Effect of Aging on Shear Behaviour of Overconsolidated clays

By

M. Krishna Murthy*

A. Sridharan**

T.S. Nagaraj**

Introduction

Many natural deposits of clay have been heavily over-consolidated in their geological history due to glaciation. They are subjected to fairly constant overburden pressures over geological ages. Further, most civil engineering activity results in soils being subjected to fairly constant loads for long periods. While it is generally agreed that sustained loading (aging) may develop additional strength in soils, in practice this aspect of soil behaviour has received very little attention.

While Bjerrum and Lo (1963) and Shen et al (1973) reported on the effect of aging on shear behaviour of undisturbed marine clays, Sridharan and Allam (1979) reported on remoulded clays. All these investigations were carried out on normally consolidated clays. Practically, there is no published information with respect to the influence of aging on overconsolidated clays. In this paper, are reported the results of an experimental investigation on the effect of aging on two remoulded clays in the normally consolidated as well as overconsolidated states. A comparison of the behaviour of soil in the two states has been brought out.

Experimental Work

CIU compression tests were carried out on two remoulded clays (*i*) Kaolinite ($W_L = 44\%$, $I_P = 22\%$, $G_s = 2.35$). Remoulded specimens were isotropically consolidated to 4 kg/cm² for periods ranging between 12 hours to 16 days and then sheared undrained to give a series of normally consolidated specimens having different periods of aging. In another series, the specimens were subjected to isotropic consolidation upto 4 kg/cm² and then rebounded to 0.5 kg/cm² varying the period of rebound between 12 hours and 16 days, thus giving a series of overconsolidated specimens ($OCR = 8$) having different periods of aging. Tests were conducted on specimens, 7.6 cm. in length and 3.8 cm. in diameter. The method of sample preparation and setting closely followed the procedure outlined by Bishop and Henkel (1962). All the samples were consolidated against a back pressure of 2 kg/cm² in order to ensure 100 percent

---

* Reader, Department of Civil Engineering, S.V. University, Tirupati, India.

** Associate Professor, Department of Civil Engineering, Indian Institute of Science, Bangalore, India.

This paper was received in October, 1979 and is open for discussion till the end of January 1981.

saturation and also to facilitate measurement of negative pore water pressures during shear. In all the tests, the axial load was applied under controlled rate of strain. A strain rate of 0.0475 percent per minute which was sufficiently slow for 95 percent equalisation of pore pressure was adopted for all tests (Blight, 1963).

Test Results and Discussion

Stress-Strain-Pore Pressure relationships

Figures 1 and 2 show the typical stress-strain-pore pressure relations for the two soils in both normally consolidated and overconsolidated states having different periods of aging. The undrained strength increased slightly in the normally consolidated state. While kaolinite showed unique pore pressure-axial strain relation as corroborated by Bjerrum and Lo (1963), in silty clay, however, the pore pressure dropped after the peak stress. This may be attributed to the development of shear plane in the aged sample, with consequent dilation and decreasing pore pressure.

In an overconsolidated state, both soils showed negligible changes in strength and exhibited unique pore pressure-axial strain relations. This implies that the effect of aging is greater in the normally consolidated state

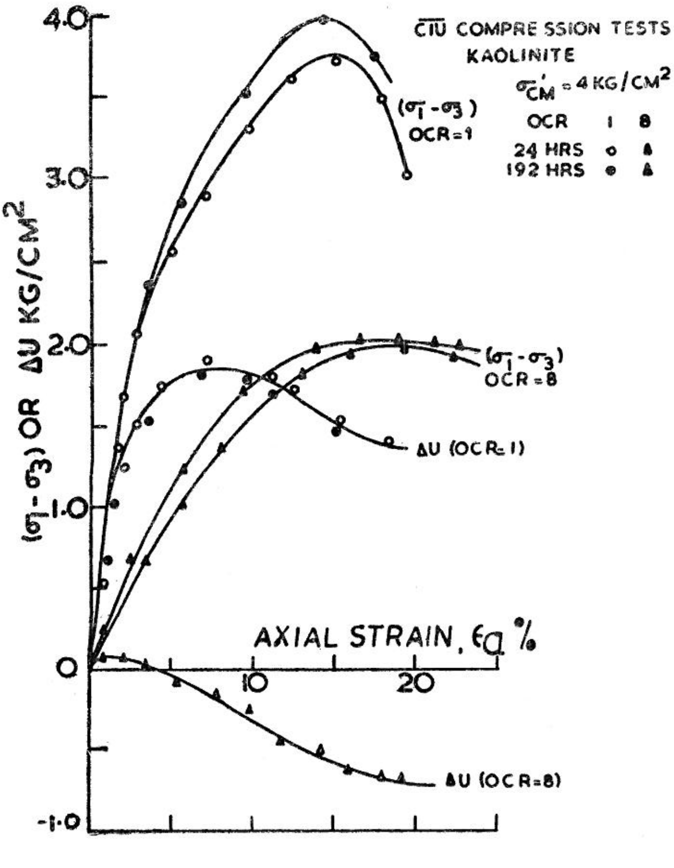

FIGURE 1 Effect of aging on stress-strain pore pressure behaviour of Kaolinite

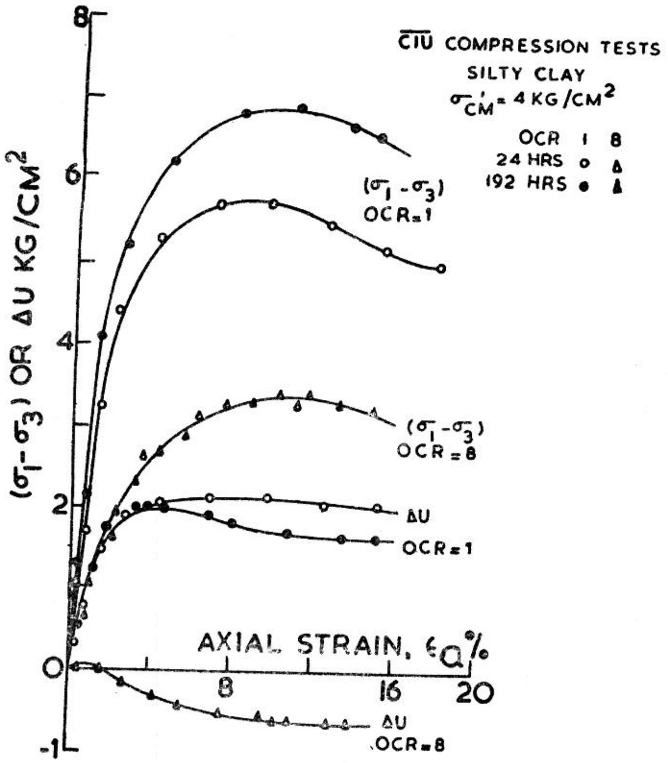

FIGURE 2 Effect of aging on stress-strain-pore pressure behaviour of silty clay

than in the overconsolidated state in relation to either undrained strength or the pore pressure changes. This aspect is further discussed in the following sections.

Stress-strain modulus

The stress-strain modulus of a natural clay deposit is influenced by its geological time history. The strong dependence of the initial tangent modulus on the time allowed for aging prior to undrained shear has been observed for several normally consolidated clays (Bjerrum and Lo, 1963; Ladd 1964; Sridharan and Allam, 1979). There is either negligible or no published information on the influence of aging on the undrained modulus of overconsolidated clays. Figure 3 shows the effect of aging on secant modulus, E_4 for the two soils. E_4 represents the secant modulus at a stress level equal to one-fourth of the maximum principal stress difference [i.e. $FS = (\sigma_1 - \sigma_3)f/(\sigma_1 - \sigma_3) = 4$]. Except for overconsolidated samples of Kaolinite, the secant modulus shows an increasing trend in all others. While the effect of aging is marginal in overconsolidated clays, it increases by 20 percent over a period of 8 days for normally consolidated silty clay.

Pore pressure coefficient, A_f.

The effect of aging on the pore pressure coefficient, A_f, is shown in Figure 4. A_f, decreases in the normally consolidated state which is in

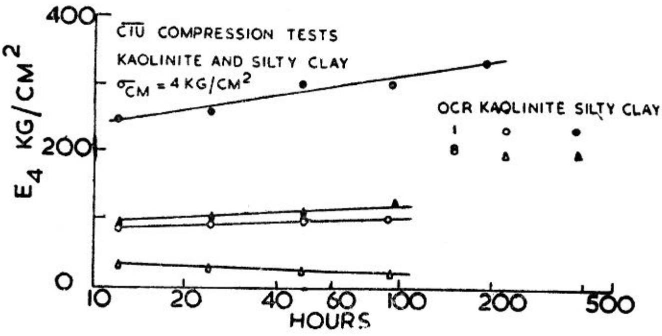

FIGURE 3 Effect of aging on secant modulus

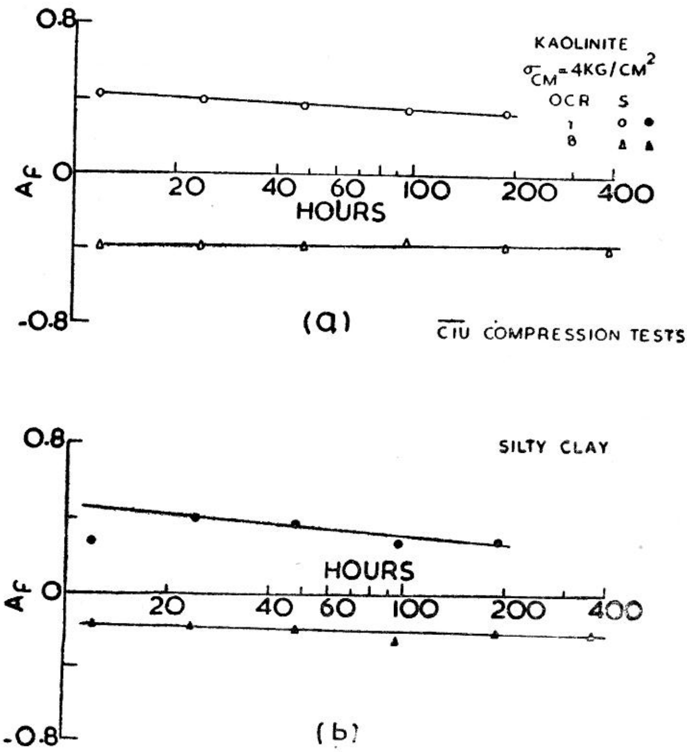

FIGURE 4 Effect of aging on A_f

agreement with the results of Bjerrum and Lo (1963) and Shen et al (1973). This is to be expected, since the strength increased slightly due to aging while there was no corresponding change in the pore pressure (Figures 1 and 2). The pore pressure coefficient, A_f which represents the pore pressure change in proportion to the deviator stress, thus decreases. However, the effect of aging on overconsolidated clays seems to be negligible. Because, the deviator stress and the pore pressure changes in overconsolidated samples are not affected and hence the coefficient, A_f is also not affected.

Undrained strength

The influence of aging on the undrained strength defined at maximum principal stress difference is shown in Figure 5. In the normally consolidated state, Kaolinite shows only a small increase (5%) in the strength but silty clay shows a moderate increase (15%) over a period of 16 days. It may be attributed to the effect of secondary consolidation in the soil. In contrast, there is practically no change in the undrained strength of over-consolidated samples which implies that the there is negligible secondary swelling and hence negligible effect of aging on undrained strength.

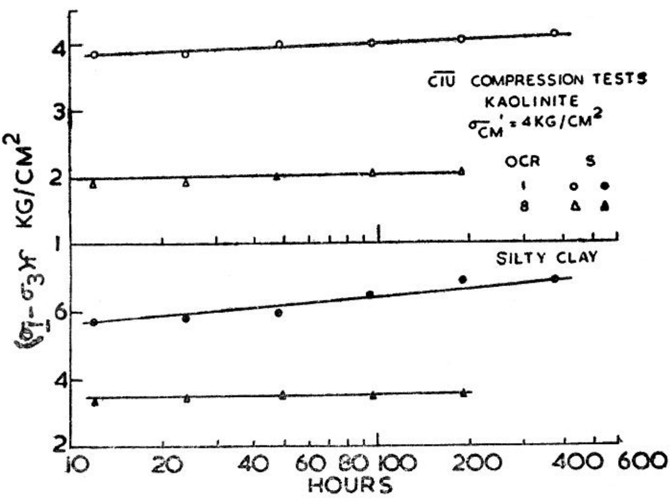

FIGURE 5 Effect of aging on undrained compression strength

Conclusions

Normally consolidated clays displayed slight increase in the secant modulus, E_4 and in the undrained strength and decrease in pore pressure coefficient, A_f due to aging. Also unique pore pressure-axial strain relationship was observed. These findings are in agreement with those of previous investigators. In contrast, the effect of aging on overconsolidated clays was found to be either negligible or nil for the time periods used in this investigation. This is attributed to the negligible secondary swelling in the soil during aging in an overconsolidated state.

References

BISHOP, A.W. and HENKEL, D.J. (1962), "The measurement of soil properties in the triaxial test", *Edward Arnold* (Publishers) *Ltd.*, London.

BLIGHT, G.E. (1963), "The effect of non uniform pore pressure on laboratory measurements of the shear strength of soils," *JSMFD*, ASCE, Vol. 94, SM2, pp. 407-419.

BJERRUM, L. and LO, K.V. (1963), "Effect of aging on the shear strength properties of a normally consolidated clay," *Geotechnique*, Vol. 13, No. 2. pp. 147-157.

LADD, C.C. (1964), "Stress-strain modulus of clay in undrained shear," *JSMFD*, ASCE, Vol. 90, No. SM5, pp. 103-132.

SHEAN, C.K., ARULANANDAN, K. and SMITH, W.S. (1973), "Secondary consolidation and strength of a clay," *JSMFD*, ASCE, Vol. 99, No. SM1, pp. 95-110.

ALLAM, M.M. and SRIDHARAN, A. (1979), "The influence of aging on the shear strength behaviour of two fine grained soils," *Canadian Geotechnical Journal*, Vol. 16, No. 2.