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EQUIPMENT FOR PERMEABILITY TESTING WITH HAZARDOUS AND TOXIC PERMEANTS

Jeffrey C. Evans¹ and Hsai-Yang Fang²

ABSTRACT

The measurement of the permeability of fine-grained soils utilizing hazardous and toxic permeants requires equipment specifically designed and constructed for that purpose. Interaction between the pore fluids in the soils and the resulting soil response must be considered as well as the compatibility between the test equipment and the permeants. Further, a method of modeling the state of stress and permeation relative to field conditions must be incorporated in order to arrive at a system which can adequately determine the effects of hazardous and toxic permeants upon the permeability of fine-grained soils.

The permeability testing system developed for permeability testing with hazardous and toxic permeants has three major components. These are the control panel, the permeability board and the triaxial cell. The necessary strength and compatibility was accomplished through the optimum use of stainless steel and aluminum to provide adequate rigidity while providing the ultimate compatibility through the use of Teflon[®] at any points in which the permeameter is in contact with the permeant. Equipment design and fabrication considerations in their special applicability for testing of hazardous and toxic permeants are discussed in this paper.

KEYWORDS

Equipment, Testing, Permeability, Hazardous and Toxic Wastes, Soil Mechanics, Geotechnology, Construction, Waste Containment Systems, Clay Minerals

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INTRODUCTION

Disposal of hazardous and toxic wastes in the subsurface environment has resulted in the need to adequately assess the permeability of fine-grained soils with hazardous and toxic permeants (3). The successful application of geotechnology to the design and construction of waste containment systems hinges upon our understanding of the pore-fluid soil interactions. Further, our understanding of pore-fluid clay interactions depends upon the proper use of the appropriate equipment in the laboratory. The proper design and fabrication of testing apparatus to determine the permeability of soils with hazardous and toxic permeants is essential to the successful application of geotechnology and the containment of hazardous and toxic wastes.

The measurement of the permeability of fine-grained soils utilizing hazardous and toxic permeants requires equipment specifically designed and constructed for that purpose (1,4). Interaction between the pore fluids and the soils and the resulting soil response must be considered as well as the compatibility between the test equipment and the permeants. Further, a method of modeling state of stress of the soil and the permeation relative to field conditions must be incorporated into test equipment in order to arrive at a system which can adequately determine the effects of hazardous and toxic permeants upon the permeability of fine-grained soils.

It is the purpose of this paper to examine, in detail, the equipment necessary for determination of the permeability of low-permeability soils with hazardous and toxic permeants. The equipment developed at Lehigh University (2) will be described in detail with emphasis on the unique features of this system.

PERMEABILITY TESTING SYSTEM

In order to effectively measure the permeability of soils when permeated with a wide range of hazardous and toxic wastes, it was necessary to develop a new permeameter system. This system development was required because the response of soils to hazardous and toxic wastes can differ significantly from "normal" permeability testing. The permeability testing system developed for these studies has three major components, the control panel, the permeameter board, and the triaxial cell. Each of these components are discussed separately in this chapter. Equipment design and fabrication considerations, and their special applicability for the testing of hazardous and toxic wastes permeants are included.

Triaxial Cell

The determination of permeability is highly dependent upon the state of stress on the sample. In order to control the state of stress, the triaxial cell represents the generally accepted state-of-the-art. This is particularly true with permeability testing (6). In a triaxial cell, a sample is maintained in a controlled state of triaxial stress which can be closely model the in situ state of stress.

The cell pressure is applied to membrane encapsulated sample through the cell water by a pressure application system (Control Panel) to provide an isotropic state of stress. The state of stress can be made anisotropic by providing additional loading through the top piston. Permeation is induced in response to an hydraulic gradient. The gradient is developed by applying a pressure differential across the sample between the bottom platen and the top platen. In order to improve the "flushing" of air through the sample, the higher pressure is generally applied at the bottom platen. Hence, the flow through the sample is upward.

The triaxial cell is important for permeability testing to preclude the effects of entrapped air upon the measured permeability. It has been demonstrated that entrapped air can result in unrealistically low coefficients of permeability (5). Entrapped air is best eliminated through the application of a backpressure. A backpressure is applied by using an elevated pressure on the top platen side. Correspondingly, the lower platen pressure must be elevated to develop a gradient and the cell pressure must be increased so as to maintain the same effective stress on the sample. The effective stress is defined as the total confining stress minus the pore water pressure. For example, the cell pressure of 621 kPa (90 psi) can be utilized with a bottom platen pressure of 483 kPa (70 psi) and a top platen pressure (back pressure) of 345 kPa (50 psi). The effective stress at the top of the sample in this example would be 621 kPa minus 345 kPa, or 276 kPa (40 psi). The effective stress at the bottom would be 621 kPa minus 483 kPa, or 138 kPa (20 psi). The

average effective stress would therefore be 207 kPa (30 psi). By regulating top and bottom pressures, and confining pressure, it is possible to simulate an average in situ state of stress as well as develop appropriate gradients to establish reasonable test times, and/or simulate field conditions.

Note that the simulation of confining stresses is not possible in a fixed wall permeameter. With this type of equipment, the permeameter walls are rigid, and the state of stress is both uncontrolled and unknown.

Another important advantage of the triaxial cell in permeability testing relates to the potential for bulk transport of fluids between the sample and the equipment. In a triaxial cell permeameter, the sample is maintained encapsulated in a flexible membrane. Conversely, in a fixed-wall permeameter, there is a sample-permeameter wall interface. The wall is rigid and cannot move. Therefore, if the sample shrinks, bulk transport of fluids at the interface of the sample and permeameter wall can result. Should sample shrinking occur while testing in a triaxial cell, the membrane is simply maintained against the sample because of the confining stress maintained on the sample. Further, shrinking or swelling of the sample in the triaxial cell does not change the state of stress. In a fixed wall permeameter, as the sample shrinks, the confining stress is reduced. Conversely, as the sample swells, the confining stress is increased. This aspect is very important, since certain clayey soils may be initially consolidating due to the effect of hazardous and toxic pore fluids upon the sample. In a fixed-walled permeameter, at the point that the sample shrinks enough to develop a void space

between the sample and the permeameter wall, an open channel is available for bulk transport of permeant. This results in large increases in the calculated value of permeability. From the data obtained utilizing a fixed wall permeameter, therefore, it is difficult to assess the actual effect of pore fluid upon the soil due to masking by the bulk transport mechanisms.

Having thus established the need to utilize triaxial cells for permeability testing, the unique features of the triaxial cells developed at Lehigh University (2) for these studies require further elucidation. As stated, one of the more significant laboratory difficulties which must be overcome for the determination of permeability with hazardous and toxic permeants, is the compatibility between the testing equipment and the permeant. For example, a typical triaxial cell is constructed of aluminum. Aluminum exposed to even relatively dilute concentrations of acids or bases, will tend to corrode and dissolve. A triaxial cell material for a study such as this must therefore be compatible with a wide range of permeants in order to be functional. The logical choice is the use of Teflon^R for the ultimate in hazardous and toxic permeant and equipment compatibility. Teflon^R, however, is extremely flexible. Therefore, Teflon^R cannot typically maintain the high pressures required to provide back pressure saturation and an adequate effective stress. The structural rigidity of aluminum or steel is therefore necessary to provide rigidity to the triaxial equipment. This dichotomy of goals was satisfied through the specially designed and fabricated triaxial cells shown schematically in Fig. 1. These cells optimize the use of stainless steel and aluminum to provide adequate rigidity, but they provide the

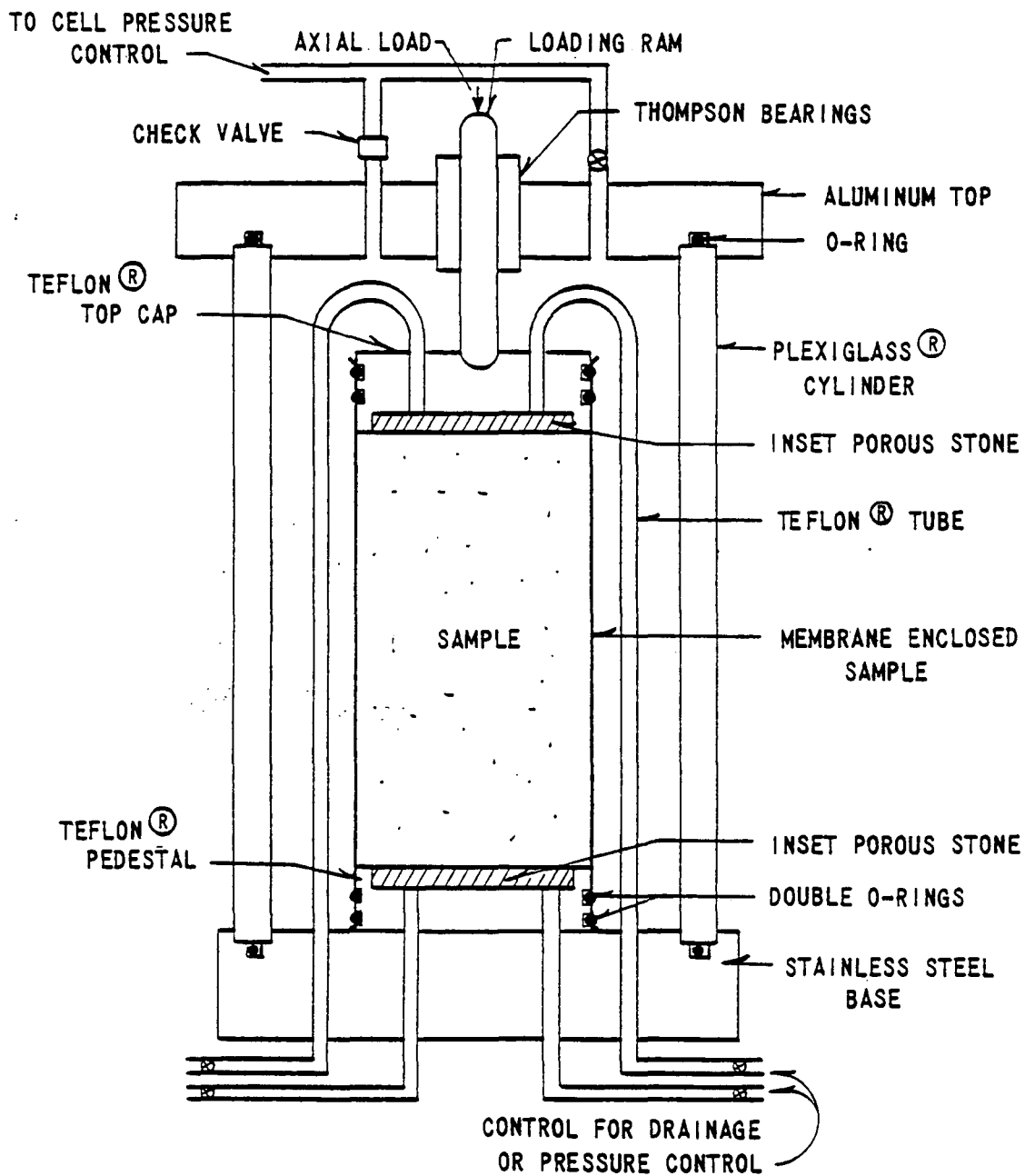


FIGURE 1. LEHIGH TRIAXIAL CELL SCHEMATIC

ultimate in compatibility through the use of Teflon^R at any points in which the permeameter is in contact with the permeant.

Details for the Lehigh triaxial cells are shown on Figs. 2, 3, 4 and 5. The base is constructed of 316 stainless steel. The pedestals and associated tubing are all of Teflon^R. Special fittings were designed and constructed to allow passage of the tubing and permeant through the stainless steel base while within the Teflon^R tubing. Special design requirements had to be met to insure no leakage of cell pressure in the areas where the tubing passes through the base. All O-rings are of chemically resistant Viton.

In addition to the advances in permeant-equipment compatibility, the triaxial cell developed for this testing includes the ability to flush all the air from the platens and porous stones through the use of a double-line drainage system feeding each of the two platens (see Figs. 2 and 3). In addition, friction is minimized during the loading of the sample through the use of Thompson bearings placed in the aluminum caps of the triaxial cell. These bushings, with a minimum friction, minimize the leakage that would occur in friction seals that do not make the use of bearings. Finally, several additional ports are provided in order to permit other types of monitoring which may be required with these cells. This would include the installation of pore pressure transducers, as well as monitoring of changes in cell water volume due to shrinking or swelling of the sample or, leakage, or osmotic diffusion of permeants through the membrane.

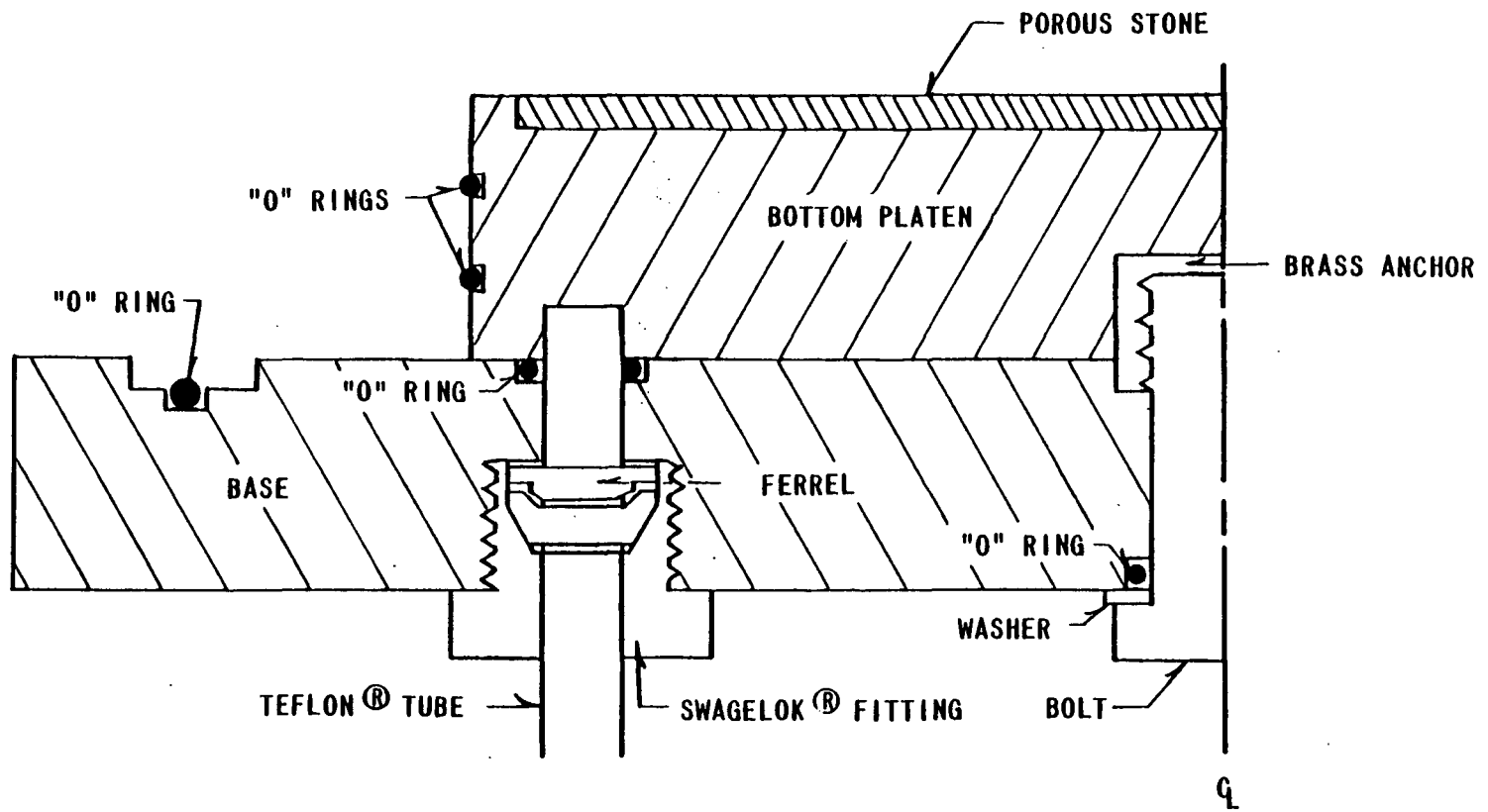


FIGURE 2 LEHIGH TRIAXIAL CELL DETAILS

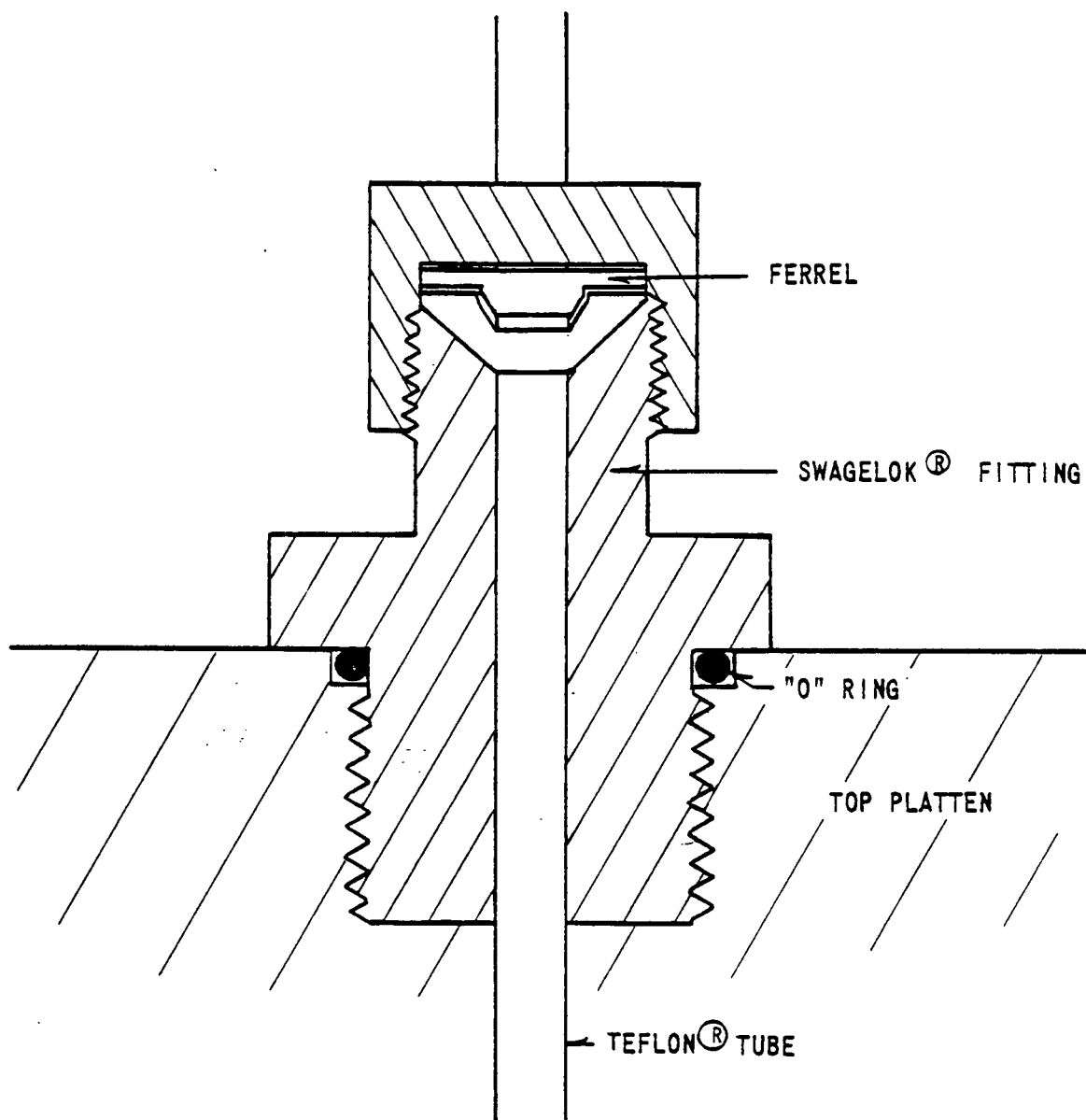


FIGURE 3 LEHIGH TRIAXIAL CELL DETAILS



FIGURE 4 LEHIGH TRIAXIAL CELL PHOTOGRAPH

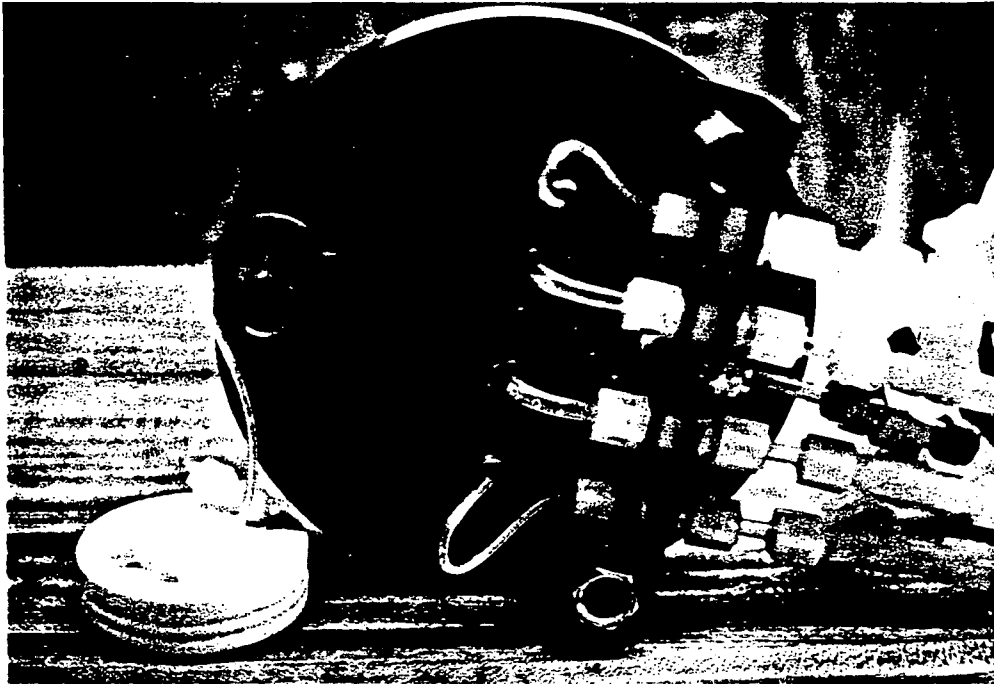
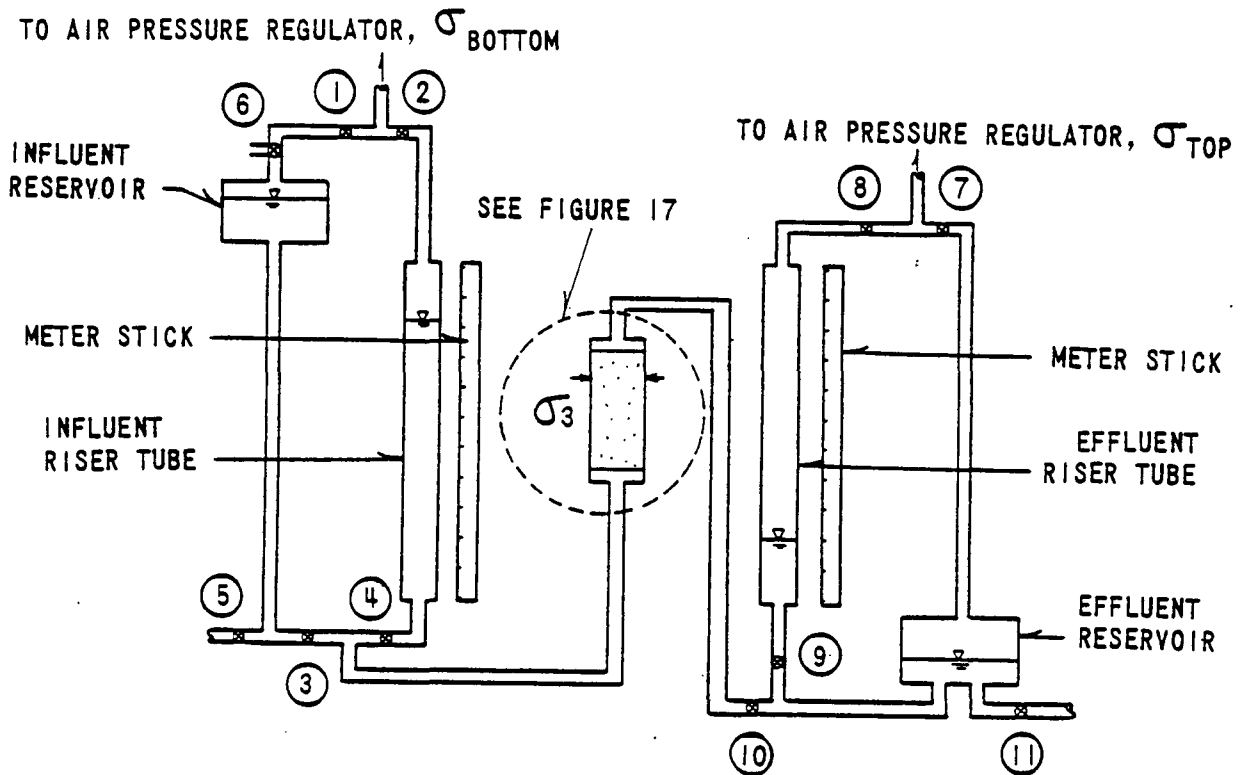


FIGURE 5 LEHIGH TRIAXIAL CELL PHOTOGRAPH

Permeability Board

A permeability board was designed, constructed, and tested in order to fully satisfy the objectives and constraints required to monitor the permeation of soils with hazardous and toxic permeants. This board, shown schematically in Fig. 6, has several unique features. The ability to measure both inflow and outflow volumes has been incorporated into the permeability board design. Readings are taken on an inflow riser pipe as well as an outflow riser pipe. In this way, volume changes in the sample, apparatus leaks, or permeant diffusion can be evaluated by notice the differences between readings in the inflow and outflow riser pipes. In addition, the permeability board is designed to allow permeants to be changed and the inflow riser pipes either filled or emptied without changing the state of stress on the sample. This is an important aspect of the system design. In order to maintain the proper experimental accuracy, it is necessary to read small changes in the volume of permeant that penetrates this sample. However, to read these small changes, the inflow and outflow riser pipes are quickly emptied and filled, respectively. Hence, it is necessary to refill the inflow riser pipe and empty the outflow riser pipe frequently throughout the testing period. In order to preclude sample changes that may occur due to repeated changes of stress on the sample, it was necessary to enable the permeameter board to be "rezeroed" without changing the state of stress on the sample. This was done by means of incorporating influent and effluent reservoirs into the pressure system as shown in detail on Fig. 6. For example, the inflow reservoir can be pressurized to the same background pressure as the inflow riser pipe. Then because of the additional gravimetric head provided



LEGEND:

VALVE	VALVE NAME/FUNCTION - MATERIAL
①	INFLUENT RESERVOIR PRESSURE CONTROL VALVE - BRASS
②	INFLUENT RISER TUBE PRESSURE CONTROL VALVE - BRASS
③	INFLUENT RISER TUBE FILL VALVE - TEFLON [®]
④	INFLUENT RISER TUBE BY-PASS VALVE - TEFLON [®]
⑤	INFLUENT RESERVOIR DRAIN VALVE - TEFLON [®]
⑥	INFLUENT RESERVOIR PRESSURE RELIEF VALVE (THREE-WAY) - BRASS
⑦	EFFLUENT RESERVOIR PRESSURE CONTROL VALVE - BRASS
⑧	EFFLUENT RISER TUBE PRESSURE CONTROL VALVE - BRASS
⑨	EFFLUENT RISER TUBE DRAIN VALVE - TEFLON [®]
⑩	EFFLUENT RISER TUBE BY-PASS VALVE - TEFLON [®]
⑪	EFFLUENT RESERVOIR DRAIN VALVE - TEFLON [®]

FIGURE 6 LEHIGH CONTROL PANEL SCHEMATIC

by the influent reservoir, the influent fill valve can be opened allowing a gravity refilling of the inflow reservoir. The system is reversed for draining of the effluent riser pipe.

The permeability board was designed to accommodate the wide range of stresses required for permeability testing. As shown on Fig. 6, this system has been developed to accommodate stresses up to a maximum of 897 kPa (130 psi). This is necessary in order to be able to model a wide range of stresses that could potentially be encountered in the field and to permit adequate backpressure to insure saturation.

In addition to the functional criteria that were incorporated in the design of the permeability board shown on Fig. 6, the question of permeant-equipment compatibility was again addressed. Essentially all valves, fittings, and tubings shown on Fig. 6 which come in contact with the permeant are constructed of Teflon^R. Valves which simply control air pressures to modify stresses and do not come in contact with the permeant are typically constructed of brass or stainless steel. A photograph of the board is shown in Fig. 7.

Control Panel

The control panel developed to conduct permeability tests with hazardous and toxic permeants is shown in Fig. 8. The functional criteria of the control panel design included the necessity to control the back pressure, gradient,

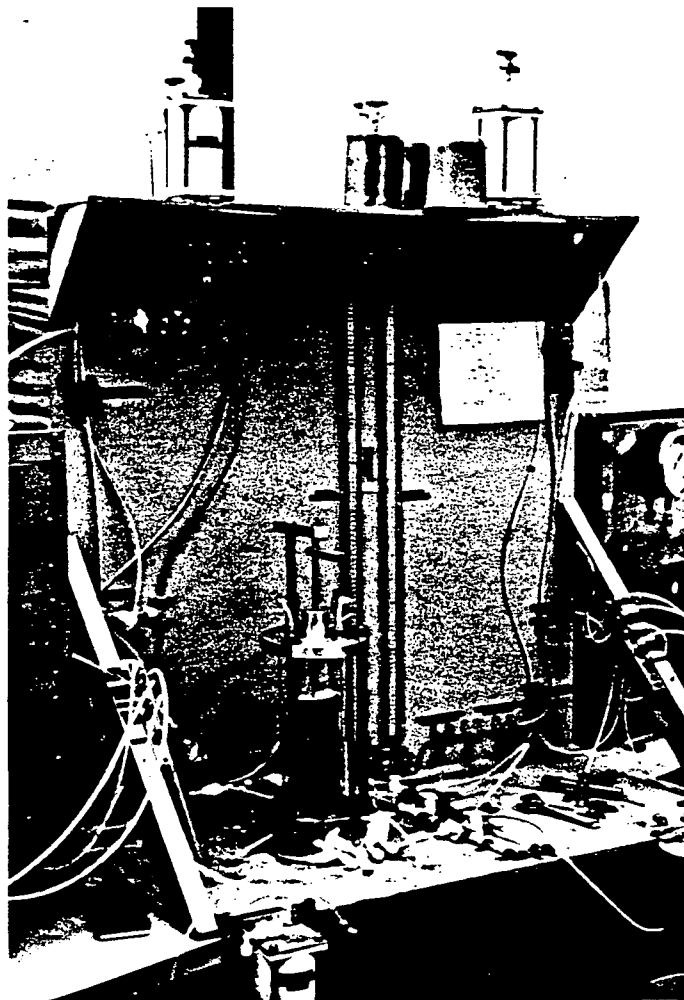


FIGURE 7 LEHIGH PERMEABILITY BOARD PHOTOGRAPH

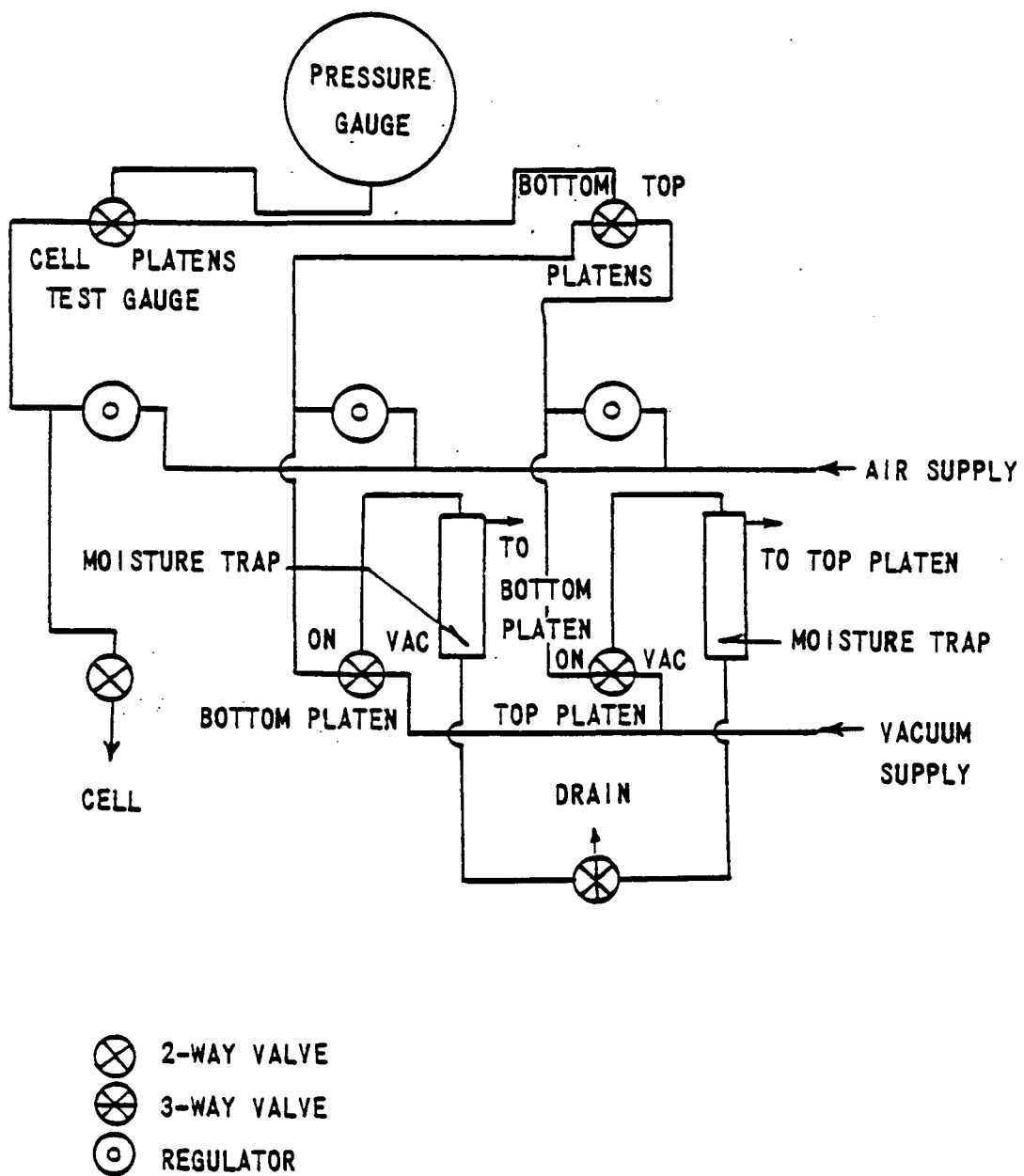


FIGURE 8 LEHIGH CONTROL BOARD SCHEMATIC

and confining stress to maintain the effective stress conditions. Further, the control panel must permit refilling of reservoirs at the beginning and during the test. Shown on Fig. 8 is a detailed schematic of the control panel and on Fig. 9, a photograph of the control panel. The uniqueness of the control panel is limited to its functional ability to supply the appropriate pressures to the permeability board.

Additional Equipment

In addition to the triaxial cell permeability board and control panel, certain additional equipment is necessary to conduct the permeability tests. Of primary importance is the triaxial cell membrane used to encapsulate the sample. Three materials are presently available for membrane materials. These are neoprene, butyl rubber and latex. Membranes of all three types were purchased for this research and a compatibility chart was checked prior to permeation with the selected pore fluid to insure compatibility between the membrane selected and the pore fluid to be utilized.

Each of the triaxial cells have the porous stone seated in both the top and bottom platens. These porous stones were obtained from a soil testing equipment vendor and consists of 6.4 mm (1/4-inch) thick, 63.5 mm (2.5 inch) diameter, carborundum stones.

In order to fabricate samples in the laboratory of the specified dimensions, sample molds were required. These were custom designed and



FIGURE 9 LEHIGH CONTROL PANEL PHOTOGRAPH

fabricated of aluminum in order to be utilized with the triaxial cell Teflons^R and platens. Although the concept of split-ring sample molds is not unique, it was necessary to fabricate these molds in order to insure the proper dimensions consistent with the triaxial equipment utilized for these studies.

TYPICAL RESULTS

Shown on Fig. 10 are the results of the typical triaxial cell permeability tests where the effect of acetic acid upon the permeability of a soil-bentonite mixture was investigated. Note that after the initial application, saturation and permeation with water, the system achieved equilibrium and, at that point in time, acetic acid permeant was added. Permeability in response to the acetic acid permeant was monitored for a total pore volume displacement of approximately 8. As a gradual increase in permeability resulting from changes in the double layer as well as dissolution of the mineralogical structure. Additional details regarding procedure and analysis of specific permeability test results are contained in Reference 2. Utilizing the same equipment, the stress-strain relationship was developed after permeation for this sample as shown in Fig. 11.

SUMMARY AND CONCLUSIONS

Permeability testing equipment was designed and constructed to conduct triaxial permeability tests with a wide range of chemical permeants.

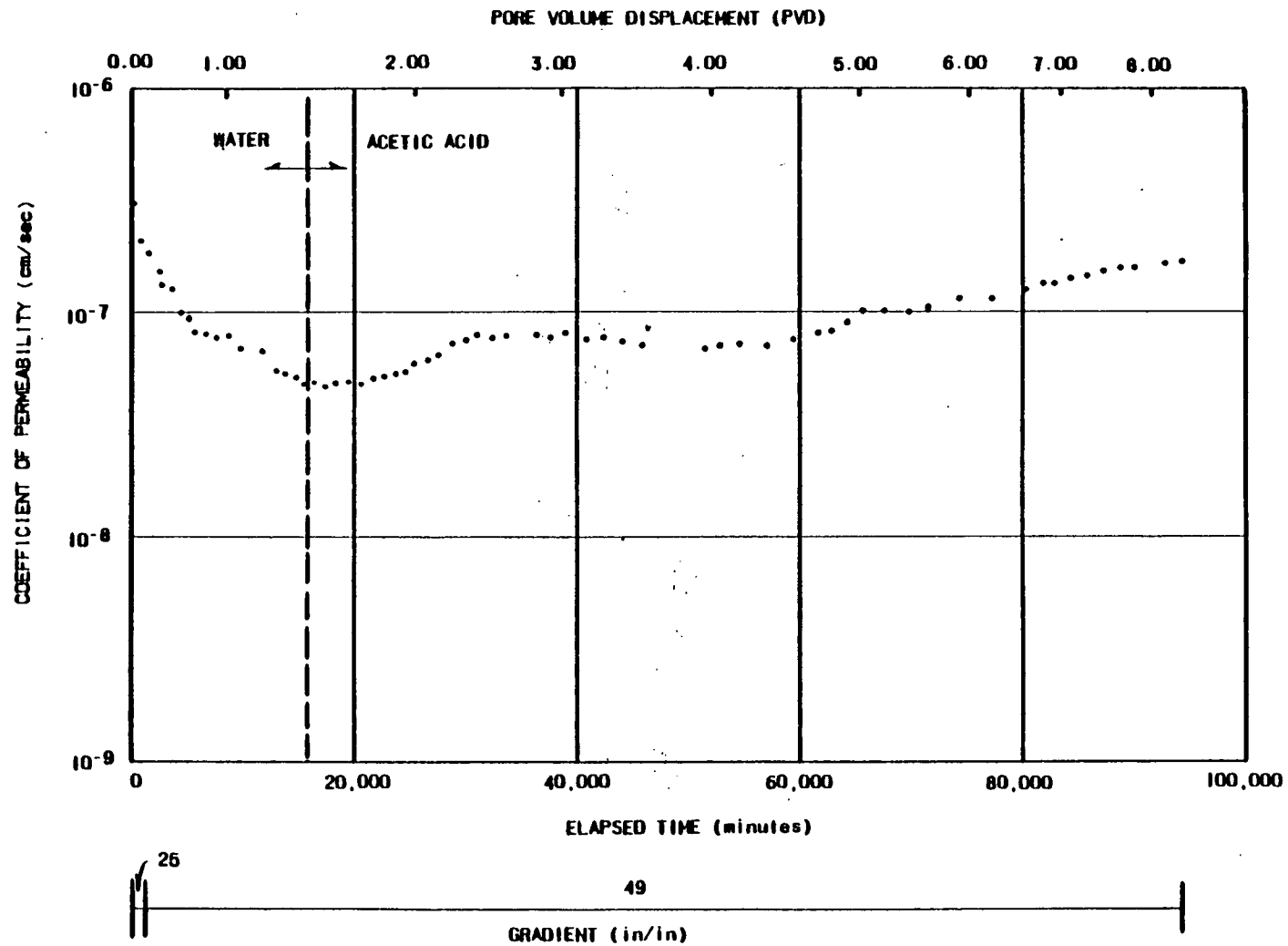


FIGURE 10 PERMEABILITY TEST RESULTS - SAMPLE NUMBER S-15

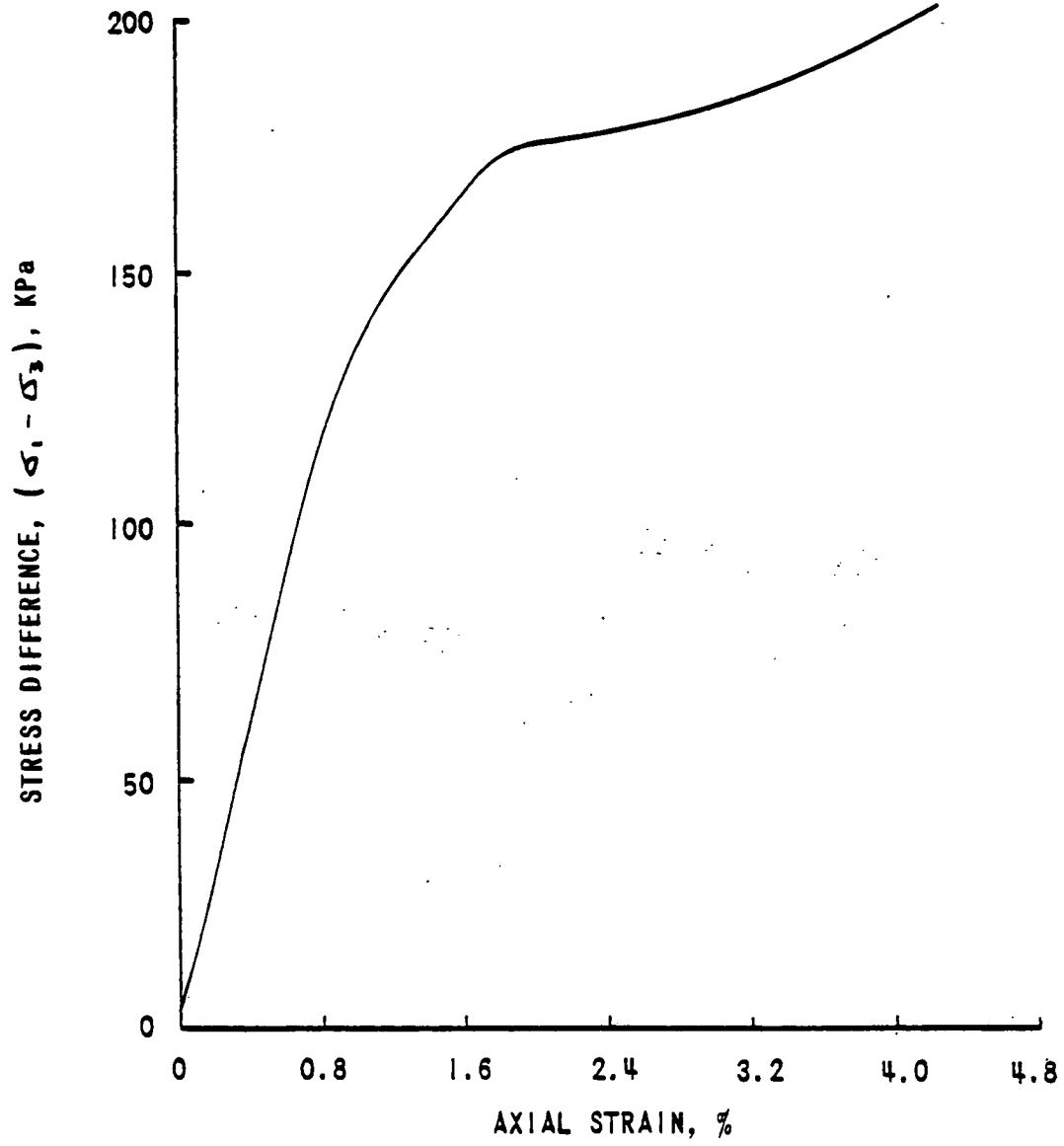


FIGURE 11 STRESS-STRAIN RELATIONSHIP - SAMPLE NUMBER S-15

Based upon the equipment development work and the results of numerous permeability tests conducted utilizing this equipment, it is concluded that the triaxial cell permeability equipment can be successfully utilized to examine the influence of hazardous and toxic permeants upon the permeability of fine-grained soils.

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