LOCAL STRAINS IN CYLINDRICAL SPECIMENS OF KAOLIN DURING CONSOLIDATION

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SYNOPSIS

This paper summarises the method adopted and the local strains measured in cylindrical specimens of kaolin 1.5 inch and 4 inch diameter during one dimensional consolidation and subsequent isotropic consolidation. The local strains were measured by an X-ray technique where the strains were determined from the displacement of lead shot markers embedded in the clay. Since it is customary to prepare remoulded specimens of clay by one dimensional consolidation and subsequent isotropic consolidation prior to shear in the conventional triaxial apparatus, the results presented here will be of value in ascertaining the uniformity of the sample at the end of consolidation and prior to shear. From the local strains, local voids ratios are calculated and from these values pore pressure isochrones are determined. The results also indicated that for isotropic stresses of similar magnitude to the initial one dimensional stress, the strains induced by increments of isotropic stresses were anisotropic. However, for specimens which were isotropically consolidated to approximately three times the initial one dimensional stress the effect of anisotropy was found to be small.

INTRODUCTION

Non-destructive technique using X-rays has been developed for the determination of internal strains and voids ratio in cylindricals pecimens of kaolin during one dimensional and isotropic consolidation. The method is used to study the local deformation as well as to check the uniformity of deformation.

An X-ray technique was first developed by Roscoe et al (1963) for determining the strain patterns under plane strain conditions from the measurements of the displacements of lead shot markers embedded in sand. The method was subsequently modified and used by Sirwan (1965) for the measurement of local strains in triaxial specimens of sand during shear. Burland (1967) and Burland & Roscoe (1969) described the local strains during one dimensional consolidation of kaolin in a model clay footing. This paper summarises the method adopted and the local strains measured in cylindrical specimens of kaolin 1.5 inch and 4 inch diameter during one dimensional consolidation and subsequent isotropic consolidation. Since it is customary to subject remoulded specimens of clay to one dimensional and

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isotropic consolidation prior to shear in the conventional triaxial apparatus, the results presented here will be of value in ascertaining the uniformity of the sample at the end of consolidation.

In addition to the measurement of local strains, the side friction between the clay and the surface of the former in which the clay is consolidating is assessed by making use of a load cell at the base of the sample.

APPARATUS

Consolidometer

The consolidometer was mainly used for X-ray work. Hence it was essential to select a material which has an absorption coefficient which is as small as possible. Perspex and aluminium were selected because of their relatively low X-ray absorption coefficients.

The description of the way in which the pedestal of the base of a commercially available triaxial cell was modified to incorporate a load cell has been given by BURLAND (1967). The special consolidometer used to study the uniformity of strains during one dimensional consolidation of the clay is shown in Fig. 1. It consists of a perspex tube made in two parts and connected by a collar. The internal face of the tube is highly polished and is 1.5 inch diameter. The two parts are held together by two metal end plates connected by four screwed rods L. The bottom metal plate forms a seal against the rubber cap on the pedestal containing the load cell. The piston M is made of PTFE to reduce friction between it and the side walls. Its lower face contains a porous stone (3/16 inch thick and type UNI 150 KV) and this is the only drainage face for the sample. The casette N for the X-ray films rests in a special holder with reference markers such as P fixed in rows on both sides of this holder. The whole apparatus is mounted on the square base plate Q which can be fixed at

Fig. 1. Perspex consolidometer.

one end of a test bed while the X-ray head is mounted at the other end. Loads are applied to the piston M by a hanger.
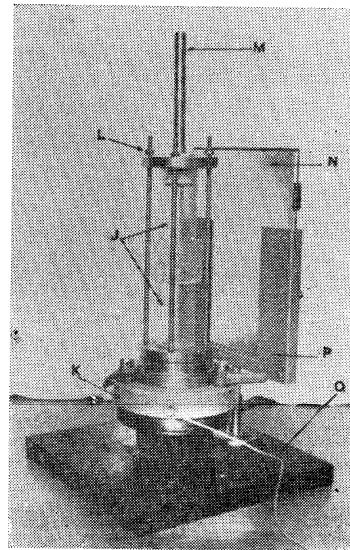
One test, to investigate the effects of side friction during one dimensional consolidation was carried out with the perspex tubes replaced by tubes of duralumin.

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When not wishing to study deformation during one dimensional consolidation, clay samples were prepared in an adaption of the sand sample formers made by THURAIRAJAH (1961). This former is described in BALASUBRAMANIAM (1969).

Experimental Set Up for Taking Radiographs

All tests with radiographic work was carried out in an X-ray compound shielded with double-lined lead screens. With 1.5 inch diameter samples a focal film distance of 4 feet was found to be necessary for good definition of the images of the lead markers on the radiographs. Test beds six feet long were made. The 1.5 inch triaxial cells were each mounted on a special base plate with a highly polished upper surface covered with a thin layer of lubricant. The 1.5 inch triaxial cell could then be rotated about a vertical axis and could be clamped in two mutually perpendicular directions. The casette holder was mounted on the same base plate at the back of the triaxial cell. Two vertical columns of lead markers, each 0.080 inch diameter were fixed to both sides of the casette holder. The images of these markers were used as references to locate the true axes of the triaxial system in the radiographs. The triaxial cell pressure was supplied through a flexible pressure tubing connecting to the base of the triaxial cell. The X-ray head was mounted on a plate similar to the triaxial cell but on the other end of the same test bed. The position of the two base plates could be varied along the length of the test bed.

Sample Preparation

Air-dried kaolin was mixed with 160% of distilled water in a commercial pugmill for about three hours under a vacuum of 20 inches of mercury. The properties of kaolin are liquid limit = 74%, plastic limit = 42%, plasticity index = 32% and specific gravity = 2.61. The kaolin slurry was carefully placed in the consolidation former with a long handled spoon. A perspex jig and a probe are used for placing the lead markers in the clay. The perspex jig can be slid into the top of the consolidometer former so that it is located by the two pins projecting above this former. The lower surface of the jig is then nearly in contact with the upper surface of kaolin. The holes in the jig are spaced in a manner in which any desired pattern of lead markers can be arranged in two mutually perpendicular directions. The probe has a small cavity at one end in which the lead markers sit while being forced down to their respective positions. This method of placing lead markers was found to be satisfactory even with the four inch diameter sample in which some of the lead markers were located correctly at a depth of 17 inches below the jig.

Equipment for Non-destructive Tests

The X-ray equipment used was a Meuller M.G. 150 Industrial set. Detailed description of the set is given by JAMES (1965). Briefly the X-ray set can be operated with a fine focal spot of 1.5 mm or a coarse focal spot of 4 mm. The maximum range of tube voltage was from 50 kV to 150 kV. The maximum tube current was 20 milliamp with the coarse focal spot and 8 milliamp with the fine focal spot. The input voltage was stabilised within 0.1 % using a regulator in the range 190 to 260 volts.

Kodak Industrex type D films were used for most of the radiographs. The film was placed between two lead screens (0.004 inch thick at the back and 0.006 inch thick in the front) inside a standard Kodak steel casette.

The exposure time was selected by trial and error to obtain an optimum film density of 1.0 as suggested by JAMES (1965). The exposure time used for the one dimensional consolidation tests on 1.5 inch diameter samples varied from 1.5 to 2 minutes at 70 kV with a tube current of 15 mA and the fine focal spot. A focal film distance of 50 inches was employed. Approximately identical exposure conditions were used for all triaxial work on 1.5 inch diameter samples. Two types of exposure conditions were employed with the four inch diameter samples depending on the focal film distance (f.f.d.). With f.f.d.'s of 50 and 120 inches, exposures of 4 mA for one minute and 6 mA for 8 minutes at 130 kV were used.

The exposed films were developed in DX-80 developer for four minutes. The films were agitated while being developed for about 10 times at the end of each minute. The films were then fixed in acid fixative for 12 minutes. Afterwards they were washed in running water and dried. The developed films were kept in boxes and stored in a cool dark place.

Measurement of the Positions of the Images of the Lead Markers on the X-ray Films

The radiographs taken in the earliest tests carried out were measured in the orthogonal displacement meter described by ROSCOE, et al (1963). Subsequent measurements were carried out 1965 in the Cambridge University, Cavendish Laboratory using a machine (called CLARA) which is described in detail by LORD (1969). Late in the test programme a new measuring machine designed and developed by JAMES (1965) in the Cambridge University Engineering Laboratory became available and was used for all measurements on the 4 inch diameter samples.

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In the 1.5 inch diameter samples the lead markers were arranged in two mutually perpendicular vertical planes containing the axis of the sample as shown in Fig. 2. This method was adopted to be able to compare the strains from one plane with those in the orthogonal plane.

With the 4 inch diameter samples, again the lead markers were arranged in two perpendicular planes. The number of columns in any one plane varied from 6 to 9 while the number of rows varied from 8 to 16. The computation of the coordinates of each marker is described in detail in BALASUBRAMANIAM (1969).

Two methods were adopted for the calculation of strains from the displacement of the lead markers. In the first method the axial and radial strains were computed directly from the axial displacements and the radial displacements of four markers lying in the same vertical plane. The axial strain ε_y and the radial strain ε_x are given by :

$$\varepsilon_x = \log \left[(x_1 - x_2) \left/ \left\{ (x_1 - x_2) + (c_1 - c_2) \right\} \right. \right]$$

$$\varepsilon_y = \log \left[(y_3 - y_4) \left/ \left\{ (y_3 - y_4) + (d_3 - d_4) \right\} \right. \right]$$

where x_1, x_2 are the x coordinates of the markers in the same horizontal plane and c_1 and c_2 are the corresponding displacements in the x direction. y_3 and y_4 are the y coordinates of the markers in the same vertical line and d_3, d_4 are their corresponding displacements.

In the second method the strains were computed from the displacements of three markers, by assuming a linear homogeneous function for the displacement in terms of the coordinates.

The general assumptions made in the derivation of strains from the measurements of displacements of lead shot markers are (i) the mass of soil within the smallest grid deforms uniformly and (ii) there is no relative movement between the lead markers and the surrounding soil. The experimental observations in support of these assumptions have already been presented for sand by ROSCOE et al (1963). The validity of these assumptions for clay will be considered in the latter sections.
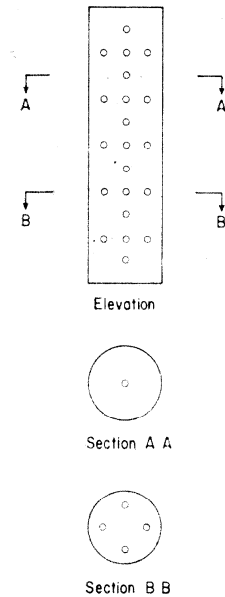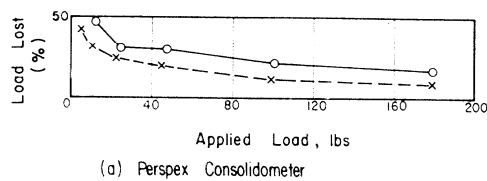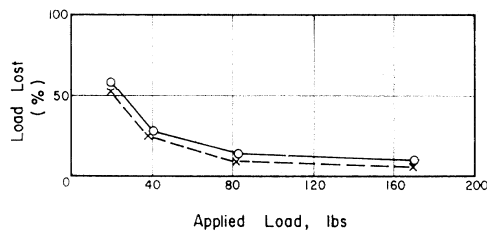

Fig. 2. Arrangement of lead markers in triaxial samples.

ONE DIMENSIONAL CONSOLIDATION TESTS WITH LEAD SHOT TECHNIQUE FOR THE MEASUREMENT OF LOCAL STRAINS
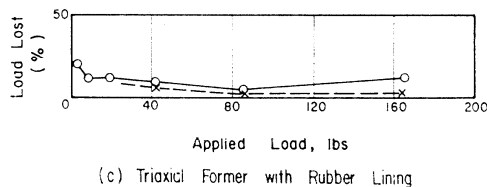
The structure of clay particles is assumed to have no preferred orientation after remoulding. However such orientation may develop during subsequent consolidation. HVORSLEV (1960) suggested that during the uniaxial consolidation of a remoulded clay that the particles developed a preferred orientation in a direction perpendicular to that of the major principal stress. THOMPSON (1962) suggested that this preferred orientation did not develop to the same extent simultaneously throughout any such sample, but he did not measure local strains within his samples. SIRWAN (1965) using the lead shot technique to measure local strains in consolidometer samples observed that the consolidation during the first application of load was larger in layers close to the free draining surfaces than for the other layers in the samples. For subsequent load increments he observed that the consolidation was larger in layers which were remote from the free draining surfaces than for those that were close. It must be emphasised that the mechanism of one dimensional consolidation is further complicated by the effects of side friction. Side friction measurements in consolidometers have been carried out by LEONARDS & GIRAULT (1961), THOMPSON (1962) and BURLAND (1967) among others. These measurements indicate that the magnitude of side wall friction can be reduced to a very small order by lubricating the walls with silicone grease. The one dimensional consolidation experimental results will be presented in the following sections. In addition to the strains the magnitude of side friction was measured by making use of a load cell at the base of the sample.

(a) Perspex Consolidometer

(b) Duralumin Consolidometer

(c) Triaxial Former with Rubber Lining

Fig. 3. Friction loss in consolidometers.

Results of Side Friction Tests

Figure 3 indicates the percentage load lost in friction of the specimen during one dimensional consolidation in the perspex and in the duralumin consolidometers and in the triaxial former with the rubber lining. A layer of silicone grease (about 0.01 inch thick) was smeared over the inside surface of these consolidometers prior to introducing clay. The dashed lines in Fig. 3 refer to the percentage load

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lost in friction immediately after applying a load increment. The full lines refer to conditions two days after applying an increment. It is evident that the side friction was a minimum in the triaxial former which was lined with a rubber membrane.

Equilibrium Voids Ratio (e) vs. log (stress σ) Plot for One Dimensional Consolidation

In Fig. 4 the full lines give the observed relationship between the equilibrium voids ratio (as measured from the final moisture content and the measured heights of the sample and the logarithm of the axial stress as calculated from the piston load. The dashed curves show the same relationship but now the stress is as recorded by the load cell at the base of the sample. The full lines have a slope $C_c = 0.31$, while for the dashed lines $C_c = 0.29$. For both types of swelling curves, their slopes k were approximately identical and equal to 0.045. The value of $C_c = 0.29$ may be compared to that of 0.25-0.26 obtained during isotropic consolidation in conventional triaxial specimens.
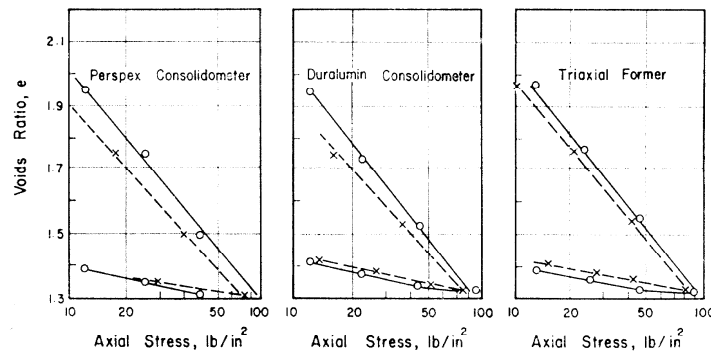

Fig. 4. Voids ratio-log pressure plot for one dimensional consolidation.

Variation of Consolidation with Depth during One Dimensional Consolidation

(i) *Consolidation during the first increment of stress:* Figure 5 illustrates the vertical displacement y of lead shot markers with respect to their vertical coordinates y as measured from the impermeable boundary of the sample. The three different symbols in this diagram refer to three different vertical columns or markers within the sample. It is evident that the sample was uniformly deforming since the displacement of all markers were linearly proportional to their initial vertical coordinates, for this first stress increment of 3 lb/in^2. During this increment of stress the clay, in the form of a slurry at 157% moisture content, was consolidated from a height of 8.5 inches to

about 5.7 inches. The corresponding cumulative vertical strain being approximately 33%. In Fig. 5 the topmost layer of lead shot markers is about 0.7 inches below the free draining surface. Since no markers were arranged along this surface, the consolidation in the element of clay closest to it (which is about 0.7 inch thick) cannot be included in Fig. 5. Similar lead shot measurements carried out by SIRWAN (1965) during one dimensional consolidation of a slurry with an initial stress increment of only 0.26 lb/in², indicated that the consolidation in layers closest to the free draining surface is higher than the rest of the sample for this increment of stress.
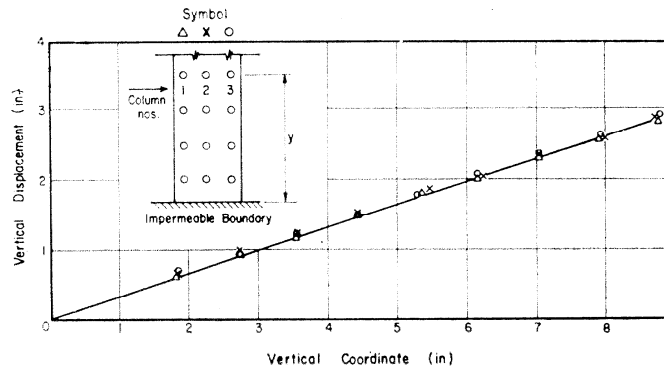
Fig. 5. Incremental vertical displacement of markers for first increment of stress during one dimensional consolidation from slurry.
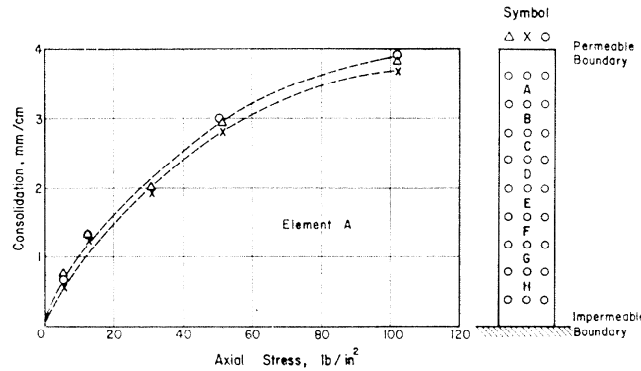
Fig. 6. Consolidation of 3 vertical columns in element A plotted with respect to the major principal effective stress.

(ii) *Consolidation during Subsequent Increment of Stress :* The subsequent stress increments were applied with a stress increment ratio of one, up to a maximum stress of 102 lb/in². Figures 6 to 8 show the variation of consolidation in mm/cm with the major principal stress for three horizontal elements A,D, and H at depths close to the free draining surface (element A), the mid height of specimen (element D) and the impermeable boundary (element H). It is observed in Figs. 6 to 8 that the consolidation of any hori-
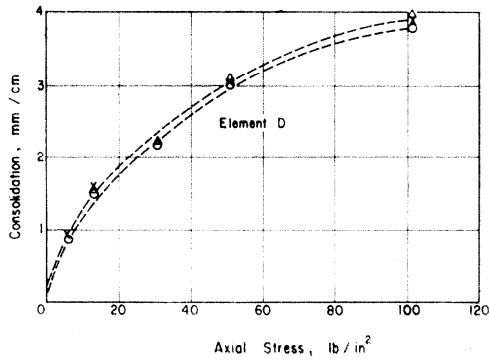
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Fig. 7. Consolidation of 3 vertical columns in element D plotted with respect to the major principal effective stress.
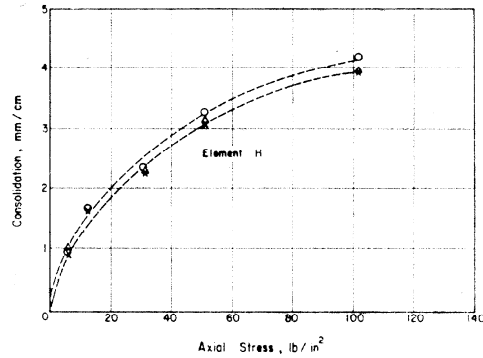

Fig. 8. Consolidation of 3 vertical columns in element H plotted with respect to major principal stress.

zontal element was uniform over its three vertical columns up to the maximum consolidation stress of 100 lb/in². Also in Fig. 9, the element A which was closest to the free draining surface had the least consolidation. The greatest consolidation was observed on the element H which was closest to the impermeable boundary. Element D which was approximately at mid section had roughly the average value of the consolidation of elements A and H. A similar phenomenon was observed by SIRWAN (1965) during increments subsequent to the first.
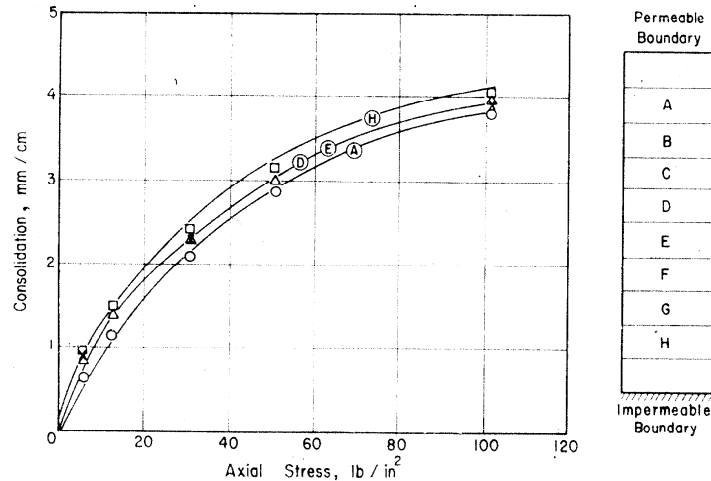

Fig. 9. Consolidation of 4 elements A, D, E and H plotted with respect to the major principal stress.

Comparison of the Average Overall Voids Ratio from Boundary Measurements with the Overall Average of the Local Values as Computed from the Lead Shot Measurement

The overall average voids ratio at the end of each increment of stress was computed from the final moisture content and the change in height of the

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sample. Using the overall average voids ratio thus computed at the end of the first increment of stress subsequent local voids ratios were calculated from the displacements of the lead markers. When doing this the specimen was divided into eight horizontal sections A to H and the voids ratio of each element was calculated from its axial strain. Fig. 10 illustrates the variation of voids ratio from boundary measurements with respect to those computed from the average of the local voids ratio for the range of stress 0-100 lb/in^2. The excellent agreement between the two values indicates the power of the lead shot technique for the measurement of strains and voids ratios in clay specimens.

Variation of Voids Ratio with Time during a Stress Increment

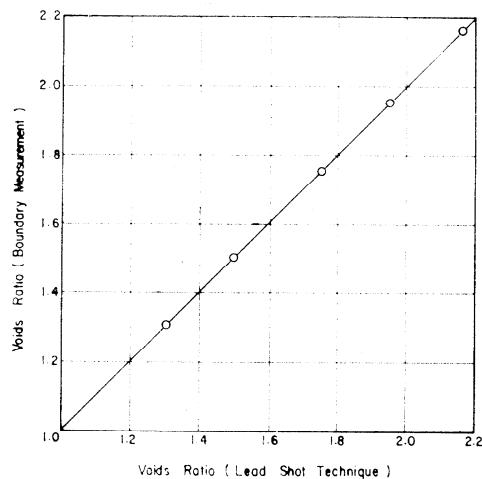The axial strain within each element (A-H) at specific intervals of time after the application of a stress increment was computed from the displacement of the lead markers. The corresponding local voids ratios were determined from these strains. Using the Modified Theory of consolidation of DAVIS & RAYMOND (1965), the local voids ratio change with time at different depths in the specimen was calculated by the numerical method reported by RICHART (1957) from his equation 43. The experimental observations and the theoretical predictions are compared in Figs. 11 and 12. The local voids ratios computed from the displacements of the lead markers are in good agreement with the theoretical predictions for the top half of the sample. However for elements far from the free draining surface (z/H > 0.6: see Fig. 11) the experimental observations are found to deviate from the theoretical predictions.

Fig. 10. **Comparison of overall average voids ratio computed from the local measurements and the average overall voids ratio determined from the moisture content and change in heights of the sample.**

These deviations may in part be due to the effects of secondary consolidation occurring simultaneously with the primary consolidation. Such a model incorporating primary and secondary consolidation is described by BRINCH HANSEN (1961).

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PORE PRESSURE ISOCHRONES AS DETERMINED FROM THE LOCAL VOIDS RATIO

The local effective stresses were calculated from the local voids ratio, using the logarithmic relationship between the voids ratio and the major principal effective stress shown in Fig. 4. The local pore pressures in the elements were then determined from the applied total stress and the calculated effective stress. Figures 13 (a) and (b) illustrate the pore pressure isochrones determined in this way with the curves drawn through the mean points. These isochrones are similar in form to those observed by actual local pore pressure measurements by BURLAND (1967) during one dimensional consolidation in a large consolidometer.
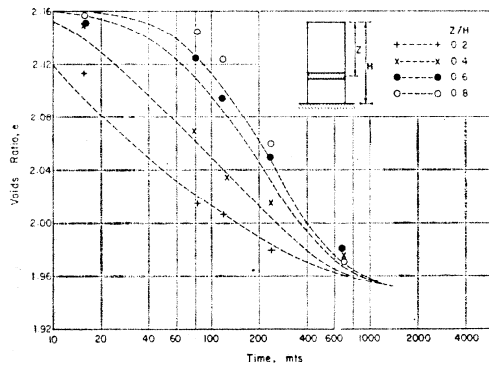
Fig. 11. Comparison of local voids ratios and the theoretical voids ratios at different depths during pore pressure dissipation for stress increment of 6 to 12 psi.
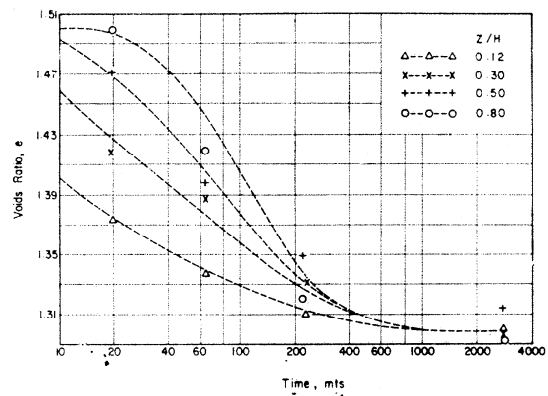
Fig. 12. Comparison of local voids ratios and the theoretical voids ratios at different depths during pore pressure dissipation for stress increment of 51 to 102 psi.
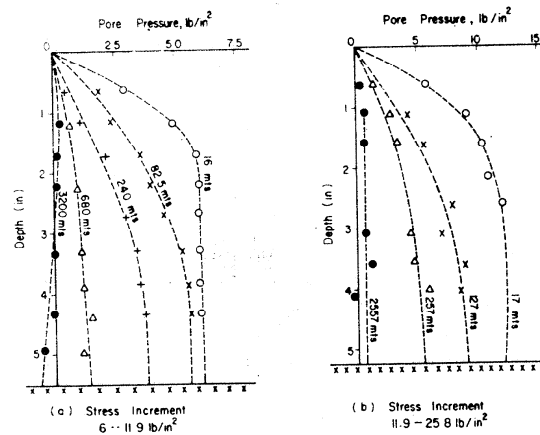
Fig. 13. Pore pressure isochrones determined from the local
(a-b)   measurements of voids ratios for two stress increments.

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ISOTROPIC CONSOLIDATION AND SWELLING USING LEAD SHOT TECHNIQUE FOR STRAIN MEASUREMENT

In the investigation discussed in this section, specimens of kaolin initially prepared by one dimensional consolidation were subsequently further consolidated in the triaxial apparatus under isotropic stress conditions. The patterns of the axial and radial strain distributions during this isotropic consolidation were studied in detail for 1.5 inch diameter and the 4 inch diameter triaxial samples.

Effect of End Restraint on the Local Strains during Isotropic Consolidation of 1.5 inch Diameter × 3 inch High Samples

Figures 14 (a) to (d) show the distribution along the axis of a 1.5 inch diameter sample, of the local (a) axial, (b) radial, (c) volumetric and (d) shear strains respectively that occur during the application of three successive increments of isotropic stress, the sample was contained between conventional friction type ends. In these figures it was observed for each increment of stress that

(i) the axial strain was lowest at the top of the specimen and increased towards the bottom and

(ii) the radial strain was a maximum at the top and a minimum at the base.

These distribution of strains are as to be expected if significant friction is present on the ends of the sample. A large porous stone (type UNI 150 kV) of 1.5 inch diameter was used at the base of the specimen. The effect of friction due to the porous rough surface was to reduce the lateral movement of the sample at the base and thereby decrease the radial strain. Fig. 14 (c) shows that the volumetric strain was virtually uniform throughout the sample. Hence the consolidation due to the isotropic stress increment is also uniform throughout the sample despite the observed nonuniformities of axial and radial strains. From Fig. 14 (d) it can be seen that the shear strain varies from − 2 to + 3% within the specimen. This may be due to the development of local anisotropy within the sample and will be discussed further. Figures 15 (a) to (d) refer to a similar series of tests to those discussed for Figs. 14 (a) to (d) but instead of frictional conventional ends the samples had lubricated conventional ends. Conventional lubricated ends were provided by replacing the porous stone used in the rough end by a 3/16 inch thick highly polished brass disc covered with a thin layer of silicone grease. The strains throughout the samples with these lubricated ends were far more uniform than those with frictional ends.
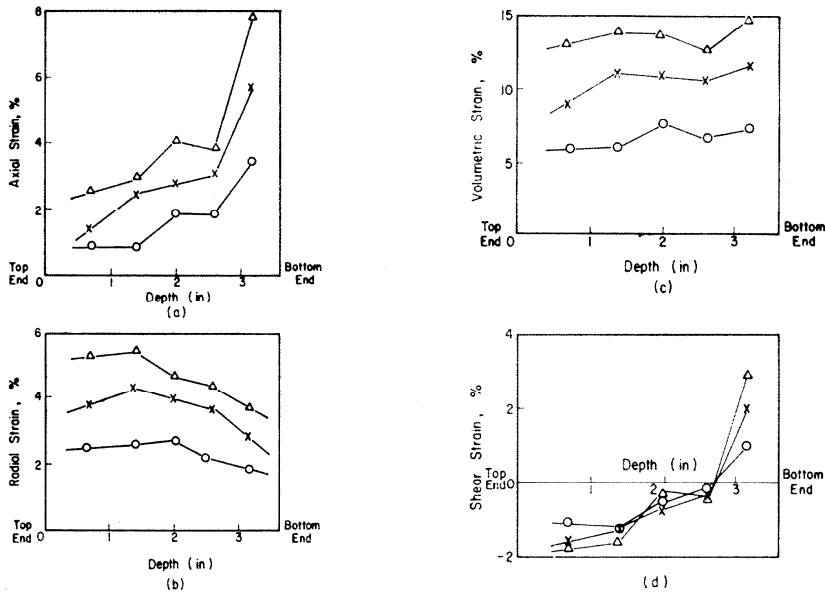
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Fig. 14. Strain distributions plotted against the height of the sample
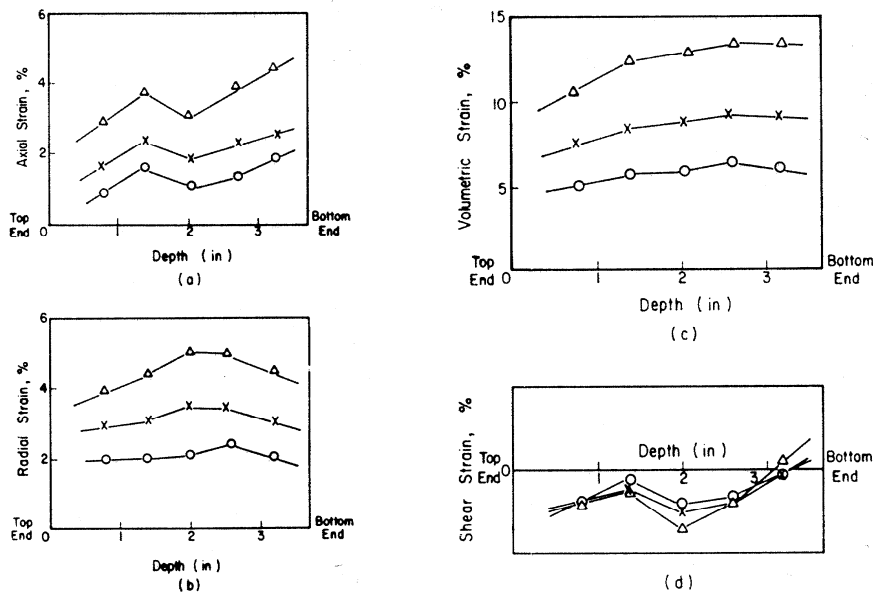**(a-d)   during isotropic consolidation (conventional frictional ends).**

Fig. 15. Strain distributions plotted against the height of the sample during
(a-d)   isotropic consolidation (conventional lubricated ends).

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Distribution of Vertical and Horizontal Displacements of Lead Markers during Isotropic Consolidation in a 4 inch Diameter × 4 inch High Sample

In the previous section it was noted that the lubricated end condition produces more uniform strains during isotropic consolidation than the rough end condition. A detailed investigation of the radial and axial displacements of the lead markers in two perpendicular vertical planes passing through the axis of the specimen was then carried out in a 4 inch diameter triaxial sample. The objective was two-fold in that

(i) the radial strain distribution cannot be studied in detail with the 1.5 inch diameter sample and

(ii) any effect of the increase in length of drainage paths due to the small porous stones which were used with the lubricated ends should show up markedly in a larger sample.

The markers were arranged in two perpendicular planes as illustrated in Figs. 16 and 17. The vertical displacement patterns with respect to height within the sample and the horizontal displacement patterns at different radii within the sample are shown in Figs. 18 and 19. The remarkably linear variations of the displacement patterns indicate that both the axial and radial strains are uniform. Similar results are obtained from the displacement of the lead markers in the perpendicular plane. Therefore the assumption $\varepsilon_2 = \varepsilon_3$ made in the calculations of strains in triaxial specimens is justified.
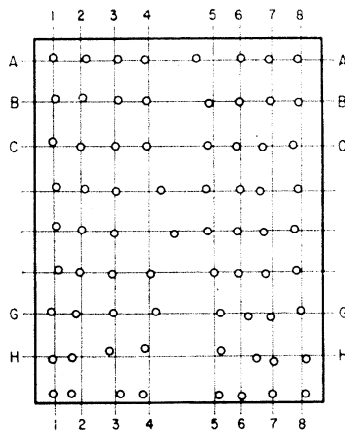

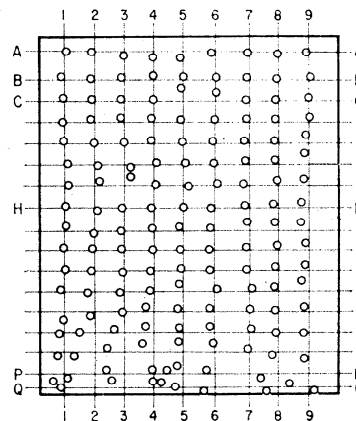Fig. 16. Positions of lead markers in plane 1 of 4 inch diameter sample.

Fig. 17. Positions of lead marker in plane 2 of 4 inch diameter sample.

Effect of Anisotropy on the Axial and Radial Strains during Consolidation under Isotropic Stress

It has already been stated that all the specimens were initially prepared under one dimensional consolidation conditions. Hence all specimens were
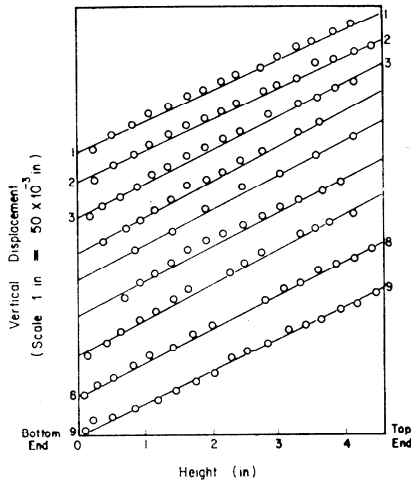
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Fig. 18. Incremental vertical displacements of markers plotted against the height of the markers above the base for nine vertical columns in plane 2 of 4 inch diameter sample during isotropic consolidation.
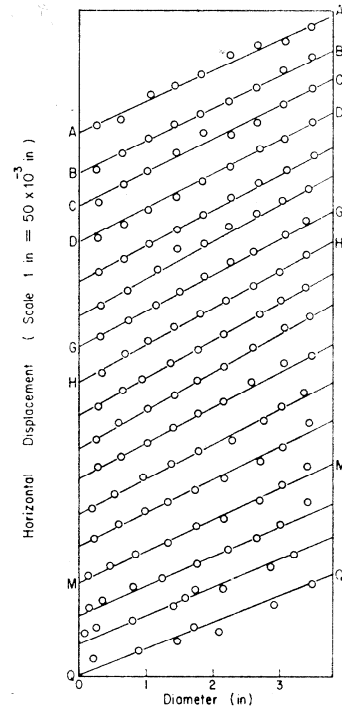

Fig. 19. Incremental horizontal displacement of markers plotted against their distances along the diameter for seventeen horizontal rows in plane 2 during isotropic consolidation.

subjected to an initial shearing process. The subsequent application of increasing isotropic stress gradually erases the effect of the initial one dimensional consolidation. This is best illustrated in Fig. 15 (d) where it is observed that during the application of the first increment of isotropic stress, a shear strain with a maximum value of 1% is observed. Subsequent increase in isotropic stresses do not produce any further increase in the shear strain, indicating that the strains due to these increments of stress are isotropic. The data suggests that specimens isotropically consolidated to approximately three times the initial one dimensional stress can be assumed to have lost their previous shear stress history effects. A similar observation was also noted by LOUDON (1967) using a different technique for the strain measurement.

Slopes of the Isotropic Consolidation Lines in the (e, log p) Plot for Overall Voids Ratio as Determined from the Average Local Voids Ratio

The average volumetric strain in the sample during an increment of isotropic stress was determined from the local measurements of strains. The

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overall voids ratio at the end of each increment was obtained from the final overall average voids ratio of the sample (obtained from the final moisture content determination) and the average volumetric strains computed from the lead shot measurements. Figs. 20 (a) and (b) illustrate the variation of these voids ratio with log p for tests carried out with the two types of end conditions discussed before. These relationships are linear in the (e, log p) plot with the slope λ varying from 0.25 to 0.26. This value of λ is extensively used in the Stress Strain Theories developed at Cambridge (see ROSCOE et al (1963), ROSCOE & BURLAND (1968) and hence the lead shot technique offers a mean by which this value of λ could be assessed independently. Conventionally the value of λ is determined from isotropic consolidation tests and on the assessment of the change in voids ratio as indicated by the change in volume of water in a burette connected to the base of the sample. The leakage of cell fluid into the specimen and the leakage of water from the specimen and from the drainage connections could thus cause an error in the assessment of λ from the volumetric measurements as made from the burette readings.
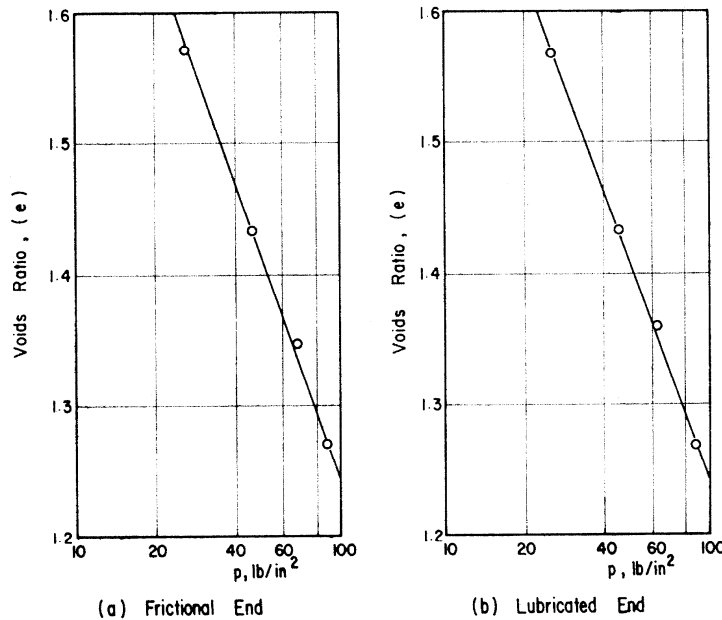

(a) Frictional End   (b) Lubricated End

Fig. 20. Voids ratio-log. pressure plot during isotropic consolidation.

Distribution of Vertical and Horizontal Displacements of the Lead Markers during Isotropic Swelling

Figures 21 and 22 illustrate the vertical and horizontal displacements of the lead markers during isotropic swelling. The displacements are seen to be linear. Similar linear displacement patterns are noted in the orthogonal plane. However the slopes of the lines corresponding to the horizontal displacements

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at the bottom end of the sample are considerably less than for the other lines. Hence the radial strains at the bottom end of the sample were lower than in the rest of the sample. This reduction in strain was in part due to errors in measurement as the markers were placed extremely close to the cell pedestal and the scattered radiation from this pedestal tended to blur the images of the markers in the radiograph, thereby reducing the contrast and definition of these images. The average axial and radial strains as determined from the mean slopes of the lines during swelling under isotropic stress are -2.66 and -1.34% respectively. These results indicate that the strains were anisotropic during swelling under isotropic stress conditions. A similar phenomenon was also observed by BURLAND (1967) during isotropic swelling using a different technique for the measurement of strains.
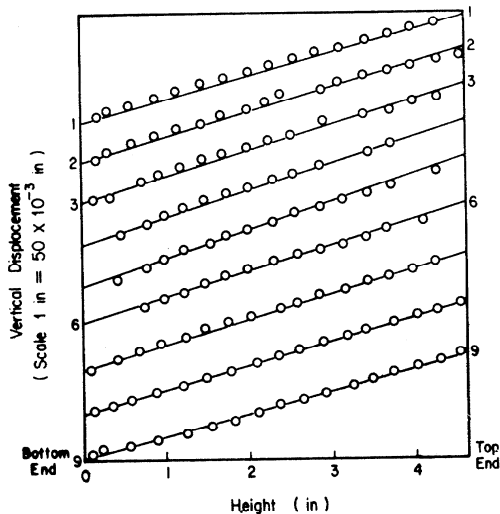
Fig. 21. Incremental vertical displacements of lead markers plotted against their heights above base for nine vertical columns in plane 2 of 4 inch diameter sample during isotropic swelling.
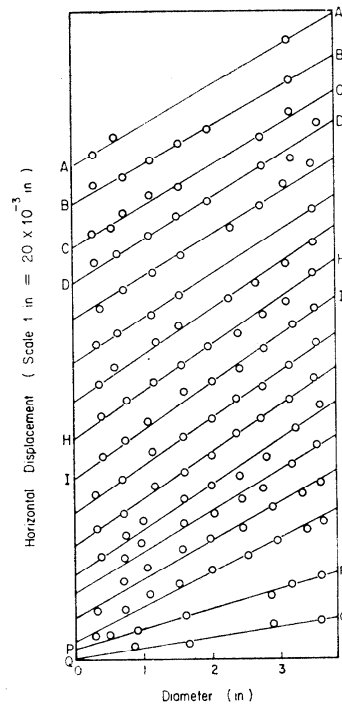
Fig. 22. Incremental horizontal displacements of lead markers plotted against their distances along the diameter for 17 horizontal rows in plane 2 of 4 inch diameter sample during isotropic swelling.

CONCLUSIONS

(1) The friction measurements carried out during one dimensional consolidation indicates that the percentage load lost in friction can be reduced

to as low as 10% by lining the inner surface of the consolidometer with a rubber membrane lubricated with a thin layer of silicone grease.

(2) The local measurements of strains carried out with the lead shot technique show that the consolidation was uniform throughout the sample for the first increment of stress, when the clay (initially in the form of a slurry 160% moisture content) was consolidated to about two-thirds of its original height. For subsequent stress increments, elements of clay nearest to the free draining surface were found to experience less consolidation than elements further from it.

(3) The change of overall voids ratio as computed by summing the local values obtained from the local measurements of strains were in excellent agreement with those determined directly from the boundary measurements at all stress levels.

(4) The observed local voids ratio changes with time when compared with the corresponding theoretical values as derived from the Modified Theory of DAVIS & RAYMOND (1965) using the numerical procedure of RICHART (1957) illustrate (a) the observed local voids ratio was in good agreement with the theoretical predictions for the top half of the specimen which was close to the free draining surface (b) for elements far from the free draining surface the experimental observations deviated from the theoretical predictions.

The pore pressure isochrones determined from the local measurements of voids ratio were similar to those observed by actual local pore pressure measurements by BURLAND (1967).

(5) For specimens contained between frictional ends, the axial and radial strains were found to be nonuniform during isotropic consolidation. With the use of lubricated ends this nonuniformity in strains was reduced to a minimum. In both specimens the local volumetric strains were observed to be uniform throughout the sample.

(6) For isotropic stresses of similar magnitude to the initial one dimensional stress, the strains induced by increments of isotropic stresses were found to be anisotropic. However for specimens which were isotropically consolidated to approximately three times the initial one dimensional stress, the effect of anisotropy was found to be small.

(7) Experiments performed on 4 inch diameter samples showed that the axial and radial strains were uniform but not equal during swelling under isotropic stresses.

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