3 o √

DEVELOPMENT OF THE MULTI-CHANNEL VARIABLE STRESS PERMEAMETER

by

TERRENCE EUGENE ARNOLD

B.S., Kansas State University, 1977

A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1978

Approved by:

Major Professor

ACKNOWLEDGMENTS

The author wishes to express his sincere gratitude and appreciation to each of the following individuals for their valuable help and assistance: To Dr. M. L. Hayden for his enthusiastic and unending guidance and assistance throughout this study. To Dr. J. J. Zovne for the encouragement and assistance he provided in the completion of this study. To his committee members, Dr. E. R. Russell and Dr. H. L. Manges, for their interest and encouragement. To his wife, Ruth Ann, for her encouragement and assistance throughout this study. To his parents for being the wonderful parents they are. To Peggy Selvidge for typing the report. To Judy Hayden for her help in the preparation of the graphical portions of this report. To Russ Gillespie and Jim Richardson for their assistance in the construction phase of this study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The interaction between soil and water and its subsequent effect on the structural integrity of earthen projects is of major importance to soil and foundation engineers. The recognition, evaluation, and control of both drainage and erosion is becoming more important to the engineer as increasingly rigid environmental constraints are placed on the design and construction of various water projects. In recent years, considerable effort has been made in quantifying the characteristics of flow through a soil media.

The evaluation of the coefficient of permeability of a soil is not new to the engineering profession. However, the need for more accurate permeability determinations is increasing faster than advancements are being made in the testing procedures. As the water supplies continue to dwindle in the western portion of the United States and various environmental controls on the infiltration from sewage lagoons and tailing ponds are tightened, more accurate evaluations of the permeability characteristics of a soil are an economic necessity.

The identification and evaluation of dispersive clay soils is a relatively new concept in engineering. Until recently the extent of slope failures and dam breaches caused by dispersive soils were not known. It is now believed that the identification of potentially dispersive soils is an essential design consideration on a world wide basis.

Purpose of Study

The purpose of this study was to evaluate and develop the capabilities of the Soil Mechanics Laboratory at Kansas State University to conduct advanced research in the measurements of permeability and dispersive characteristics of clay soils. A need was found to design and construct a new testing apparatus which would allow for the accurate evaluation of various key parameters. In addition to having the capabilities of conducting advanced research, the development of the testing apparatus was subjected to the following constraints: 1) utilize principles and techniques familiar to practicing engineers, 2) have the capacity for quantitative and qualitative measures of soil-water interactions, 3) be based on simple operating procedures requiring no special training, and 4) use practical construction techniques and materials which would be economically acceptable.

Scope of Study

A comprehensive review of the available literature relating to permeability and dispersive characteristics of clay soils was conducted during this study. Based upon the literature investigation and the criteria previously presented, the multi-channel variable stress permeameter was designed and constructed. Verification of the design and testing procedures developed during this study was made by conducting a limited testing program of several soils. The test results were analyzed to determine the applicability of the apparatus and procedures for use in future research studies. The development of several conclusions and recommendations for future equipment modifications completed this study.

CONCEPTS AND CURRENT PREDICTIVE METHODS

The purpose of this section is to provide a review of the basic concepts and theories used in evaluating both the permeability and dispersion potential of clay soils. This portion of the report is divided into two sections. The first section presents a critique of the methods currently used to estimate the permeability characteristics of various soils. Included in this section is a review and correlation of results expected from laboratory and field tests. The second section presents the theories and principles currently employed in evaluating the dispersive potential of clay soils. The newly developed physical tests, in addition to the chemical tests, are presented in this section.

Permeability

One of the most fundamental and important properties of either a natural or compacted soil is the hydraulic characteristic known as permeability. The permeability of a soil is its capacity to transmit water when subjected to a differential hydraulic head. Thus the concept of permeability enters into nearly all seepage, settlement and stability problems confronting the geotechnical engineer. Typical examples in which the permeability of a soil is of primary importance are: the flow of fluid through and under earthen embankments, the rate and extent of building settlement, and the liquefaction potential of various soils when subjected to dynamic loading.

The importance of accurately evaluating the permeability characteristics of a soil has long been recognized. Darcy (1), in the 1850's, pioneered this field when he experimentally found the interrelationship between flow velocity of a fluid through a porous media and the hydraulic gradient. This interrelationship, shown in Equation (1), is commonly referred to as Darcy's Law.

$$V = -K_o \frac{\gamma w}{\mu} \frac{dh}{ds} \tag{1}$$

where

V = seepage velocity

K_o = intrinsic permeability

γw = unit weight of fluid

μ = coefficient of viscosity

h = total head

s = distance of flow

Since that time Darcy's Law, in its modified form, as represented by Equation (2), has been used extensively to analyze the characteristics of fluid flow in soils under various conditions.

$$Q = K\ i\ A \tag{2}$$

where

Q = fluid flow rate

K = coefficient of permeability ($K_o \gamma w/\mu$)

i = hydraulic gradient ($-dh/ds$)

A = cross-sectional area

The modified form of Darcy's Law has also been used in conjunction with testing methods to analyze wells and aquifers. The most commonly used methods of analysis were developed by Thiem (2) and Theis (3) for equilibrium and non-equilibrium flow conditions. Their procedures, while based on several simplifying assumptions (i.e., soil properties, aquifer structure, flow characteristics, etc.), use permeability values determined from field testing. The field tests usually consist of pumping water from a well at a known rate, thus lowering the piezometric surface around the well and creating a cone of depression. By knowing the rate in which the depression cone forms, in addition to its ultimate shape, the hydraulic characteristics of the water bearing aquifer can be estimated. The hydraulic characteristics can then be used to evaluate the coefficient of permeability.

The use of infiltration tests provides another means of determining field permeability. By measuring the rate of decrease in elevation of the water level in an augered hole, or the volume of water required to maintain a constant elevation, the coefficient of permeability can be evaluated using the methods developed by Kirkham and van Bavel (4) and Schmid (5). The use of the infiltration test is suitable for soils both above and below the ground water table. Although the test can be used for any soil, best results are obtained when used on relatively low permeable soils. The primary advantages of this test, when compared to the pumping test, are the relatively low cost and speed with which the testing can be accomplished. The principal disadvantage is the accuracy of the results obtainable. Errors of several orders of magnitude are often encountered in the values determined for the coefficient of permeability, therefore infiltration tests should be used only where these errors are tolerable.

The disadvantage of the tests previously presented is that they fail to accurately describe the variability in permeability with depth. The variability may consist of local fluctuations in the permeability of a soil stratum caused by fissures or bedding planes. The most serious fluctuation from a design consideration is the presence of either a concentrated leak or a highly permeable strata. Kirkham (6) discusses the use of piezometers to identify and locate these problem areas. Piezometers equipped with transducers or risers can be used to determine the permeability of the soil at any point within the soil mass. The advantage of using piezometers is that the permeability of each stratum may be determined as the piezometer is advanced into the soil. However, the disadvantage is the relatively high cost of installation, and the soil disturbance which may occur as a result of drilling the pilot hole.

The flow of fluid through a partially saturated media does not directly follow the generalized theory developed by Darcy. This results from the fact that in nonsaturated soils the voids are only partially filled with water while the rest of the void is entrapped air. Since the air voids can block the movement of water, the permeability of a soil varies directly with the degree of saturation. Therefore, modifications of the basic concept postulated by Darcy have been proposed by Richards (7) for use when nonsaturated flow conditions are encountered.

Field permeability tests utilize a significantly larger sample and corresponding zone of influence than do laboratory tests, which necessarily require the testing of small representative samples. Since the results obtained from laboratory testing must be extrapolated to include the entire stratum, the estimates of the permeability characteristics in stratified soils are directly dependent on the quality of the field sampling program. The disadvantage of laboratory testing is that the exact duplication of the various boundary conditions which exist in the field cannot be accomplished. Although there are some disadvantages to laboratory testing, there are several advantages which are significant.

Laboratory testing facilitates a large number of tests to be conducted within normal project economic constraints. This advantage enhances the use of a testing program to evaluate alternate design considerations. It also reduces the testing time which would normally be required in the field. Thus, a multi-faceted testing program could be conducted in the laboratory using less time and money than a similar program conducted in the field. An example of the importance of laboratory testing is exhibited in the design of sewage lagoons. As environmental controls are increased, it becomes important for the engineer to have the flexibility to conduct the necessary testing without being hindered by excessive cost or time constraints.

Measurements of permeability in the laboratory are generally made using either a variable or constant hydraulic head test. The variable head permeability test is generally used in determining the permeability of saturated cohesionless soil. This is because of the relatively large coefficient of permeability exhibited by cohesionless soils and the degree of saturation of a nonsaturated soil which changes during the test. The coefficient of permeability can be determined using the procedures given in standard texts on Soil Mechanics (8).

The constant head permeability test, however, can be used on all types of soils, although the required instrumentation is more complicated than for the variable head test. The coefficient of permeability of a soil at various void ratios can be estimated using the modified form of Darcy's Law and physical properties of the test (i.e., hydraulic head, length and cross-sectional area).

The results of the tests are usually presented to illustrate the dependence of the coefficient of permeability on the void ratio of the soil. The permeability of a soil at a particular void ratio can then be interpolated from this relationship.

The results of a consolidation test can also be used to estimate the coefficient of permeability for a clayey soil. It has been theoretically shown that the rate at which water is forced out of a saturated sample during consolidation is directly dependent upon the permeability and loading conditions of the soil (9). The disadvantage of this method of analysis is that the coefficient is estimated using several simplifying assumptions rather than by direct measurement. It is generally believed that this method of determining the permeability characteristics of a particular soil is inferior to that using the laboratory tests which were described previously.

Dispersive Clays

Dispersive clay soils are predominantly fine grained soils, which because of a lack of net attractive electrochemical forces or bonds, are not aggregated or flocculated. The distinct physical features, which are often associated with these problem soils, are the presence of slick spots, gullies, tunnels and jugs. These features are a result of the characteristic erosion which develops from the interaction between rainfall runoff and this type of soil.

Tunnels and jugs in dispersive clays develop from the infiltration of surface water into drying or settlement cracks, thus removing any dispersed fines before the cracks can swell closed. The term 'jug' is used to indicate the vertical portion of the underground erosion tunnel which is formed when surface soils are less erodible than the subsurface material. The presence of dispersive clays along flat slopes are indicated when slick spots develop in the surface soils upon wetting and then forms a hard cracked crust upon drying. Recent investigations have shown that these soils cause engineering problems world wide.

The development of methods for identifying dispersive clay soils had its beginning in 1937. It was at this time that Volk (10) first correlated the dispersive characteristics of clay soils with the failure of several small earthen dams, dikes and road fills constructed in the southwestern portion of the United States. The observed failures were categorized into two types. The first type of failure occurred during initial wetting after construction, while the second type occurred as a result of the development of shrinkage and/or settlement cracks. Based on Volk's personal observations and study, two conditions were deemed necessary for the failure of a structure compacted from clay soils. These conditions were: 1) Either the existence of cracks or relatively large voids as a result of dessication and/or settlement of the embankment, and 2) the presence of sufficient clay sized material dispersive enough to allow enlargement of cracks or passages under a relatively small head once piping has begun.

Volk recognized the need for a method of determining the degree of dispersion, which could be related to by practicing engineers for engineering erosion control. The method he proposed was the first widely accepted procedure and with only minor modifications is still used by the Soil Conservation Service (SCS). The Laboratory Dispersion Test (LDT) currently used by the SCS determines the percent dispersion by conducting two hydrometer tests simultaneously. This test compares the particle size distribution obtained using a standard hydrometer test to a second hydrometer test conducted without the use of mechanical agitation or chemical dispersants. The difference in the distribution obtained from each method is a measure of the natural dispersion of the clay. The major disadvantage to this test is the results are not always reproducible. The reproducibility can be increased slightly by testing the samples at their natural moisture content.

A modification of the LDT to include testing the effect of the reservoir or river water on the flow through a soil crack was made by Coumoulus (11). It was observed that on some soils, percentages of material finer than 0.005 mm obtained using the double hydrometer test were higher than those obtained using the triple hydrometer test. This fact suggests that some soils may be more dispersive in ambient waters than if eroded by distilled water in the laboratory. It should be noted that 0.005 mm is defined as clay size material by the soil scientist in contrast to the engineering definition of 0.002 mm.

Studies of dispersive clay soils indicate that they are primarily composed of montmorillonitic and illitic clays which are sodium saturated. The percent sodium (degree of sodium saturation) in the pore water of a sample can be determined from an evaluation of the soluble salts in the pore water. Pore water evaluation has long been a standard test for the agricultural soil scientist, but is generally unfamiliar to civil engineers.

This test, as used by the U.S. Department of Agriculture (12), is briefly described as follows. A sample of soil is mixed with distilled water to a consistency near the Atterberg liquid limit, and a pore water sample (saturation extract) is forced through a filter by use of a vacuum. The saturation extract is then tested to determine the quantities of the four main cations in solution (calcium, magnesium, sodium and potassium). The percent sodium is determined by dividing the quantity of sodium in the extract by the Total Dissolved Salts (TDS). The TDS is defined as the total quantity of the four main cations previously mentioned.

Australian investigators, Aitchison, Ingles, et al. (13, 14) have postulated that the two main factors governing soil dispersion are: 1) the Exchangeable Sodium Percentage (ESP), and 2) the relationship between the TDS and Sodium Absorption Ratio (SAR) of the eroding media. The ESP of a soil is the concentration of sodium ions on the exchange complex divided by the Cation Exchange Capacity (CEC) of the soil. The second index, the SAR, is obtained by dividing the concentration of the sodium ions in the saturation extract by the square root of the average of concentrations of calcium and magnesium.

In the case of pure eroding water (TDS much less than 0.5 meq/ℓ), their criteria shows that all soils are dispersive if the pore water SAR exceeds one or two. It was also found that an ESP in excess of 10 to 15 would be sufficient to cause dispersion of the soil particles. Soils with an ESP value greater than 15 are believed to possess serious piping potential when leached with water having less than 15 meq/ℓ TDS, while soils with ESP values from 7 to 10 percent with relatively pure water percolating through it are thought to be moderately dispersive. Identification of dispersive clay soils by determining the soluble pore water salts is a reliable method, however it is expensive, time consuming, and the results are qualitative rather than quantitative in nature. Also, the use of soil chemistry tests as a basis for designs is unfamiliar to most practicing engineers.

Arulanandan, et al. (15, 16), attempted to relate the boundary between the flocculated and deflocculated states to the shear stresses required to initiate dispersion. The apparatus they used was a rotating cylinder similar to that described by Heinzen and Arulanandan (17). A cylindrical specimen of soil was mounted concentrically inside a transparent cylinder. An annular space between the specimen and the rotating cylinder was filled with the eroding media, generally distilled water. The rotation of the outer fluid imparted a shear stress to the soil surface thus causing some dispersion of the soil mass. The erosional loss was measured at different rpm's, while the cumulative losses were determined for each rpm. Both the erosional and cumulative losses were expressed as a function of time. These relationships were represented graphically as the erosion rate versus the applied shear stress. The zero intercept of the applied shear stress axis gives the value of the critical shear stress. A soil possessing a critical shear stress equal to zero is therefore considered potentially highly dispersive.

In 1967, Australian scientist W. W. Emerson (18) developed a field identification test for assessing the dispersive potential of clay soils. The test, termed the Crumb Test, consisted of placing a small soil clod at its natural water content into either a beaker of distilled water or a dilute sodium hydroxide solution. If the soil was dispersive, a cloud of colloidal clay developed around the clod. If the soil was not dispersive, no colloidal clay could be seen around the clod. Although this test is sometimes used, it provides only a qualitative indication of the relatively dispersive character of the soils and cannot be relied upon to give accurate results.

Sherard (19) attempted to quantify the Crumb Test results by developing a rating system for the visual interpretation of the results. The rating system he developed consisted of four grades with the following description:

Grade 1. No Reaction (Non-dispersive). Crumb may slake and run out on bottom of the beaker in a flat pile, but no sign of cloudy water caused by colloids in suspension.

Grade 2. Slight Reaction. Shows a hint of cloud in water at the surface of crumb (If the cloud is easily visible use Grade 3).

Grade 3. Moderate Reaction. Easily recognizable cloud of colloids in suspension, usually spreading out in thin streaks on bottom of beaker.

Grade 4. Strong Reaction (Highly dispersive). Colloidal cloud covers nearly whole bottom of beaker, usually in a thin layer. In extreme cases all the water in the beaker becomes cloudy.

However, even using this rating system the Crumb Test alone has not proved a reliable method of identifying most dispersive soils.

In an effort to improve on the Crumb Test, the SCS (20) in 1968 developed the Dilution-Turbidity Test (Turbidity Ratio). This test was basically a modification of the Laboratory Dispersion Test and was designed to measure the natural dispersibility of the soil fraction having an average grain size diameter of 0.005 mm or smaller. The dispersion potential is determined by comparing the turbidity of the fractional portion of the soil-water suspension created, with the turbidity of the soil-water suspension obtained from using naturally occurring soils. The comparison is made by diluting a sample of the artificially dispersed suspension until the turbidity is visually comparable to the turbidity of the untreated sample. Correlations made between this test and the LDT indicate that a dilution ratio of 4 or 5 is approximately equivalent to dispersion values of 35 to 40 percent. Dilution ratios of 1 or 2 indicate the presence of highly dispersive clays, while dilution ratios of 9 or greater indicate clay which is non-dispersive.

The pinhole test was developed by Sherard, et al. (21) to simulate in the laboratory the dispersive clay erosion which might occur as a result of water moving under a small hydraulic head.

The test procedure is based on the flow of distilled water through a small hole punched in a sample of clay. The dispersion classification of the soil sample is determined by the color of the effluent and the changes in flow rate under various heads at specified time intervals. Dispersive soils are classified as either D1 or D2 for samples that erode rapidly under a head of 2 in. Intermediate or transition soils, classified as ND4 and ND3, are identified by erosion which progresses slowly under a 2 in. or 7 in. head, while the classification of ND2 or ND1 is used to denote a non-dispersive soil which exhibits no significant erosion under either a 15 in. or 40 in. head.

A comparison of the results obtained from using the pinhole test to the sodium content of the pore water has provided further verification of the interrelationship between erodibility and sodium content. In a study conducted by Sherard, et al. (19), a criteria was proposed for the identification of dispersive clay soils based on the relationship of the percentage of sodium as a function of the TDS. This relationship is shown in Figure 1. An additional correlation presented in Figure 2 shows the results of the pinhole tests expressed as a function of percentage of pore water salts. In comparing these two Figures, it can be seen that the identification of dispersive soils by using the pinhole test differs from that used in Figure 1. The basic difference results from the fact that Figure 2 correlates the results of both the pinhole test and soil chemistry tests to potential dispersion while Figure 1 is based solely on the results of soil chemistry testing. It should be noted that both Figures were developed from empirical observations made by these

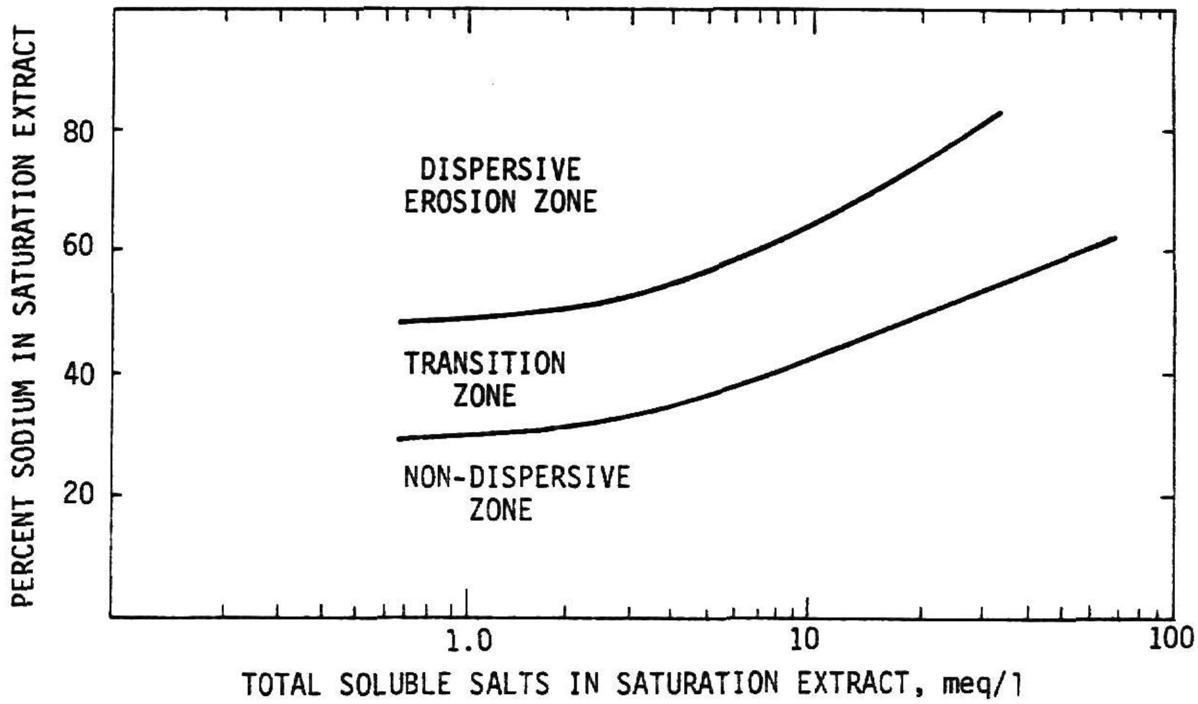

Figure 1. Relationship of Field Behavior and Solution Extract Chemical Properties. (After Sherard, et al. 1972)

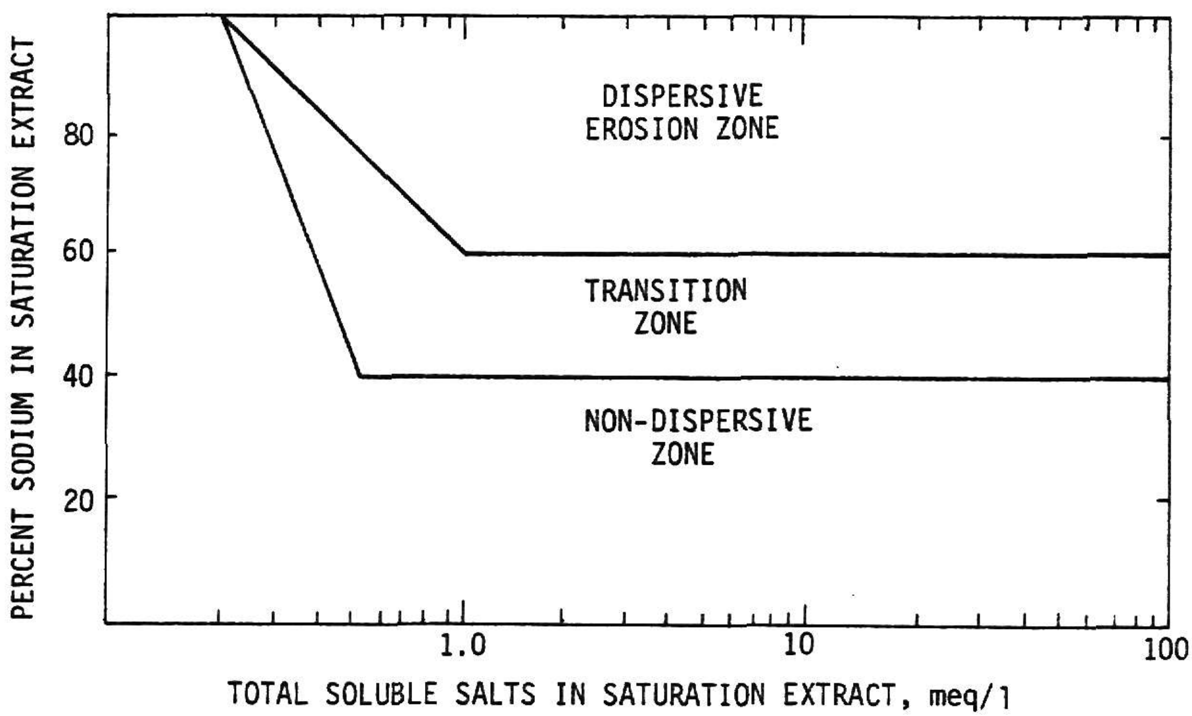

Figure 2. Correlation of Pinhole Test to Field Behavior as Determined by Solution Extract Chemical Properties. (After Sherard, et al. 1976)

researchers. It has been found, however, that a few high sodium soils, where the percent dispersion indicated by chemical analysis was above 50, were shown to be non-dispersive using the pinhole test.

The pinhole test is an empirical test based on the subjective evaluation of the occurrence of dispersion and is qualitative in nature. Results obtained from this test can only be used to indicate whether a soil is potentially dispersive or not. It does not quantify the degree of dispersion.

In 1974 Petry (22) developed a new testing procedure, termed the Physical Erosion Test (PET), to quantify the potential dispersion of clay soils. The purpose of the test was to simulate field conditions and accelerate the dispersion in a procedure that would be applicable to engineering practice. It was felt that this test would be especially appealing to engineers, because it provides both a quantitative and qualitative measure of dispersion while utilizing testing procedures familiar to most geotechnical engineers.

Field conditions were simulated by the intermittent flow of pressurized water through a compacted soil sample. The flow could be regulated by a system of reservoirs, regulators, timers and valves. A reduction in testing time was accomplished by drilling three longitudinal holes in the soil sample. The holes were 0.125 inch in diameter, thus allowing for either dispersion or swelling to occur.

A clear lucite test cell was used to contain the compacted soil sample, thus allowing the person conducting the test to make qualitative estimates of the erosion process. As the erosional process progresses, the soil slakes and disperses into a soil water suspension which is periodically removed by intermittent flushing. The percent dispersion is determined as a percentage of the dry soil remaining at completion to that at the start of the test, thus eliminating any subjective evaluation based on visual observations.

Flanagan and Holmgren (23) believed a more reliable field method of identifying dispersive clay soils using soil chemistry techniques was needed. They proposed new identification procedures for measuring the soluble salts in the pore water, using special equipment which could be transported to the field site. Their suggested method of determining TDS was based on the use of a Sodium Electrode, various Chemical Reagents and a Wheatstone Bridge. A detailed procedure of their suggested methods can be found in the cited reference. The results obtained from this method of testing appear to be reliable based on the regression analysis and atomic absorption data presented. The disadvantages are the unfamiliarity of this method of approach to most engineers and the relatively long testing time.

DESIGN AND CONSTRUCTION

The primary objective of this study was to evaluate and develop the capabilities of the soil mechanics laboratories at Kansas State University for conducting advanced studies on the permeability and erosional characteristics of clay soils. After a review of the laboratories, it was determined that additional testing equipment was needed. Therefore as part of this study, The Permeability-Physical Erosion Testing Apparatus (PPETA) was designed and built using available university facilities.

The material presented first in this section is the criteria used during the initial design phase of this study. Although the PPETA was designed principally for research, it was believed by this investigator that the design should be general enough to allow for a wide range of applications. The last portion of this section describes the techniques used in constructing the apparatus. Since standard construction practices were used, the major emphasis is on the equipment modifications which were necessary to utilize existing materials.

Design

Geotechnical engineers are often concerned with the evaluation of the inherent properties of a soil (i.e., strength, erosional and permeability characteristics, etc.). The determination of these properties is usually accomplished by testing a soil under carefully controlled conditions. Therefore, the PPETA was designed to maximize control of the testing process while minimizing equipment induced error. This design concept was achieved by using a system of reservoirs, regulators and valves which could be accurately controlled and monitored by precision test gauges.

The primary concept which had to be incorporated into the design was the ability to simulate permeability and erosional characteristics likely to occur in the field. Since it was not within the scope of this study to develop new testing procedures to simulate field conditions, the apparatus had to be designed to incorporate previously accepted standards for testing. Therefore, the procedures and equipment suggested by the American Society for Testing Materials (D-2434) in addition to the requirements for physical erosion testing formed the basis of the design.

The PPETA which was developed during this study is unique in that it allows either four tests to be conducted simultaneously at differently applied stress levels or four different soils to be tested simultaneously at the same stress level. This concept was devised to expedite the testing process in addition to increasing the versatility of the apparatus. To facilitate this design, four identical mutually independent channels are used. Each channel can be controlled and monitored either separately or in series with the other channels.

The apparatus was designed to be self-contained except for the outside attachments necessary to provide the air and power supply. There were four basic constraints which had to be incorporated into the overall design. These constraints were: 1) construction had to be principally achieved using available resources, 2) sufficient storage space had to be provided for the central water supply and wastewater containers, 3) ample room had to be included on the testing panel to allow for future expansion, and 4) the regulators, gauges, switches and shut-off valves had to be centralized on a control panel.

The design phase of this study also had to incorporate a generalized sequence of construction events. This was necessary to minimize construction time and provide a systematic method of approach. Figure 3 shows a generalized flow diagram used during the design and construction phase of this study. The prototype which was developed during this study is represented by the schematic diagrams presented in Figures 4 and 5.

Construction

This section presents a discussion of the construction techniques and various components used to implement the design criteria previously presented. Although the presentations of the design and construction phase have been separated in this report, they were, however, interdependent. Therefore, the purpose of this section is to provide the reader with sufficient background information to facilitate a more complete understanding of the concepts used in the design and development of the PPETA.

Flow System

The water flow system is the primary component of the apparatus. It is composed of a primary and secondary storage tank, piping and a channel splitting system. The flow system provides for a constant uniform supply of water to the test cells. A conceptual drawing of the flow system is shown in Figure 6.

As can be seen in this Figure, a central pressurized tank provides the water supply for the entire system. The tank which has a capacity of 25 gallons is sufficient to provide the quantity of water necessary to conduct either two separate sets of physical erosion tests or one long-term permeability test without refilling. Since refilling of the tank requires that it be disconnected and moved, it has been mounted on casters to facilitate transportation.

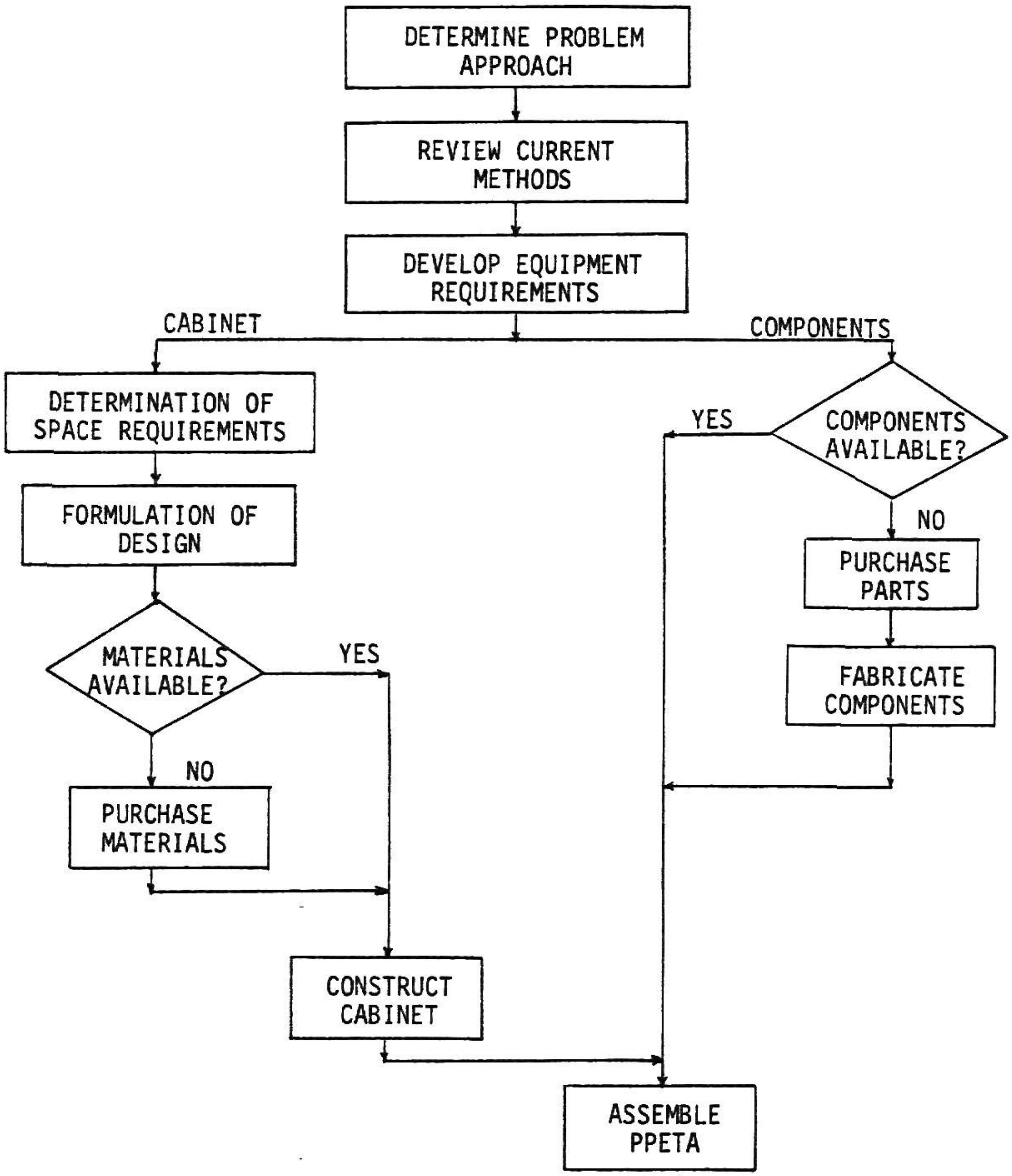

Figure 3. General Construction Sequence

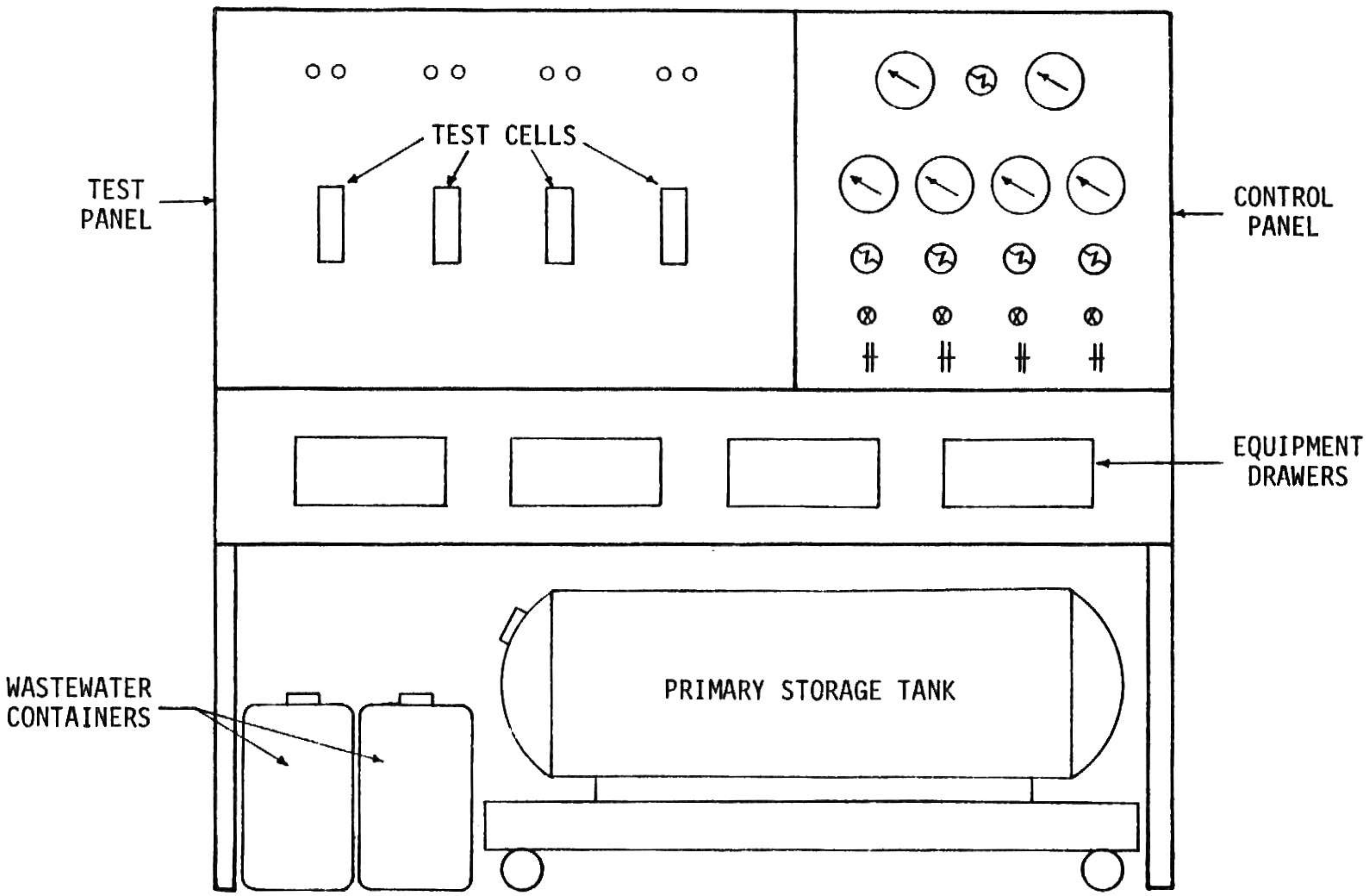

Figure 4. Front View of the PPETA.

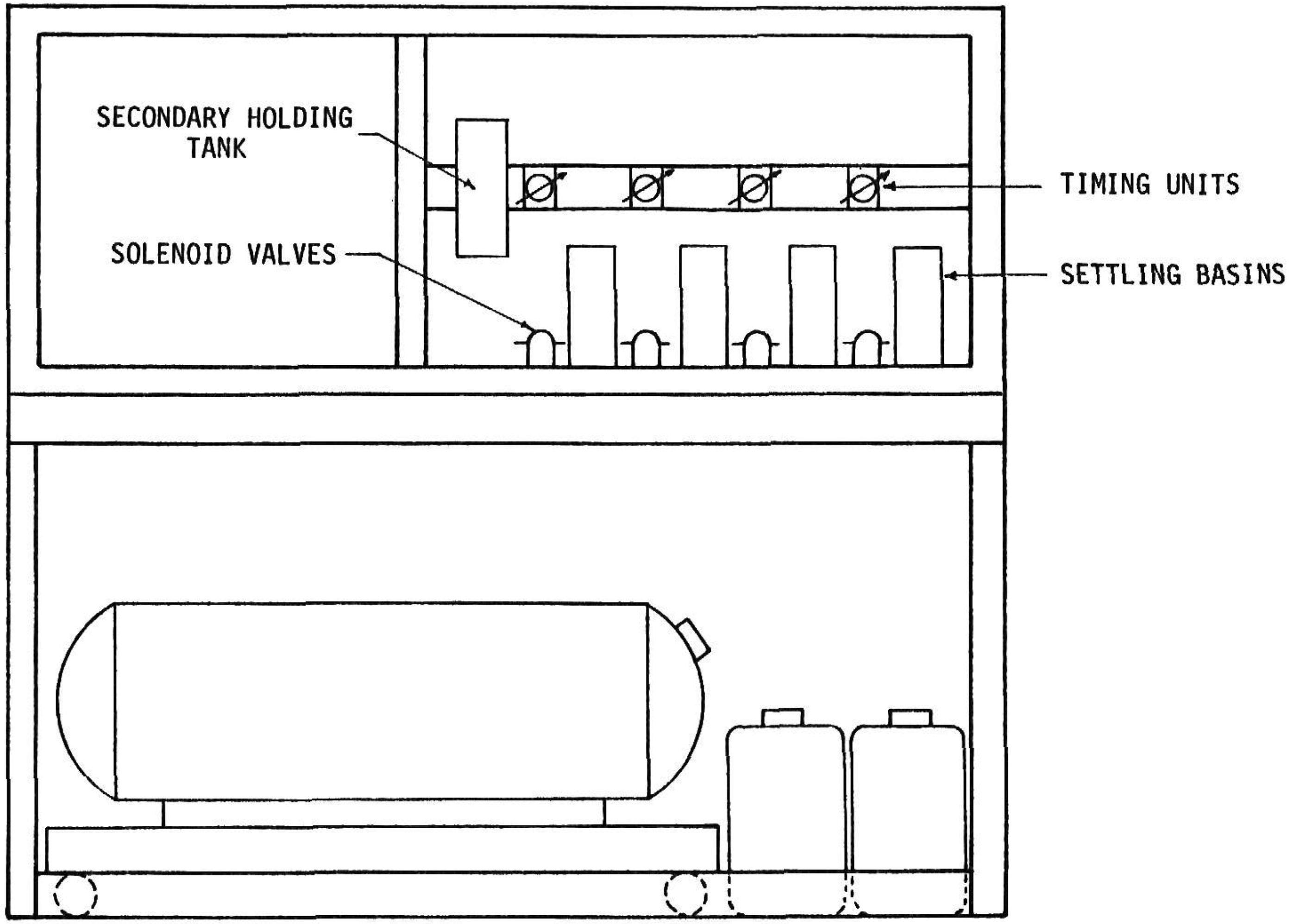

Figure 5. Rear View of the PPETA.

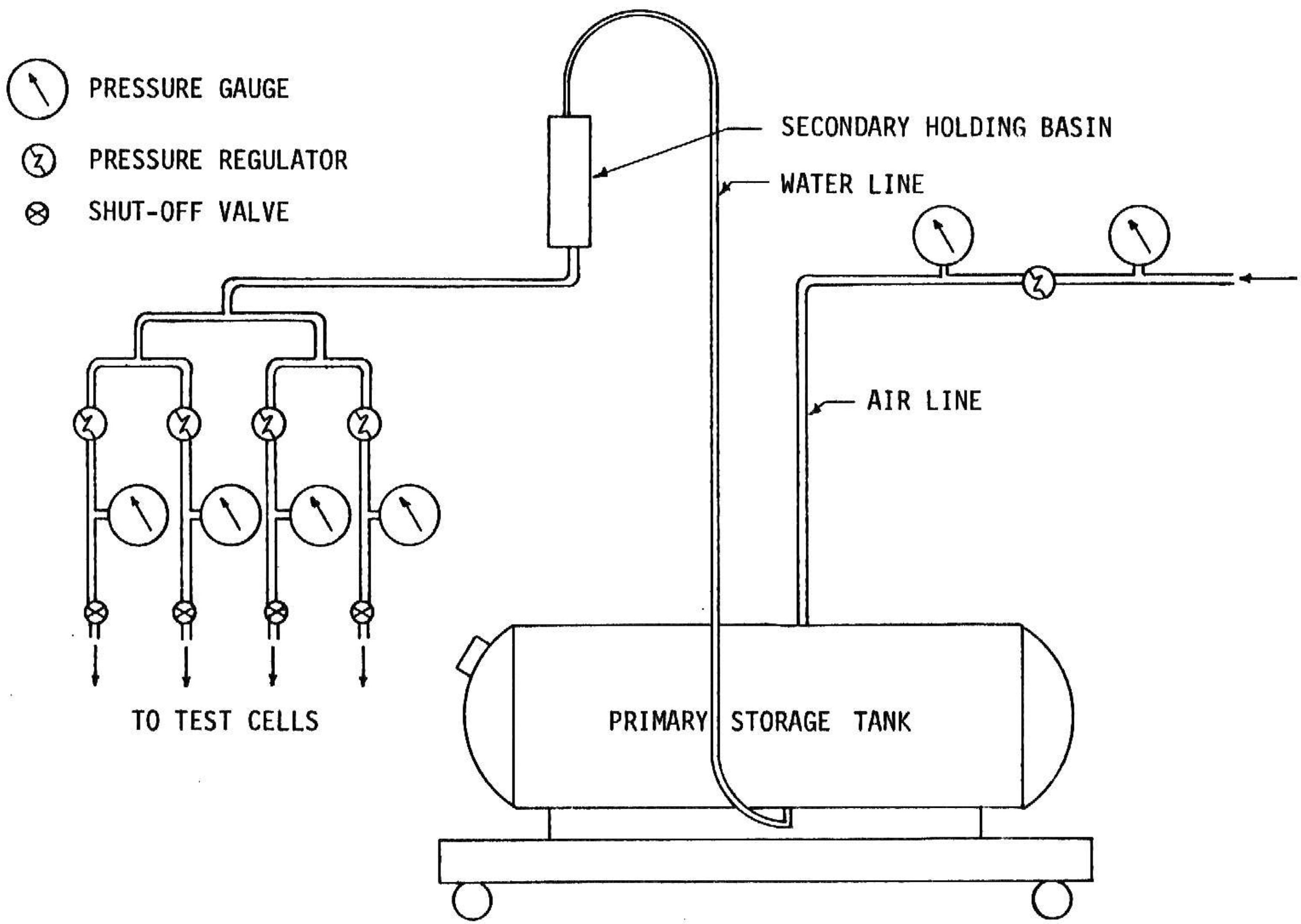

Figure 6. Schematic of the Water Flow System for the PPETA.

The water is routed from the central holding tank to a secondary holding tank. This tank, constructed from a one liter lucite cylinder, reduces the possibility of any fluctuation in the supply of water to the test cells. The use of this secondary holding tank also allows smaller supply piping to be used than would be required without it.

From the secondary holding tank the water is routed to a channel splitter. As can be seen in Figure 6, the splitter divides the primary supply line into four separate lines which lead to the test cells. The channel splitter was designed in a parallel configuration to provide the same water pressure to each of the four channels.

The water in each channel is then directed through a separate regulator which controls the pressure applied to each test cell. In addition to the regulators, separate pressure gauges have been included to monitor the actual water pressure in each channel. From the regulator the water is routed through a shut-off valve which can be used to regulate the quantity of flow to each cell.

Timing Units and Solenoid Valves

To simulate field conditions, the physical erosion test utilizes an intermittent flow of water through each test cell. To incorporate this function, as well as provide a continuous flow of water required for permeability testing, the flow in each channel can be controlled by a system of electric solenoid valves and timing units. This system provides for an intermittent flow of water by activating and deactivating the solenoid valves. When the valve is activated, the water is allowed to flow freely from the secondary holding tank to the test cells.

The timing units are cam operated microswitches which use a 110 volt, 6 rpm constant speed electric motor. These units can be activated and deactivated by the use of switches mounted on the control panel. Two indicator lights have been included on the test panel above each cell to monitor the operation of the valves. The left hand light indicates when the timer is activated. The right hand light is used to indicate when the solenoid valve is activated. For permeability testing the solenoid valves are bypassed and the flow of water is then controlled by manually operating the shut-off valves.

Control Panel

The control panel, as shown in Figure 7, has been provided to centralize all the controls necessary to operate the PPETA. Each channel of the apparatus is operated by a separate set of controls located in a vertical column on the lower portion of the control panel. The upper portion of the panel contains the regulator and gauges necessary to control and monitor the pressure in the primary holding tank. In addition to facilitating ease of operation, the control panel provides an aesthetic quality to the PPETA.

Test Cells

The test cells, constructed from clear lucite cylinders, are used to securely hold the soil samples during the testing process. The use of clear lucite facilitates visual inspection of the sample during testing. The size of the test cell used in the PPETA, in conforming to the size requirements for physical erosion testing, provides a size compatible for permeability testing. A conceptual drawing is shown in Figure 8 of the test cell and soil cylinder.

The end caps for the test cylinders were fabricated from clear solid lucite. These caps have been fitted with 'o' rings to provide a watertight

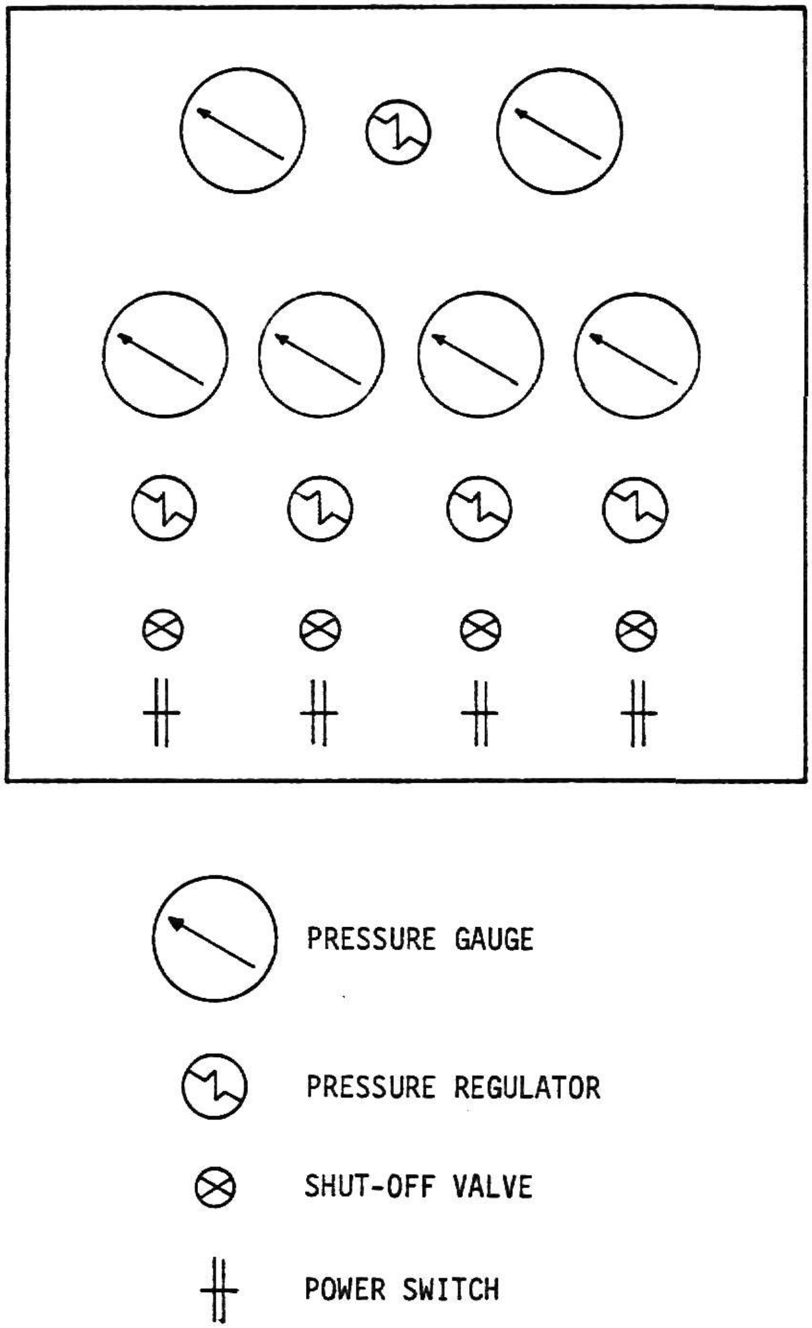

Figure 7. PPETA Control Panel

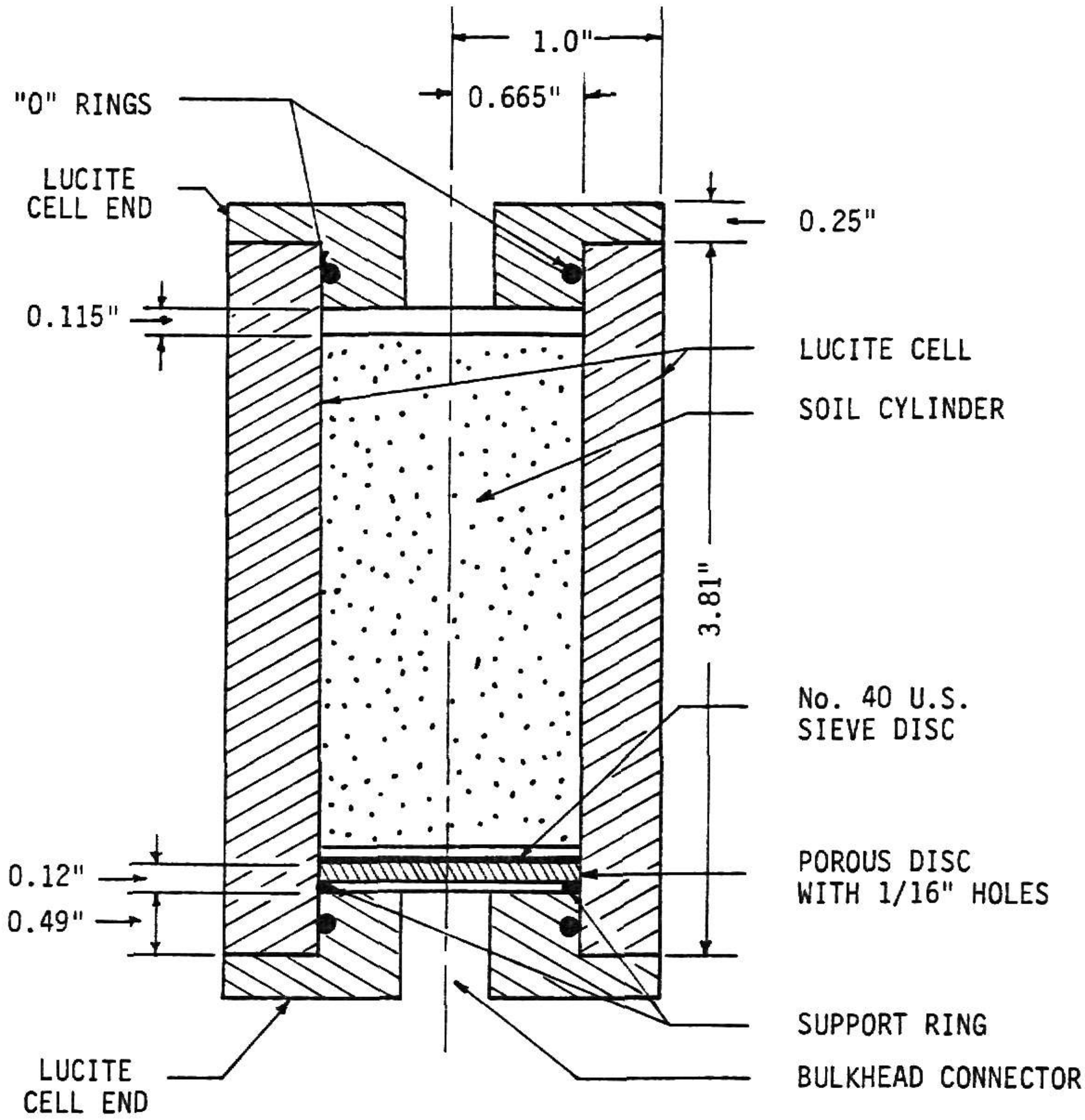

Figure 8. Assembled Test Cell with Soil Cylinder.

seal when properly seated. The flow of water to and from the test cell is facilitated by the use of bulkhead connectors which are attached to the end caps. The primary advantage of using bulkhead connectors is their ready attachment to the cell mounting or 'c' bracket. These brackets were designed to secure the test cells on the test panel. They were constructed from a steel strap shaped into a 'c' with slots in the ends. The test cells, with the end caps in place, are set into the 'c' brackets and the bulkhead connectors are then tightened. This method of design prevents any movement of the cell during the test.

A space between the soil sample and the end cap has been provided to enable water to collect and flow from the cell. This space is attained by inserting a U.S. No. 40 sieve, a porous disc and a spacer ring between the soil and the end cap. The purpose of the sieve and porous disc is to prevent the large soil particles from leaving the test cell. In addition to more accurately simulating field conditions, the sieve and porous disc also help to prevent the system from becoming clogged.

Settling Basins

Since some of the soil fines may wash through the test cell, settling basins have been placed before each solenoid to prevent damage to the solenoid valve diaphragms. These basins were constructed from lucite cylinders having a diameter of three and one-half inches and a height of ten inches. The height was maximized to enhance settling of the fines. Since this basin serves as a soil trap during testing, periodic cleaning is required. Therefore to facilitate cleaning, plugs have been placed in the top of the cylinders which may be removed to flush and clean the basins.

Cabinet

A cabinet was constructed to organize and contain the testing equipment. The cabinet is approximately six feet in length, five and one-half feet in height and two and one-half feet in width. This relatively large size was required to provide sufficient storage space, under the working area, for the primary tank and wastewater containers. To provide for easy access to these containers, a removable door was designed and constructed.

An additional door was built into the table behind the test panel. This door provides access to the settling basins, solenoid valves and timers for periodic cleaning and maintenance. Four drawers were constructed in the front portion of the cabinet to provide additional storage space for equipment.

A portion of the cabinet directly under the test and control panel was designed to be utilized as a working surface. This area has been covered with formica to provide a durable, water resistant surface. Although only a foot wide, this area furnishes adequate work space during testing.

TESTING AND ANALYSIS

This section of the report describes the testing program which was conducted to verify the design, construction and test procedures developed during this study. In addition, the general engineering properties for all samples tested and selected soil chemistry properties for the erosionally tested samples are presented and discussed.

Test Procedures

The testing procedures developed during this study were designed to yield both quantitative and qualitative results based on principles familiar to most geotechnical engineers. In addition, the proposed procedures, presented in Appendix A and B, were designed to facilitate standardized testing techniques, thus allowing a technician to conduct the required procedures without specialized training or education. Although the new test procedures are based on standard concepts and principles, they were specifically designed to be used in conjunction with the newly developed apparatus.

Permeability Testing

The determination of the coefficient of permeability is performed by controlling the hydraulic head applied and measuring the corresponding volume of water which flows through the sample during a specified period of time. The application of the desired hydraulic head can be controlled by adjusting the water pressure regulating valve located on the control panel. The pressure head can be controlled separately for each channel. Separate outflow lines from the test cells have been provided, thereby bypassing the solenoid valves. These lines are connected to the bottom of the test cell with the free end placed in a graduated cylinder. This concept provides for direct, uninterrupted flow through the test sample into the collection basin.

By using generalized relationships presented in standard texts on Soil Mechanics (8), the coefficient of permeability can be determined. Since the total volume of flow, hydraulic head, geometry of the sample and the time frame used during the test can be accurately determined, the coefficient of permeability can be easily calculated.

A testing program was conducted to evaluate the permeability coefficient of two soil samples at different void ratios. The samples consisted of two sands with different gradations. One sample was an Ottawa sand used in standard density measurements and the other was a general river run sand with the fines removed. The reason for using sand in the permeability test was twofold. The primary reason was that the coefficient of permeability determined from PPETA testing could be correlated with results published elsewhere. The other reason was the reduced testing time required, since the permeability coefficient for sand is several orders of magnitude higher than that for a compacted clayey silt, the required testing period is reduced by several orders of magnitude.

Physical Erosion Test

In this study, all samples tested for dispersion potential were compacted utilizing the Harvard Miniature compaction technique (24). The samples were compacted to a density equivalent to the maximum Standard Proctor Density, as specified by the American Society for Testing Materials (ASTM D-698). However, compaction of the soil samples would usually be determined by the design conditions which are to be analyzed.

The physical erosion potential of a soil is determined by subjecting a sample to an intermittent flow of water. Field conditions are simulated by drilling three equidistant longitudinal holes in the sample prior to the start of the test. By the use of pressure regulators and gauges, the system can be adjusted and maintained at the desired pressure head of 15 psi. The intermittent flow of water is continued for a period of four hours after which the sample remaining in the test cell is removed and placed in a drying oven. The percent dispersion can then be determined by using the relationship developed by Petry (25).

During this study, the physical erosion test was conducted on three different soil samples. The samples were composed predominately of silt sized particles with varying percentages of clay. The tests were conducted according to the procedure outlined in Appendix B.

Description of Test Samples

Verification of the PPETA design and the testing procedures were obtained by conducting tests on five different samples of soil. It was believed that these soils would provide sufficient evidence to substantiate the validity of the design and testing procedures developed during this study. The soil samples selected consisted of two sands and three clayey silts.

The sands used in this study consisted of a uniformly graded Ottawa sand labeled Sample 101 and a river sand labeled Sample 102. Sample 101 was purchased from a commercial outlet while Sample 102 was taken from the Kansas River just south of the bridge on U.S. Highway 177 east of Manhattan, Kansas. The results of a grain size analysis conducted on these materials is presented in Table 1. As can be seen from this table, Sample 102 is more well graded than Sample 101, and thus indicating that the permeability coefficient would differ.

TABLE 1

GRAIN SIZE ANALYSIS

Percent Finer (U.S. Sieve No. or Equivalent Stokes Diameter)								
Sample	#40	#60	#140	#200	0.05mm	0.02mm	0.005mm	0.002mm
101	27	2	--	--	--	--	--	--
102	42	4	--	--	--	--	--	--
103	100	94	82	77	68	32	18	12
104	100	96	86	81	73	44	26	18
105	98	95	86	82	70	30	14	11

TABLE 2

ENGINEERING PROPERTIES

Sample Number	Specific Gravity	Liquid Limit	Plastic Limit	Volumetric Shrinkage %	Linear Shrink-age %	Standard Proctor γ_d(max.) pcf	Compaction W_{opt} %
101	2.66	--	--	--	--	--	--
102	2.65	--	--	--	--	--	--
103	2.65	32	14	22	7	105.2	16.0
104	2.66	37	14	27	10	113.5	18.2
105	2.64	25	18	11	4	120.4	13.8

Visual observation of the development of piping tunnels and sheet erosion was used to locate the potentially dispersive soils. Evidence of potential dispersion was observed in an embankment on the north side of U.S. Highway 24 approximately one-half mile east of its intersection with U.S. Highway 99 in Wamego, Kansas. The embankment, which was approximately thirty feet in height, had been created to facilitate the leveling of adjacent land for new construction. Based on this observation, two samples were obtained from this embankment approximately 100 feet apart. One sample, Sample 103, was obtained at a location approximately fifteen feet higher than the second, Sample 104. Although these samples were obtained in the same area, there was observable difference in their color and erosional pattern.

The fifth sample chosen, Sample 105, was a soil which had been extensively used for classroom instruction in the soil mechanics laboratory at Kansas State University. Since the soil was originally obtained from a highway cut in a loessial deposit at the east end of the Kansas Turnpike near Kansas City, Kansas, it was believed to be non-dispersive. Therefore, this sample was used as a control for the physical erosion test.

Engineering Properties

The engineering properties of all the samples used were determined to provide background data. Tests performed included Atterberg limits, shrinkage determination, grain size analysis and Standard Proctor compaction. All samples were oven dried prior to the testing.

Liquid and plastic limits were determined using ASTM D423-61T and D425-59 recommended procedures. The shrinkage properties were obtained using the Texas Highway Department's method (Tex 107-E) for determining linear and volumetric shrinkage. Grain size analysis was accomplished by the hydrometer method (ASTM D422-61T). The maximum Standard Proctor Density and optimum water content were obtained using the ASTM D698-70 recommended procedure. A summary of these properties is presented in Tables 1 and 2.

Chemical Properties

The soil chemistry properties were determined by the Soil Testing Laboratory which is within the Department of Agronomy at Kansas State University. The data obtained from these tests, shown in Table 3, were correlated with the results of the physical erosion test. It can be seen from this data that the calcium content of Samples 103 and 104 are high in comparison with the other soluble salts present. This fact is to be expected since considerable amounts of limestone existed in the area. Sample 105 did not contain any calcium in the pore water extract. This was also expected, since this sample was an aeolian deposit of silt with a clay binder.

Correlation of Results

The comparison of the variation in void ratio with the coefficient of permeability for Sample 101, as shown in Figure 9, correlates well with the values reported by Lambe and Whitman (26). The major differences in these two relationships may be attributed to differences in saturation, temperature, and small variations in void ratio. Since these properties of the sand used by the authors were not given, precise correlations could not be made. Based upon the results presented by the authors, the coefficient of permeability determined for Sample 102 for the various void ratios used, is reasonable. Because of the

TABLE 3

SOIL CHEMISTRY PROPERTIES

Sample Number	Sodium meq/1	Potassium meq/1	Magnesium meq/1	Calcium meq/1	Percent Sodium	pH	CEC	SAR	ESP
103	3.9	3.1	68.3	217.4	0.1	6.1	12.7	0.0	3.1
104	4.2	3.5	59.2	149.6	1.9	5.9	16.3	0.4	2.6
105	5.1	3.8	68.3	0	6.6	7.3	----	0.9	---

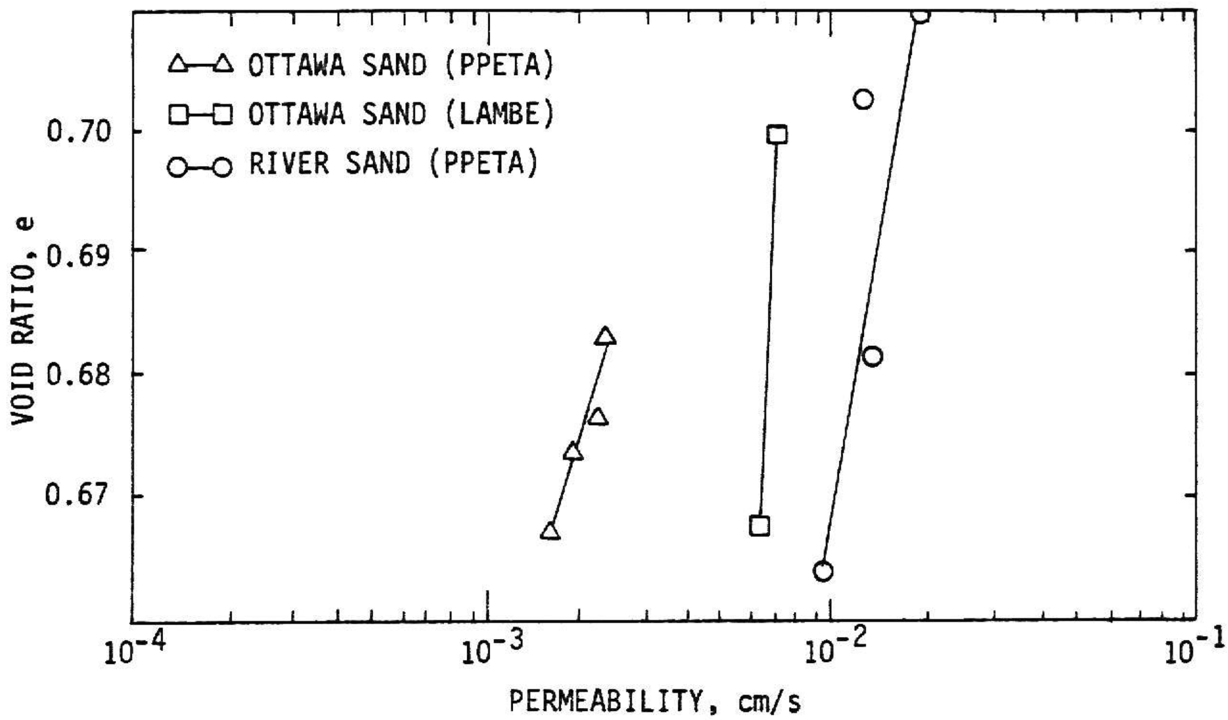

Figure 9. Relationship Between Void Ratio and Coefficient of Permeability.

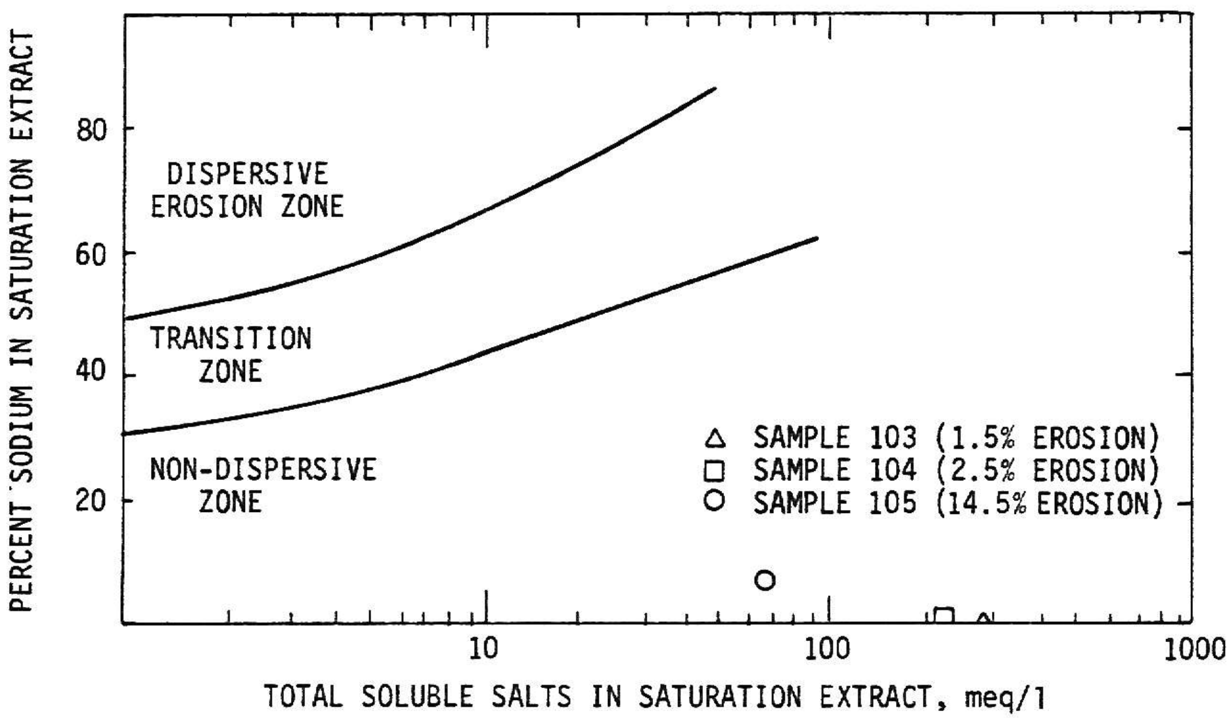

Figure 10. Correlation of Physical Erosion Test Results to Field Behavior as Determined by Solution Extract Chemical Properties.

dependence of permeability on a number of testing parameters, exact correlation with published results is not possible.

The results of tests conducted to evaluate the physical erosion potential of Samples 103, 104 and 105 are presented in Figure 10. Interpretation of this Figure illustrates that all of the samples were non-dispersive. This fact is supported by the results obtained from the chemical analysis. The variation between the results obtained by testing for Samples 103 and 104 and those indicated by visual observation can be explained by the high calcium content in the pore water and the relative small percentage of clay in the samples. These facts collectively indicate that the soils are not dispersive, but rather they have low resistance to surface or sheet erosion.

As shown in Figure 10, Sample 105 exhibited a slightly larger percent dispersion than Samples 103 and 104. This fact can be explained by the difference in the exchangeable cations of the clay constituents. As can be seen in Table 3, Sample 105 possesses a higher percentage of sodium and a lower percentage of calcium than Samples 103 and 104. Based on this observation it would be expected that Sample 105 would exhibit slightly more potential for dispersion than the other samples.

CONCLUSIONS AND RECOMMENDATIONS

The primary objective of this study was to evaluate and develop the capabilities of the soil mechanics laboratory at Kansas State University to conduct advanced studies on soil-water systems. This objective was accomplished by the design and construction of a new testing apparatus. In addition, new testing procedures were developed based on previously accepted standards. From the knowledge gained during this study, the following conclusions may be made:

1. The apparatus and procedures developed during this study provide an efficient method of determining the permeability and the dispersional characteristics of soils.

2. The PPETA can be effectively used by trained technicians without any additional training or indoctrination.

3. The results of a limited testing program confirm the applicability of the apparatus for potential research studies.

In the course of this study, several recommendations for future modifications of the PPETA were developed. These recommendations are:

1. Modify the size of test cells to accommodate larger samples for permeability testing.

2. Modify the control system of the PPETA to provide the capability of conducting a falling head permeability test.

3. Develop special collection containers to accumulate and measure the volume of flow from the test cells during permeability testing.

4. Design new settling basins which can be cleaned more easily.

REFERENCES

1. Terzaghi, K., Theoretical Soil Mechanics, New York: John Wiley and Sons, Inc., 1943, p. 238.

2. Thiem, G., Hydrologische Methoden (Hydrolic Methods), J. M. Gebhardt, Leipzig, Germany, 1906, p. 56.

3. Theis, C. V., "The Relation Between the Lowering at the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Ground-water Storage," American Geophysical Union Transactions, Pt. 2 (1935), pp. 519-524.

4. Kirkham, D. and van Bavel, C. H., "Theory of Seepage into Auger Holes," Proceedings, Soil Science Society of America, Vol. 13 (1949), pp. 75-82.

5. Schmid, W. E., "Field Determination of Permeability by the Infiltration Tests," Permeability and Capillarity of Soils, ASTM STP 417, American Society for Testing and Materials, 1967, pp. 142-159.

6. Kirkham, D., "Measurement of the Hydraulic Conductivity of Soil in Place," Symposium on Permeability of Soils, ASTM STP 163, American Society for Testing and Materials, 1954, pp. 80-97.

7. Richards, B. G., "Moisture Flow and Equilibrium in Unsaturated Soils for Shallow Foundations," Permeability and Capillarity of Soils, ASTM STP 417, American Society for Testing and Materials, 1967, pp. 4-32.

8. Means, R. E. and Parcher, J. V., Physical Properties of Soils, Columbus, Ohio: Charles E. Merrill Books, Inc., 1963.

9. Lambe, T. W., Soil Testing for Engineers, New York: John Wiley and Sons, Inc., 1951, pp. 52-62.

10. Volk, G. M., "Method of Determination of Degree of Dispersion of the Clay Fraction of Soils," Proceedings of Soil Science Society of America, Vol. 11 (1937), pp. 561-565.

11. Coumoulus, D. G., "Experience with Studies of Clay Erodibility in Greece," Dispersive Clays, Related Piping and Erosion in Geotechnical Projects, ASTM STP 623, J. L. Sherard and R. S. Decker Eds., American Society for Testing and Materials, 1977, pp. 42-57.

12. "Soil Survey Laboratory Methods and Procedures for Collecting Soil Samples," Soil Conservation Service, Soil Survey Investigation Report No. 1, Department of Agriculture, Washington, D. C., 1967.

13. Aitchison, M. E., Ingles, O. G. and Wood, C. C., "Post-Construction Deflocculation as a Contributory Factor in Failure of Earth Dams," Proceedings, Fourth Australia - New Zealand Conference on Soil Mechanics and Foundation Engineering, Montreal, Canada, 1963, pp. 275-279.

14. Ingles, O. G. and Metcalf, Soil Stabilization, Butterworths, Sydney, Australia, 1972.

15. Arulanandan, K., Loganathan, P., and Krone, R. B., "Pore and Eroding Fluid Influences in the Surface Erosion of a Soil," Journal of Geotechnical Engineering Division, American Society of Civil Engineers, 1975, pp. 53-66.

16. Dunn, I. S., "Tractive Resistance of Cohesive Channels," Journal of the American Society of Civil Engineers, Vol. 55, No. SM3, 1959.

17. Heinzen, R. T. and Arulanandan, K., "Factors Influencing Dispersive Clays and Methods of Identification," Dispersive Clays, Related Piping, and Erosion in Geotechnical Projects, ASTM STP 623, J. L. Sherard and R. S. Decker, Eds., American Society for Testing and Materials, 1977, pp. 202-217.

18. Emerson, W. W., "A Classification of Soil Aggregates Based on Their Coherence in Water," Australian Journal of Soil Research, Melbourne, 1967, p. 47.

19. Sherard, J. L., Dunningan, L. P., and Decker, R. S., "Identification and Nature of Dispersive Soils," Journal of the Geotechnical Engineering Division, American Society of Civil Engineers, Vol. 102, No. GT4, April 1976, pp. 287-301.

20. Holmgren, G. G. S. and Flanagan, C. P., "Factors Affecting Spontaneous Dispersion of Soil Materials as Evidenced by the Crumb Test," Dispersive Clays, Related Piping, and Erosion in Geotechnical Projects, ASTM STP 623, J. I. Sherard and R. S. Decker, Eds., American Society for Testing and Materials, 1977, pp. 218-239.

21. Sherard, F., Dunningan, L., Decker, R. S., and Steele, E., "Pinhole Test for Identifying Dispersive Soils," Journal, Geotechnical Engineering Division, American Society of Civil Engineers, Vol. 102, No. GT1, Jan. 1976, pp. 69-85.

22. Haliburton, T. A., Petry, T. M. and Hayden, M. L.,"Identification and Treatment of Dispersive Clay Soils," Report to U.S. Department of the Interior, Bureau of Reclamation, School of Civil Engineering, Oklahoma State University, Stillwater, July, 1975.

23. Flanagan, C. P. and Holmgren, G. G. S., "Field Methods for Determination of Soluble Salts and Percent Sodium from Extract for Identifying Dispersive Clay Soils," Dispersive Clays, Related Piping, and Erosion in Geotechnical Projects, ASTM STP 623, J. I. Sherard and R. S. Decker, Eds., American Society for Testing and Materials, 1977, pp. 121-134.

24. Wilson, S. D., "Small Soil Compaction Apparatus Duplicates Field Results Closely," Engineering News Record, Nov. 1950, pp. 34-36.

25. Petry, T. M. and Haliburton, T. A., "Identification of Dispersive Soil Erosion by a Physical Test," TRB, Transportation Research Record 532, 1976, pp. 95-104.

26. Lambe, T. W. and Whitman, R. V., Soil Mechanics, John Wiley and Sons, Inc., 1969, pp. 283-292.

27. Sherard, J. L., Decker, R. S., and Ryker, N. L., "Piping in Earth Dams of Dispersive Clay." Proceedings of ASCE Specialty Conference on the Performance of Earth and Earth-Supported Structures, Vol. 1, Part 1, 1972, pp. 589-626.

APPENDIX A

SAMPLE PREPARATION AND PERMEABILITY TESTING PROCEDURE

1. Mix the soil sample at the desired water content and allow to equilibrate for at least 24 hours prior to actual testing.
2. Compact the prepared soil to the desired density.
3. Weigh the empty test cell. Record all data on a data sheet similar to that in Figure 11.
4. Partially extract the soil sample using the cell spacer, and trim off level with the top of the cylinder. Use the trimmings for the water content determination. If an undisturbed sample is to be used, the sample should be trimmed to the proper size using conventional methods, with the water content being determined from the trimmings.
5. Extrude the sample from the compaction mold, measure and record the length, then place into the assigned test cell. Orient the cylinder such that the top of the cylinder is at the top of the cell.
6. Weigh the cell and compacted soil to obtain the net weight of the soil used.
7. Place the sieve disk, porous disk and support ring in the bottom of the cell and securely attach the cell caps.
8. The permeability test spparatus should be checked according to the following procedure:
   a) Each settling chamber and solenoid valve should be cleaned and filled with water.
   b) Fill the primary holding tank with sufficient distilled water for a complete test (approximately 5 gallons).
   c) Connect the air pressure supply line to a source capable of supplying sufficient pressure to conduct the test at the desired pressure.
   d) The air pressure input line should be connected from the pressure

regulator to the primary holding tank. The pressurized water line should be connected to the secondary holding tank from the primary holding tank.

e) The tank should be pressurized such that the required water pressure is available to each cell.

f) Place the outflow lines in the waste containers.

9. Place the cells in the "c" brackets and secure to prevent movement. The solenoid valves are bypassed by connecting the short outflow tubing directly to the collection cylinder.
10. Apply a small pressure to each cell with the shut-off valves open to facilitate sample saturation.
11. Close the shut-off valves after saturation is complete and dial the desired testing pressure for each cell using the pressure regulator.
12. Begin the test by placing the outflow water lines in graduated cylinders and opening the shut-off valves.
13. Allow several minutes for the system to reach equilibrium and then record the graduate and time readings.
14. Final graduate and time readings are taken when a sufficient amount of water has collected in the graduated cylinder to provide for accurate volume measurement.
15. Temperature measurements should also be taken periodically during the testing period to provide for any corrections, if necessary.
16. After the test is complete, the cylinders should be removed and each cell disconnected. The soil in the cell should be completely washed into a preweighed dish. The dish and sample are then dried in an oven at 104° C for 24 hours. After drying, the dish and sample should be placed in a dessicator to cool, after which it is weighed to the nearest 0.01 gm.

SOIL MECHANICS LABORATORY
DEPARTMENT OF CIVIL ENGINEERING
KANSAS STATE UNIVERSITY
MANHATTAN, KANSAS

PERMEABILITY TEST DATA SHEET

Tested by__________ Date__________ Sheet No.______ of ______

Channel No.__________ Tested For __________

Description of Sample__________

Sample Length L	Water Temp. T°C	Time t sec.	Pressure psi.	Head h	Hydraulic Gradient h/L	Volume Q	K_T	$K_{20°C}$

	Before			After		
Tare No.						
Tare & Wet Soil						
Tare & Dry Soil						
Dry Soil, w_d						
Tare						
Wet Soil, w_s						
Water Content, w						
Specific Gravity, G_s						
Void Ratio, e						
Vol. of Voids, V_e						
Weight of Water, w_w						
Vol. of water, V_w						
Degree of Saturation, S						

$$V_e = \frac{e}{1+e} \qquad w_w = w_s - w_d \qquad V_w = \frac{w_w}{w} \qquad S = \frac{V_w}{V_e} \times 100$$

Figure 11. Permeability Test Data Sheet

APPENDIX B

SAMPLE PREPARATION AND PHYSICAL EROSION TESTING PROCEDURE

1. If the sample is to be chemically treated, follow procedures outlined by Haliburton, et al. (24).
2. Thoroughly mix the soil with sufficient distilled deionized water to obtain the desired water content. After mixing, the sample should be broken down such that all particles pass the U.S. No. 10 sieve.
3. Compact the sample to the desired density.
4. After compaction, partially extract each cylinder from the mold using the small spacing block. Trim the cylinder level with top of the mold and use a representative of the sample trimmings for water content determination. Record all data on a data sheet similar to that in Figure 12.
5. Place the compacted soil cylinder into the assigned test cell, orienting the cylinder such that the top of the cylinder is at the top of the cell.
6. Place the cell, cylinder and compression blocks in a hydraulic press with the top of the cell up. Provide sufficient compression, so that the blocks are completely seated into the test cell.
7. After compression, remove the blocks and mark the longitudinal hole locations in the top of the soil cylinders. Drill three 0.125 inch holes in the samples at a speed such that minimal sample disturbance will result. A drill press should be used to insure proper alignment.
8. Carefully clean each hole with a pipe cleaner. Then weigh each cell and cylinder to the nearest 0.01 gm.
9. The apparatus should be prepared for conducting the Physical Erosion Test by using the following procedure:
   a) Each settling basin should be cleaned and filled with water.
   b) Fill the primary holding tank with sufficient distilled water for a complete test (at least 12 gallons).

c) Connect the air pressure supply line to a source capable of supplying at least 20 psi pressure.

d) The air pressure input line should be connected from the air pressure regulator to the primary holding tank. The pressurized water line should be connected to the secondary holding tank from the primary holding tank.

e) The tank should be pressurized such that 15 psi minimum is available to each test cell.

f) Place the outflow lines in the proper waste container.

10. Place the sieve disk, porous disk and support ring in the bottom of each cell.

11. Connect each cell to the device by pushing the cell end pieces into their cells and rotating them, to ensure proper seating of the "o" rings. The cells are then placed in their "c" brackets and secured to prevent any movement of the cell during testing.

12. The secondary holding basin should be filled and pressure vented. Five minutes prior to the beginning of testing, open the shut-off valves to each cell and allow the sample to saturate. The secondary holding basin should be kept at least half full of water by intermittent filling from the main tank as needed.

13. After a five minute saturating period, each cell should be pressurized to the desired water pressure (15 psi for standard testing).

14. The test is started by switching on the timer for each channel at 15 second intervals. The timers are set to open each sclenoid valve at six minute intervals for approximately seven seconds, thus providing a system to flush out any soil suspended in the soil cylinder holes and cells (if particles would pass a U.S. No. 40 sieve), and provide fresh distilled water.

15. After 4.0 hours of elapsed testing time each unit is turned off. Prior to the last time each solenoid valve opens, its corresponding shut-off valve is closed. The power switches are then shut off as soon as each solenoid valve closes.

16. The cylinders are removed and each cell disconnected. The soil remaining in the cell should be completely washed into a pre-weighed dish. The dish and sample are then dried in an oven at 104° C for 24 hours. After drying, the sample should be placed in a dessicator to cool, after which it is weighed to the nearest 0.01 gm. The dry weight of the soil is then used to determine the soil erodibility, expressed as a percentage of the weight loss.

SOIL MECHANICS LABORATORY
DEPARTMENT OF CIVIL ENGINEERING
KANSAS STATE UNIVERSITY
MANHATTAN, KANSAS

PHYSICAL EROSION TEST DATA SHEET

Tested by__________ Test No.__________

Date__________ Sheet No. _____ of_____

Type of Compaction__________ Sample Water Content__________

Description of Samples: Test Water Pressure__________ psi

Unit #1__________

Unit #2__________

Unit #3__________

Unit #4__________

Start of Test: Day_____ Time_____ End of Test: Day_____ Time_____

UNIT NO.				
Wt. Cell and Sample w/holes				
Wt. Cell				
Wt. Sample w/holes (wet)				
Wet Density, γ_w				
TARE CAN NO.				
Wt. Sample Wet + TC				
Wt. Sample Dry + TC				
Wt. Tare Can				
Wt. Water				
Wt. Dry Soil				
Water Content, w%				
Dry Density, γ_d				
Wt. Dish + Dry Soil, End				
Wt. Dish				
Wt. Dry Soil, End				
Wt. Dry Soil, Start				
Percent Erosion				

Figure 12. Physical Erosion Test Data Sheet

DEVELOPMENT OF THE MULTI-CHANNEL
VARIABLE STRESS PERMEAMETER

by

TERRENCE EUGENE ARNOLD

B.S., Kansas State University, 1977

AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1978

ABSTRACT

The interaction between soil and water and its subsequent effect on the structural integrity of earthen projects is of major importance to soil and foundation engineers. The recognition, evaluation and control of both drainage and erosion is becoming increasingly important as rigid environmental constraints are placed on the design and construction of various water projects.

Based upon this need and a comprehensive review of the available literature relating to permeability and dispersive characteristics of clay soils, a study was undertaken to develop and construct a Permeability - Physical Erosion Testing Apparatus (PPETA) for conducting advanced studies on soil-water systems. To verify both the design and testing procedures developed, a testing program was conducted utilizing the PPETA on several locally available soils. The results of the testing program, in addition to providing the necessary verification, illustrated the general applicability of the apparatus.