the same deformations except a rotation by 90°, while the nonlinear stress-strain equations, Eq. (1) and Eq. (4) with D and G of Eq. (5), are expressed in anisotropic forms respectively. In general, however, it is supposed that the material constants, a and b, depend on directions; that is, $a_z \neq a_r$ and $b_z \neq b_r$ exist due to the inherent anisotropy which depends on the methods of preparing the samples and is independent of the principal stress axes before loading.

5. Corrected conclusions: The author's formulation which describes the dilatancy phenomena is expressed in mathematically anisotropic forms but is for a nonlinear isotropic material. To have the formula for an anisotropic material, the material constants, a and b, involved in the coefficients of deformation, must depend on directions; that is, $a_z \neq a_r$ and $b_z \neq b_r$ are required.

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A METHOD FOR ESTIMATING THE CONSOLIDATION OF A NORMALLY CONSOLIDATED CLAY OF SOME AGE*

Closure by Yukitoshi Murakami**

The author wishes to thank Prof. G. Mesri and Dr. Y. K. Choi for their detailed and instructive discussion.

First, on the ground that there is a possibility of the unsaturation of a specimen, the writers claim that the peculiar behavior of pore water pressure which the author has observed in his aged clays is not due to such an effect of adsorbed moisture as he asserts, but due to the effect of the compressibility of pore fluid in an unsaturated remolded specimen. Recalling that the consolidation tests conducted were not back-pressured and considering the fact that the compressibility of an aged clay is low for effective pressure less than quasi-preconsolidation pressure, the author accepts partly their claim. However, it should be noted that the pore water pressure measured in aged clays never exhibits the characteristics of pore water pressure which can be normally observed in unsaturated (aged) clays, except that the initial magnitude of the pore water pressure is always observed less than the magnitude of a load increment. Actually, the pore water pressure observed in an aged clay dissipates monotonously with elapsed time. The rate of dissipation is very high through the consolidation process as compared with that observed in an unsaturated clay, and is exceedingly affected by the previous loading duration, that is, the degree of aging. Moreover, in order to verify that the peculiar behavior of pore water pressure is not owing to the unsaturation of a specimen, the following experiment has been carried out. Three equivalent specimens (6 cm in diameter and 1 cm in height), which were fully saturated but not back-pressured, were consolidated to the pressure of 78.4 kN/m² and after the com-

* Vol. 20, No. 4, Dec. 1980, pp. 83-93. (Previous discussion by G. Mesri and Y. K. Choi, Vol. 21, No. 2, pp. 131-134)

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pletion of primary consolidation each of them was left for 3 minutes, 24 hours and 48 hours respectively so as to develop a certain amount of secondary compression. Subsequently, ten load increments of 4.9 kN/m² were stepwise applied to each specimen in the manner that the succeeding increment was applied as soon as the excess pore water pressure induced by one increment had substantially dissipated at a base or an equivalent mid-plane of the specimen. During the consolidation tests, the excess pore water pressure was observed at the equivalent mid-plane. The result of the observations is shown in Fig. 13. For the specimen A which has been scarcely subjected

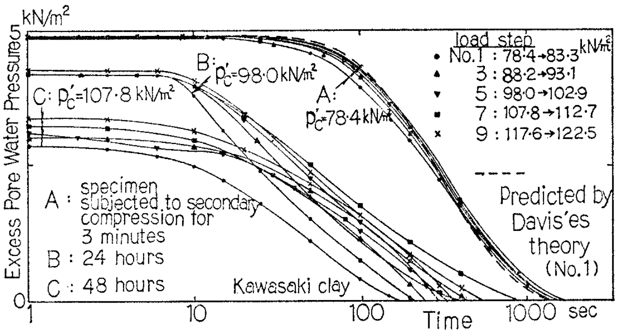

Fig. 13. Observed relationship of time-pore water pressure at mid-plane

to the secondary compression, all the excess pore water pressures induced by the load increments are nearly in accordance with that predicted by the Davis theory, which explains the behavior of excess pore water pressure in a normally consolidated, young and saturated clay (Davis and Raymond, 1965). On the other hand, for the specimens B and C which have been subjected to the effect of secondary compression, the initial magnitude of excess pore water pressure is always less than that of the load increments and the dissipation of pore water pressure is very rapid. If the peculiar behavior of pore water pressure is due to the unsaturation of a specimen as the writers claim, the behavior of pore water pressure which has been observed in the range of effective pressure greater than the quasi-preconsolidation pressure p_c' must be identical to that predicted by the Davis theory. Because, when the effective pressure becomes greater than p_c', the effect of unsaturation on the pore water pressure behavior is, if any, to be negligible on account of the gain in compressibility of a clay, as might be expected from the observed result of the specimen A. Nevertheless, the peculiar behavior of pore water pressure can be seen in the range of effective pressure greater than p_c'. Thus, the peculiar behavior of pore water pressure cannot be explained only by the unsaturation of a specimen even if unsaturated. Since the appearance of the peculiar pore water pressure behavior is closely related to the secondary compression and its effect, the author infers that the peculiar behavior in aged clays has something to do with the effect of adsorbed moisture.

Secondly, the writers assert that the author's modification of the continuity equation is in fact a correction for the effect of the compressibility of pore fluid on the pore water pressure behavior. Since the author has not explicated the rationale of an added term in the continuity equation, the meaning of the modification is misunderstood. After examining the relationship between the volume change and the pore water pressure under an undrained loading on aged clays, the added term has been introduced in order to explain the experimental fact of $\Delta u_{t=0} < \Delta p$ which might have relation to the aging effect of a clay. Consequently, as shown in Fig. 11, the modified theory fails partially to explain the behavior of pore water pressure; in particular, the rapid dissipation of pore water pressure during consolidation, which suggests a certain change in clay properties, e.g. the generation of bonding and structural viscosity. In such a sense, it can be said that the modified theory proposed is unsatisfactory yet.

Lastly, the author would like to describe his views for the writers' comments concerning the effects of some physical factors on consolidation characteristics.

Effect of load increment ratio

The author greatly appreciates the writers' detailed comment as to the effect of load increment ratio. It is quite right of the writers to insist that the shape of the settlement-logarithm of time curve is prescribed by the interrelation between the compressibilities of a clay at primary and secondary consolidation stages. Accordingly, a quasi-preconsolidation effect, which has influence on the compressibility of a clay at the primary consolidation stage, is secondarily related to the shape of the curve. The author's previous statement that the influence of a load increment ratio on a shape of consolidation curve is virtually attributed to a quasi-preconsolidation effect is not incorrect but insufficient.

Effect of loading duration

The writers claim that the rate of consolidation is not affected by the duration of a previous loading step or the aging of a clay, with regarding only primary consolidation. However, it is theoretically incorrect to discuss the consolidation of an aged clay in regard to the so-called primary consolidation, after separating the consolidation into the ranges of primary and secondary consolidation by means of using a classical fitting method. The author never describes only the rate of primary consolidation but discusses the characteristics of consolidation which includes both primary and secondary consolidation. The author insists that consolidation or consolidation settlement is retarded as the previous loading duration is longer.

Effect of thickness

The writers point out that although the author's theoretical prediction shows that the magnitude of primary settlement is practically independent of the duration of primary consolidation, this prediction does not agree with his interpretation of the data by Aboshi. The writers' indication is rather proper as longer as see the calculated result in Fig. 4. However, it can be theoretically said that the increase in a thickness of clay layer brings about the longer duration of primary consolidation and therefore the larger amount of secondary consolidation in the stage of pore water pressure dissipation or of primary consolidation. As a result, the proposed theory can explain the characteristics of consolidation in Aboshi's data.

References

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