Path Dependent Drained Creep of Clays

Fluage Drainé, Dépendant de Parcour, pour Argiles

YUDHBIR Professor, Dept. of Civil Engng., I.I.T., Kanpur,
S.K.MATHUR Reader, Dept. of Civil Engng., I.T., B.H.U., Varanasi, India

SYNOPSIS The paper presents the results of the stress controlled drained triaxial creep tests conducted along a number of stress paths on anisotropically consolidated resedimented samples of a soft marine clay. It is shown that the dependence of axial and shear logarithmic creep rates on stress path and stress ratio is marked. Volumetric creep rates are independent of stress ratio up to the "yield value", beyond which a decrease occurs. The limited data suggests that volumetric creep rates also are path dependent. Logarithmic creep rates observed for lightly overconsolidated samples (OCR = 1.25) are much smaller, compared to the corresponding rates for normally consolidated samples. It is shown that the drained creep rates of lightly overconsolidated samples may atleast qualitatively represent the insitu creep rates of soft clays. A model is proposed to predict the creep rates for any stress path from the results of P-constant and q-constant stress path creep tests. Predictions of the creep rates by this model compare very well with the rates actually measured in the laboratory.

INTRODUCTION

It is well known that the stress-strain relationships are highly stress path dependent. To get realistic estimates of the long term displacements for a given field problem, a detailed study of the drained creep behaviour of a clay under various stress paths is required. Surprisingly this important aspect has not been studied in detail at all. Drained creep under non-K_0 conditions for certain stress paths in triaxial appears to have been studied by Murayama and Shibata (1964), Barden (1969), Walker (1969), Bishop and Lovenbury (1969), Newland (1973) and Yamanouchi and Yasuhara (1975). There is at present some controversy regarding the variation of creep rates, especially the volumetric creep rate with stress ratio and stress path.

DETAILS OF EXPERIMENTAL PROCEDURE

In this study, stress-controlled drained triaxial tests were conducted on resedimented samples of a soft Indian marine clay (Liquid limit = 91 %; P.I. = 49 %; G = 2.71; clay fraction = 64 %; activity = 0.58; organic matter = 12 %). Norwegian cells were used and the volume measurement was done with the help of u-tube gauges having a least count of 0.0028 to 0.006 c.c. in an airconditioned room. Back pressure of 2 Kg/cm^2 was maintained throughout the period of the test. Samples were first anisotropically consolidated at $\eta = q/P' = 0.4$ [q is the deviator stress $= \sigma_1' - \sigma_3'$ and $P' = (\sigma_1' + 2\sigma_3')/3$; σ_1' and σ_3' are respectively the major and minor effective principal stresses] up to a pressure $P' = 1.5$ Kg/cm^2 and then sheared along a number of stress paths in four equal increments (in set Fig. 1). Only stress path A test starting from $\eta = 0.1$ was carried to failure. Tests were also carried out on lightly overconsolidated samples (OCR= 1.25) along stress paths A and B. One special test was conducted on a sample, which was allowed to undergo "prior creep" for a period of twenty days after anisotropic consolidation at $\eta = 0.4$, before shearing along stress path A.

PRESENTATION OF RESULTS

The slopes of the linear portion (steady state) of per cent strain versus log time relationship (logarithmic creep rate), referred to hereafter simply as "creep rate", have been designated as $C_{\alpha V}$, $C_{\alpha \epsilon}$ and $C_{\alpha \epsilon_1}$, for volumetric, shear and axial creep rates respectively. Details of the tests and the plots are described by Mathur (1975). The variation of $C_{\alpha \epsilon_1}$, with stress path and stress ratio is presented in Fig. 1. Fig. 2 presents the variation of $C_{\alpha V}$ and $C_{\alpha \epsilon_1}$ with η, for a number of stress paths.

DISCUSSION

Table I shows that creep rates for lightly overconsolidated samples and for the special test are quite similar and as such testing of lightly overconsolidated samples in the laboratory may give more realistic evaluation

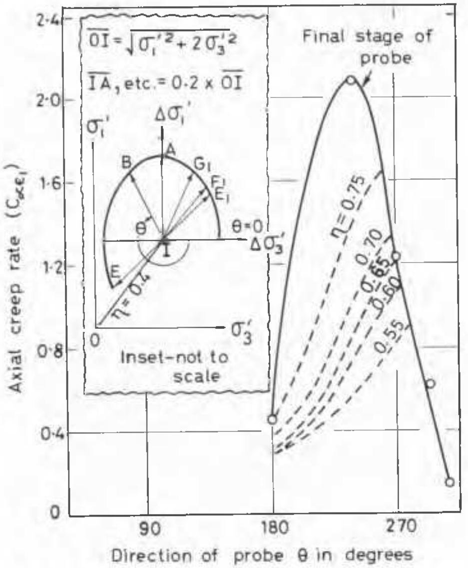

Fig. 1 Variation of Axial Creep Rate with Stress Path and Stress Ratio

of insitu creep rates. These rates are shown to be lower than those for normally consolidated samples. Fig. 1 shows that for

η	Normally consolidated		OCR = 1.25		Special test	
	$C_{\alpha v}$	$C_{\alpha\epsilon_1}$	$C_{\alpha v}$	$C_{\alpha\epsilon_1}$	$C_{\alpha v}$	$C_{\alpha\epsilon_1}$
.60	.60	1.05	.21	.14	.09	.08
.65	.42	1.23	–	.28	.16	.32

Table I Comparison of Creep Rates for Stress Path A

a given η, the variation in $C_{\alpha\epsilon_1}$, for different stress paths is very significant. Fig. 2(a) shows that $C_{\alpha\epsilon_1}$ for stress paths A and B tests, increases linearly with η up to a "yield value", after which the values increase very rapidly leading to creep rupture. For G_1, which is a non failure stress path, there is a linear variation between $C_{\alpha\epsilon_1}$ and η. For E_1 stress path, $C_{\alpha\epsilon_1}$ remains constant and does not depend on η. This substantiates the findings of Murayama and Shibata and Newland for E_1 stress path. Hence the linear variation of $C_{\alpha\epsilon_1}$ (& $C_{\alpha\epsilon}$) with η cannot be said to be general for drained creep behaviour for all stress paths.

Fig.2(b) shows that the volumetric creep rate

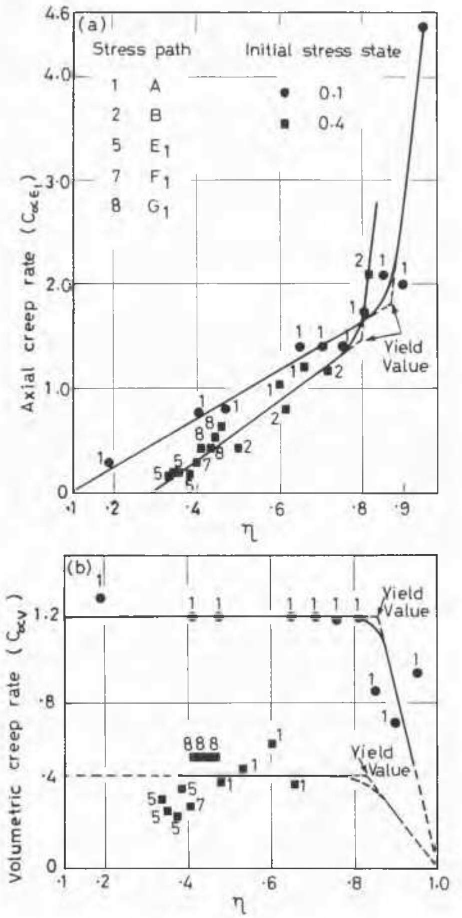

Fig. 2 Relationship between stress ratio and creep rates

$C_{\alpha v}$ essentially remains constant up to a certain stress ratio (which appears to be near the "yield value"), beyond which $C_{\alpha v}$ starts decreasing and eventually shows a tendency to approach zero value near failure. There is a difference in $C_{\alpha v}$ values for tests conducted from two basic stress states. The scatter in $C_{\alpha v}$ as observed, is of the same order as that obtained by other workers. Some of the scatter may be due to the differences in stress paths followed in the test. Also the scatter between results may be due to the likely differences in the samples used and for this reason alone separate curves are shown for the two stress states. The suggested variation of $C_{\alpha v}$ with η by

Adachi and Okano (1974) agrees well with the trend shown in Fig. 2(b). Similar trends could as well be interpreted from the results of Neuland (1973) and Yamanouchi and Yasuhara (1975) for stress paths E_1 and B respectively although the behaviour suggested by them is different.

PROPOSED MODEL TO PREDICT CREEP RATES

It is proposed that the logarithmic creep rates for various stress paths may be predicted from the creep rates of two basic tests: (i) P-constant creep test and (ii) q-constant creep test, starting from a K_o-line; the assumption being that the effect of any increment on creep rates consists of the separate effects of the corresponding increments of P and q. Thus the axial creep rate may be given as :

$$dC_{\alpha\epsilon_1} = \frac{\partial C_{\alpha\epsilon_1}}{\partial p} dp + \frac{\partial C_{\alpha\epsilon_1}}{\partial q} dq \qquad \ldots(1)$$

where $\frac{\partial C_{\alpha\epsilon_1}}{\partial p}$ and $\frac{\partial C_{\alpha\epsilon_1}}{\partial q}$ are the parameters controlling the contribution to a small change in $C_{\alpha\epsilon_1}$ ($dC_{\alpha\epsilon_1}$) during the course of a probe (dp, dq) from q-constant and P-constant tests respectively.

Evaluation of the Parameters for the Model - Fig. 3(a) shows a plot where the stress level dependence of $C_{\alpha\epsilon_1}$ is incorporated. A linear relationship is obtained both for normally and lightly overconsolidated samples. From Fig.3(a) therefore,

$$\frac{\partial C_{\alpha\epsilon_1}}{\partial \eta} = \frac{a_2}{q_f - q} \qquad \ldots(2)$$

where a_2 is a constant giving the slope as indicated in the figure, q is the shear stress at any level and q_f is the shear stress at failure.

From Fig.3(b), for E_1 stress path creep test,

$$\frac{\partial C_{\alpha\epsilon_1}}{\partial p} dp = \text{constant} = A_1 \qquad \ldots(3)$$

Hence from Eqs. (1),(2) & (3) the following Eq. is obtained

$$dC_{\alpha\epsilon_1} = A_1 + \frac{a_2}{q_f - q} dq \qquad \ldots(4)$$

A theoretical plot based on Eq. (4) in terms of $C_{\alpha\epsilon_1}$ and η would indicate a "yield value".

Comparison of predicted and measured creep rates - In general good agreement between measured and predicted (from Eq. 4) creep rates has been observed. For example, at $\eta = 0.6$, the predicted and measured values of $C_{\alpha\epsilon_1}$ are 0.93 and 1.05 respectively for stress path A. For stress path G_1, at $\eta = 0.43$, the predicted and measured values of $C_{\alpha\epsilon_1}$ are 0.465 and 0.425 respectively. For predicting $C_{\alpha v}$, it is proposed that as $C_{\alpha v}$ is independent of η up to the "yield value", E_1 stress path creep test from a K_o-line be conducted and the "yield point" can then be predicted using Eq. (4).

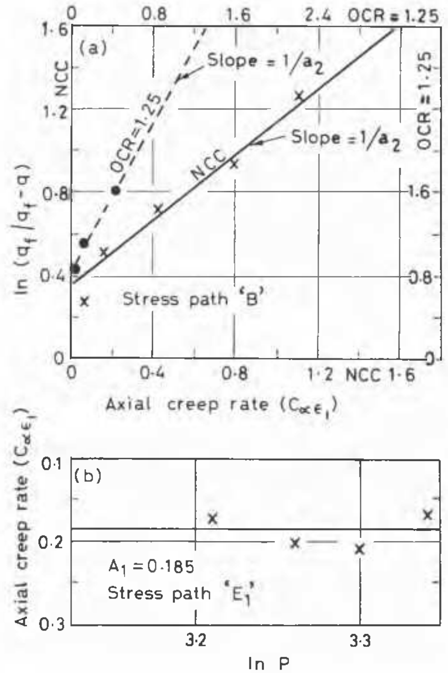

Fig. 3 Evaluation of parameters for the proposed model

FIELD APPLICATION OF THE PROPOSED MODEL

It is suggested that the drained creep settlement rates for a footing problem can be estimated by extending the Lambe's stress path method. $C_{\alpha\epsilon_1}$ for various stress paths can be predicted using Eq.(4). The creep rate so predicted for each element can then be summed up over the entire thickness of the layer to get the creep settlement rate of the footing (ρ_{cs}) as

$$\rho_{cs} = \int_0^H C_{\alpha\epsilon_1} \, dZ \qquad \ldots(5)$$

where H is the thickness of the soil layer.

CONCLUSIONS

Drained creep rates very much depend on stress path and stress ratio. $C_{\alpha\epsilon}$ and $C_{\alpha\epsilon_1}$ vary linearly with η up to an "yield value" only for certain stress paths (such as A, B, etc.), and should not be generalized, as for E_1 stress path, $C_{\alpha\epsilon}$ and $C_{\alpha\epsilon_1}$ are independent of η. $C_{\alpha v}$ is independent of η up to an "yield value", beyond which this decreases and approaches zero volumetric creep rate at failure. This appears to be the most consistent and reasonable concept at the present time (1976). Creep rates for lightly overconsolidated samples are generally lower than those for normally consolidated samples. The insitu creep rates of soft marine clays can atleast be qualitatively estimated from tests on lightly overconsolidated samples. The proposed model appears simple and can predict the creep rates quite well, at least for the loading stress paths. It is suggested that the creep rates for unloading stress paths may be predicted from E and B stress path creep tests (In set Fig. 1). The Lambe's stress path method is extended to predict the creep settlement rate of footings.

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