the whole building. The heavier sections have probably settled more than the lightly loaded east entrance since 1951. It is unfortunate that level surveys have not been carried out on the heavier parts of the structure.

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A Diffused Air Volume Indicator for Unsaturated Soils

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The diffusion of air through saturated high air entry discs presents a serious problem in the testing of unsaturated soils. When determining either the strength (drained) or volume change characteristics of unsaturated soils, a technique must be available to measure the amount of diffused air in order for the appropriate corrections to be applied to the volume–weight relationships.

The described diffused air volume indicator is a simple but effective means of measuring the quantity of diffused air. This technical note explains its construction and procedure of operation. Also outlined is the computational procedure for the correction factor that must be applied to the water volume change measurements. Numerous tests on the indicator show a reliability in the order of ±0.2 cc over a period of 2.5 weeks.

La diffusion d'air à travers des pierres poreuses fines saturées constitue un problème sérieux lors des essais des sols non saturés. Lorsqu'on détermine la résistance drainée ou les caractéristiques de changement de volume des sols non saturés, une technique doit être disponible pour mesurer la quantité d'air ayant diffusé pour appliquer les corrections appropriées à la relation volume–poids.

L'indicateur de volume d'air diffusé décrit ici est un moyen simple mais efficace de mesure de la quantité d'air ayant diffusé. La présente note technique explique la construction et le mode d'opération de l'appareil. On présente également la méthode de calcul du facteur de correction qui doit être appliqué aux mesures de changement de volume d'eau. De nombreux essais avec l'indicateur indiquent que sa précision est de l'ordre de ±0.2 cc sur une période de 2.5 semaines.

[Traduit par la Revue]

Introduction

High air entry discs are generally used to separate the air and water pressures when testing unsaturated soils (Bishop and Henkel 1962). Although saturated discs resist the passage of free air at differential pressures less than the air entry value, dissolved air diffuses through the water in the disc (Bishop and Donald 1961). The diffused air then comes out of solution below the ceramic disc. This problem continues to be one of the main problems associated with testing unsaturated soils (Bishop 1969). Unsaturated soils contain a relatively small amount of water and require lengthy periods of time for their testing. In order to obtain accurate measurements of the water in the soil at any time, it is necessary to measure the amount of air that diffuses through the high air entry disc and apply a correction to the measured water volume

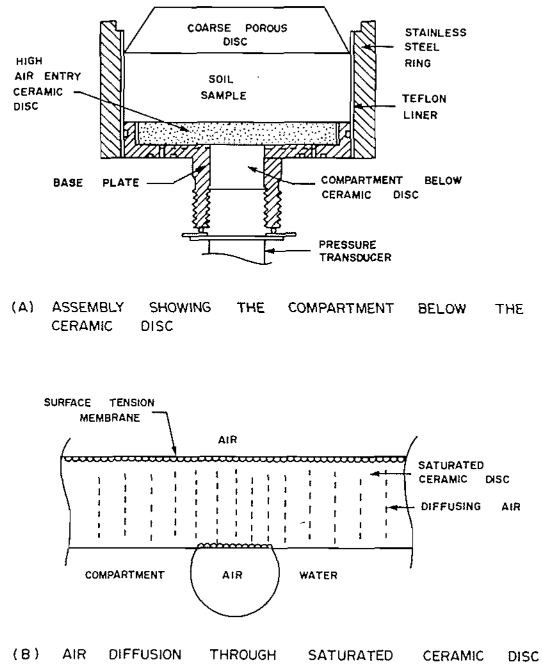

FIG. 1. Removal of water by air diffusion from below the ceramic disc.

change. The reliability of much of the past research work is open to question where the effect of diffused air has been ignored.

Undrained strength or volume change tests on unsaturated soils are performed with the water phase controlled as a closed system. As air diffuses through the high air entry disc, it comes out of solution in the compartment below the disc. The compartment is like a large void in the soil and the natural process is to cavitate and replace the water with air (Fig. 1). Therefore, the water is forced upward through the disc, back into the soil. Slowly the measured pressure changes from the original water pressure to the applied air pressure. In other words, the difference between the air and water pressure should tend toward a constant value but instead it continuously decreases due to a limitation in the measuring system. This behavior is commonly observed when attempting to perform null type measurements of matric suction (Fig. 2). The matric suction increases to a point where the diffusion of air through the disc tends to reduce the matric suction. Up to the present time, the air diffusion problem has not been resolved and nullifies the reliability of water pressures observed in unsaturated soils over long periods of time, either in the laboratory or the field (Bishop 1961).

Drained strength and volume change tests can be performed by controlling the air and water pressures. In this case, the water volume change monitored is a combination of the flow of water to and from the sample plus the flow of diffused air through the water in the high

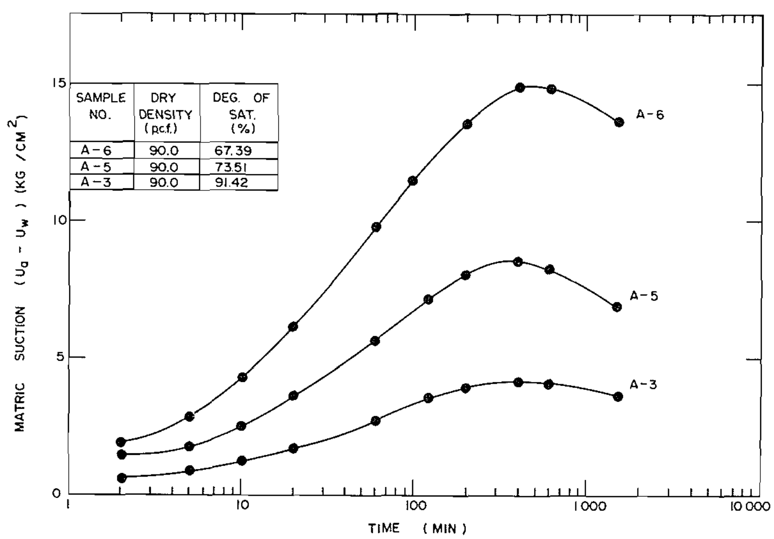

FIG. 2. Development of matric suction in statically compacted Regina clay (from Pufahl 1970).

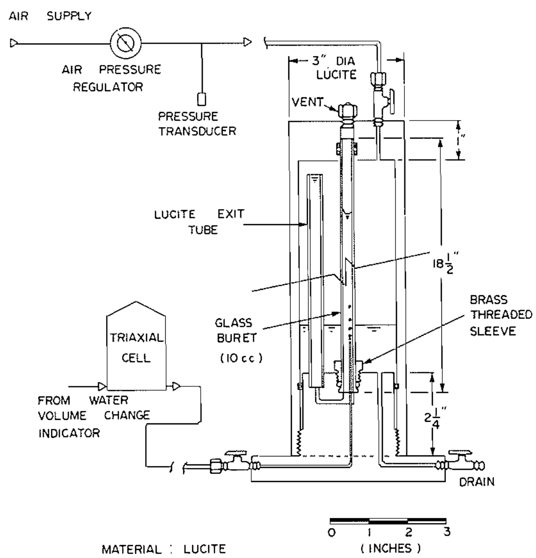

FIG. 3. Diffused air volume indicator.

air entry disc. In order to accurately assess the water volume change only, it is necessary to measure the diffused air volume and subtract it from the measured volume change.

This technical note is primarily concerned with a means of measuring diffused air under conditions where the air and water pressures are controlled or regulated (*i.e.* drained type tests). Examples of the types of tests of interest are: (i) consolidation and swelling tests and (ii) triaxial shear strength tests.

The amount of air diffusing through a high air entry disc over a period of several days can exceed the total volume of water in the sample (Fredlund 1973). In other words, the computed final water content would be negative. Based on observations from numerous tests performed by the author, it appears that any drained test in excess of 1 day should account for the diffused air volume if it is desirous to monitor changes in the water content or degree of saturation. The above time is primarily dependent on the thickness of the high air entry disc and the magnitude of the matric suction. Attempts were initially made to theoretically predict the volume of diffused air. However, there appear to be many factors affecting the rate of diffusion, rendering a strictly theoretical approach unreliable.

In 1961, Bishop and Donald built a perspex 'bubble pump' to remove and measure the volume of air collected below the high air entry disc. The device utilizes the pressure difference in a tilted U-tube containing mercury to circulate water through the base plate. Pumping applies a differential pressure across the base plate of 0.15 p.s.i. (1.03 kN/m^2) and is continued for approximately 30 s.

The diffused air volume indicator described herein uses a small differential pressure across the base plate (controlled by air pressure regulators) to flush out the diffused air. The air volume is monitored and the appropriate correction can be applied to the water volume change measurement. The diffused air volume indicator differs from the one proposed by Bishop and Donald (1961) in that it is relatively simple to build and can be operated under a back pressure of up to 70 p.s.i. (482 kN/m^2) applied to the water phase.

Description of the Diffused Air Volume Indicator

Basically the diffused air volume indicator consists of a standard 10 cc graduated buret that is inverted and placed inside a 3 in. (7.6 cm) diameter lucite cylinder (Fig. 3). The valve at the end of the buret is removed. Two rolling O-rings are placed around the top of the buret to form a seal with the lucite. A vent on the top can be opened when filling the buret and remains closed when the indicator is in operation. The seal at the base of the buret consists of a threaded brass sleeve tightened down against an O-ring. The brass sleeve is machined with a hexagonal top and an inside diameter slightly larger than the buret. The lower part of the brass sleeve is threaded into the lucite block at the base. The exit tube maintains a constant pressure head on the air in the buret.

By momentarily creating a pressure gradient of 1 to 10 p.s.i. (6.9 to 69 kN/m^2) across the base plate (*i.e.* below the high air entry disc in the triaxial or oedometer apparatus), air bubbles are flushed out and measured by displacing the water in the buret. The pressure inside the lucite cylinder can be controlled by an air pressure regulator, at a value that maintains the desired gradient across the base plate. For example, if the water pressure below the high air entry disc is controlled at 30 p.s.i. (207 kN/m^2), the lucite cylinder would

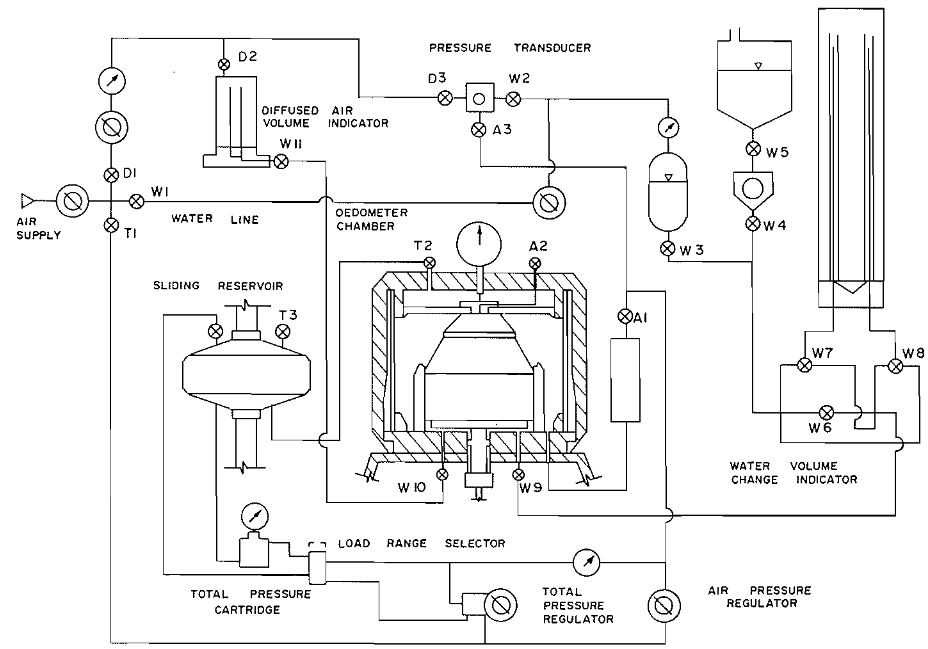

FIG. 4. Layout of entire modified Anteus oedometer.

be pressurized to approximately 25 p.s.i. (172 kN/m^2). The volume of diffused air is recorded in either of two ways:

(i) The initial buret reading is taken after the diffused air indicator chamber is pressurized (*e.g.* to 25 p.s.i.) (172 kN/m^2). The base plate is flushed out and the final buret reading is recorded. The indicator chamber pressure is measured on a pressure transducer to the nearest 1/100th of a p.s.i.

(ii) the initial buret reading is taken when the diffused air indicator chamber is at atmospheric pressure. The chamber is then pressurized (*e.g.* to 25 p.s.i. or 172 kN/m^2) and the air flushed from the base plate. The chamber is depressurized and the final buret reading is recorded. It is also possible to take into account slight fluctuations in atmospheric pressure if a barometer is located in the laboratory.

In either of the above cases, the volume occupied by the diffused air at the base of the ceramic disc is computed by applying Boyle's law to the measured volume of diffused air (Fredlund 1972). Both of the above procedures produced satisfactory results; however, the second procedure was generally used by the author. If the first of the above procedures is used, the drop in pressure from the base plate to the indicator is minimal and the amount of air that could come out of solution due to a pressure drop is negligible. Even when the second procedure was used, the amount of air immediately coming out of solution was negligible.

There are no temperature corrections necessary provided the temperature of the diffused air volume indicator and the base plate of the triaxial or oedometer apparatus are the same. All tests on the indicator were performed in an air-conditioned laboratory where the standard deviation of the temperature variations was less than ± 1.0 °C.

When the buret in the diffused air volume indicator becomes empty of water, the vent at the top is opened and the buret is filled. Initially there was some difficulty in getting the bubbles of diffused air to freely move up in the buret. This problem was overcome by filling the buret with the commercial cleaner called Fantastik. Due to its low surface tension the air bubbles readily move up the buret.

The diffused air volume indicator has been used on both triaxial and oedometer apparatus. Figure 4 shows how the indicator is used in

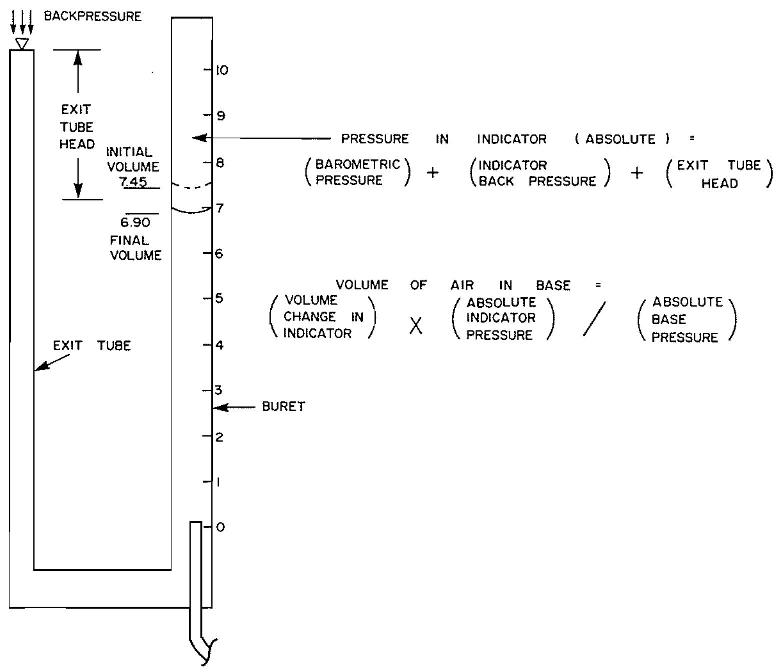

FIG. 5. Computations for the diffused air volume correction under isothermal conditions.

conjunction with a modified Anteus oedometer (Fredlund 1973). It should be noted that the water volume change indicator is bypassed when the diffused air is being flushed from the base plate.

Computation Procedure

The diffused air volume is registered on the water volume change indicator as though it were water leaving the sample. Therefore, the independently measured volume of diffused air must be subtracted from the volume flowing from the sample.

The determination of the correction for the diffused air depends on a precise evaluation of the pressure in the diffused air volume indicator as well as the base plate. The pressure on the diffused air in the indicator is equal to the applied backpressure plus the head difference between the exit tube and the air–water interface in the buret. The pressure in the base plate is measured on a pressure transducer mounted in the base plate. Figure 5 shows the detailed calculation of the air pressure and volume. The volume of diffused air is reduced to an equivalent volume in the base of the cell by means of Boyle's law.

$$V_d = \frac{\Delta V_I \cdot u_I}{u_B}$$

where V_d = volume of diffused air, ΔV_I = difference between the initial and final readings on the diffused air volume indicator, u_I = absolute pressure in the indicator, and u_B = absolute pressure in the base plate of the apparatus.

The base plate generally needs to be flushed about once each day. Corrections to intermediate water volume change readings can be made on the basis of a linear interpolation with respect to time.

Typical Test Results

The accuracy of the diffused air volume indicator can readily be checked by allowing the diffusion of air through a saturated, ceramic disc and monitoring the volume change on a water volume change indicator. Then by turning off the water volume change indicator and flushing the base plate, the volume of diffused air can directly be measured. The two results should be essentially the same if the diffused air volume indicator is performing satisfactorily.

Figure 6 shows the measured diffusion of

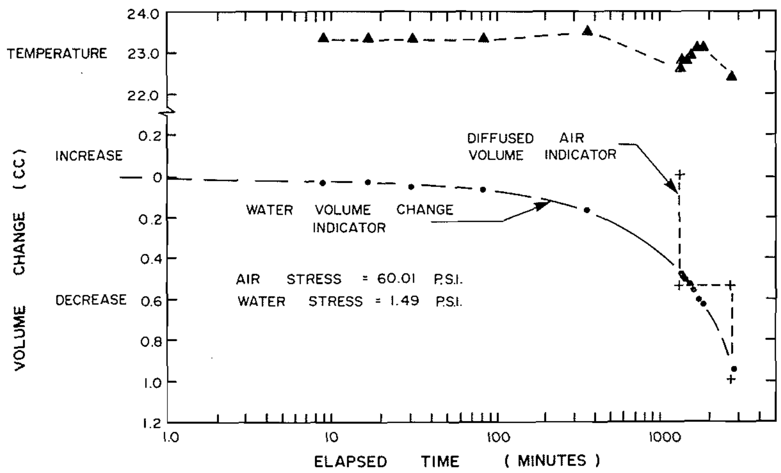

FIG. 6. Diffusion of air through saturated ceramic disc.

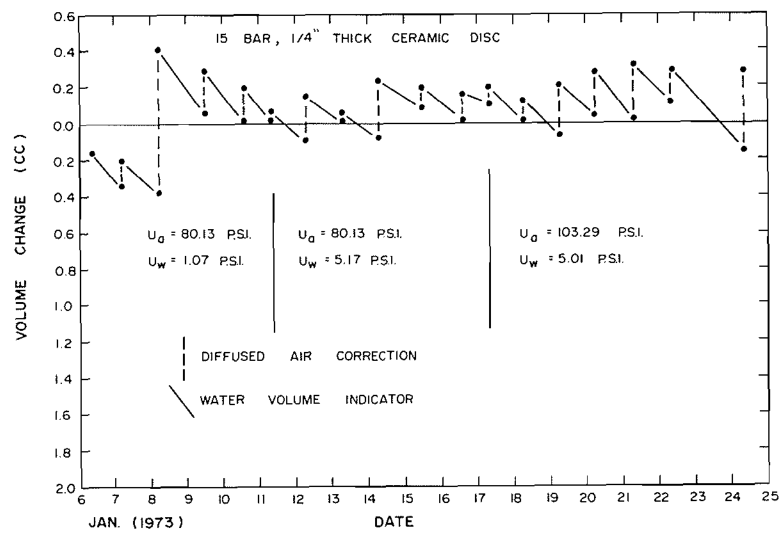

FIG. 7. Diffusion test on saturated ceramic disc.

air through a saturated, ceramic disc with an air entry value of approximately 225 p.s.i. (1551 kN/m^2). Both the water volume change indicator and the diffused air volume indicator registered essentially the same volumes of diffused air after 2 days. On an arithmetic time scale, the plots are straight lines indicating a steady state diffusion of air.

A long term diffusion test was performed on the modified Anteus oedometer using several applied air pressures. Figure 7 shows a comparison of the diffused air volumes measured by the diffused air volume indicator and the water volume change indicator. Each day, the diffused air volume indicator reading was subtracted from the water volume change reading. After 18 days, the water volume change indicator registered 4.05 cc of diffused air (*i.e.* 0.23 cc/day). The diffused air volume indicator readings are within 0.33 cc of the above volume.

The indicator was tested under relatively high air–water differentials. These pressures are indicative of the range where some laboratory testing is done (since some natural soils have similar matric suctions); however, most laboratory testing will likely be done at considerably lower air–water differentials. The lower differentials would show lower volumes of diffused air.

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