Lateral Creep in Plastic Clays

by

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Introduction

THE stress-deformation characteristics of clays show that they are not truly elastic materials and that the factor of time has to be considered in the analysis of their deformable systems ([1–8]). As such, strictly speaking, the Modulus of Elasticity and Poisson's Ratio as they are used for predicting the engineering behaviour of elastic materials, cannot be used for clays.

Although a considerable amount of work has been done in the recent past on the study of progressive deformations in clays in the direction of the application of load, the study of progressive lateral deformation at right angles to the application of load has not received as much attention. However, the lateral deformation in clays becomes of considerable importance when the progressive vertical deformation is accompanied by unacceptable heaving in the lateral direction to mention one of the common problems in foundation engineering.

It is important, therefore, to study the lateral deformation characteristics in clays, especially plastic clays, in relation to their vertical deformations inasmuch as it is important to study the Poisson's Ratio of elastic materials. It has been found that "in the case of soil, Poisson's Ratio is a tenuous value which has not been determined experimentally with any degree of exactitude"([9]).

This paper describes a simple laboratory procedure which permits both the lateral creep and the vertical creep in clays to be studied as also the effects of time and load on the ratio of lateral strain to vertical strain giving test data for three different types of clayey soils.

Selection of Soil Types

In order to include the main three types of clay minerals, *viz.*, Kaolinitic, Montmorillonitic and Illitic, the following soils were selected for this study :—

(1) Kaolinitic soil (Sp. Gr. = 2.75 ; LL = 59 ; PI = 25)

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(2) Black cotton soil (Sp. Gr.=2.76 ; LL=80 ; PI=39)

(3) Delhi alluvial soil (Sp. Gr.=2.63 ; LL=30 ; PI=15).

The degrees of saturation at which these soils were tested ranged from 95 per cent to 97 per cent.

Laboratory Testing Procedure and Test Results

The creep tests for this investigation were carried out on remoulded cylindrical specimens 3·81 cm. diameter, 7·62 cm. height. The specimens were prepared following the standard procedure adopted for the preparation of remoulded specimens as used for triaxial tests.

The specimen with a thin rubber membrane mounted over it was put in a triaxial cell which was completely filled up with water, but no pressure was imparted to the water. The triaxial cell was then connected to a volume change gauge capable of giving changes in volume of water in the cell correct up to 0·05 c.c. A constant load was applied to the specimen by means of a lever arrangement as in a consolidometer (Figure 1). After the application of the load, the deformation in the vertical direction was observed with time by means of a dial indicator and the change in volume of water contained in the cell was observed in the volume change gauge. It may be pointed out here that the conventional use of a rubber membrane around the soil specimen does provide some lateral confinement to the specimen which has been studied in detail by the authors[10]. Whereas a viscous oil (*e.g.*, SAE 90) surrounding the specimen as a substitute to the rubber membrane would have eliminated any lateral confinement to the specimen, the same was not used in this investigation because of some difficulties that it presented in the measurement of the changes in volume of specimen by a volume change gauge. Moreover, the effect of the lateral confinement by the rubber membrane on the change in volume of the loaded specimen or on the ratio of lateral strain to vertical strain cannot be expected to be appreciable in keeping with the accuracy of other measurements and the method adopted for computing the lateral strain from change in volume of specimen.

The loads chosen for this investigation were 1·35 kg., 2·7 kg., 4·05 kg. and 5·4 kg. for the Kaolinitic soil and the Delhi alluvial soil constituting different percentages of their unconfined compressive strengths 'q_u' (being 0.22 q_u, 0·45 q_u, 0·67q_u and 0·90 q_u for Kaolinitic soil and 0·19 q_u, 0·38 q_u, 0·57 q_u and 0·75 q_u for the Delhi alluvial soil) and 1·35 kg., 2·7 kg. and 4·05 kg. for black cotton soil (0·30 q_u, 0·60 q_u and 0·90 q_u). The load was increased in steps on the same specimen after allowing each load to remain for 60 minutes after which no appreciable changes in volume could be observed in the volume change gauge. For the range of loads chosen for this investigation, the loaded specimen was observed to be bulging in the central portion of its height, the amount of bulge increasing with load but no failure planes were observed. Even during the evaluation of the unconfined compressive strength (q_u) of the specimen, no failure plane was

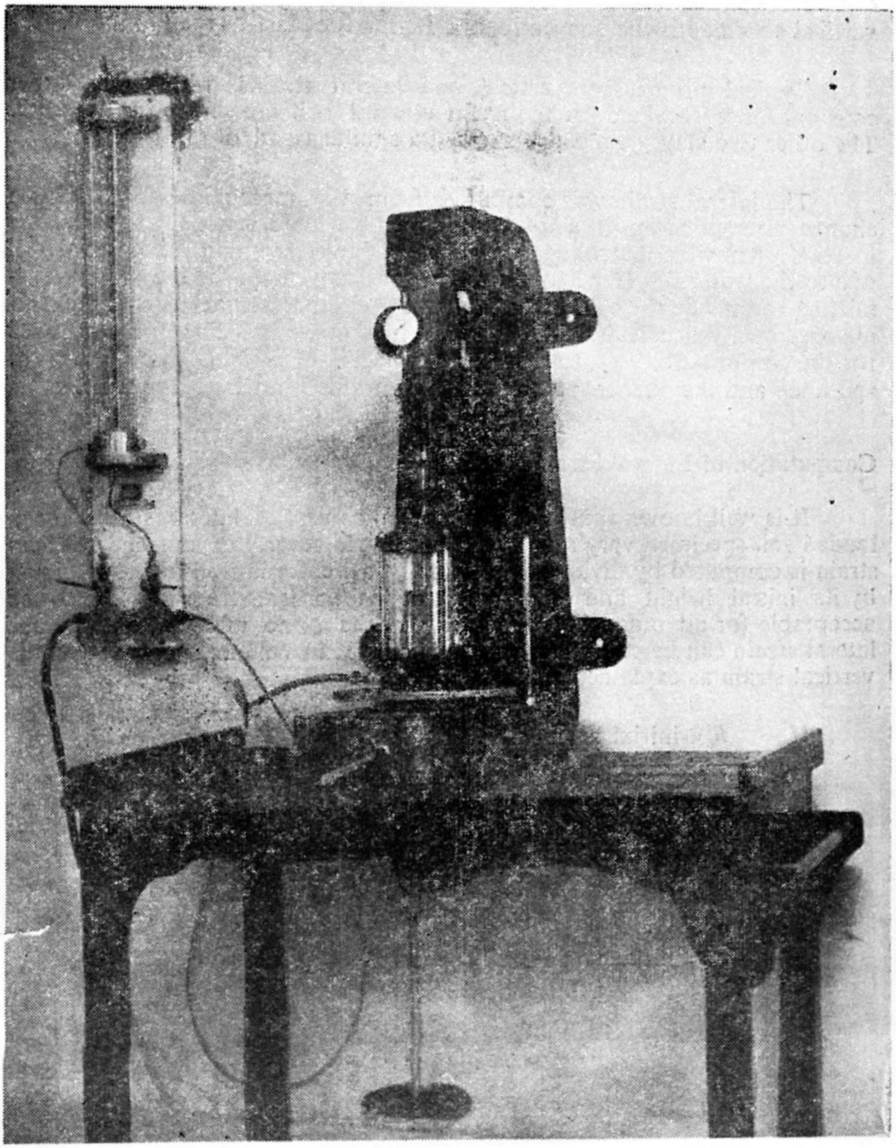

FIGURE 1 : Photograph showing the experimental set-up with a soil specimen (under a constant load) in the triaxial cell, connected to the volume change gauge on the left.

observed and "failure" was considered to have taken place at 20 per cent vertical strain as is the conventional criterion for plastic type "failure".

Typical progressive vertical and lateral strains with time, under constant loads obtained for the Delhi alluvial soil are shown in Figure 2. The other two clayey soils also showed a similar trend of results.

The lateral strain was computed from the measurement of volume change corresponding to a particular vertical deformation at the same instant. Knowing the change in volume of water within the triaxial cell due to the water displaced by the downward movement of the load transmitting rod inside the cell, the actual change in the volume of the deforming specimen was calculated at different time intervals. The formula used for the computation of lateral strain from the change in the volume of specimen and the vertical strain is derived in the following paragraph.

Computation of Lateral Strain

It is well-known that both the vertical as well as lateral strains in a loaded soil specimen vary along its height. However, an average vertical strain is computed by dividing the total vertical deformation of the specimen by its initial height and such a value of the vertical strain is found to be acceptable for all practical purposes. In the same manner, an average lateral strain can be computed from the change in volume and the average vertical strain as explained below :

If h_o = initial height of specimen

d_o = initial diameter of specimen

a_o = initial area of cross-section $= \frac{\pi}{4} d_o^2$

v_o = initial volume of specimen $= \frac{\pi}{4} d_o^2 h_o$

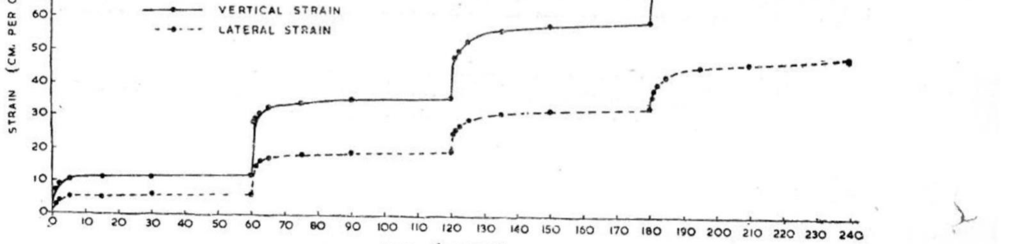

FIGURE 2 : Strain-time curves—Delhi alluvial soil.

$\triangle h$ and $\triangle v$=changes in height and volume respectively in the specimen at time t after application of the load,

and ϵ_v=vertical strain$=-\dfrac{\triangle h}{h_o}$ (the negative sign introduced because the height of specimen decreases with time)

the average area of cross-section 'a' at the time 't' can be obtained from :

$$a(h_o+\triangle h)=v_o+\triangle v$$

or $$a=\frac{v_o+\triangle v}{h_o+\triangle h}$$

$$=\frac{1+\triangle v/v_o}{1+\triangle h/h_o}\times\frac{v_o}{h_o}=\frac{1+\triangle v/v_o}{1-\epsilon v}\,a_o$$

or $$\frac{a}{a_o}=\frac{1+\triangle v/v_o}{1-\epsilon_v}.$$

As $\dfrac{a}{a_o}=\dfrac{d^2}{d_o^{\,2}}$ where d is the equivalent diameter at time t,

$$\therefore\ \frac{d}{d_o}=\left[\frac{1+\triangle v/v_o}{1-\epsilon_v}\right]^{1/2}.$$

Lateral strain $$=\frac{d-d_o}{d_o}=\left[\frac{1+\triangle v/v_o}{1-\epsilon_v}\right]^{12/}-1.$$

Discussion of Test Results

It can be seen from Figure 2 that both the vertical as well as lateral strains progressively increase with time and their rate increases with increasing loads. The same trends were recorded for the other two types of soils studied for this investigation.

For studying the effects of time and load on the progressive lateral strain, it was considered desirable to study the average lateral strain with respect to the average vertical strain, computed from the directly measured vertical deformations. The ratio of the lateral strain to the vertical strain which is known as *Poisson's Ratio* for elastic materials takes a different meaning for clays in the sense that it is not a constant but varies with time and load.

The variation in the ratio of lateral strain to vertical strain (computed from deformation at 1 minute after application of load) with the change in load is shown in Figure 3 for all the three soils. It can be seen from this figure that this ratio (ν) increases with the increasing load but the rate

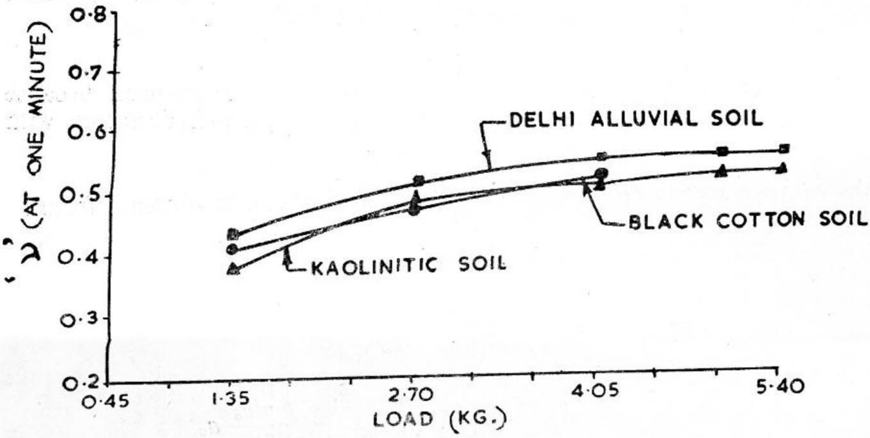

FIGURE 3 : Variation of 'ν' with load.

$$\nu = \frac{\text{Lateral strain}}{\text{Vertical strain}}$$

of increase in the value decreases with increasing load. The increase in the value of 'ν' with load may be attributed to the additional lateral deformations caused by internal radial stresses that are developed within the sample as a result of externally applied vertical compressive stress to which the unconfined sample is subjected during a test. As a result of these additional lateral deformations caused by the internal radial stresses, the 'bulge' of the sample or lateral strain increases in relation to the corresponding vertical strain under the same load, consequently increasing the value of 'ν'. Since the development of internal radial stresses is non-linear in character with respect to the vertical load imposed over the sample, hence the changes in the increase in value of 'ν' with increasing load as observed in this investigation. A graphical illustration of the above-mentioned explanation can also be given by drawing stress trajectories within the sample, indicating the combined stresses leading to lateral deformations of the same nature as observed in the lateral bulging of the sample.

The minimum and maximum values of the ratio 'ν' obtained in this investigation are 0·375 for Kaolinitic soil under a constant load of 1·35 kg. (0·22 q_u) and 0·559 for Delhi alluvial soil due to a loading of 5·4 kg. (0·75 q_u). It is interesting to note in this context that Tsytovich[11] recommends the values of Poisson's Ratio as : 0·10 to 0·25 for sand or sandy soils ; 0·30 to 0·35 for clay with some silt and sand and 0·35 to 0·40 for clays. The effects of time and load on Poisson's Ratio have not been mentioned.

In order to study the change in lateral strain in relation to vertical strain with respect to time, the computed values of 'ν' under a constant load of 2·7 kg. have been plotted against time in Figure 4. It can be seen

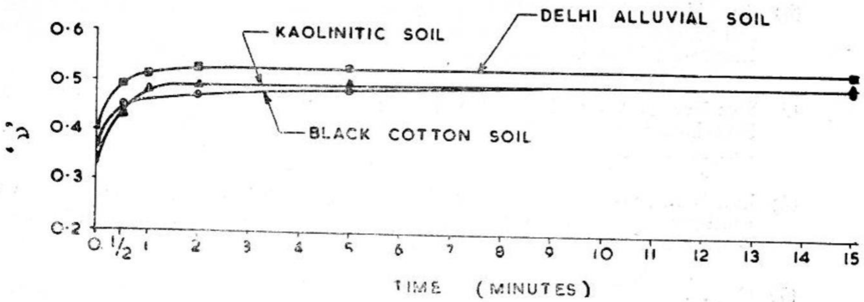

FIGURE 4 : Variation of 'ν' with time under a constant load of 2·70 kg.

$$\text{'}\nu\text{'} = \frac{\text{Lateral strain}}{\text{Vertical strain}}$$

from this figure that 'ν' increases only for the first few minutes after which it tends to be constant. For all practical purposes, the values of 'ν' can be taken to be increasing for the first five minutes after which it can be assumed to remain constant.

Conclusions

A simple laboratory procedure has been effectively employed to study the progressive lateral strains in clayey soil specimens under a constant load as also the effects of time and load on the ratio of lateral strain to vertical strain. The test results indicate that the ratio of lateral strain to vertical strain increases with load, presumably due to the development of pore water pressure in the specimen and tends to be constant for all practical purposes under a constant load after a short interval of time.

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