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# Triaxial Shear Equipment for Gravelly Soils

## Appareil d'essai de cisaillement triaxial pour sols graveleux

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### Summary

This paper gives description of the construction and operation of triaxial shear equipment for testing soils with maximum particle sizes of 2 inches or more.

The pressure chamber was designed for a specimen 9 inches in diameter by 22½ inches high with a maximum lateral pressure of 100 psi. High strength heat-treated aluminium alloy was used extensively to decrease the weight, although both an aluminium and a transparent plastic pressure cylinder were provided. The axial load is applied by a compression machine equipped with an automatic stress-strain recorder and rate indicators.

The soil specimen is enclosed in a rubber membrane which is sealed to aluminium end plates with porous inserts which permit drainage or saturation of the specimen and the measurement of pore fluid pressures for sealed conditions. An electronic recorder is available for recording the pore pressures.

The purpose of this paper is to describe the construction and operation of triaxial-shear equipment for testing gravelly soils with a maximum particle size of 2 inches or more.

The construction of this equipment was undertaken in 1950 because of the need for economical design data on the shearing properties of gravelly soils. Since many of the projects constructed by the Bureau of Reclamation are in localities where gravelly or rocky soils are prevalent, facilities for testing these soils are essential.

Although a specimen diameter of five times the largest particle size is technically desirable, the size of the specimen was limited by the loading device available. Therefore, a 9 inch diameter specimen was selected as a practical size and since the loading machine had ample height a height-diameter ratio of 2½ was chosen to minimize the effect of the specimen end plates. This specimen size was considered satisfactory for materials containing particles up to 2 inches in diameter and of use in studying materials containing up to 3 inch maximum particles.

### Sommaire

Cet article décrit la construction et l'utilisation d'un appareil de cisaillement triaxial pour mesurer la force de compression des sols ayant un grain maximum de 2 pouces ou plus.

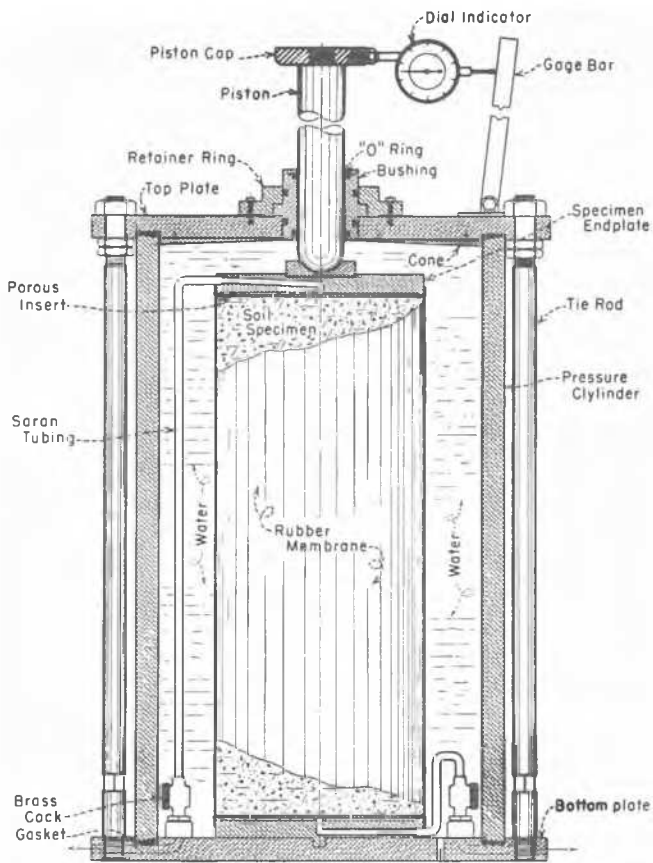
La chambre de compression a été construite pour supporter une pression latérale maxima de 100 livres par pouce carré et peut contenir des échantillons cylindriques de 9 pouces de diamètre et de 22,5 pouces de hauteur. Pour réduire le poids on a surtout employé un alliage d'aluminium de haute résistance, traité thermiquement, bien que l'appareil fût muni d'un cylindre de compression d'aluminium et d'un cylindre de matière plastique transparente. La pression axiale est exercée par une machine de compression munie d'un enregistreur automatique de pression et d'un indicateur de vitesse.

L'échantillon de sol est placé dans une enveloppe de caoutchouc. Cette dernière est soudée à des plaques d'aluminium, dans lesquelles se trouve un dispositif poreux, qui permettent le drainage ou la saturation des échantillons, et la mesure de la pression du liquide dans les pores. Un enregistreur électronique est utilisé pour mesurer les pressions interstitielles.

Of course, the validity of test results on this latter study will have to be determined.

A maximum lateral pressure of 100 pounds per square inch was used in the design of the pressure chamber. Since water was to be used for the pressure medium around the specimen, rustproof material was needed for the entire pressure chamber. To meet these requirements and attain a minimum weight to facilitate handling, high-strength heat-treated aluminium alloy was used extensively in its fabrication. Two interchangeable pressure cylinders, one of soft aluminium and one of clear plastic (plexiglass) were made for the pressure chamber. The plastic cylinder was made to permit observation of the specimen during testing, which is desirable in some cases. However, the plastic cylinder has the disadvantage of flowing under stress and requires annealing from time to time to relieve the stresses.

Since plastic tubing of the proper size and wall thickness for the pressure cylinder was not available, sheet stock was used. Plexiglass of 1 inch thickness was found to provide an ade-



quate safety factor. Therefore, the 1-inch sheet plastic was rolled and edges joined to form a cylinder with an inside diameter of approximately 14 inches. This work was performed by a local plastic fabricating company. A plastic strip  $\frac{1}{2}$  inch thick by 1 inch wide was cemented over the joint on the outside. The formed cylinder was not exactly round so each end for a distance of about  $\frac{3}{8}$  inch from the end was machined both inside and out to produce true circles with as thick a wall as possible. The ends were machined parallel and beveled on the inside edge as shown in Fig. 1 to concentrate the stress, when assembled, on the outside portion of the gasket. When used to an appreciable amount, the plastic cylinder is annealed at 2- or 3-month intervals to relieve the internal stresses. The annealing is accomplished by heating in an oven at 122° F for 24 hours, then cooling slowly by turning the oven off and allowing all to cool together.

The aluminium-pressure cylinder was made by forming  $\frac{3}{8}$  inch thick soft sheet stock and welding the joint, then machining the outside diameter and length to correspond to the plastic-pressure cylinder.

The top and bottom chamber plates, Fig. 1, were machined from 1-inch heat-treated aluminium alloy plate. The bottom plate was threaded for six equally spaced stainless steel tie rods and the top plate was drilled to fit over these rods and secured by nuts on top.

Fig. 1 Sectional view of Triaxial Shear Pressure Chamber  
Coupe transversale de la chambre de pression de cisaillement triaxial

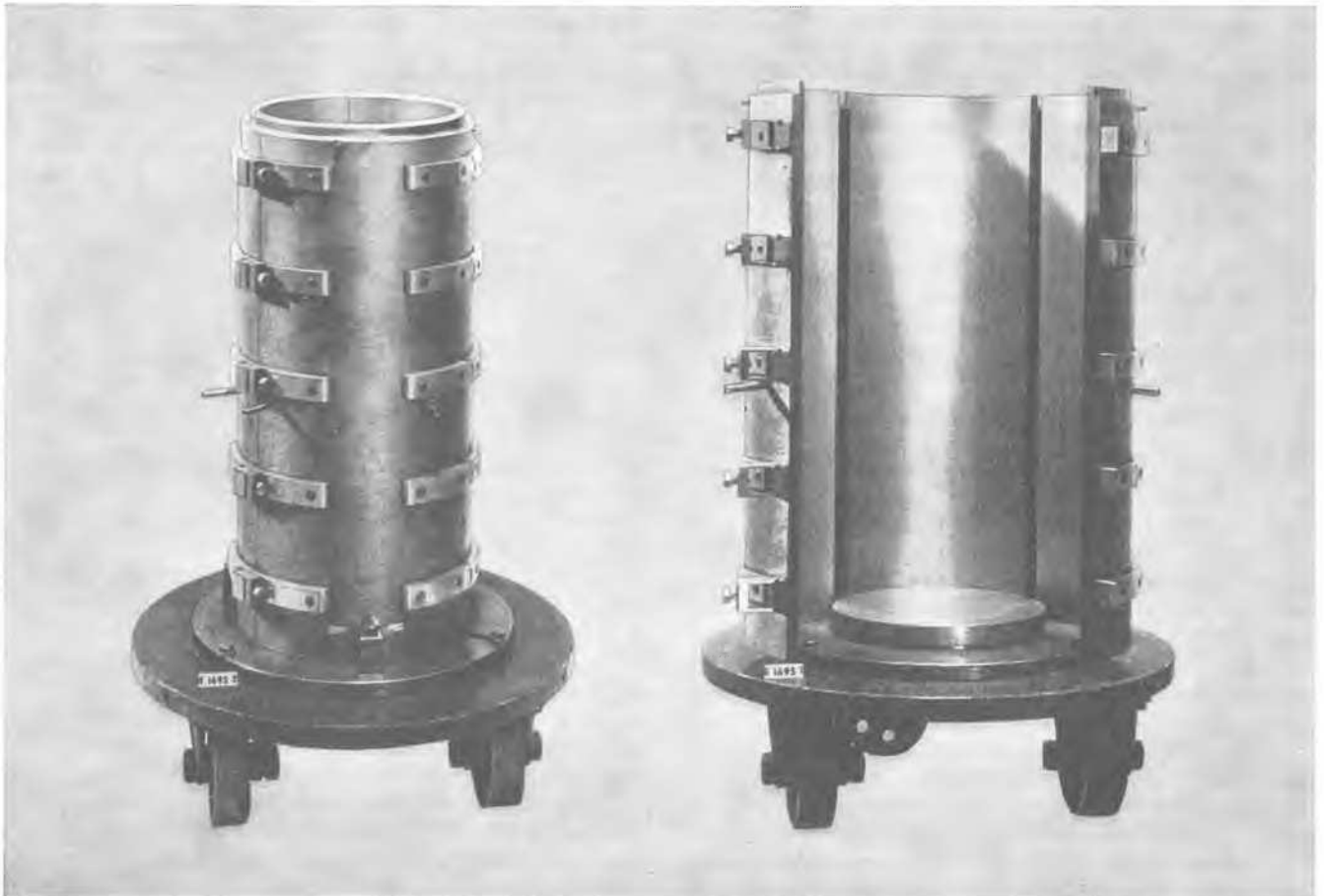


Fig. 2 Specimen Mold Assembly on Dolly  
Moule cylindrique sur plateforme

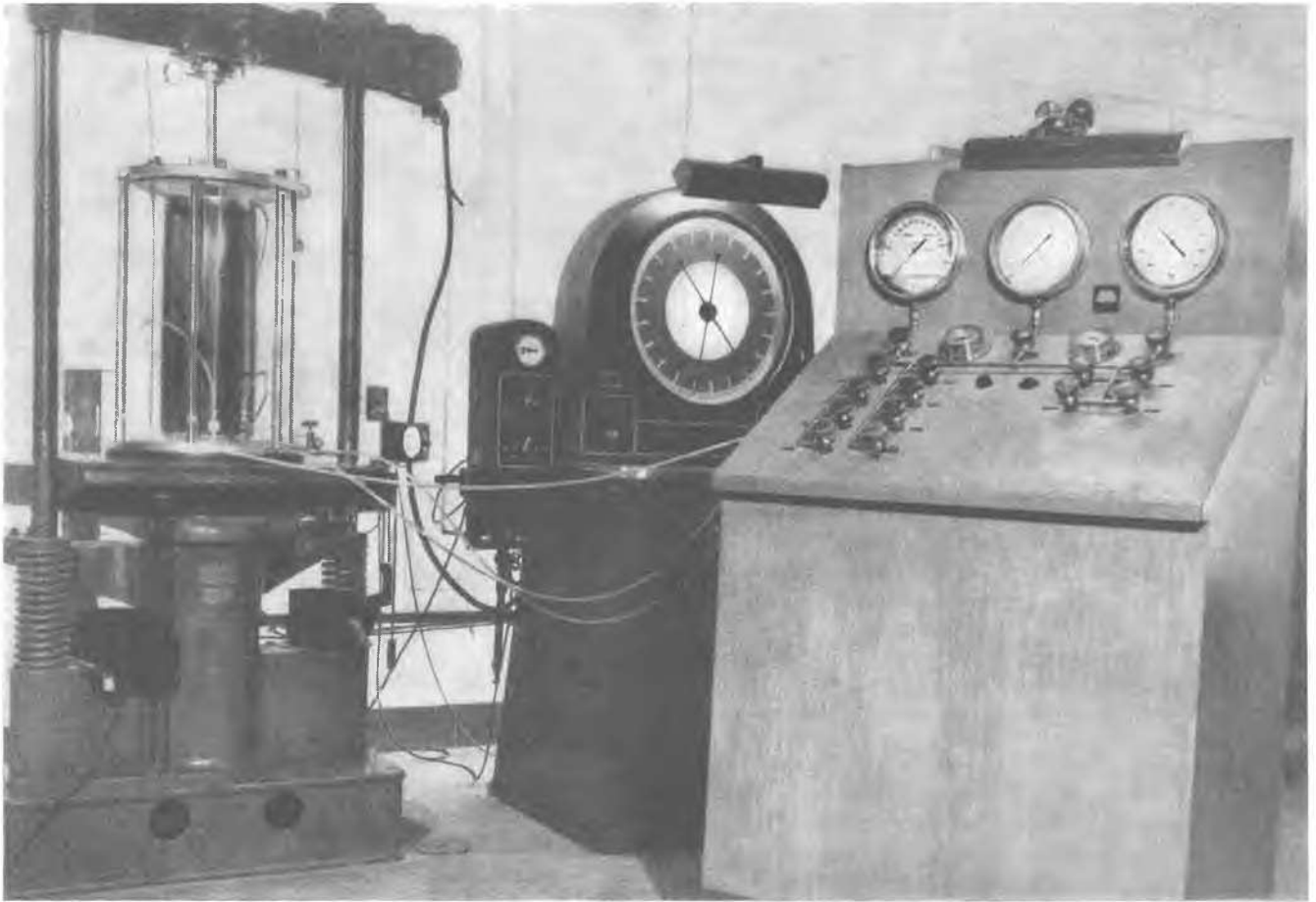


Fig. 3 Assembled Triaxial Shear Pressure Chamber With Loading Machine and Control Panel  
Chambre de pression de cisaillement triaxial assemblée avec machine de charge et panneau de contrôle

Gaskets for sealing the top and bottom plates to the pressure cylinder were made from  $\frac{3}{16}$  inch thick sheet rubber gasket stock. Since the pressure cylinder fits the gasket groove with a clearance of only 0.005 inch in outside diameter, there was no chance for the gasket to move out under lateral pressure and a positive seal was assured each time the pressure chamber was assembled.

Specimen end plates were made from a 1-inch rolled aluminum alloy plate and recessed on the specimen side for a porous bronze insert. The porous bronze plates were furnished by the manufacturer approximately  $\frac{1}{8}$  inch thick and in the proper diameter so that no machining was necessary. They are not fastened to the end plates, therefore, may be readily removed for cleaning with water or air. The bottom end plate has a dowel for centering the specimen in the pressure chamber. The top end plate was recessed, as illustrated in Fig. 1, for a stainless steel load block in which the piston seats during axial loading of the specimen. Both specimen end plates were fitted with  $\frac{3}{8}$  inch outside diameter Saran tubing and brass cocks for connecting to drainage or saturation tanks and pore pressure cells. Saran tubing was used because of its flexibility and ability to withstand the 100 psi lateral pressure without collapsing.

The piston, through which the axial load is applied to the soil specimen, was made of stainless steel 2 inches in diameter with the circumference finished by grinding. A stainless steel plate  $\frac{3}{4}$  inch thick by 4 inches in diameter was threaded to the top of the piston to serve as a bearing plate for the head of the compression machine. Onto this plate was mounted a dial indicator having 1 inch travel and 0.001 inch graduations.

Then a bar was attached to the top plate of the pressure chamber as shown in Fig. 1 so that the dial indicates the piston movement to 0.01 inch. A total piston travel of 7 inches or approximately 30-percent axial strain for the 22 $\frac{1}{2}$ -inch high specimen was used in the design. A gage block was made for checking the angle of the bar each time the pressure chamber is assembled. However, experience has shown that with care in handling, many tests may be performed without any movement of the bar.

A bronze bushing serves as a guide for the piston and was bored to a diameter 0.002 inch larger than the piston. Two "O" rings were recessed into this bushing to give a positive seal around the piston with a very small amount of friction. An "O" ring was also used to seal between the bushing and the top plate of the pressure chamber. The bushing is held in place by a retainer ring but may be turned with a spanner wrench. However, extensive testing of the equipment for piston friction indicated that turning the bushing during testing had very little effect, therefore has not been practiced as part of the standard test procedure. The bottom of the bushing was machined to align with a cone attached to the inside of the top plate of the pressure chamber to aid the air escape through the piston hole as the chamber is filled with water.

As previously mentioned, the top and bottom plates of the pressure chamber are held in place by six stainless steel tie rods 1 inch in diameter turned down and threaded  $\frac{7}{8}$  inch at each end. Coarse machine threads, nine per inch, were used on the lower end of these rods and they are screwed directly into the

bottom aluminium alloy plate. They are not removed from this plate during test preparation. Fine machine threads, 14 per inch, were used on the top end to permit better adjustment in securing the top plate. By experimentation a satisfactory amount of compression of the cylinder gaskets was determined and stop nuts were accurately placed on all six tie rods to assure that the top and bottom chamber plates would be parallel every time the unit is assembled. As an added precaution, a torque indicating wrench is used for tightening the nuts securing the top plate so that equal stress is applied to each nut.

The rubber membranes used for enclosing the soil specimen were purchased from a rubber specialty company. They were furnished as seamless tubes 9 inches in diameter by about 24 inches long with a wall thickness between  $\frac{1}{32}$  inch and  $\frac{1}{16}$  inch. In general, the wall thickness is thick at one end and thin at the other. In order to provide a little greater cushioning for the end plate clamp, a strip of sheet rubber about  $\frac{1}{32}$  inch thick by  $\frac{1}{2}$  inch wide was cemented with rubber cement around the outside of the tube on the thin end. Stainless steel clamps, "Aero-Seal", of the worm screw type manufactured for industrial uses, were found to give a good seal and be convenient to use.

The soil specimen mold assembly shown in Fig. 2 is made of three sections fastened together at two joints with hinges and at the third with clamps to permit easy removal from the specimen. The mold was made from an aluminium alloy casting and finished with a wall thickness of about  $\frac{3}{4}$  inch so is very sturdy yet not too heavy to handle. The mold is provided with two projections on the outside near the middle to receive a bail for lifting the mold and specimen with a hoist. The three-wheeled dolly on which the mold is mounted in Fig. 2 was found to be very convenient for transporting the mold and specimen. During the compaction of the soil specimen the dolly is set on wooden blocks so the wheels are not subjected to the impact of the compaction hammer. A heavy paper liner is used in the mold during compaction to keep the soil from sticking to the mold. After the mold is removed the paper is readily peeled off without damaging the specimen. Some very gravelly materials, which have been tested in this equipment, were compacted moist and the paper liner left around the specimen for support until it dried. Holes were torn in the paper from time to time to facilitate drying. The specimens were then saturated in the pressure chamber where a low lateral pressure was used to stabilize them. All specimens are compacted on a plain aluminium end plate covered with a disk of paper to facilitate its removal.

In preparation to placing the rubber membrane around the specimen, it is expanded by a vacuum to conform to the inside of a metal tube  $9\frac{1}{2}$  inches inside diameter. This permits the membrane to be placed over the specimen without touching it, and when in the proper position and the vacuum released the rubber sleeve fits snugly around the specimen.

Saran tubing,  $\frac{3}{8}$ -inch outside diameter with a wall thickness of  $\frac{1}{16}$  inch, was found to be satisfactory for all connecting lines between the control panel and the pressure chamber. Brass unions were used for connecting the plastic tubing to the base plate of the pressure chamber so the lines can be easily disconnected when desired, but the lines are long enough that it is not necessary to disconnect them between each test. High pressure air hose with quick couplers were used to connect the portable control panel to air and vacuum supplies.

The lateral pressure for the specimen is maintained by a pressure regulator in conjunction with an air tank of about 40 gallons capacity. A small "air bleed" in this tank eliminates the

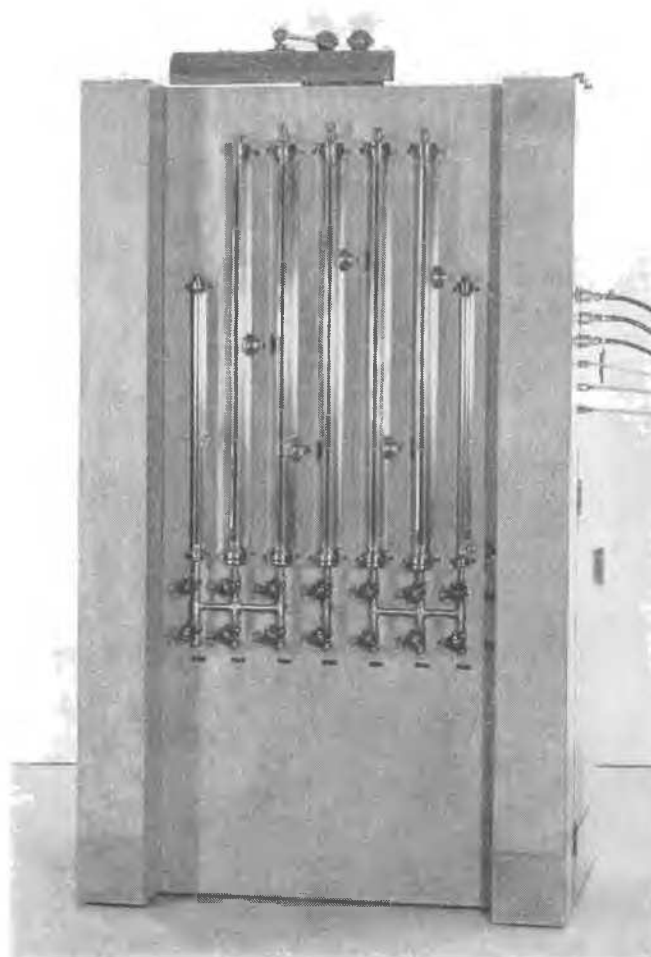


Fig. 4 Back of Control Panel Showing Water Gages  
Panneau de contrôle (vu de dos) montrant les indicateurs de l'eau

possibility of the lateral pressure rising above the regulator setting during the specimen deformation. The lateral pressure and pore-water pressure are read by means of "no-flow" pressure cells on the control panel, which is equipped with three pressure gages of different capacities as shown in Fig. 3. Water gages with reading glasses are mounted on the back side (Fig. 4) of the control panel for reading the volume change of the specimen and the amount of water taken up or expelled by the specimen. Brass valves with bronze stems were used in the water lines, and commercial diaphragm type refrigeration valves were used for air control on the front of the control panel.

A  $\frac{1}{4}$ -ton chain hoist was mounted on a track which extends directly over the compression machine. A special carriage of strap brass and chain was made for handling the soil specimen during preparation and disassembly of the testing equipment. Eyebolts in the top chamber plate and a yoke are used for attaching the hoist when the entire pressure chamber is to be moved. The initial volume of the soil specimen is determined in the pressure chamber by the water displacement method. After the pressure chamber is initially calibrated, only two weighings are required for each specimen, one of the specimen and container and the other of the pressure chamber containing the specimen and water up to the calibration point, which must be above the specimen.

This equipment permits the testing of soils under any desired condition of consolidation and drainage, and under a wide

range of lateral pressures. The three most used conditions for testing soils are as follows:—

(1) “Unconsolidated-Undrained,” in which the lateral pressure is applied and the shear strength determined immediately without allowing any drainage from the specimen;

(2) “Consolidated-Undrained,” in which the soil specimen is allowed to consolidate under lateral pressure, and then sheared without allowing any drainage from the specimen;

(3) “Drained,” in which the specimen is allowed to drain throughout the consolidation and shearing periods of the test.

The “Drained” test is conducted only on free-draining materials, in which the pore-water pressure gradient within the soil specimen is very small. For the more impervious soils the “Undrained” test is conducted with pore-water pressure measurements which permit the determination of the shearing

strength of the soil under zero pore-water pressure conditions. A three-channel electronic strip recorder equipped with pressure transducers is available in the laboratory and may be used for recording the pore-water pressures at three points within the specimen. By the use of this recorder, a study can be made of the pore-water pressures developed at various points within the soil specimen during the triaxial shear test.

#### Acknowledgment

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