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STRESS HISTORY EFFECTS ON STRESS-STRAIN BEHAVIOUR OF A SATURATED CLAY

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SYNOPSIS

This paper summarizes data illustrating the effects of stress history on the stress-strain behaviour of remoulded specimens of kaolin tested in the conventional triaxial apparatus under stress controlled conditions. The effects considered are initial one-dimensional consolidation stress used in sample preparation, load increment, magnitude of isotropic consolidation stress prior to shear, and type of applied stress path. It is shown that these factors influence the deformation characteristics of a saturated clay. Methods which take account of these effects are proposed to correlate the test results. The results are useful in investigating the possibility of including these effects in the existing stress-strain theories.

INTRODUCTION

The successful development of a theory for the adequate description of the stress-strain relationship for clays requires a detailed experimental investigation of the material behaviour. Often, the stress history experienced by the sample prior to shear and the stress increments used during testing influence the stress-strain behaviour. A knowledge of the magnitude of these effects is needed to establish approximate limits for the variability of the test results.

The major factors that influence the stress-strain behaviour of remoulded specimens during shear are:

(i) initial one-dimensional consolidation stress used in sample preparation,
(ii) load increment,
(iii) magnitude of isotropic consolidation stress prior to shear,
(iv) type of applied stress path during testing.

The effects of these factors on the stress-strain behaviour are discussed in detail and methods are proposed to correlate the test results.

STRESS AND STRAIN PARAMETERS

The stress parameters p and q are defined by :

$$p = (\bar{\sigma}_1 + 2\bar{\sigma}_3)/3$$
$$q = (\bar{\sigma}_1 + \bar{\sigma}_3),$$

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where $\bar{\sigma}_1$, $\bar{\sigma}_2$ and $\bar{\sigma}_3$ are the principal effective compressive stresses, and $\bar{\sigma}_2 = \bar{\sigma}_3$ under the triaxial stress system. Similarly, the strain parameters v and ε are given by

$$v = \varepsilon_1 + 2\varepsilon_3$$
$$\varepsilon = 2(\varepsilon_1 - \varepsilon_3)/3$$

where ε_1, ε_2 and ε_3 are the principal compressive strains, and $\varepsilon_2 = \varepsilon_3$ under the triaxial stress system.

MATERIAL TESTED, SAMPLE PREPARATION AND TESTING PROCEDURE

All specimens were prepared from air-dried kaolin (liquid limit = 72%, plastic limit = 42% and specific gravity = 2.61) mixed with water to a slurry. Unless otherwise stated, the initial moisture content of the slurry was 160% and the slurry was one-dimensionally consolidated in a special former to a maximum pressure of 22.6 lb/in^2. Subsequently, the former was removed and the sample was isotropically consolidated to the required cell pressure. For a detailed description of the sample preparation and testing procedure see BALASUBRAMANIAM (1969).

EFFECT OF INITIAL ONE-DIMENSIONAL CONSOLIDATION STRESS

Figure 1 illustrates the stress paths followed by three specimens which were subjected to different one-dimensional consolidation pressures and subsequently brought to the same isotropic stress. In this figure, the points A, B and C correspond to specimens AU, AB and AR which were subjected to one-dimensional consolidation stresses of 11, 22 and 55 lb/in^2 respectively.

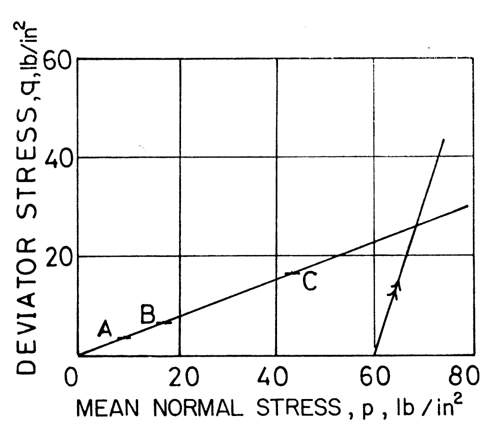

Fig. 1. States of three specimens in the (q, p) stress plane at the end of one-dimensional consolidation and isotropic consolidation.

Experimental Observation on Fully Drained Tests

Since all the specimens were subjected to the same applied stress paths of slope 3 commencing from the same isotropic stress of 60 lb/in^2, any stress point (q,p) can be uniquely represented by the parameter q/p. Figures 2 and 3 illustrate the variations of the volumetric and shear strains with respect to this parameter. It is clear that (i) at any particular stress ratio, specimens with high initial one-dimensional consolidation pressure have low volumetric and shear strains, and (ii) except for the specimen with the one-dimensional consolidation stress of 55 lb/in^2, the $(q/p$, v$)$ characteristics are the same. Hence, any further reduction of the one-dimensional consolidation stress below

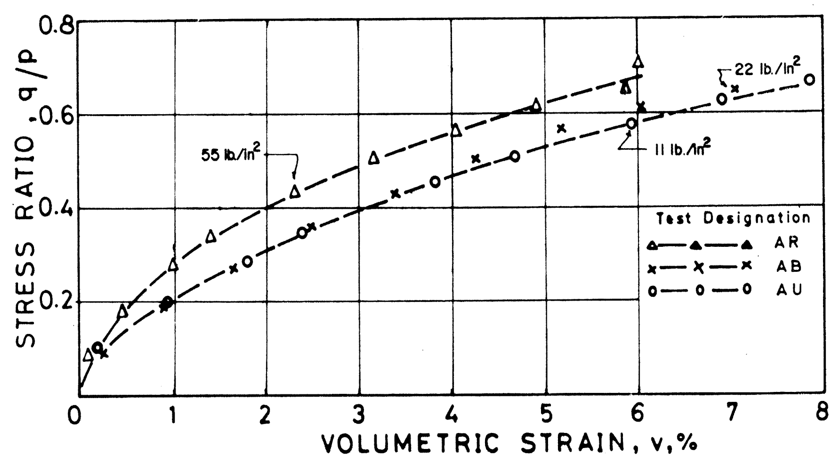

Fig. 2. The (q/p, v) characteristics of specimens prepared with different initial one-dimensional stress and sheared under fully drained conditions from an isotropic stress of 60 lb/in^2 with constant cell pressure.

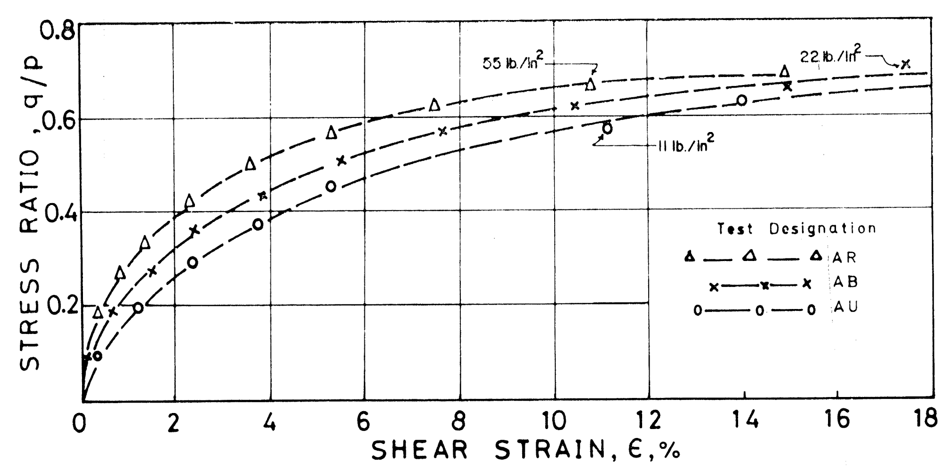

Fig. 3. The (q/p, ε) characteristics of specimens prepared with different initial one-dimensional stresses and sheared under fully drained conditions from an isotropic stress of 60 lb/in^2 with constant cell pressure.

11 lb/in^2 will not have an appreciable effect on the volumetric strain-stress ratio relationship.

Correlation of Drained Test Results with Initial Consolidation Stress

The assumption made in the calculation of the initial shear stress experienced by a specimen during one-dimensional consolidation is that the ratio of the minor principal stress to the major principal stress is a constant during the initial one-dimensional consolidation. This ratio is taken to be 0.7 (K_0) and is in agreement with the lateral pressure measurements carried out by THOMPSON (1962) and BURLAND (1967), during one-dimensional consolidation of cylindrical specimens. The corresponding value of q/p is 0.375.

Two methods (designated as Method I and Method II) will be studied for the correlation of the observations on the specimens prepared with different initial one-dimensional stresses. These methods are based on two different additional assumptions.

Method I—In this method, it is assumed that there is a unique relationship between q/p and v, and q/p and ε during shear under a given applied stress path of all specimens if they are initially prepared under truly isotropic stress conditions (i.e. the specimens are assumed to be initially isotropically consolidated from the slurry, instead of being subjected to a one-dimensional consolidation). Since all specimens prepared by the author were initially sheared to a stress ratio of 0.375 during one-dimensional consolidation, one would expect them to exhibit strains of small magnitude during the initial

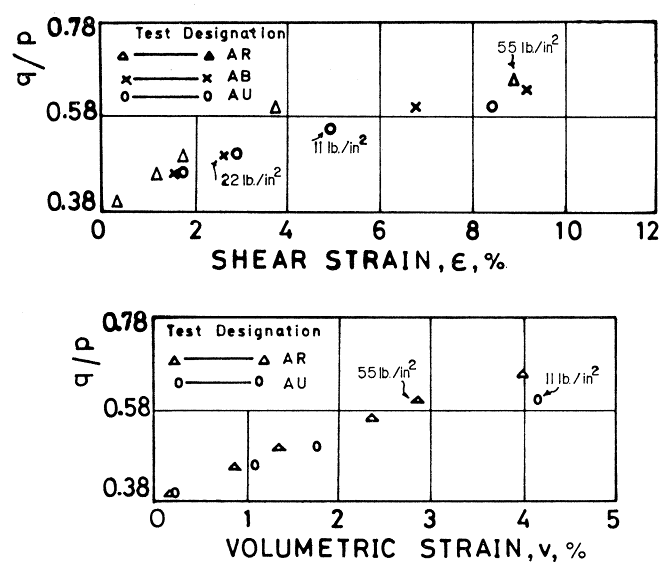

Fig. 4. The (q/p, ε) and (q/p, v) characteristics beyond a stress ratio of 0.375.

phase of the subsequent shear in the triaxial apparatus, until the stress ratio of 0.375 (experienced by the specimen during one-dimensional consolidation) was exceeded. Therefore, the behaviour of all these specimens beyond a stress ratio of 0.375 should be identical in the $(q/p, v)$ and $(q/p, \varepsilon)$ spaces, irrespective of their initial one-dimensional consolidation stress. Figure 4 illustrates the $(q/p, \varepsilon)$ and the $(q/p, v)$ relationships of the specimens for stress ratios higher than 0.375. It is observed that, even after allowing for the initial shear effects based on the K_0 condition, the stress-strain behaviour in the $(q/p, v)$ and the $(q/p, \varepsilon)$ spaces is not unique.

Method II—In this method, only one different assumption is made to those used in Method I. In the previous method, it was assumed that the stress-strain behaviour during shear of all the specimens might be unique once the stress ratio, q/p, had exceeded the value corresponding to the K_0 condition. In Method II, it is assumed instead that the behaviour of all specimens might be unique once the deviator stress, q, has exceeded the value attained during the initial one-dimensional consolidation. The initial shear stresses experienced by the three specimens prepared under the initial one-dimensional stresses of 11, 22 and 55 lb/in^2 were 3.3, 6.6 and 16.5 lb/in^2 respectively. In this method of correlation, it is suggested that the behaviour of the three specimens before each reaches its initial shear stress of 3.3, 6.6 and 16.5 lb/in^2 respectively may be different. However, thereafter the behaviour of the specimens should be identical. The modified stress-strain relationship for the specimens AU, AB and AR are shown in Figs. 5 and 6. It is observed that the behaviour of the three specimens in Figs. 5 and 6 are still not unique. The correlation is somewhat better, however, than that produced by Method I.

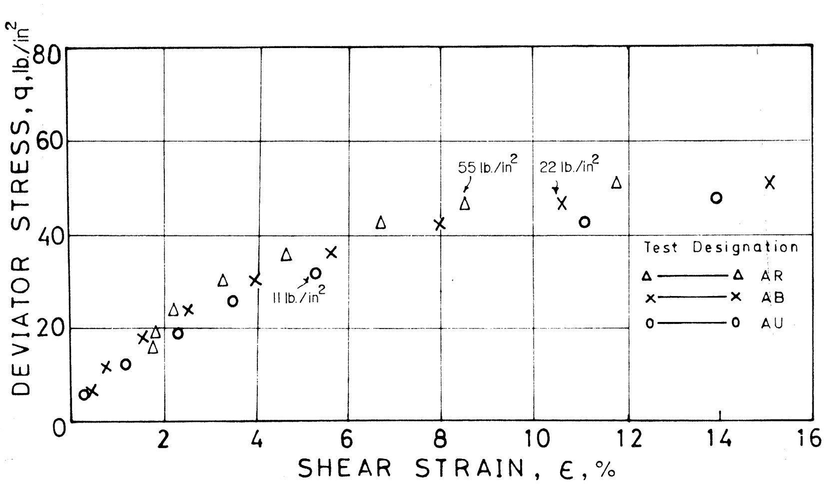

Fig. 5. The (q, ε) characteristic of Specimen AU, and the modified (q, ε) characteristics of Specimens AR and AB.

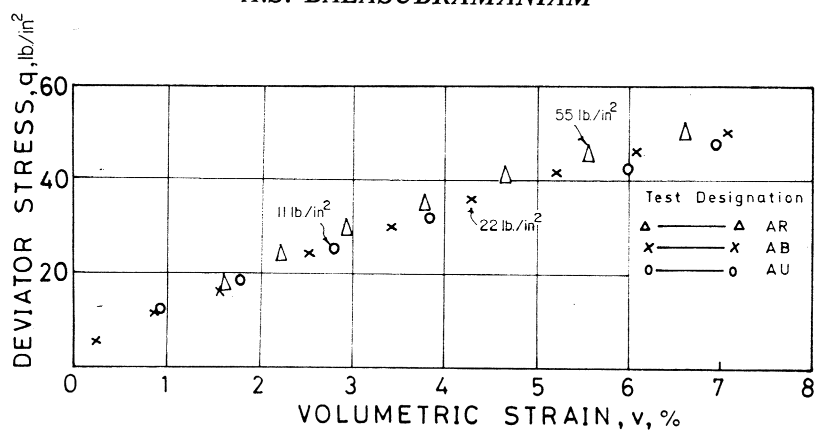

Fig. 6. The (q, v) characteristics of Specimen AU, and the modified (q, v) characteristics of Specimens AR and AB.

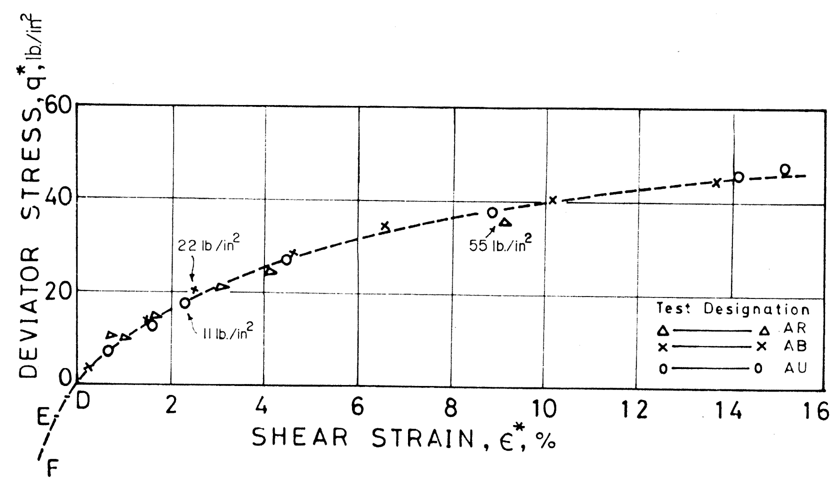

Fig. 7. The (q*, ε*) characteristics of Specimens AR, AB and AU prepared under different initial one-dimensional consolidation stresses and sheared under fully drained conditions from an isotropic stress of 60 lb/in2 with constant cell pressure.

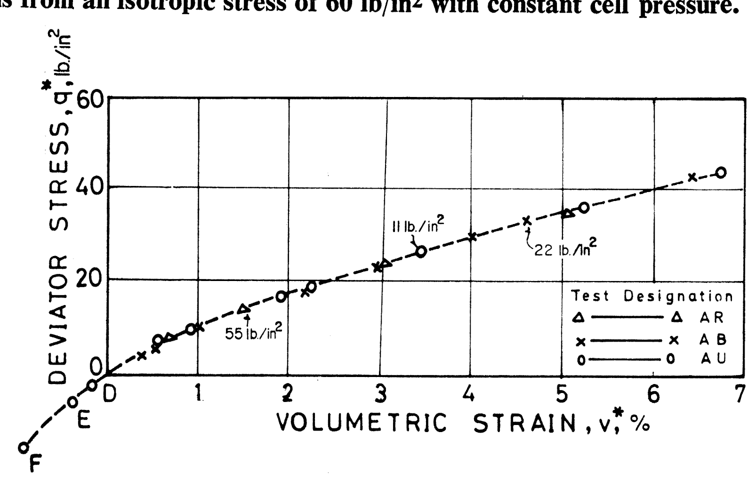

Fig. 8. The *(q*, v*)* characteristics of Specimens AR, AB and AU prepared under different initial one-dimensional stresses and sheared under fully drained conditions from an isotropic stress of 60 lb/in2 with constant cell pressure.

Shift of Origin of Stress-Strain Curve with Consolidation Stress

An alternative method by which the author was able to correlate the stress-strain behaviour of the three specimens satisfactorily will now be discussed. In this method, it is suggested that the behaviour of the specimens in the plots (q^*, ε^*) and (q^*, v^*) are unique, where :

$$q^* = q - q_{Ko} \quad \ldots \ldots \ldots \ldots \quad (1)$$

$$v^* = v - v_{Ko} \quad \ldots \ldots \ldots \ldots \quad (2)$$

$$\varepsilon^* = \varepsilon - \varepsilon_{Ko} \quad \ldots \ldots \ldots \ldots \quad (3)$$

In these expressions, q_{Ko} is the magnitude of the initial shear stress due to one-dimensional consolidation, and v_{Ko} and ε_{Ko} correspond to volumetric and shear strain experienced by the specimens during the subsequent shear in the triaxial apparatus up to a deviator stress of q_{Ko}. The results are plotted as the modified plots (q^*, ε^*) and (q^*, v^*) in Figs. 7 and 8. The unique relationships revealed by these plots indicate that the origin of the stress-strain curve, denoted by D, E and F in the (q, ε) and (q, v) plots, shift by amounts $(-q_{Ko}, -\varepsilon_{Ko})$ and $(-q_{Ko}, -v_{Ko})$ respectively. It is of interest to note that the stress-strain behaviour for a deviator stress less than q_{Ko}, i.e. for negative values of q^*, ε^* and v^*, also appears to be unique and occurs as a continuation of the curve describing the behaviour in the positive range of q.

The method suggested in this section for the correlation of the stresses and strains of specimens subjected to varying one-dimensional consolidation stresses and subsequently sheared from an isotropic stress condition, has an important field application. Specimens which are in the normally consolidated state under a K_o condition in the field when tested in the triaxial apparatus at an isotropic stress (greater than the initial one-dimensional consolidation stress) will only give unique behaviour in the (q^*, ε^*) plot and not in the conventional (q, ε) or $(q/p, \varepsilon)$ plots. The initial one-dimensional consolidation stress experienced in the field by a specimen could be determined by performing a single one-dimensional consolidation test in the laboratory on the specimen. Then, by doing a single drained triaxial test after isotropic consolidation at a cell pressure higher than the initial one-dimensional consolidation stress, it would be possible to established the (q^*, ε^*) and (q^*, v^*) behaviour of the field specimen.

Effect of Initial Consolidation Stress on Undrained Test Results

The observations during undrained tests on two specimens designated as T_7 and T_4 will now be presented, and an attempt will then be made to correlate the data. Specimen T_7 was prepared from a slurry by initial one-dimensional consolidation under a vertical stress of 3 lb/in^2 which corresponds to an applied deviatoric stress of 1 lb/in^2. This specimen was then isotropically consolidated under a pressure of 60 lb/in^2 and was subsequently sheared in a conventional triaxial apparatus under undrained conditions. Sample T_4 was subjected to a similar treatment but was subjected to a one-dimensional consolidation stress of 22 lb/in^2, corresponding to an initial shear stress of 6.6 lb/in^2.

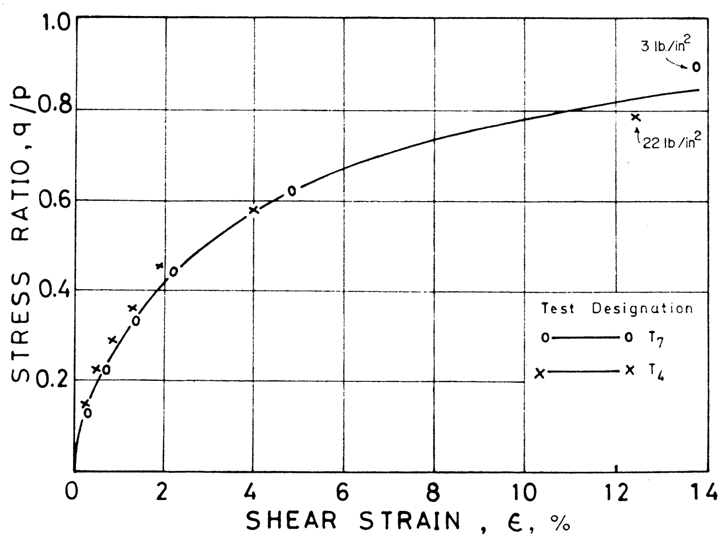

Fig. 9. The (q/p, ε) characteristics of specimens prepared under different initial one-dimensional consolidation stresses and sheared under undrained condition from an isotropic stress of 60 lb/in2 with constant cell pressure.

Experimental data from undrained tests—In Fig. 9 the $(q/p, \varepsilon)$ relationships observed during triaxial shear tests T_7 and T_4 are plotted and these can be seen to be virtually identical. The magnitudes of the parameters ε and q were both taken to be zero at the commencement of the triaxial shear phase of the tests (i.e. after the isotropic consolidation to 60 lb/in^2). This unique $(q/p, \varepsilon)$ relationship is independent, therefore, of the previous shear stress (or strain) history which had been imposed on the samples during the initial one-dimensional consolidation. The fact that no such uniqueness was observed in drained tests will be discussed later.

Two methods which attempt to correlate the results of undrained tests T_7 and T_4 will now be considered. The first is the same as the $(q^*, v^*, \varepsilon^*)$ method used in correlating drained test reslts.

Correlation of undrained test results : Method A — If, during the initial one-dimensional consolidation, a sample is subjected to a shear stress q_{K_o} and undergoes a shear strain ε_{K_o}, then, during subsequent shear in the triaxial shear phase of a test, $q^* = q - q_{K_o}$ and $\varepsilon^* = \varepsilon - \varepsilon_{K_o}$. The (q^*, ε^*) relations for specimens T_7 and T_4 can be seen to be completely different in Fig. 10. The

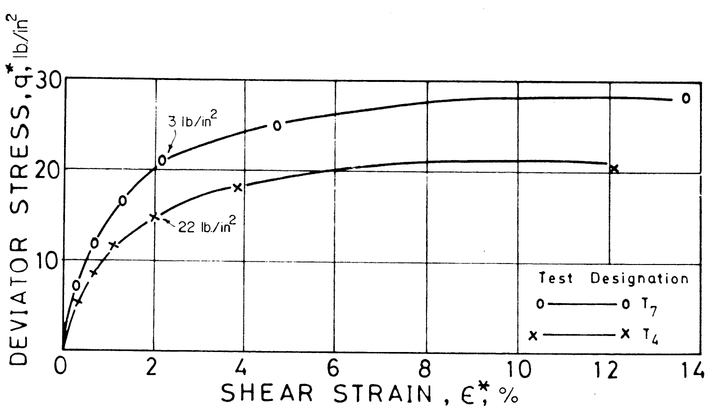

Fig. 10. The (q*, ε*) characteristics of specimens prepared under different initial one-dimensional consolidation stresses and sheared under undrained condition from an isotropic stress of 60 lb/in² with constant cell pressure.

($q^*/p^*, \varepsilon^*$) relations were also found to be different. In deriving p^* it was assumed that :

$$p^* = p_o + \tfrac{1}{3}\, q^* - u \quad \dots\dots\dots\dots \quad (4)$$

A possible explanation for the fact that both the (q^*, ε^*) and the ($q^*/p^*, \varepsilon^*$) relationships are not unique for undrained tests on samples with different shear stress (or strain) histories, whereas they were for drained tests, will be discussed later.

Correlation of undrained test results : Method B — In this method, it is assumed that (i) a unique (q, u) relationship exists during triaxial shear of any specimen that has been prepared from a slurry under isotropic conditions only (i.e. without any initial one-dimensional consolidation), and (ii) the changes in q and u actually observed during triaxial shear of a sample, which has in its history previously experienced a shear stress of q, would only be the same as those for an isotropic sample for values of $q > q_1$. In Fig. 11, the values of q_1 for samples T_7 and T_4 correspond to points A and B respectively. If the two assumptions stated above are correct, then curve BY when B is displaced to C (where C is at the same value of q as B) should coincide with curve CX. This can be seen to be the case in Fig. 12. Hence, the (q, u) relations for the two specimens are identical for all values of q larger than the highest value of q_1 imposed on either specimen during the preliminary one-dimensional consolidation. If, however, the values of u shown in Fig. 12 are used to calculate the revised values of p during the shear tests on specimens T_7 and T_4, it is found that the ($q/p, \varepsilon$) relationship is not unique at higher values of q/p, as shown in Fig. 13. It will be recalled in Fig. 9 that, when the experimentally observed values of u were used to calculate p, the ($q/p, \varepsilon$) curve was unique for all values of q/p. In the light of the evidence provided so far, it is concluded that the

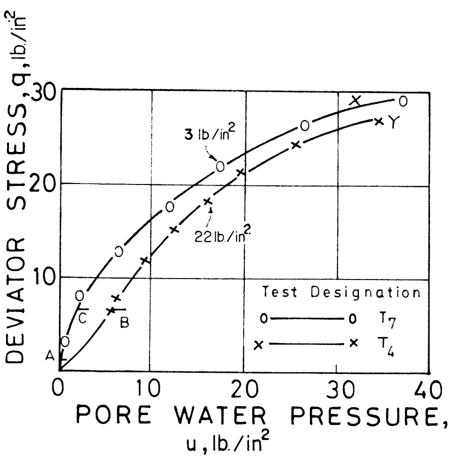

Fig. 11. The (q, u) characteristics for Specimens T7 and T4.

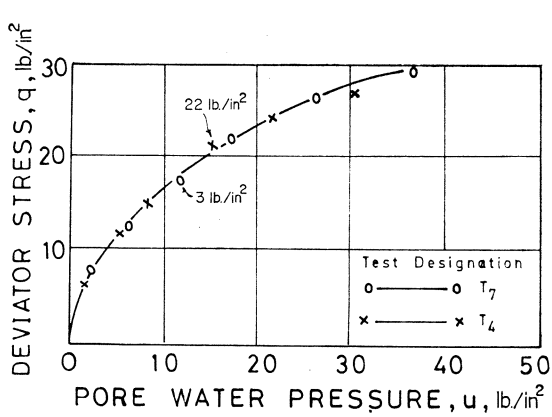

Fig. 12. Modified (q, u) relations for Specimens T7 and T4.

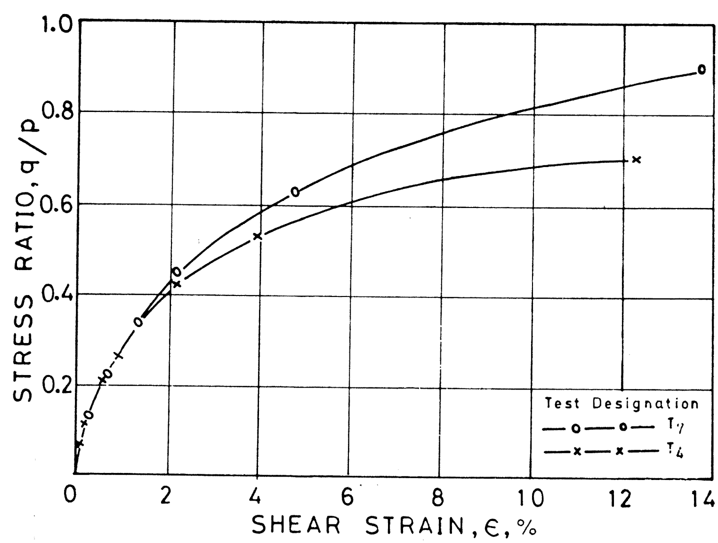

Fig. 13. Modified (q/p, ε) relationships for Specimens T7 and T4.

(q/p, ε) relation actually observed in undrained tests is unique and is not affected by the previous shear stress, q_1, imposed during one-dimensional consolidation. Furthermore, the pore pressures observed during triaxial shear are dependent on q_1, but deviations from the values observed with isotropically prepared samples occur in the range $0 < q < q_1$.

It will be recalled that the *(q/p, ε)* relationship observed in drained tests was affected by the initial shear stress. The apparent contradiction between this and the conclusion made above for undrained tests may be explained by appealing to the hypothesis of ROSCOE & POOROOSHASB (1963) or its modification by ROSCOE & BURLAND (1968). The basic equation used by Roscoe &

Poorooshasb has been discussed in detail by BALASUBRAMANIAM (1969). This equation can be expressed in terms of shear strain, ε, as :

$$d\varepsilon = \left(\frac{d\varepsilon}{d\eta}\right)_v d\eta + \left(\frac{d\varepsilon}{dv}\right)_\eta dv \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (5)$$

where $(d\varepsilon/d\eta)_v$ corresponds to the slope of the (ε, η) characteristic in an undrained test, and $(dv/d\varepsilon)_\eta$ refers to the slope of the anisotropic consolidation path in a (v, ε) space. Consequently, an increment of shear strain during any test in which there is a reduction of volume can be considered to be made up of two components, namely :

(i) an undrained component as represented by the first term on the right-hand side of Eq. 5,

and (ii) an anisotropic consolidation component as represented by the second term in Eq. 5.

Hence, it is possible for the undrained component of the shear strain to be independent of the initial shear stress history while the anisotropic consolidation component *does* depend on the initial shear stress history for the range $0 < q < q_1$. It can be seen that the anisotropic consolidation component in Eq. 5 is itself the product of two components, namely:

(i) a component $(d\varepsilon/dv)_\eta$ which is obtained from the results of anisotropic consolidation tests,

and (ii) the volume change, dv, which is predicted by projecting the imposed stress increment onto the state boundary surface (see ROSCOE & POOROOSHASB, 1963).

This latter surface is assumed to be unique and to be best represented by data from undrained tests. The author believes, from his own data and from that of POOROOSHASB (1961) and THURAIRAJAH (1961), that $(d\varepsilon/dv)_\eta$ is not dependent on the magnitude of the shear stress, q. This implies that the volumetric strains experienced during triaxial shear tests with geometrically similar stress paths are not uniquely related to q/p until $q > q_1$.

EFFECT OF LOAD INCREMENT SIZE ON THE STRESS-STRAIN BEHAVIOUR

In studying the effect of stress paths on the stress-strain behaviour it is essential to keep the magnitude of pore pressure associated with a stress increment as low as possible. Fully drained compression tests at constant cell pressures with large increments can cause high pore pressures to develop. Hence, the specimen will be virtually subjected initially to an undrained stress path and, subsequently, to a q-constant stress path. Though this type of stress path is more likely to occur in engineering practice, it would give a totally misleading picture in the laboratory if it was there assumed that this path referred to the stress-strain behaviour under fully drained conditions.

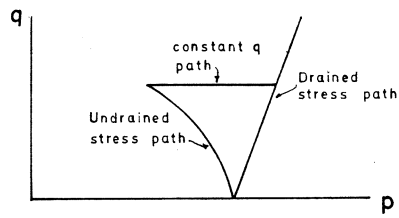

Fig. 14. Stress paths followed by a specimen subjected to a large load increment.

The stress path actually followed by a 'drained' test specimen subjected to a large increment is indicated in Fig. 14, where it is evident that the specimen has been subjected to a stress path which is totally different from the one intended. Also, the stress ratio at the end of the undrained phase is higher than the stress ratio at the end of the q-constant phase. Hence, the specimen will have been subjected to a higher stress ratio than the recorded value at the end of its pore pressure dissipation. In this section, the effects of the load increment size on the stress-strain behaviour of the specimens (sheared under fully drained conditions from a cell pressure of 60 lb/in^2) will be investigated. The stress history of each specimen was identical prior to shear, namely a one-dimensional stress of 22 lb/in^2 and an isotropic stress of 60 lb/in^2.

Experimental Observations Illustrating the Effects of Load Increment Size

Experimental observations on four fully drained tests (Tests No. Z, R, X and Y) are presented in this section. In Test Z, stress increments of 0.7 lb/in^2 were applied at 3 hour intervals. Five stress increments were applied during a day, and the equilibrium readings were taken before applying the next increment in the following morning. In Test R, stress increments of 7 lb/in^2 were applied at two days intervals. Stress increments of 14 lb/in^2 were applied in Test X at two day intervals, and in Test Y a single stress increment of 26 lb/in^2 was used.

The (q, ε) characteristics of the specimens are as shown in Fig. 15. It is seen that the shear strain corresponding to any particular deviator stress is different for each of the tests, indicating that the magnitude of the applied stress increment has an important effect on the results obtained in drained tests. The results indicate that ε is path dependent. The (q, ε) characteristics of the specimen in Test Z before and after application of the load increments is illustrated in Fig. 16. It is evident that the difference in strains caused by each stress increment is so small that the deviation of shear strains before and immediately after the application of the stress increment are within the limits of the experimental accuracy.

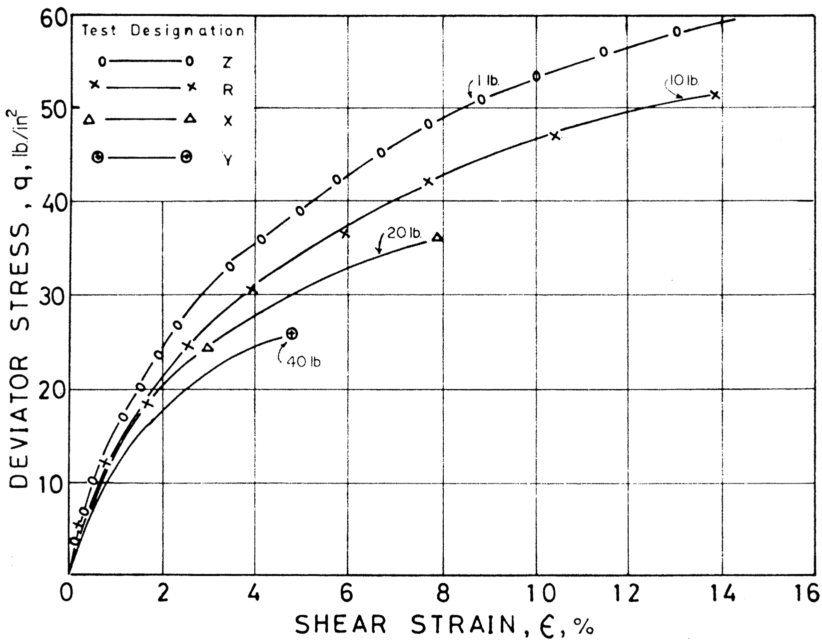

Fig. 15. The (q, ε) relationships of specimens sheared under fully drained condition from an isotropic stress of 60 lb/in² with different load increment sizes.

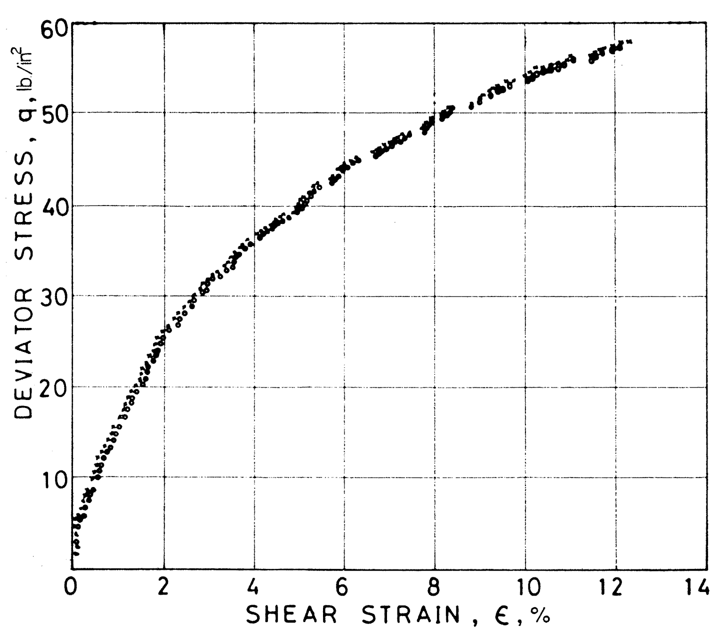

Fig. 16. The (q, ε) relationship for Specimen Z sheared under small load increments.

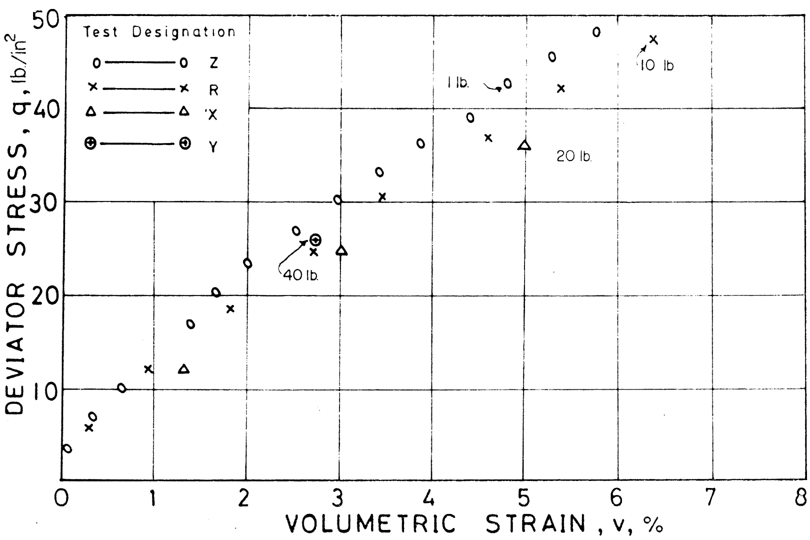

Fig. 17. The (q, v) relationships of specimens sheared under fully drained conditions from an isotropic stress of 60 lb/in^2 with different load increment sizes.

Figure 17 illustrates the *(q,* v*)* relationships for all the specimens. The *(q,* v*)* relationships of the specimens are seen to be different. There is no orderly behaviour in the *(q,* v*)* relationships of these samples. One would expect this discrepancy since it has already been established that the pore pressures

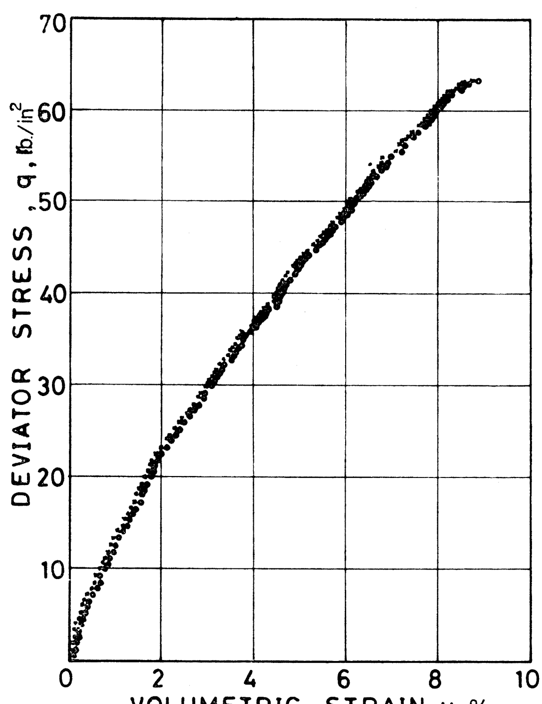

Fig. 18. The (q, v) relationship for Specimen Z sheared under small load increments.

developed in undrained tests and the volumetric strains experienced in drained tests are affected by the initial shear stress effects caused by the preliminary one-dimensional consolidation. It is suggested that, if the effect of the initial shear stress history had not existed, then there would have been a unique (q, v) relationship independent of the load increment size.

Figure 18 illustrates the (q, v) relationship for Specimen Z; it should be noted that the stress increment is so reduced that the stress-strain behaviour before and after the application of the load lies within a narrow band.

STRESS-STRAIN CURVES OF SPECIMENS SHEARED AT DIFFERENT LEVELS OF ISOTROPIC STRESS WITH SIMILAR APPLIED STRESS PATHS

In this section, the author will discuss the stress-strain behaviour of specimens sheared from isotropic stress levels of 30, 60 and 90 lb/in^2 when subjected to three different types of imposed stress path. The imposed stress paths were those of (i) an undrained test, (ii) a p-constant test, and (iii) a fully drained test (applied stress path of slope $dq/dp = 3$). All specimens were initially prepared under a one-dimensional consolidation stress of 22 lb/in^2 and were subsequently isotropically consolidated to the relevant level of isotropic stress. The experimental observations on each type of test are first presented and subsequently discussed.

Experimental Observations on Undrained Tests

Figure 19 illustrates the variation of shear strain, ε, with stress ratio, q/p

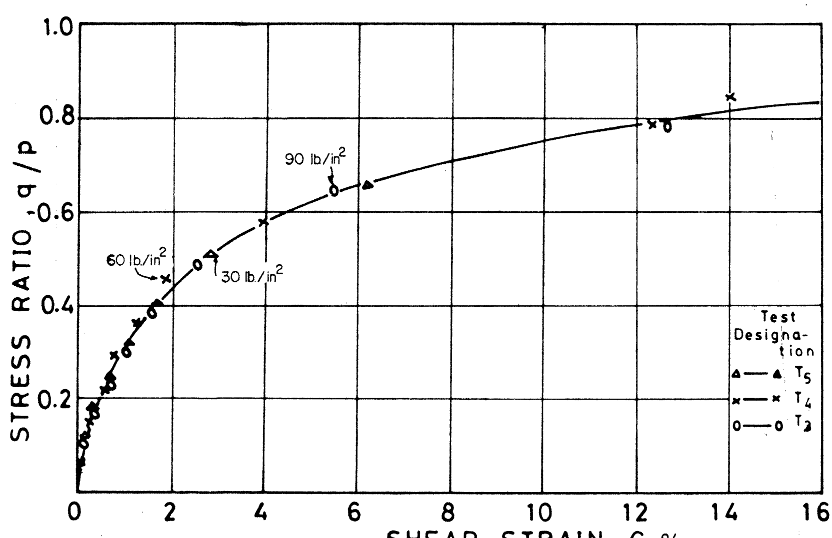

Fig. 19. The (q/p, ε) characteristics of Specimens T3, T4 and T5 prepared under an initial one-dimensional stress of 22 lb/in^2 and sheared under undrained conditions from isotropic stresses of 30, 60 and 90 lb/in^2 respectively.

for three undrained compression tests. It is seen that the variation of q/p with ε is unique for all three tests.

Experimental Observations on p-Constant Tests

Figure 20 illustrates the variation of shear strain, ε, with stress ratio q/p for three specimens AJ, AQ and AO sheared from isotropic stresses of 30, 60

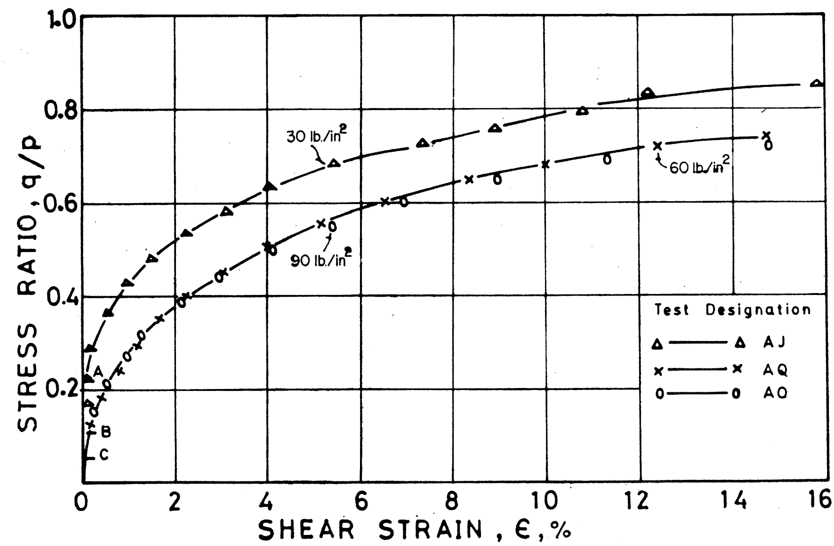

Fig. 20. The (q/p, ε) characteristics of Specimens AJ, AQ and AO prepared under an initial one-dimensional stress of 22 lb/in^2 and sheared under p-constant cuoditions from isotropic stresses of 30, 60 and 90 lb/in^2 respectively.

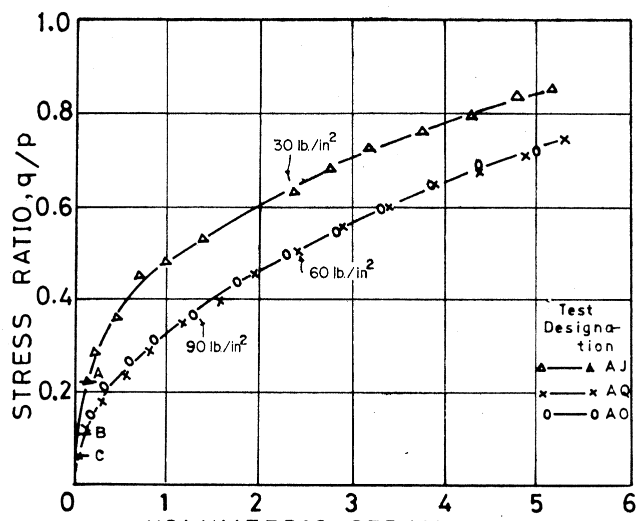

Fig. 21. The (q/p, v) characteristics of Specimens AJ, AQ and AO prepared under an initial one-dimensional consolidation stress of 22 lb/in^2 and sheared under p-constant condition from isotropic stresses of 30, 60 and 90 lb/in^2 respectively.

and 90 lb/in² respectively. It is seen that the *(q/p, ε)* characteristics for the 30 lb/in² specimen (Test AJ) are quite different from those of the other two. Similar differences are observed in the *(q/p, v)* relationships of the three specimens in Fig. 21. However, the *(v, ε)* characteristics for the three specimens AJ, AQ and AO were found to be approximately unique. During a *p*-constant test, the volumetric strain is assumed to be only a function of the deviator stress. If elastic volumetric strain were assumed to be dependent on the mean normal stress, *p*, and if elastic shear strain were neglected, then the *(v, ε)* relationship would refer to plastic strains. Consequently, the slope of this curve would represent that of the plastic strain rate vector which has been extensively used in some of the Cambridge stress-strain theories (see ROSCOE et al, 1963; ROSCOE & BURLAND, 1968; SCHOFIELD & WROTH, 1968).

Correlation of p-constant test data— For the correlation of the experimental observations of *p*-constant tests, two assumptions will be made namely :

(i) unique relationships exist between (a) q^* and ε^* and between q^* and v^*, where q^*, ε^* and v^* are as defined before,

(ii) these unique relationships are similar for all specimens sheared from isotropic stress states; this entails the use of the parameter q^*/p^* for the comparison of strains in specimens sheared after consolidation to different isotropic stress levels.

The results are presented in the $(q^*/p^*, \varepsilon^*)$ and $(q^*/p^*, v^*)$ plots in Figs. 22 and 23 respectively. The unique relationships in both these plots indicate that the assumptions (i) and (ii) made above are valid for the correlation of the test

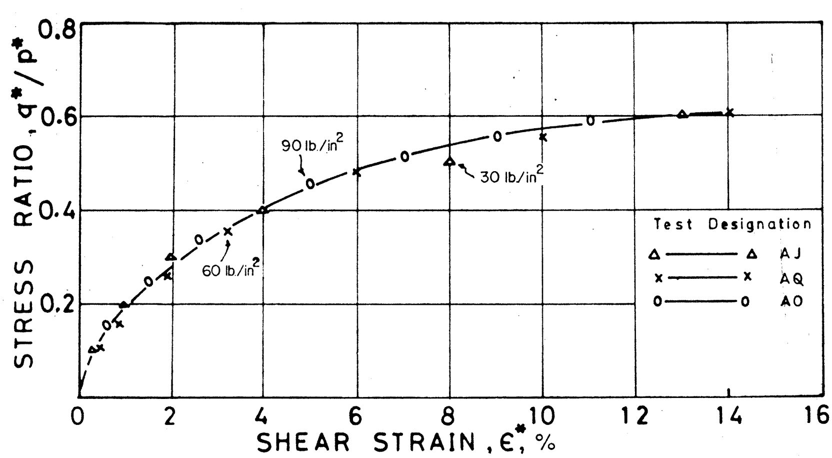

Fig. 22. The (q*/p*, ε*) characteristics of Specimens AJ, AQ and AO prepared under an initial one-dimensional consolidation stress of 22 lb/in² and sheared under p-constant conditions from isotropic stresses of 30, 60 and 90 lb/in² respectively.

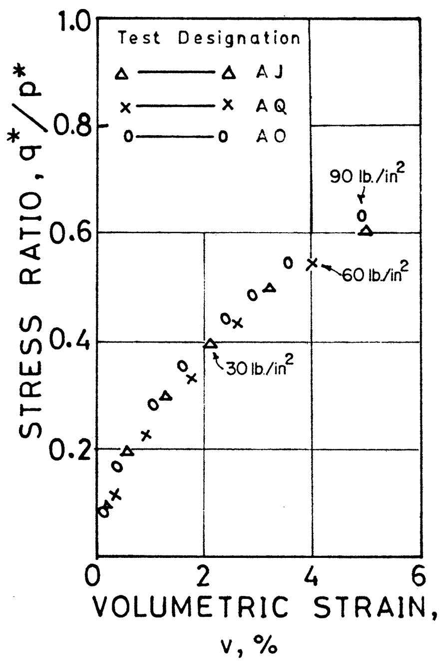

Fig. 23. The (q*/p*, v*) characteristics of Specimens AJ, AQ and AO prepared under an initial one-dimensional consolidation stress of 22 lb/in² and sheared under p-constant condition from isotropic stresses of 30, 60 and 90 lb/in² respectively.

results. Furthermore, since q^* and ε^*, and q^* and v^*, are uniquely related, the relationship between v* and ε* is also unique.

Experimental Observations on Fully Drained Tests

Figure 24 illustrates the variation of ε with q/p for the fully drained tests

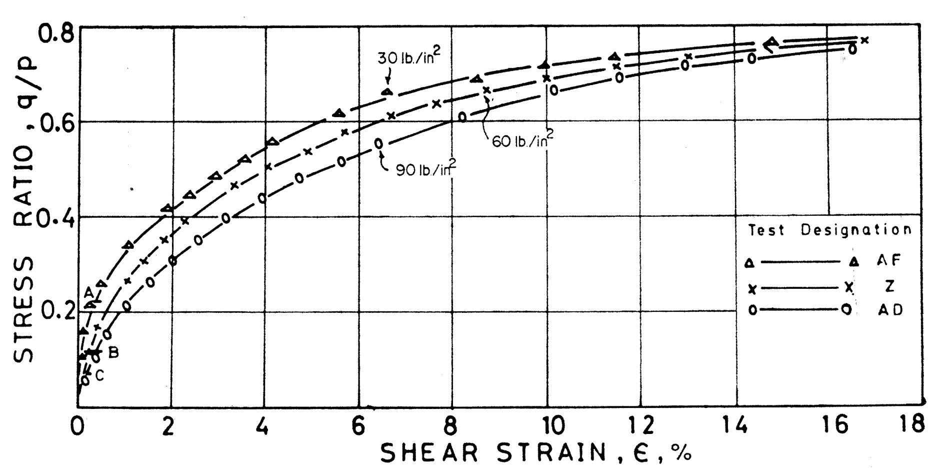

Fig. 24. The (q/p, ε) characteristics of Specimens AF, Z and AD prepared under an initial one-dimensional stress of 22 lb/in² and sheared under fully drained conditions from isotropic stresses of 30, 60 and 90 lb/in² respectively.

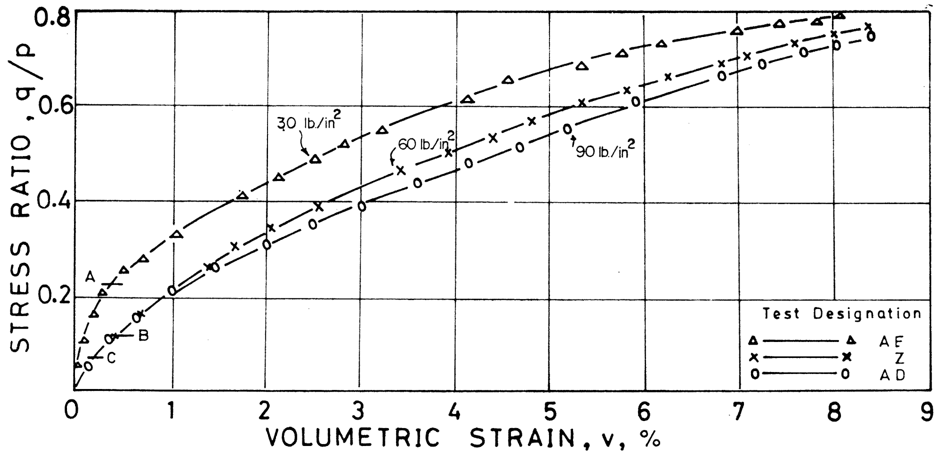

Fig. 25. The (q/p, v) characteristics of Specimens AF, Z and AD prepared under an initial one-dimensional stress of 22 lb/in² and sheared under fully drained conditions from isotropic stresses of 30, 60 and 90 lb/in² respectively.

carried out on specimens AF, Z and AD sheared from isotropic stresses of 30, 60 and 90 lb/in². These characteristics are all different. A similar behaviour is also noted in the $(q/p, v)$ characteristics in Fig. 25. In both figures the specimen sheared from the 30 lb/in² isotropic stress had smaller strains than the other two specimens.

The assumptions made for the correlation of the stress-strain behaviour of the fully drained tests are the same as those mentioned for the correlation of p-constant test results. These results are presented in the $(q^*/p^*, \varepsilon^*)$ plot and $(q^*/p^*, v^*)$ plot in Figs. 26 and 27. The unique relationships in these plots indicate that the (v^*, ε^*) characteristic must be unique and, furthermore, that the assumptions made are valid for the correlation of the fully drained test results.

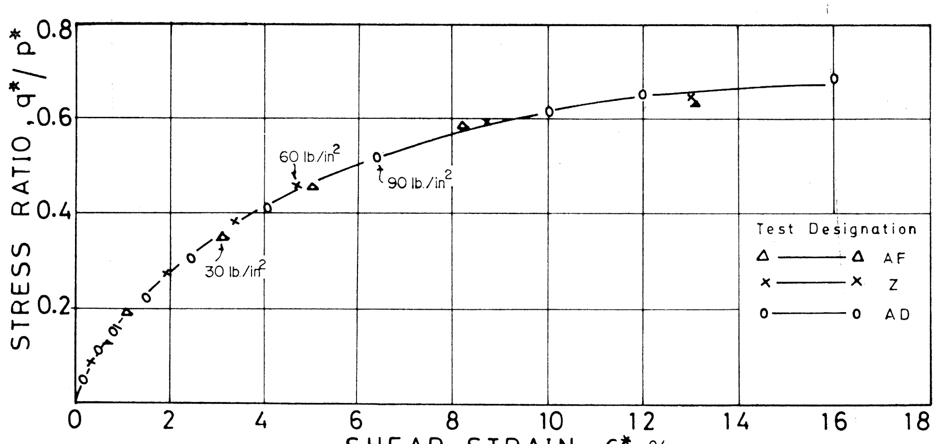

Fig. 26. The (q*/p*, ε*) characteristics of Specimens AF, Z and AD.

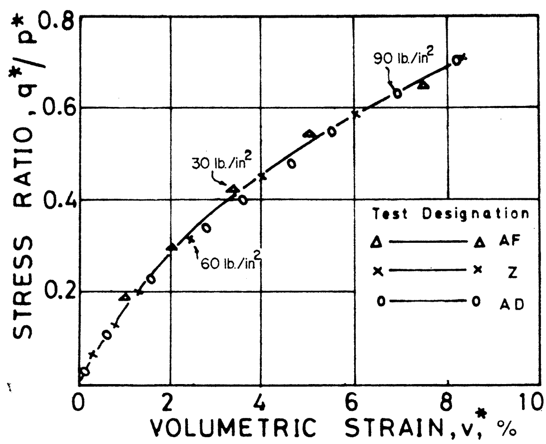

Fig. 27. The (q*/p*, v*) characteristics of Specimens AF, Z and AD.

CONCLUSIONS

Fully drained tests on specimens prepared with different initial one-dimensional stresses and subsequently consolidated under the same isotropic stress showed that the $(q/p, v)$ and the $(q/p, \varepsilon)$ relationships were dependent on the magnitude of the initial one-dimensional consolidation stress. The stress-strain behaviour of all these samples was found to be unique when presented in terms of the alternative parameters q^*, v^* and ε^*. A set of undrained tests performed on samples prepared in a similar manner showed that the $(q/p, \varepsilon)$ relationship was unique at all stress levels.

The stress-strain behaviour of drained test specimens ($dq/dp = 3$) was found to be dependent on the load increment size, and this effect was shown to be entirely due to the difference in stress paths followed by specimens which had been subjected to different load increment sizes. The load increment size was then reduced to such an extent that its effect on the (q, ε) and the (q, v) relationships during any application of load was within the limits of the experimental accuracy.

The stress-strain behaviour for three types of test (undrained, p-constant and fully drained with $dq/dp = 3$) on specimens prepared with the same initial one-dimensional stress condition and subsequently sheared from three isotropic stress levels were studied in detail. The observed $(q/p, \varepsilon)$ relationship for undrained tests was found to be independent of the previous isotropic consolidation stress level. The $(q/p, v)$ and $(q/p, \varepsilon)$ relationships for p-constant tests and the fully drained tests were also found to be dependent on the magnitude of the isotropic consolidation subsequent to the initial one-dimensional consolidation stress prior to shear. Based on the initial shear stress due to one-dimensional consolidation, the results were successfully correlated using the parameters q^*, v^* and ε^* to give unique behaviour.

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