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DISCUSSION

KENNETH PEAKER AND D. H. SHIELDS[1]—The two questions asked about this work are (1) What is the influence of evaporation on the test for initial soil suction, and (2) What is the effect of repeatedly flooding the base of the specimen during the compression test?

The author quotes Terzaghi's comments on the large negative pore pressures that can be built up during dessication. In spite of the author's assurances, the question remains whether dessication occurs during the initial soil suction test. Figure 7 shows that the droplets of water visible on the inside of the sealed jar are the result of condensation of water vapor from the soil specimen. The results reported in Fig. 5 could be interpreted to support the hypothesis that dessication does influence the test. Evaporation during the period immediately after the experiment is set up will produce capillary tensions in the soil specimen and the ceramic. The tension in the ceramic will be larger, however, because of its smaller pore size. Water will be drawn from the specimen. When the evaporation rate decreases, the high negative pore pressure in the ceramic will be relieved by the flow of water from the soil—as the test results show. With the more porous specimens the rate of flow into the ceramic will prevent very high pore pressures from forming before the rate of evaporation decreases. Thus the high negative pore pressures that are measured could be a property of the ceramic and not the soil. Have tests been run on the ceramic without the soil specimen?

The author claims to have tested the influence of opening the water supply valve during compression tests. The method of test was to observe the rate of build up of a sheen of water on the ceramic. Was this test performed with a head of water on the order of 30 ft to simulate the suction that had been allowed to build up with the specimen in place? It would be of interest to compare the amount of water allowed to flow from the supply—a small-diameter supply tube may be required to measure this accurately—with the amount of water actually in the low-saturation specimen at the start of the test.

While over-all measurements of moisture content may be approximately the same, it is possible that the opening of the water supply valve and the consequent flow of water will have increased the moisture content of the specimen near the base. If such were the case, this would greatly affect the soil suction properties of the specimens tested.

H. J. GIBBS (*author*)—The questions raised by Messrs. Peaker and Shields are important and were considered during development of the research study, because precautions were particularly desired to prevent possibility of the indicated negative measurements being higher than the true value. Therefore, evaporation within the sealed chamber was carefully checked and a moist sponge was included in the chamber to maintain a high humidity. Tests were performed

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on only the fine ceramic end plates enclosed in the chamber in exactly the same manner as that used for the soil test. It was found that the ceramic end plates do not develop negative pressure while in the enclosed humid atmosphere, but develop it when exposed freely to air.

FIG. 7—Condensation of Moisture From a Soil Specimen Sealed in a Glass Container.

Therefore, it is expected that the soil specimen would not be affected by evaporation.

Messrs. Peaker and Shields also questioned the procedure described for preventing excessive tension from developing in the measuring system by opening and quickly closing the valve leading to a water supply. It should be understood that any time a negative (tension) force is registered in the measuring device, the opening of this valve will not cause drainage from the specimen. Also, Messrs. Peaker and Shields were incorrect in referring to this as flooding the end plate. The only thing that does occur in this short time is the retracting of negative pressures to zero. Although this may be thought of as pulling a slight amount of water into the end plate, it must be understood that the amount is extremely small and considered insignificant. The final reading is one of equilibrium with the soil, which means that all menisci in the soil and the ceramic are the same and not different at the specimen ends. The proof of this conclusion has been checked several times in the exposed end plate test by repeating the test several times on the same soil specimen and obtaining excellent reproducibility of results.

Y. YOSHIMI[2]—Mr. Gibbs showed an ingenious method for measuring negative pore water pressure in partially saturated cohesive soils. During his initial capillary pressure tests, the soil specimens were subjected to ambient air pressures up to 55 psi for more than 10 hr without suffering any apparent damage. This agrees with test data on Vicksburg silty clay specimens compacted on the dry side of the optimum water content.[3]

In order not to cause any volume change under a high ambient air pressure, most if not all air voids in the soil must be connected to the exposed surface. On the basis of air permeability tests and drained compression tests, Yoshimi and Osterberg[4] inferred that the air voids in

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[3] O. H. Gilbert, "The Influence of Negative Pore Water Pressures on the Strength of Compacted Clays," M.S. Thesis, Massachusetts Institute of Technology, 1959.

[4] Y. Yoshimi and J. O. Osterberg, "Compression of Partially Saturated Soils," *Journal of the Soil Mechanics and Foundation Division*, Am. Soc. Civil Engrs., Vol. 89, No. SM4, July, 1963.

their silty clay compacted on the dry side of the optimum water content were interconnected.

According to Bishop's pore pressure expression (Eq 4 of Gibbs's paper), the effective stress σ' is:

$$\sigma' = \sigma - (1 - X)u_a - Xu_w \quad \ldots\ldots (1)$$

in which σ is the total stress. Using subscripts 1 and 2 for before and after the application of an ambient air pressure p, and assuming no change in the value of X, we get the following expression for the change in effective stress:

$$\sigma_2' - \sigma_1' = p - (1 - X)(u_{a2} - u_{a1}) - X(u_{w2} - u_{w1}) \quad \ldots (2)$$

According to the effective stress concept, we associate no volume change with no change in the effective stress. In order to have no change in the effective stress for any value of p and X, we must require:

$$u_{a2} - u_{a1} = u_{w2} - u_{w1} = p \quad \ldots\ldots (3)$$

If the air voids are isolated from the ambient air, the increase in the air pressure in Eq 3 must be accompanied by a decrease in the volume of the air voids. A reduction in the volume of the isolated air voids without allowing reduction in the total soil volume will involve movement of moisture toward the core of the soil specimen. The Jamin effect makes such moisture movement highly improbable. Even if the moisture does move inward, it will not take place without changing the total soil volume through desiccation of the exterior part of the soil.

On the other hand, if the air voids are completely interconnected, and the curvature of the menisci remains the same, we satisfy Eq 3 since $u_{a1} = 0$, $u_{a2} = p$, and $u_{a2} - u_{a1} = u_{w2} - u_{w1}$. Thus, the effective stress concept and the assumption of interconnected air voids are compatible with the observed fact that an ambient air pressure caused no volume change.

Figure 6 of Gibbs's paper shows that undrained compression caused considerable increase in pore water pressure from initially negative values to positive values. It is conceivable, however, that drained tests on the same soils would have caused much less increase in pore water pressure because of dissipation of pore air pressure through interconnected air voids, and that the pore water pressure would have remained negative. In such a case the pore water could not have flowed out against gradient and remained in the soil. This is what happened to a compacted silty clay subjected to laterally confined, drained compression.[4]

Whether a compacted fill in the field undergoes undrained or drained compression may depend on the environments. However, the possibility that drainage (of soil air) has a considerable effect on the pore water pressure in partially saturated cohesive soils might suggest the need for investigating both the undrained and drained cases.

H. J. GIBBS (*author*)—Mr. Yoshimi raises a question regarding volume change when ambient air pressure is applied to the soil specimen during the exposed test. It is true that this may be a question for soil of sufficient moisture content that the air voids are not interconnected. However, experience has shown that measurements of density, moisture content, and degree of saturation, made before and after tests, check very close, within the limits of practical soil testing measurements. It is expected that if the ambient pressure were abruptly applied in rather large amounts that the volume change problem may be significant. It should be understood that this ambient pressure is applied in small increments (5 psi was used) and no faster than that needed for equalization of the menisci developing on the ceramic end plate. The pressure changes developing throughout the soil are being transmitted from void to void through the pore water and the pore air. Since the specimen does not change in moisture content, materials are not moved appreciably through the specimen. Therefore, it is expected that the transfer of pressure will be relatively fast, and compression of the particle structure is not significant under the gradually applied small increments which could be even smaller, if necessary, than the 5 psi used. These appear to be the results of the tests.