes. Also measure the mass of the cylinder, M_C; mass of the high air entry porous stone, M_{PS}; and base fixture, M_{BF}; mass of the cap, M_{cap}.
4.	Place the cylinder inside the aluminum base plate (Figure A.3). Make sure that the cylinder is levelled and properly seated inside the groove of the base plate. Use mallet if necessary for leveling. Now screw the threaded rods in the four holes at the corner of the base plate and place the collar on top of the cylinder. Use wing nuts to ensure proper placement of collar.
5.	The specimen shall be compacted in 5 cm (2 inch) layers. A standard Proctor Hammer is dropped 25 times on each lift to compact the dense-graded base material in three layers.
6.	After compaction remove collar and remove any excess material. Carefully remove the cylinder from the base plate and measure the mass of the cylinder plus dense-graded base material, M_{CS}.

Specimen Preparation (continued)

Step	Action
7.	Invert the cylinder (with the specimen) and spread a thin layer of silica flour on the base of the specimen. Apply a thin layer of silicone caulking on the circumference of the high air entry porous stone and inside the groove of the cylinder. Place the high air entry porous stone in the groove inside the cylinder. Spread out any excess silicone insuring that there are no gaps between high air entry porous stone and cylinder. Wait for 24 hrs for silicone to dry.
8.	After silicone is dry, place the specimen into the base assembly and secure with set screws. Apply three to five layer of Teflon tape to each threaded sides of the cylinders. Screw on the cap until the cap has properly seated on the cylinder. Apply silicone to the edge of the cap and spread out the excess silicone covering any air gaps. Allow 24 hrs for silicone to dry. Measure the mass of the water retention specimen holder (including the mass of the cap, base fixture, high air entry porous stone, and dense-graded base material), M_T.

Procedure

Step	Action
1.	Move the water retention specimen holder inside the base pan. Fill the base pan with distilled or deionized water until it reaches to the top of the base pan. Apply a vacuum of 2.5 cm (1 inch) of Hg by connecting the vacuum valve to a vacuum pump or an aspirator for 5 minutes. After five minutes, open the water access valve for about 5 seconds and then close the water access valve. Keep on applying vacuum until water level reaches above the specimen. The water level can be checked through the transparent plexiglass on the cap. After this remove the vacuum and leave the setup for 24 hrs for equilibration.
2	Next day, take the water retention specimen holder out of the pan and keep it on a table, wait for 2 minutes, and then wipe out any excess water. Weigh the water retention specimen holder, M_{T+W}. After measuring the initial mass, M_{T+W}, move the water retention specimen holder to the base pan and connect the valve 1 to the air supply and apply an air pressure of 7 KPa (1 psi).
3.	Next day come back and remove the air pressure and measure the mass, M_{T+W} , as mentioned in step 2. This step should be repeated every day until the mass of the water retention specimen holder does not change or the change is negligible.

Procedure (continued)

Step	Action
4.	Dismantle the specimen after equilibrium is reached. Take the specimen out of the water retention cylinder using press. Oven dry the specimen and perform wet sieve analysis (Tex-110-E test method) of the specimen.
5.	Note any important findings on the data sheet.

Calculations

The level of saturation of the dense-graded base material specimen is defined based on the water retention capacity of the dense-graded base material and can be calculated as follows:

$$Saturation\ (\%) = \frac{V_W}{V_V} * 100 \qquad \textbf{(A.1)}$$

where:
V_V = volume of voids in the specimen,
V_W = volume of water in the specimen.
Calculate the volume of voids V_V using the following equation:

$$V_v = V_T - V_S \qquad \textbf{(A.2)}$$

where:
V_T = total volume of the specimen,
V_S = volume of the dense-graded base material solids in the specimen.

The total volume of the specimen is equal to $\pi*(D/2)^2*$Height of the specimen and both height and diameter of the cylinder can be measured, as suggested in the step 3 of the specimen preparation. The volume of dense-graded base material solids can be calculated using following equation:

$$V_S = \frac{M_S}{\rho_S} \qquad \textbf{(A.3)}$$

where:
M_S = mass of the dense-graded base material solids,
ρ_S = density of the dense-graded base material solids.

The specific gravity of the dense-graded base material can be determined using Tex-108-E test method. The mass of the dense-graded base material solids can be calculated:

$$M_S = \frac{M_{CS} - M_C}{1 + M_{MC}/100} \qquad \textbf{(A.4)}$$

where:

M_{CS} = mass of dense-graded base material plus mass of the cylinder,
M_C = mass of the cylinder,
M_{MC} = Actual moisture content of the specimen in percent.

The volume of water inside the voids, V_W, is equal to the mass of water, M_W, inside the specimen (assuming density of water equal to 1 g/cc). M_W can be calculated using the following equation:

$$M_W = M_{T+W} - M_T + \left(\frac{M_S \cdot M_{MC}}{100}\right) \qquad \textbf{(A.5)}$$

where:

M_W = mass of the water in the voids of the specimen,
M_{T+W} = total mass of the specimen plus water from step 2 of the procedure,
M_T = total mass measured in step 8 of the specimen preparation.

Report

The report of water retention capacity of dense-graded base material shall include the following information:

- water retention characteristics test data sheet,
- grain size analysis,
- specific gravity of the dense-graded base material,
- a statement of any departures from these test conditions, so the results can be evaluated and used, and
- a plot of mass of water, M_W versus elapsed time.

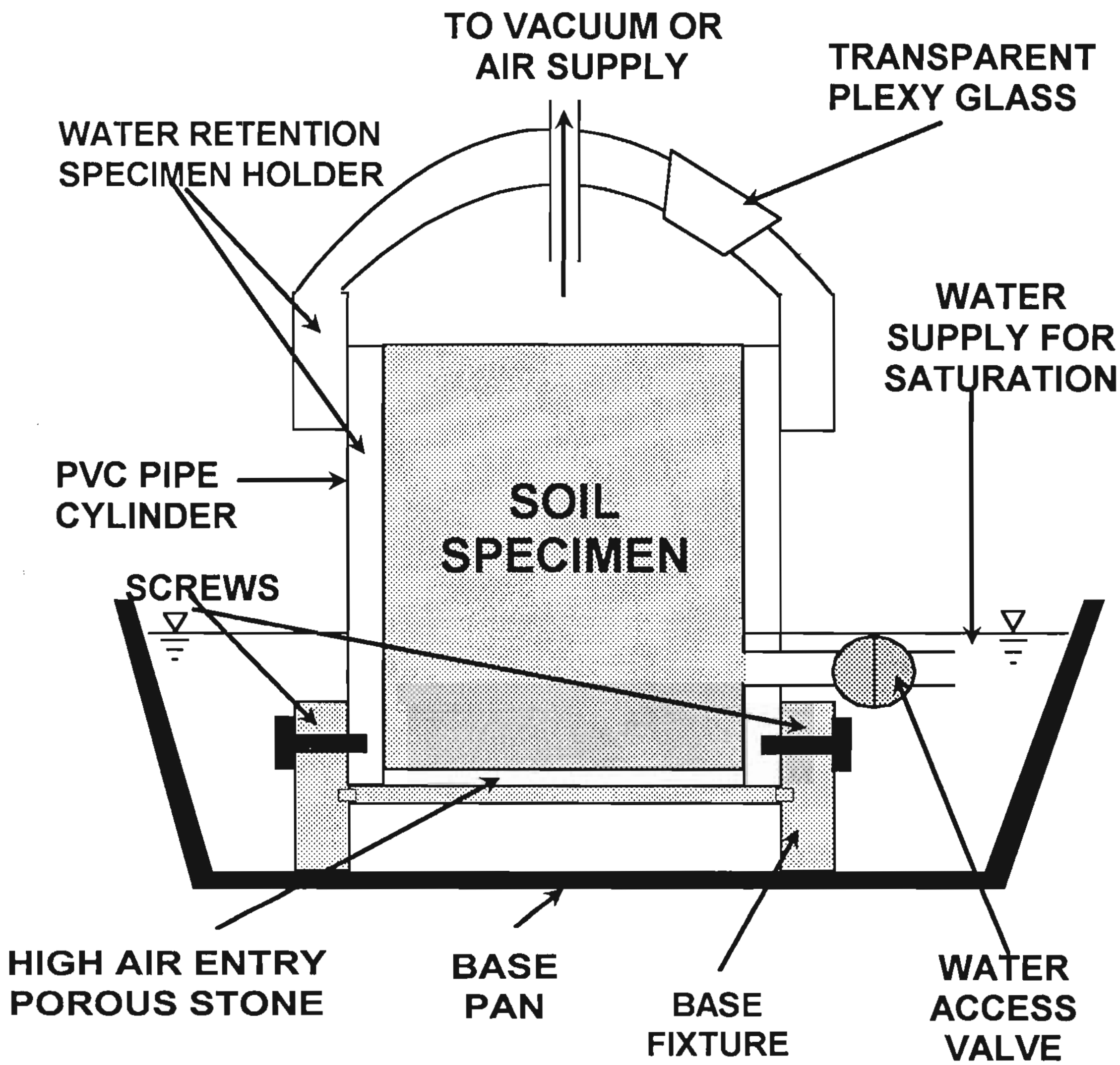

Figure A.1 Water Retention Test Setup for Base Materials

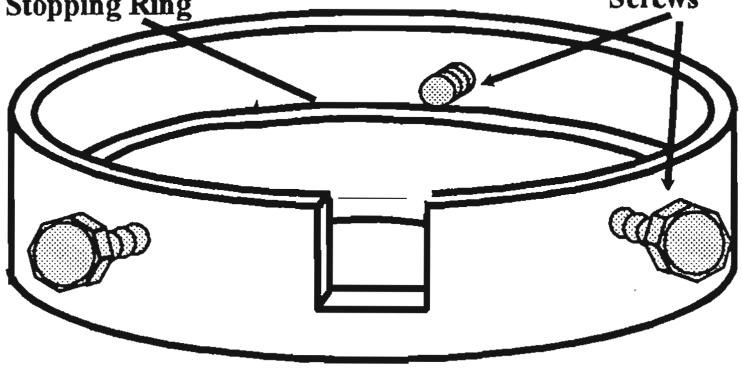

Figure A.2 Base Fixture for Water Retention Test Setup for Base Materials

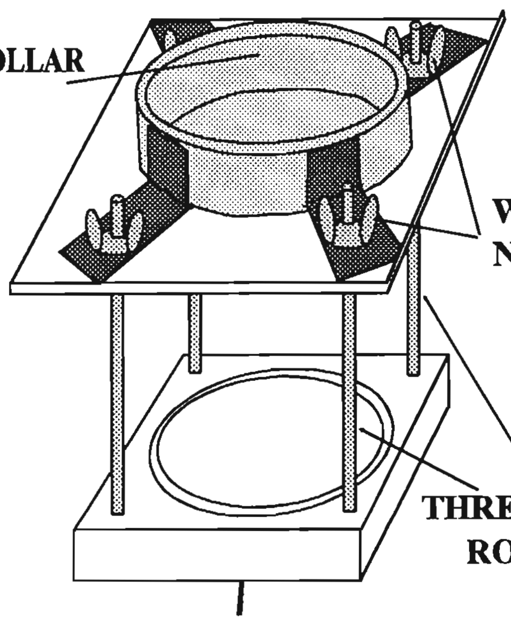

Figure A.3 Compaction Mold for Base Materials

Soil Water Retention Test of Dense-Graded Base Materials

Specimen Number : __________ Starting Date : __________
File Name : __________ Soil Identification : __________
Soil Description : __________ Cylinder Number : __________
Average Diameter, D =(________________) / 3 = ______ cm
Average Height, H =(________________) / 3 = ______ cm
Cross-Sectional Area of Specimen = __________ cm^2
Mass of Cylinder, M_C = __________ g Mass of Base Fixture, M_{BF} = ______ g
Mass of Cap, M_{CAP} = __________ g Mass of Porous Stone, M_{PS} = ______ g
Mass of Cylinder + Mass of Specimen, M_{CS} = __________ g
Target Moisture Content = __________ % Actual Moisture Content, M_C = ____ %
Dry Mass of the Specimen, M_S = ______ g Total Mass, M_T = _______ g
Total Saturated Mass, M_{T+W} = _______ g Mass of Water in Voids, M_W = ____ g
Sp. Gravity of Fine Aggregate = ______ Sp. Gravity of Coarse Aggregate = _____
Average Sp. Gravity of Dense-graded Base Material = __________

DATE	HRS: MIN	Total Time (hr)	Total Saturated Mass, M_{T+W} (g)	Mass of Water, M_W (g)	pH of Water	Conductivity of Water (µSiemmens)

Figure A.4 Soil Water Retention Test Data Sheet for Dense-Graded Base Material

APPENDIX B

DRAFT PROTOCOL FOR SOIL WATER RETENTION TESTING OF CEMENT-STABILIZED BASE MATERIAL

WATER RETENTION CAPACITY OF CEMENT-STABILIZED BASE MATERIALS

This method covers a test procedure for determining water retention capacity of cement-stabilized base material.

Test Conditions

The following ideal test conditions are prerequisite for the water retention capacity of cement-stabilized base material:

- Continuous saturation of high air entry porous stone during a test.
- Continuous supply of air pressure for maintaining constant pressure.
- Removal of all the air bubbles inside the cement-stabilized base material voids.

Apparatus

- Water retention specimen holder, as shown in Figure A.1, shall consist of a cylinder (preferably PVC) with an average diameter of 150 mm (6 inches) and a height of approximately 160 mm (6.25 inches). The cylinder shall have groves at the bottom for proper fitting of high air entry porous stone and threads on the outer side of the cylinder (top only). A cap with matching threads shall be used to properly seal the top of the cylinder. The caps shall also have a viewing window (Figure A.1) to see the level of water above the specimen. A base fixture, as shown in Figure A.2, for preventing the movement of high air entry porous stone due to air pressure and continuous exposure of high air entry porous stone to the water.
- In general, tap water has salts and may alter the cement-stabilized gravel composition. Hence, it is necessary to remove salts from the tap water and can be easily eliminated by de-ionizing water.
- A one bar high air entry porous stone.
- Specimen shall be compacted inside the cylinder using standard compaction equipment i.e. standard proctor hammer and the compaction unit as shown in Figure A.3.
- Vacuum pump or water faucet aspirator, for evacuating and for saturating cement-stabilized gravel under full vacuum.
- Air compressor (or laboratory compressed air faucet), for applying constant air pressure on the specimen.
- Miscellaneous Apparatus, including, vernier calliper, pan, mixing pan, scoop, drying oven, balance, hydraulic press, moisture content cans, simple microscope, silicone gun and Teflon tape, pH and conductivity meter, valves, gages, tubes, fittings, and data sheets.

Specimen Preparation

Step	Action
1.	A representative sample of saturated-surface-dry gravel (3/8 and above) shall be selected. Approximately, 5 Kg (11 lb) of gravel is needed for 150x150 mm (6x6 inch) specimen. Acquire the selected amount of water and cement. Thoroughly mix cement and water. Add cement paste to the gravel and mix thoroughly until all gravel is completely covered with cement paste.
2.	Get the desired cylinder and make the following measurements using vernier calliper and record on the test data sheet (Figure B.1): the inside diameter, D, of the cylinder at three different locations; the height, H, measured at three different locations above the groove for the high air entry porous stone. Calculate the average height, diameter and cross sectional area of the cylinder. These numbers will correspond to the specimen sizes. Also measure the mass of the cylinder, M_C; mass of the high air entry porous stone, M_{PS}; and base fixture, M_{BF}; mass of the cap, M_{cap}.
3.	Place the cylinder inside the aluminum base plate (Figure A.3). Make sure that the cylinder is levelled and properly seated inside the groove of the base plate. Use mallet if necessary for leveling. Now screw the threaded rods in the four holes at the corner of the base plate and place the collar on top of the cylinder. Use wing nuts to ensure proper placement of collar.
5.	The specimen shall be compacted in 5 cm (2 inch) layers. A standard Proctor Hammer is dropped 25 times on each lift to compact the cement-stabilized base material in three layers.
6.	After compaction remove collar and remove any excess material. Carefully remove the cylinder from the base plate and measure the mass of the cylinder plus cement-stabilized base material, M_{CS}.
7.	Invert the cylinder and spread a thin layer of silica flour on the base of the specimen. Apply a thin layer of silicone caulking on the circumference of the high air entry porous stone and inside the groove of the cylinder. Place the high air entry porous stone in the groove and spread out any excess silicone insuring that there are no gaps. Wait 24 hrs for silicone to dry.
8.	After silicone is dry, place the specimen in the base fixture and secure it with set screws. Apply 3 to 5 layers of Teflon tape to the threaded sides of the cylinders. Screw on the cap until the cap has properly seated on the cylinder. Apply silicone to the edge of the cap and spread out the excess silicone covering any air gaps. Allow 24 hrs for silicone to dry. Measure the mass of the water retention specimen holder (including the mass of the cap, base fixture, high air entry porous stone, and cement-stabilized gravel), M_T.

Procedure

Step	Action
1.	Move the water retention specimen holder inside the base pan. Fill the base pan with distilled or deionized water until it reaches to the top of the base pan. Apply a vacuum of 2.5 cm (1 inch) of Hg by connecting vacuum to a vacuum pump or an aspirator for 5 minutes. After five minutes, open the water access valve for about 5 seconds and close the water access valve. Keep on applying vacuum until water level reaches above the specimen. The water level can be checked through the transparent plexiglass on the cap. After this remove the vacuum and leave the setup for 24 hrs for equilibration.
2.	Next day, take the water retention specimen holder out of the pan and keep it on a table, wait for 2 minutes, and then wipe out any excess water. Weigh the water retention specimen holder, M_{T+W}. After measuring the initial mass, M_{T+W}, move the water retention specimen holder to the base pan and connect the valve 1 to the air supply and apply an air pressure of 7 KPa (1 psi).
3.	Next day come back and remove the air pressure and measure the mass, M_{T+W} , as mentioned in step 2. This step should be repeated every day until the mass of the water retention specimen holder does not change or the change is negligible.
4.	Dismantle the specimen after equilibrium is reached. Take the specimen out of the cylinder using press. Oven dry the specimen and perform bulk specific gravity (Tex-207-F) test on the specimen.
5.	Note any important findings on the data sheet.

Calculations

The level of saturation of the cement-stabilized specimen is defined based on the water retention capacity of the cement-stabilized base material and can be calculated as follows:

$$Saturation\ (\%) = \frac{V_W}{V_V} * 100 \qquad \textbf{(B.1)}$$

where:

V_V = volume of voids in the specimen,

V_W = volume of water in the specimen.

Calculate the volume of voids V_V using the following equation:

$$V_v = V_T - V_S \qquad \textbf{(B.2)}$$

where:

V_T = total volume of the specimen,

V_S = volume of the cement-stabilized gravel in the specimen.

The total volume of the specimen is equal to π *(D/2)^2*Height of the specimen and both height and diameter of the cylinder can be measured, as suggested in the step 3 of the specimen preparation. The volume of cement-stabilized gravel can be calculated using following equation:

$$V_S = \frac{M_S}{\rho_S} \qquad \textbf{(B.3)}$$

where:

M_S = mass of the cement-stabilized gravel,

ρ_S = density of the cement-stabilized gravel.

The specific gravity of the cement-stabilized gravel can be determined using Tex-207-F test method. The mass of the cement-stabilized gravel can be calculated:

$$M_S = M_{CS} - M_C \qquad \textbf{(B.4)}$$

where:

M_{CS} = mass of cement-stabilized gravel plus mass of the cylinder,

M_C = mass of the cylinder.

The volume of water inside the voids, V_W, is equal to the mass of water, M_W, inside the specimen (assuming density of water equal to 1 g/cc). M_W can be calculated using the following equation:

$$M_W = M_{T+W} - M_T \qquad \textbf{(B.5)}$$

where:

M_W = mass of the water in the voids of the specimen,

M_{T+W} = total mass of the specimen plus water from step 2 of the procedure,

M_T = total mass measured in step 8 of the specimen preparation.

Report

The report of water retention capacity of cement-stabilized base material shall include the following information:

- water retention characteristics test data sheet,
- grain size analysis,
- specific gravity of the cement-stabilized base material,
- a statement of any departures from these test conditions, so the results can be evaluated and used, and
- a plot of mass of water, M_W versus elapsed time.

Soil Water Retention Test of Cement-Stabilized Base Materials

Specimen Number : ________ Starting Date : ________
File Name : ________ Soil Identification : ________
Soil Description : ________ Cylinder Number : ________
Average Diameter, D =(______________) / 3 = _____ cm
Average Height, H =(______________) / 3 = _____ cm
Cross-Sectional Area of Specimen = ________ cm^2
Mass of Cylinder, M_C = ________ g Mass of Base Fixture, M_{BF} = _____ g
Mass of Cap, M_{CAP} = ________ g Mass of Porous Stone, M_{PS} = _____ g
Mass of Cylinder + Mass of Specimen, M_{CS} = ________ g
Target Moisture Content = ________ % Actual Moisture Content, M_C = ____ %
Dry Mass of the Specimen, M_S = _____ g Total Mass, M_T = ______ g
Total Saturated Mass, M_{T+W} = ______ g Mass of Water in Voids, M_W = ____ g
Bulk Specific Gravity of Cement-Stabilized Base Material = ________

DATE	HRS: MIN	Total Time (hr)	Total Saturated Mass, M_{T+W} (g)	Mass of Water, M_W (g)	pH of Water	Conductivity of Water (μSiemmens)

Figure B.1 Soil Water Retention Test Data Sheet for Cement-Stabilized Base Material

APPENDIX C

DRAFT PROTOCOL FOR COEFFICIENT OF PERMEABILITY TESTING OF DENSE-GRADED BASE MATERIAL

(This test procedure is modified from the original AASHTO Test Procedure T 215-70)

PERMEABILITY OF DENSE GRADED-BASE MATERIALS (CONSTANT HEAD)

This method covers a test procedure for determining the coefficient of permeability by a constant-head method for the laminar flow of water through dense-graded base material.

Test Conditions

The following ideal test conditions are prerequisite for the laminar flow of water through dense-graded base material under constant head conditions:

- Continuity of flow with little or no dense-graded base material volume changes during a test.
- Flow with the voids saturated with water and no air bubbles in the voids.
- Direct proportionality of velocity of flow with hydraulic gradients below certain critical values, where turbulent flow starts.
- All other types of flow involving partial saturation of voids, turbulent flow, and unsteady state of flow are transient in character and yield variable and time-dependent coefficients of permeability; therefore, they require special test conditions and procedures.

Apparatus

- Permeameter, as shown in Figure C.1, shall consist of a cylinder with an average diameter of 150 mm (6 inches) and a height of approximately 300 mm (12 inches) or higher. The permeameter cylinder shall have groves at the top and bottom for proper fitting of porous stones with openings sufficiently small to prevent movement of particles. Also, the permeameter shall have caps with stoppers (Figure B.1) to prevent changes in the placement density and volume of specimen during the saturation and permeability testing. This step will satisfy the proposed test conditions.
- In general, tap water has air in solution and interferes with the fundamental test conditions of the test. Hence, it is necessary to remove air from the tap water. The air can be removed by allowing the water to pass through misters and apply vacuum to remove the air. This concept is used to develop a de-airing tank. De-airing tank, as shown in Figure C.1, shall be used to remove most of the air from tap water. The de-airing tank consists of a steel drum, a PVC drum, valves and fittings, and a series of misters. The steel drum shall have a minimum capacity of 0.19 m^3 (50 gallons) and PVC drum shall have a minimum capacity of 0.15 m^3 (40 gallons). These requirements are to ensure sufficient supply of de-aired water. The PVC drum shall be kept inside the steel drum (if only PVC drum is used then the drum will collapse due to vacuum and if only steel drum is used then the life of steel drum is reduced because of rusting). Five to eight misters can be used for spraying the water in the tank. A constant vacuum of 130 mm of Hg (5 inch of Hg) shall be maintained in the tank for continuous removal of air and at the same time to store the de-aired water inside the tank.

The tank shall have four valves: 1) valve 1 is used to supply the tap water, 2) valve 2 is used to drain the de-aired water for constant head tank, 3) valve 3 is used for applying the vacuum inside the tank, and 4) valve 4 is used finding the level of water inside the tank . Usually, it takes about four to six hours to de-air 0.075 m^3 (20 gallons) of water.

- A water pumping system is required to pump the water to the water storage tank. This system is necessary to avoid any air contact before the water goes to the constant head tank. The water pumping system, as shown in Figure C.1 consists of a bladder, an acrylic cylinder, valves and fittings, and two end plates. The de-aired water is pumped in and out of the cylinder to the storage tank by alternating vacuum or air supply to the bladder.
- Water storage tanks, as shown in Figure C.1, shall be used to supply the water to constant head tank. Two water storage tanks are necessary to maintain constant head throughout the testing of a specimen.
- Constant Head Tank, as shown in Figure C.1, shall be used for maintaining the constant head on the specimen. The tank consists of two slits. The slits on both sides are to ensure the maintenance of constant head.
- Specimen shall be compacted inside the permeameter using standard compaction equipment i.e. standard proctor hammer and the compaction unit as shown in Figure A.3.
- Vacuum pump or water faucet aspirator, for evacuating and for saturating specimens under full vacuum.
- Air compressor (or laboratory compressed air faucet), for pumping the water from water pumping system to the water storage tank.
- Manometer tubes and a scale, as shown in Figure C.1, is needed for measuring the water head loss.
- Miscellaneous Apparatus, including thermometer, stop watch, vernier calipers, 500 ml graduate, quart jar, mixing pan, scoop, drying oven, balance, hydraulic press, moisture content cans, simple microscope, silicone gun and Teflon tape, pH and conductivity meter, geotextile patch, mesh, valves, gages, tubes, fittings, and data sheets.

Specimen Preparation

Step	Action
1	A representative sample of oven dried dense-graded base material shall be selected. Approximately, 17 Kg (36.5 lb) of base material is needed for 150 by 300 mm (6 by 12 inches) specimen. Add the amount of water necessary for achieving the 5% moisture content and mix the dense-graded base material and water thoroughly until a homogenous mixture is obtained.
2	A small portion of the sample shall be taken for moisture content determination (Tex-103-E). Also, perform specific gravity tests on fine aggregates (Tex-108-E) and coarse aggregate (Tex-403-E) portions of the dense-graded base materials. The average of the coarse and fine aggregate shall be used as the specific gravity of dense-graded base material. Record moisture content, specific gravity of coarse and fine aggregate, and average specific gravity of dense-graded base material on test data sheet (Figure C.2).
3.	Get the desired cylinder and make the following measurements using vernier calliper and record on the test data sheet (Figure C.2): the inside diameter, D, of the cylinder at three different locations; the height, H, measured at three different locations above the grooves for porous stones at both ends. Calculate the average height, diameter and cross-sectional area of the cylinder. These numbers will correspond to the specimen sizes. Also measure the mass of the cylinder, M_C.
4.	Place the cylinder inside the aluminum base plate (Figure A.3). Make sure that the cylinder is levelled and properly seated inside the groove of the base plate. Use mallet if necessary for leveling. Now screw the threaded rods in the four holes at the corner of the base plate and place the collar on top of the cylinder. Use wing nuts to ensure proper placement of collar.
5.	The specimen shall be compacted in 5 cm (2 inch) layers. A standard Proctor Hammer is dropped 25 times on each lift to compact the dense-graded base material in six layers.
6.	After compaction remove collar and remove any excess soil.
7.	Apply a thin layer of silicone caulking on the circumference of the porous stone and inside the groove of the permeameter. Place the porous stone in the groove inside the permeameter. Spread out any excess silicone insuring that there are no gaps between porous stone and cylinders. Allow three to four hours for drying and carefully remove the permeameter from the base plate. Carefully invert the specimen by making sure that the porous stone does not loose contact with the permeameter. Repeat the process of placing the porous stone with silicone on the other end. Wait for 24 hrs for silicone to dry.

Specimen Preparation (Continued)

Step	Action
8.	Apply three to five layer of Teflon tape to threaded sides of the cylinders. Screw caps on the top and bottom until the stoppers (inside the caps) have properly seated on the top of the porous stone. Apply silicone to the edge (where the cap meets the cylinder on both sides) of the cap and spread out the excess silicone covering any air gaps. Allow 24 hrs for silicone to dry. Affix the specimen on the specimen stand using bars and wing nuts.

Procedure

Step	Action
1.	Start the water de-airing process at least 5 hrs before saturation of the specimen. Check the water level inside the de-airing tank and stop the flow of tap water when water level indicates sufficient de-aired water inside the tank. Close valves 4, 5, and 6. Open Valves 1, 2 (towards vacuum), and 3. Apply vacuum to the bladder until no air is left inside the bladder. Open valve 4 and let the cylinder fill up with de-aired water. Close valve 4, open valve 3 and 2 (towards compressed air). Keep on applying the air pressure until half of the acrylic cylinder is full. Close Valve 3, switch valve 2 towards vacuum and open valve 4. Repeat this process until the desired amount of water is stored in the storage tank. At this time close valve 2, 3, and 4.
2.	After filling the constant head tank, move it below the specimen. Connect the manometer tubes to the permeameter. Close valves 2, 5, 8, 9, and 10. Open valves 1, 6, and 7. Apply a vacuum (using a vacuum pump or an aspirator) of 500 mm (20 inch) of Hg. for a minimum of fifteen minutes to ensure removal of air adhering to specimen particles and in the voids. After fifteen minutes of vacuum, valve 8 is minutely opened to allow the flow of water. The amount of water flowing through the valve 8 is increased until the water level reaches valve 6. At this point valve 8 is closed again and the constant head tank is moved 2 m above the specimen. Now, valve 1 is closed and the outflow pipe is moved above the storage head tank to prevent any flow. After this step, the valves 8 and 6 are opened and the specimen is left overnight under a column of 2 m.
3.	Next day, initiate the water flow by supplying the water to the constant head tank, by connecting the manometer tubes, by opening valves 9 and 10, and by moving the outlet flow pipe below the constant head tank.

Procedure (Continued)

Step	Action
4.	After 5 minutes close valves 7 and 8 to check degree of saturation achieved in the specimen by raising the specimen about 30 cm (1 foot) and by measuring the change in the height of water in the manometer tubes. The change in height is measured and degree of saturation can be calculated using ideal gas law. At least 98% of saturation should be achieved before proceeding with the constant head permeability test.
5.	Open valves 7 and 8. Regulate the flow of water through storage tanks to maintain the constant head and avoid any excess wastage of de-aired water. Move outlet pipe below the constant head tank to achieve a minimum head loss. Delay measurements of quantity of flow and head loss until a stable head condition without appreciable drift in water manometer levels is attained. Measure and record time, t, head loss, h, quantity of flow, Q, and keep a sample to measure pH and conductivity of the outflow water.
6.	Repeat test runs at heads increasing by minimum to establish accurately the region of laminar flow with discharge q, (where q=Q/At) directly proportional to hydraulic gradient, i, (where i=h/L). When departure from linear relation become apparent, indicating the initiation of turbulent flow conditions, the test should be stopped (A review of literature has suggested that the head loss below 0.05 should be used to ensure laminar flow).
7.	At the completion of the permeability test, drain the specimen and inspect it to establish whether it was essentially homogenous and isotropic in character.
8.	Perform Tex-110-E on the recovered dense-graded base material to determine the gradation of the material used in this analysis.
9.	Note any important findings on the data sheet.

Calculations

Calculate the permeability coefficient using Darcy's Law:

$$k = \frac{Q \cdot L}{A \cdot t \cdot h} \qquad \text{(C.1)}$$

where:

k = permeability coefficient,

Q = quantity of water discharged,
L = distance between manometers,
A = cross-sectional area of specimen,
t = total time of discharge,
h = difference in head on manometers (or head loss).

However, this equation is valid only if the water flow occurs under laminar flow conditions. At higher velocities, a transitional flow occurs which can be characterized by the equation:

$$i = aq + bq^2 \qquad \textbf{(C.2)}$$

where:
i = hydraulic gradient (h/L)
q = discharge velocity (Q/At)
a = regression constant of the first order
b = regression constant of the second order

Using observed i and q data, regression constant a and b can be found. The inverse of regression constant a should be used as a permeability coefficient.

Report

The report of permeability test shall include the following information:

- Permeability test data sheet,
- Grain size analysis,
- A statement of any departures from these test conditions, so the results can be evaluated and used,
- A plot of permeability coefficient versus hydraulic gradient,
- A plot of hydraulic gradients versus discharge velocity. The plot should have three plotted data: 1) one data set should show the relationship between observed i and q, 2) the second data set should show relationship between predicted i (equation 2) and observed q, and 3) the third data set should show predicted i (using a of equation 2) and observed q. This plot will show both laminar and transitional flow.

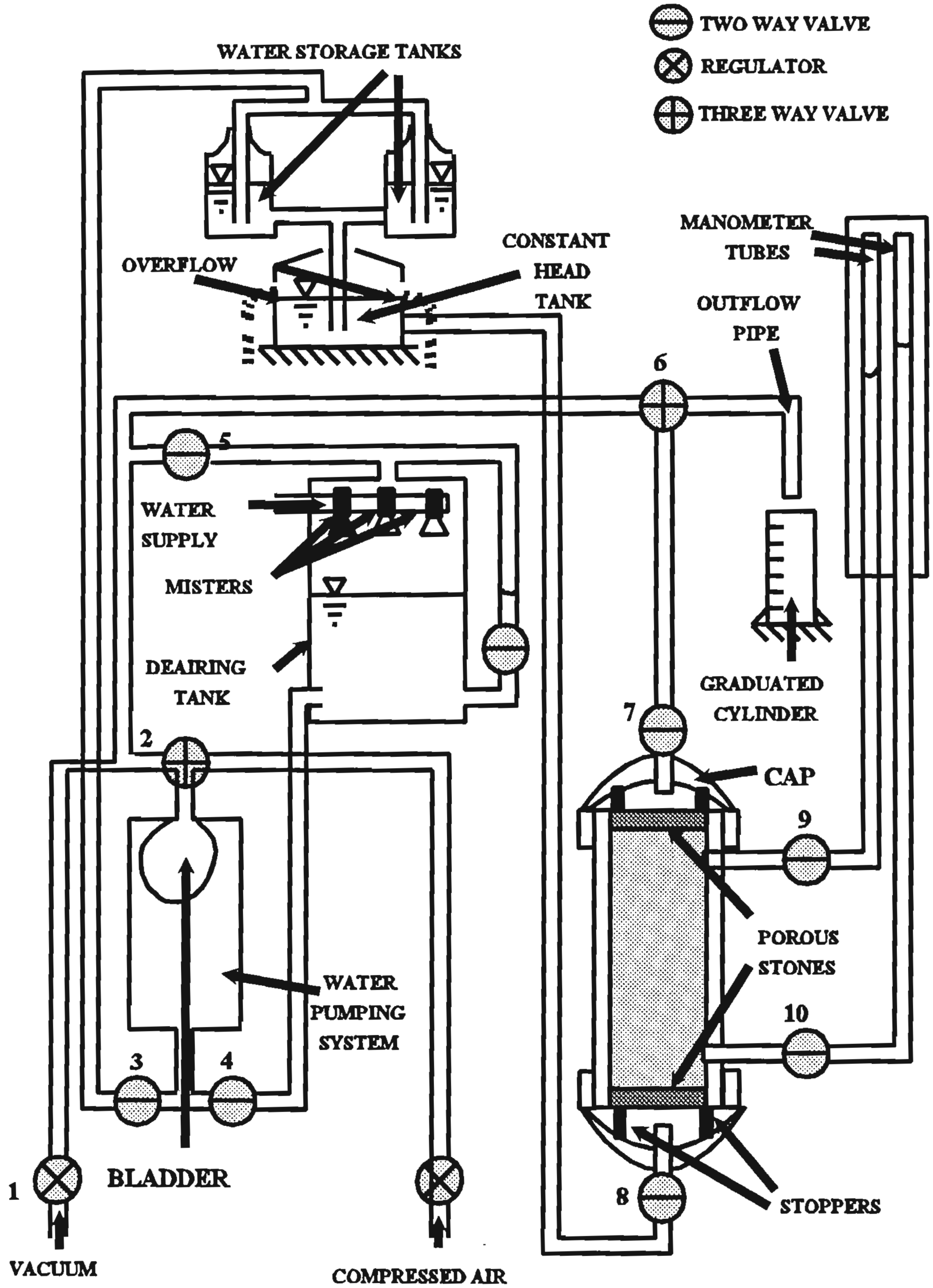

Figure C.1 Permeability Test Setup for Dense-Graded Base Material

Permeability Test of Dense-Graded Base Materials

Specimen Number : ________ Starting Date : ________
File Name : ________ Soil Identification : ________
Soil Description : ________ Cylinder Number : ________
Average Diameter, D =(______________) / 3 = _____ cm
Average Height, H =(______________) / 3 = _____ cm
Cross-Sectional Area of Specimen = ________ cm^2
Mass of Cylinder, M_C = ________ g
Target Moisture Content = ________ % Actual Moisture Content, M_C = ____ %
Distance Between the Two Manometers, L = ______ cm

Test No.	Difference in Manometer Heads, h (cm)	Total Discharge, Q (ml)	Discharge Time, t (sec)	Discharge Velocity, q=Q/At (cm/sec)	Hydraulic Gradient, i=h/L	Coefficient of Permeability, k=q/i (cm/sec)	pH of Water	Temperature of Water (° C)	Conductivity of Water (μSiemmens)

Figure C.2 Permeability Test Data Sheet for Dense-Graded Base Material

APPENDIX D

DRAFT PROTOCOL FOR COEFFICIENT OF PERMEABILITY TESTING OF CEMENT-STABILIZED BASE MATERIAL

(This test procedure is modified from the original AASHTO Test Procedure T 215-70)

PERMEABILITY OF CEMENT-STABILIZED BASE MATERIALS (CONSTANT HEAD)

This method covers a test procedure for determining the coefficient of permeability by a constant-head method for the laminar flow of water through cement-stabilized base material.

Test Conditions

The following ideal test conditions are prerequisite for the laminar flow of water through dense graded base material under constant head conditions:

- Continuity of flow with little or no specimen volume changes during a test.
- Flow with the soil voids saturated with water and no air bubbles in the voids.
- Direct proportionality of velocity of flow with hydraulic gradients below certain critical values, where turbulent flow starts.
- All other types of flow involving partial saturation of soil voids, turbulent flow, and unsteady state of flow are transient in character and yield variable and time-dependent coefficients of permeability; therefore, they require special test conditions and procedures.

Apparatus

- Permeameter, as shown in Figure D.1, shall consist of a top and bottom hollow cylinders (or end caps) with an average inside diameter of 15.56 cm (6.125 inch) and a height of approximately 15.51 cm (6.5 inch). Both cylinders shall have one end closed with a plate and an opening for inlet or outlet of water. Opening on both cylinders should have valves as shown in Figure D.1. Also, the hollow cylinders should have two grooves for O-rings and three set screws for properly securing the cylinders to the specimen, and opening and pipe fittings for manometer tubes.
- A split mold for specimen preparation, a hollow cylinder (stretcher) of size 155 mm by 300 mm (6.5 by 12 inch) for enclosing the specimen in latex membrane.
- In general, tap water has free air and interferes with the fundamental test conditions of the test. Hence, it is necessary to remove free air from the tap water. The free air can be removed by allowing the water to pass through misters and apply vacuum to remove the free air. This concept is used to develop a de-airing tank. De-airing tank, shown in Figure C.1, shall be used to remove most of the air from tap water. The de-airing tank consists of a steel drum, a PVC drum, valves and fittings, and a series of misters. The steel drum shall have a minimum capacity of 0.19 m^3 (50 gallons) and PVC drum shall have a minimum capacity of 0.15 m^3 (40 gallons). These requirements are to ensure sufficient supply of de-aired water. The PVC drum shall be kept inside the steel drum (if only PVC drum is used then the drum will collapse due to vacuum and if only steel drum is used then the life of steel drum is reduced because of rusting). Five to eight misters can be used for spraying the water in the tank. A constant vacuum of 12.7 cm of Hg (5 inch of Hg) shall be maintained in the tank for

continuous removal of air and at the same time to store the de-aired water inside the tank. The tank shall have four valves: 1) valve 1 is used to supply the tap water, 2) valve 2 is used to drain the de-aired water for constant head tank, 3) valve 3 is used for applying the vacuum inside the tank, and 4) valve 4 is used to find the level of water inside the tank . Usually, it takes about four to six hours to de-air 0.075 m^3 (20 gallons) of water.

- Water storage tanks, as shown in Figure D.1, shall be used to supply the water to constant head tank. Five water storage tanks are necessary to maintain constant head throughout the testing of a specimen.
- Constant Head Tank, as shown in Figure D.1 shall be used for maintaining the constant head on the specimen. The tank incorporates two slits and two blocking plates. The slits on both sides is to ensure the maintenance of constant head and blockers are used for maintaining static head rather than dynamic head due to water currents. In other words, the greater amount of water flow for maintaining constant head can cause turbulence inside the constant head tank. This turbulence may not allow a constant head level on the specimen even though the water level inside the constant head remains the same.
- Specimen shall be compacted inside the permeameter using standard compaction equipment i.e. standard proctor hammer and the compaction unit as shown in Figure A.3.
- Vacuum pump or water faucet aspirator, for evacuating and for saturating specimens under full vacuum.
- Air compressor (or laboratory compressed air faucet), for pumping the water from water pumping system to the water storage tank.
- Manometer tubes and a scale, as shown in Figure D.1, is needed for measuring the water head loss.
- Miscellaneous Apparatus, including latex membrane, thermometer, stop watch, vernier calipers, 500 ml graduate, quart jar, mixing pan, scoop, drying oven, balance, hydraulic press, moisture content cans, simple microscope, silicone gun and Teflon tape, pH and conductivity meter, geotextile patch, mesh, valves, gages, tubes, fittings, and data sheets.

Specimen Preparation

Step	Action
1	A representative sample of saturated-surface-dry gravel material (3/8 sieve and above) shall be selected. Approximately, 20 Kg (44 lb) of gravel is needed for 150x300 mm (6 by 12 inch) specimen. Acquire the selected amount of water and cement. Mix cement and water until thoroughly mixed. Add the cement paste to the gravel and mix thoroughly until gravel is completely covered with cement paste.
2.	Make the following measurements using vernier calipers and record on the test data sheet (Figure D.2): the diameter, D, of the specimen at three different locations; the length, L, between manometer outlets; the height, H, of the specimen measured at three different locations. Calculate the average height, diameter and cross sectional area of the specimen.

Specimen Preparation (continued)

Step	Action
3.	Place the split mold inside the aluminum base plate (Figure A.3). Make sure that the mold is levelled and properly seated inside the groove of the base plate. Use mallet if necessary for leveling. Now screw the threaded roads in to the four holes at the corner of the base plate and place the collar on top of the specimen. Use wing nuts to ensure proper placement of collar.
4.	The specimen shall be compacted in 5 cm (2 inch) layers. A standard Proctor Hammer is dropped 25 times on each lift to compact the cement-stabilized base material. After compaction remove collar and remove any excess stabilized gravel.
5.	Place the specimen along with the aluminum plate inside the curing room for 24 hrs. After the specimen has set, open the mold, and gently hammer the base plate sideways to separate the specimen from the base plate.
6.	Take a latex membrane and stretch the membrane on the stretcher using vacuum. Once the membrane is stretched, place the specimen inside the membrane and release the vacuum. Move the membrane 6 cm back on both edges of the specimen. Place a nail in the manometer opening of both end caps. Place the specimen inside both end caps and secure the end caps with set screws.
7.	Pull the latex membrane up and above the end caps until the membranes are above the two grooves for the O-ring. Place O-rings on the grooves of both end caps. Remove nails from the manometer openings and place caps on the manometer openings. Close valves on one of the end cap and apply vacuum through other end cap valve. Vacuum should be applied until the membrane is snugly fit on the specimen and wait to check for possible leakages. Wrap three to five rounds of duct tape around the specimen to cover all the specimen. Remove vacuum after wrapping duct tape.
8.	Place the specimen in specimen stand (Figure D.1) and secure with bar and wing nuts.

Procedure

Step	Action
1.	Start the water de-airing process at least 5 hrs before saturation of the specimen. Check the water level inside the de-airing tank and stop the flow of tap water when water level indicates sufficient de-aired water inside the tank. Since it is difficult to pump 0.075 m^3 (20 gallons) of de-aired water, just move the water storage tanks below de-airing tank and fill them by opening valve 4.
2.	After filling constant head tanks, connect the manometer tubes to the permeameter. Close valves 2, 5, 8, 9, and 10. Open Valves 1, 6, and 7. Apply a vacuum (using a vacuum pump or an aspirator) of 500 mm (20 inch) of Hg. for a minimum of fifteen minutes to ensure removal of air adhering to soil particles and in the voids. After fifteen minutes of vacuum, valve 8 is minutely opened to allow the flow of water. The amount of water flow through the valve 8 is increased until the water level reaches valve 6. At this point valve 8 is closed again and the constant head tank is moved 2 m above the specimen. Now valve 1 is closed and the outflow pipe is moved above the storage head tank to prevent any flow. After this step, the valves 8 and 6 are opened and the specimen is left overnight under a column of 2 m.
3.	Next day, initiate the water flow by supplying the water to the constant head tank, by connecting the manometer tubes, by opening valves 9 and 10, and by moving the outlet flow pipe below the constant head tank.
4.	After 5 minutes close valves 7 and 8 to check degree of saturation achieved in the specimen by raising the specimen about 30 cm (1 foot) and by measuring the change in the height of water in the manometer tubes. The change in height is measured and degree of saturation can be calculated using ideal gas law. At least 98% of saturation should be achieved before proceeding with the constant head permeability test.
5.	Open valves 7 and 8. Regulate the flow of water through storage tanks to maintain the constant head and avoid any excess wastage of de-aired water. Move outlet pipe below the constant head tank to achieve a minimum head loss. Delay measurements of quantity of flow and head loss until a stable head condition without appreciable drift in water manometer levels is attained. Measure and record time, t, head loss, h, quantity of flow, Q, and keep a sample to measure pH and conductivity of the outflow water.

Procedure (continued)

Step	Action
6.	Repeat test runs at heads increasing by minimum to establish accurately the region of laminar flow with discharge q, (where q=Q/At) directly proportional to hydraulic gradient, i, (where i=h/L). When departure from linear relation become apparent, indicating the initiation of turbulent flow conditions, the test should be stopped (A review of literature has suggested that a hydraulic gradient below 0.05 should be used to ensure laminar flow).
7.	At the completion of the permeability test, drain the specimen and inspect it to establish whether it was essentially homogenous and isotropic in character.
8.	Note any important findings on the data sheet.

Calculations

Calculate the permeability coefficient using Darcy's Law:

$$k = \frac{Q \cdot L}{A \cdot t \cdot h} \qquad \textbf{(25)}$$

where:
k = permeability coefficient,
Q = quantity of water discharged,
L = distance between manometers,
A = cross-sectional area of specimen,
t = total time of discharge,
h = difference in head on manometers (or head loss).

However, this equation is valid only if the water flow occurs under laminar flow conditions. At higher velocities, a transitional flow occurs which can be characterized by the equation:

$$i = aq + bq^2 \qquad \textbf{(26)}$$

where:
i = hydraulic gradient (h/L)
q = discharge velocity (Q/At)
a = regression constant of the first order
b = regression constant of the second order

Using observed i and q data, regression constant a and b can be found. The inverse of regression constant a is the permeability coefficient.

Report

The report of permeability test shall include the following information:

- Permeability test data sheet,
- Specific Gravity of the specimen,
- A statement of any departures from these test conditions, so the results can be evaluated and used,
- A plot of permeability coefficient versus hydraulic gradient,

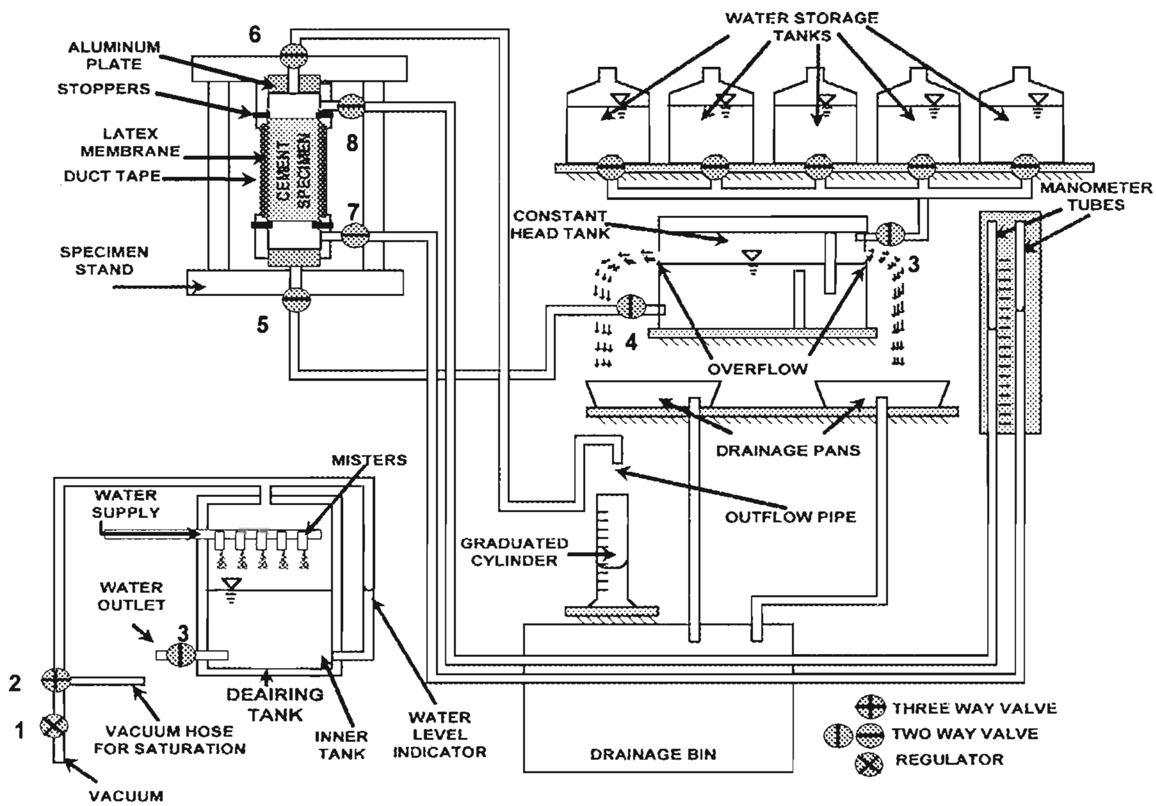

Figure D.1 Permeability Test Setup for Cement-Stabilized Base Material

Permeability Test of Cement-Stabilized Base Materials

Specimen Number : __________ Starting Date : __________
File Name : __________ Soil Identification : __________
Soil Description : __________ Cylinder Number : __________
Average Diameter, D =(________________) / 3 = ______ cm
Average Height, H =(________________) / 3 = ______ cm
Cross-Sectional Area of Specimen = __________ cm^2
Target Moisture Content = __________ % Actual Moisture Content, M_C = ____ %
Distance Between the Two Manometers, L = _______ cm

Test No.	Difference in Manometer Heads, h (cm)	Total Discharge, Q (ml)	Discharge Time, t (sec)	Discharge Velocity, q=Q/At (cm/sec)	Hydraulic Gradient, i=h/L	Coefficient of Permeability, k=q/i (cm/sec)	pH of Water	Temperature of Water (° C)	Conductivity of Water (μSiemmens)

Figure D.2 Permeability Test Data Sheet for Cement-Stabilized Base Material

APPENDIX E

SOIL WATER RETENTION TESTS RESULTS OF DENSE-GRADED BASE MATERIALS

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 1 **STARTING DATE '** 10/20/95
File Name : BROWO1SO.XLS
Soil Identification : Brownwood(old)
Soil description : Soil Water Retention
Cylinder Number :

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.08 15.07 15.07) / 3 = 15.07 cm.
Avg Ht. = (15.01 15.11 15.08) / 3 = 15.07 cm.
Area of Specimen = 178.45 cm^2 Vol. of Specimen = 2688.60 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1431.20 gm.
Total Wt. (without the Cap)= 7509.6 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 8240 gm. Actual moisture cont. 5.62 %
Dry Wt. of Soil Specimen = 5754.97 gm. Total Wt. (Sat.)= 8568.1 gm.
Wt. of Water in Sat. Specimen= 651.53 gm.
Initial pH of Water= Initial Conductivity of Water=

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
10/21/95	17 0	0.00	8568.10	651.53		
10/23/95	11 12	42.20	8321.20	404.63	8.23	1387
10/24/95	15 15	70.25	8368.30	451.73		
10/25/95	12 0	91.00	8364.50	447.93	8.25	1501
10/26/95	11 45	114.75	8364.30	447.73	7.92	1763
10/27/95	12 10	139.17	8362.20	445.63	8.11	1669
10/30/95	11 45	210.75	8353.60	437.03	8.12	1994
10/31/95	13 56	236.93	8350.90	434.33	8.51	1859
11/1/95	11 21	258.35	8349.20	432.63	8.18	1920
11/2/95	11 0	282.00	8347.90	431.33	8.21	2000
11/3/95	11 21	306.35	8333.60	417.03	8.22	2100

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 2 **STARTING DATE** 12/31/95
File Name : BROWO2SO.XLS
Soil Identification : Brownwood Soil (Old)
Soil description : Soil Water Retention
Cylinder Number :

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.04 15.05 14.99) / 3 = 15.03 cm.
Avg Ht. = (15.07 15.09 15.05) / 3 = 15.07 cm.
Area of Specimen = 177.34 cm^2 Vol. of Specimen = 2672.57 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1847.10 gm.
Total Wt. (without the Cap)= 7680.9 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 8401.3 gm. Actual moisture cont. 6.09 %
Dry Wt. of Soil Specimen = 5498.75 gm. Total Wt. (Sat.)= 8772.7 gm.
Wt. of Water in Sat. Specimen= 706.45 gm.
Initial pH of Water= 8.13 Initial Conductivity of Water= 1072

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
1/2/96	10 58	0.00	8772.70	706.45	8.13	1072
1/3/96	11 50	24.87	8507.70	441.45	8.37	1224
1/4/96	11 28	48.50	8498.00	431.75	8.45	1327
1/5/96	11 27	72.48	8492.70	426.45	8.19	1419
1/6/96	8 28	93.50	8488.60	422.35	8.31	1516
1/8/96	11 34	144.60	8482.10	415.85	8.29	1791
1/9/96	11 3	168.08	8479.60	413.35	8.36	1942
1/10/96	11 51	192.88	8478.00	411.75	8.44	1748
1/11/96	12 23	217.42	8476.60	410.35	8.43	997
1/12/96	13 52	242.90	8475.80	409.55	8.08	1076
1/15/96	10 52	311.90	8474.00	407.75	8.24	1257
1/16/96	8 46	333.80	8474.40	408.15	8.17	1008
1/17/96	13 9	362.18	8467.10	400.85	8.11	1004
1/18/96	11 11	384.22	8473.60	407.35	8.26	1074
1/19/96	13 17	410.32	8472.10	405.85	8.09	890

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 1 **STARTING DATE** 10/4/95
File Name : CHILO1SO.XLS
Soil Identification : Childress Soil (Old)
Soil description : Soil Water Retention
Cylinder Number :

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.38 15.38 15.33) / 3 = 15.36 cm.
Avg Ht. = (14.85 14.92 14.88) / 3 = 14.88 cm.
Area of Specimen = 185.31 cm^2 Vol. of Specimen = 2757.59 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1726.10 gm.
Total Wt. (without the Cap)= 7529.80 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 8214.00 gm. Actual moisture cont. 12.6 %
Dry Wt. of Soil Specimen = 5154.26 gm. Total Wt. (Sat.)= 8910.10 gm.
Wt. of Water in Sat. Specimen= 1345.54 gm.
Initial pH of Water= Initial Conductivity of Water=

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
10/4/95	13 0	0.00	8910.10	1345.54		
10/6/95	12 9	47.15	8476.70	912.14	8.13	1314
10/9/95	11 46	118.77	8470.20	905.64	8.03	1391
10/10/95	12 45	143.75	8468.40	903.84		
10/11/95	11 0	166.00	8463.70	899.14	8.04	1522
10/13/95	12 13	215.22	8452.50	887.94	8.22	1657
10/16/95	16 0	291.00	8442.00	877.44	8.22	1679
10/17/95	10 20	309.33	8440.50	875.94		
10/18/95	11 24	334.40	8432.10	867.54	7.98	1932
10/20/95	12 52	383.87	8413.30	848.74	8.07	
10/23/95	11 0	454.00	8404.30	839.74	8.23	2.42
10/24/95	15 15	482.25	8416.00	851.44		
10/25/95	11 58	502.97	8412.10	847.54	8.19	2370
10/26/95	14 45	529.75	8409.30	844.74		
10/27/95	12 8	551.13	8405.70	841.14	8.15	2540

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 2 **STARTING DATE** 1/10/96
File Name : CHILO2SO.XLS
Soil Identification : Childress Soil (Old)
Soil description : Soil Water Retention
Cylinder Number :

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.28 15.29 15.25) / 3 = 15.27 cm.
Avg Ht. = (14.89 15.00 14.79) / 3 = 14.89 cm.
Area of Specimen = 183.21 cm^2 Vol. of Specimen = 2728.66 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1730.20 gm.
Total Wt. (without the Cap)= 7738.6 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 8453.6 gm. Actual moisture cont. 5.73 %
Dry Wt. of Soil Specimen = 5682.82 gm. Total Wt. (Sat.)= 9583.1 gm.
Wt. of Water in Sat. Specimen= 1455.1 gm.
Initial pH of Water= 8.05 Initial Conductivity of Water= 38.7

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
1/12/96	11 40	0.00	9583.10	1455.08	8.05	38.7
1/15/96	10 57	71.28	8653.80	525.78	7.64	206
1/16/96	8 50	93.17	8648.30	503.48	7.7	218
1/17/96	13 13	121.55	8626.00	516.78	7.85	229
1/18/96	11 20	143.67	8639.30	512.68	7.99	243
1/19/96	13 25	169.75	8635.20	512.68	7.83	221

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 1 **STARTING DATE** 9/13/95
File Name : CORPN1SO.XLS
Soil Identification : Corpus Christi Soil (New)
Soil description : Soil Water Retention
Cylinder Number :

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.06 15.11 15.05) / 3 = 15.08 cm.
Avg Ht. = (14.95 15.00 14.96) / 3 = 14.97 cm.
Area of Specimen = 178.49 cm^2 Vol. of Specimen = 2672.04 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1719.30 gm.
Total Wt. (without the Cap)= 6408.5 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 7142.2 gm. Actual moisture cont. 5.59 %
Dry Wt. of Soil Specimen = 4440.95 gm. Total Wt. (Sat.)= 8272.1 gm.
Wt. of Water in Sat. Specimen= 1378.15 gm.
Initial pH of Water= Initial Conductivity of Water=

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
9/13/95	14 42	0.00	8272.10	1378.15		
9/14/95	12 50	22.13	8336.30	1442.35		
9/16/95	13 45	71.05	7910.20	1016.25		
9/18/95	11 0	116.30	7892.30	998.35		
9/19/95	13 50	143.13	7891.80	997.85		
9/20/95	15 40	168.97	7887.20	993.25		
9/21/95	13 50	191.13	7883.40	989.45		
9/22/95	11 30	212.80	7882.90	988.95		
9/23/95	11 30	236.80	7883.60	989.65		
9/25/95	11 35	284.88	7886.50	992.55		
9/26/95	11 35	308.88	7887.20	993.25		
9/27/95	11 40	332.97	7888.60	994.65		
9/28/95	11 30	356.80	7837.60	943.65		
9/29/95	15 10	384.47	7809.90	915.95		
10/2/95	12 6	453.40	7867.50	973.55	4.79	
10/4/95	11 35	500.88	7890.60	996.65	7.25	1096
10/6/95	11 26	548.73	7891.00	997.05	7.9	1211
10/9/95	11 23	620.68	7889.10	995.15	8.09	1385

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 2 **STARTING DATE** 1/10/96
File Name : CORPN2SO.XLS
Soil Identification : Corpus Christi Soil(New)
Soil description : Soil Water Retention
Cylinder Number :

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.12 15.00 15.03) / 3 = 15.05 cm.
Avg Ht. = (15.01 14.97 14.50) / 3 = 14.83 cm.
Area of Specimen = 177.89 cm^2 Vol. of Specimen = 2637.58 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1894.40 gm.
Total Wt. (without the Cap)= 6086.8 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 6797.1 gm. Actual moisture cont. 12.25 %
Dry Wt. of Soil Specimen = 3734.90 gm. Total Wt. (Sat.)= 8090.5 gm.
Wt. of Water in Sat. Specimen= 1750.90 gm.
Initial pH of Water= 8.18 Initial Conductivity of Water= 229

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
1/10/96	12 25	0.00	8090.50	1750.90		
1/11/96	11 25	23.00	7681.00	1341.40	8.18	229
1/12/96	13 54	49.48	7675.10	1335.50	7.91	263
1/15/96	10 56	118.52	7647.80	1308.20	8.08	390
1/16/96	8 49	140.40	7654.80	1315.20	8.09	332
1/17/96	13 12	168.78	7655.90	1316.30	8.11	342
1/18/96	11 20	190.92	7665.80	1326.20	8.26	386
1/19/96	13 22	216.95	7665.40	1325.80	7.98	322

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 1 **STARTING DATE** 9/18/1995
File Name : ELPAN1SO.XLS
Soil Identification : El Paso Montana (New)
Soil description : Soil Water Retention
Cylinder Number :

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.09 15.04 15.07) / 3 = 15.07 cm.
Avg Ht. = (15.09 15.18 15.03) / 3 = 15.10 cm.
Area of Specimen = 178.29 cm^2 Vol. of Specimen = 2692.16 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1826.70 gm.
Total Wt. (without the Cap)= 7699.5 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 8419.5 gm. Actual moisture cont. 6.7 %
Dry Wt. of Soil Specimen = 5504.03 gm. Total Wt. (Sat.)= 9268.90 gm.
Wt. of Water in Sat. Specimen= 1218.17 gm.
Initial pH of Water= Initial Conductivity of Water=

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
11/1/95	12 45	0.00	9268.90	1218.17		
11/2/95	10 44	21.98	8599.00	548.27	8.36	2150
11/3/95	11 8	46.38	8576.20	525.47	8.32	2320
11/6/95	11 15	118.50	8526.30	475.57	8.18	2750
11/7/95	11 13	142.47	8455.10	404.37	8.27	2920
11/8/95	11 16	166.52	8288.20	237.47	8.24	2690
11/9/95	10 52	190.12	8446.10	395.37	8.04	2780
11/10/95	11 16	214.52	8529.30	478.57	8.25	3000
11/13/95	10 59	286.23	8573.10	522.37	8.32	3230
11/14/95	10 48	310.05	8540.80	490.07	8.26	3330
11/15/95	10 52	334.12	8511.90	461.17	8.23	3520
11/16/95	10 41	357.93	8522.80	472.07		3130
11/17/95	11 18	382.55	8534.00	483.27		3310
11/20/95	10 48	454.05	8563.20	512.47		3310
11/21/95	9 16	476.52	8530.60	479.87		3580
11/22/95	11 1	502.27	8505.70	454.97		3860
11/24/95	14 5	553.33	8523.10	472.37		4670
11/27/95	11 30	622.75	8558.10	507.37		5920
11/28/95	10 53	646.13	8570.00	519.27		2770
11/29/95	10 54	670.15	8570.00	519.27		3160
11/30/95	9 37	692.87	8569.50	518.77		3280
12/1/95	10 58	718.22	8570.30	519.57		3570
12/4/95	10 49	790.07	8570.00	519.27		4560
12/5/95	12 57	816.20	8569.70	518.97		3540
12/8/95	11 22	886.62	8570.00	519.27		4300

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 2 **STARTING DATE** 12/31/95
File Name : ELPANSO2.XLS
Soil Identification : El Paso Montana Soil(New)
Soil description : Soil Water Retention
Cylinder Number :

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.06 15.02 15.03) / 3 = 15.04 cm.
Avg Ht. = (15.12 15.02 15.11) / 3 = 15.08 cm.
Area of Specimen = 177.58 cm^2 Vol. of Specimen = 2678.49 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1885.20 gm.
Total Wt. (without the Cap)= 7863.5 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 8597.8 gm. Actual moisture cont. 7.62 %
Dry Wt. of Soil Specimen = 5554.79 gm. Total Wt. (Sat.)= 9382.1 gm.
Wt. of Water in Sat. Specimen= 1207.81 gm.
Initial pH of Water= 7.52 Initial Conductivity of Water= 884

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water
1/2/96	10 58	0.00	9382.10	1207.81	7.52	884
1/3/96	11 51	24.88	8712.50	538.21	8.32	1322
1/4/96	11 29	48.52	8707.70	533.41	8.43	1396
1/5/96	11 28	72.50	8705.80	531.51	8.06	1476
1/6/96	8 29	93.52	8698.40	524.11	8.23	1521
1/8/96	11 35	144.62	8701.00	526.71	8.29	1700
1/9/96	11 4	168.10	8699.30	525.01	8.32	1790
1/10/96	11 52	192.90	8698.00	523.71	8.34	1871
1/11/96	12 24	217.43	8701.40	527.11	8.44	1354
1/12/96	13 53	242.92	8698.80	524.51	8.2	1417
1/15/96	10 53	311.92	8698.10	523.81	8.31	1603
1/16/96	8 47	333.82	8702.60	528.31	8.2	1290
1/17/96	13 10	362.20	8688.90	514.61	8.2	1426
1/18/96	11 11	384.22	8692.00	517.71	8.36	1471
1/19/96	13 19	410.35	8697.30	523.01	8.14	1263

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 1 **STARTING DATE** 9/18/1995
File Name : ODESN1SO.XLS
Soil Identification : Odessa Soil (New)
Soil description : Soil Water Retention
Cylinder Number :

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.08 15.05 15.07) / 3 = 15.07 cm.
Avg Ht. = (15.07 15.07 15.05) / 3 = 15.06 cm.
Area of Specimen = 178.29 cm^2 Vol. of Specimen = 2685.62 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1634.10 gm.
Total Wt. (without the Cap)= 6875 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 7596.1 gm. Actual moisture cont. 5.56 %
Dry Wt. of Soil Specimen = 4964.85 gm. Total Wt. (Sat.)= 8155.60 gm.
Wt. of Water in Sat. Specimen= 835.55 gm.
Initial pH of Water= Initial Conductivity of Water=

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
9/13/95	14 42	0.00	8155.60	835.55		
9/14/95	12 55	22.22	8141.80	821.75		
9/15/95	12 45	46.05	7968.10	648.05		
9/18/95	11 0	116.30	7952.90	632.85		
9/19/95	13 50	143.13	7950.30	630.25		
9/20/95	15 44	169.03	7948.60	628.55		
9/21/95	13 50	191.13	7944.70	624.65		
9/22/95	11 30	212.80	7943.20	623.15		
9/23/95	11 30	236.80	7941.60	621.55		
9/25/95	11 35	284.88	7940.40	620.35		
9/26/95	11 35	308.88	7939.80	619.75		
9/27/95	11 40	332.97	7937.10	617.05		
9/28/95	13 30	358.80	7876.90	556.85		
9/29/95	15 10	384.47	7864.80	544.75		
10/2/95	12 11	453.48	7906.10	586.05		
10/4/95	11 53	501.18	7930.00	609.95	7.01	967
10/6/95	11 21	548.65	7940.90	620.85	7.73	1114
10/9/95	11 20	620.63	7944.30	624.25	7.99	1366

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 2 **STARTING DATE** 12/23/95
File Name : ODESN2SO.XLS
Soil Identification : Odessa Soil (New)
Soil description : Soil Water Retention
Cylinder Number :

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.04 15.03 15.13) / 3 = 15.07 cm.
Avg Ht. = (15.10 15.06 15.10) / 3 = 15.09 cm.
Area of Specimen = 178.29 cm^2 Vol. of Specimen = 2689.78 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1776.10 gm.
Total Wt. (without the Cap)= 7088.6 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 7739.7 gm. Actual moisture cont. 6.50 %
Dry Wt. of Soil Specimen = 4988.26 gm. Total Wt. (Sat.)= 8720.9 gm.
Wt. of Water in Sat. Specimen= 1305.44 gm.
Initial pH of Water= 8.36 Initial Conductivity of Water= 967

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
12/27/95	9 35	0.00	8720.90	1305.44	8.36	967
12/28/95	12 5	26.50	8182.10	766.64	8.06	1550
12/29/95	10 0	48.42	8179.70	764.24	8.15	754
12/30/95	13 36	76.02	8055.50	640.04	8.15	1787
1/2/96	10 45	145.17	8166.30	750.84	8.11	937
1/3/96	11 48	170.22	8163.90	748.44	7.93	954
1/4/96	11 26	193.85	8162.10	746.64	7.85	1088
1/5/96	11 26	217.85	8163.90	748.44	7.66	1103
1/6/96	8 27	238.87	8162.00	746.54	7.6	1156
1/8/96	11 31	289.93	8158.70	743.24	7.77	1308
1/9/96	11 3	313.47	8157.60	742.14	7.78	1392
1/10/96	11 6	337.52	8156.20	740.74	7.35	1199
1/11/96	12 22	362.78	8162.20	746.74	8.28	993
1/12/96	13 51	388.27	8159.60	744.14	7.62	1014
1/15/96	10 50	457.25	8164.40	748.94	7.84	1147
1/16/96	8 45	479.17	8158.70	743.24	7.59	841
1/17/96	13 7	507.53	8157.80	742.34	8.01	887
1/18/96	11 9	529.57	8157.00	741.54	8.26	1057
1/19/96	13 13	555.63	8160.30	744.84	8.02	844

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 1 **STARTING DATE** 9/18/96
File Name : PARIN1SO.XLS
Soil Identification : Paris Soil (New)
Soil description : Soil Water Retention
Cylinder Number :

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.29 15.28 15.28) / 3 = 15.28 cm.
Avg Ht. = (14.37 15.07 14.40) / 3 = 14.61 cm.
Area of Specimen = 183.45 cm^2 Vol. of Specimen = 2680.87 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1668.50 gm.
Total Wt. (without the Cap)= 6733.70 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 7422.00 gm. Actual moisture cont. 2.37 %
Dry Wt. of Soil Specimen = 4947.93 gm. Total Wt. (Sat.)= 8085.10 gm.
Wt. of Water in Sat. Specimen= 780.37 gm.
Initial pH of Water= Initial Conductivity of Water=

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
9/18/95	11 0	0.00	8085.10	780.37		
9/19/95	13 50	26.83	7668.70	363.97		
9/20/95	15 53	52.88	7655.50	350.77		
9/21/95	13 30	74.50	7649.90	345.17		
9/22/95	11 30	96.50	7646.60	341.87		
9/23/95	11 35	120.58	7642.80	338.07		
9/25/95	11 30	168.50	7637.20	332.47		
9/26/95	11 40	192.67	7636.60	331.87		
9/27/95	11 30	216.50	7635.10	330.37		
9/28/95	13 10	242.17	7634.70	329.97		
9/29/95	15 52	268.87	7633.90	329.17		
10/2/95	11 43	336.72	7636.40	331.67		
10/4/95	11 5	384.08	7635.00	330.27	7.32	1061
10/6/95	12 42	433.70	7631.20	326.47	8.37	1131
10/9/95	11 45	504.75	7626.90	322.17	8.29	1336
10/10/95	12 21	529.35	7626.40	321.67		
10/11/95	11 50	552.83	7625.30	320.57	7.97	1415
10/13/95	11 47	600.78	7626.10	321.37	7.86	1489
10/16/95	15 20	676.33	7624.50	319.77	8.12	1528
10/17/95	10 20	695.33	7624.20	319.47		
10/18/95	11 0	720.00	7624.6	319.87	8.28	1660
10/20/95	12 48	769.80	7605.70	300.97	8.47	1836
10/23/95	11 0	840.00	7602.90	298.17	8.24	2028
10/24/95	15 15	868.25	7621.50	316.77		
10/25/95	11 55	888.92	7616.40	311.67	8.22	2050
10/26/95	14 45	915.75	7621.40	316.67		
10/27/95	12 5	937.08	7619.4	314.67	8.11	2330
10/30/95	11 45	1008.75	7618.3	313.57	8.06	2700

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 2 **STARTING DATE** 12/23/95

File Name : PARIN2SO.XLS

Soil Identification : Paris Soil (New)

Soil description : Soil Water Retention

Cylinder Number :

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.30 15.26 15.28) / 3 = 15.28 cm.

Avg Ht. = (14.36 14.42 14.38) / 3 = 14.39 cm.

Area of Specimen = 183.37 cm^2 Vol. of Specimen = 2638.13 cm^3

Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1751.60 gm.

Total Wt. (without the Cap)= 6527.1 gm. Target moisture cont. 5 %

Total Wt. (with the Cap) = 7231.6 gm. Actual moisture cont. 6.51 %

Dry Wt. of Soil Specimen = 4483.42 gm. Total Wt. (Sat.)= 7730.0 gm.

Wt. of Water in Sat. Specimen= 790.48 gm.

Initial pH of Water= 7.27 Initial Conductivity of Water= 300

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
12/29/95	10 5	0.00	7730.00	790.48	7.27	300
12/30/95	13 49	27.73	7500.40	560.88	8.09	342
1/2/96	10 40	96.58	7459.10	519.58	7.99	509
1/3/96	11 54	121.82	7456.20	516.68	8.21	588
1/4/96	11 35	145.50	7455.60	516.08	8.21	634
1/5/96	11 32	169.45	7454.90	515.38	8.15	688
1/6/96	8 31	190.43	7454.60	515.08	8.23	711
1/8/96	11 37	241.53	7454.30	514.78	7.28	811
1/9/96	11 6	265.02	7454.00	514.48	8.14	864
1/10/96	11 53	289.80	7454.00	514.48	8.22	868
1/11/96	11 26	313.35	7453.60	514.08	8.08	521
1/12/96	13 55	339.83	7453.70	514.18	7.85	562
1/15/96	10 58	408.88	7443.20	503.68	7.45	703
1/16/96	8 51	430.77	7451.90	512.38	7.89	461
1/17/96	10 13	456.13	7461.30	521.78	7.85	496
1/18/96	11 21	481.27	7453.30	513.78	7.99	519
1/19/96	13 26	507.35	7452.40	512.88	7.8	426

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 1 **STARTING DATE'** 10/18/95
File Name : SANAN1SO.XLS
Soil Identification : San Angelo (new)
Soil description : Soil Water Retention
Cylinder Number :

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(14.33 14.33 14.29) / 3 = 14.32 cm.
Avg Ht. = (15.21 15.28 15.17) / 3 = 15.22 cm.
Area of Specimen = 160.98 cm^2 Vol. of Specimen = 2450.13 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1645.00 gm.
Total Wt. (without the Cap)= 6987.2 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 7642 gm. Actual moisture cont. 4.53 %
Dry Wt. of Soil Specimen = 5110.69 gm. Total Wt. (Sat.)= 8318.6 gm.
Wt. of Water in Sat. Specimen= 908.11 gm.
Initial pH of Water= Initial Conductivity of Water=

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
10/18/95	8 45	0.00	8318.60	908.11	8.06	1302
10/20/95	17 0	56.25	7895.20	484.71		
10/23/95	11 12	122.45	7888.40	477.91	7.99	1488
10/24/95	15 15	150.50	7903.20	492.71		
10/25/95	12 0	171.25	7899.50	489.01	8.14	1494
10/26/95	11 45	195.00	7903.00	492.51		
10/27/95	12 10	219.42	7901.50	491.01	8.11	1661
10/30/95	11 45	291.00	7899.70	489.21	8	1966
10/31/95	13 56	317.18	7899.40	488.91	7.76	1782
11/1/95	11 21	338.60	7899.00	488.51	8	1866
11/2/95	11 0	362.25	7899.60	489.11	7.95	1948
11/3/95	11 21	386.60	7856.30	445.81	8.13	2060
11/6/95	11 29	458.73	7844.6	434.11	8.15	2470
11/7/95	11 20	482.58	7869.00	458.51	8.16	2600
11/8/95	11 23	506.63	7841.00	430.51	8.23	2350

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 2 **STARTING DATE** 1/10/96
File Name : SANAN2SO.XLS
Soil Identification : San Angelo Soil (New)
Soil description : Soil Water Retention
Cylinder Number :

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.30 15.25 15.29) / 3 = 15.28 cm.
Avg Ht. = (14.14 14.38 14.93) / 3 = 14.48 cm.
Area of Specimen = 183.37 cm^2 Vol. of Specimen = 2655.86 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1709.40 gm.
Total Wt. (without the Cap)= 6946 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 7655.4 gm. Actual moisture cont. 5.78 %
Dry Wt. of Soil Specimen = 4950.48 gm. Total Wt. (Sat.)= 8250.8 gm.
Wt. of Water in Sat. Specimen= 881.52 gm.
Initial pH of Water= 8.38 Initial Conductivity of Water= 162.3

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
1/12/96	11 40	0.00	8250.80	881.52	8.38	162.3
1/15/96	10 51	71.18	7795.60	426.32	7.98	258
1/16/96	8 45	93.08	7796.70	427.42	7.99	234
1/17/96	13 8	121.47	7796.30	427.02	8.15	264
1/18/96	11 11	143.52	7796.10	426.82	8.37	268
1/19/96	13 17	169.62	7796.00	426.72	8.19	217

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 1 **STARTING DATE** 9/13/95
File Name : SANTO1SO.XLS
Soil Identification : San Antonio Soil (New)
Soil description : Soil Water Retention
Cylinder Number :

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.01 15.11 15.04) / 3 = 15.05 cm.
Avg Ht. = (15.08 15.08 15.10) / 3 = 15.09 cm.
Area of Specimen = 177.97 cm^2 Vol. of Specimen = 2685.03 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1552.10 gm.
Total Wt. (without the Cap)= 7022.8 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 7756.5 gm. Actual moisture cont. 4.98 %
Dry Wt. of Soil Specimen = 5211.18 gm. Total Wt. (Sat.)= 8650.7 gm.
Wt. of Water in Sat. Specimen= 1153.72 gm.
Initial pH of Water= Initial Conductivity of Water=

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
9/13/95	14 23	0.00	8650.70	1153.72		
9/14/95	12 55	22.53	8534.40	1037.42		
9/16/95	13 45	71.37	8010.90	513.92		
9/18/95	11 0	116.62	8006.70	509.72		
9/19/95	13 50	143.45	8003.60	506.62		
9/20/95	15 47	169.40	8005.20	508.22		
9/21/95	13 50	191.45	8004.40	507.42		
9/22/95	11 30	213.12	8003.90	506.92		
9/23/95	11 30	237.12	8003.60	506.62		
9/25/95	11 35	285.20	8002.70	505.72		
9/26/95	11 30	309.12	8002.90	505.92		
9/27/95	11 40	333.28	8003.70	506.72		
9/28/95	11 30	357.12	7985.30	488.32		
9/29/95	15 10	384.78	7918.00	421.02		
10/2/95	12 14	453.85	8001.50	504.52		
10/3/95	16 25	482.03	8001.60	504.62		
10/4/95	11 15	500.87	8001.10	504.12		
10/6/95	11 16	548.88	8002.90	505.92	7.09	1763
10/9/95	11 18	620.92	8007.20	510.22	8.1	1990

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 2 **STARTING DATE** 12/23/95

File Name : SANTO2SO.XLS

Soil Identification : San Antonio Soil (Old)

Soil description : Soil Water Retention

Cylinder Number :

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.06 15.11 15.03) / 3 = 15.07 cm.

Avg Ht. = (15.08 15.09 15.09) / 3 = 15.09 cm.

Area of Specimen = 178.29 cm^2 Vol. of Specimen = 2689.78 cm^3

Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1706.80 gm.

Total Wt. (without the Cap)= 7070.5 gm. Target moisture cont. 5 %

Total Wt. (with the Cap) = 7694 gm. Actual moisture cont. 5.98 %

Dry Wt. of Soil Specimen = 5061.05 gm. Total Wt. (Sat.)= 8575.9 gm.

Wt. of Water in Sat. Specimen= 1184.55 gm.

Initial pH of Water= 8.37 Initial Conductivity of Water= 640

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
12/27/95	9 35	0.00	8575.90	1184.55	8.37	640
12/28/95	12 6	26.52	8062.10	670.75	8.02	695
12/29/95	10 0	48.42	8058.80	667.45	8.11	1644
12/30/95	13 36	76.02	8174.30	782.95	8.22	793
1/2/96	10 45	145.17	8049.00	657.65	8.51	1383
1/3/96	11 48	170.22	8046.10	654.75	8.43	1496
1/4/96	11 26	193.85	8044.80	653.45	8.58	1646
1/5/96	11 26	217.85	8048.30	656.95	8.19	1353
1/6/96	8 27	238.87	8047.50	656.15	8.2	1434
1/8/96	11 31	289.93	8046.10	654.75	8.22	1668
1/9/96	11 3	313.47	8046.30	654.95	8.25	1825
1/10/96	11 6	337.52	8045.50	654.15	8.38	1989
1/11/96	12 22	362.78	8045.60	654.25	8.53	1178
1/12/96	13 51	388.27	8046.80	655.45	8.14	1250
1/15/96	10 50	457.25	8046.60	655.25	8.39	1517
1/16/96	8 45	479.17	8048.40	657.05	8.29	1117
1/17/96	13 7	507.53	8047.30	655.95	8.2	1195
1/18/96	11 9	529.57	8048.60	657.25	8.37	1240
1/19/96	13 13	555.63	8047.50	656.15	8.23	1092

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 1 **STARTING DATE** 9/15/95
File Name : TYLEN1SO.XLS
Soil Identification : Tyler Soil (New)
Soil description : Soil Water Retention
Cylinder Number :

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.28 15.31 15.25) / 3 = 15.28 cm.
Avg Ht. = (13.64 13.63 13.63) / 3 = 13.63 cm.
Area of Specimen = 183.34 cm^2 Vol. of Specimen = 2499.69 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1527.50 gm.
Total Wt. (without the Cap)= 7030.50 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 7719.00 gm. Actual moisture cont. 6 %
Dry Wt. of Soil Specimen = 5191.51 gm. Total Wt. (Sat.)= 8225.70 gm.
Wt. of Water in Sat. Specimen= 818.19 gm.
Initial pH of Water= Initial Conductivity of Water=

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
9/26/95	13 45	0.00	8225.70	818.19		
9/27/95	11 40	21.92	8034.10	626.59		
9/28/95	13 30	47.75	8029.70	622.19		
9/29/95	15 0	73.25	8023.40	615.89		
10/2/95	12 0	142.25	8023.40	615.89		
10/4/95	11 55	190.17	8021.70	614.19	7.58	322
10/6/95	12 0	238.25	8011.20	603.69	8.15	505
10/9/95	11 45	310.00	8002.50	594.99	8.09	598
10/10/95	12 45	335.00	8001.20	593.69		
10/11/95	11 10	357.42	7999.90	592.39	8.01	640
10/13/95	12 5	406.33	7998.60	591.09	8.08	904
10/16/95	16 0	482.25	7995.20	587.69	8.26	1109
10/17/95	10 20	500.58	7995.30	587.79		
10/18/95	11 14	525.48	7993.00	585.49	8.3	1202
10/20/95	12 52	575.12	7928.10	520.59	8.44	1318
10/23/95	11 0	645.25	7972.00	564.49	8.19	1570
10/24/95	15 15	673.50	7988.30	580.79		
10/25/95	11 57	694.20	7987.30	579.79	8.27	1576
10/26/95	14 45	721.00	7988.40	580.89		
10/27/95	12 7	742.37	7985.80	578.29	8.17	1738
10/30/95	11 45	814.00	7985.1	577.59	8.27	2100
10/31/95	13 53	840.13	7985.20	577.69	8.11	1937
11/1/95	11 18	861.55	7983.20	575.69	8.15	2040
11/2/95	10 58	885.22	7984.20	576.69	8.17	2140

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 2 **STARTING DATE** 12/23/95
File Name : TYLEN2SO.XLS
Soil Identification : Tyler Soil (New)
Soil description : Soil Water Retention
Cylinder Number :

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.27 15.76 15.21) / 3 = 15.41 cm.
Avg Ht. = (13.64 13.64 13.69) / 3 = 13.66 cm.
Area of Specimen = 186.59 cm^2 Vol. of Specimen = 2548.17 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1518.30 gm.
Total Wt. (without the Cap)= 6322.4 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 6965.2 gm. Actual moisture cont. 7.08 %
Dry Wt. of Soil Specimen = 4486.46 gm. Total Wt. (Sat.)= 7493.7 gm.
Wt. of Water in Sat. Specimen= 846.14 gm.
Initial pH of Water= 7.34 Initial Conductivity of Water= 149.1

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
12/29/95	10 5	0.00	7493.70	846.14	7.34	149.1
12/30/95	13 51	27.77	7219.10	571.54	7.57	190.2
1/2/96	10 55	96.83	7201.10	553.54	7.73	247
1/3/96	11 56	121.85	7194.60	547.04	7.66	363
1/4/96	11 37	145.53	7192.70	545.14	7.74	399
1/5/96	11 33	169.47	7191.90	544.34	7.59	487
1/6/96	8 32	190.45	7191.70	544.14	7.49	514
1/8/96	11 38	241.55	7189.00	541.44	7.33	609
1/9/96	11 8	265.05	7187.90	540.34	7.63	679
1/10/96	11 56	289.85	7187.40	539.84	7.53	553
1/11/96	11 28	313.38	7188.40	540.84	7.74	337
1/12/96	13 57	339.87	7188.70	541.14	7.47	364
1/15/96	10 59	408.90	7188.70	541.14	7.59	447
1/16/96	8 51	430.77	7189.50	541.94	7.59	287
1/17/96	10 14	456.15	7189.00	541.44	7.61	312
1/18/96	11 22	481.28	7188.80	541.24	7.77	326
1/19/96	13 12	507.12	7187.00	539.44	7.65	251

APPENDIX F

PERMEABILITY TESTS RESULTS OF DENSE-GRADED BASE MATERIALS

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 1 DATE OF TEST : 2/16/96
File Name : Brownwood.per
Soil Identification : Brownwood Old
Soil description :
Cylinder Number : 2

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (15.28 15.28 15.30) / 3 = 15.29 cm
Avg Ht. specimen (h) = (30.49 30.50 30.52) / 3 = 30.50 cm
Area (A) = 183.534 cm^2
Mass of soil = 15012 gm
Distance between the two manometers (L)= 21.28 cm
Target moisture content = 5% pH of inflow water = 8.30
Condutivity of inflow water = 785 Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q ,(ml).	Discharge Time t (sec.)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k = q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	0.803	285	658.22	0.002	0.038	0.063	5.33	1721
2	0.805	229	508.15	0.002	0.038	0.065	5.94	1627
3	2.764	375	239.13	0.009	0.130	0.066	6.48	1429
4	2.764	387	250.96	0.008	0.130	0.065	6.59	1269
5	4.575	338	139.38	0.013	0.215	0.061	6.61	1197
6	4.578	374	152.09	0.013	0.215	0.062	6.73	1128
7	5.599	363	124.15	0.016	0.263	0.061	6.81	1071
8	5.599	314	107.25	0.016	0.263	0.061	6.89	1025
9	6.616	339	97.62	0.019	0.311	0.061	7.07	935
10	6.616	440	126.44	0.019	0.311	0.061	7.04	968
11	7.700	390	97.78	0.022	0.362	0.060	7.21	906
12	7.699	300	74.25	0.022	0.362	0.061	7.21	904
13	8.582	391	89.44	0.024	0.403	0.059	7.25	877
14	8.583	351	79.06	0.024	0.403	0.060	7.27	863
15	9.317	438	91.94	0.026	0.438	0.059	7.32	847
16	9.317	354	73.44	0.026	0.438	0.060	7.36	852
17	10.191	385	74.08	0.028	0.479	0.059	7.38	830
18	10.191	332	63.75	0.028	0.479	0.059	7.43	835
19	11.488	362	62.49	0.032	0.540	0.058	7.44	828
20	11.490	299	51.47	0.032	0.540	0.059	7.43	822
21	11.932	356	59.50	0.033	0.561	0.058	7.43	821

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 2 **DATE OF TEST : 4/8/96**
File Name : Brownwood2.per
Soil Identification : Brownwood Old
Soil description : ____
Cylinder Number : 3

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (15.32 15.26 15.33) / 3 = 15.30 cm
Avg Ht. specimen (h) = (44.00 44.10 43.90) / 3 = 44.00 cm
Area (A) = 183.934 cm^2
Mass of soil = ____ gm
Distance between the two manometers (L)= 21.28 cm
Target moisture content = 5% pH of inflow water = 7.86
Condutivity of inflow water = 1045 Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q ,(ml).	Discharge Time t (sec.)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k = q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	2.663	264	760.84	0.002	0.125	0.015	6.64	2290
2	2.663	310	904.59	0.002	0.125	0.015	6.78	2140
3	7.282	382	452.06	0.005	0.342	0.013	6.91	1885
4	7.283	312	368.88	0.005	0.342	0.013	6.99	1712
5	8.869	396	390.97	0.006	0.417	0.013	7.07	1506
6	8.869	358	353.80	0.006	0.417	0.013	7.18	1407
7	10.956	408	333.37	0.007	0.515	0.013	7.24	1373
8	10.958	391	320.40	0.007	0.515	0.013	7.30	1226
9	13.067	408	283.41	0.008	0.614	0.013	7.35	1143
10	13.067	424	295.22	0.008	0.614	0.013	7.39	1074
11	14.873	418	259.34	0.009	0.699	0.013	7.36	1023
12	14.873	436	271.91	0.009	0.699	0.012	7.52	1332
13	15.500	425	202.31	0.011	0.728	0.016	7.65	967
14	15.500	437	207.31	0.011	0.728	0.016	7.76	935
15	17.200	405	174.81	0.013	0.808	0.016	7.77	917
16	17.200	438	190.60	0.012	0.808	0.015	7.73	939
17	21.600	409	127.50	0.017	1.015	0.017	7.75	929
18	21.600	440	138.10	0.017	1.015	0.017	7.72	922
19	25.950	405	111.18	0.020	1.220	0.016	7.79	914
20	25.950	445	123.13	0.020	1.220	0.016	7.84	908
21	27.550	417	110.07	0.021	1.295	0.016	7.62	884
22	27.550	460	122.35	0.020	1.295	0.016	7.80	969
23	29.550	441	110.81	0.022	1.389	0.016	7.87	909
24	29.550	413	104.46	0.021	1.389	0.015	7.87	906

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 1 DATE OF TEST : 10/30/95

File Name : Childress.per

Soil Identification : Childress D-25 Old

Soil description :

Cylinder Number : 1

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (15.35 15.27 15.27) / 3 = 15.30 cm

Avg Ht. specimen (h) = (29.02 28.88 28.80) / 3 = 28.90 cm

Area (A) = 183.774 cm^2

Mass of soil (m) = ______ gm

Distance between the two manometers (L) = 21.28 cm

Target moisture content = 5%

pH of inflow water = 7.70

Condutivity of inflow water = 1069 Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q (ml	Discharge Time t (sec)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k = q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	14.404	80.00	2700.00	0.00016	0.677	0.00024	6.64	2290
2	14.404	104.00	3483.00	0.00016	0.677	0.00024	6.78	2140
3	15.038	95.00	2906.00	0.00018	0.707	0.00025	6.91	1885
4	15.038	98.00	3074.00	0.00017	0.707	0.00025	6.99	1712
5	18.850	106.00	2677.00	0.00022	0.886	0.00024	7.07	1506
6	18.850	132.00	3240.00	0.00022	0.886	0.00025	7.18	1407
7	21.650	91.00	1951.00	0.00025	1.018	0.00025	7.24	1373
8	21.650	105.00	2158.00	0.00026	1.018	0.00026	7.3	1226
9	24.5	108.00	1925.00	0.00031	1.151	0.00027	7.35	1143
10	24.500	119.00	2048.00	0.00032	1.151	0.00027	7.39	1074
11	26.850	115.00	1782.00	0.00035	1.262	0.00028	7.36	1023
12	26.850	122.00	1876.00	0.00035	1.262	0.00028	7.52	1332
13	28.450	81.00	1587.04	0.00028	1.337	0.00021	7.65	967
14	28.450	84.00	1719.27	0.00027	1.337	0.00020	7.76	935
15	33.050	62.00	1061.72	0.00032	1.553	0.00020	7.77	917
16	33.050	74.00	1281.21	0.00031	1.553	0.00020	7.73	939
17	43.500	73.00	960.22	0.00041	2.044	0.00020	7.75	929
18	43.500	75.00	920.06	0.00044	2.044	0.00022	7.72	922
19	50.150	79.00	860.94	0.00050	2.357	0.00021	7.79	914
20	50.150	103.00	1088.16	0.00052	2.357	0.00022	7.79	914

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 2 DATE OF TEST : 2/22/96
File Name : Childress2.PER
Soil Identification : Childress Soil New
Soil description :
Cylinder Number : 1

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (15.11 15.04 15.08) / 3 = 15.08 cm
Avg Ht. specimen (h) = (30.45 30.65 30.50) / 3 = 30.53 cm
Area (A) = 178.526 cm^2
Mass of soil (m) = 10910 gm
Distance between the two manometers (L) = 22.60 cm
Target moisture content = 5% pH of inflow water = 8.12
Condutivity of inflow water = 757 Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q (ml)	Discharge Time t (sec)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k= q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	0.089	300	455.53	0.0037	0.004	0.93675	6.01	1585
2	0.090	344	523.03	0.0037	0.004	0.92512	6.01	1537
3	2.428	464	254.34	0.0102	0.107	0.09512	6.27	1545
4	2.430	403	219.90	0.0103	0.108	0.09547	6.44	1512
5	3.123	429	189.03	0.0127	0.138	0.09199	6.55	1478
6	3.126	478	209.18	0.0128	0.138	0.09254	6.66	1442
7	3.905	378	137.90	0.0154	0.173	0.08886	6.79	1440
8	3.905	442	160.56	0.0154	0.173	0.08924	6.81	1409
9	4.623	419	133.44	0.0176	0.205	0.08598	6.78	1409
10	4.623	477	152.56	0.0175	0.205	0.08562	6.81	1422
11	5.068	382	108.37	0.0197	0.224	0.08805	6.89	1364
12	5.064	349	99.56	0.0196	0.224	0.08763	6.83	1353
13	5.648	436	115.53	0.0211	0.250	0.08459	6.8	1342
14	5.648	425	112.97	0.0211	0.250	0.08432	6.91	1305
15	5.884	433	105.13	0.0231	0.260	0.08861	6.88	1294
16	5.884	452	111.47	0.0227	0.260	0.08724	6.86	1203
17	6.139	355	82.56	0.0241	0.272	0.08867	6.92	1262
18	6.136	459	108.16	0.0238	0.272	0.08755	6.91	1243
19	6.337	418	91.25	0.0257	0.280	0.09151	6.96	1227
20	6.337	392	85.82	0.0256	0.280	0.09125	7	1189
21	6.431	470	101.40	0.0260	0.285	0.09124	7.02	995
22	6.431	419	90.88	0.0258	0.285	0.09076	7	1119
23	7.150	414	82.97	0.0279	0.316	0.08834	7.07	1036
24	7.150	362	72.72	0.0279	0.316	0.08814	7.03	1070

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 1 DATE OF TEST : 12/7/95

File Name : Corpus Christi.per

Soil Identification : Corpus Christi Old

Soil description :

Cylinder Number : 2

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (15.28 15.26 15.28) / 3 = 15.27 cm

Avg Ht. specimen (h) = (30.54 30.54 30.50) / 3 = 30.53 cm

Area (A) = 183.190 cm^2

Mass of soil (m) = ______ gm

Distance between the two manometers (L) = 22.66 cm

Target moisture content = 5% pH of inflow water = 7.65

Condutivity of inflow water = 1088 Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q (ml)	Discharge Time t (sec)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k= q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	10.947	32	2703.00	0.0001	0.483	0.00013	7.8	1361
2	10.947	33	2916.00	0.0001	0.483	0.00013	7.88	1320
3	13.596	35	2735.00	0.0001	0.600	0.00012	7.82	1333
4	13.596	34	2713.00	0.0001	0.600	0.00011	7.71	1336
5	15.950	42	2716.00	0.0001	0.704	0.00012	7.82	1290
6	15.950	41	2700.00	0.0001	0.704	0.00012	7.81	1280
7	17.800	43	2735.00	0.0001	0.786	0.00011	7.77	1270
8	17.800	44	2833.00	0.0001	0.786	0.00011	7.76	1242
9	19.55	45	2620.00	0.0001	0.863	0.00011	7.65	1245
10	19.550	48	2815.00	0.0001	0.863	0.00011	7.69	1220

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 2 **DATE OF TEST : 12/7/95**
File Name : Corpus Christi2.per
Soil Identification : Corpus Christi Old
Soil description :
Cylinder Number : 3

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (15.28 15.32 15.30) / 3 = 15.30 cm
Avg Ht. specimen (h) = (43.82 43.89 43.91) / 3 = 43.87 cm
Area (A) = 183.862 cm^2
Mass of soil (m) = 14037 gm
Distance between the two manometers (L) = 33.84 cm
Target moisture content = 5% pH of inflow water = 7.97
Condutivity of inflow water = 923 Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q (ml)	Discharge Time t (sec)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k= q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	11.975	34	3816.00	0.0000	0.354	0.00014	7.64	11990
2	11.979	32	3627.00	0.0000	0.354	0.00014	7.63	11510
3	21.800	45	2809.00	0.0001	0.644	0.00014	7.61	11380
4	21.800	60	4099.00	0.0001	0.644	0.00012	7.59	11220
5	34.300	55	2359.00	0.0001	1.014	0.00013	7.53	10730
6	34.300	44	1899.00	0.0001	1.014	0.00012	7.52	10960
7	38.600	76	2909.00	0.0001	1.141	0.00012	7.5	10580
8	38.600	62	2503.00	0.0001	1.141	0.00012	7.45	10090
9	42.150	62	2040.00	0.0002	1.246	0.00013	7.44	9900
10	42.150	53	1849.00	0.0002	1.246	0.00013	7.58	9200
11	45.650	64	2027.00	0.0002	1.349	0.00013	7.44	8900
12	45.650	60	1928.00	0.0002	1.349	0.00013	7.43	8740
13	14.331	29	2626.00	0.0001	0.423	0.00014	7.66	8850
14	14.334	41	3710.00	0.0001	0.424	0.00014	6.96	8460
15	20.000	43	2921.00	0.0001	0.591	0.00014	7.33	7730
16	20.000	46	3230.00	0.0001	0.591	0.00013	7.23	7800
17	19.850	29	2190.00	0.0001	0.587	0.00012	7.89	8280
18	19.850	40	3446.00	0.0001	0.587	0.00011	7.86	7690
19	27.050	35	2076.00	0.0001	0.799	0.00011	7.89	7000
20	27.050	34	2014.00	0.0001	0.799	0.00011	8.07	6520
21	32.100	39	2037.00	0.0001	0.949	0.00011	8.02	6600
22	36.750	44	1990.00	0.0001	1.086	0.00011	8.01	6550
23	36.750	50	2457.00	0.0001	1.086	0.00010	8.02	6550
24	40.500	55	2390.00	0.0001	1.197	0.00010	8.03	6160
25	40.500	53	2268	0.0001	1.197	0.00011	8.27	5870

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 1 **DATE OF TEST :**
File Name : El Paso.per
Soil Identification : El Paso Old
Soil description :
Cylinder Number :

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (15.09 15.11 15.07) / 3 = 15.09 cm
Avg Ht. specimen (h) = ( ) / 3 = 0.00 cm
Area (A) = 178.778 cm^2
Mass of soil (m) = ______ gm
Distance between the two manometers (L) = 21.28 cm
Target moisture content = 5% pH of inflow water =
Condutivity of inflow water = ______ Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q (ml)	Discharge Time t (sec)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k= q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	0.260	217	493.13	0.0025	0.012	0.20177		
2	0.270	191	407.38	0.0026	0.013	0.20654		
3	0.270	227	484.38	0.0026	0.013	0.20645		
4	0.638	249	301.25	0.0046	0.030	0.15414		
5	0.638	212	266.15	0.0045	0.030	0.14854		
6	0.447	245	332.34	0.0041	0.021	0.19639		
7	0.447	237	326.21	0.0041	0.021	0.19355		
8	0.730	327	317.88	0.0058	0.034	0.16778		
9	0.730	452	437.16	0.0058	0.034	0.16864		
10	0.638	215	251.94	0.0048	0.030	0.15914		
11	0.883	387	332.22	0.0065	0.041	0.15703		
12	0.883	370	317.91	0.0065	0.041	0.15689		
13	0.934	392	307.85	0.0071	0.044	0.16226		
14	0.934	397	312.03	0.0071	0.044	0.16213		
15	1.313	226	138.70	0.0091	0.062	0.14774		
16	1.313	222	136.19	0.0091	0.062	0.14780		
17	1.247	470	305.21	0.0086	0.059	0.14700		

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 2 **DATE OF TEST :** 3/9/96

File Name : El Paso2.per

Soil Identification : El Paso Old

Soil description :

Cylinder Number : 2

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (15.28 15.31 15.24) / 3 = 15.28 cm

Avg Ht. specimen (h) = (28.81 28.79 28.64) / 3 = 28.75 cm

Area (A) = 183.294 cm^2

Mass of soil (m) = 12037 gm

Distance between the two manometers (L) = 24.43 cm

Target moisture content = 5% pH of inflow water = 7.87

Condutivity of inflow water = 965 Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q (ml)	Discharge Time t (sec)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k= q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	3.340	54	1785.12	0.0002	0.137	0.00121	8.21	2310
2	3.340	90	2322.00	0.0002	0.137	0.00155	8.15	2430
3	8.689	155	1809.97	0.0005	0.356	0.00131	8	2450
4	8.689	168	2007.00	0.0005	0.356	0.00128	7.93	2410
5	10.712	130	1356.22	0.0005	0.438	0.00119	7.7	2370
6	10.712	91	942.43	0.0005	0.438	0.00120	7.68	2240
7	13.397	142	1317.13	0.0006	0.548	0.00107	8.01	2160
8	13.397	149	1419.16	0.0006	0.548	0.00104	7.88	2130
9	16.200	184	1548.50	0.0006	0.663	0.00098	7.8	2030
10	16.200	228	1972.00	0.0006	0.663	0.00095	7.8	1914
11	18.550	145	1039.66	0.0008	0.759	0.00100	7.84	1837
12	18.550	158	1160.72	0.0007	0.759	0.00098	7.87	1759
13	21.900	197	1297.66	0.0008	0.896	0.00092	7.9	1679
14	21.900	265	1778.97	0.0008	0.896	0.00091	7.92	1570
15	24.700	216	1576.85	0.0007	1.011	0.00074	7.88	1527
16	24.700	262	1987.00	0.0007	1.011	0.00071	7.87	1397
17	26.250	204	1772.29	0.0006	1.074	0.00058	8.01	1359
18	26.250	206	1872.00	0.0006	1.074	0.00056	8.04	1310
19	32.100	204	1653.75	0.0007	1.314	0.00051	8.08	1232
20	32.100	281	2165.00	0.0007	1.314	0.00054	8.07	1189

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 1 **DATE OF TEST : 2/8/96**
File Name : Odessa.PER
Soil Identification : Odessa Soil New
Soil description :
Cylinder Number : 1

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (15.25 15.26 15.27) / 3 = 15.26 cm
Avg Ht. specimen (h) = (30.50 30.52 30.47) / 3 = 30.50 cm
Area (A) = 182.854 cm^2
Mass of soil (m) = 16824 gm
Distance between the two manometers (L) = 30.50 cm
Target moisture content = 5% pH of inflow water = 7.53
Condutivity of inflow water = 967 Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q (ml)	Discharge Time t (sec)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k= q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	5.427	147	747.00	0.0011	0.178	0.00605	7.53	967
2	5.540	151	745.00	0.0011	0.182	0.00610	7.86	895
3	10.149	208	572.00	0.0020	0.333	0.00598	7.91	889
4	10.732	205	557.00	0.0020	0.352	0.00572	7.94	886
5	12.273	211	464.00	0.0025	0.402	0.00618	7.93	882
6	12.879	209	455.00	0.0025	0.422	0.00595	7.95	872
7	16.477	256	439.00	0.0032	0.540	0.00590	7.96	849

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 2 DATE OF TEST : 1/11/96

File Name : Odessa2.PER

Soil Identification : Odessa Soil New

Soil description :

Cylinder Number : 1

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (15.31 15.14 15.11) / 3 = 15.18 cm

Avg Ht. specimen (h) = (30.50 30.52 30.47) / 3 = 30.50 cm

Area (A) = 181.085 cm^2

Mass of soil (m) = ______ gm

Distance between the two manometers (L) = 22.89 cm

Target moisture content = 5% pH of inflow water = 6.82

Condutivity of inflow water = 1383 Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q (ml)	Discharge Time t (sec)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k= q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	4.430	129	2100.00	0.0003	0.194	0.00175	6.82	1383
2	4.470	120	1920.00	0.0003	0.195	0.00177	7.00	1336
3	6.894	125	1320.00	0.0005	0.301	0.00174	6.98	1289
4	6.920	126	1260.00	0.0006	0.302	0.00183	7.00	1266
5	7.185	194	1909.00	0.0006	0.314	0.00179	7.34	1187
6	7.197	132	1271.69	0.0006	0.314	0.00182	7.58	1183
7	9.509	140	1023.63	0.0008	0.415	0.00182	7.63	1149
8	9.529	160	1148.44	0.0008	0.416	0.00185	7.50	1227
9	11.664	169	1000.38	0.0009	0.510	0.00183	7.51	1265

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 1 **DATE OF TEST :** 12/15/95
File Name : Paris.PER
Soil Identification : Paris Soil New
Soil description :
Cylinder Number : 1

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (15.38 15.14 15.11) / 3 = 15.21 cm
Avg Ht. specimen (h) = (30.50 30.52 30.47) / 3 = 30.50 cm
Area (A) = 181.665 cm^2
Mass of soil (m) = ______ gm
Distance between the two manometers (L) = 22.66 cm
Target moisture content = 5% pH of inflow water = 7.60
Condutivity of inflow water = 1085 Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q (ml)	Discharge Time t (sec)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k= q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	0.138	204	312.00	0.0036	0.006	0.59100	7.52	1039
2	0.145	204	325.00	0.0035	0.006	0.53997	7.61	1020
3	0.657	368	92.00	0.0220	0.029	0.75942	7.69	963
4	0.675	394	93.00	0.0233	0.030	0.78288	7.83	927
5	0.875	380	69.00	0.0303	0.039	0.78508	7.85	827
6	0.881	391	70.00	0.0307	0.039	0.79084	7.83	803
7	0.949	403	61.00	0.0364	0.042	0.86835	7.95	776
8	0.950	402	60.00	0.0369	0.042	0.87971	7.96	770
9	1.254	477	50.00	0.0525	0.055	0.94894	7.92	766

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : **2** **DATE OF TEST :** 4/3/96

File Name : Paris2.PER

Soil Identification : Paris Soil New

Soil description :

Cylinder Number : **1**

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (15.05 15.10 15.04) / 3 = 15.06 cm

Avg Ht. specimen (h) = (34.90 35.50 34.80) / 3 = 35.07 cm

Area (A) = 178.210 cm^2

Mass of soil (m) = 10019 gm

Distance between the two manometers (L) = 22.70 cm

Target moisture content = 5% pH of inflow water = 8.33

Condutivity of inflow water = 802 Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q (ml)	Discharge Time t (sec)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k= q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	1.350	310	954.44	0.0018	0.059	0.03065	7.21	1421
2	1.352	330	993.72	0.0019	0.060	0.03129	7.10	1455
3	3.916	370	459.85	0.0045	0.173	0.02617	7.03	1560
4	3.916	336	408.69	0.0046	0.173	0.02674	7.01	1482
5	5.186	391	369.09	0.0059	0.228	0.02602	7.07	1325
6	5.187	411	393.72	0.0059	0.229	0.02563	7.17	1185
7	6.359	434	337.22	0.0072	0.280	0.02578	7.18	1020
8	6.359	447	350.78	0.0072	0.280	0.02553	7.20	1057
9	7.439	435	300.25	0.0081	0.328	0.02481	7.19	967
10	7.345	423	293.69	0.0081	0.324	0.02498	7.26	620
11	8.626	490	300.50	0.0091	0.380	0.02408	7.31	889
12	8.624	411	250.03	0.0092	0.380	0.02428	7.28	869
13	10.103	433	234.90	0.0103	0.445	0.02324	7.42	859
14	10.102	475	258.00	0.0103	0.445	0.02321	7.42	841
15	11.396	463	228.40	0.0114	0.502	0.02266	7.47	831

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number :	1	**DATE OF TEST :** 2/13/16
File Name :	San Angleo.Per	
Soil Identification :	San Angelo New	
Soil description :		
Cylinder Number :	3	

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (15.30 15.27 15.29) / 3 = 15.29 cm

Avg Ht. specimen (h) = (43.91 43.94 43.89) / 3 = 43.91 cm

Area (A) = 183.534 cm^2

Mass of soil (m) = 16612 gm

Distance between the two manometers (L) = 30.50 cm

Target moisture content = 5% pH of inflow water = 8.14

Condutivity of inflow water = 762 Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q (ml)	Discharge Time t (sec)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k= q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	1.352	348	177.66	0.0107	0.044	0.24077	6.24	1549
2	1.351	253	128.03	0.0108	0.044	0.24307	6.54	1572
3	1.994	312	116.84	0.0145	0.065	0.22255	6.72	1437
4	1.994	293	109.06	0.0146	0.065	0.22390	6.83	1319
5	2.628	299	86.75	0.0188	0.086	0.21795	6.93	1319
6	2.628	365	105.40	0.0189	0.086	0.21898	7.03	1125
7	3.089	334	83.90	0.0217	0.101	0.21417	7.16	1048
8	3.089	301	75.59	0.0217	0.101	0.21422	7.26	991
9	3.731	327	70.57	0.0252	0.122	0.20639	7.43	942
10	3.731	385	83.12	0.0252	0.122	0.20631	7.5	925
11	4.238	340	65.40	0.0283	0.139	0.20386	7.55	801
12	4.238	270	51.81	0.0284	0.139	0.20435	7.65	866
13	4.751	313	54.03	0.0316	0.156	0.20263	7.7	849
14	4.751	383	65.91	0.0317	0.156	0.20326	7.8	822
15	5.188	266	41.28	0.0351	0.170	0.20641	7.82	839
16	5.188	351	54.84	0.0349	0.170	0.20502	7.7	826
17	5.757	329	45.59	0.0393	0.189	0.20831	7.79	841
18	5.757	389	53.80	0.0394	0.189	0.20872	7.89	875
19	6.002	341	45.28	0.0410	0.197	0.20851	7.89	836
20	6.002	307	40.29	0.0415	0.197	0.21097	7.96	811
21	6.769	380	45.22	0.0458	0.222	0.20631	7.98	795
22	6.769	327	38.87	0.0458	0.222	0.20653	8.04	777
23	6.652	340	39.75	0.0466	0.218	0.21368	8.07	815
24	6.652	375	49.31	0.0414	0.218	0.18999	7.94	844

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 2 DATE OF TEST : 3/29/96
File Name : San Angleo2.Per
Soil Identification : San Angelo New
Soil description :
Cylinder Number : 2

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (15.34 15.28 15.30) / 3 = 15.31 cm
Avg Ht. specimen (h) = (28.83 28.88 28.90) / 3 = 28.87 cm
Area (A) = 184.014 cm^2
Mass of soil (m) = 10678 gm
Distance between the two manometers (L) = 24.20 cm
Target moisture content = 5% pH of inflow water = 7.68
Condutivity of inflow water = 795 Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q (ml)	Discharge Time t (sec)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k= q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	0.351	352	680.47	0.0028	0.015	0.19382	5.84	1291
2	0.351	254	496.43	0.0028	0.015	0.19170	6.13	1285
3	10.017	310	252.63	0.0067	0.414	0.01611	6.42	1286
4	10.016	440	370.63	0.0065	0.414	0.01559	6.55	1184
5	1.190	334	232.94	0.0078	0.049	0.15846	6.65	1101
6	1.190	385	276.94	0.0076	0.049	0.15364	6.75	1052
7	1.826	376	187.07	0.0109	0.075	0.14476	6.70	1099
8	1.826	408	207.66	0.0107	0.075	0.14150	6.99	1058
9	2.278	379	155.40	0.0133	0.094	0.14080	7.12	1003
10	2.278	367	151.34	0.0132	0.094	0.14000	7.19	941
11	2.702	442	150.62	0.0159	0.112	0.14283	7.27	881
12	2.703	379	163.00	0.0126	0.112	0.11313	7.31	873
13	2.943	429	133.53	0.0175	0.122	0.14357	7.35	840
14	2.941	397	125.00	0.0173	0.122	0.14202	7.37	822
15	3.340	414	120.96	0.0186	0.138	0.13476	7.41	813
16	3.341	359	106.87	0.0183	0.138	0.13223	7.44	810
17	3.685	435	111.03	0.0213	0.152	0.13982	7.47	800
18	3.685	385	98.81	0.0212	0.152	0.13905	7.47	793
19	3.780	412	99.91	0.0224	0.156	0.14347	7.57	792
20	3.779	369	90.37	0.0222	0.156	0.14210	7.53	799
21	4.090	453	103.28	0.0238	0.169	0.14103	7.54	881
22	4.092	400	91.31	0.0238	0.169	0.14079	7.53	957
23	4.147	427	93.90	0.0247	0.171	0.14421	7.67	818
24	4.147	443	99.00	0.0243	0.171	0.14191	7.68	812

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 1 **DATE OF TEST :** 10/24/95

File Name : San Antonio.Per

Soil Identification : San Antonio Soil New

Soil description :

Cylinder Number : 1

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (15.32 15.27 15.30) / 3 = 15.30 cm

Avg Ht. specimen (h) = ( ) / 3 = 0.00 cm

Area (A) = 183.790 cm^2

Mass of soil (m) = ________ gm

Distance between the two manometers (L) = 24.96 cm

Target moisture content = 5% pH of inflow water = 7.74

Condutivity of inflow water = 1312 Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q (ml)	Discharge Time t (sec)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k= q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	0.142	250	193.37	0.0070	0.006	1.23648	7.74	1312
2	0.142	253	196.37	0.0070	0.006	1.23220	7.74	1256
3	0.279	315	121.50	0.0141	0.011	1.26198	7.80	1189
4	0.279	293	112.37	0.0142	0.011	1.26922	7.74	1133
5	0.484	340	83.82	0.0221	0.019	1.13818	7.87	1049
6	0.485	345	85.00	0.0221	0.019	1.13653	7.91	1079
7	0.513	352	78.12	0.0245	0.021	1.19285		
8	0.514	340	74.82	0.0247	0.021	1.20066	8.30	1016
9	0.516	373	87.69	0.0231	0.021	1.11952	7.81	1100
10	0.518	345	81.06	0.0232	0.021	1.11585	7.91	1081
11	0.733	427	72.97	0.0318	0.029	1.08418		
12	0.733	437	75.32	0.0316	0.029	1.07496	8.13	1032
13	0.742	369	63.75	0.0315	0.030	1.05941	7.89	1015
14	0.744	362	62.65	0.0314	0.030	1.05472	7.97	1003
15	0.898	377	49.44	0.0415	0.036	1.15321	8.20	1016
16	0.898	421	54.03	0.0424	0.036	1.17840		
17	0.940	396	52.65	0.0409	0.038	1.08666	8.02	988
18	0.944	392	52.06	0.0410	0.038	1.08326	8.02	992
19	1.010	390	46.97	0.0452	0.040	1.11647	8.15	1031
20	1.010	426	52.58	0.0441	0.040	1.08941		
21	1.153	384	43.53	0.0480	0.046	1.03905		
22	1.154	375	42.87	0.0476	0.046	1.02943	8.16	1003
23	1.205	423	46.44	0.0496	0.048	1.02656	8.21	1000
24	1.206	404	43.50	0.0505	0.048	1.04585		

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 1 **DATE OF TEST :**

File Name : San Antonio2.Per

Soil Identification : San Antonio Soil New

Soil description : ____________

Cylinder Number : ____________

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (15.09 15.11 15.06) / 3 = 15.09 cm

Avg Ht. specimen (h) = ( ) / 3 = 0.00 cm

Area (A) = 178.731 cm^2

Mass of soil (m) = ________ gm

Distance between the two manometers (L) = 21.28 cm

Target moisture content = 5% pH of inflow water = ________

Condutivity of inflow water = ________ Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q (ml)	Discharge Time t (sec)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k= q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	0.279	163	286.22	0.0032	0.013	0.24303		
2	0.279	124	247.56	0.0028	0.013	0.21375		
3	0.348	182	269.65	0.0038	0.016	0.23092		
4	0.349	166	259.38	0.0036	0.016	0.21833		
5	0.413	203	277.06	0.0041	0.019	0.21122		
6	0.440	150	189.56	0.0044	0.021	0.21412		
7	0.441	111	148.66	0.0042	0.021	0.20159		
8	0.441	112	154.25	0.0041	0.021	0.19603		
9	0.441	112	153.97	0.0041	0.021	0.19639		
10	0.440	151	186.34	0.0045	0.021	0.21928		
11	0.441	128	158.97	0.0045	0.021	0.21738		
12	0.493	122	146.57	0.0047	0.023	0.20102		
13	0.511	130	146.43	0.0050	0.024	0.20685		
14	0.511	135	153.63	0.0049	0.024	0.20474		
15	0.537	120	127.37	0.0053	0.025	0.20889		
16	0.539	136	140.35	0.0054	0.025	0.21405		
17	0.539	132	137.16	0.0054	0.025	0.21258		
18	0.461	220	241.60	0.0051	0.022	0.23518		
19	0.462	213	225.57	0.0053	0.022	0.24335		
20	0.723	208	140.75	0.0083	0.034	0.24336		
21	0.725	235	156.84	0.0084	0.034	0.24606		
22	0.777	194	126.13	0.0086	0.037	0.23569		
23	0.777	213	138.41	0.0086	0.037	0.23581		
24	0.883	208	123.00	0.0095	0.041	0.22802		

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 1 DATE OF TEST : 1/10/95
File Name : Tyler.PER
Soil Identification : Tyler Soil New
Soil description :
Cylinder Number : 1

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (15.29 15.16 15.34) / 3 = 15.26 cm
Avg Ht. specimen (h) = (43.75 43.70 43.75) / 3 = 43.73 cm
Area (A) = 182.878 cm^2
Mass of soil (m) = 18131 gm
Distance between the two manometers (L) = 24.95 cm
Target moisture content = 5% pH of inflow water = 7.69
Condutivity of inflow water = 9220 Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q (ml)	Discharge Time t (sec)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k= q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	4.889	30	2705.00	0.0001	0.196	0.00031	7.69	9220
2	4.889	33	2899.00	0.0001	0.196	0.00032	7.75	9330
3	7.178	35	2034.00	0.0001	0.288	0.00033	7.79	9060
4	7.178	37	2124.00	0.0001	0.288	0.00033	7.68	8390
5	9.604	44	1823.00	0.0001	0.385	0.00034	7.75	8770
6	9.604	40	1690.00	0.0001	0.385	0.00034	7.72	8710
7	11.138	45	1614.00	0.0002	0.446	0.00034	7.54	8210
8	11.138	49	1746.00	0.0002	0.446	0.00034	7.84	8160
9	13.189	54	1592.34	0.0002	0.529	0.00035	7.52	8070

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 2 **DATE OF TEST : 1/17/96**

File Name : Tyler2.PER

Soil Identification : Tyler Soil New

Soil description :

Cylinder Number : 2

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (15.24 15.29 15.28) / 3 = 15.27 cm

Avg Ht. specimen (h) = (28.80 28.78 28.80) / 3 = 28.79 cm

Area (A) = 183.134 cm^2

Mass of soil (m) = 11871 gm

Distance between the two manometers (L) = 22.64 cm

Target moisture content = 5% pH of inflow water = 7.55

Condutivity of inflow water = 860 Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q (ml)	Discharge Time t (sec)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k= q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	4.228	255	1059.00	0.0013	0.187	0.00704	7.14	1425
2	4.224	189	776.85	0.0013	0.187	0.00712	6.46	1431
3	6.287	225	680.72	0.0018	0.278	0.00650	6.57	1316
4	6.287	383	1071.75	0.0020	0.278	0.00703	6.74	1220
5	8.572	261	520.03	0.0027	0.379	0.00724	6.72	1302
6	8.572	339	800.34	0.0023	0.379	0.00611	6.85	1266
7	10.445	301	490.28	0.0034	0.461	0.00727	6.92	1289
8	10.445	290	471.47	0.0034	0.461	0.00728	6.90	1178
9	12.553	351	568.19	0.0034	0.554	0.00608	6.99	1182

APPENDIX G

SOIL WATER RETENTION TEST RESULTS OF OPEN-GRADED BASE MATERIALS

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 1 **STARTING DATE** 2/2/96
File Name : ELP200S1.XLS
Soil Identification : El Paso Montana # 200 and Above
Soil description : Soil Water Retention
Cylinder Number : 1

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.06 15.08 15.01) / 3 = 15.05 cm.
Avg Ht. = (15.09 15.12 15.05) / 3 = 15.09 cm.
Area of Specimen = 177.89 cm^2 Vol. of Specimen = 2683.84 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1684.80 gm.
Total Wt. (without the Cap)= 7172.8 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 8233.5 gm. Actual moisture cont. 6.32 %
Dry Wt. of Soil Specimen = 5161.78 gm. Total Wt. (Sat.)= 8697.0 gm.
Wt. of Water in Sat. Specimen= 789.72 gm.
Initial pH of Water= 7.90 Initial Conductivity of Water= 106.2

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
2/7/96	11 33	0.00	8679.00	789.72	7.9	106.2
2/8/96	15 52	28.32	8410.20	520.92	7.29	522
2/9/96	13 20	49.78	8395.10	505.82	7.63	644
2/12/96	14 12	122.65	8360.10	470.82	7.33	616
2/13/96	15 18	147.75	8348.40	459.12	7.87	664
2/14/96	13 14	169.68	8344.10	454.82	7.87	750
2/15/96	17 5	197.53	8337.90	448.62	7.73	828
2/16/96	12 29	216.93	8333.80	444.52	7.79	838
2/19/96	12 8	288.58	8322.10	432.82	8.07	699
2/20/96	13 54	314.35	8321.30	432.02	7.75	753
2/21/96	12 57	337.40	8320.90	431.62	7.93	829
2/22/96	11 7	359.57	8318.30	429.02	7.99	900
2/23/96	13 21	385.80	8320.10	430.82	8.04	570
2/26/96	11 57	456.40	8312.00	422.72	8.12	660
2/27/96	11 9	479.60	8314.20	424.92	7.95	723
2/28/96	11 59	504.43	8312.30	423.02	7.97	665

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number :	2	STARTING DATE'	5/17/96
File Name :	ELP200S2.XLS		
Soil Identification :	El Paso # 200 & Above		
Soil description :	Soil Water Retention		
Cylinder Number :	1		

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.28 15.31 15.30) / 3 = 15.30 cm.
Avg Ht. = (14.38 14.37 14.39) / 3 = 14.38 cm.
Area of Specimen = 183.77 cm^2 Vol. of Specimen = 2642.67 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1645.00 gm.
Total Wt. (without the Cap)= 6964.3 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 7682.8 gm. Actual moisture cont. 4.52 %
Dry Wt. of Soil Specimen = 5089.27 gm. Total Wt. (Sat.)= 8347.5 gm.
Wt. of Water in Sat. Specimen= 894.73 gm.
Initial pH of Water= 8.25 Initial Conductivity of Water= 238

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)	
5/22/96	14 4	0.00	8347.50	894.73	8.25	238	1 psi
5/23/96	11 40	21.60	7769.90	317.13	8.18	407	
5/24/96	12 1	45.95	7752.40	299.63	8.19	395	
5/27/96	10 57	116.88	7738.30	285.53	8.51	502	
5/28/96	12 51	142.78	7735.30	282.53	8.2	513	
5/29/96	12 49	166.75	7734.30	281.53	8.14	358	
5/30/96	12 3	189.98	7733.50	280.73	8.29	369	
5/31/96	11 50	213.77	7731.80	279.03	7.85	393	
6/3/96	10 46	284.70	7729.30	276.53	7.94	403	
6/4/96	12 21	310.28	7729.50	276.73	7.88	472	
6/5/96	12 29	334.42	7728.90	276.13	7.85	491	
6/6/96	12 0	357.93	7728.80	276.03	8.04	521	
6/7/96	11 53	381.82	7728.8	276.03	8.04	369	
6/10/96	12 3	453.98	7727.90	275.13	8.45	424	
6/11/96	12 10	478.10	7726.90	274.13	8.3	450	
6/12/96	12 22	502.30	7717.80	265.03	8.17	501	2 psi
6/13/96	14 33	528.48	7712.50	259.73	7.46	513	
6/14/96	13 21	551.28	7721.10	268.33	7.78	477	
6/17/96	10 0	619.93	7713.10	260.33	6.78	468	
6/18/96	12 43	646.65	7711.00	258.23	6.73	421	3 psi
6/19/96	13 15	671.18	7712.00	259.23	6.8	473	
6/20/96	13 10	695.10	7708.80	256.03	7.97	518	
6/24/96	11 13	789.15	7671.00	218.23	7.48	660	
6/25/96	11 44	813.67	7675.70	222.93	7.83	406	
6/26/96	11 19	837.25	7674.80	222.03	7.69	431	4 psi
6/27/96	9 41	859.62	7669.80	217.03	7.45	446	
6/28/96	12 56	886.87	7663.30	210.53	8.06	455	
7/1/96	11 36	957.53	7655.20	202.43	8.02	533	

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 1 **STARTING DATE** 2/2/96
File Name : ELP40S1.XLS
Soil Identification : El Paso Montana #40 and Above
Soil description : Soil Water Retention
Cylinder Number : 2

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(14.44 15.24 15.27) / 3 = 14.98 cm.
Avg Ht. = (14.35 14.32 14.32) / 3 = 14.33 cm.
Area of Specimen = 176.32 cm^2 Vol. of Specimen = 2526.70 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1662.70 gm.
Total Wt. (without the Cap)= 7515.5 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 7880.5 gm. Actual moisture cont. 7.32 %
Dry Wt. of Soil Specimen = 5453.60 gm. Total Wt. (Sat.)= 8576.3 gm.
Wt. of Water in Sat. Specimen= 1095.00 gm.
Initial pH of Water= 7.45 Initial Conductivity of Water= 173.7

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
2/7/96	11 37	0.00	8576.30	1095.00	7.45	173.7
2/8/96	15 51	28.23	7958.70	477.40	7.26	772
2/9/96	13 20	49.72	7949.90	468.60	7.43	838
2/12/96	14 13	122.60	7941.50	460.20	7.39	833
2/13/96	15 20	147.72	7940.30	459.00	7.69	904
2/14/96	13 15	169.63	7925.00	443.70	7.82	986
2/15/96	17 6	197.48	7938.20	456.90	7.6	1066
2/16/96	12 30	216.88	7936.40	455.10	7.72	1128
2/19/96	12 9	288.53	7935.90	454.60	7.83	1017
2/20/96	13 55	314.30	7934.90	453.60	7.69	1082
2/21/96	12 58	337.35	7933.70	452.40	7.67	1201
2/22/96	11 7	359.50	7932.80	451.50	7.85	1297
2/23/96	13 22	385.75	7932.70	451.40	7.85	768
2/26/96	11 58	456.35	7932.30	451.00	7.87	933
2/27/96	11 10	479.55	7931.50	450.20	7.65	998
2/28/96	12 0	504.38	7931.90	450.60	7.67	906

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 2 **STARTING DATE'** 5/17/96
File Name : ELP40S2.XLS
Soil Identification : El Paso # 40 & Above
Soil description : Soil Water Retention
Cylinder Number : 2

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.05 15.02 15.03) / 3 = 15.03 cm.
Avg Ht. = (15.13 15.08 15.10) / 3 = 15.10 cm.
Area of Specimen = 177.50 cm^2 Vol. of Specimen = 2680.85 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1668.70 gm.
Total Wt. (without the Cap)= 6731 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 7404 gm. Actual moisture cont. 6.97 %
Dry Wt. of Soil Specimen = 4732.45 gm. Total Wt. (Sat.)= 8519.4 gm.
Wt. of Water in Sat. Specimen= 1445.25 gm.
Initial pH of Water= 8.37 Initial Conductivity of Water= 127

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)	
5/22/96	14 5	0.00	8519.40	1445.25	8.37	127	1 psi
5/23/96	11 41	21.60	7497.60	423.45	8.18	299	
5/24/96	12 2	45.95	7487.90	413.75	8.08	310	
5/27/96	10 58	116.88	7477.60	403.45	8.34	389	
5/28/96	12 52	142.78	7475.40	401.25	8.19	426	
5/29/96	12 50	166.75	7474.90	400.75	8.13	243	
5/30/96	12 9	190.07	7473.40	399.25	8.15	284	
5/31/96	11 52	213.78	7472.10	397.95	7.87	302	
6/3/96	10 46	284.68	7471.30	397.15	8.05	345	
6/4/96	12 21	310.27	7471.30	397.15	7.79	369	
6/5/96	12 30	334.42	7471.60	397.45	7.94	383	
6/6/96	12 1	357.93	7471.60	397.45	8.08	405	
6/7/96	11 54	381.82	7469.9	395.75	7.97	319	
6/10/96	12 4	453.98	7470.70	396.55	8.21	355	
6/11/96	12 10	478.08	7471.60	397.45	8.14	391	
6/12/96	12 22	502.28	7467.90	393.75	7.88	401	2 psi
6/13/96	14 34	528.48	7468.60	394.45	7.7	436	
6/14/96	13 31	551.43	7467.10	392.95	8.02	450	
6/17/96	10 0	619.92	7465.90	391.75	6.9	395	
6/18/96	12 43	646.63	7466.00	391.85	7	413	3 psi
6/19/96	13 15	671.17	7469.30	395.15	7	428	
6/20/96	13 10	695.08	7465.10	390.95	7.85	464	
6/24/96	11 15	789.17	7461.80	387.65	7.84	486	
6/25/96	11 45	813.67	7462.70	388.55	7.68	304	
6/26/96	11 20	837.25	7460.50	386.35	7.57	311	4 psi
6/27/96	9 41	859.60	7460.10	385.95	7.5	337	
6/28/96	10 2	883.95	7459.90	385.75	7.91	346	

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 1 **STARTING DATE** 2/2/96
File Name : ELP10S1.XLS
Soil Identification : El Paso Montana #10 and Above
Soil description : Soil Water Retention
Cylinder Number : 3

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.14 15.02 15.07) / 3 = 15.08 cm.
Avg Ht. = (15.06 15.10 15.07) / 3 = 15.08 cm.
Area of Specimen = 178.53 cm^2 Vol. of Specimen = 2691.57 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1792.30 gm.
Total Wt. (without the Cap)= 6670.2 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 7359 gm. Actual moisture cont. 2.04 %
Dry Wt. of Soil Specimen = 4780.38 gm. Total Wt. (Sat.)= 8192.2 gm.
Wt. of Water in Sat. Specimen= 930.72 gm.
Initial pH of Water= 7.59 Initial Conductivity of Water= 214

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
2/9/96	11 34	0.00	8192.20	930.72	7.59	214
2/12/96	14 15	74.68	7373.30	111.82	7.55	283
2/13/96	15 24	99.83	7366.40	104.92	7.91	311
2/14/96	15 15	123.68	7363.10	101.62	7.98	346
2/15/96	17 6	149.53	7357.10	95.62	7.74	365
2/16/96	12 31	168.95	7356.90	95.42	8.09	381
2/19/96	12 10	240.60	7352.60	91.12	8.09	385
2/20/96	14 8	266.57	7351.50	90.02	8.06	411
2/21/96	12 59	289.42	7349.60	88.12	8.03	434
2/22/96	11 11	311.62	7349.10	87.62	8.19	427
2/23/96	13 26	337.87	7349.20	87.72	8.09	317
2/26/96	12 1	408.45	7346.60	85.12	8.22	375
2/27/96	11 12	431.63	7345.20	83.72	8.22	397
2/28/96	12 1	456.45	7344.00	82.52	8.22	354

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 2 **STARTING DATE'** 5/17/96
File Name : ELP10S2.XLS
Soil Identification : El Paso # 10 & Above
Soil description : Soil Water Retention
Cylinder Number : 3

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.00 15.05 15.02) / 3 = 15.02 cm.
Avg Ht. = (15.04 15.02 14.97) / 3 = 15.01 cm.
Area of Specimen = 177.26 cm^2 Vol. of Specimen = 2660.74 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1763.10 gm.
Total Wt. (without the Cap)= 6273.4 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 6968.9 gm. Actual moisture cont. 3.75 %
Dry Wt. of Soil Specimen = 4347.28 gm. Total Wt. (Sat.)= 7834.7 gm.
Wt. of Water in Sat. Specimen= 1028.82 gm.
Initial pH of Water= 8.41 Initial Conductivity of Water= 132.4

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)	
5/22/96	14 6	0.00	7834.70	1028.82	8.41	132.4	1 psi
5/23/96	11 42	21.60	7076.60	270.72	8.05	184.7	
5/24/96	12 2	45.93	7067.90	262.02	8.08	201	
5/27/96	10 58	116.87	7062.10	256.22	8.28	253	
5/28/96	12 52	142.77	7062.10	256.22	8.16	272	
5/29/96	12 50	166.73	7059.10	253.22	8.13	212	
5/30/96	12 14	190.13	7057.40	251.52	8.12	227	
5/31/96	11 52	213.77	7055.70	249.82	7.95	244	
6/3/96	10 47	284.68	7055.70	249.82	8.03	279	
6/4/96	12 21	310.25	7055.30	249.42	7.75	308	
6/5/96	12 30	334.40	7054.70	248.82	8.08	314	
6/6/96	12 1	357.92	7055.00	249.12	8.09	336	
6/7/96	11 54	381.80	7054.80	248.92	7.96	252	
6/10/96	12 4	453.97	7054.50	248.62	8.02	276	
6/11/96	12 11	478.08	7054.40	248.52	8.01	310	
6/12/96	12 23	502.28	7053.40	247.52	7.93	310	2 psi
6/13/96	14 35	528.48	7053.00	247.12	7.69	340	
6/14/96	11 32	549.43	7057.20	251.32	7.93	350	
6/17/96	10 0	619.90	7048.20	242.32	6.83	292	
6/18/96	12 45	646.65	7045.70	239.82	7	293	3 psi
6/19/96	13 15	671.15	7046.90	241.02	7.1	321	
6/20/96	13 11	695.08	7044.80	238.92	7.83	349	
6/24/96	11 15	789.15	7038.40	232.52	7.28	417	
6/25/96	11 45	813.65	7044.70	238.82	7.62	229	

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 1 STARTING DATE 2/4/96
File Name : ELP4S1.XLS
Soil Identification : El Paso Montana # 4and Above
Soil description : Soil Water Retention
Cylinder Number : 4

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.28 15.26 15.27) / 3 = 15.27 cm.
14.4 14.40 14.35 14.39) / 3 = 14.38 cm.
Area of Specimen = 183.13 cm^2 Vol. of Specimen = 2633.46 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1673.40 gm.
Total Wt. (without the Cap)= 6311.3 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 7030 gm. Actual moisture cont. 1.7 %
Dry Wt. of Soil Specimen = 4560.37 gm. Total Wt. (Sat.)= 7626.0 gm.
Wt. of Water in Sat. Specimen= 673.53 gm.
Initial pH of Water= 7.86 Initial Conductivity of Water= 224

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
2/8/96	10 39	0.00	7626.00	673.53	7.86	224
2/9/96	13 21	26.70	7072.70	120.23	7.71	270
2/12/96	14 14	99.58	7056.00	103.53	7.41	282
2/13/96	15 21	124.70	7054.30	101.83	7.63	303
2/14/96	13 15	146.60	7044.50	92.03	7.85	336
2/15/96	17 6	174.45	7050.50	98.03	7.6	366
2/16/96	12 30	193.85	7050.10	97.63	7.74	434
2/19/96	12 9	265.50	7049.20	96.73	7.87	382
2/20/96	14 7	291.47	7049.40	96.93	7.76	417
2/21/96	12 59	314.33	7048.20	95.73	7.76	452
2/22/96	11 11	336.53	7046.90	94.43	7.96	487
2/23/96	13 24	362.75	7047.60	95.13	7.92	288
2/26/96	12 0	433.35	7048.30	95.83	7.95	346
2/27/96	11 11	456.53	7048.00	95.53	7.76	381
2/28/96	12 0	481.35	7048.30	95.83	7.76	341

<u>SOIL WATER RETENTION TEST OF DRAINABLE BASES</u>

Specimen Number : 2 **STARTING DATE'** 5/17/96
File Name : ELP4S2.XLS
Soil Identification : El Paso # 4 & Above
Soil description : Soil Water Retention
Cylinder Number : 4

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.29 15.27 15.28) / 3 = 15.28 cm.
Avg Ht. = (13.68 13.71 13.65) / 3 = 13.68 cm.
Area of Specimen = 183.37 cm^2 Vol. of Specimen = 2508.55 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1573.20 gm.
Total Wt. (without the Cap)= 5725.4 gm. Target moisture cont. 5 %
Total Wt. (with the Cap) = 6423.1 gm. Actual moisture cont. 1.82 %
Dry Wt. of Soil Specimen = 4077.98 gm. Total Wt. (Sat.)= 7072.1 gm.
Wt. of Water in Sat. Specimen= 723.22 gm.
Initial pH of Water= 8.51 Initial Conductivity of Water= 138.3

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)	
5/22/96	14 6	0.00	7027.80	723.22	8.51	138.3	1 psi
5/23/96	11 42	21.60	6515.30	210.72	8.03	157.6	
5/24/96	12 3	45.95	6509.60	205.02	8.07	169.4	
5/27/96	10 59	116.88	6503.90	199.32	8.24	218	
5/28/96	12 52	142.77	6502.20	197.62	8.11	234	
5/29/96	12 51	166.75	6501.60	197.02	8.12	163.1	
5/30/96	12 15	190.15	6500.90	196.32	8.09	186.9	
5/31/96	11 55	213.82	6499.20	194.62	7.9	198	
6/3/96	10 48	284.70	6499.90	195.32	8.05	222	
6/4/96	12 14	310.13	6499.60	195.02	7.88	240	
6/5/96	12 30	334.40	6499.20	194.62	8.02	249	
6/6/96	12 1	357.92	6499.20	194.62	8.04	263	
6/7/96	11 55	381.82	6499.70	195.12	7.95	197.8	
6/10/96	12 5	453.98	6499.60	195.02	8.03	227	
6/11/96	12 11	478.08	6499.50	194.92	8.01	267	
6/12/96	12 25	502.32	6512.00	207.42	8.02	251	2 psi
6/13/96	14 35	528.48	6514.20	209.62	7.5	267	

APPENDIX H

RESILIENT MODULUS TEST RESULTS OF CEMENT-STABILIZED BASE MATERIALS

Description: San Antonio 5% Cement Specimen

Specimen: #1

Before testing:

Diameter:	152	*mm*
Height:	305	*mm*
Weight:	9.75	*kg*
Volume:	5.54E-03	m^3
Unit Weight	1760	kg/m^3
Gage length:	102	*mm*

Gradation :

Sieve No.	Wt. Retained (kg)
1	3.00
3/4	2.68
1/2	2.72
3/8	1.5

Wt. of Cement (kg)	0.739
Wt. of Water (kg)	0.332
W/C Ratio:	0.45

Cycle	Deviatoric Stress (kPa)	Confining Pressure (kPa)	Axial Strain	Lateral Strain	Resilient Modulus (MPa)
1	120	0	.133E-04	.353E-05	8994
2	179	0	.228E-04	.107E-04	7838
3	235	0	.491E-04	.183E-04	4795
4	119	35	.744E-05	.244E-05	15958
5	178	35	.103E-04	.454E-05	17244
6	235	35	.148E-04	.910E-05	15867
7	119	70	.158E-04	.487E-05	7501
9	234	70	.356E-04	.102E-04	6567
10	296	70	.419E-04	.178E-04	7053
11	177	105	.173E-04	.969E-05	10211
12	233	105	.317E-04	.186E-04	7360
14	359	105	.489E-04	.187E-04	7339
16	360	140	.530E-04	.195E-04	6791
17	462	140	.675E-04	.256E-04	6840
18	563	140	.858E-04	.264E-04	6557
19	663	140	.104E-03	.253E-04	6377
20	762	140	.115E-03	.242E-04	6630
21	871	140	.130E-03	.312E-04	6697
22	964	140	.129E-03	.324E-04	7471

Description: San Antonio
5% Cement Specimen

Specimen: #2

Before testing:

Diameter:	152	*mm*
Height:	305	*mm*
Weight:	9.75	*kg*
Volume:	5.54E-03	m^3
Unit Weight	1760	kg / m^3
Gage length:	102	*mm*

Gradation :

Sieve No.	Wt. Retained (kg)
1	3.00
3/4	2.68
1/2	2.72
3/8	1.5

Wt. of Cement (kg)	0.739
Wt. of Water (kg)	0.351
W/C Ratio:	0.475

Cycle	Deviatoric Stress (kPa)	Confining Pressure (kPa)	Axial Strain	Lateral Strain	Resilient Modulus (MPa)
1	111	0	.232E-04	.448E-04	4791
2	167	0	.346E-04	.106E-03	4824
3	221	0	.527E-04	.141E-03	4192
4	113	35	.192E-04	.693E-04	5882
5	167	35	.331E-04	.623E-04	5045
6	221	35	.359E-04	.769E-04	6155
7	167	70	.298E-04	.432E-04	5618
8	279	70	.491E-04	.697E-04	5687
9	167	105	.295E-04	.452E-04	5670
10	221	105	.370E-04	.530E-04	5978
11	279	105	.492E-04	.631E-04	5666
12	339	105	.696E-04	.814E-04	4876
13	221	140	.403E-04	.503E-04	5476
14	340	140	.705E-04	.685E-04	4827
15	435	140	.923E-04	.905E-04	4715
16	532	140	.972E-04	.111E-03	5470
17	627	140	.955E-04	.143E-03	6560
18	721	140	.107E-03	.226E-03	6738
19	821	140	.115E-03	.262E-03	7141
20	905	140	.124E-03	.290E-03	7297

Description: San Antonio
7% Cement Specimen

Specimen: #1

Before testing:

Diameter:	150	mm
Height:	305	mm
Weight:	9.75	kg
Volume:	5.42E-03	m^3
Unit Weight	1799	kg/m^3
Gage length:	102	mm

Gradation :

Sieve No.	Wt. Retained (kg)
1	3.00
3/4	2.68
1/2	2.72
3/8	1.5

Wt. of Cement (kg)	0.739
Wt. of Water (kg)	0.332
W/C Ratio:	0.45

Cycle	Deviatoric Stress (kPa)	Confining Pressure (kPa)	Axial Strain	Lateral Strain	Resilient Modulus (MPa)
1	120	0	.164E-04	.677E-05	7328
2	179	0	.244E-04	.108E-04	7330
3	236	0	.347E-04	.177E-04	6797
4	120	35	.138E-04	.923E-05	8668
5	178	35	.210E-04	.107E-04	8484
6	235	35	.308E-04	.982E-05	7645
7	119	70	.136E-04	.717E-05	8760
8	178	70	.196E-04	.122E-04	9065
9	235	70	.295E-04	.103E-04	7951
10	296	70	.352E-04	.117E-04	8397
11	177	105	.251E-04	.803E-05	7065
12	234	105	.317E-04	.836E-05	7382
13	296	105	.352E-04	.908E-05	8395
14	360	105	.368E-04	.117E-04	9791
15	234	140	.331E-04	.114E-04	7061
16	360	140	.500E-04	.118E-04	7202
17	462	140	.599E-04	.151E-04	7712
18	563	140	.746E-04	.149E-04	7548
19	662	140	.997E-04	.132E-04	6638
20	764	140	.119E-03	.154E-04	6421
21	871	140	.137E-03	.172E-04	6360
22	963	140	.154E-03	.169E-04	6254

Description: San Antonio
7% Cement Specimen

Specimen: #2

Before testing:

Diameter:	152	mm
Height:	307	mm
Weight:	9.75	kg
Volume:	5.61E-03	m^3
Unit Weight	1740	kg / m^3
Gage length:	102	mm

Gradation :

Sieve No.	Wt. Retained (kg)
1	3.00
3/4	2.68
1/2	2.72
3/8	1.5

Wt. of Cement (kg)	0.739
Wt. of Water (kg)	0.351
W/C Ratio:	0.475

Cycle	Deviatoric Stress (kPa)	Confining Pressure (kPa)	Axial Strain	Lateral Strain	Resilient Modulus (MPa)
1	108	0	.131E-04	.804E-04	8253
2	162	0	.158E-04	.116E-03	10229
3	213	0	.368E-04	.165E-03	5780
4	107	35	.139E-04	.874E-04	7708
5	161	35	.222E-04	.132E-03	7252
6	212	35	.285E-04	.158E-03	7451
7	107	70	.191E-04	.946E-04	5628
8	161	70	.201E-04	.137E-03	7999
9	212	70	.330E-04	.167E-03	6420
10	268	70	.280E-04	.212E-03	9576
11	161	105	.220E-04	.132E-03	7302
12	212	105	.380E-04	.161E-03	5570
13	268	105	.370E-04	.195E-03	7234
14	326	105	.511E-04	.232E-03	6386
15	212	140	.268E-04	.173E-03	7893
16	326	140	.472E-04	.231E-03	6909
17	419	140	.452E-04	.265E-03	9261
18	510	140	.410E-04	.262E-03	12451
19	601	140	.548E-04	.268E-03	10972
20	691	140	.575E-04	.257E-03	12023
21	788	140	.597E-04	.268E-03	13202
22	874	140	.689E-04	.287E-03	12692

Description: Corpus Christi
5% Cement Specimen

Specimen: #1

Before testing:

Diameter:	149	mm
Height:	305	mm
Weight:	9.66	kg
Volume:	5.29E-03	m^3
Unit Weight	1828	kg/m^3
Gage length:	102	mm

Gradation :

Sieve No.	Wt. Retained (kg)
1	2.13
3/4	2.81
1/2	2.81
3/8	2.2
Wt. of Cement (kg)	0.739
Wt. of Water (kg)	0.332
W/C Ratio:	0.45

Cycle	Deviatoric Stress (kPa)	Confining Pressure (kPa)	Axial Strain	Lateral Strain	Resilient Modulus (MPa)
1	109	35	.618E-04	.320E-04	1769
2	164	35	.835E-04	.251E-04	1966
3	217	35	.105E-03	.396E-04	2068
4	108	70	.350E-04	.138E-04	3087
5	163	70	.829E-04	.464E-04	1964
6	216	70	.109E-03	.330E-04	1979
7	502	70	.559E-03	.213E-03	899
8	161	105	.108E-03	.416E-04	1493
9	213	105	.150E-03	.482E-04	1423
10	270	105	.199E-03	.640E-04	1356
11	329	105	.253E-03	.882E-04	1300
12	213	140	.149E-03	.500E-04	1429
13	329	140	.251E-03	.925E-04	1311
14	423	140	.333E-03	.123E-03	1270
15	515	140	.391E-03	.148E-04	1318
16	610	140	.468E-03	.173E-03	1303
17	711	140	.535E-03	.205E-03	1330
18	802	140	.590E-03	.228E-03	1360

Description: Corpus Christi 7% Cement Specimen

Specimen: #1

Before testing:

Diameter:	150	*mm*
Height:	305	*mm*
Weight:	9.75	*kg*
Volume:	5.42E-03	m^3
Unit Weight	1799	kg / m^3
Gage length:	102	*mm*

Gradation :

Sieve No.	Wt. Retained (kg)
1	2.13
3/4	2.81
1/2	2.81
3/8	2.2

Wt. of Cement (kg)	0.739
Wt. of Water (kg)	0.332
W/C Ratio:	0.45

Cycle	Deviatoric Stress (kPa)	Confining Pressure (kPa)	Axial Strain	Lateral Strain	Resilient Modulus (MPa)
1	110	35	.396E-04	.139E-04	2768
3	218	35	.967E-04	.351E-04	2251
4	109	70	.362E-04	.176E-04	3007
5	163	70	.639E-04	.265E-04	2555
6	216	70	.867E-04	.324E-04	2496
7	272	70	.115E-03	.434E-04	2369
8	162	105	.468E-04	.258E-04	3469
9	215	105	.861E-04	.351E-04	2497
10	272	105	.133E-03	.409E-04	2044
11	331	105	.153E-03	.521E-04	2164
12	214	140	.744E-04	.353E-04	2876
13	331	140	.148E-03	.543E-04	2234
14	424	140	.198E-03	.685E-04	2141
15	517	140	.251E-03	.877E-04	2059
16	609	140	.294E-03	.100E-03	2073
17	711	140	.355E-03	.121E-03	2004
18	803	140	.414E-03	.136E-03	1941
19	883	140	.499E-03	.158E-03	1771

Description: Corpus Christi 7% Cement Specimen

Specimen: #2

Before testing:

Diameter:	155	*mm*
Height:	304	*mm*
Weight:	9.75	*kg*
Volume:	5.72E-03	m^3
Unit Weight	1704	kg/m^3
Gage length:	102	*mm*

Gradation :

Sieve No.	Wt. Retained (kg)
1	2.13
3/4	2.81
1/2	2.81
3/8	2.2

Wt. of Cement (kg)	0.739
Wt. of Water (kg)	0.351
W/C Ratio:	0.475

Cycle	Deviatoric Stress (kPa)	Confining Pressure (kPa)	Axial Strain	Lateral Strain	Resilient Modulus (MPa)	Poisson's Ratio
1	111	0	.332E-04	.149E-04	3339	0.45
2	166	0	.560E-04	.127E-04	2962	0.23
3	218	0	.489E-04	.143E-04	4461	0.29
4	111	35	.309E-04	.932E-05	3577	0.30
5	166	35	.517E-04	.874E-05	3203	0.17
6	219	35	.457E-04	.118E-04	4787	0.26
7	165	70	.468E-04	.169E-05	3536	0.04
8	218	70	.585E-04	.616E-05	3729	0.11
9	275	70	.533E-04	.167E-04	5155	0.31
10	335	70	.818E-04	.210E-04	4099	0.26
11	218	105	.531E-04	.149E-04	4100	0.28
12	336	105	.891E-04	.276E-04	3766	0.31
13	430	105	.120E-03	.274E-04	3587	0.23
14	524	105	.896E-04	.301E-04	5846	0.34

Description: Childress
5% Cement Specimen

Specimen: #1

Before testing:

Diameter:	150	*mm*
Height:	305	*mm*
Weight:	9.75	*kg*
Volume:	5.42E-03	m^3
Unit Weight	1799	kg / m^3
Gage length:	102	*mm*

Gradation :

Sieve No.	Wt. Retained (kg)
1	0.50
3/4	2.4
1/2	2.2
3/8	1.91

Wt. of Cement (kg)	0.739
Wt. of Water (kg)	0.332
W/C Ratio:	0.45

Cycle	Deviatoric Stress (kPa)	Confining Pressure (kPa)	Axial Strain	Lateral Strain	Resilient Modulus (MPa)
1	111	35	.142E-04	.347E-05	7783
2	165	35	.334E-04	.371E-05	4944
3	218	70	.350E-04	.132E-04	6215
5	164	70	.233E-04	.139E-04	7052
6	216	70	.338E-04	.938E-05	6389
7	273	70	.520E-04	.189E-04	5253
8	163	105	.357E-04	.710E-05	4571
9	215	105	.235E-04	.428E-05	9139
10	272	105	.462E-04	.160E-04	5889
11	215	105	.294E-04	.857E-05	7298
12	215	140	.405E-04	.983E-05	5305
13	331	140	.573E-04	.141E-04	5779
14	424	140	.694E-04	.190E-04	6109
15	517	140	.868E-04	.296E-04	5958
16	609	140	.105E-03	.345E-04	5801
17	709	140	.114E-03	.378E-04	6216
18	806	140	.140E-03	.423E-04	5757
19	849	140	.149E-03	.461E-04	5699
20	888	140	.165E-03	.446E-04	5380
21	900	140	.160E-03	.447E-04	5624

Description: Childress 5% Cement Specimen

Specimen: #2

Before testing:

Diameter:	152	*mm*
Height:	302	*mm*
Weight:	9.75	*kg*
Volume:	5.51E-03	m^3
Unit Weight	1769	kg/m^3
Gage length:	102	*mm*

Gradation :

Sieve No.	Wt. Retained (kg)
1	0.50
3/4	2.4
1/2	2.2
3/8	1.91

Wt. of Cement (kg)	0.739
Wt. of Water (kg)	0.351
W/C Ratio:	0.475

Cycle	Deviatoric Stress (kPa)	Confining Pressure (kPa)	Axial Strain	Lateral Strain	Resilient Modulus (MPa)
1	112	0	.102E-04	.428E-05	10951
2	169	0	.151E-04	.152E-05	11223
3	221	0	.102E-04	.907E-05	21691
4	114	35	.125E-04	.756E-05	9123
5	223	35	.136E-04	.309E-05	16416
6	112	35	.863E-05	.304E-04	13007
7	167	70	.128E-04	.279E-05	13062
8	222	70	.667E-05	.111E-05	33264
9	280	70	.128E-04	.364E-05	21842
10	167	70	.104E-04	.370E-05	16097
11	279	105	.225E-04	.333E-05	12404
12	339	105	.181E-04	.215E-05	18757
13	221	105	.121E-04	.211E-05	18280
14	340	105	.247E-04	.325E-04	13767
15	436	140	.735E-04	.348E-04	5937
16	532	140	.632E-04	.386E-04	8421
17	626	140	.717E-04	.273E-04	8734
18	721	140	.531E-04	.155E-04	13578
19	823	140	.671E-04	.184E-04	12263
20	910	140	.617E-04	.182E-04	14754

Description: Childress
7% Cement Specimen

Specimen: #1

Before testing:

Diameter:	152	*mm*
Height:	302	*mm*
Weight:	9.75	*kg*
Volume:	5.51E-03	m^3
Unit Weight	1769	kg/m^3
Gage length:	102	*mm*

Gradation :

Sieve No.	Wt. Retained (kg)
1	0.50
3/4	2.4
1/2	2.2
3/8	1.91

Wt. of Cement (kg)	0.739
Wt. of Water (kg)	0.332
W/C Ratio:	0.45

Cycle	Deviatoric Stress (kPa)	Confining Pressure (kPa)	Axial Strain	Lateral Strain	Resilient Modulus (MPa)
4	112	35	.237E-04	.821E-05	4730
5	168	35	.363E-04	.119E-04	4616
6	222	35	.283E-04	.107E-04	7835
7	112	70	.288E-04	.680E-05	3893
8	167	70	.271E-04	.767E-05	6159
16	341	140	.203E-04	.729E-05	16799
17	438	140	.365E-04	.117E-04	11993
18	533	140	.491E-04	.160E-04	10846
19	627	140	.452E-04	.112E-04	13872
20	723	140	.563E-04	.114E-04	12838
21	825	140	.637E-04	.112E-04	12952
22	910	140	.843E-04	.842E-05	10791

Description: Childress
7% Cement Specimen

Specimen: #2

Before testing:

Diameter:	151	*mm*
Height:	305	*mm*
Weight:	9.75	*kg*
Volume:	5.47E-03	m^3
Unit Weight	1784	kg/m^3
Gage length:	102	*mm*

Gradation :

Sieve No.	Wt. Retained (kg)
1	0.50
3/4	2.4
1/2	2.2
3/8	1.91

Wt. of Cement (kg)	0.739
Wt. of Water (kg)	0.351
W/C Ratio:	0.475

Cycle	Deviatoric Stress (kPa)	Confining Pressure (kPa)	Axial Strain	Lateral Strain	Resilient Modulus (MPa)	Poisson's Ratio
2	169	0	.107E-03	.136E-04	1579	0.13
3	222	0	.122E-03	.156E-04	1816	0.13
4	112	35	.553E-04	.947E-05	2024	0.17
5	167	35	.974E-04	.983E-05	1719	0.10
6	221	35	.117E-03	.202E-04	1890	0.17
7	112	70	.565E-04	.515E-05	1977	0.09
8	167	70	.944E-04	.140E-04	1770	0.15
9	220	70	.120E-03	.150E-04	1836	0.13
10	279	70	.150E-03	.144E-04	1858	0.10
11	167	105	.955E-04	.119E-04	1746	0.12
12	221	105	.121E-03	.124E-04	1823	0.10
13	278	105	.136E-03	.138E-04	2046	0.10
14	339	105	.177E-03	.190E-04	1913	0.11
16	338	140	.165E-03	.191E-04	2050	0.12
17	434	140	.217E-03	.296E-04	2001	0.14
18	529	140	.280E-03	.257E-04	1891	0.09
19	622	140	.302E-03	.346E-04	2058	0.11
20	819	140	.355E-03	.414E-04	2306	0.12

APPENDIX I

SOIL WATER RETENTION TEST RESULTS OF CEMENT-STABILIZED BASE MATERIALS

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 2 **STARTING DATE** 7/15/96
File Name : 1A.XLS
Soil Identification : El Paso 5% Cement @ Water .45
Soil description : Soil Water Retention
Cylinder Number : 1A

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(14.75 14.58 14.65) / 3 = 14.66 cm.
Avg Ht. = (14.48 14.61 14.71) / 3 = 14.60 cm.
Area of Specimen = 168.79 cm^2 Vol. of Specimen = 2464.4 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 2006.70 gm.
Total Wt. (without the Cap)= 6560.5 gm.
Total Wt. (with the Cap) = 7265.2 gm. Water-Cement Ratio 0.45
Dry Wt. of Soil Specimen = 4553.80 gm. Total Wt. (Sat.)= 8238.1 gm.
Wt. of Water in Sat. Specimen= 972.90 gm.
Initial pH of Water= 9.32 Initial Conductivity of Water= 99

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
7/23/96	9 43	0.00	8238.10	972.90	9.32	99
7/24/96	10 15	24.53	7328.50	63.30	10.01	108.6
7/25/96	9 25	47.70	7325.20	60.00	10.75	155.9
7/26/96	10 5	72.37	7324.10	58.90	10.35	553
7/29/96	15 55	150.20	7321.80	56.60	9.10	235
7/30/96	17 21	175.63	7323.70	58.50	8.51	235
7/31/96	12 11	194.47	7323.60	58.40	7.75	160.7
8/1/96	12 4	218.35	7323.70	58.50	7.92	175.5
8/2/96	11 30	241.78	7325.30	60.10	8.06	194.5
8/5/96	11 37	313.90	7327.80	62.60	7.93	174.6
8/6/96	10 29	336.77	7327.40	62.20	7.94	181.6
8/7/96	11 1	361.30	7327.30	62.10	7.84	189.8
8/8/96	11 54	386.18	7323.90	58.70	8.02	197
8/9/96	11 50	410.12	7323.90	58.70	8.14	88
8/12/96	11 24	481.68	7324.40	59.20	8.05	137.8
8/13/96	11 49	506.10	7325.80	60.60	7.95	16638
8/14/96	11 36	529.88	7324.60	59.40	7.90	175.3
8/15/96	11 37	553.90	7326.20	61.00	8.07	191.4
8/16/96	11 27	577.73	7325.00	59.80	7.97	193.8
8/19/96	11 30	649.78	7324.60	59.40	8.07	193.7
8/20/96	9 32	671.82	7325.60	60.40	8.10	215
8/21/96	9 15	695.53	7324.40	59.20	8.08	236
8/22/96	9 39	719.93	7323.20	58.00	7.44	193
8/23/96	9 20	743.62	7323.10	57.90	7.95	203
8/26/96	9 35	815.87	7323.70	58.50	8.02	224
8/27/96	9 30	839.78	7325.00	59.80	7.90	226
8/28/96	9 45	864.03	7326.40	61.20	8.00	248

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 2 **STARTING DATE** 7/16/96
File Name : 3A.XLS
Soil Identification : El Paso 5% Cement @ Water .475
Soil description : Soil Water Retention
Cylinder Number : 3A

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(14.52 14.73 14.56) / 3 = 14.60 cm.
Avg Ht. = (14.48 14.51 14.48) / 3 = 14.49 cm.
Area of Specimen = 167.49 cm^2 Vol. of Specimen = 2427.0 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1926.40 gm.
Total Wt. (without the Cap)= 6503.2 gm.
Total Wt. (with the Cap) = 7217.2 gm. Water-Cement Ratio 0.475
Dry Wt. of Soil Specimen = 4576.80 gm. Total Wt. (Sat.)= 8558.2 gm.
Wt. of Water in Sat. Specimen= 1341.00 gm.
Initial pH of Water= 9.62 Initial Conductivity of Water= 637

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
7/24/96	10 17	0.00	8558.20	1341.00	9.62	637
7/25/96	9 25	23.13	7356.10	138.90	11.00	-
7/26/96	10 5	47.80	7354.40	137.20	10.93	-
7/29/96	15 56	125.65	7349.70	132.50	9.64	394
7/30/96	17 22	151.08	7351.20	134.00	9.64	381
7/31/96	12 11	169.90	7339.30	122.10	8.44	396
8/1/96	12 5	193.80	7336.40	119.20	8.66	396
8/2/96	11 30	217.22	7337.10	119.90	8.55	397
8/5/96	11 36	289.32	7336.10	118.90	8.33	359
8/6/96	10 30	312.22	7335.20	118.00	8.32	369
8/7/96	11 31	337.23	7335.20	118.00	8.29	375
8/8/96	11 55	361.63	7333.70	116.50	8.37	394
8/9/96	11 50	385.55	7335.10	117.90	8.52	131.5
8/12/96	11 24	457.12	7337.10	119.90	8.29	148
8/13/96	11 50	481.55	7335.90	118.70	8.20	206
8/14/96	11 37	505.33	7335.30	118.10	8.15	280
8/15/96	11 38	529.35	7336.10	118.90	8.38	297
8/16/96	14 27	556.17	7335.00	117.80	8.19	300
8/19/96	11 30	625.22	7334.00	116.80	8.33	298
8/20/96	11 32	649.25	7333.60	116.40	8.33	325
8/21/96	9 16	670.98	7332.80	115.60	8.23	360
8/22/96	9 39	695.37	7333.00	115.80	8.31	284
8/23/96	9 20	719.05	7333.10	115.90	8.21	307
8/26/96	9 35	791.30	7333.40	116.20	8.23	330

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 2 **STARTING DATE** 7/16/96
File Name : 2A.XLS
Soil Identification : El Paso 7% Cement @ Water .45
Soil description : Soil Water Retention
Cylinder Number : 2A

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.07 15.09 15.00) / 3 = 15.05 cm.
Avg Ht. = (15.10 15.06 15.08) / 3 = 15.08 cm.
Area of Specimen = 177.97 cm^2 Vol. of Specimen = 2683.8 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1840.20 gm.
Total Wt. (without the Cap)= 6331.4 gm.
Total Wt. (with the Cap) = 7421.5 gm. Water-Cement Ratio 0.45
Dry Wt. of Soil Specimen = 4491.20 gm. Total Wt. (Sat.)= 8576.6 gm.
Wt. of Water in Sat. Specimen= 1155.10 gm.
Initial pH of Water= 10.97 Initial Conductivity of Water= 605

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
7/29/96	16 0	0.00	8576.90	1155.10	8.92	160.4
7/30/96	17 23	25.38	7434.50	12.70	11.35	2260
7/31/96	12 12	44.20	7433.40	11.60	9.83	1293
8/1/96	12 6	68.10	7431.80	10.00	10.15	701
8/2/96	11 31	91.52	7432.20	10.40	9.73	468
8/5/96	11 38	163.63	7430.70	8.90	9.06	367
8/6/96	10 31	186.52	7430.40	8.60	8.88	331
8/7/96	11 3	211.05	7430.10	8.30	8.79	368
8/8/96	11 56	235.93	7428.30	6.50	8.72	340
8/9/96	11 51	259.85	7428.10	6.30	8.80	149.7
8/12/96	11 26	331.43	7429.50	7.70	8.39	171.7
8/13/96	11 50	355.83	7428.70	6.90	8.36	304
8/14/96	11 40	379.67	7428.40	6.60	8.34	316
8/15/96	11 39	403.65	7429.60	7.80	8.39	314
8/16/96	11 28	427.47	7428.50	6.70	8.28	307
8/19/96	11 31	499.52	7428.80	7.00	8.35	271
8/20/96	11 33	523.55	7428.60	6.80	8.36	344
8/21/96	9 16	545.27	7427.50	5.70	8.32	358
8/22/96	9 42	569.70	7426.40	4.60	8.70	319
8/23/96	9 21	593.35	7426.90	5.10	8.36	344
8/26/96	9 36	665.60	7427.30	5.50	8.35	357
8/27/96	9 31	689.52	7427.90	6.10	8.32	359
8/28/96	9 45	713.75	7428.30	6.50	8.22	380

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 2 **STARTING DATE** 8/6/96
File Name : 4A.XLS
Soil Identification : El Paso 7% Cement @ Water .475
Soil description : Soil Water Retention
Cylinder Number : 4A

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.03 15.04 14.97) / 3 = 15.01 cm.
Avg Ht. = (15.11 15.06 15.03) / 3 = 15.07 cm.
Area of Specimen = 177.03 cm^2 Vol. of Specimen = 2667.2 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1906.10 gm.
Total Wt. (without the Cap)= 6621.6 gm.
Total Wt. (with the Cap) = 7340 gm. Water-Cement Ratio 0.475
Dry Wt. of Soil Specimen = 4715.50 gm. Total Wt. (Sat.)= 8477.6 gm.
Wt. of Water in Sat. Specimen= 1137.60 gm.
Initial pH of Water= 9.43 Initial Conductivity of Water= 39.2

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
8/9/96	11 52	0.00	8477.60	1137.60	9.43	39.2
8/12/96	11 26	71.57	7428.00	88.00	10.64	867
8/13/96	11 50	95.97	7426.20	86.20	10.35	714
8/14/96	11 40	119.80	7426.20	86.20	9.91	742
8/15/96	11 39	143.78	7426.30	86.30	9.52	401
8/16/96	14 28	170.60	7425.80	85.80	9.10	403
8/19/96	11 31	239.65	7426.40	86.40	8.81	365
8/20/96	11 33	263.68	7425.50	85.50	8.69	455
8/21/96	9 17	285.42	7425.00	85.00	8.57	457
8/22/96	9 44	309.87	7424.50	84.50	9.05	389
8/23/96	9 21	333.48	7424.50	84.50	8.53	417
8/26/96	9 38	405.77	7424.70	84.70	9.41	447
8/27/96	9 32	429.67	7424.80	84.80	8.30	448
8/28/96	9 45	453.88	7425.20	85.20	8.33	484
8/29/96	9 50	477.97	7426.00	86.00	8..15	509
8/30/96	9 49	501.95	7425.20	85.20	8.50	523
9/3/96	9 28	597.60	7424.40	84.40	8.17	579
9/4/96	9 23	621.52	7424.10	84.10	8.32	597
9/5/96	9 50	645.97	7424.10	84.10	8.40	389
9/6/96	9 56	670.07	7424.70	84.70	8.46	402
9/9/96	9 31	741.65	7424.20	84.20	8.26	421
9/10/96	9 21	765.48	7424.40	84.40	8.24	434

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 1 **STARTING DATE** 5/23/96
File Name : 1B.XLS
Soil Identification : Odessa 5% Cement @ Water .45
Soil description : Soil Water Retention
Cylinder Number : 1B

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.13 15.07 15.01) / 3 = 15.07 cm.
Avg Ht. = (16.89 16.84 16.81) / 3 = 16.85 cm.
Area of Specimen = 178.37 cm^2 Vol. of Specimen = 3004.9 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1993.10 gm.
Total Wt. (without the Cap)= 6654.7 gm.
Total Wt. (with the Cap) = 7382 gm. Water-Cement Ratio 0.45
Dry Wt. of Soil Specimen = 4661.60 gm. Total Wt. (Sat.)= 8756.2 gm.
Wt. of Water in Sat. Specimen= 1374.20 gm.
Initial pH of Water= 10.08 Initial Conductivity of Water= 93.9

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
6/6/96	12 3	0.00	8756.20	1374.20	10.58	93.9
6/7/96	11 57	23.90	8023.90	641.90	11.57	1352
6/10/96	12 7	96.07	7785.30	403.30	10.68	514
6/11/96	12 13	120.17	7755.90	373.90	10.38	536
6/12/96	12 26	144.38	7496.40	114.40	10.34	674
6/13/96	14 36	170.55	7491.30	109.30	10.31	643
6/14/96	11 35	191.53	7488.50	106.50	9.55	660
6/17/96	10 10	262.12	7485.90	103.90	8.38	730
6/18/96	12 46	288.72	7483.50	101.50	8.54	814
6/19/96	13 20	313.28	7484.90	102.90	8.27	854
6/20/96	13 13	337.17	7483.40	101.40	8.34	894
6/24/96	11 21	431.30	7477.20	95.20	8.54	598
6/25/96	11 48	455.75	7477.70	95.70	8.61	501
6/26/96	11 22	479.32	7477.20	95.20	8.45	575
6/27/96	9 44	501.68	7476.00	94.00	8.45	535
6/28/96	10 8	526.08	7475.70	93.70	8.38	587
7/1/96	11 37	599.57	7475.90	93.90	8.43	615
7/2/96	12 9	624.10	7475.50	93.50	8.47	648
7/3/96	12 5	648.03	7475.30	93.30	8.58	669
7/5/96	11 29	695.43	7474.80	92.80	7.56	714
7/8/96	11 12	767.15	7474.60	92.60	8.41	603
7/9/96	11 32	791.48	7474.40	92.40	8.45	618
7/10/96	10 9	814.10	7473.50	91.50	8.36	655
7/11/96	11 48	839.75	7473.40	91.40	8.30	680
7/12/96	11 57	863.90	7473.40	91.40	7.97	700
7/15/96	12 50	936.78	7471.60	89.60	8.00	785
7/16/96	9 46	957.72	7472.10	90.10	7.98	797
7/17/96	13 2	984.98	7471.70	89.70	7.99	547

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 1 **STARTING DATE** 8/6/96
File Name : 3B.XLS
Soil Identification : Corpus Christi 5% Cement @ Water .475
Soil description : Soil Water Retention
Cylinder Number : 3B

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.25 15.27 15.27) / 3 = 15.26 cm.
Avg Ht. = (14.98 15.01 14.96) / 3 = 14.98 cm.
Area of Specimen = 182.97 cm^2 Vol. of Specimen = 2741.6 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1667.90 gm.
Total Wt. (without the Cap)= 5708.8 gm.
Total Wt. (with the Cap) = 6421.7 gm. Water-Cement Ratio 0.475
Dry Wt. of Soil Specimen = 4040.90 gm. Total Wt. (Sat.)= 7185.8 gm.
Wt. of Water in Sat. Specimen= 764.10 gm.
Initial pH of Water= 9.89 Initial Conductivity of Water= 250

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
8/15/96	11 27	0.00	7185.80	764.10	9.89	250
8/16/96	14 29	27.03	6611.30	189.60	9.82	390
8/19/96	11 32	96.08	6607.20	185.50	8.74	181.1
8/20/96	11 34	120.12	6604.70	183.00	8.56	200
8/21/96	9 17	141.83	6602.90	181.20	8.33	214
8/22/96	9 48	166.35	6600.70	179.00	8.56	191.2
8/23/96	9 22	189.92	6599.40	177.70	8.25	205
8/26/96	9 38	262.18	6593.50	171.80	8.08	229
8/27/96	9 35	286.13	6591.60	169.90	8.52	239
8/28/96	9 45	310.30	6589.60	167.90	8.00	259
8/29/96	8 51	333.40	6587.60	165.90	7.96	261
8/30/96	9 50	358.38	6583.10	161.40	8.03	261
9/3/96	9 28	454.02	6564.80	143.10	8.05	302
9/4/96	9 23	477.93	6560.20	138.50	8.09	320
9/5/96	9 53	502.43	6555.50	133.80	8.09	219
9/6/96	9 57	526.50	6552.10	130.40	8.13	230
9/9/96	9 32	598.08	6540.00	118.30	8.07	252
9/10/96	9 22	621.92	6535.40	113.70	8.07	260
9/11/96	9 27	646.00	6540.10	118.40	8.00	298

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 1 **STARTING DATE** 6/3/96
File Name : 2B.XLS
Soil Identification : Odessa 7% Cement @ Water .45
Soil description : Soil Water Retention
Cylinder Number : 2B

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.04 15.06 15.07) / 3 = 15.06 cm.
Avg Ht. = (14.95 14.96 15.00) / 3 = 14.97 cm.
Area of Specimen = 178.05 cm^2 Vol. of Specimen = 2665.4 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1808.10 gm.
Total Wt. (without the Cap)= 6316.1 gm.
Total Wt. (with the Cap) = 7000.7 gm. Water-Cement Ratio 0.45
Dry Wt. of Soil Specimen = 4508.00 gm. Total Wt. (Sat.)= 7952.7 gm.
Wt. of Water in Sat. Specimen= 952.00 gm.
Initial pH of Water= 11.16 Initial Conductivity of Water= 536

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
6/10/96	11 27	0.00	7952.70	952.00	11.16	536
6/11/96	12 13	24.77	7485.50	484.80	11.3	856
6/12/96	12 27	49.00	7130.90	130.20	11.08	1147
6/13/96	14 38	75.18	7123.00	122.30	9.55	655
6/14/96	11 35	96.13	7119.70	119.00	10.19	580
6/17/96	10 10	166.72	7110.00	109.30	9.06	691
6/18/96	12 47	193.33	7105.30	104.60	9.1	610
6/19/96	13 21	217.90	7101.50	100.80	8.59	591
6/20/96	13 15	241.80	7097.90	97.20	8.55	601
6/24/96	11 23	335.93	7081.60	80.90	8.73	890
6/25/96	11 48	360.35	7078.90	78.20	8.74	420
6/26/96	11 22	383.92	7076.20	75.50	8.36	432
6/27/96	9 45	406.30	7073.40	72.70	8.67	436
6/28/96	10 9	430.70	7071.40	70.70	8.56	469
7/1/96	11 38	504.18	7066.50	65.80	8.55	518
7/2/96	12 10	528.72	7063.20	62.50	8.67	551
7/3/96	12 6	552.65	7062.90	62.20	8.71	565
7/5/96	11 30	600.05	7057.20	56.50	7.75	601
7/8/96	11 13	671.77	7051.60	50.90	8.54	443
7/9/96	11 33	696.10	7048.70	48.00	8.56	453
7/10/96	10 10	718.72	7046.40	45.70	8.54	485
7/11/96	11 50	744.38	7047.50	46.80	8.56	509
7/12/96	11 58	768.52	7043.30	42.60	8.06	526
7/15/96	12 50	841.38	7033.10	32.40	8.09	581
7/16/96	9 46	862.32	7029.90	29.20	8.02	596
7/17/96	13 3	889.60	7026.80	26.10	8.06	405
7/18/96	13 39	914.20	7024.70	24.00	8.14	422
7/19/96	12 45	937.30	7021.70	21.00	8.37	435

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 1 **STARTING DATE** 8/6/96
File Name : 4B.XLS
Soil Identification : Corpus Christi 7% Cement @ Water .475
Soil description : Soil Water Retention
Cylinder Number : 4B

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.31 15.27 15.25) / 3 = 15.28 cm.
Avg Ht. = (14.86 14.84 14.82) / 3 = 14.84 cm.
Area of Specimen = 183.29 cm^2 Vol. of Specimen = 2720.1 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1757.70 gm.
Total Wt. (without the Cap)= 6136 gm.
Total Wt. (with the Cap) = 6819.9 gm. Water-Cement Ratio 0.475
Dry Wt. of Soil Specimen = 4378.30 gm. Total Wt. (Sat.)= 8259.0 gm.
Wt. of Water in Sat. Specimen= 1439.10 gm.
Initial pH of Water= 8.96 Initial Conductivity of Water= 80.3

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
8/19/96	11 33	0.00	8259.00	1439.10	8.96	80.3
8/20/96	11 35	24.03	7875.40	1055.50	9.82	276
8/21/96	9 18	45.75	7463.60	643.70	9.97	471
8/22/96	9 49	70.27	7056.10	236.20	11.02	598
8/23/96	9 23	93.83	6963.90	144.00	9.77	424
8/26/96	9 39	166.10	6954.80	134.90	9.01	350
8/27/96	9 35	190.03	6953.90	134.00	8.75	355
8/28/96	9 47	214.23	6954.30	134.40	8.54	369
8/29/96	9 51	238.30	6953.40	133.50	8.4	376
8/30/96	9 50	262.28	6951.90	132.00	8.34	385
9/3/96	9 28	357.92	6948.60	128.70	8.16	436
9/4/96	9 25	381.87	6944.10	124.20	8.25	450
9/5/96	9 54	406.35	6944.50	124.60	8.26	382
9/6/96	10 1	430.47	6943.90	124.00	8.33	394
9/9/96	9 32	501.98	6938.90	119.00	8.21	421
9/10/96	9 23	525.83	6937.50	117.60	8.29	443

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 1 **STARTING DATE** 6/3/96
File Name : 1C.XLS
Soil Identification : Childress 5% Cement @ Water .45
Soil description : Soil Water Retention
Cylinder Number : 1C

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.03 15.06 15.06) / 3 = 15.05 cm.
Avg Ht. = (15.11 15.14 15.11) / 3 = 15.12 cm.
Area of Specimen = 177.89 cm^2 Vol. of Specimen = 2689.8 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1780.90 gm.
Total Wt. (without the Cap)= 6282.8 gm.
Total Wt. (with the Cap) = 6996.7 gm. Water-Cement Ratio 0.45
Dry Wt. of Soil Specimen = 4501.90 gm. Total Wt. (Sat.)= 8167.9 gm.
Wt. of Water in Sat. Specimen= 1171.20 gm.
Initial pH of Water= 9.71 Initial Conductivity of Water= 168.3

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
6/12/96	12 18	0.00	8176.90	1171.20	9.71	168.3
6/13/96	14 39	26.35	7116.70	111.00	10.88	1605
6/14/96	11 36	47.30	7114.00	108.30	11.11	709
6/17/96	10 11	117.88	7110.60	104.90	9.04	437
6/18/96	12 47	144.48	7109.80	104.10	9.19	446
6/19/96	13 21	169.05	7109.50	103.80	8.97	440
6/20/96	13 20	193.03	7110.50	104.80	8.55	739
6/24/96	11 23	287.08	7105.40	99.70	8.57	601
6/25/96	11 49	311.52	7105.50	99.80	8.52	281

SOIL WATER RETENTION TEST OF DRAINABLE BAS

Specimen Number : 1 **STARTING DATE** 6/13/96
File Name : 2C.XLS
Soil Identification : Childress 7% Cement @ Water .45
Soil description : Soil Water Retention
Cylinder Number : 2C

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.30 15.27 15.29) / 3 = 15.29 cm.
Avg Ht. = (14.85 14.82 14.87) / 3 = 14.85 cm.
Area of Specimen = 183.53 cm^2 Vol. of Specimen = 2724.9 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1705.40 gm.
Total Wt. (without the Cap)= 6386.4 gm.
Total Wt. (with the Cap) = 7084.2 gm. Water-Cement Ratio 0.45
Dry Wt. of Soil Specimen = 4681.00 gm. Total Wt. (Sat.)= 8091.0
Wt. of Water in Sat. Specimen= 1006.80 gm.
Initial pH of Water= 9.45 Initial Conductivity of Water= 135.3

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water
6/13/96	14 40	0.00	8091.00	1006.80	9.45	135.3
6/14/96	11 37	20.95	7184.30	100.10	11.52	1689
6/17/96	10 17	91.62	7184.90	100.70	9.98	382
6/18/96	12 48	118.13	7184.80	100.60	9.74	279
6/19/96	13 21	142.68	7185.60	101.40	8.76	264
6/20/96	13 21	166.68	7187.50	103.30	8.77	254
6/24/96	11 24	260.73	7180.90	96.70	8.27	272
6/25/96	11 49	285.15	7182.80	98.60	8.31	200
6/26/96	11 23	308.72	7182.90	98.70	8.04	212
6/27/96	9 45	331.08	7182.60	98.40	8.19	227
6/28/96	10 9	355.48	7184.00	99.80	8.23	252
7/1/96	11 39	428.98	7183.20	99.00	8.24	243
7/2/96	12 11	453.52	7138.10	53.90	0.32	280
7/3/96	12 7	477.45	7184.40	100.20	8.33	261
7/5/96	11 30	524.83	7183.50	99.30	7.53	276
7/8/96	11 13	596.55	7184.20	100.00	8.12	229
7/9/96	11 34	620.90	7183.70	99.50	8.16	224
7/10/96	10 11	643.52	7184.20	100.00	8.14	236
7/11/96	11 52	669.20	7183.70	99.50	8.06	247
7/12/96	11 58	693.30	7184.10	99.90	7.77	251
7/15/96	12 51	766.18	7183.90	99.70	7.75	276
7/16/96	9 47	787.12	7181.60	97.40	7.72	283
7/17/96	13 4	814.40	7181.70	97.50	7.79	224
7/18/96	13 40	839.00	7182.60	98.40	7.90	229
7/19/96	12 45	862.08	7184.70	100.50	8.17	235
7/22/96	12 50	934.17	7183.30	99.10	8.79	274
7/23/96	9 48	955.13	7183.50	99.30	8.01	268
7/24/96	10 35	979.92	7160.50	76.30	7.98	307

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 1 **STARTING DATE** 8/16/96
File Name : 3C.XLS
Soil Identification : Childress 5% Cement @ Water .475
Soil description : Soil Water Retention
Cylinder Number : 3C

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(14.65 14.73 14.61) / 3 = 14.66 cm.
Avg Ht. = (14.51 14.57 14.51) / 3 = 14.53 cm.
Area of Specimen = 168.87 cm^2 Vol. of Specimen = 2453.7 cm^3
Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1905.60 gm.
Total Wt. (without the Cap)= 6581.1 gm.
Total Wt. (with the Cap) = 7245.9 gm. Water-Cement Ratio 0.45
Dry Wt. of Soil Specimen = 4675.50 gm. Total Wt. (Sat.)= 7747.7 gm.
Wt. of Water in Sat. Specimen= 501.80 gm.
Initial pH of Water= 9.83 Initial Conductivity of Water= 529

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
9/5/96	9 56	0.00	7747.70	501.80	9.83	529
9/6/96	9 0	23.07	7320.70	74.80	10.47	1126
9/9/96	9 33	95.62	7316.40	70.50	9.11	167.7
9/10/96	9 24	119.47	7316.20	70.30	8.89	171.4
9/11/96	9 27	143.52	7315.20	69.30	8.31	185.9
9/12/96	9 23	167.45	7315.40	69.50	8.07	178.5
9/13/96	9 47	191.85	7314.50	68.60	7.75	206
9/16/96	9 31	263.58	7313.80	67.90	7.77	234
9/17/96	9 38	287.70	7314.00	68.10	7.85	162.4
9/18/96	9 0	311.07	7314.50	68.60	7.82	175.3

SOIL WATER RETENTION TEST OF DRAINABLE BASES

Specimen Number : 1 STARTING DATE 8/20/96

File Name : 4C.XLS

Soil Identification : Childress 7% Cement @ Water .475

Soil description : Soil Water Retention

Cylinder Number : 4C

UNIT WEIGHT DETERMINATIONS:

Avg. Dia.=(15.02 15.09 15.05) / 3 = 15.05 cm.

Avg Ht. = (14.96 14.94 15.01) / 3 = 14.97 cm.

Area of Specimen = 177.97 cm^2 Vol. of Specimen = 2664.3 cm^3

Wt. of Cylinder + Wt. of Base + Wt. of Ceramic Plate= 1816.20 gm.

Total Wt. (without the Cap)= 6702.6 gm.

Total Wt. (with the Cap) = 7396.4 gm. Water-Cement Ratio 0.45

Dry Wt. of Soil Specimen = 4886.40 gm. Total Wt. (Sat.)= 8562.7 gm.

Wt. of Water in Sat. Specimen= 1166.30 gm.

Initial pH of Water= 10.37 Initial Conductivity of Water= 941

DATE	HRS: MIN	Tot.Time (hrs)	Total Wt. (gm.)	Wt. of Water (gm.)	pH of Water	Conductivity of Water (Micro Siemmens)
8/26/96	9 41	0.00	8562.70	1166.30	10.37	941
8/27/96	9 33	23.87	7497.30	100.90	10.85	2430
8/28/96	9 46	48.08	7495.80	99.40	10.39	1312
8/29/96	9 52	72.18	7493.90	97.50	9.86	688
8/30/96	9 51	96.17	7493.20	96.80	9.45	537
9/3/96	9 30	191.82	7492.80	96.40	8.59	535
9/4/96	9 25	215.73	7492.60	96.20	8.55	554
9/5/96	10 55	241.23	7492.40	96.00	8.45	411
9/6/96	9 1	263.33	7493.10	96.70	8.45	439
9/9/96	9 34	335.88	7492.50	96.10	8.39	454
9/10/96	9 25	359.73	7493.00	96.60	8.36	472

APPENDIX J

PERMEABILITY TEST RESULTS OF CEMENT-STABILIZED BASE MATERIALS

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 1 **DATE OF TEST : 2/16/96**
File Name : 5A.XLS
Soil Identification : San Antonio 5% Cement @ Water .45
Soil description :
Cylinder Number : 5A

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (14.30 14.60 14.50) / 3 = 14.47 cm
Avg Ht. specimen (h) = (31.30 31.40 31.30) / 3 = 31.33 cm
Area (A) = 164.372 cm^2
Mass of soil = 9797.54 gm
Distance between the two manometers (L)= 31.33 cm
Percentage of Water = .45 pH of inflow water =
Condutivity of inflow water = Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q ,(ml).	Discharge Time t (sec.)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k = q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	0.130	473	16.60	0.17335	0.004	41.782		
2	0.130	459	16.30	0.17132	0.004	41.292		
3	0.130	475	15.52	0.18620	0.004	44.878		
4	0.130	490	16.05	0.18574	0.004	44.767		
5	0.180	490	14.91	0.19994	0.006	34.804		
6	0.180	475	14.43	0.20026	0.006	34.861		
7	0.210	485	14.07	0.20971	0.007	31.290		
8	0.200	490	14.20	0.20993	0.006	32.890		
9	0.18	490	13.60	0.21919	0.006	38.156		
10	0.180	483	13.38	0.21962	0.006	38.229		
11	0.230	480	12.79	0.22832	0.007	31.104		
12	0.220	503	13.41	0.22820	0.007	32.501		
13	0.190	440	10.91	0.24536	0.006	40.463		
14	0.190	461	11.58	0.24220	0.006	39.941		
15	0.210	457	11.11	0.25025	0.007	37.339		
16	0.210	449	10.79	0.25316	0.007	37.773		
17	0.120	457	16.05	0.17323	0.004	45.231		
18	0.120	477	15.74	0.18437	0.004	48.141		
19	0.170	485	14.82	0.19910	0.005	36.696		
20	0.180	495	14.43	0.20869	0.006	36.328		
21	0.220	490	13.73	0.21712	0.007	30.923		
22	0.140	490	13.06	0.22826	0.004	51.086		
23	0.190	495	12.42	0.24247	0.006	39.986		
24	0.220	475	11.57	0.24977	0.007	35.573		

SAN ANTONIO 5% CEMENT @ WATER .45

Test No.	Manometer Head Loss h (cm)	Total Discharge Q ,(ml).	Discharge Time t (sec.)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k = q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
25	0.210	465	10.82	0.26146	0.007	39.011		
26	0.250	436	10.32	0.25703	0.008	32.214		
27	0.220	443	10.71	0.25164	0.007	35.840		
28	0.170	460	11.68	0.23960	0.005	44.162		
29	0.200	485	13.51	0.21840	0.006	34.217		
30	0.160	476	17.00	0.17035	0.005	33.359		
31	0.160	474	16.78	0.17185	0.005	33.655		
32	0.180	486	16.28	0.18162	0.006	31.615		
33	0.180	483	16.03	0.18331	0.006	31.910		
34	0.200	490	15.22	0.19586	0.006	30.685		
35	0.190	473	14.72	0.19549	0.006	32.239		
36	0.190	481	14.03	0.20857	0.006	34.396		
37	0.210	478	13.92	0.20891	0.007	31.171		
38	0.220	483	13.44	0.21864	0.007	31.139		
39	0.2	480	13.47	0.21679	0.006	33.964		
40	0.22	487	12.90	0.22967	0.007	32.711		
41	0.2	499	13.38	0.22689	0.006	35.546		
42	0.19	470	11.78	0.24273	0.006	40.029		
43	0.2	473	12.25	0.23491	0.006	36.802		

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 1 **DATE OF TEST :**
File Name : 7A.XLS
Soil Identification : Brownwood 5% Cement @ Water .475
Soil description :
Cylinder Number : 7A

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (14.70 14.50 14.50) / 3 = 14.57 cm
Avg Ht. specimen (h) = (30.80 30.90 30.80) / 3 = 30.83 cm
Area (A) = 166.652 cm^2
Mass of soil = 9797.54 gm
Distance between the two manometers (L)= 30.83 cm
Percentage of Water = .45 pH of inflow water =
Condutivity of inflow water = Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q ,(ml).	Discharge Time t (sec.)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k = q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	0.150	500	17.53	0.17115	0.005	35.181		
2	0.150	488	16.93	0.17296	0.005	35.553		
3	0.130	488	15.98	0.18325	0.004	43.462		
4	0.140	489	15.92	0.18431	0.005	40.593		
5	0.170	494	15.38	0.19273	0.006	34.957		
6	0.170	480	14.76	0.19514	0.006	35.393		
7	0.150	470	13.91	0.20275	0.005	41.676		
8	0.180	477	13.90	0.20592	0.006	35.273		
9	0.18	468	12.88	0.21803	0.006	37.348		
10	0.170	475	13.28	0.21463	0.006	38.928		
11	0.200	469	12.42	0.22659	0.006	34.933		
12	0.200	469	12.40	0.22696	0.006	34.989		
13	0.200	481	12.19	0.23677	0.006	36.502		
14	0.310	473	11.89	0.23871	0.010	23.743		
15	0.230	472	11.57	0.24479	0.007	32.816		
16	0.250	470	11.57	0.24376	0.008	30.063		
17	0.210	475	11.19	0.25471	0.007	37.399		
18	0.180	480	11.32	0.25444	0.006	43.585		
19	0.130	485	17.19	0.16930	0.004	40.154		
20	0.140	480	16.88	0.17063	0.005	37.579		
21	0.150	475	15.63	0.18236	0.005	37.485		
22	0.150	485	15.97	0.18223	0.005	37.459		
23	0.150	479	14.76	0.19473	0.005	40.028		
24	0.170	485	15.12	0.19248	0.006	34.910		

BROWNWOOD 5% CEMENT @ WATER .475

Test No.	Manometer Head Loss h (cm)	Total Discharge Q ,(ml).	Discharge Time t (sec.)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k = q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
25	0.180	486	14.20	0.20537	0.006	35.179		
26	0.160	480	14.11	0.20413	0.005	39.337		
27	0.190	485	13.51	0.21542	0.006	34.958		
28	0.210	487	13.39	0.21824	0.007	32.043		
29	0.200	481	12.87	0.22426	0.006	34.574		
30	0.180	479	12.74	0.22561	0.006	38.646		
33	0.210	476	11.98	0.23842	0.007	35.006		
34	0.200	477	12.08	0.23694	0.006	36.528		
35	0.200	480	11.68	0.24660	0.006	38.017		
36	0.210	483	12.21	0.23737	0.007	34.852		
37	0.250	474	11.03	0.25787	0.008	31.803		
38	0.250	480	11.31	0.25466	0.008	31.409		
39	0.130	480	16.97	0.16973	0.004	40.256		
40	0.130	488	16.99	0.17235	0.004	40.878		
41	0.180	477	15.71	0.18219	0.006	31.209		
42	0.15	485	16.01	0.18178	0.005	37.365		
43	0.16	490	15.09	0.19485	0.005	37.549		
45	0.18	483	15.01	0.19309	0.006	33.075		
46	0.19	480	13.85	0.20796	0.006	33.748		
47	0.15	484	14.01	0.20730	0.005	42.611		
48	0.15	482	13.51	0.21408	0.005	44.006		
49	0.15	455	12.51	0.21824	0.005	44.861		
50	0.1	477	12.77	0.22414	0.003	69.109		
51	0.13	482	12.89	0.22438	0.004	53.218		
52	0.15	483	12.29	0.23582	0.005	48.475		
53	0.22	475	12.12	0.23517	0.007	32.959		
54	0.2	487	12.03	0.24291	0.006	37.449		
55	0.21	491	12.03	0.24491	0.007	35.959		
56	0.23	471	11.10	0.25462	0.007	34.133		
57	0.21	465	10.89	0.25622	0.007	37.620		

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 1 **DATE OF TEST : 2/16/96**
File Name : 6A.XLS
Soil Identification : Brownwood 7% Cement @ Water .45
Soil description :
Cylinder Number : 6A

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (14.70 14.50 14.50) / 3 = 14.57 cm
Avg Ht. specimen (h) = (30.80 30.90 30.80) / 3 = 30.83 cm
Area (A) = 166.652 cm^2
Mass of soil = 9797.54 gm
Distance between the two manometers (L)= 30.83 cm
Target moisture content = 5% pH of inflow water =
Condutivity of inflow water = Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q ,(ml).	Discharge Time t (sec.)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k = q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	0.150	481	17	0.17324	0.005	35.611		
2	0.140	475	17	0.17181	0.005	37.838		
3	0.160	464	15	0.18366	0.005	35.392		
4	0.160	473	15	0.18394	0.005	35.447		
5	0.260	461	14	0.19453	0.008	23.070		
6	0.250	459	14	0.19715	0.008	24.316		
7	0.160	474	14	0.20822	0.005	40.125		
8	0.160	473	14	0.20597	0.005	39.692		
9	0.2	470	13	0.21913	0.006	33.783		
10	0.190	468	13	0.21769	0.006	35.327		
11	0.150	474	12	0.23467	0.005	48.239		
12	0.180	478	12	0.23131	0.006	39.623		
13	0.200	463	13	0.21962	0.006	33.859		
14	0.180	475	13	0.22027	0.006	37.731		
15	0.100	473	16	0.17370	0.003	53.557		
16	0.130	475	17	0.17170	0.004	40.724		
17	0.150	466	15	0.18567	0.005	38.166		
18	0.130	463	15	0.18411	0.004	43.668		
19	0.170	458	14	0.19547	0.006	35.452		
20	0.170	465	14	0.19581	0.006	35.514		
21	0.290	459	13	0.20740	0.009	22.051		
22	0.220	467	14	0.20757	0.007	29.092		
23	0.180	463	13	0.21470	0.006	36.778		
24	0.150	449	13	0.21400	0.005	43.989		

BROWNWOOD 7% CEMENT @ WATER .45

Test No.	Manometer Head Loss h (cm)	Total Discharge Q ,(ml).	Discharge Time t (sec.)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k = q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
25	0.250	435	12	0.22348	0.008	27.562	7.43	821
26	0.230	455	12	0.22943	0.007	30.757	7.43	821
27	0.198	457	16	0.17411	0.006	27.113	7.43	821
28	0.184	458	15	0.18322	0.006	30.702	7.43	821
29	0.200	475	15	0.19603	0.006	30.221	7.43	821
30	0.310	463	13	0.20702	0.010	20.591	7.43	821
31	0.280	464	13	0.21889	0.009	24.104	7.43	821
32	0.230	445	12	0.22345	0.007	29.955	7.43	821
33	0.280	463	12	0.23786	0.009	26.193	7.43	821
34	0.280	450	11	0.24437	0.009	26.909	7.43	821
35	0.270	453	11	0.25523	0.009	29.147	7.43	821
36	0.240	453	11	0.25692	0.008	33.007	7.43	821
37	0.270	446	11	0.24553	0.009	28.039	7.43	821
38	0.190	459	12	0.23500	0.006	38.137	7.43	821
39	0.170	450	12	0.22825	0.006	41.399	7.43	821
40	0.19	465	13	0.21580	0.006	35.020	7.43	821
41	0.28	460	13	0.20661	0.009	22.751	7.43	821
42	0.21	473	14	0.20854	0.007	30.619	7.43	821
43	0.21	475	13	0.21774	0.007	31.970	7.43	821
44	0.2	475	13	0.21908	0.006	33.775	7.43	821
45	0.2	475	13	0.22585	0.006	34.819	7.43	821
46	0.2	475	13	0.22675	0.006	34.957	7.43	821
47	0.21	478	12	0.24002	0.007	35.241	7.43	821
48	0.17	464	12	0.23817	0.006	43.198	7.43	821
49	0.25	480	12	0.25046	0.008	30.890	7.43	821
50	0.23	455	11	0.24866	0.007	33.334	7.43	821
51	0.24	460	11	0.25605	0.008	32.896	8.43	821
52	0.23	451	10	0.25798	0.007	34.585	9.43	821

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 1 **DATE OF TEST :** 2/16/96
File Name : 8A.XLS
Soil Identification : Brownwood 7% Cement @ Water .475
Soil description :
Cylinder Number : 8A

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (14.60 14.70 14.70) / 3 = 14.67 cm
Avg Ht. specimen (h) = (29.50 29.30 29.80) / 3 = 29.53 cm
Area (A) = 168.948 cm^2
Mass of soil = 9797.54 gm
Distance between the two manometers (L)= 29.53 cm
Target moisture content = 5% pH of inflow water = 8.30
Condutivity of inflow water = 785 Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q ,(ml).	Discharge Time t (sec.)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k = q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	0.200	459	15.97	0.17012	0.007	25.121	5.33	1721
2	0.180	456	16.03	0.16838	0.006	27.626	5.94	1627
3	0.250	460	14.88	0.18298	0.008	21.616	6.48	1429
4	0.240	455	14.75	0.18259	0.008	22.468	6.59	1269
5	0.250	457	13.97	0.19363	0.008	22.874	6.61	1197
6	0.250	478	14.56	0.19432	0.008	22.955	6.73	1128
7	0.240	404	11.69	0.20456	0.008	25.172	6.81	1071
8	0.240	462	13.34	0.20499	0.008	25.225	6.89	1025
9	0.25	420	11.55	0.21524	0.008	25.427	7.07	935
10	0.210	440	12.16	0.21417	0.007	30.120	7.04	968
11	0.300	460	12.12	0.22465	0.010	22.115	7.21	906
12	0.250	452	11.90	0.22482	0.008	26.559	7.21	904
13	0.250	435	10.85	0.23730	0.008	28.034	7.25	877
14	0.240	473	12.06	0.23215	0.008	28.567	7.27	863
15	0.210	475	11.57	0.24300	0.007	34.174	7.32	847
16	0.260	465	11.40	0.24143	0.009	27.424	7.36	852
17	0.170	475	16.81	0.16725	0.006	29.056	7.38	830
18	0.170	465	15.25	0.18048	0.006	31.354	7.43	835
19	0.200	470	14.34	0.19400	0.007	28.647	7.44	828
20	0.200	470	13.62	0.20425	0.007	30.161	7.43	822
21	0.190	475	13.25	0.21219	0.006	32.983	7.43	821
22	0.120	475	12.59	0.22331	0.004	54.960		
23	0.210	474	12.06	0.23264	0.007	32.717		
24	0.220	458	11.19	0.24226	0.007	32.522		

BROWNWOOD 7% CEMENT @ WATER .475

Test No.	Manometer Head Loss h (cm)	Total Discharge Q ,(ml).	Discharge Time t (sec.)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k = q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
25	0.190	458	10.75	0.25218	0.006	39.198		
26	0.210	480	11.22	0.25322	0.007	35.611		
27	0.210	485	10.82	0.26531	0.007	37.313		
28	0.290	476	12.03	0.23420	0.010	23.851		
29	0.190	475	12.60	0.22314	0.006	34.684		
30	0.170	471	13.06	0.21346	0.006	37.084		
31	0.180	460	13.34	0.20410	0.006	33.488		
32	0.180	430	13.09	0.19444	0.006	31.902		
33	0.190	489	15.94	0.18158	0.006	28.225		
34	0.170	457	15.82	0.17098	0.006	29.704		
35	0.120	447	15.78	0.16767	0.004	41.265		
36	0.120	463	16.12	0.17001	0.004	41.840		
37	0.140	468	15.84	0.17488	0.005	36.891		
38	0.140	470	14.63	0.19015	0.005	40.113		
39	0.150	455	13.88	0.19403	0.005	38.202		
40	0.15	484	13.81	0.20744	0.005	40.843		
41	0.21	480	13.53	0.20999	0.007	29.531		
42	0.21	473	13.61	0.20571	0.007	28.930		
43	0.21	475	13.09	0.21478	0.007	30.206		
44	0.2	475	13.01	0.21610	0.007	31.911		
45	0.2	475	12.62	0.22278	0.007	32.898		
46	0.2	475	12.57	0.22367	0.007	33.028		
47	0.21	478	11.95	0.23676	0.007	33.297		
48	0.17	464	11.69	0.23494	0.006	40.814		
49	0.25	480	11.50	0.24705	0.008	29.185		
50	0.23	455	10.98	0.24528	0.008	31.495		
51	0.24	460.00	10.78	0.25257	0.008	31.080		
52	0.23	451.00	10.49	0.25448	0.008	32.676		

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 1 **DATE OF TEST :**

File Name : 5C.XLS

Soil Identification : Childress 5% Cement @ Water .45

Soil description :

Cylinder Number : 5C

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (14.70 14.50 14.70) / 3 = 14.63 cm

Avg Ht. specimen (h) = (29.50 29.60 29.80) / 3 = 29.63 cm

Area (A) = 168.181 cm^2

Mass of soil = 9797.54 gm

Distance between the two manometers (L)= 29.63 cm

Percentage of Water = .45 pH of inflow water =

Condutivity of inflow water = Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q ,(ml).	Discharge Time t (sec.)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k = q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	0.140	480	16.75	0.17039	0.005	36.066		
2	0.130	474	16.25	0.17344	0.004	39.535		
3	0.150	480	15.53	0.18378	0.005	36.306		
4	0.150	480	15.59	0.18307	0.005	36.167		
5	0.200	468	14.31	0.19446	0.007	28.812		
6	0.190	470	14.12	0.19792	0.006	30.868		
7	0.570	446	12.83	0.20670	0.019	10.746		
8	0.600	490	14.05	0.20737	0.020	10.242		
9	0.2	468	12.78	0.21774	0.007	32.262		
10	0.200	493	13.45	0.21795	0.007	32.292		
11	0.200	468	12.20	0.22809	0.007	33.796		
12	0.200	475	12.49	0.22613	0.007	33.505		
13	0.150	478	16.72	0.16999	0.005	33.582		
14	0.150	479	16.57	0.17188	0.005	33.957		
15	0.200	463	15.09	0.18244	0.007	27.031		
16	0.200	475	15.48	0.18245	0.007	27.033		
17	0.230	478	14.68	0.19361	0.008	24.945		
18	0.200	475	14.45	0.19546	0.007	28.960		
19	0.270	467	13.45	0.20645	0.009	22.659		
20	0.190	474	13.82	0.20394	0.006	31.807		
21	0.250	473	13.03	0.21584	0.008	25.585		
22	0.230	470	12.86	0.21731	0.008	27.998		
23	0.150	473	12.26	0.22940	0.005	45.319		
24	0.200	485	12.88	0.22390	0.007	33.174		

CHILDRESS 5% @ WATER .45

Test No.	Manometer Head Loss h (cm)	Total Discharge Q ,(ml).	Discharge Time t (sec.)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k = q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
25	0.240	477	12.03	0.23576	0.008	29.110		
26	0.230	465	11.70	0.23631	0.008	30.447		
27	0.200	455	11.01	0.24572	0.007	36.408		
28	0.220	470	11.44	0.24428	0.007	32.904		
29	0.230	470	11.04	0.25314	0.008	32.614		
30	0.220	460	10.69	0.25586	0.007	34.464		
33	0.150	474	16.39	0.17196	0.005	33.971		
34	0.150	472	16.37	0.17144	0.005	33.869		
35	0.160	495	16.16	0.18213	0.005	33.732		
36	0.140	483	15.69	0.18304	0.005	38.744		
37	0.100	484	14.81	0.19432	0.003	57.583		
38	0.180	471	14.48	0.19341	0.006	31.841		
39	0.180	470	13.57	0.20594	0.006	33.904		
40	0.150	474	13.51	0.20862	0.005	41.213		
41	0.150	470	12.91	0.21647	0.005	42.765		
42	0.17	474	13.18	0.21384	0.006	37.275		
43	0.2	473	12.51	0.22482	0.007	33.310		
45	0.21	474	12.47	0.22601	0.007	31.893		
46	0.21	490	12.22	0.23842	0.007	33.644		
47	0.15	484	12.11	0.23764	0.005	46.948		
48	0.2	480	11.48	0.24861	0.007	36.836		
49	0.2	471	11.36	0.24653	0.007	36.527		
50	0.16	473	10.94	0.25708	0.005	47.613		
51	0.2	455	10.76	0.25143	0.007	37.254		
52	0.21	471	11.75	0.23835	0.007	33.633		
53	0.16	470	11.42	0.24471	0.005	45.323		
54								
55								
55								
55								

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 1 **DATE OF TEST : 2/16/96**
File Name : 7C.XLS
Soil Identification : Childress 5% Cement @ Water .475
Soil description :
Cylinder Number : 7C

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (14.75 14.80 14.60) / 3 = 14.72 cm
Avg Ht. specimen (h) = (30.60 30.70 30.60) / 3 = 30.63 cm
Area (A) = 170.102 cm^2
Mass of soil = 9797.54 gm
Distance between the two manometers (L)= 30.63 cm
Target moisture content = 5% pH of inflow water =
Condutivity of inflow water = Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q ,(ml).	Discharge Time t (sec.)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k = q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	0.110	484	17.01	0.16728	0.004	46.584		
2	0.120	483	16.86	0.16842	0.004	42.993		
3	0.120	490	15.98	0.18026	0.004	46.018		
4	0.110	471	15.41	0.17968	0.004	50.039		
5	0.180	484	14.84	0.19174	0.006	32.631		
6	0.170	490	15.03	0.19166	0.006	34.536		
7	0.180	500	14.53	0.20230	0.006	34.428		
8	0.180	499	14.39	0.20386	0.006	34.694		
9	0.23	489	13.54	0.21232	0.008	28.278		
10	0.290	489	13.55	0.21216	0.009	22.411		
11	0.190	486	12.85	0.22234	0.006	35.848		
12	0.190	490	12.96	0.22227	0.006	35.836		
13	0.200	482	12.01	0.23594	0.007	36.138		
14	0.220	488	12.22	0.23477	0.007	32.690		
15	0.200	504	12.20	0.24286	0.007	37.199		
16	0.190	469	11.27	0.24465	0.006	39.444		
17	0.190	447	10.47	0.25099	0.006	40.466		
18	0.210	470	10.83	0.25513	0.007	37.217		
19	0.130	483	16.86	0.16842	0.004	39.685		
20	0.120	484	16.88	0.16856	0.004	43.031		
21	0.120	485	15.84	0.18000	0.004	45.951		
22	0.140	480	15.64	0.18042	0.005	39.479		
23	0.150	465	14.13	0.19346	0.005	39.510		
24	0.150	474	14.53	0.19178	0.005	39.166		

CHILDRESS 5% @ Water .475

Test No.	Manometer Head Loss h (cm)	Total Discharge Q ,(ml).	Discharge Time t (sec.)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k = q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
25	0.180	470	13.70	0.20168	0.006	34.323	7.43	821
26	0.180	506	14.42	0.20629	0.006	35.107	7.43	821
27	0.220	477	12.97	0.21621	0.007	30.105	7.43	821
28	0.180	473	12.89	0.21572	0.006	36.713	7.43	821
29	0.190	480	12.64	0.22325	0.006	35.994	7.43	821
30	0.180	483	12.80	0.22183	0.006	37.753	7.43	821
31	0.180	470	11.99	0.23045	0.006	39.219	7.43	821
32	0.210	465	11.70	0.23365	0.007	34.083	7.43	821
33	0.220	488	12.05	0.23808	0.007	33.151	7.43	821
34	0.280	495	11.99	0.24270	0.009	26.553	7.43	821
35	0.140	483	16.90	0.16802	0.005	36.764	7.43	821
36	0.150	484	16.90	0.16836	0.005	34.384	7.43	821
37	0.180	484	15.87	0.17929	0.006	30.513	7.43	821
38	0.200	473	15.52	0.17917	0.007	27.443	7.43	821
39	0.180	488	14.99	0.19139	0.006	32.571	7.43	821
40	0.18	485	15.02	0.18983	0.006	32.306	7.43	821
41	0.2	482	13.82	0.20504	0.007	31.405	7.43	821
42	0.18	490	14.23	0.20243	0.006	34.451	7.43	821
43	0.27	480	13.32	0.21185	0.009	24.036	7.43	821
44	0.21	495	13.79	0.21102	0.007	30.783	7.43	821
45	0.27	480	13.02	0.21673	0.009	24.590	7.43	821
46	0.26	484	12.87	0.22108	0.008	26.048	7.43	821
47	0.19	488	12.47	0.23006	0.006	37.092	7.43	821
48	0.18	467	11.88	0.23110	0.006	39.329	7.43	821
49	0.21	471	11.75	0.23565	0.007	34.376	7.43	821
50	0.16	470	11.42	0.24195	0.005	46.323	7.43	821
51								
52								

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 1 **DATE OF TEST : 2/16/96**
File Name : 6C.XLS
Soil Identification : Childress 7% Cement @ Water .45
Soil description :
Cylinder Number : 6C

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (14.50 14.90 14.70) / 3 = 14.70 cm
Avg Ht. specimen (h) = (31.00 30.80 30.40) / 3 = 30.73 cm
Area (A) = 169.717 cm^2
Mass of soil = 9797.54 gm
Distance between the two manometers (L)= 30.73 cm
Target moisture content = 5% pH of inflow water =
Condutivity of inflow water = Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q ,(ml).	Discharge Time t (sec.)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k = q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	0.140	472	16.53	0.16825	0.005	36.934		
2	0.130	480	16.75	0.16885	0.004	39.918		
3	0.140	479	15.72	0.17954	0.005	39.413		
4	0.130	465	15.46	0.17722	0.004	41.897		
5	0.150	474	14.82	0.18845	0.005	38.612		
6	0.150	470	14.63	0.18929	0.005	38.784		
7	0.180	470	13.88	0.19952	0.006	34.066		
8	0.180	473	13.79	0.20210	0.006	34.507		
9	0.22	480	13.69	0.20659	0.007	28.860		
10	0.210	465	13.00	0.21076	0.007	30.844		
11	0.250	468	12.25	0.22511	0.008	27.673		
12	0.260	470	12.47	0.22208	0.008	26.251		
13	0.210	456	11.47	0.23425	0.007	34.282		
14	0.230	471	11.85	0.23420	0.007	31.294		
15	0.220	466	11.40	0.24086	0.007	33.647		
16	0.200	472	11.50	0.24184	0.007	37.162		
17	0.170	479	17.02	0.16583	0.006	29.979		
18	0.170	468	16.36	0.16855	0.006	30.472		
19	0.200	471	15.48	0.17928	0.007	27.549		
20	0.200	482	15.89	0.17873	0.007	27.465		
21	0.200	471	14.63	0.18969	0.007	29.150		
22	0.220	474	14.71	0.18986	0.007	26.523		
23	0.210	479	14.03	0.20117	0.007	29.440		
24	0.200	483	14.08	0.20212	0.007	31.060		

CHILDRESS 7% CEMENT @ WATER .45

Test No.	Manometer Head Loss h (cm)	Total Discharge Q ,(ml).	Discharge Time t (sec.)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k = q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
25	0.350	475	13.33	0.20996	0.011	18.437	7.43	821
26	0.200	473	13.23	0.21066	0.007	32.371	7.43	821
27	0.210	468	12.51	0.22043	0.007	32.259	7.43	821
28	0.200	480	12.81	0.22078	0.007	33.927	7.43	821
29	0.130	480	16.83	0.16805	0.004	39.728	7.43	821
30	0.150	479	16.97	0.16631	0.005	34.076	7.43	821
31	0.190	477	15.61	0.18005	0.006	29.124	7.43	821
32	0.190	478	15.83	0.17792	0.006	28.779	7.43	821
33	0.190	469	14.44	0.19137	0.006	30.955	7.43	821
34	0.210	470	14.55	0.19033	0.007	27.855	7.43	821
35	0.110	467	13.57	0.20277	0.004	56.654	7.43	821
36	0.230	496	14.38	0.20323	0.007	27.157	7.43	821
37	0.150	476	13.16	0.21312	0.005	43.666	7.43	821
38	0.200	479	13.35	0.21141	0.007	32.487	7.43	821
39	0.270	483	12.84	0.22164	0.009	25.229	7.43	821
40	0.24	480	12.83	0.22044	0.008	28.229	7.43	821
41	0.27	473	12.02	0.23186	0.009	26.392	7.43	821
42	0.27	480	12.17	0.23239	0.009	26.453	7.43	821
43	0.29	484	11.86	0.24046	0.009	25.483	7.43	821
44	0.29	471	11.45	0.24238	0.009	25.686	7.43	821
45	0.3	463	11.02	0.24756	0.010	25.361	7.43	821
46	0.3	470	11.08	0.24994	0.010	25.605	7.43	821

PERMEABILITY TEST ON GRANULAR SOIL

Specimen number : 1 DATE OF TEST : 2/16/96
File Name : 8C.XLS
Soil Identification : Childress 7% Cement @ Water .475
Soil description :
Cylinder Number : 8C

UNIT WEIGHT DETERMINATIONS:

Avg. Diameter (d) = (14.50 14.20 14.50) / 3 = 14.40 cm
Avg Ht. specimen (h) = (30.20 30.20 30.00) / 3 = 30.13 cm
Area (A) = 162.860 cm^2
Mass of soil = 9797.54 gm
Distance between the two manometers (L)= 30.13 cm
Target moisture content = .475% pH of inflow water =
Condutivity of inflow water = Micro Siemmens

PERMEABILITY TEST DATA (DEGREE OF COMPACTNESS)

Test No.	Manometer Head Loss h (cm)	Total Discharge Q ,(ml).	Discharge Time t (sec.)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k = q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
1	0.160	494	17.43	0.17403	0.005	32.775		
2	0.140	490	17.04	0.17657	0.005	38.004		
3	0.150	485	15.91	0.18718	0.005	37.602		
4	0.150	494	16.12	0.18817	0.005	37.801		
5	0.180	483	14.77	0.20079	0.006	33.614		
6	0.200	483	14.85	0.19971	0.007	30.090		
7	0.240	484	13.89	0.21396	0.008	26.864		
8	0.200	470	13.51	0.21361	0.007	32.184		
9	0.21	480	13.20	0.22328	0.007	32.039		
10	0.170	477	13.03	0.22478	0.006	39.843		
11	0.290	483	12.87	0.23044	0.010	23.944		
12	0.250	485	12.97	0.22961	0.008	27.675		
13	0.270	484	12.31	0.24142	0.009	26.944		
14	0.250	475	11.97	0.24366	0.008	29.369		
15	0.230	478	11.66	0.25172	0.008	32.979		
16	0.260	480	11.73	0.25126	0.009	29.121		
17	0.140	485	17.16	0.17354	0.005	37.353		
18	0.150	480	16.67	0.17680	0.005	35.518		
19	0.190	490	16.14	0.18641	0.006	29.565		
20	0.170	490	16.09	0.18699	0.006	33.145		
21	0.210	486	15.04	0.19841	0.007	28.471		
22	0.220	491	15.12	0.19940	0.007	27.311		
23	0.220	487	14.32	0.20882	0.007	28.602		
24	0.230	484	13.96	0.21289	0.008	27.891		

Childress 7% Cement @ Water .475

Test No.	Manometer Head Loss h (cm)	Total Discharge Q ,(ml).	Discharge Time t (sec.)	Flow rate q=Q/At (cm/sec)	Hydraulic Gradient i = h / L	Coeff. of permeability k = q / I (cm/sec)	pH of outflow	Conductivity of outflow (10^ -6)
25	0.210	484	13.29	0.22362	0.007	32.087		
26	0.260	488	13.78	0.21745	0.009	25.202		
27	0.240	470	12.51	0.23069	0.008	28.964		
28	0.280	478	12.66	0.23184	0.009	24.950		
29	0.290	471	12.09	0.23921	0.010	24.856		
30	0.280	484	12.88	0.23074	0.009	24.832		
31	0.390	484	11.88	0.25016	0.013	19.328		
32	0.310	480	11.80	0.24977	0.010	24.279		
33	0.320	480	11.32	0.26036	0.011	24.518		
34	0.320	478	11.24	0.26112	0.011	24.589		
35	0.230	480	16.88	0.17460	0.008	22.876		
36	0.180	488	17.06	0.17564	0.006	29.404		
37	0.240	487	15.94	0.18760	0.008	23.554		
38	0.220	485	15.93	0.18694	0.007	25.606		
39	0.250	484	15.01	0.19799	0.008	23.865		
40	0.21	476	14.77	0.19788	0.007	28.395		
41	0.25	485	13.82	0.21549	0.008	25.973		
42	0.28	485	14.19	0.20987	0.009	22.586		
43	0.25	485	13.55	0.21978	0.008	26.491		
44	0.3	479	13.33	0.22064	0.010	22.162		
45	0.3	475	12.63	0.23093	0.010	23.195		
46	0.3	480	12.91	0.22830	0.010	22.931		
47	0.28	471	12.04	0.24020	0.009	25.850		
48	0.24	470	12.10	0.23851	0.008	29.946		
49	0.3	490	12.17	0.24722	0.010	24.832		
50	0.34	485	11.69	0.25475	0.011	22.578		
51	0.35	474.00	11.25	0.25871	0.012	22.274		
52	0.35	490.00	11.61	0.25915	0.012	22.311		