Improved Soil Testing Methods

New instruments for consolidation, shear and permeability tests contributed to the soil investigations on the Muskingum project

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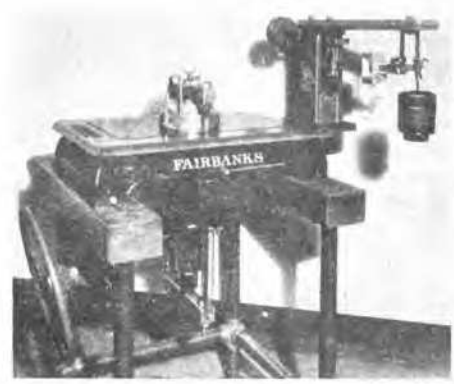


FIG. 2—A JACK combined with a modified platform scale proves a convenient loading rig for both consolidation and shear tests.

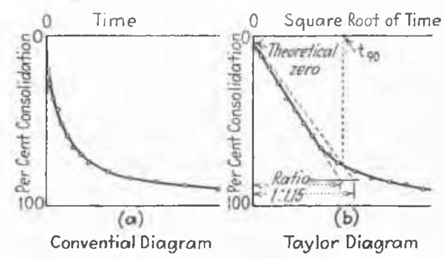


FIG. 3—EVALUATING the results of consolidation tests is facilitated by a new method of plotting.

IN THE RAPIDLY growing field of soil mechanics an ever-present problem is the development of new apparatus and methods of testing. Some recent advances with which the writer has been closely associated resulted in improved instruments and methods, which are here briefly described in the hope that they may be of assistance to other investigators.

Consolidation tests

The basic idea of the consolidation test on clay is now so generally understood that no detailed description need be given here. Briefly, it is a test in which a cylinder of clay, short in proportion to diameter, and laterally restrained, can be compressed or allowed to expand, with provision for free passage of water out of or into the voids as load is applied or released.(1)

Subsequent to the studies of Dr Arthur Casagrande on consolidated marine clays, which showed the necessity of testing undisturbed samples, (2) the piston-and-cylinder apparatus developed at M.I.T. under Dr. Charles Terzaghi (1) was superseded by a ring device illustrated in Fig. 1. In preparation, the ring can be separated from the rest of the apparatus, thus allowing the sample to be fitted into place with a minimum of distortion. Disks of porous refractory material provide free drainage top and bottom. An L-shaped sealing ring of thin bronze has been found efficacious in preventing soft clay from squeezing past the upper disk. A cylinder of thin sheet rubber, bound into the depressions in the ring and the top bearing plate, prevents evaporation from the upper surface.

Fig. 2 shows the device mounted in the newest type of loading machine. The latter, utilizing a platform scale and a screw jack, is a distinct improvement over the old dead-weight arrangements. The modifications made in the scale are as follows:

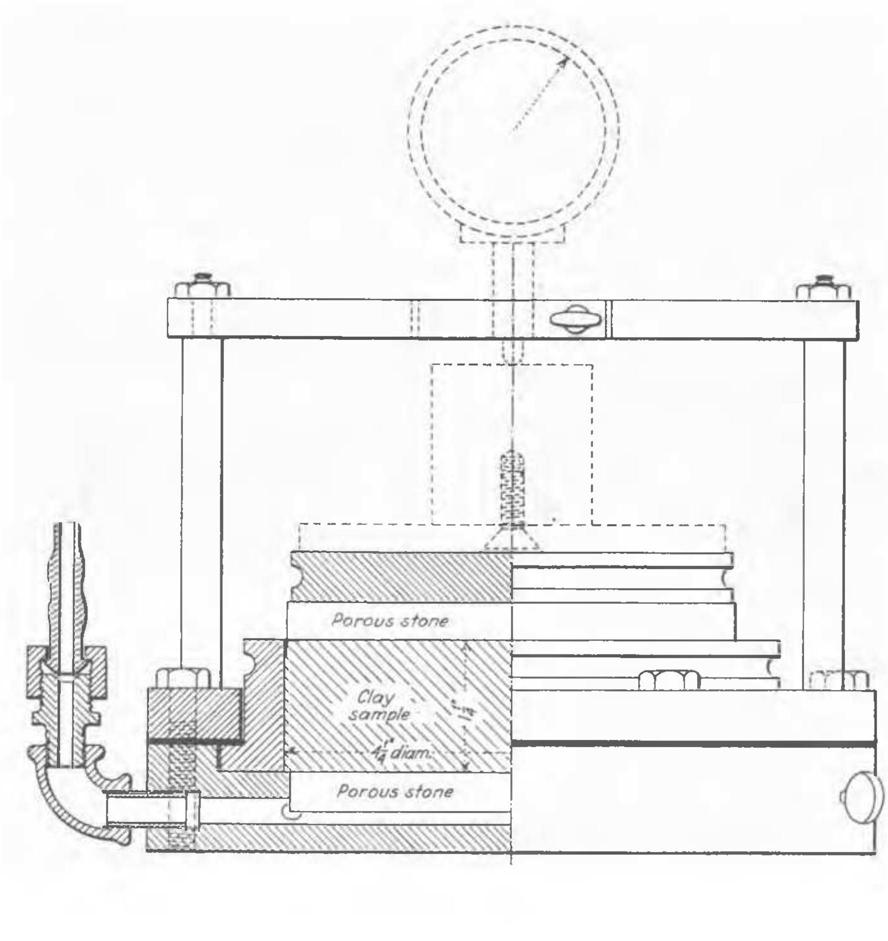
1. The sheet-steel platform is reinforced by a ⅝-in. steel plate underneath to provide greater rigidity.
2. A small counterweight is applied to the beam just forward of the fulcrum to bring the center of gravity of the beam assembly into the plane of the knife-edges. This corrects the slight eccentricity introduced by the manufacturer to provide a damping characteristic for ordinary weighing, and makes the load on the platform independent of the tilt of the beam.
3. The horizontal bars in the beam-stop are cut out, allowing the end of the beam a free travel of 7½ in. Thus the platform can move 0.075 in. without any change of load.
4. The vertical members of the beam-stop are drilled and tapped for two opposing thumb-screws, which are used to lock the beam when the load is being changed.
5. The pillar is cut short for better appearance and greater ease of operation.

The yoke is guided by sleeves in the supporting framework, and its weight is counterbalanced by springs. Friction in the jack and in the guides has no effect whatever on the load applied to the sample.

Analysis of consolidation curves

Determination of the coefficient of consolidation of a soil from a time-consolidation curve has in the past been

FIG. 1—CONSOLIDATION measurements of clays were made on undisturbed samples in a ring instrument with pressure plates of porous stone.



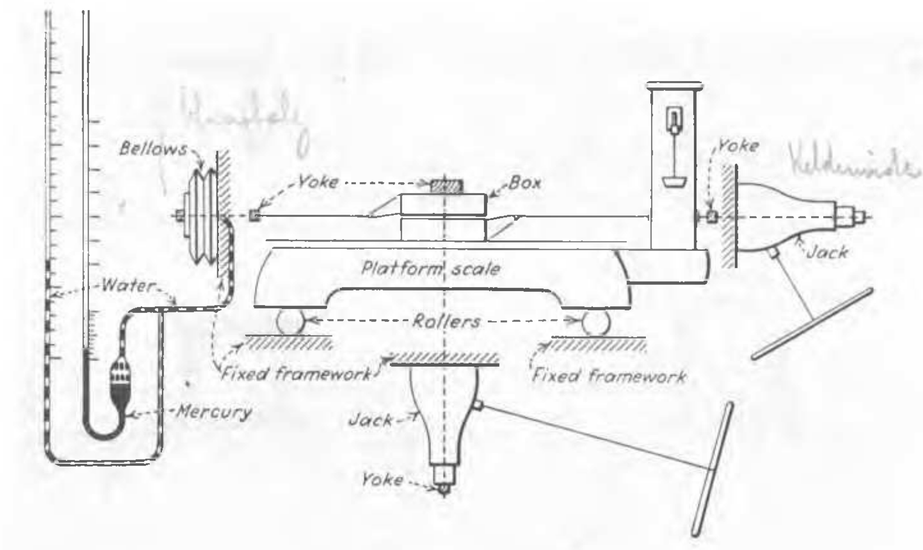


FIG. 4—SHEAR TESTS OF SOIL SAMPLES are made in a device that permits vertical movement under maintained load.

a rather tedious process.(¹) A new method, devised by Mr. Taylor, shortens the work considerably. Instead of the conventional plot, shown in Fig. 3a, values of per cent consolidation are plotted against the *square root of the time,* as in Fig. 3b. The upper portion of the curve comes out a straight line. Minor deviations due to errors of observation can be adjusted by eye. The point where the straight line intersects the vertical axis is the theoretical zero. If another straight line is drawn through the theoretical zero in such a manner that its horizontal intercept is to that of the first line as $\sqrt{5.33}$ is to $\sqrt{4}$, or as 1.15 is to 1, the point where this line cuts the curve represents theoretical 90% consolidation. If the time corresponding to this point is called t_{90}, the coefficient of consolidation, c, is given by the relation

$$c = \frac{0.848\, h_o^2}{t_{90}}$$

wherein h_o is the reduced length of path of percolation in the soil sample.

The recent studies have also brought out the fact that the equation for the theoretical consolidation curve can be replaced, with an error of less than one-half of one per cent, by the simple expressions:

$T = 0.7854\ Q^2$, for Q from 0 to 0.5, and $T = -0.9332\ log\ (1-Q) - 0.0851$ for Q from 0.5 to 1.0.

In these equations, Q is per cent consolidation expressed as a decimal and T is the time factor, an abstract number equal to the ratio $\frac{ct}{h_o^2}$, wherein t is actual time and c and h_o are the characteristics of the actual soil mass as defined above.

Shear tests

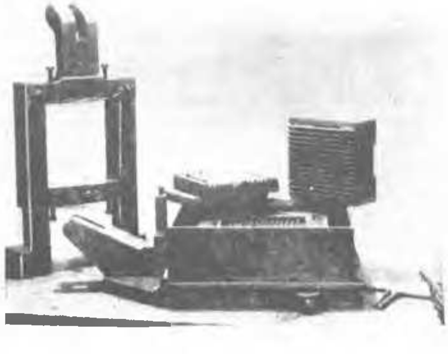
Numerous devices have been designed for measuring the shearing resistance of soils. A common type is one in which the soil is held in a shallow box divided horizontally into a lower and upper section which can be moved relative to one another in a horizontal sense. A vertical load is applied to the soil, and the force required to produce failure in shear on the plane of separation is measured. Ridges or teeth are usually provided in the two elements to ensure an approximately uniform distribution of shearing stress.

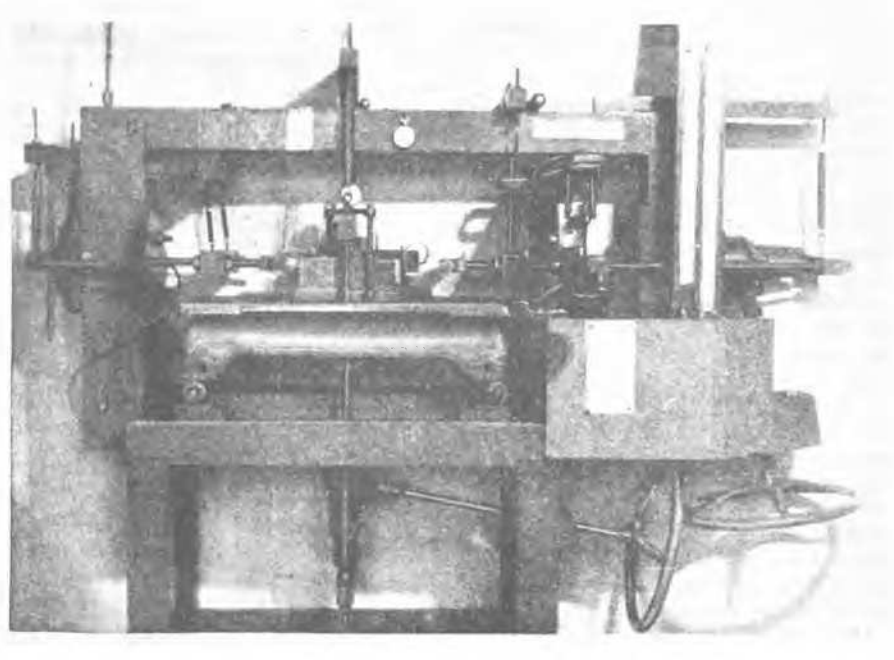
An important item, overlooked in some designs, is that during the shearing process the sample must be free to deform vertically without change of load. When this condition is not fulfilled, tests on compact granular soils, which expand appreciably when sheared, give high friction angles under low loads, decreasing as load increases.

In the summer of 1934 a shearing machine embodying certain interesting features was designed by the writer for the soils laboratory of the U. S. Engineer Office at Zanesville, Ohio. The essential parts are shown schematically in Fig 4. Vertical load is applied in a manner identical with that in the consolidation device previously described. The scale and the lower section of the box are moved as a unit by the horizontal jack. The reaction, which is the net shearing force, is measured by a Powers bellows filled with water and connected to manometers, mercury for heavy loads, water for light. The areas of the manometer tubes are small compared to the bellows, so that the upper section of the box is practically stationary in a horizontal sense. Constancy of vertical pressure irrespective of expansion or contraction of the sample during shear is assured by allowing the scale beam to float freely.

Fig. 5 is a photograph of the device. Due to the pressure of time, the simplest type of timber framework was used. However, the parts which really mattered were constructed with the requisite accuracy, and the apparatus functioned smoothly from the start. Fig. 6 shows

FIGS. 5 AND 6—THE shear testing device (right) and the smooth face obtained in a typical shear test (below).





the shearing box and a sample after a test, illustrating the clean-cut shear failures obtained.

Sampling—Test pits sunk for exploration in the Zanesville District disclosed considerable material of a type which has always been difficult to sample; a mixture of grains of widely varying sizes, with enough fine material to produce appreciable cohesion, and enough gravel and pebbles to prohibit the use of an edged sampling cylinder.

To obtain samples for permeability tests, the writer developed a scheme utilizing a wooden sampling box of 1-ft. cube, assembled with screws and long bolts and waterproofed with aluminum paint.

The first operation is to excavate half the pit to a depth of about 2 ft. below the existing bottom. On the ledge thus formed a column of soil about 10 in. square is isolated by careful excavation with a trowel or other small tool. The box, without top or bottom, is lowered around the soil column. The spaces at the sides are filled with damp sand, tamped carefully in small amounts, filling the holes left by small stones, and forming a snug packing between box and sample (Fig. 7a). The top of the sample is trimmed down to about 1 in. below the upper edge of the box and covered with sand. The sand is compacted and struck off flush with the top of the box. The cover is applied and screwed into place (Fig. 7b).

A spade is forced into the soil a few inches below the box, and the whole thing is turned over (Fig. 7c). The excess soil (now at the top) is trimmed down, the sand packing is finished and struck off, and the sixth face of the box is fastened in place (Fig. 7d).

Testing—In the laboratory the four faces of the sample through which water is not going to pass are successively sealed with paraffin (Fig. 7e). During this operation measurements are taken to determine the average net dimensions of the sample.

The sample thus encased is placed in a test box, with a filter and screen at the bottom, and the paraffined sides are sealed to the box by local melting. The sample is saturated by slow immersion, allowing water to percolate from bottom to top. Then a standpipe assembly is fastened to the top of the box, and the permeability is measured by filling the standpipe and observing the fall in head as a function of time. The apparatus is shown schematically in Fig. 7f. For photographs of the sampling and testing devices see ENR, April 9, 1936, p. 533.

One of the principal advantages of this method is the simplicity and compactness of the field equipment and the ease with which the sample is obtained, even by a person unskilled in laboratory work. The tedious part is the application of the paraffin seals, and it is hoped that an improved procedure can be evolved before long.

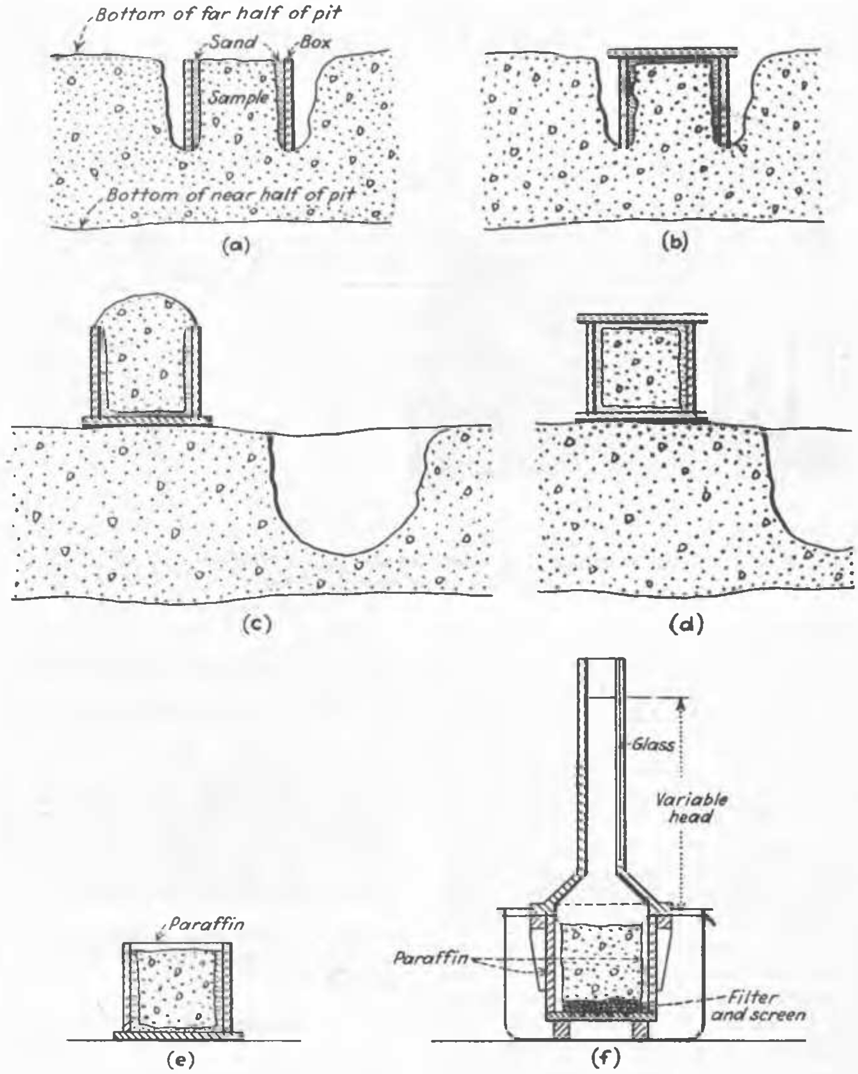


FIG. 7—TAKING permeability samples and testing them.

The Zanesville project is under the direction of Lt. Col. J. D. Arthur, Jr., District Engineer, with T. T. Knappen as Chief Engineer. Special credit is due R. R. Philippe, Director of the Soils Laboratory, and B. K. Hough, Jr., and J. P. Hartman, formerly of the laboratory staff, but now stationed at Passamaquoddy and Fort Peck respectively.

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