CONTRACT REPORT NO. 3-101

CONSOLIDATED-UNDRAINED PLANE STRAIN SHEAR TESTS ON BOSTON BLUE CLAY

RESEARCH IN EARTH PHYSICS, PHASE REPORT NO. 15

by

C. C. Ladd, R. B. Bovee, L. Edgers, J. J. Rixner

March 1971

Sponsored by U. S. Army Materiel Command and
Office, Chief of Engineers, U. S. Army

Conducted for U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

Under Contract No. DA-22-079-eng-457

By Soil Mechanics Division, Department of Civil Engineering
Massachusetts Institute of Technology

248

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U.S. Army Materiel Command
Project No. 1-V-0-14501-B-52A-01
and by the
Office, Chief of Engineers
Directorate of Military Engineering
Project 4A061102B52E
under
Contract No. DA-22-079-eng-457
with
U.S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

Soil Mechanics Division
Department of Civil Engineering
Massachusetts Institute of Technology

Research Report R71-13
Soils Publication 273

ABSTRACT

Results of consolidated-undrained plane strain active ($\sigma_{1f} = \sigma_{vf}$) and passive ($\sigma_{1f} = \sigma_{hf}$) tests are reported on K_o consolidated samples of resedimented Boston Blue Clay at overconsolidation ratios of one, two, and four. The plane strain equipment, developed at M.I.T., uses a sample with dimensions 3.5 in. high by 3.5 in. wide by 1.4 in. deep. The vertical and horizontal stresses can be independently varied. The magnitude of the cell pressure during consolidation yields values of K_o and pressure transducers in the fixed end platens yield values of K_o and σ_2. The apparatus gives reliable stress-strain data for active tests; for passive tests the data become unreliable beyond 3 ± 1 per cent axial strain due to various sources of "friction" and due to necking. However, a failure criteria based on the maximum obliquity of principal stresses gave fairly reliable undrained strength parameters for passive conditions.

The active and passive test data show that Boston Blue Clay has highly anisotropic undrained strength properties. For normally consolidated clay, $s_u/\bar{\sigma}_{vc} = 0.34$ and 0.19 for active and passive conditions; the corresponding ratios at an OCR of four are 0.95 and 0.67. These strength ratios have been verified by undrained model footing bearing capacity tests. A comparison of plane strain and triaxial test data shows that $\overline{CK_oU}$ triaxial compression tests yield results very similar to those obtained by the active tests. However, $\overline{CK_oU}$ triaxial extension tests will underestimate the undrained passive strength.

FOREWORD

The work described in this report was performed under Contract No. DA-22-079-eng-457 entitled, "Research Studies in the Field of Earth Physics" between the U.S. Army Engineer Waterways Experiment Station and the Massachusetts Institute of Technology. This research is sponsored by the U.S. Army Materiel Command, Project No. 1-V-0-14501-B-52A-01, and by the Office, Chief of Engineers, Directorate of Military Engineering, Project 4A061102B52E.

This contract was monitored at the Waterways Experiment Station by Messrs. W.E. Strohm, Jr., Engineering Studies Section, and B.N. MacIver, Laboratory Research Section, under the general supervision of Mr. J.R. Compton, Chief, Embankment and Foundation Branch. Messrs. W.J. Turnbull (retired) and J.P. Sale were Chiefs, Soils Division, and Mr. Maxwell (deceased) was Assistant Chief, Soils Division during the contract period. Contracting Officers were COL Alex G. Sutton, Jr., CE, COL John R. Oswalt, Jr., CE, and COL Levi A. Brown, CE.

The general objective of Research in Earth Physics is the development of a fundamental understanding of the behavior of particulate systems, especially cohesive soils, under varying conditions of stress and environment. Work on the project, initiated in May 1962, has been carried out in the Soil Mechanics Division of the Civil Engineering Department under the supervision of Dr. Charles C. Ladd, Professor of Civil Engineering.

This report presents only one portion of the overall research conducted under the contract. Phases that were under investigation are:

1. In Situ Strength and Compression Properties of Natural Clays
    (a) Effects of stress-system variables (anisotropic consolidation, intermediate principal stress, rotation of principal planes) on stress-strain behavior of clays during drained and undrained shear.
    (b) Effects of sample disturbance (i.e. excessive shear strains) on the undrained strength, stress-strain modulus, and one-dimensional compression behavior of natural clays.
    (c) Correlation of predicted versus observed behavior via model loading tests and field measurements.

2. Influence of Environment on Strength and Compression Properties of granular systems
    (a) Fundamental friction properties of granular systems.

3. The Structure of Clay
    (a) Fabric of kaolinite

Many of the above topics complement and/or draw information from other research projects in the Soil Mechanics Division.

The data presented in this report were obtained through the efforts of many persons. Mr. Joseph W. Dickey, former Research Assistant, designed and assembled the prototype plane strain device and performed the first tests on Boston Blue Clay during 1966-1967. Mr. Joseph J. Rixner, former Research Assistant, carried on the experimental program during 1967-1968 and, with Mr. Dickey, developed the "production" model apparatus. Mr. Richard B. Bovee, former Research Assistant, then spent two years evaluating and modifying the equipment and test procedures; he also performed most of the passive tests and assisted in preparation of this report. Dr. Edward B. Kinner, former Research Assistant, aided in analysis of the data. Finally, Mr. Lewis Edgers, Research Assistant, performed some check tests and helped prepare this report.

This report constitutes work on Item b of Article 1 of the forementioned Contract No. DA-22-079-eng-457.

Pertinent reports under Research in Earth Physics are:

1. "Research in Earth Physics, Progress Report for the Period June 1962 - December 1962," Department of Civil Engineering Publication R63-9, M.I.T., February 1963.

2. Ladd, C.C., "Stress-Strain Behavior of Saturated Clay and Basic Strength Principles," Phase Report No. 1, Part 1, Department of Civil Engineering, Publication R64-17, M.I.T., April, 1964.

3. Bromwell, L.G., "Adsorption and Friction Behavior of Minerals in Vacuum," Phase Report No. 2, Department of Civil Engineering Publication R64-42, M.I.T., March, 1965.

4. Bailey, W.A., "The Effects of Salt on the Consolidation Behavior of Saturated Remolded Clays," Phase Report No. 3, Department of Civil Engineering Publication R65-19, M.I.T., May, 1965.

5. Ladd, C.C. and J. Varallyay, "The Influence of Stress System on the Behavior of Saturated Clays during Undrained Shear," Phase Report No. 1, Part II, Department of Civil Engineering Publication R65-11, M.I.T., July, 1965.

6. Martin, R.T., "Quantitative Fabric of Consolidated Kaolinite," Phase Report No. 4, Department of Civil Engineering Publication R65-47, M.I.T., September, 1965.

7. Ladd, R.S., "Use of Electrical Pressure Transducers to Measure Soil Pressure," Phase Report No. 5, Department of Civil Engineering Publication R65-48, M.I.T., September, 1965.

8. Ladd, C.C. and W.B. Preston, "On the Secondary Compression of Saturated Clays," Phase Report No. 6, Department of Civil Engineering Publication R65-59, M.I.T., December, 1965.

9. Bromwell, L.G., "The Friction of Quartz in High Vacuum," Phase Report No. 7, Department of Civil Engineering Publication R66-18, M.I.T., May, 1966.

10. Ladd, C.C. and E.B. Kinner, "The Strength of Clays at Low Effective Stress," Phase Report No. 8, Department of Civil Engineering Publication R67-4, M.I.T., January, 1967.

11. Ladd, C.C. and R.T. Martin, "The Effects of Pore Fluid on the Undrained Strength of Kaolinite," Phase Report No. 9, Department of Civil Engineering Publication R67-15, M.I.T., March, 1967.

12. Dickey, J.W., C.C. Ladd and J.J. Rixner, "A Plane Strain Shear Device for Testing Clays", Phase Report No. 10, Department of Civil Engineering Publication R68-3, Soils Publication 237, M.I.T., January, 1968.

13. Martin, R.T. and C.C. Ladd, "Fabric of Consolidated Kaolinite", Phase Report No. 11, Department of Civil Engineering Publication R70-15, Soils Publication 254, M.I.T., February, 1970.

14. Bovee, R.B. and C.C. Ladd, "M.I.T. Plane Strain Shear Device", Phase Report No. 12, Department of Civil Engineering Publication R70-24, Soils Publication 257, M.I.T., July 1970.

15. Kinner, E.B. and C.C. Ladd, "Load-Deformation Behavior of Saturated Clays during Undrained Shear", Phase Report No. 13, Department of Civil Engineering Publication R70-27, Soils Publication 259, M.I.T., May 1970.

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1. INTRODUCTION

1.1 BACKGROUND

Stability analyses based on undrained shear strengths are generally required for the design of structures placed on soft clay deposits. In many instances, the determination of undrained strengths by conventional procedures, such as via field vane tests or unconfined compression tests on "undisturbed" samples, leads to conflicting results. Research in Earth Physics has been developing a new approach for estimating the in situ undrained strength and stress-strain behavior of saturated clays. This approach employs consolidated-undrained (CU) shear tests and expresses the resulting stress-strain-strength data in a "normalized" fashion. The normalized parameters are related to the overconsolidation ratio(OCR) of the test samples. These relationships and a knowledge of the in situ stress history of the clay deposit are then used to yield estimates of the in situ properties.

This approach, called SHANSEP for Stress History and Normalized Soil Engineering Properties, has several major advantages over conventional procedures:

(1) The effects of sample disturbance are minimized.

(2) It can study the influence of the in situ mode of failure.

(3) It provides stress-strain data for finite element deformation analyses

(4) The normalized parameters can be used to estimate changes in strength and deformation properties with in situ consolidation and rebound.

One of the objectives of Research in Earth Physics has been the generation of a set of normalized stress-strain-strength data versus overconsolidation ratio for a variety of clays for undrained shear conditions that are representative of typical in situ modes of failure. Those selected for study were:

	In situ Condition		Laboratory Test
1.	Under centerline of a circular footing	1.	Triaxial compression
2.	Under centerline of a circular excavation	2.	Triaxial extension
3.	Under centerline of a strip loading	3.	Plane strain "active"
4.	Under centerline of a strip excavation	4.	Plane strain "passive"
5.	Horizontal failure plane under stabilizing berm	5.	Direct-simple shear

Ladd and Varallyay (1965) reported the results of triaxial compression and extension tests on normally consolidated Boston Blue Clay. Phase Report No. 16 will present direct-simple shear data versus OCR for several clays, including Boston Blue Clay. This report presents the results of plane strain tests on Boston Blue Clay.

M.I.T. started development of a plane strain device suitable for testing undisturbed samples of soft clay in 1966. The "prototype" device and some of the preliminary data were described by Dickey, Ladd and Rixner (1968). Subsequently, a second device, called Model B, was developed. A detailed description of this device and the test procedures are presented by Bovee and Ladd (1970).

1.2 SCOPE

This report presents data obtained from consolidated-undrained plane strain tests with pore pressure measurements on Boston Blue Clay. The testing program included active and passive tests run on K_o consolidated specimens at overconsolidation ratios of one, two and four using both the prototype and model B devices. Section 2 summarizes the test procedures and plane strain equipment. Data obtained during the consolidation phase of the tests are presented in Section 3. Undrained strength and stress-strain data are contained in Section 4; these data are compared to triaxial test data and the findings of others in Section 5.

As pointed out in Bovee and Ladd (1970), problems have been experienced from various sources of "friction" in the plane strain devices, particularly during passive tests at large strains. The main body of the report presents the authors' interpretation of the data. However, measured stress-strain data are tabulated and plotted in appendices so that the reader is free to draw his own conclusions.

A plane strain test involves a considerable collection of data and lengthy calculations. Consequently, the results that are presented undoubtedly contain some inconsistencies and errors because of the difficulties in checking all of the data, especially since the tests were run over a period of several years with changing test equipment, procedures, and personnel. However, the authors believe that considerable data with some minor errors are preferable to a limited set of error free data.

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2. TEST PROCEDURES AND EQUIPMENT

2.1 PREPARATION AND PROPERTIES OF BOSTON BLUE CLAY

Batches of resedimented Boston Blue Clay were prepared by consolidating a clay slurry using the procedures described in Appendix B. The procedure yields a fairly uniform source of clay with strength and consolidation properties similar to those of natural Boston Blue Clay (Ladd and Luscher, 1965).

A slurry with a water content of 100 percent and a salt concentration of 16 g/l of NaCl is placed in an evacuated 12 in. diameter consolidometer and consolidated in increments to 1.5 kg/cm^2. The consolidated cake, four to six inches high, is extruded and stored in transformer oil prior to testing. Specimens are then cut from the cake for consolidated-undrained tests that employed a maximum consolidation stress of about four kg/cm^2.

Table B-1 of Appendix B summarizes the properties of the eleven batches that were used for testing over a three year period. Typical properties were:

Batch water content = 36 ± 2%
Liquid Limit = 41 ± 2%
Plastic Limit = 20 ± 2%
Plasticity Index = 21 ± 3%

The Boston Blue Clay has a specific gravity of 2.79, contains approximately 50 percent clay size (minus two microns) material, and has the following approximate mineralogical composition:

Quartz	15 - 20%
Chlorite	5%
Illite	30 - 45%

2.2 PLANE STRAIN APPARATUS

Figure 2-1 shows a photograph of the prototype and Model B M.I.T. plane strain devices. Both devices have the following features:

(1) Sample dimensions are 3.5 by 3.5 by 1.4 in., thus enabling trimming from a four inch diameter tube.

(2) The major principal stress may be applied in either the horizontal or vertical direction, providing both active and passive shear tests.

(3) K_o consolidation is obtained using fixed end platens and removable side platens.

(4) Values of K_o during consolidation and σ_2 during shear can be measured.

(5) Both drained and undrained tests with either stress or strain controlled loading are possible.

Dickey et. al (1968) and Bovee and Ladd (1970) present a detailed description of the equipment and test procedures. This Section will summarize the main features of the apparatus. Pertinent test procedures are summarized in connection with presentation of the data.

Figure 2-2 shows the vertical loading system used in both devices. During consolidation, the test specimen is back pressured through one of the push-pull valves attached to the base plate. During shear, the pore pressure is monitored through the other push-pull valve.

Figure 2-3 shows the fixed end platens used in the prototype plane strain device. The end platens maintain K_o conditions during consolidation and prevent straining in the σ_2 direction during shear. The pressure plate and force transducer in Figure 2-3 were later replaced by two flush diaphragm transducers. This provided measurement of σ_h at various heights. Figure 2-4 shows the removable side platens used by the prototype device to maintain K_o consolidation and provide an additional measure of σ_h during consolidation.

Figure 2-5 shows the horizontal loading system used in the Model B device. These side platens are of the same design as the right side platen in the prototype device. The fixed end platen in the Model B device, shown in Figure 2-6, has one flush diaphragm transducer at mid-height of the test specimen. Measurements of σ_h for the Model B device are obtained using the flush diaphragm transducer during consolidation and for σ_2 during shear. The cell pressure at the end of consolidation also furnishes a measure of σ_h for determination of K_o at the end of consolidation. A top view of the Model B device is shown in Figure 2-7.

The letters P and B are used to denote which device was used for a particular plane strain tests.

2.3 TEST PROGRAM

Table 2-1 outlines the types of consolidated-undrained tests that can be run with the M.I.T. plane strain devices.

An active test refers to shear wherein the major principal stress at failure acts in the in situ vertical direction, i.e., $\sigma_{1f} = \sigma_{vf}$ and $\sigma_{3f} = \sigma_{hf}$. If K_o is less than one, σ_1, always acts in the vertical direction and there is no rotation of principal stresses during shear. A "standard" test is run by strain controlled vertical loading.

A passive test usually refers to shear wherein the major principal stress at failure acts in the in situ horizontal direction, i.e., $\sigma_{1f} = \sigma_{hf}$. If K_o is less than one, the direction of σ_1 rotates 90 degrees during shear. A "standard" test is run by strain controlled vertical unloading.

In passive tests of the type described above, the sample is liable to neck at large strains. This situation can be avoided by performing a passive test on a"horizontally" K_o consolidated specimen. In this case, the major principal stress at consolidation acts in the horizontal direction in the apparatus, which corresponds to the in situ vertical direction. Undrained strained controlled shear is conducted by increasing the vertical stress in the apparatus. In theory, both types of passive tests should yield identical stress-strain behavior in terms of effective stresses. In fact, they do not because of friction along the sides of the sample and/or in the loading piston.

The program of $\overline{CU}$ plane strain tests on Boston Blue Clay consisted of active and passive tests run on samples with nominal overconsolidation ratios of one, two and four. Results from 23 tests, distributed as follows, are reported:

OCR	Active	Passive
1	6	5 + 1H
2	2	1 + 2H
4	2	2 + 2H

The H designation for the passive tests refers to passive tests on horizontally consolidated specimens.

TYPICAL TYPES OF CONSOLIDATED-UNDRAINED PLANE STRAIN SHEAR TESTS WITH THE M.I.T. DEVICE

K_o Consolidation

"Standard"	$\bar{\sigma}_{hc} = K_o \bar{\sigma}_{vc}$; side plates prevent lateral movement during consolidation.
Horizontal K_o	$\bar{\sigma}_{vc} = K_o \bar{\sigma}_{hc}$; sample trimmed at 90 degrees from usual direction and vertical height of sample maintained constant during consolidation.

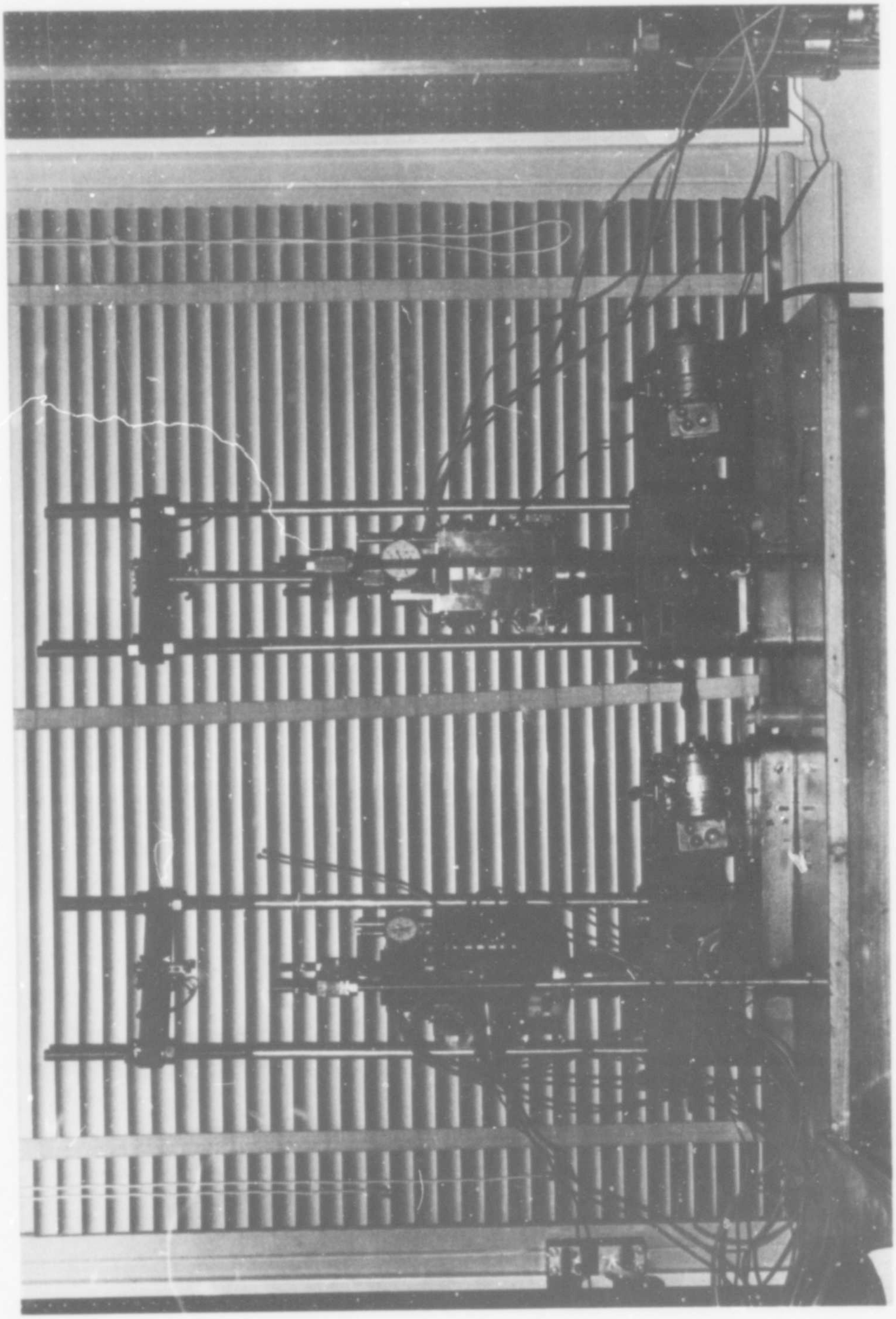
$\overline{CK_oU}$ Plane Strain Active Tests ($\overline{CK_oU}$ PSA)

"Standard"	Strain controlled vertical loading (σ_v increased) at constant horizontal stress ($\Delta\sigma_h = 0$)
Typical Variations	Stress controlled vertical loading (σ_v increased) or stress controlled - horizontal unloading (σ_h decreased).

$\overline{CK_oU}$ Plane Strain Passive Tests ($\overline{CK_oU}$ PSP)

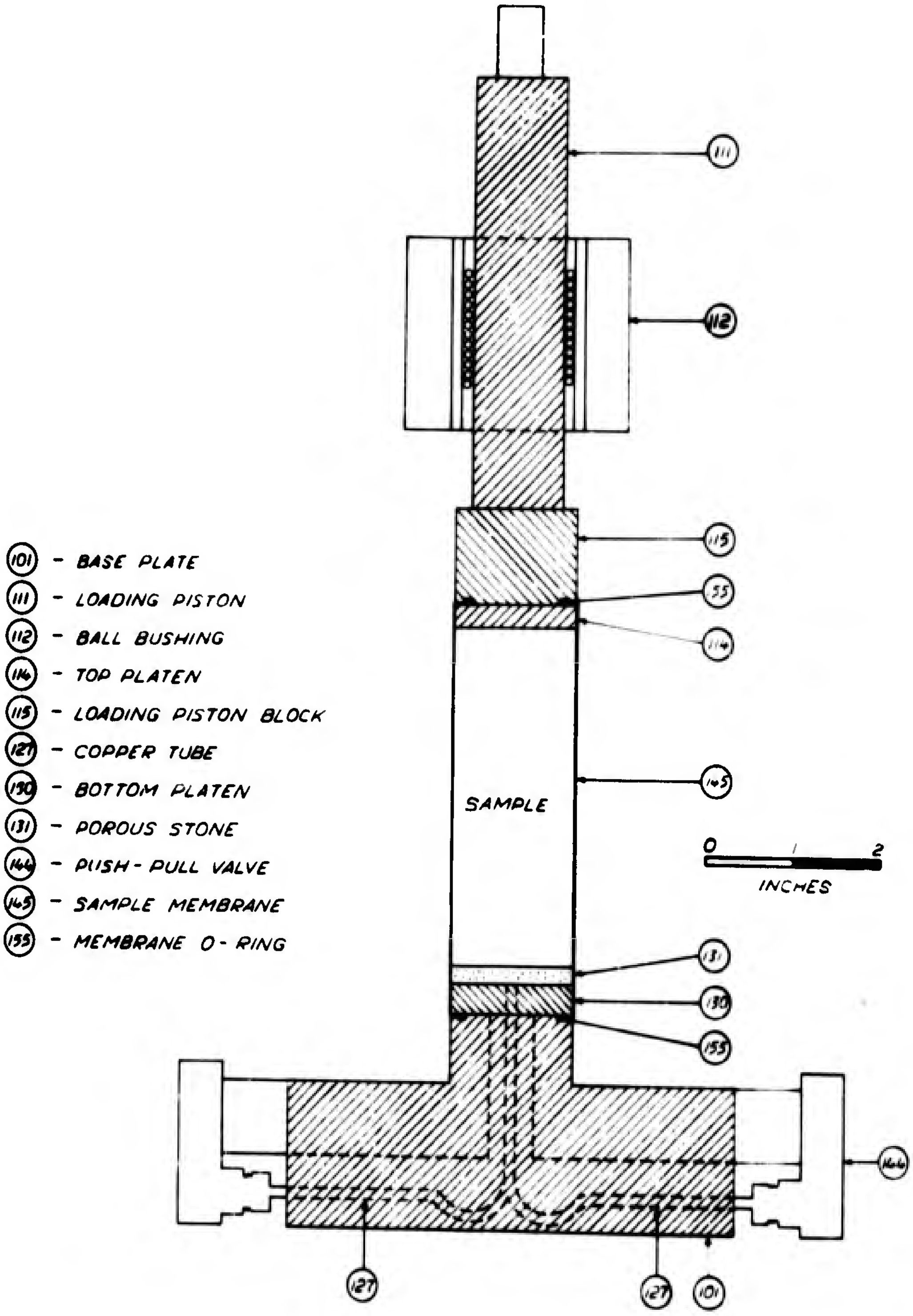
"Standard"	Strain controlled vertical unloading (σ_v decreased) at constant horizontal stress ($\Delta\sigma_h = 0$).
Typical Variations	Stress controlled vertical unloading (σ_v decreased) or stress controlled horizontal loading(σ_h increased)
After Horizontal K_o Consolidation	Strain controlled vertical loading (σ_v increased) at constant horizontal stress ($\Delta\sigma_h = 0$).

TABLE 2-1



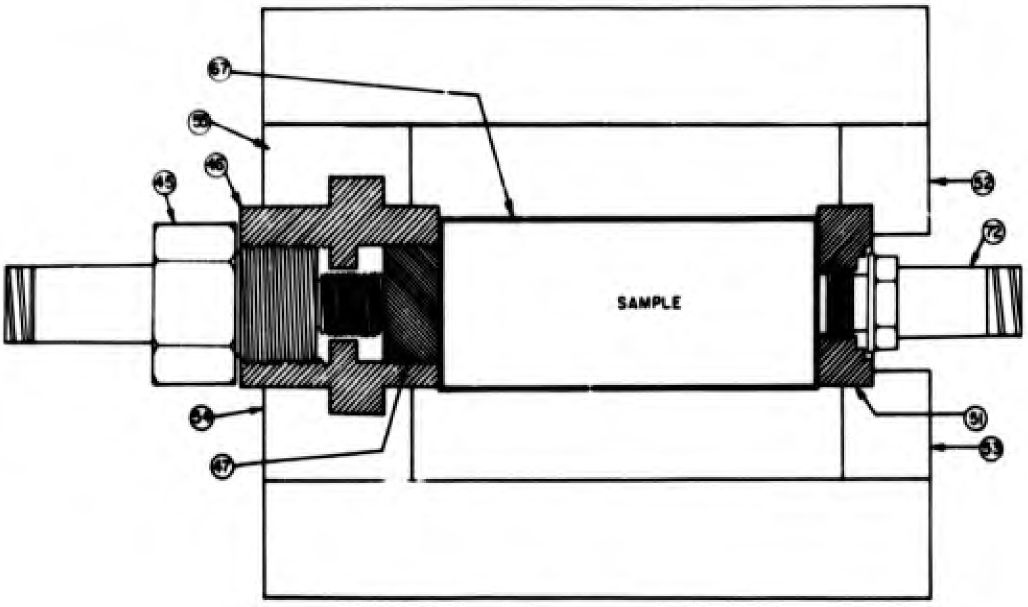
PROTOTYPE AND MODEL B PLANE STRAIN DEVICES

FIGURE 2-1

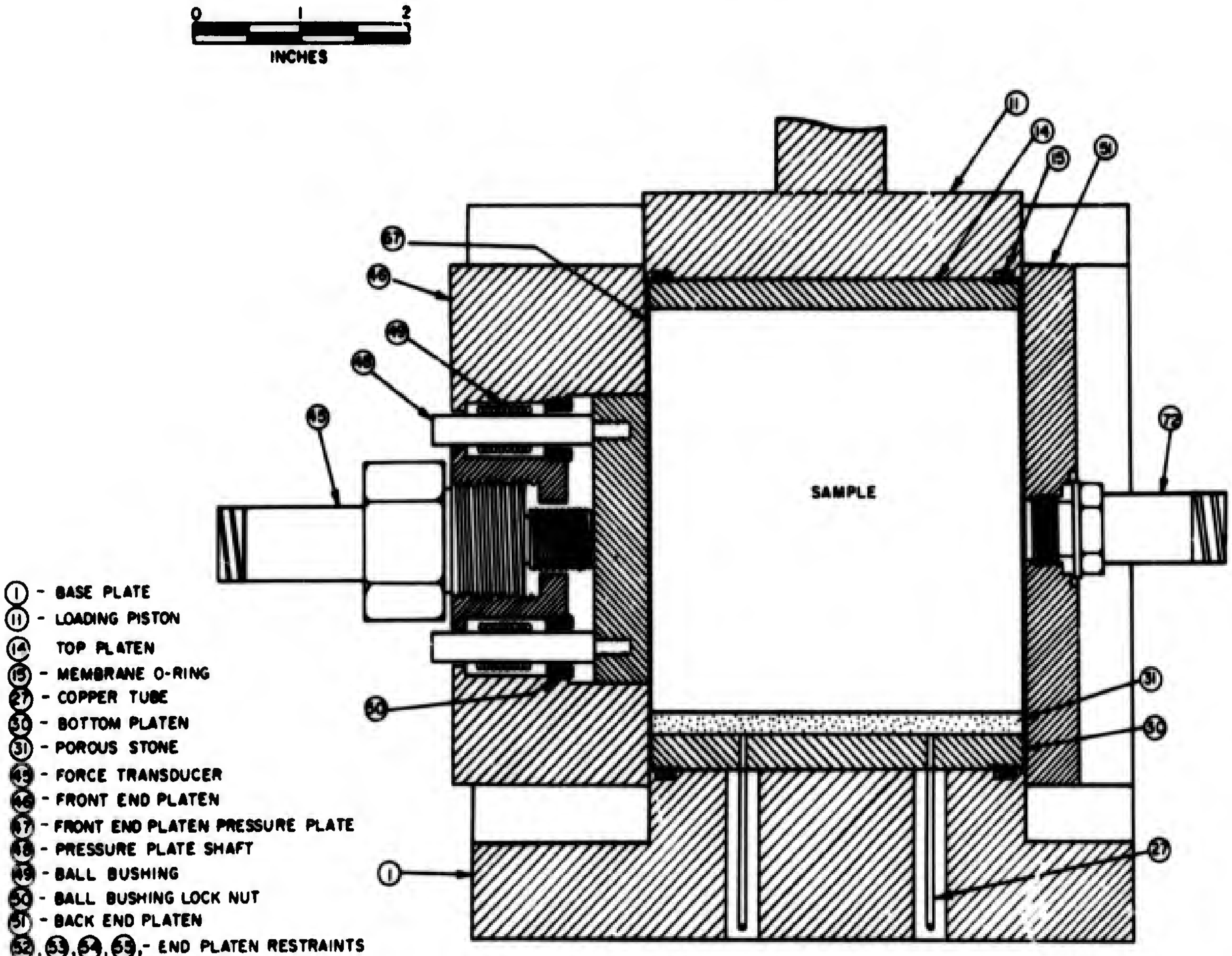


VERTICAL LOADING SYSTEM -
BOTH DEVICES

FIGURE 2-2



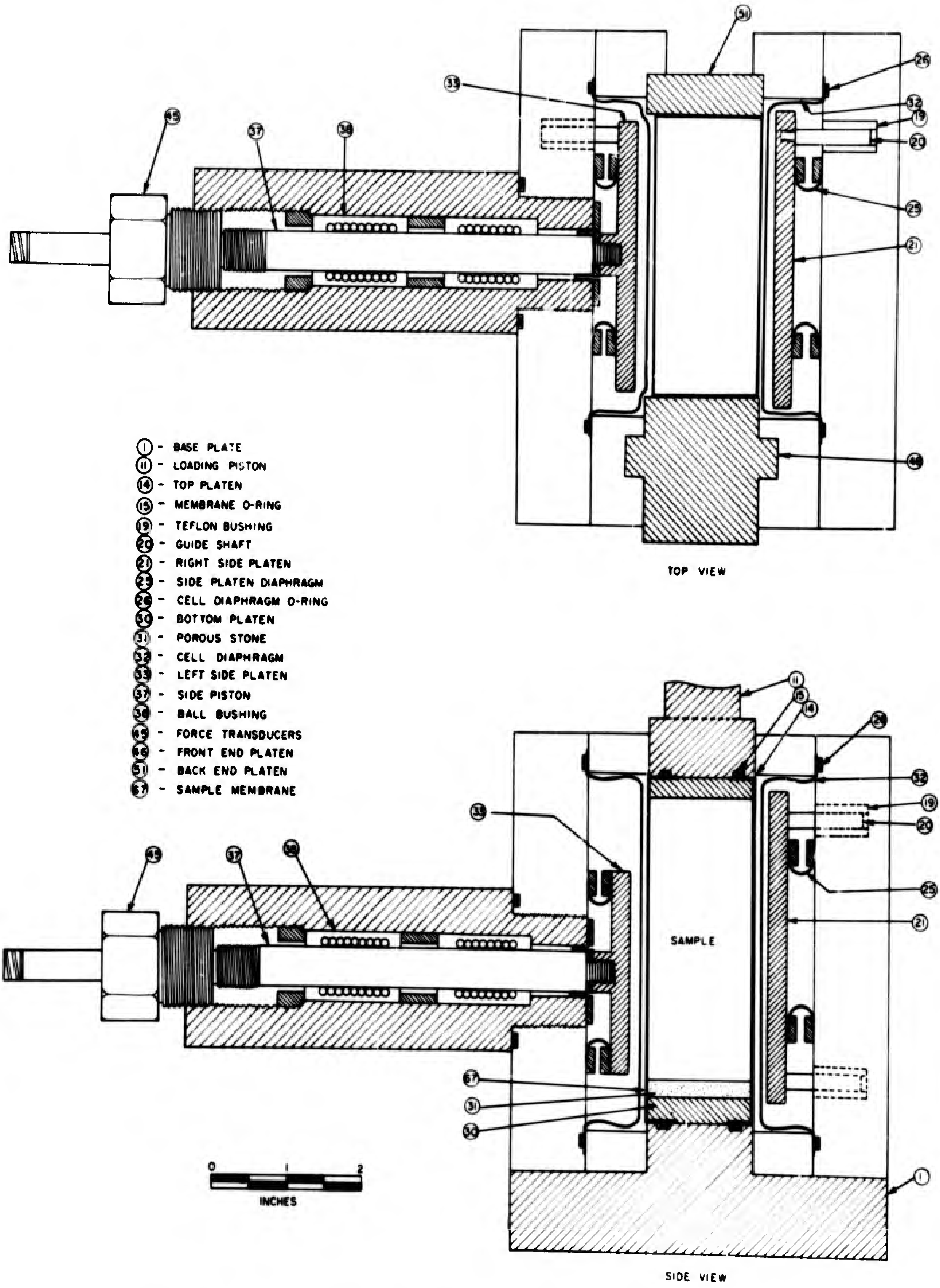
TOP VIEW



SIDE VIEW

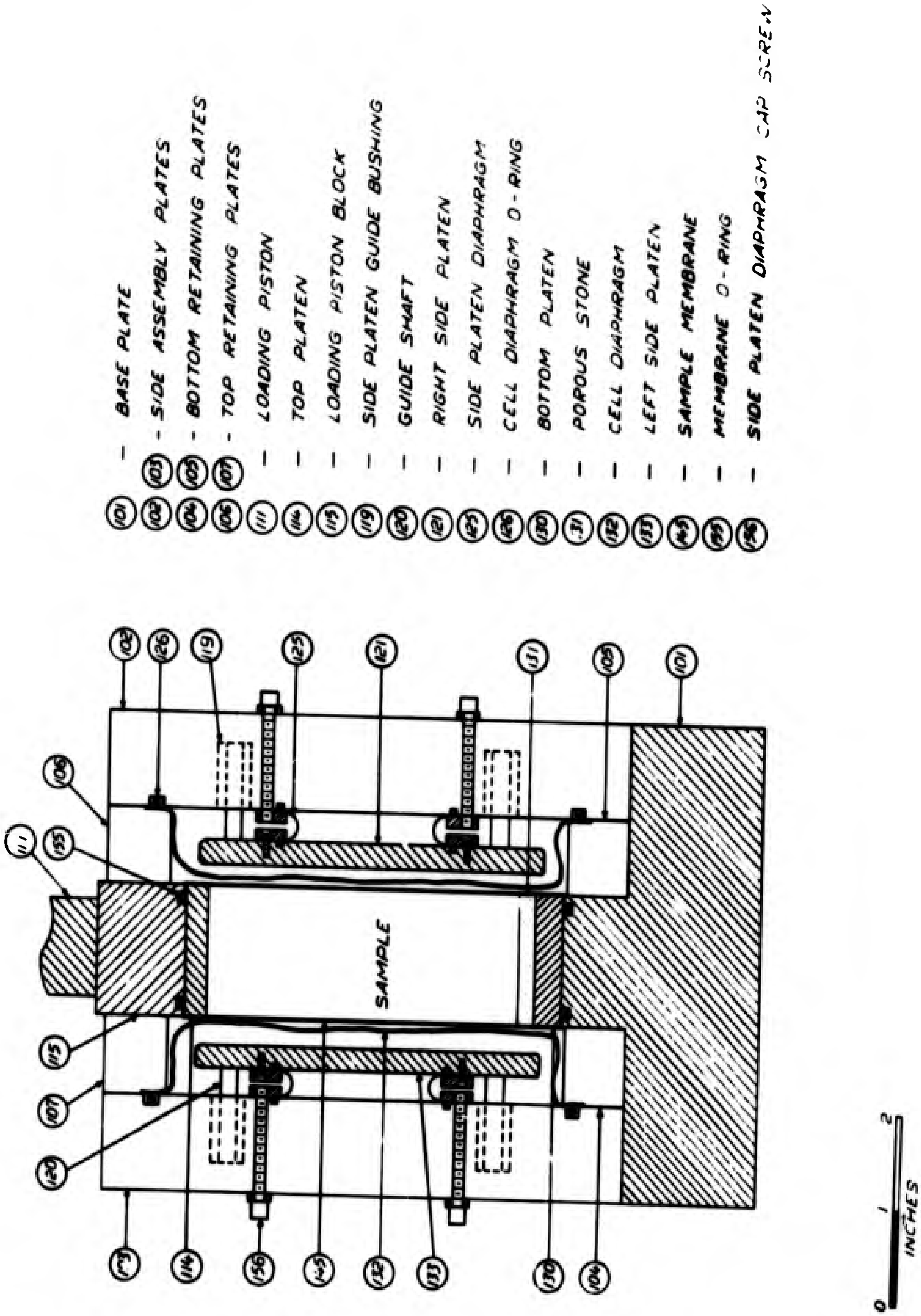
FIXED END PLATEN ASSEMBLIES - PROTOTYPE DEVICE
(after Dickey, et. al. 1968)

Figure 2 - 3



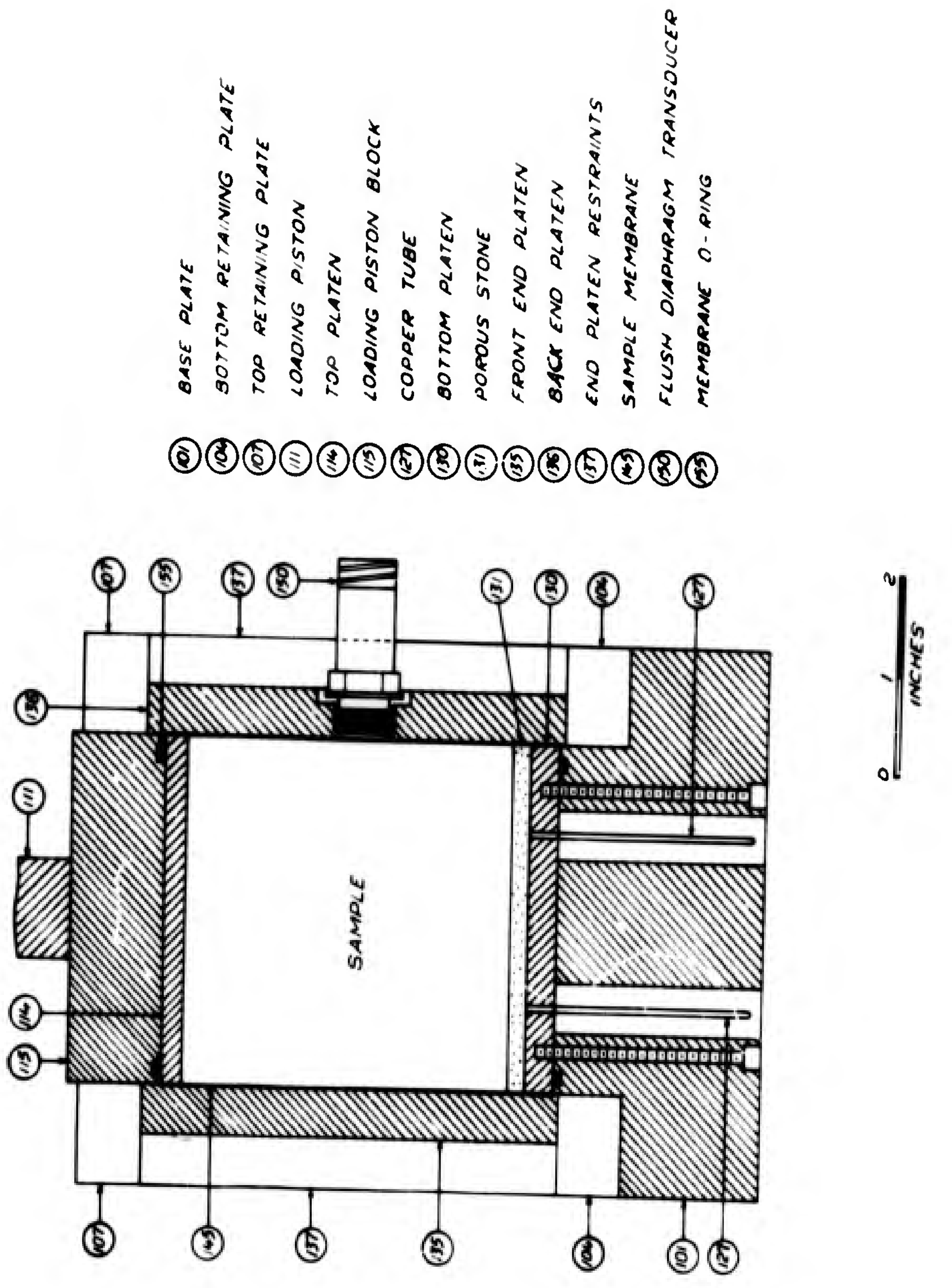
HORIZONTAL LOADING SYSTEMS - PROTOTYPE DEVICE
(afte Dickey, et. al 1968)

Figure 2-4



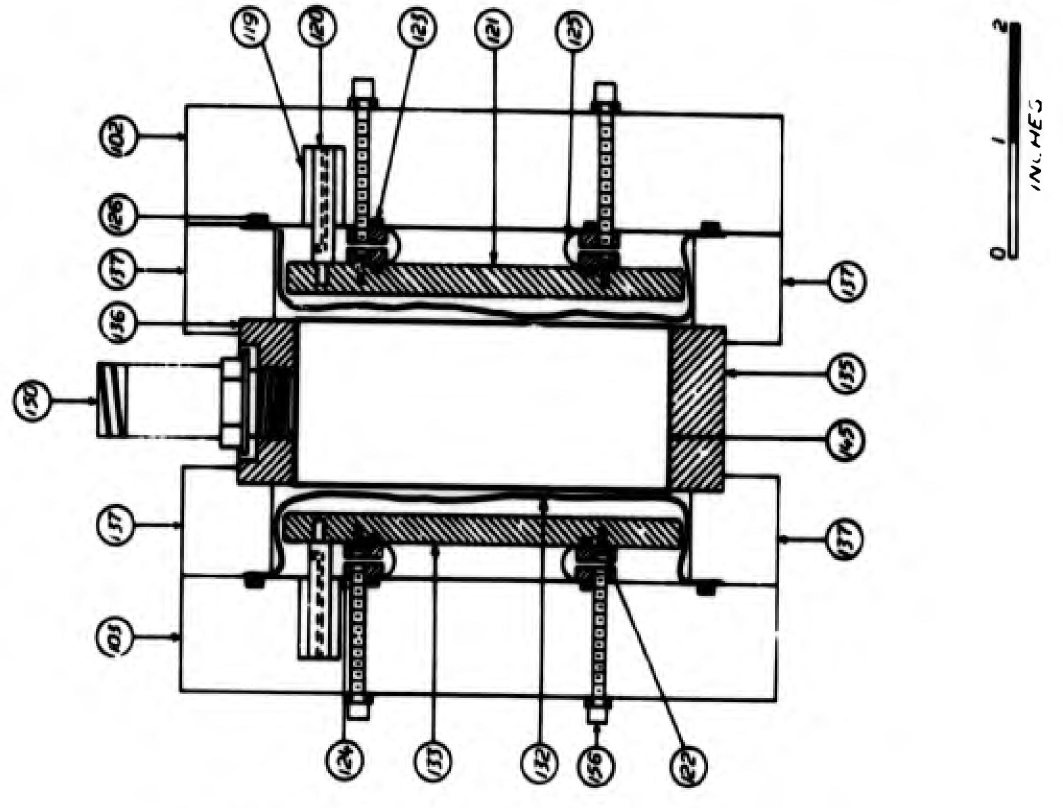
HORIZONTAL LOADING SYSTEM
(MODEL B DEVICE)

FIGURE 2-5



FIXED END PLATENS
(MODEL B DEVICE)

FIGURE 2-6



(102) (103) - SIDE ASSEMBLY PLATES
(119) - SIDE PLATEN GUIDE BUSHING
(120) - SIDE PLATEN GUIDE
(121) - RIGHT SIDE PLATEN
(122) - SIDE PLATEN DIAPHRAGM SCREW
(123) - SIDE PLATEN DIAPHRAGM O-RING
(124) - SIDE PLATEN DIAPHRAGM RING
(125) - SIDE PLATEN DIAPHRAGM
(126) - CELL DIAPHRAGM O-RING
(132) - CELL DIAPHRAGM
(133) - LEFT SIDE PLATEN
(135) - FRONT END PLATEN
(136) - BACK END PLATEN
(137) - END PLATEN RESTRAINTS
(145) - SAMPLE MEMBRANE
(150) - FLUSH DIAPHRAGM TRANSDUCER
(156) - SIDE PLATEN DIAPHRAGM CAP SCREW

TOP VIEW OF MODEL B DEVICE

FIGURE 2- 7

3. BEHAVIOR DURING CONSOLIDATION

3.1 INTRODUCTION

All samples were consolidated one-dimensionally prior to undrained shear. The active tests and eight of the passive tests used "vertical K_o" consolidation where the major principal stress acted in the vertical direction, i.e. $\bar{\sigma}_{1c}=\bar{\sigma}_{vc}$. Five of the passive tests employed "horizontal K_o" consolidation where the major principal stress acted in the horizontal direction, i.e. $\bar{\sigma}_{1c}=\bar{\sigma}_{hc}$.

For vertical consolidation, the major principal stress is applied via the top loading piston (Fig. 2-2). Lateral deformations are prevented by the fixed end platens and the removable side platens (Fig. 2-3 through 2-7). The side platens are pushed into contact with the sample at the start of each consolidation increment. After a few hours of consolidation, when most of consolidation has occurred, the side platens are removed in order to reduce side friction along the sample. Throughout the consolidation process, the cell pressure is varied in order to maintain, as closely as possible, equal volumetric and axial strains. During rebound, the side platens were not used so that K_o conditions had to depend on variations in cell pressure.

Vertical loads were applied by lead weights placed on a vertical hanger (Fig. 2-1). The lateral (cell) pressure was obtained from a screw pump or a self-compensating mercury pot system.

The following measurements were taken during consolidation:

(1) Axial movement with a 0.0001 inch dial.

(2) Volume change with 5 ml. burettes.

(3) Cell pressure with a Bourdon gage.

(4) Horizontal stress at the end platens with a pressure plate (front end platen) and/or flush diaphragm tranducers (back end platen), as shown in Figs. 2-3, 2-6, and 2-7.

(5) Horizontal stress on the side of the sample with a special side platen (see Fig. 2-4).

Items (1) - (3) above were always measured. The type of horizontal stress measurement depended on which device was being used and whether or not all transducers were operational.

During horizontal K_o consolidation, the cell pressure equalled the major principal stress. Lateral deformation was prevented by the end platens and by holding the vertical loading piston in place.

For normally consolidated specimens, the consolidation stresses equalled 0.5, 1, 2 and 4 kg/cm^2, after applying an initial stress of 0.05 - 0.2 kg/cm^2. For overconsolidated samples, the consolidation stress was usually reduced by 50 percent for each increment.

Testing procedures employed during consolidation are presented in detail in Dickey et. al (1968) for the prototype device and in Bovee and Ladd (1970) for the Model B device.

3.2 COMPRESSIBILITY

Three types of behavior will be discussed: compression curves, axial versus volumetric strain, and strain versus time.

3.2.1 Compression Curves

Figures 3-1 and 3-2 present plots of axial (vertical) strain versus consolidation stress (log scale) from nine active and nine passive tests. These compression curves were obtained with both the prototype and Model B devices by several different people over a three year period. The samples were taken from ten different batches, the properties of which are listed in Table B-1. The compression curves generally show a"break"near a stress of 1.5 kg/cm^2, the final consolidation stress used to prepare the batches of resedimented clay.

Figure 3-3 compares compression curves for five plane strain tests from batch 1200 with one-dimensional compression data obtained with the Geonor direct-simple shear device. This device achieves K_o consolidation via a wire reinforced rubber membrane (Bjerrum and Landva, 1966). The general agreement suggests that the plane strain devices yield reasonably good one-dimensional compression curves.

3.2.2 Axial Versus Volumetric Strain

If one-dimensional compression is achieved precisely, axial and volumetric strains are identical. Measured final values of axial and volumetric strain are presented in Table 3-1 and Fig. 3-4.* Data obtained during individual increments are summarized in Table 3-2. In test A-7, the recorded volumetric strain was too low, perhaps because of an undetected leak. The final axial strain recorded for test P-1 was questionable. Otherwise, there was either excellent agreement, or the measured volumetric strains appeared to be somewhat too large. The latter trend would occur if the cell pressure was too large, or if there was excessive friction along the ends and sides of the sample (this would restrain vertical movement more than horizontal movement). The incremental data in Table 3-2 suggest that the volumetric strains become larger than axial strains as

* Compression data are presented from some tests for which strength data are not reported, and vice versa.

(3) Cell pressure with a Bourdon gage.

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If one-dimensional compression is achieved precisely, axial and volumetric strains are identical. Measured final values of axial and volumetric strain are presented in Table 3-1 and Fig. 3-4.* Data obtained during individual increments are summarized in Table 3-2. In test A-7, the recorded volumetric strain was too low, perhaps because of an undetected leak. The final axial strain recorded for test P-1 was questionable. Otherwise, there was either excellent agreement, or the measured volumetric strains appeared to be somewhat too large. The latter trend would occur if the cell pressure was too large, or if there was excessive friction along the ends and sides of the sample (this would restrain vertical movement more than horizontal movement). The incremental data in Table 3-2 suggest that the volumetric strains become larger than axial strains as

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* Compression data are presented from some tests for which strength data are not reported, and vice versa.

the consolidation stress increases. This behavior is consistant with the effects of end and side friction.

It is concluded, however, that the device yields a reasonable approximation of one-dimensional consolidation. It should also be pointed out that the consolidation procedure is far easier and more rapid than is possible with a conventional triaxial cell where K_o consolidation must occur in very small increments in order not to cause excessive undrained shear strains.

3.2.3 Strains During Consolidation

Figures C-1 through C-14 in Appendix C present plots of changes in sample volume and height versus log time from six active and eight passive tests. A volume change of two cubic centimeters corresponds to an axial movement of 0.025 in. for zero lateral strain. The scales are such that the volume and height change curves should theoretically be identical. The agreement is, in fact, generally fairly good for the tests having the larger test numbers since the test procedures and absence of leaks improved with time.

3.3 HORIZONTAL STRESSES

3.3.1 Types of Measurements

Measurements of horizontal stress were made in a variety of ways, as summarized over:

Location	Method (Figure No.)	Remarks
Side	Applied cell pressure (2-4, 2-5)	Both devices
Side	Force transducer on left side platen (2-4)	Prototype only
Front End Platen	Pressure plate and force transducer (2-3)	Prototype only; later replaced by 1 or 2 pressure transducers
Back End Platen	Pressure transducer at one or two heights	Both devices

The prototype device contained several methods in order to investigate the reliability of alternate schemes. After concluding that the end platen pressure transducers yielded data as reliable as that from the more complicated schemes, this method was adopted for the Model B device.

A consolidation increment contains the following steps (see Bovee and Ladd, 1970):

(1) Close all drainage lines

(2) Push side platens into contact with the sides of the specimen (butts against the end platens)

(3) Increase cell pressure, σ_c, and vertical stress, σ_v (via dead weights on the hanger) by equal amounts to the desired level.

(4) Take readings and open drainage lines

(5) Vary cell pressure so that axial and volumetric strains are equal.

(6) After several hours, release the side platens and continue to vary the cell pressure.

The side platens prevent a lateral bulging. But since the cell pressure can act between the sample and the side platens, it has to be reduced in order to prevent a lateral contraction. In other words, K_o consolidation can be achieved if the cell pressure is too low, but not if the cell pressure is too high.

3.3.2 Initial Values

For one-dimensional loading of a saturated sample, $\Delta\sigma_v = \Delta\sigma_h = \Delta u$. Table 3-3 presents measured values of $\Delta\sigma_h/\Delta\sigma_v$ from increments during several tests with the prototype device. The values of $\Delta\sigma_h$ were measured by the end platen pressure plate and pressure transducers. The values of $\Delta\sigma_v$ were based on the applied load adjusted for filter paper, membrane and piston friction corrections (see Bovee and Ladd, 1970).

During loading, $\Delta\sigma_h/\Delta\sigma_v$ generally fell within 10 per cent of unity. The few very high values probably resulted from an additional horizontal load that occurred when the side platens were forced into position (the height of the sample increased during the application of these increments). Values of $\Delta\sigma_h/\Delta\sigma_v$ less than unity would be caused by incomplete saturation, compliance in the system (i.e. lateral strain), and friction.

During unloading, the decrease in σ_h was only 50 to 75 percent of the decrease in σ_v. The discrepancy is due to the fact that the cell pressure was seldom decreased by as much as the vertical stress.

3.3.3 Variation with Time

Figures C-15 through C-28 in Appendix C present plots of total horizontal stress versus log time during the consolidation increments. Values of σ_h measured at the end platens generally fell below that measured by the side platen force transducer. Because of friction along the side platens and difficulties in maintaining a cell pressure exactly corresponding to K_o conditions, these data are probably not very significant.

3.3.4 Values of K_o

Values of K_o measured by the various methods are tabulated in Table 3-4(a) and (b). The data are for the end of individual consolidation increments at stresses greater that the batch consolidation stress of 1.5 kg/cm^2.

Figure 3-5 shows the variation in K_o with type of measurement and consolidation stress for normally consolidated samples. There is more scatter than desirable. Moreover, there is a significant difference in average values, as shown below:

Measured By	Mean K_o	Standard Deviation
1. Cell Pressure	0.53	0.03
2. Side Platen	0.50	0.025
3. Front End Pressure Plate	0.45	-
4. Back End Pressure Transducers	0.47	0.05

R. Ladd (1965) measured $K_o = 0.48$ on resedimented Boston Blue Clay using a square oedometer with a pressure transducer inserted into one of the vertical faces.

The cell pressure generally yielded the highest values of K_o. The fact that volumetric strains often exceeded axial strains by a slight amount during consolidation (see Table 3-2) suggests that the applied cell pressures may have been too large. Thus the corresponding values of K_o would be too large.

The side platen assembly generally yielded fairly consistant values of K_o that are judged to be quite reliable. However, this procedure is complicated to use.

The front end pressure plate gave fairly erratic results that appear to be on the low side. In any case, this procedure offers little advantage over the simpler pressure transducers.

The end platen pressure transducer yielded average results that are judged to be somewhat low and they exhibited considerable scatter. A brief study of the influence of transducer location did not yield any consistent pattern of variation in K_o with the height of the transducer.

K_o data for rebounded samples are presented in Figure 3-6. The relationship obtained by R. Ladd (1965), which is considered to be reliable, is shown for comparison. It appears that most of the measurement techniques yielded values of K_o that are too low, often by a considerable amount. The reasons for the large discrepancies are not known.

It is tentatively concluded that:

(1) The cell pressure can yield reasonably reliable values of K_o if one very carefully maintains volumetric strains equal to axial strains.

(2) Pressure transducers inserted in the end platens will frequently give erratic results. Thus many measurements

are required. Average values appear to be only slightly low in the normally consolidated range, but much too low at increasing overconsolidation ratios.

3.4 PORE PRESSURE RESPONSE

At the conclusion of the final consolidation increment and prior to undrained shear, the pore pressure response was checked. This consisted of measuring Skempton's B parameter for an increased total stress of one kg/cm^2. The results are summarized in Table 3-5.

During the initial phases of testing, B was measured by increasing the cell pressure while "restraining" the top loading piston (denoted by TPR in Table 3-5). The resulting values of B generally equalled 80 ± 10 per cent. These values are too low because some vertical strain did in fact occur. Thus the vertical stress did not increase as much as the cell pressure. Moreover, there was probably some movement in the σ_2 direction. In other words, the sample did not experience a uniform increase in total pressure and, therefore, the pore pressure response was less than unity even though the sample may have been saturated.

After noting the above improper procedure, both the vertical stress and the cell pressure were increased by like amounts during measurements of the pore pressure response (denoted by IVS in Table 3-5). The resulting values of B equalled 96 ± 4 per cent, indicating a high degree of saturation for back pressures generally ranging from two to three kg/cm^2.

TOTAL AXIAL AND VOLUMETRIC STRAINS AFTER FINAL CONSOLIDATION

Test No.	Back Pressure (kg/cm^2)	Axial Strain (1) $\Delta H/Ho$(%)	Volumetric Strain (2) $\frac{\Delta V}{Vo}$ (%)	Final		Device (3)
				$\bar{\sigma}_{1c}$ (kg/cm^2)	OCR	
A-2	1.0	7.57	7.55	3.62	1.0	P
A-3	1.5	5.83	-	3.82	1.0	P
A-4	1.5	9.51	9.57	3.88	1.0	P
A-5	1.5	7.28	(6)	0.73	3.9	P
A-6	3.0	9.76	11.79	3.80	1.0	P
A-7 (5)	3.0	5.19	2.95	1.46	4.1	P
A-8	3.0	7.73	8.65	1.96	2.0	P
A-9	2.0	7.89	8.39	2.00	2.0	B
A-10	2.0	9.24	9.52	3.96	1.0	B
A-11	2.0	6.60	9.41 (8)	3.95	1.0	B
P-1	2.0	13.51 (7)	10.80	4.51	1.0	P
P-2	1.0	9.53	10.39	3.85	1.0	P
P-3	1.0	10.68	(6)	0.91	4.2	P
P-4H	2.0	(4)	9.29	4.03	1.0	P
P-9H	3.0	(4)	9.96	2.09	2.0	P
P-10 (5)	2.5	10.97	10.90	3.98	1.0	B
P-11	2.0	8.54	9.51	3.97	1.0	B
P-12H	2.0	(4)	8.88	1.01	4.0	B
P-17H	2.0	(4)	6.94	2.00	2.0	B

(1) From Dial Readings
(2) From Burette Readings
(3) P = Prototype, B = Model B
(4) Horizontal K_o Consolidation
(5) Strains Recorded for final set up only
(6) Leakage in drainage line known to have occurred
(7) Questionable strain reading for last increment
(8) Discrepancy occurred during first increment where $\Delta H/Ho = 0.2\%$ and $\Delta V/Vo = 2.6\%$

TABLE 3-1

INCREMENTAL VALUES OF AXIAL AND VOLUMETRIC STRAINS

Final $\bar{\sigma}_{vc}^{(1)}$ (kg/cm^2)	$\Delta H/Ho$ %			$\Delta V/Vo$ %		
	Average	Range	Number of Tests	Average	Range	Number of Tests
1.0	1.83	1.04 - 3.38	11	1.58	0.83 - 4.40	14
2.0	2.14	1.50 - 2.41	12	2.32	1.33 - 3.37	16
4.0	3.29	1.16 - 4.63	10	3.89	1.93 - 5.12	12
4.0 → 1.0	-0.41	-0.40 -0.42	2	-0.38	-0.31 - -0.44	5
2.0 → 1.0	-0.64	-	1	-1.25	-1.08 -1.42	2

(1) Nominal values

TABLE 3-2

MEASURED CHANGES IN INITIAL TOTAL HORIZONTAL STRESS WITH PROTOTYPE DEVICE

All Stresses in kg/cm^2

Test No.	σ_v	$\Delta\sigma_v$	Initial $\Delta\sigma_h$		Initial $\Delta\sigma_h/\Delta\sigma_v$		Vertical Strain$^{(5)}$ (%)
			BEP$^{(1)}$	FEP$^{(2)}$	BEP$^{(1)}$	FEP$^{(2)}$	
A-3	2.47 - 3.41	0.94	1.32	1.36	1.41	1.45	-0.25
	3.41 - 5.35	1.94	2.01	2.05	1.03	1.06	-0.12
A-4	2.42 - 3.40	0.98	1.40	1.33	1.43	1.36	-0.17
	3.40 - 5.38	1.98	1.98	2.17	1.00	1.10	+0.40
A-5	2.42 - 3.40	0.98	0.96	0.90	0.98	0.92	+0.08
	3.40 - 4.39	0.99	0.90	0.88	0.91	0.89	+0.06
	4.39 - 3.70	-0.69	-0.47	-0.42	0.68	0.61	-0.01
	3.70 - 2.95	-0.75	-0.42	-0.57	0.56	0.77	-0.08
	2.95 - 2.20	-0.75	-	-0.47	-	0.63	-0.03
A-6$^{(3)}$	3.21 - 3.52	0.31	0.28	0.32	0.90	1.03	+0.08
	3.99 - 4.99	1.00	1.07	0.94	1.07	0.94	+0.05
	4.99 - 7.03	2.04	2.15	1.90	1.05	0.93	+0.24
P-2	1.93 - 2.92	0.99	1.41	1.38	1.42	1.39	-0.01
	2.92 - 4.87	1.95	2.30	2.34	1.18	1.20	0
P-3	2.41 - 3.39	0.98	0.96	0.95	0.98	0.97	+0.05
	3.39 - 5.37	1.98	1.85	1.82	0.93	0.92	+0.31
	5.37 - 4.50	-0.87	-0.44	-0.44	0.50	0.50	-0.03
	4.50 - 3.42	-1.08	-0.56	-0.51	0.52	0.47	-0.05
	3.42 - 2.43	-0.99	-0.63	-0.62	0.64	0.63	-0.10
P-4H$^{(4)}$	3.20 - 3.50	0.30	0.22	0.31	0.73	1.03	-
	3.50 - 4.00	0.50	0.48	0.46	0.96	0.92	-
	4.00 - 5.00	1.00	0.91	0.97	0.91	0.97	-
	5.00 - 7.03	2.03	1.50	2.02	0.74	0.99	-

(1) Flush Diaphragm Transducer
(2) Force Transducer and Pressure Plate
(3) Front end platen contains two flush diaphragm transducers
(4) $\Delta\sigma_v$ for horizontal K_o test is Δ cell pressure
(5) During application of increment. Plus indicates vertical compression

TABLE 3-3

VALUES OF K_o

Test No. (Device)	$\bar{\sigma}_{vc}$ kg/cm^2	OCR	K_o Measured By				
			Cell Pressure	Side Platen	Front End Pressure Plate	Front End Pressure Transducer	Back End Pressure Transducer
A-2	1.91	1.0	-	0.47	0.35	-	0.40
(P)	3.86	1.0	0.49	-	0.50	-	0.50
A-3	1.90	1.0	-	0.45	0.49	-	0.48
(P)	3.82	1.0	0.50	-	0.48	-	0.39
A-4	1.90	1.0	-	0.49	0.34	-	0.42
(P)	3.88	1.0	0.47	-	0.44	-	0.46
	1.90	1.0	-	0.50	0.52	-	0.49
A-5	2.89	1.0	-	0.50	0.47	-	0.45
(P)	2.20	1.31	-	0.51	0.59	-	0.50
	1.45	1.99	-	0.72	0.63	-	-
	0.73	3.95	0.89	-	0.92	-	0.74
A-6	1.99	1.0	-	0.53	-	0.41	0.41
(P)	3.80	1.0	0.55	-	-	0.42	0.49
	2.09	1.0	0.58	-	-	0.48	0.55
	2.99	1.0	0.66?	-	-	0.51	0.51
	3.91	1.0	0.54	-	-	0.48	0.48
A-7	5.01	1.0	0.52	-	-	0.50	0.44
(P)	5.99	1.0	0.55	-	-	0.47	0.42
	5.49	1.09	0.54	-	-	-	-
	3.99	1.50	0.54	-	-	0.56	0.44
	2.48	2.41	0.60	-	-	-	-
	1.46	4.10	0.89	-	-	0.78	0.80
A-8	1.95	1.0	0.50	-	-	-	-
(P)	3.94	1.0	0.52	-	-	-	-
	1.96	2.01	0.71	-	-	-	0.59
A-9	1.94	1.0	0.58	-	-	-	-
(B)	3.93	1.0	0.54	-	-	-	-
	2.01	1.95	0.73	-	-	-	-

TABLE 3-4(a)

VALUES OF K_o (Continued)

Test No. (Device)	$\bar{\sigma}_{vc}$ kg/cm²	OCR	K_o Measured By				
			Cell Pressure	Side Platen	Front End Pressure Plate	Front End Pressure Transducer	Back End Pressure Transducer
A-10	1.94	1.00	0.53	-	-	-	0.45
(B)	3.96	1.00	0.51	-	-	-	0.44
A-11	1.96	1.00	0.57	-	-	0.41[1] ±0.09	0.42
(B)	3.95	1.00	0.57	-	-	0.49 ±0.02	0.53
P-1	2.26	1.00	-	0.35	0.30	-	0.34
(P)	4.51	1.00	0.50	-	0.41	-	0.48
P-2	1.92	1.00	-	0.50	0.47	-	0.59
(P)	3.85	1.00	0.51	-	0.50	-	0.52
	1.87	1.00	-	0.52	0.44	-	0.44
	3.85	1.00	-	0.53	0.47	-	0.42
P-3	2.98	1.29	-	0.52	0.45	-	-
(P)	1.90	2.02	-	0.61	0.54	-	-
	0.91	4.25	0.85	-	0.57	-	0.66
P-4H	2.00	1.00	-	-	0.37	-	0.49
(P)	4.03	1.00	-	-	0.47	-	0.46
P-9H	1.99	1.00	-	-	-	0.50	0.52
(P)	4.20	1.00	-	-	-	0.56	0.45
	2.09	2.01	-	-	-	0.68	0.61
P-10	1.95	1.00	0.51	-	-	-	-
(B)	3.98	1.00	0.49	-	-	-	0.50
P-11	1.99	1.00	0.56	-	-	-	-
(B)	3.97	1.00	0.52	-	-	-	-
P-12H(B)	1.01	3.98	-	-	-	-	0.65
P-17H(B)	2.01	1.00	-	-	-	-	0.62
	4.01	1.00	-	-	-	-	0.60
	2.01	2.00	-	-	-	-	0.79

(1)Average of top and bottom transducers

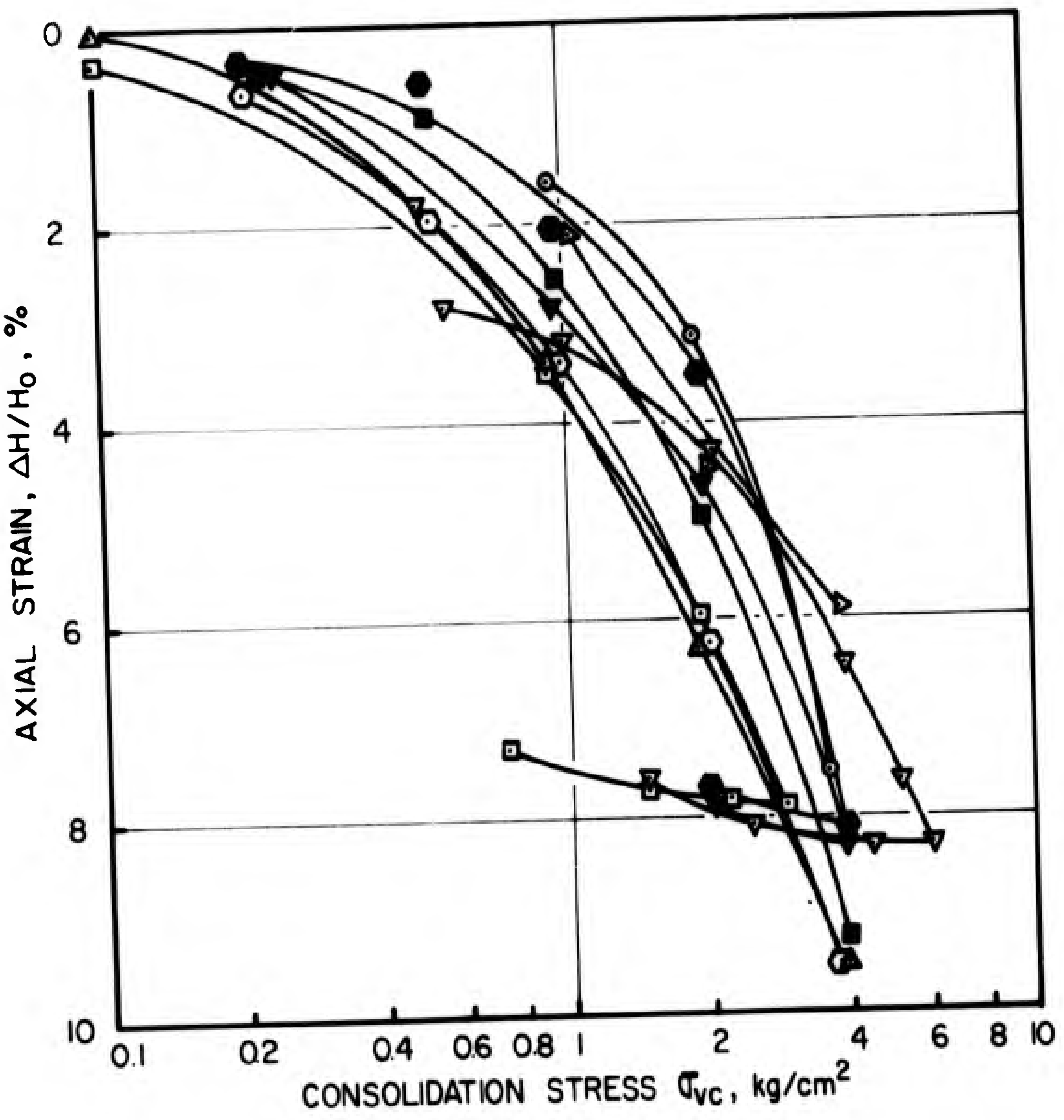
TABLE 3-4(b)

PORE PRESSURE RESPONSE

Test No.	$\bar{\sigma}_{vc}$ kg/cm^2	OCR	u_B kg/cm^2	Device	Method$^{(1)}$	B,%
A-2	3.62	1.00	1.0	P	TPR	85
A-3	3.82	1.00	1.5	P	TPR	55
A-4	3.88	1.00	1.5	P	TPR	72
A-5	0.73	3.94	1.5	P	IVS	94
A-6	3.80	1.00	3.0	P	TPR	91
A-7	1.46	4.08	3.0	P	TPR	74
A-8	1.96	2.01	2.0	P	IVS	95 ± 5
A-9	2.00	1.95	2.0	B	IVS	98
A-10	3.96	1.00	2.0	B	IVS	100
A-11	3.93	1.00	2.0	B	IVS	92 ± 2
P-1	4.51	1.00	1.0	P	TPR	80
P-2	3.85	1.00	1.0	P	TPR	71
P-3	0.91	4.25	2.0	P	TPR	86
P-4H	4.03	1.00	3.0	P	TPR	89
P-9H	2.09	2.01	3.5	P	IVS	94
P-10	3.98	1.00	2.0	B	IVS	95
P-11	3.97	1.00	2.0	B	IVS	98
P-12H	1.01	3.98	3.0	B	IVS	99
P-13	1.98	2.00	2.0	B	IVS	99
P-22	4.24	1.00	2.0	B	IVS	100

(1) TPR = Top piston restrained (old method)
IVS = Increased vertical stress (new Method)

TABLE 3-5

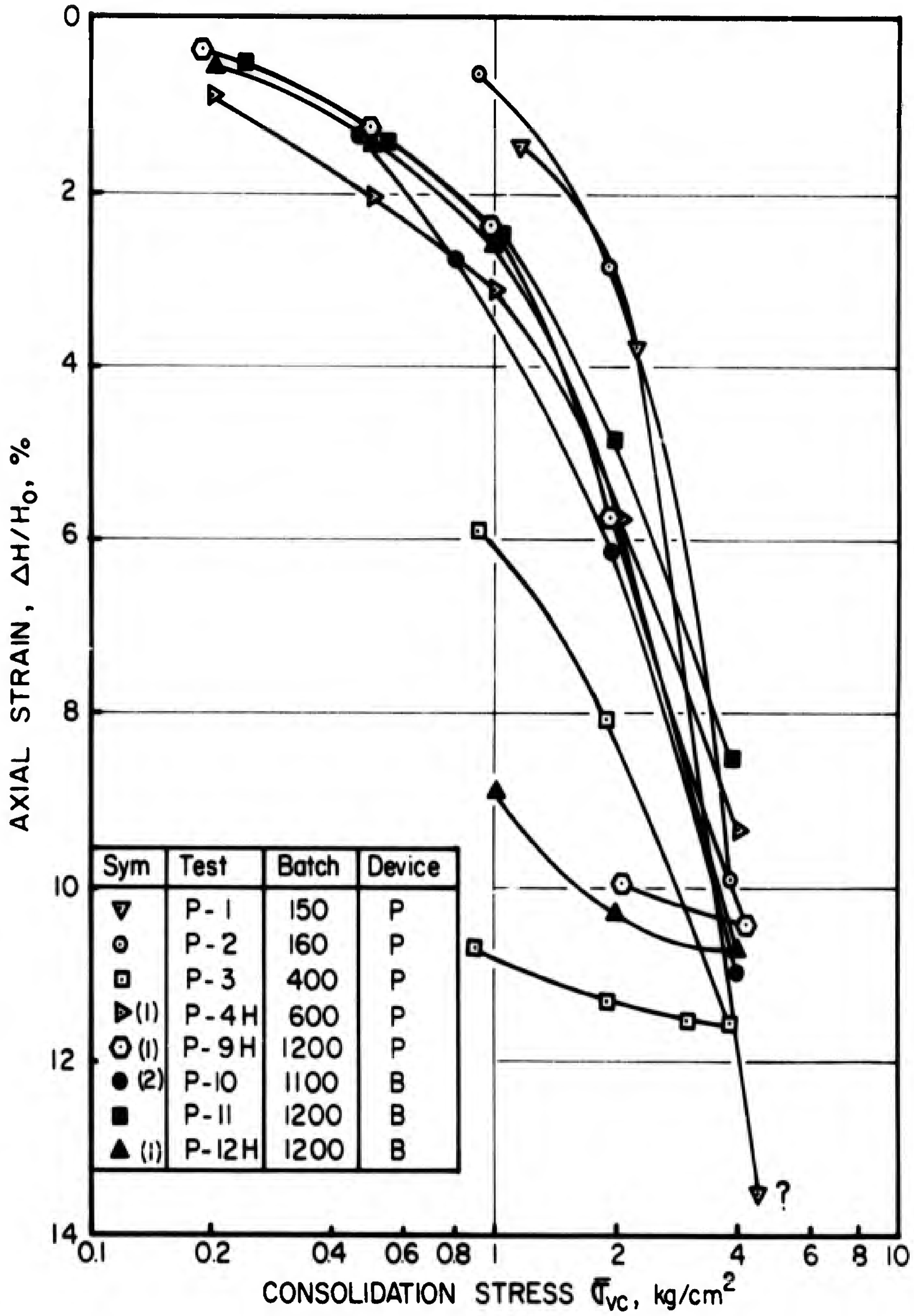


Symbol	Test	Batch	Device
⊙	A - 2	150	P
▷	A - 3	160	P
△	A - 4	300	P
⊡	A - 5	400	P
⬡	A - 6	700	P
▽ (1)	A - 7	1000	P
⬢	A - 8	1200	P
▼	A - 9	1200	B
■	A - 10	1200	B

(1) Accounts for strain prior to rupturing diaphragm

AXIAL STRAIN VS CONSOLIDATION STRESS: ACTIVE TESTS

FIGURE 3-1

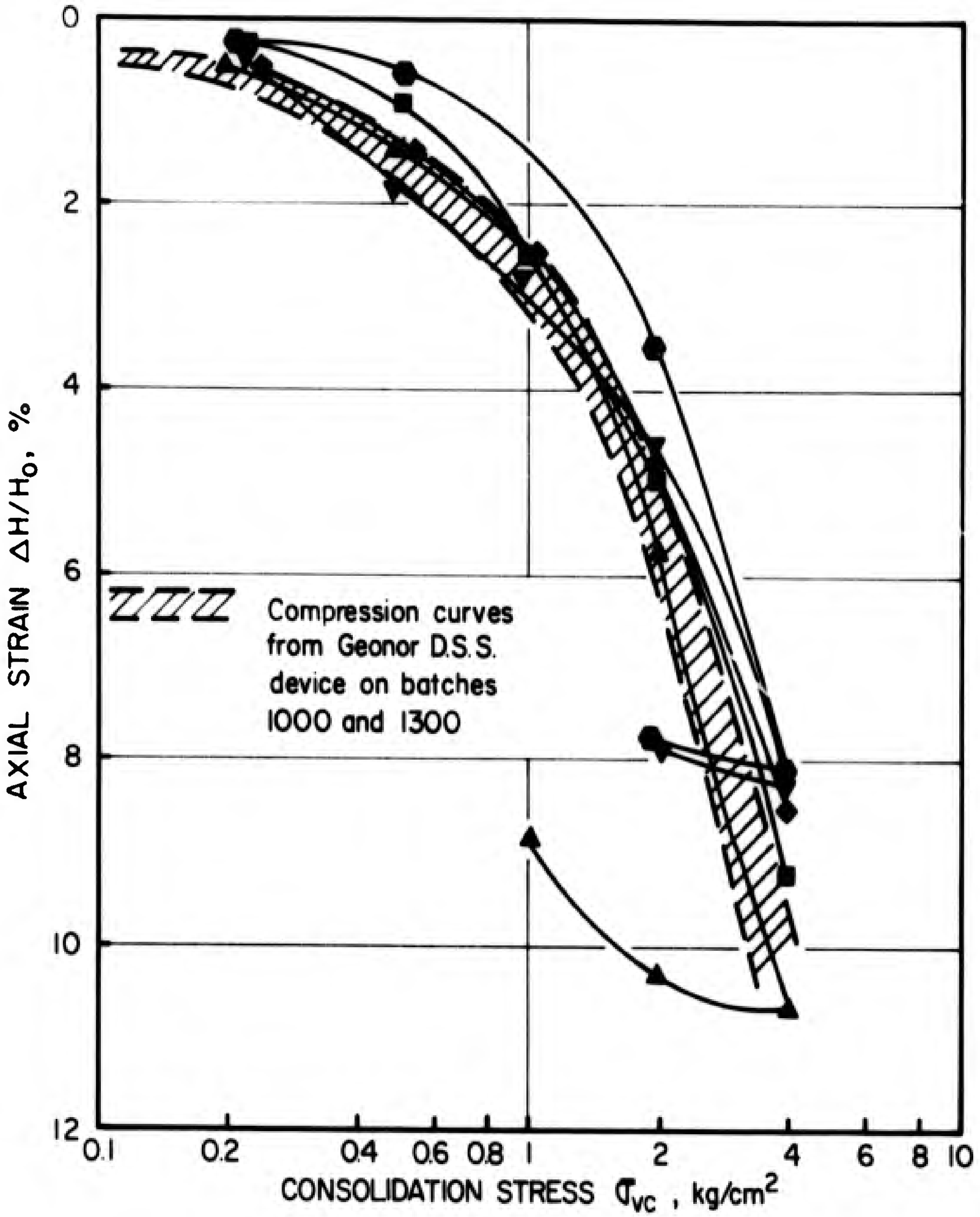


(1) Horizontal K_0 tests used $\Delta V/V_0$ in place of $\Delta H/H_0$

(2) Second set up only

AXIAL STRAIN VS CONSOLIDATION STRESS: PASSIVE TESTS

FIGURE 3-2

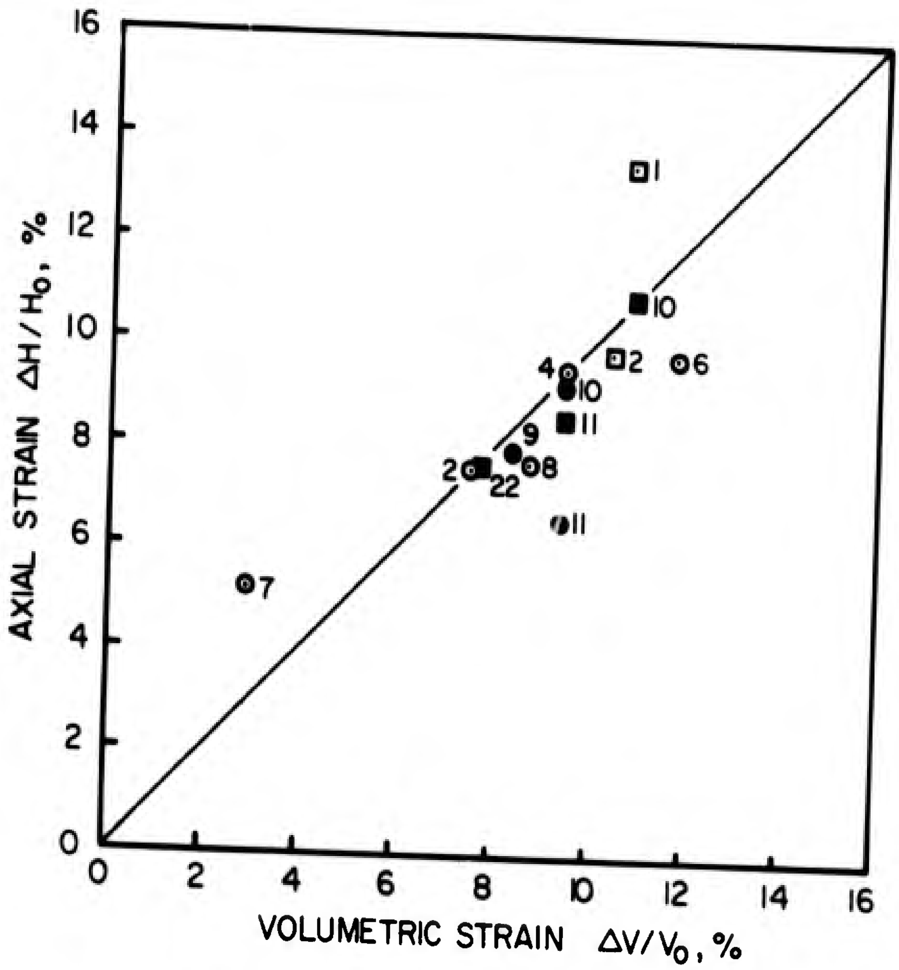


Symbol	Test	Water content	Device
●	A - 8	38.7	P
▼	A - 9	37.1	B
■	A - 10	39.1	B
◆	P - 11	37.9	B
▲ (1)	P - 12H	38.5	B

(1) Horizontal K_0 test, $\Delta V/V_0$ plotted

COMPARISON OF COMPRESSION CURVES FROM PLANE STRAIN AND DIRECT-SIMPLE SHEAR DEVICES

FIGURE 3-3

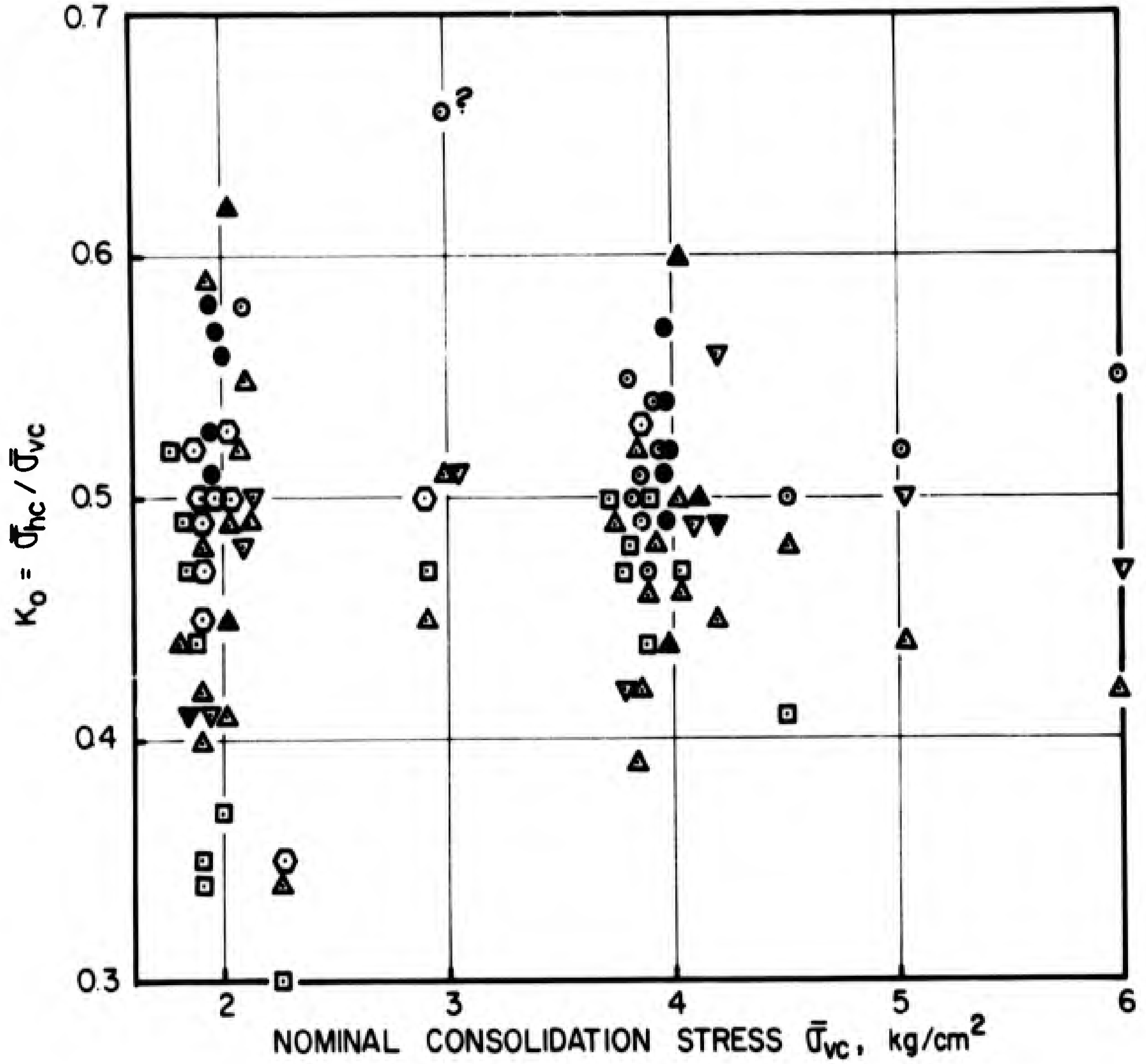


Test Device	Prototype	Model B
Active	○	●
Passive	□	■

Notes: (1) A-7 and P-10, data for second set-up only
(2) Numbers besides points show test no.

FINAL AXIAL VS FINAL VOLUMETRIC STRAINS

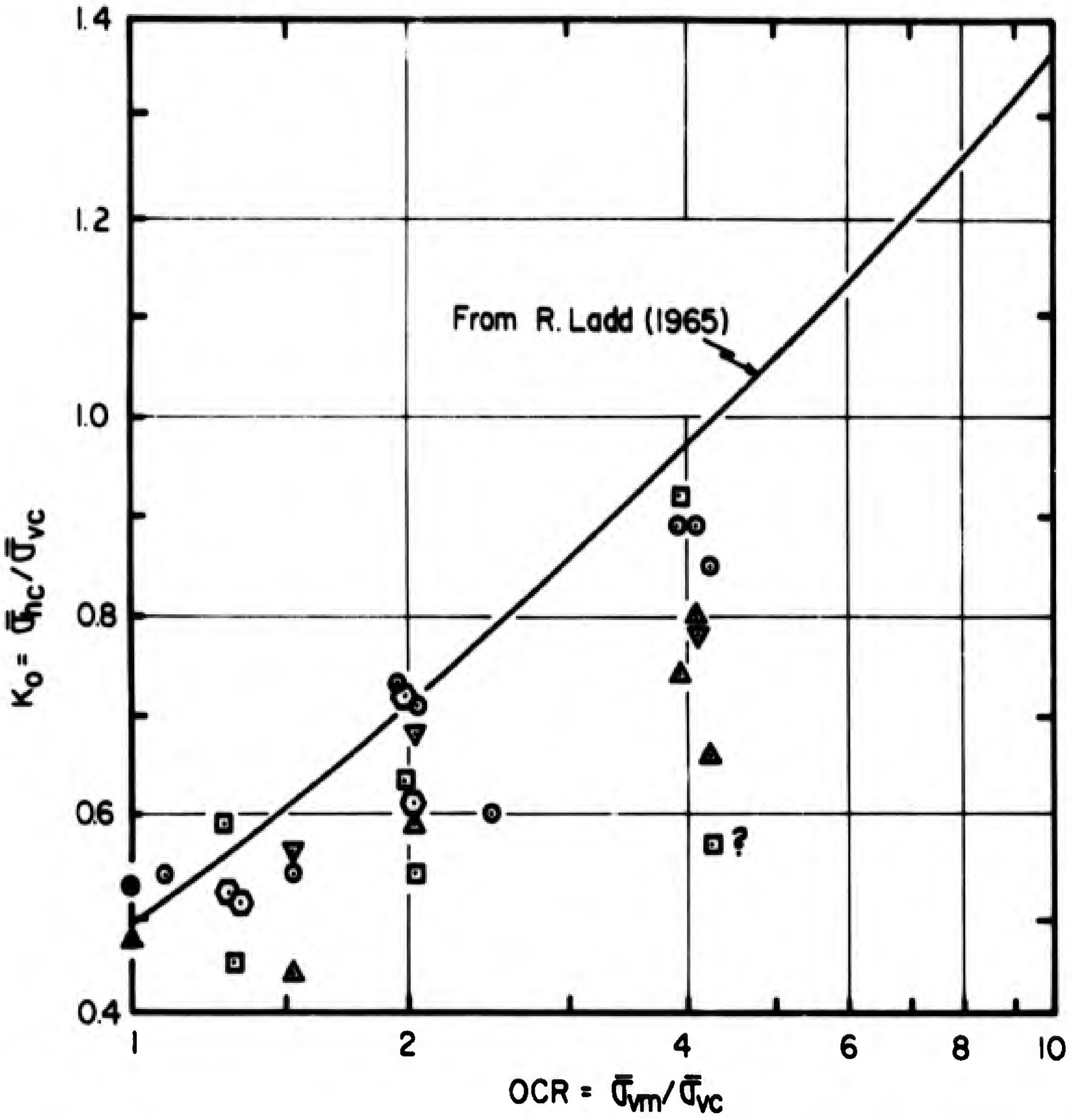
FIGURE 3 - 4



K_o measured by	Device	
	P	B
Cell pressure	○	●
Side platen	⬡	
Front end pressure plate	□	
Front end pressure transducer	▽	▼
Back end pressure transducer	△	▲

K_o VERSUS CONSOLIDATION STRESS FOR OCR = 1

FIGURE 3-5



K_o measured by	Symbol
Cell pressure	○ ●
Side platen	◯
Front end pressure plate	⊡
Front end pressure transducer	▽
Back end pressure transducer	△ ▲

Note: ● and ▲ are average values for OCR = 1

K_o VERSUS OCR

FIGURE 3 - 6

4. BEHAVIOR DURING UNDRAINED SHEAR

4.1 INTRODUCTION

This Section presents strength parameters, stress-strain curves, and stress paths* from consolidated-undrained plane strain active and passive tests at overconsolidation ratios of one, two and four. These data are based on the authors' interpretation of the results of over twenty plane strain tests. Appendix D presents stress-strain curves and stress paths from individual tests; Appendix E presents the data in tabulated form for most of the tests. Thus the reader is free to draw his own conclusions.

Emphasis is placed on the values of the undrained strength ratio, the parameters controlling this ratio, and the effects of overconsolidation ratio. Some conclusions regarding the reliability of the data are included. Section 5 compares active and passive tests and compares plane strain data with that obtained by triaxial tests and discusses the results in light of what others have found.

4.2 NORMALLY CONSOLIDATED ACTIVE TESTS

4.2.1 Strength Parameters

The undrained strength ratio, $s_u/\bar{\sigma}_{vc} = q_f/\bar{\sigma}_{vc}$, is a function of the K ratio at consolidation, K_c; the pore pressure parameter A_f; and the effective friction angle, $\bar{\phi}$ (assuming zero cohesion intercept). The equation relating these parameters is:

$$\frac{q_f}{\bar{\sigma}_{vc}} = \frac{\left[K_c + (1 - K_c)\, A_f\right] \sin \bar{\phi}}{1 + (2A_f - 1) \sin \bar{\phi}} \qquad \text{(Eq. 4.1)}$$

---

* The peak point on the Mohr circle is plotted where:

$q = (\sigma_1 - \sigma_3)/2$ and $\bar{p} = (\bar{\sigma}_1 + \bar{\sigma}_3)/2$

Values of these parameters, as well as other pertinent information, for the active tests are presented in Table 4-1. A total of six tests were run on normally consolidated (OCR=1) samples. However, two of these tests (A-2,3) had a very short period of consolidation under the last increment without the side platens. The much lower value of t_c lead to significantly higher values of the strain at failure, A_f and $\bar{\phi}$. Consequently, these data will be discounted.

The remaining four tests (A-4, 6, 10 and 11), which were run by three different people over a three year period with two difficult devices, showed:

At $(\sigma_1-\sigma_3)$ max

$q_f/\bar{\sigma}_{vc}$ = 0.34 (range = 0.32 - 0.35)
K_c = 0.52 ± 0.05
A_f = 0.8 ± 0.15
$\bar{\phi}_u$ = 29° (27 - 30)
ε_f = 0.4 ± 0.15%

At $(\bar{\sigma}_1/\bar{\sigma}_3)$ max

$q/\bar{\sigma}_{vc}$ = 0.29 ± 0.03
$\bar{\phi}_{max}$ = 34 ± 1°
ε = 3.5 ± 1%

The magnitude of $q_f/\bar{\sigma}_{vc}$ did not vary in a consistent fashion with K_c, A_f, or $\bar{\phi}_u$. However, there is a fairly consistent increase in the ratio with decreasing water content at failure, w_f. This is contrary to the results of Ladd and Varallyay (1965), who found little effect of w_f for $\overline{CU}$ triaxial compression tests on Boston Blue Clay.

By in large, the strength parameters show relatively little scatter. The value of $\bar{\phi}$ at maximum obliquity is particularly consistent.

4.2.2 Stress-Strain and Stress Path Characteristics

Figures D-1 and 2 in Appendix D present stress-strain curves from the six individual tests run on normally consolidated samples. These data have been synthesized to produce the stress-strain relationships shown in Figure 4-1. Similarly, the stress path data in Figures D-5 and 6 have been reduced to the representative curve shown in Figure 4-3.

The following characteristics are noted:

(1) The peak strength occurs at a very low strain; thereafter, there is a substantial drop off in strength (strain softening) with increasing strain. Beyond six to seven percent strain, the value of $q/\bar{\sigma}_{vc}$ drops below that at consolidation. Many of the samples exhibited a distinct failure plane (see Figures B-1 and B-2, Appendix B).

(2) Maximum obliquity occurs at a much larger strain than the undrained strength. The corresponding increase in $\bar{\phi}$ is about five degrees. After maximum obliquity, the decrease in $(\bar{\sigma}_1/\bar{\sigma}_3)$ is slight.

(3) Thus the substantial strain softening effect is due primarily to decreases in effective stress (increased pore pressures), rather than decreases in obliquity.

(4) Skempton's A parameter starts off with a value of about 0.5 and increases rapidly with strain. Beyond a few tenths percent strain, the stress

difference is decreasing while the excess pore pressures continue to increase. Thus the A parameter loses its physical significance. At large strains, A becomes infinite, then negative when $(\sigma_1-\sigma_3)$ drops below the initial value at consolidation.

(5) The magnitude of the excess pore pressures generated during a test varied with the K ratio at consolidation. However, if the effect of K_c is accounted for, the results are quite consistent, as shown below for the four tests A-4, 6 10 and 11:

Axial Strain, %	$(\Delta u+\Delta\sigma_3)/\bar{\sigma}_{vc}$	$(\Delta u+\Delta\sigma_3)/\bar{\sigma}_{vc}+(1-K_c)$
0.5	0.11 to 0.20	0.64 ± 0.01
4	0.20 to 0.34	0.76 ± 0.03

(6) The tabulated data in Appendix E show that $\bar{\sigma}_2/\bar{p}$ starts off with a value of about 0.67 (corresponding to $K_c = 0.5$). This ratio appears to increase somewhat during shear, reaching a value of 0.74 ± 0.05 at maximum obliquity. The scatter in the data reflect the fact that the end platen pressure transducer readings tend to be erratic. Bishop (1966) suggested the empirical relationship, $\bar{\sigma}_{2f}/\bar{p}_f = \cos^2 \bar{\phi}$, for plane strain tests on sands. For $\bar{\phi} = 34$ degrees, this yields $\bar{\sigma}_{2f}/\bar{p}_f = 0.65$. Thus the measured values are higher than that predicted by this correlation. For $\bar{\sigma}_2/\bar{p} = 0.74$, the corresponding value of Poisson's ratio, $\bar{\nu}$, is 0.37 for an isotropic elastic material ($\bar{\nu} = \bar{\sigma}_2/2\bar{p}$).

Kinner and Ladd(1970) have presented an extensive analysis of the values of secant modulus determined from $\overline{CK_oU}$ plane strain active and passive tests. The secant modulus is defined as:

$$E_s = 0.75 \left[\frac{\Delta(\sigma_1 - \sigma_3)}{\varepsilon}\right]$$

where ε = vertical (axial) strain. The 0.75 factor enters because of plane strain conditions. It equals $(1 - \nu^2)$, where $\nu = 0.5$, Poisson's ratio for undrained shear.

Figure 4-5 presents values of the normalized secant modulus plotted versus the applied shear stress ratio for representative $\overline{CK_oU}$ plane strain active tests. The applied shear stress ratio is defined as the increment of shear stress divided by the change in shear stress to cause failure. For normally consolidated samples:

$\Delta q/\Delta q_f$	$E_s/\bar{\sigma}_{vc}$	Nominal Strain, %
0.2	600 ± 200	0.005
0.5	250 ± 50	0.025
0.8	110 ± 10	0.1

4.3 OVERCONSOLIDATED ACTIVE TESTS

4.3.1 Strength Parameters

Two tests each were run at OCR values of two and four. The tests are summarized in Table 4-1. The resulting undrained strength ratios, values of A_f, and obliquity (expressed as $q_f/\bar{p}_f$) are plotted versus OCR in Figure 4-4. The two tests with OCR = 2 were very consistent, whereas the two with OCR = 4 exhibited somewhat erratic behavior.*

The following trends occur with increasing overconsolidation ratio:

(1) The undrained strength ratio, $q_f/\bar{\sigma}_{vc}$, increases markedly from 0.34 to 0.95.

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* Both tests had testing problems. Moreover, the maximum past pressures were quite different (2.9 and 6.0 kg/cm^2 for Tests A-5 and A-7 respectively).

(2) The strain at failure increases from 0.4 to 1.8 percent.

(3) Skempton's A parameter at failure decreases from about 0.8 down to 0.14.

(4) The obliquity at undrained failure increases, as does the maximum obliquity. However, there are insufficient data with which to determine a reliable failure envelope for overconsolidated clay.

4.3.2 Stress-Strain and Stress Path Characteristics

Individual stress-strain curves and stress paths are presented in Figures D-3,4 and D-7,8 respectively. Figure 4-2 shows the synthesized stress-strain curves and Figure 4-3 presents normalized stress-paths. In the latter figure, the values of q and $\bar{p}$ have been divided by the maximum past pressure, $\bar{\sigma}_{vm}$, so that both normally consolidated and overconsolidated samples can be shown on the same plot.

The following characteristics are noted:

(1) The overconsolidated samples exhibit less strain softening than occurred for the normally consolidated clay.

(2) Maximum obliquity occurs before maximum stress difference for the heavily overconsolidated soil (OCR = 4).

(3) The A parameter again starts out with a value of about one-half, but it decreases with increasing strain and then increases (OCR = 2) or remains almost constant (OCR = 4).

(4) The magnitude of $(\Delta u - \Delta\sigma_3)/\bar{\sigma}_{vc}$ at small strains increases with increasing overconsolidation ratio. This seemingly unusual behavior is the result of

a much larger increase in normalized stress difference, due in part to the higher values of K_c. The corresponding pore pressure ratios are: (based on the synthesized curves):

Strain, %	OCR	$(\Delta u-\Delta\sigma_3)/\bar{\sigma}_{vc}$	$(\Delta u-\Delta\sigma_3)/\bar{\sigma}_{vc}+(1-K_c)$
0.5	1	0.17	0.65
	2	0.24	0.52
	4	0.35	0.46
4	1	0.30	0.78
	2	0.38	0.66
	4	0.27	0.38

(5) The stress paths in Figure 4-3 show the characteristic change in shape as the samples become more overconsolidated.

Values of normalized secant modulus for overconsolidated samples are presented in Figure 4-5. It is difficult to ascertain trends because of the variation in modulus for samples with the same OCR. However, whereas all samples appear to start off with about the same normalized modulus, the more overconsolidated samples exhibit a somewhat less rapid decrease in modulus as failure is approached.

If the secant modulus is normalized with respect to undrained shear strength, s_u, rather than consolidation stress, the resulting ratio decreases with increasing OCR, as shown below:

$\Delta q/\Delta q_f$	OCR	E_s/s_u
0.2	1	2000 ± 500
	2	825 ± 75
	4	750 ± 50

$\Delta q/\Delta q_f$	OCR	E_s/s_u
0.5	1	750 ± 50
	2	600 ± 100
	4	475 ± 25

4.4 NORMALLY CONSOLIDATED PASSIVE TESTS

4.4.1 Failure Criteria

Because of various sources of "friction" in the device, most of the passive tests with vertical K_o consolidation yielded obviously incorrect data at large strains, particularly with normally consolidated samples. The error occurs because the measured magnitude of the vertical stress is too low, thus resulting in excessively high values of obliquity ($\bar{\sigma}_1/\bar{\sigma}_3 = \bar{\sigma}_h/\bar{\sigma}_v$). In some cases, the computed value of vertical effective stress, $\bar{\sigma}_v$, became negative.

Standard passive tests with vertical K_o consolidation involve a strain controlled decrease in the vertical stress, with a constant value of horizontal stress (constant cell pressure). Thus the height of the sample is increasing during shear. The value of vertical stress measured via a proving ring or load cell placed at the top of the loading piston will be smaller than the actual (or average) vertical stress acting on the sample for the following reasons (also see Bovee and Ladd, 1970):

(1) Friction between the loading piston assembly and the ball bushing and/or the top retaining plates (Figures 2-2 and 2-5);

(2) Friction between the top platen and the end platens (Figures 2-3 and 2-6);

(3) Friction between the ends of the sample and the end platens (Figures 2-3 through 2-7).

(4) Friction between the sides of the sample and the cell diaphragm (Figures 2-4 and 2-5).

(5) Resistance caused by stretching of the sample membrane and the vertical filter strips.

Items (1) and (2) are considered via a calibration based on loading a water filled sample membrane. Item (5) is considered via theoretical equations. The reliability of the calibration and equations is unknown. No attempt is made to correct measured data for the effects of Items (3) and (4). Estimates of the effect indicate that full mobilization of friction along the sides and ends of the sample might reduce the measured value of vertical stress by up to 0.5 kg/cm^2 (Bovee and Ladd, 1970). An error of this magnitude could easily result in computed values of vertical effective stress that approach zero, or even become negative.

Plane strain passive tests should be run where the vertical load is measured at both the top and bottom of the sample.

Some of the passive tests developed necking at large strains (see Figures B-3 and B-4, Appendix B). When this occurs, the computed value of vertical stress is again too small since the actual area of the sample is less than assumed.

The question is how to interpret test data that contain errors because of unknown amounts of friction (and/or necking). The approach will be based on an evaluation of the obliquity of principal stresses, $\bar{\sigma}_1/\bar{\sigma}_3 = \bar{\sigma}_h/\bar{\sigma}_v$. That is, undrained failure will be defined in terms of when the measured obliquity of stresses reaches a certain value. This approach is used because:

(1) Measured values of $\bar{\sigma}_h = \sigma_h - u$ should be fairly reliable;

(2) Thus the uncertainty lies in $\bar{\sigma}_v = \sigma_v - u$;

(3) Because the undrained failure occurs at fairly large strains, the "friction" of the clay should be fully mobilized; that is, maximum stress difference and maximum obliquity should occur at essentially the same strain.

A failure criteria based on the obliquity of principal stresses will yield the maximum possible value of undrained strength,

$$s_u = q_f = 0.5\ (\sigma_h - \sigma_v) = 0.5\ (\bar{\sigma}_h - \bar{\sigma}_v)$$

if the value of $\bar{\sigma}_h$ is constant, or decreasing, while the obliquity is still increasing. This condition will occur if the incremental A parameter* is equal to or greater than unity.

The $\overline{CK_oU}$ plane strain active tests yielded the following values of maximum obliquity:

OCR	$(\bar{\sigma}_1/\bar{\sigma}_3)_{max}$	Corresponding $\bar{\phi}$, Degrees
1	3.70 ± 0.15	35 ± 1
4	4.25 - 4.40	38.6 ± 0.4

Triaxial extension tests on normally consolidated Boston Blue clay from Ladd and Varallyay (1965) yielded:

Type of Consolidation	$(\bar{\sigma}_1/\bar{\sigma}_3)_{max}$	Corresponding $\bar{\phi}$, Degrees	Remarks
$K_c = 1.00$	4.50 ± 0.10	39.5 ± 0.5	Problem with Necking
$K_c = 0.50$	4.20 ± 0.4	38 ± 2	Problem with Necking
$K_c = 2.0$	3.85 ± 0.15	36 ± 1	No Necking

* For passive tests with vertical consolidation:

$$A = \frac{\Delta u - \Delta\sigma_3}{\Delta\sigma_1 - \Delta\sigma_3} = \frac{\Delta u - \Delta\sigma_v}{\Delta\sigma_h - \Delta\sigma_v}$$

Based on the above data, the following values of obliquity were selected for use as failure criteria for normally consolidated passive tests:

Obliquity Condition	$(\bar{\sigma}_1/\bar{\sigma}_3)$	Corresponding $\bar{\phi}$, Degrees
Minimum Possible	3.85	36
Reasonable Upper Limit	4.60	40
Maximum Possible Upper Limit	∞	($\bar{\sigma}_v$ equals zero)

The application of the above failure criteria to six passive tests run on normally consolidated samples results in the data presented in Table 4-2. (Appendix D presents individual stress-strain and stress path data for these tests.) Tests P-1 and 2 were run during the very early phases of testing when there were numerous problems with leakage of membranes and pore pressure lines. Test P-4H employed horizontal K_o consolidation; during undrained shear, the cell pressure was first reduced until $\sigma_v = \sigma_h$, then σ_v was increased by strain controlled loading. Tests P-10, 11 and 22 were run with the Model B device using the standard test procedures. Test P-10 exhibited the best overall behavior. It also had the highest initial water content (see Table 4-3) and underwent the largest vertical strain during consolidation.*

The following average results are obtained from Tests P-4H through P-22 for the various failure criteria:

Failure Criteria	Vertical Strain, %	$q_f/\bar{\sigma}_{1c}$	A_f
$(\bar{\sigma}_1/\bar{\sigma}_3)=3.85$	3.4	0.18	1.015
$(\bar{\sigma}_1/\bar{\sigma}_3)=4.60$	4.3	0.19	1.02
q_{max} or $\bar{\sigma}_v=0$	6	0.205	1.035

* At the start of shear, Test P-10 had a sample height equal to 84 percent of the original height, whereas 90 percent was typical of the other tests. The larger vertical strain at the start of shear may have been a significant factor in the superior behavior of this test.

All three failure criteria produce fairly consistent data. Moreover, the quite different values of obliquity do not result in very large variations in $q_f/\bar{\sigma}_{1c}$, even though the vertical strain almost doubles. Changes in A_f are negligible.

A failure criteria based on a maximum obliquity of 4.60 ($\bar{\phi}$ = 40 degrees) will be selected. This criteria should yield a reasonable estimate of the maximum possible undrained strength from passive tests. However, it should be realized that the actual strengths may be somewhat smaller than assumed.

4.4.2 Strength Parameters

The equation relating $q_f/\bar{\sigma}_{1c}$, K_c, A_f and $\bar{\phi}$ for passive tests with vertical consolidation is:

$$\frac{q_f}{\bar{\sigma}_{1c}} = \frac{\left[1-(1-K_c)A_f\right]\sin\bar{\phi}}{1+(2A_f-1)\sin\bar{\phi}} \qquad \text{(Eq. 4.2)}$$

where $A_f = \dfrac{\Delta u - \Delta\sigma_3}{\Delta\sigma_1 - \Delta\sigma_3} = \dfrac{\Delta u - \Delta\sigma_v}{\Delta\sigma_h - \Delta\sigma_v}$

For the standard passive test:

$$\Delta\sigma_h = 0$$
$$\Delta\sigma_v = -\bar{\sigma}_{1c}(1-K_c) - 2q_f$$

Therefore $$A_f = \frac{\Delta u_f + \bar{\sigma}_{1c}(1-K_c) + 2q_f}{\bar{\sigma}_{1c}(1-K_c) + 2q_f}$$

Because q_f appears in both the numerator and denominator, errors in q_f will have a minor effect on the magnitude of A_f.

For passive tests on horizontally consolidated samples, where $\bar{\sigma}_{1c} = \bar{\sigma}_{hc}$ and $\bar{\sigma}_{3c} = \bar{\sigma}_{vc}$:

$$A_f = \frac{\Delta u - \Delta\sigma_3}{\Delta\sigma_1 - \Delta\sigma_3} = \frac{\Delta u - \Delta\sigma_h}{\Delta\sigma_v - \Delta\sigma_h}$$

$$= \frac{\Delta u_f}{\bar{\sigma}_{1c}(1-K_c) + 2q_f}$$

Table 4-3 summarizes the results of six passive tests on normally consolidated samples. Individual stress-strain curves and stress paths are presented in Appendix D and detailed tabulations are contained in Appendix E for most of the tests. Table 4-3 contains strength parameters based on two criteria:

(1) At $(\bar{\sigma}_1/\bar{\sigma}_3) \leq 4.60$ (corresponds to $\bar{\phi} = 40°$)

(2) At q_{max} or when $\bar{\sigma}_v$ becomes zero.

Based on the four tests P-4H, P-10, P-11, and P-22 and the 40 degree obliquity criteria, it is concluded that:

$q_f/\bar{\sigma}_{1c}$ = 0.19 (range = 0.17 - 0.215)
K_c = 0.50 (0.45 - 0.52)
A_f = 1.015 (0.96 - 1.06)
$\bar{\phi}$ = 40° based on failure criteria
ε_f = 4.3 ± 1.5 %

It should be remembered that the use of the maximum obliquity criteria is thought to yield a reasonable estimate of the maximum possible value of $q_f/\bar{\sigma}_{1c}$. It may be that the actual undrained strength ratio is somewhat smaller than 0.19.

Because of the problems with "friction" in the apparatus, it is not possible to reliably determine an effective stress envelope, or to study strain softening effects.

4.4.3 Stress-Strain and Stress Path Characteristics

Figures D-9 and 10 in Appendix D present stress-strain curves from six tests run on normally consolidated samples. These data have been synthesized to produce the stress-strain relationships shown in Figure 4-6. Similarly, the stress path data in Figures D-13 and 14 have been reduced to the representative curve shown in Figure 4-8.

The following characteristics are noted:

(1) The peak strength occurs at a relatively large strain, which is an order of magnitude larger than that determined from active tests. There is probably little strain softening beyond the peak strength.

(2) Throughout undrained shear, there is a continuous decrease in the average effective stress, $\bar{p}$. The rate of decrease becomes particularly pronounced after the principal planes have been rotated, i.e., when σ_v is less than σ_h.

(3) The A parameter starts out with a value of about 0.75 and continuously increases to a maximum of about 1.01 ± 0.05.

(4) At the point where $q = 0$, i.e., $\sigma_v = \sigma_h$, the A parameter equalled 0.82 ± 0.06 from five of the six tests. This condition corresponds to "perfect sampling" if one discounts the σ_2 direction. The A parameter for unloading

$$A_u = \frac{\Delta u - \Delta\sigma_h}{\Delta\sigma_v - \Delta\sigma_h}$$

is equal to 1-A. Therefore, $A_u = 0.18 \pm 0.06$.

This agrees exactly with $A_u = 0.18 \pm 0.06$ reported by Ladd and Varallyay (1965) for perfect sampling of Boston Blue Clay in a triaxial cell after K_o consolidation.

(5) The excess pore pressure, $(\Delta u - \Delta\sigma_3)/\bar{\sigma}_{1c}$, increases rapidly, reaching a maximum of 0.89 ± 0.03 at failure (some "measured" values exceeded this range because of apparatus friction).

(6) The tabulated data in Appendix E show that $\bar{\sigma}_2/\bar{p}$ increases during shear (except for P-4H) reaching a value of 0.92 ± 0.13 at failure. There were considerable scatter in the data.

Figure 4-10 presents values of the normalized secant modulus plotted versus the applied shear stress ratio for representative $\overline{CK_oU}$ plane strain passive tests. The applied shear stress ratio is defined as the increment of applied shear stress divided by the change in applied shear stress to cause failure. For the standard passive test, this would equal $\Delta\sigma_v/\Delta\sigma_{vf}$, although it is still denoted by $\Delta q/\Delta q_f$. For representative normally consolidated samples:

$\Delta q/\Delta q_f$	$E_s/\bar{\sigma}_{vc}$	Nominal Strain, %
0.2	450	0.03
0.5	150	0.22
0.8	55	0.95

For a perfectly operating plane strain device, passive tests on vertically and horizontally K_o consolidated samples should yield identical results. Friction in the apparatus precludes this ideal situation. However, the two types of tests appear to yield reasonably similar strength parameters and stress-strain behavior at low strains. The parameters from P-4H agree moderately well with those from vertically

K_o consolidated samples with an OCR of one. The normalized stress difference versus strain from Test P-8H* agreed almost exactly with that from Test P-22 (see Figure 4-10), which fell between that for Tests P-10 and P-11. Data from the two types of tests on overconsolidated samples also showed good agreement at OCR = 2.

4.5 OVERCONSOLIDATED PASSIVE TESTS

4.5.1 Failure Criteria and Strength Parameters

Various sources of friction also affected the overconsolidated tests, although the magnitude of the side friction may have been less important because of the reduced total horizontal stress, especially at an OCR equal to four. Failure criteria based on a maximum obliquity were again used, but the results are less definitive than for the normally consolidated tests.

The results of seven passive tests on overconsolidated samples are summarized in Table 4-4. Detailed stress-strain and stress path data for three of the tests are presented in Appendix D and E.

At an OCR of two, the average effective stress at failure divided by the maximum past pressure, $\bar{p}_f/\bar{\sigma}_{vm}$, equalled about 0.25. An extrapolation of the failure envelope from the active tests (see Figure 4-3) suggests the following conditions of maximum obliquity:

$$\bar{\sigma}_1/\bar{\sigma}_3 = 5.80$$

$$\text{or} \quad q/\bar{p} = 0.707$$

which corresponds to a friction angle of 45 degrees for zero cohesion intercept. The application of this criteria

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* Data from this test are not presented because of an apparent leak in the pore pressure line.

to Tests P-13 and P-23 yields:

$q/\bar{\sigma}_{1c} = 0.36 - 0.385$

$A_f = 0.85 \pm 0.01$

Test P-9H, which used horizontal K_o consolidation, yielded:

$q/\bar{\sigma}_{1c} = 0.39$

$\bar{\sigma}_1/\bar{\sigma}_3 = 5.10$

$A_f = 0.72$

at the measured value of q_{max}.

The above strength parameters are plotted versus OCR in Figure 4-9. An undrained strength ratio of 0.38 corresponds to an undrained shear strength that equals the undrained strength at the maximum past pressure*. Since one would expect some decrease in strength with unloading, a value of $s_u/\bar{\sigma}_{vc}$ equal to or greater than 0.38 is considered unlikely.

It is concluded that for an OCR of two:

$q_f/\bar{\sigma}_{1c} = 0.37$

$K_c = 0.71$ (which equals K_o)

$A_f = 0.82$

$q_f/\bar{p}_f = 0.707$ based on failure criteria

$\varepsilon_f = 5.5\%$ (an estimate)

Table 4-4 summarizes the results of four tests with an OCR of four. Only one of these, P-12H, yielded satisfactory stress-strain data. Pertinent comments on the other tests are:

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* Assume that $\bar{\sigma}_{vm} = 4.00$ kg/cm^2. Therefore:

At OCR = 1.0, $s_u = (s_u/\bar{\sigma}_{vc})(\bar{\sigma}_{vc}) = (0.19)(4.00) = 0.76$

At OCR = 2.0, $s_u = (s_u/\bar{\sigma}_{vc})(\bar{\sigma}_{vc}) = (0.38)(2.00) = 0.76$

Test P-3: Slight pore pressure leak invalidates effective stress data, but undrained strength considered reliable.

P-5H: Initial stress-strain data no good, and s_u considered too large, but $(\bar{\sigma}_1/\bar{\sigma}_3)_{max} = 6.0$ at $\varepsilon = 5.5$ to 6.5%.

P-7: Test set-up twice so final water content too low; measured s_u much too high.

Based on the active tests and Tests P-5H and P-12H, a maximum obliquity of $\bar{\sigma}_1/\bar{\sigma}_3 = 6.00$ was selected ($q_f/\bar{p}_f = 0.715$). The resulting parameters are plotted in Figure 4-9. Based on no loss in s_u during rebound to an OCR of four,

$$s_u/\bar{\sigma}_{vc} = (4)(0.19) = 0.76$$

Thus Tests P-5H and P-7 with ratios of 0.85 and 0.835 are obviously incorrect.

It is concluded that for passive tests with an OCR of four:

$q_f/\bar{\sigma}_{1c} = 0.67$

$K_c = 0.85$ (less than $K_o = 0.97$)

$A_f = 0.49$

$q_f/\bar{p}_f = 0.715$ based on failure criteria

$\varepsilon_f = 7\%$ (an estimate)

4.5.2 Stress-Strain and Stress Path Characteristics

Measured stress-strain and stress path data in Appendix D and E have been synthesized to produce the stress-strain relationships in Figure 4-7 and the normalized stress paths in Figure 4-8. Normalized secant modulus data for representative tests are plotted versus the applied shear stress ratio in Figure 4-10.

The following comments are in order:

(1) Increasing overconsolidation probably increases the strain at failure. It has been assumed that ε_f = 5.5 and 7.0 percent at OCR = 2 and 4 respectively.

(2) There is probably little if any strain softening.

(3) The A parameter starts out with a value of 0.4 ± 0.1 (versus about 0.75 for normally consolidated passive tests). It increases to about 0.8 for an OCR of two and to about 0.5 for an OCR of four.

There appears to be a slight increase with OCR of the secant modulus normalized with respect to the vertical consolidation stress. The data at an OCR of one and two are very consistent, whereas the data at an OCR of four are erratic.

If the secant modulus is normalized with respect to undrained shear strength, s_u, rather than consolidation stress, the resulting ratio decreases with increasing OCR, as shown below:

$\Delta q/\Delta q_f$	OCR	E_s/s_u
0.2	1	2500
	2	1500
	4	1100 (approximate)
0.5	1	800
	2	535
	4	350 (approximate)

TEST	STRESS HISTORY			At $(\sigma_1 - \sigma_3)_{max}$					At $(\bar{\sigma}_1 / \bar{\sigma}_3)_{max}$				REMARKS
NO.	OCR	$\bar{\sigma}_{vc}$ $\bar{\sigma}_{hc}$	K_c (1) t_c (2)	ε (3) %	$\frac{q}{\bar{\sigma}_{vc}}$	A	q $\bar{p}$	$\bar{\Phi}_u$ (4) $q/\bar{p}$	ε (3) %	q $\bar{p}$	$\bar{\Phi}_{max}$ (4) $q/\bar{p}$	ω_i % ω_f %	(Strain rate) (5)
A - 2	1.00	3.62 1.78	0.49 0.5	1.5	0.336	1.24	1.215 2.255	32.6 0.54	2.0	1.20 2.16	33.7 0.555	33.6 30.1	t_c too low (1.0)
A - 3	1.00	3.82 1.95	0.51 1.5	1.7	0.356	1.01	1.36 2.45	33.7 0.555	3.4	1.36 2.32	35.9 0.586	34.6 29.2	t_c too low (0.2)
A - 4	1.00	3.88 1.82	0.47 16	0.5	0.350	0.66	1.355 2.74	29.7 0.495	3.4	1.24 2.265	33.1 0.546	36.0 28.1	(1.0)
A - 5	3.94	0.732 0.653	0.89 23	1.8	0.900	0.09	0.66 1.20	– 0.55	9.5 (6)	0.61 0.99	– 0.616	36.9 31.2	*Leakage in pore pressure line* (0.5)
A - 6	1.00	3.80 2.095	0.55 16	0.55	0.334	0.96	1.27 2.56	29.8 0.496	2.8	1.12 1.96	34.9 0.571	36.5 29.5	(1.0)
A - 7	4.10	1.46 1.31	0.895 22	1.7	0.995	0.19	1.45 2.23	– 0.65	1.4	1.43 2.185	– 0.655	36.5 29.6	*Test set up twice* (0.5)
A - 8	2.02	1.955 1.39	0.71 6	1.2	0.579	0.34	1.13 1.935	– 0.585	5.2	0.95 1.52	– 0.625	38.7 32.6	(0.5)
A - 9	1.96	2.00 1.46	0.73 16	1.4	0.560	0.34	1.12 2.00	– 0.56	2.9	1.065 1.825	– 0.584	37.1 32.2	(0.5)
A - 10	1.00	3.96 2.03	0.515 20	0.3	0.320	0.86	1.27 2.77	27.3 0.459	4.0	1.04 1.835	34.5 0.566	39.1 30.4	(1.0)
A - 11	1.00	3.93 2.23	0.57 29	0.25	0.333	0.68	1.305 2.91	26.7 0.449	4.2	1.00 1.86	32.5 0.539	37.1 30.3	(1.0)

All stress in kg/cm^2

(1) Based on cell pressure

(2) Time in hours after removal of side platens; at $\bar{\sigma}_{vm}$ for O.C. tests

(3) Vertical strain = $\Delta H/H_i$

(4) $\bar{\Phi} = \sin^{-1}(q/\bar{p})$ in degrees

(5) Nominal rate, percent vertical strain per hour

(6) Data are questionable due to possible leakage

RESULTS OF $\overline{CK_0U}$ PLANE STRAIN ACTIVE TESTS

TABLE 4 - 1

TEST NO.	STRESS HISTORY		At $(\bar{\sigma}_1/\bar{\sigma}_3) = 3.85$			At $(\bar{\sigma}_1/\bar{\sigma}_3) = 4.60$			At q_{max} or At $\bar{\sigma}_v = 0$				
	$\bar{\sigma}_{vc}$ $\bar{\sigma}_{hc}$	K_c t_c	ε %	$q/\bar{\sigma}_{1c}$	A	ε %	$q/\bar{\sigma}_{1c}$	A	CRITERIA	ε %	$q/\bar{\sigma}_{1c}$	A	$\bar{\sigma}_1/\bar{\sigma}_3$
P-1	4.51 2.35	0.52 3.8	3.4	0.205	0.96	4.0	0.22	0.96	q_{max}	6.0	0.25	0.93	5.65
P-2	3.85 1.98	0.515 15	3.5	0.22	0.91	4.2	0.24	0.90	q_{max}	5.2	0.265	0.89	5.63
P-4H	2.09 4.03	0.52 23	4.1	0.205	0.96	5.8	0.214 at q_{max}	0.96	q_{max}	5.8	0.214	0.96	4.49
P-10	3.98 1.98	0.498 21	3.8	0.17	1.05	4.7	0.175	1.06	q_{max}	7.0	0.185	1.06	5.55
P-11	3.97 2.07	0.52 22	3.1	0.18	1.04	3.5	0.19	1.05	$\bar{\sigma}_v = 0$	6	0.225	1.07	∞
P-22	4.24 1.91	0.45 32	2.5	0.163	1.01	2.8	0.173	1.02	$\bar{\sigma}_v = 0$	4.5	0.206	1.045	∞
Average without P-1 and P-2		0.50 –	3.4	0.179	1.015	4.3	0.188	1.02	–	6	0.205	1.035	–

EFFECT OF FAILURE CRITERIA ON STRENGTH PARAMETERS FROM $\overline{CK_0U}$ PLANE STRAIN PASSIVE TESTS ON NORMALLY CONSOLIDATED SAMPLES

TABLE 4-2

TEST NO.	STRESS HISTORY			At $(\bar{\sigma}_1/\bar{\sigma}_3) \le 4.60$					At q_{max} or $\bar{\sigma}_v = 0$			ω_i % ω_f %	REMARKS (Strain rate)$^{(5)}$	
	OCR	$\bar{\sigma}_{vc}$ $\bar{\sigma}_{hc}$	$K_c^{(1)}$ $t_c^{(2)}$	ε % $^{(3)}$	$\frac{q}{\bar{\sigma}_{1c}}$	A	$\frac{q}{\bar{p}}$	$\bar{\phi}_u^{(4)}$ $q/\bar{p}$	ε % $^{(3)}$	$\frac{q}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_1}{\bar{\sigma}_3}$			
P-1	1.00	4.51 2.35	0.52 3.8	4.0	0.220	0.96	0.995 1.55	40 0.643	6.0	0.25	5.65	34.7 27.0	t_c very low	(1.0)
P-2	1.00	3.85 1.98	0.515 15	4.2	0.240	0.90	0.925 1.44	40 0.643	5.2	0.265	5.63	34.2 27.8	Δu may be too low	(1.0)
P-4H	1.00	2.09 4.03	0.52 23	5.8	0.214	0.96	0.865 1355	39.5 0.636	5.8	0.214	4.49	33.6 26.3		(1.0)
P-10	1.00	3.98 1.98	0.498 21	4.7	0.175	1.06	0.696 1.08	40 0.643	7.0	0.185	5.55	43.4 30.9		(1.0)
P-11	1.00	3.97 2.07	0.52 22	3.5	0.190	1.05	0.755 1.17	40 0.643	6.0	0.225	∞	37.9 30.8		(0.5)
P-22	1.00	4.24 1.91	0.45 32	2.8	0.173	1.02	0.735 1.14	40 0.643	45	0.206	∞	35.5 30.0		(0.5)

All stresses in kg/cm^2

(1) Based on cell pressure

(2) Time in hours after removal of side platens

(3) Vertical strain = $\Delta H/H_i$

(4) $\bar{\phi} = \sin^{-1}(q/\bar{p})$ in degrees

(5) Nominal rate, percent vertical strain per hour

RESULTS OF $\overline{CK_oU}$ PLANE STRAIN PASSIVE TESTS ON NORMALLY CONSOLIDATED SAMPLES

TABLE 4-3

TEST	STRESS HISTORY			AT UNDRAINED FAILURE							(3) REMARKS
NO.	OCR	$\bar{\sigma}_{vc}$ $\bar{\sigma}_{hc}$	(1) K_c	(2) ε %	$\frac{q}{\bar{\sigma}_{1c}}$	A	$\frac{q}{\bar{p}}$	$\bar{\sigma}_1/\bar{\sigma}_3$	FAILURE CRITERIA	ω_i % ω_f %	
P-3	4.25	0.908 0.77	0.85	11.5	0.72	—	—	—	At measured q_{max} adjusted for necking	36.5 29.7	Pore pressure leak so $\bar{\sigma}$ no good
P-5H	4.00	0.796 1.001	0.80	5.4	0.85 ?	0.63	0.85 1.19	6.00	At measured q_{max} but may have excessive friction	33.9 —	Initial σ-ε no good due to friction ?
P-7	4.15	1.444 1.288	0.893	2.0	0.835 ?	0.38	1.21 1.69	6.00	Selected at $\bar{\sigma}_1/\bar{\sigma}_3 = 6.0$ but q still too high	35.2 —	Sample set up twice so ω_f too low. Initial σ-ε erratic
P-9H (4)	2.00	1.39 2.09	0.665	6.5	0.39	0.72	0.82 1.22	5.10	At measured q_{max}	38.2 30.7	σ-ε erratic at $\varepsilon > 5$ %
P-12H (4)	3.96	0.85 1.01	0.84	6.5	0.64	0.50	0.645 0.91	5.87	At measured q_{max}	38.5 31.9	Good test
P-13 (4)	2.01	1.98 1.40	0.708	3.0	0.36	0.84	0.715 1.01	5.80	Selected at $\bar{\sigma}_1/\bar{\sigma}_3 = 5.80$	36.0 31.1	$q/\bar{\sigma}_{1c}$ increased to 0.41 at larger ε
P-23	2.21	2.716 2.158	0.795	2.1	0.385	0.86	1.045 1.48	5.80	Selected at $\bar{\sigma}_1/\bar{\sigma}_3 = 5.8$	35.8 30.4	$q/\bar{\sigma}_{1c} = 0.425$ at $\varepsilon = 4.4$ when $\bar{\sigma}_v = 0$

All stresses in kg/cm^2

(1) Based on cell pressure

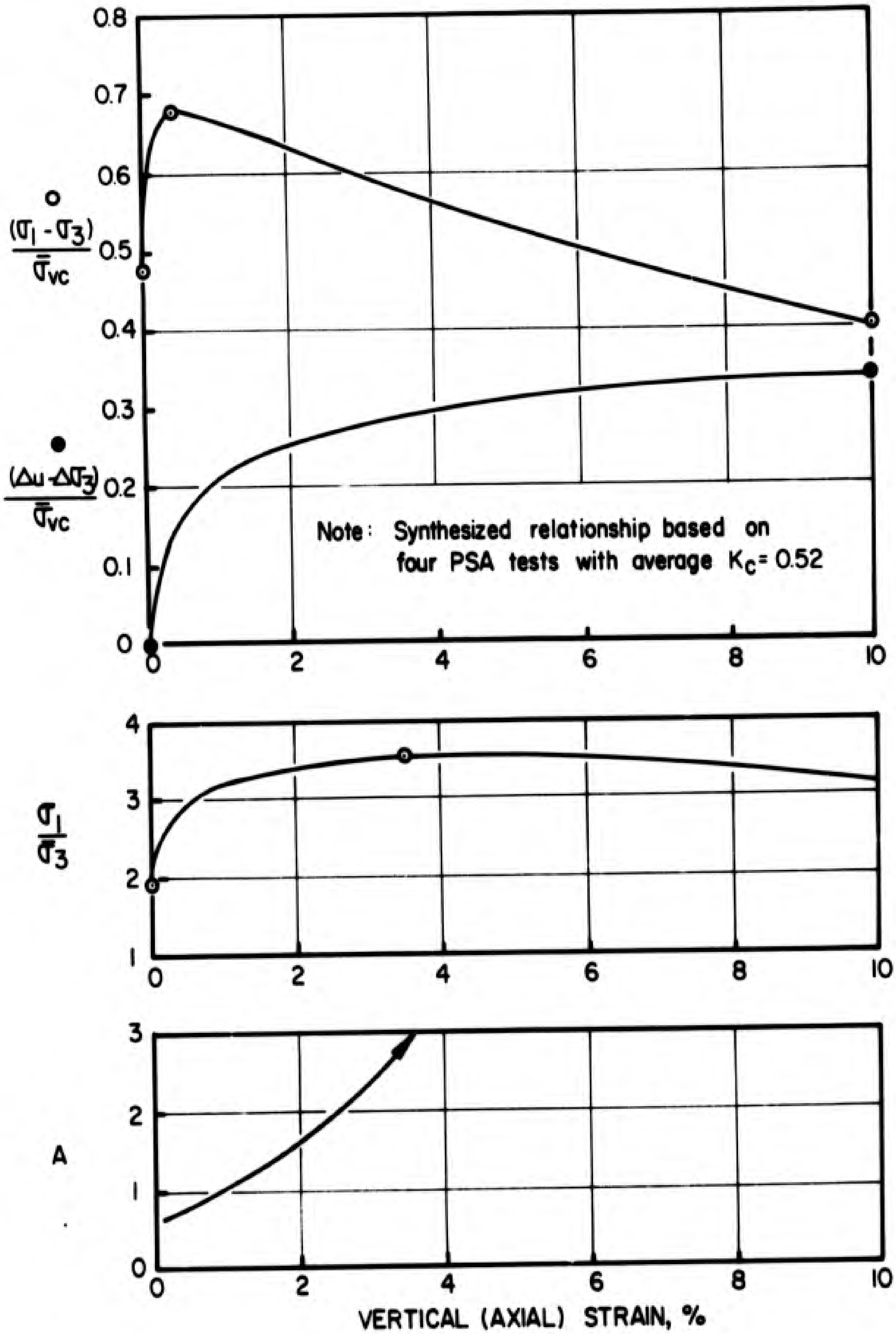
(2) Vertical strain

(3) Nominal strain rate = 0.5 %/hr.

(4) See Appendix D and E for detailed test data

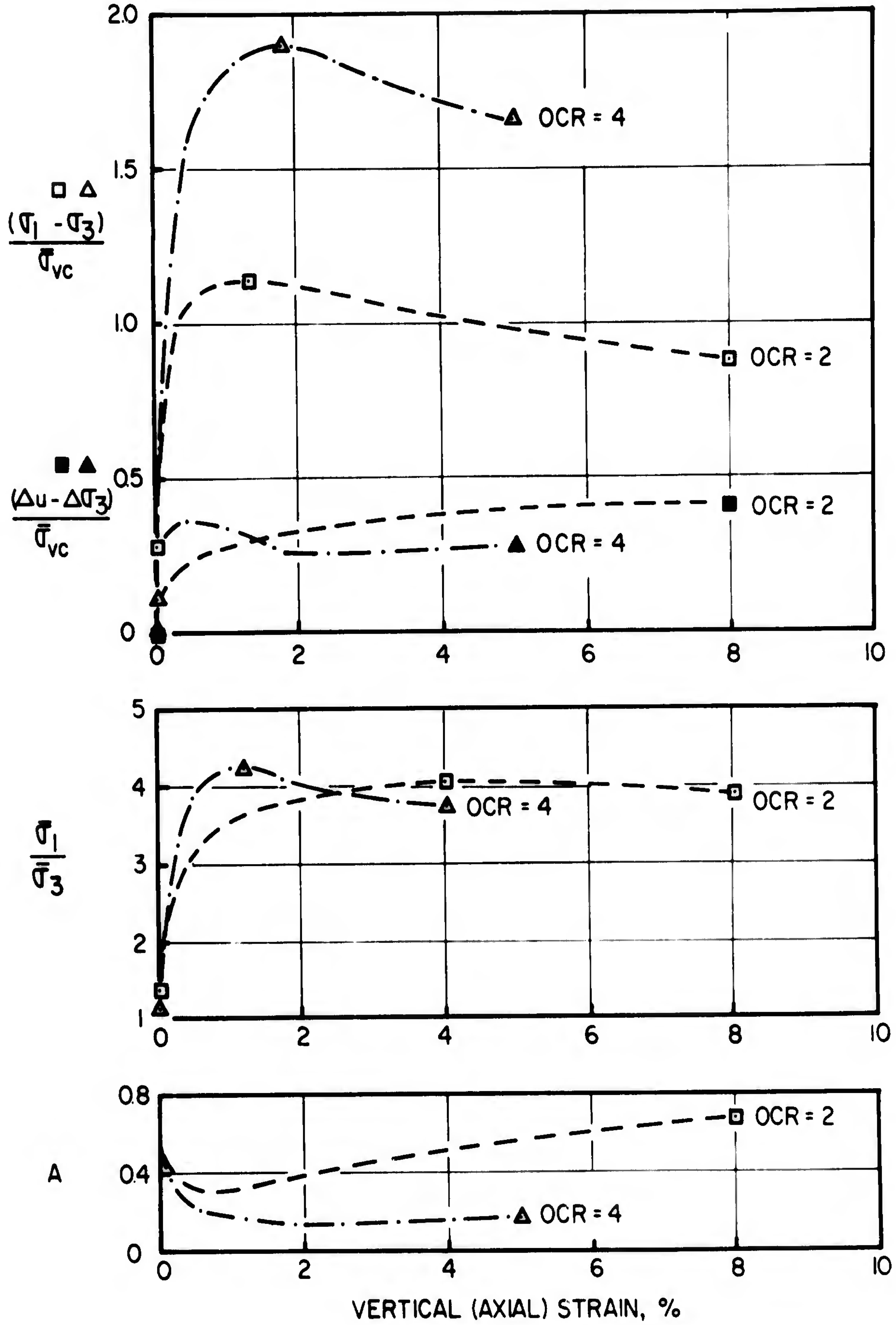
RESULTS OF $\overline{CK_oU}$ PLANE STRAIN PASSIVE TESTS ON OVERCONSOLIDATED SAMPLES

TABLE 4 - 4



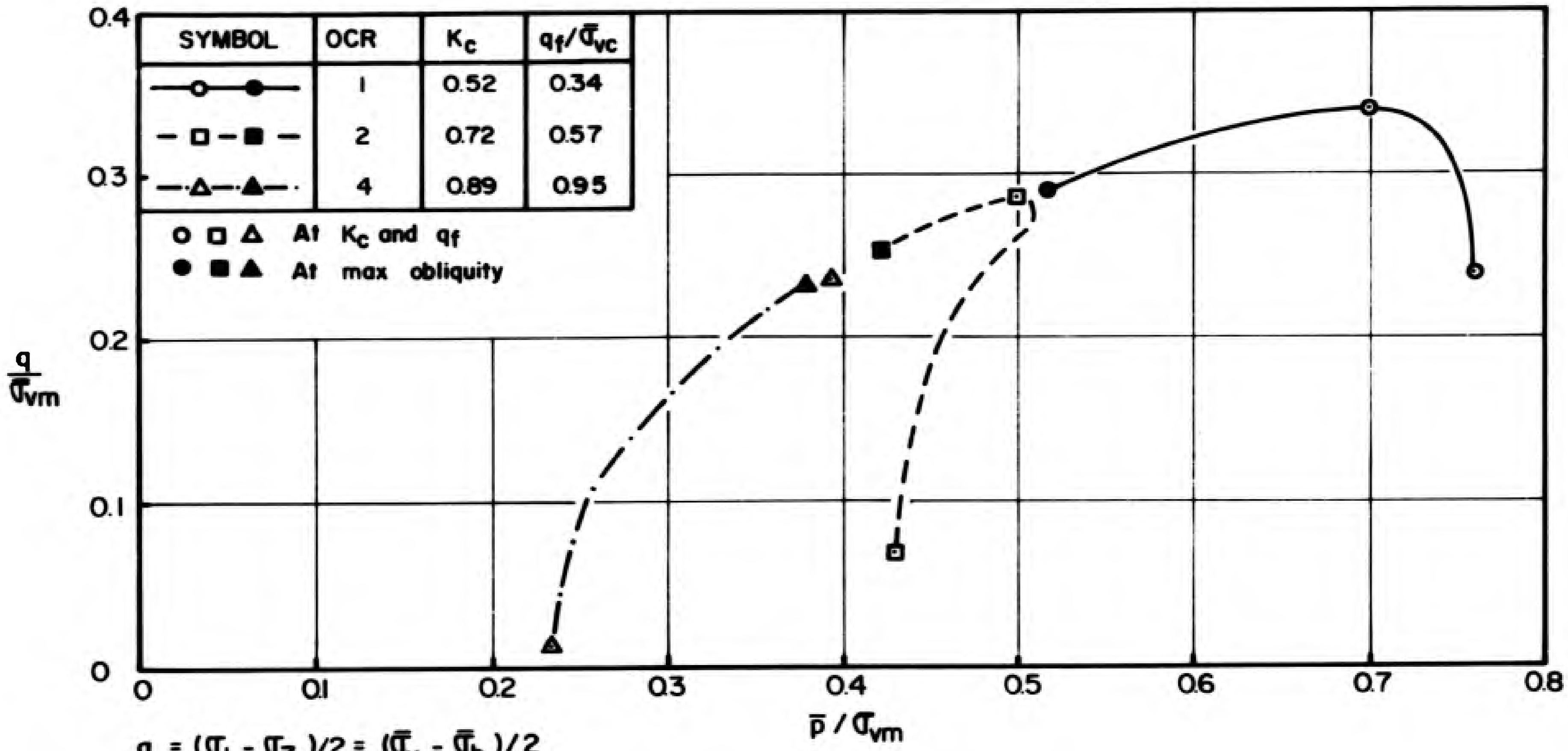
STRESS VS STRAIN FOR $\overline{CK_0U}$ PLANE STRAIN ACTIVE TESTS, OCR = 1

FIGURE 4 - 1



STRESS VS STRAIN FOR $\overline{CK_0U}$ PLANE STRAIN ACTIVE TESTS, OCR = 2 AND 4

FIGURE 4 - 2

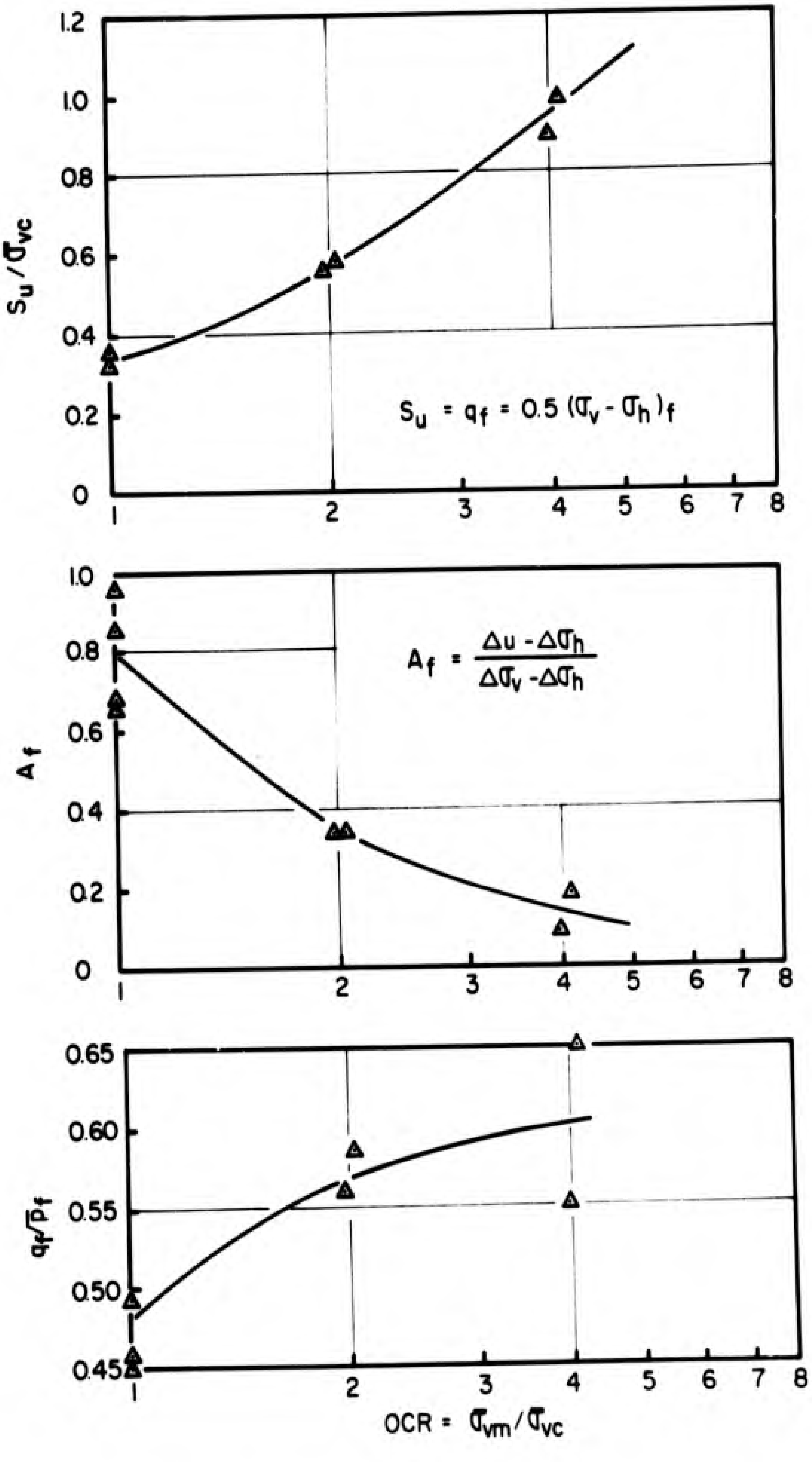


$q = (\sigma_1 - \sigma_3)/2 = (\bar{\sigma}_v - \bar{\sigma}_h)/2$

$\bar{p} = (\bar{\sigma}_1 + \bar{\sigma}_3)/2 = (\bar{\sigma}_v + \bar{\sigma}_h)/2$

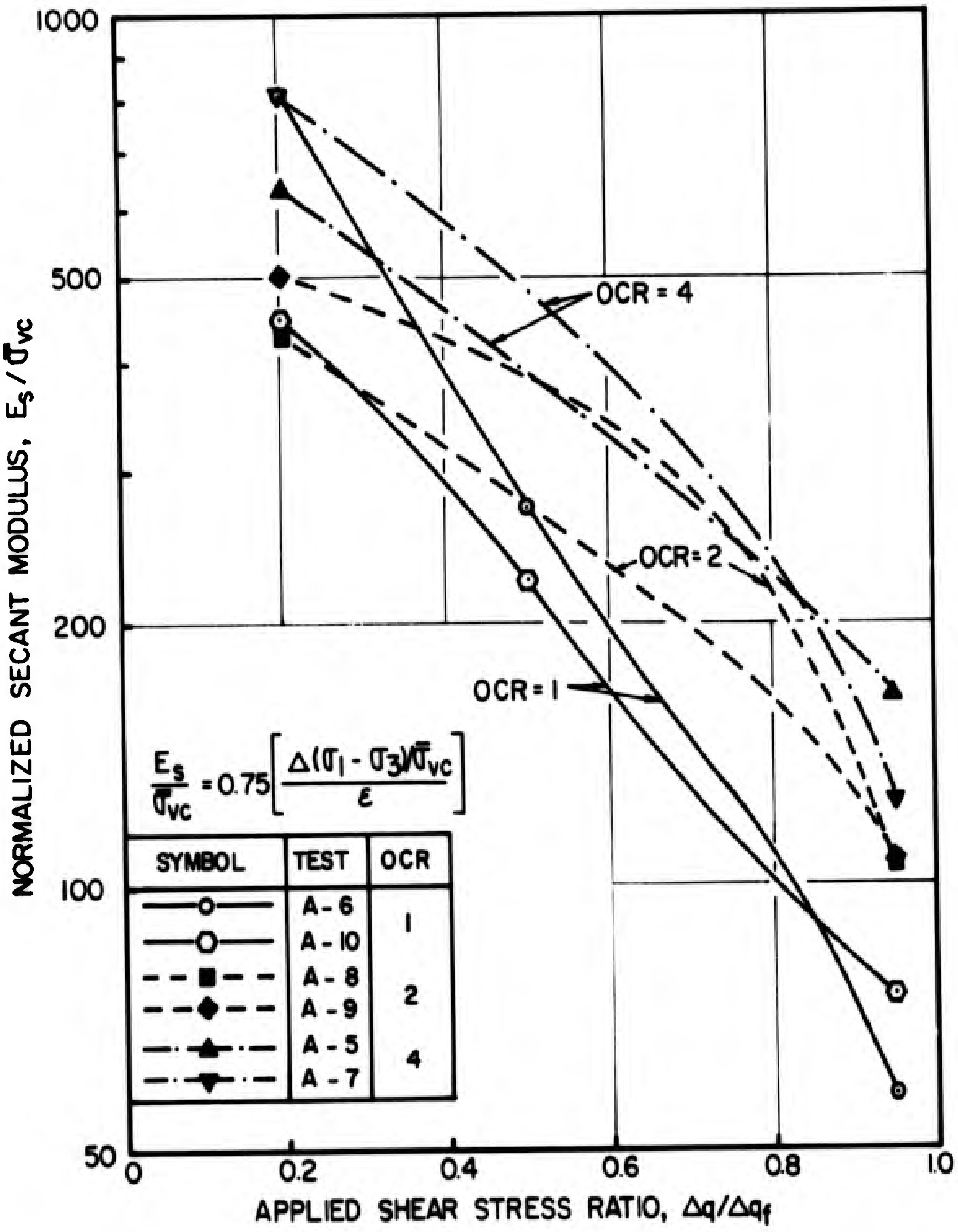
NORMALIZED STRESS PATHS FOR $\overline{CK_0U}$ PLANE STRAIN ACTIVE TESTS, OCR = 1, 2 AND 4

FIGURE 4-3



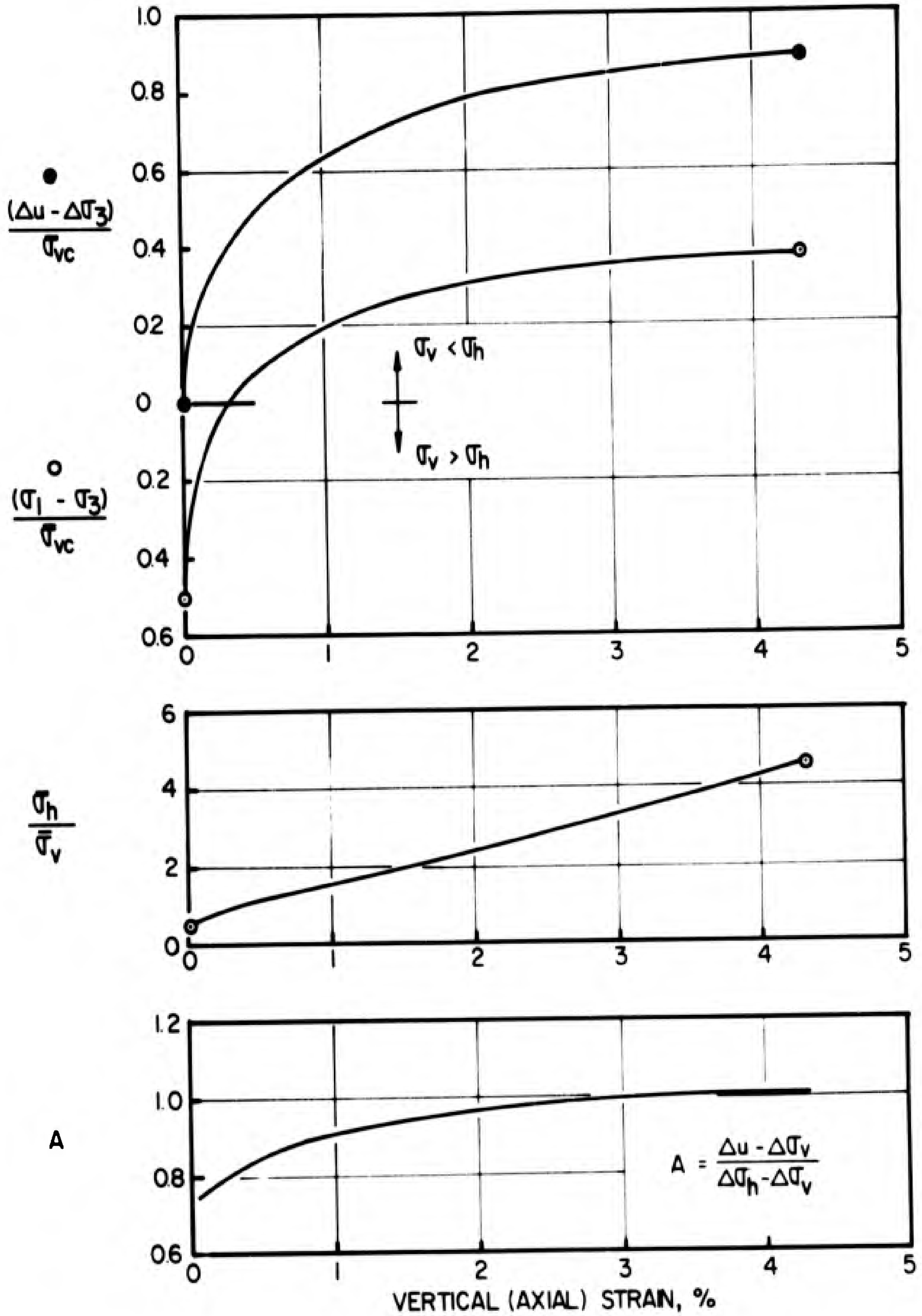
UNDRAINED STRENGTH PARAMETERS VS OCR FOR $\overline{CK_oU}$ PLANE STRAIN ACTIVE TESTS

FIGURE 4-4



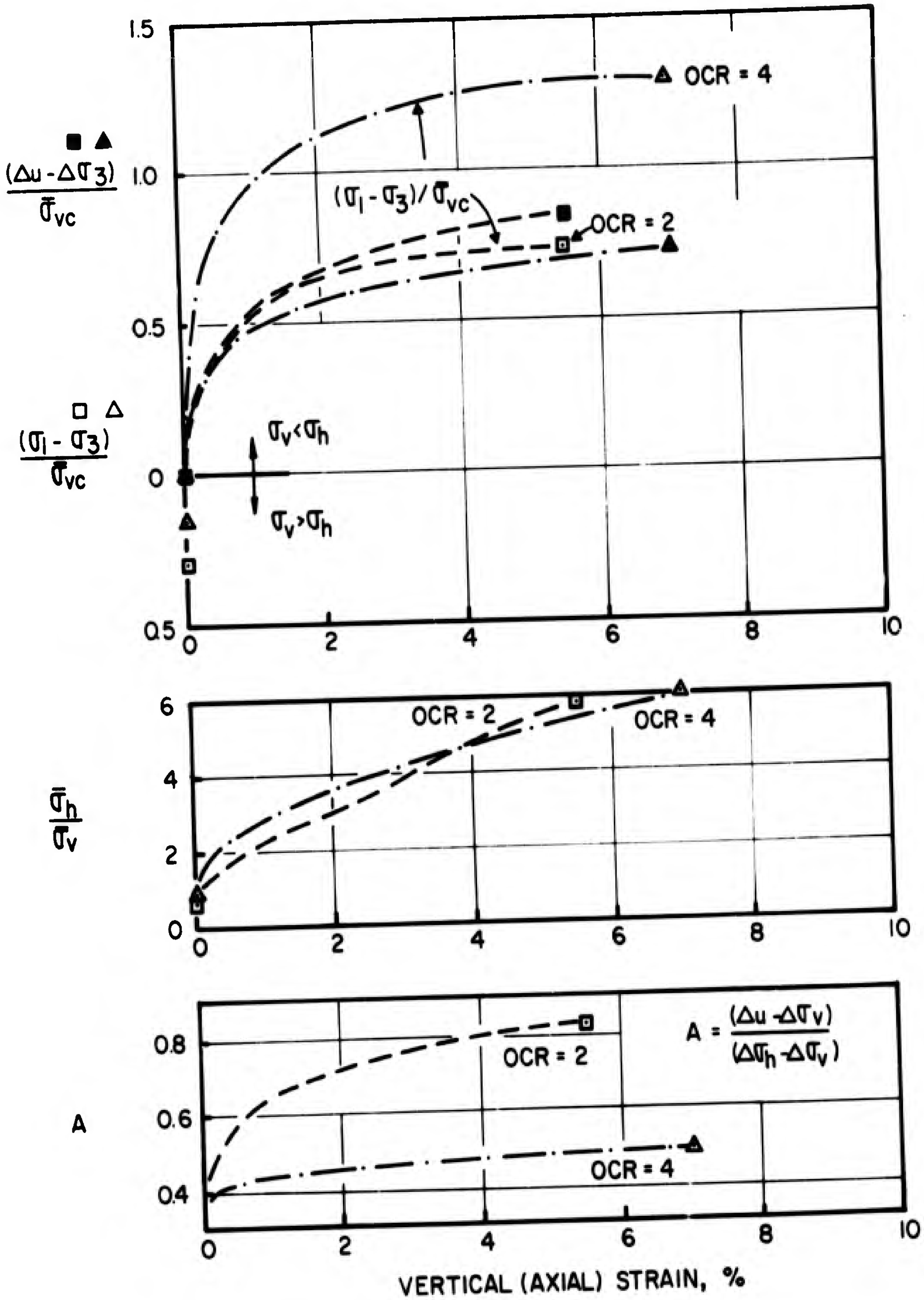
NORMALIZED SECANT MODULUS VS APPLIED SHEAR STRESS RATIO FOR $\overline{CK_0U}$ PLANE STRAIN ACTIVE TESTS

FIGURE 4-5



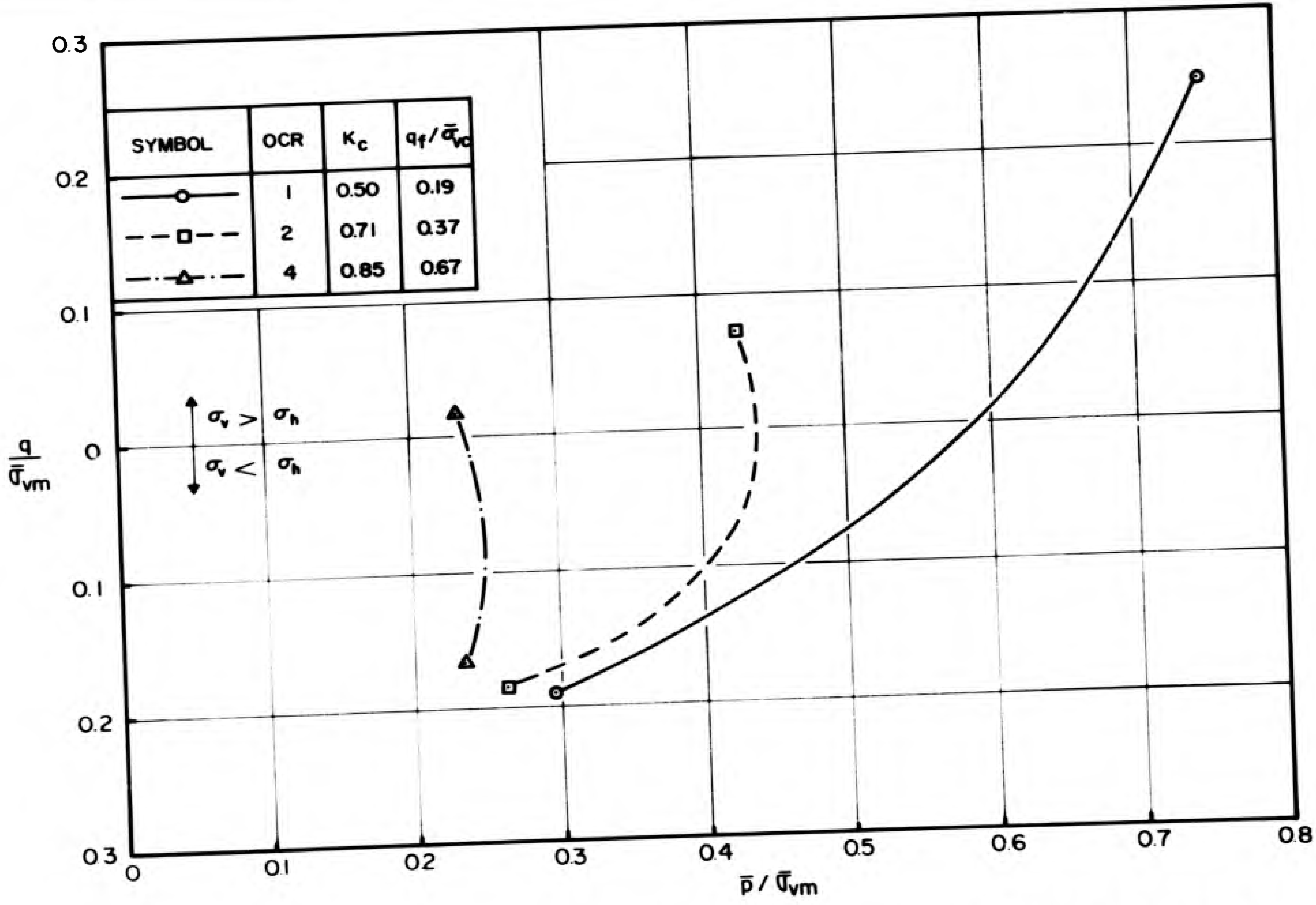
STRESS VS STRAIN FOR $\overline{CK_0U}$ PLANE STRAIN PASSIVE TESTS, OCR = 1

FIGURE 4-6



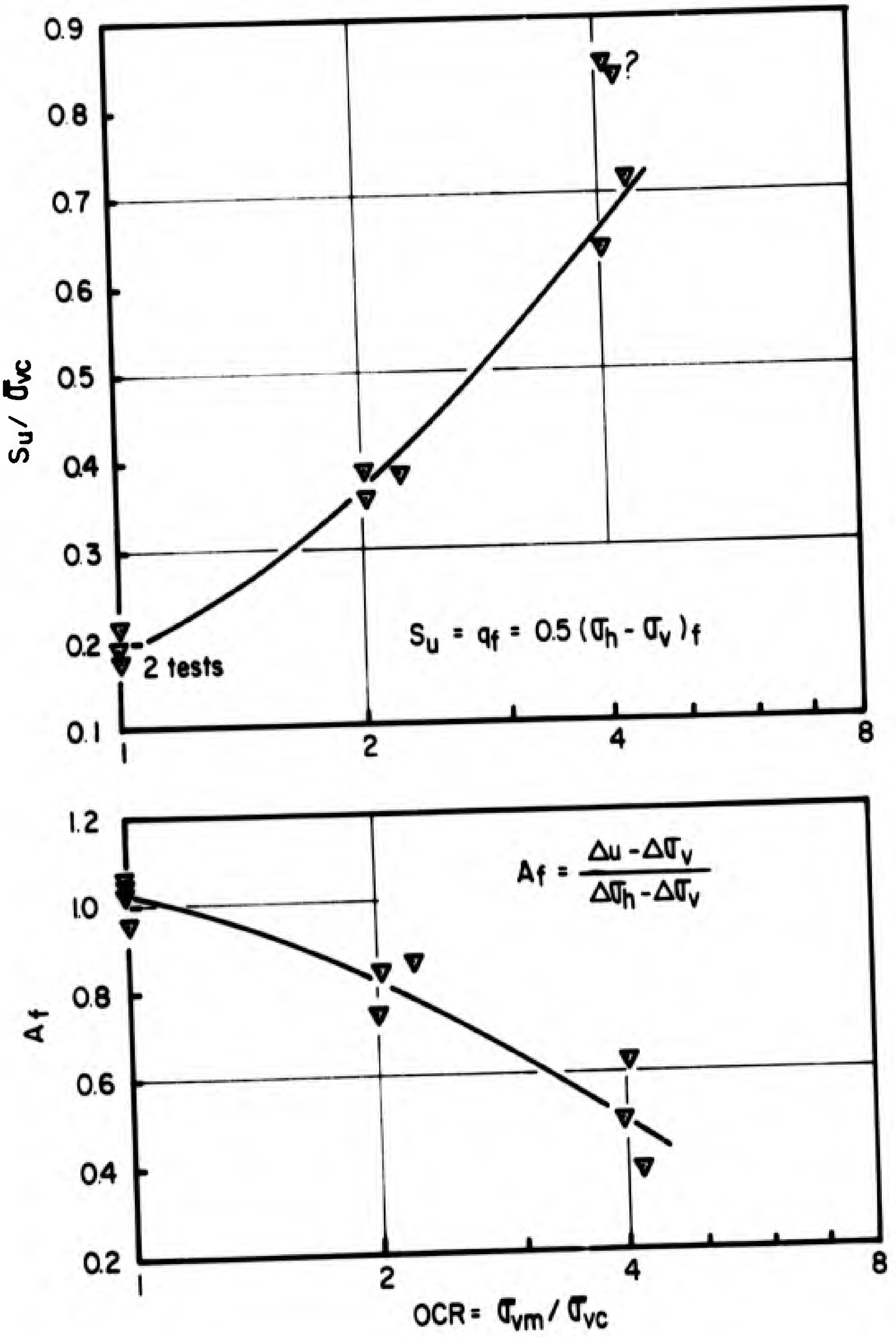
STRESS VS STRAIN FOR $\overline{CK_0U}$ PLANE STRAIN PASSIVE TESTS, OCR = 2 AND 4

FIGURE 4-7



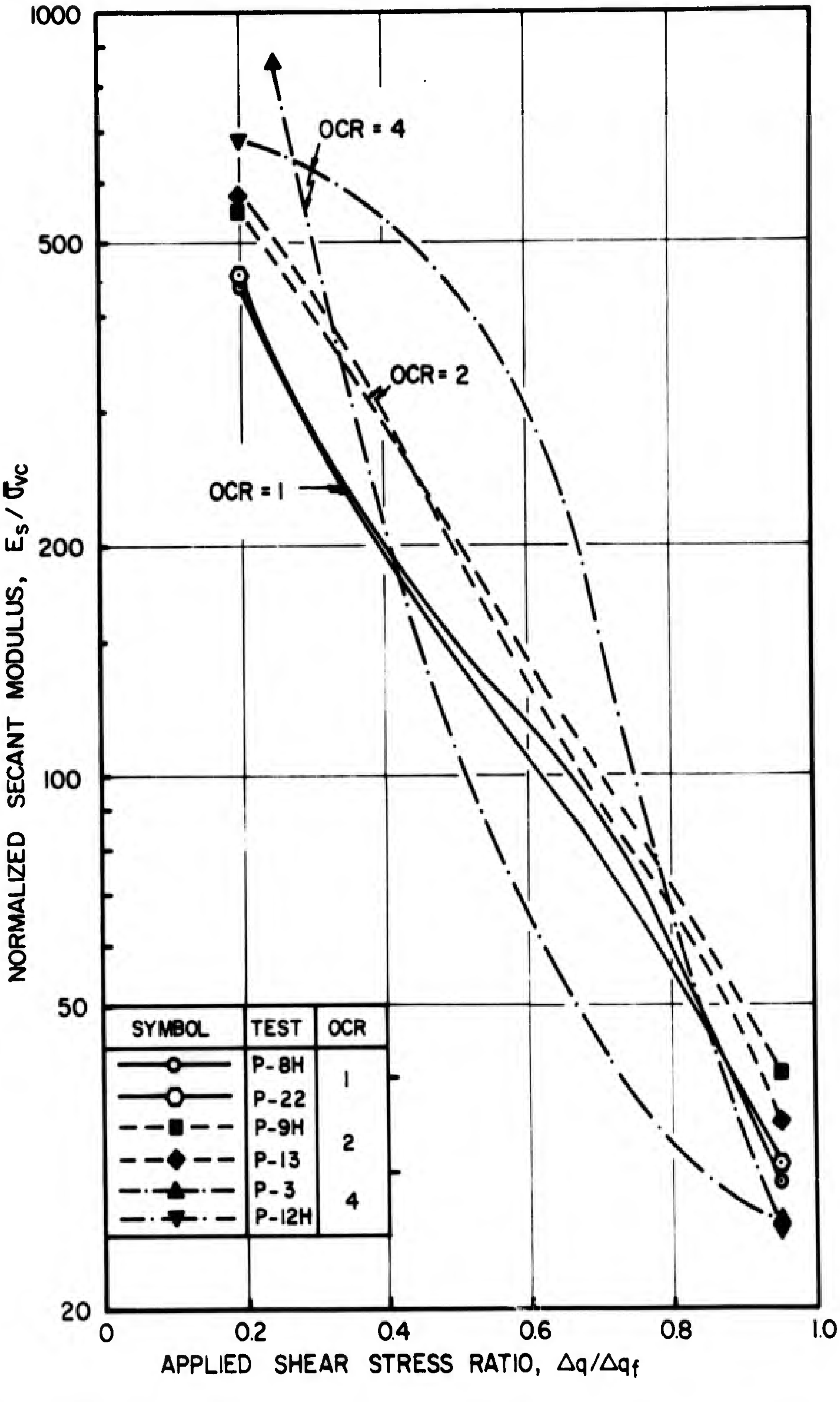
NORMALIZED STRESS PATHS FOR $\overline{CK_0U}$ PLANE STRAIN PASSIVE TESTS, OCR = 1, 2 AND 4

FIGURE 4-8



UNDRAINED STRENGTH PARAMETERS VS OCR FOR $\overline{CK_oU}$ PLANE STRAIN PASSIVE TESTS

FIGURE 4 - 9



NORMALIZED SECANT MODULUS VS APPLIED SHEAR STRESS RATIO FOR $\overline{CK_0U}$ PLANE STRAIN PASSIVE TESTS

FIGURE 4-10

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5. DISCUSSION AND COMPARISON OF RESULTS

5.1 INTRODUCTION

In plane strain active tests, the major principal stress always acts in the vertical direction (for $K_o \leq 1$), and thus there is no rotation of the principal stresses during shear. This stress system duplicates conditions under the centerline of a strip load or behind a retaining wall with an active state of stress. In plane strain passive tests, the major principal stress at failure acts in the horizontal direction, and thus the principal stresses have rotated through 90 degrees. This stress system duplicates conditions in the "passive" wedge of a strip load or behind a retaining wall with a passive state of stress. The two stress states represented by the active and passive conditions will generally represent extreme cases for most plane strain stability problems. Thus the results of active and passive tests will usually yield the largest degree of anisotropic strength behavior. This section will summarize and compare the results of the active and passive tests on Boston Blue Clay at OCR values of one, two and four.

Plane strain test equipment and procedures are obviously more complicated than those of conventional triaxial tests. Comparisons of plane strain and triaxial data are needed for a variety of soils and stress histories in order to ascertain the limitations of conventional triaxial tests. For normally consolidated Boston Blue Clay, a detailed comparison will be made between: $\overline{CK_oU}$ plane strain active tests and triaxial compression tests and between $\overline{CK_oU}$ plane strain passive tests and triaxial extension tests. Finally, $\overline{CK_oU}$ plane strain active tests will be compared to $\overline{CK_oU}$ and $\overline{CIU}$ triaxial compression tests as a function of overconsolidation ratio.

The above findings with Boston Blue Clay will be compared to triaxial and plane strain data obtained by others on saturated clays. These data are summarized in the next section.

5.2 RESULTS OF PLANE STRAIN AND TRIAXIAL TESTS ON SATURATED CLAYS FROM THE LITERATURE

Duncan and Seed (1965, 1966) performed $\overline{CK_oU}$ plane strain active and passive tests on undisturbed samples of the highly plastic San Francisco Bay Mud. These data, and the results of companion $\overline{CU}$ triaxial compression tests, are summarized in Table 5-1. The plane strain apparatus was similar to the M.I.T. device, except that passive tests had to employ horizontal K_o consolidation, followed by vertical loading.

Henkel and Wade (1966) ran a series of $\overline{CK_oU}$ plane strain active tests on remolded samples of the Weald Clay and compared the results to $\overline{CIU}$ and $\overline{CK_oU}$ triaxial compression tests. Table 5-1 also summarizes these data. The plane strain apparatus used samples 4 in. high, 2 in. wide and 16 in. long.

Lee and Shubeck (1971) performed an extensive series of $\overline{CAU}$ plane strain active tests on two compacted clays over a wide range of consolidation stresses with a device similar to the Berkeley apparatus. The two clays were:

Compacted Kaolinite (w_L = 44%, w_p = 21%) with
  static compaction to optimum + 5%
Compacted Higgins Clay (w_L = 38%, w_p = 21%) with
  static compaction to optimum ± 5%.

The results were compared to $\overline{CIU}$ and $\overline{CAU}$ triaxial compression tests. For $\overline{CAU}$ tests with K_c = 0.5, the plane strain active tests showed the following results compared to the triaxial compression tests:

(1) Same undrained shear strength, value of A_f, and effective stress envelope

(2) Lower strain at failure and more strain softening (more brittle type stress-strain curve).

Shibata and Karube (1965, 1967) ran $\overline{\text{CIU}}$ and some $\overline{\text{CAU}}$ "triaxial" tests with varying intermediate principal stress on normally consolidated samples of remolded Osaka alluvial clay (w_L = 64-69%, w_p = 20-27.5%). The 1965 data, restricted to $\overline{\text{CIU}}$ tests, showed increased excess pore pressures and a lower strain at failure with increasing $(\sigma_2 - \sigma_3)/(\sigma_1 - \sigma_3)$; the maximum undrained strength occurred at an intermediate value of σ_2. The 1967 data showed that plane strain conditions increased the friction angle at $(\sigma_1 - \sigma_3)_{max}$, relative to triaxial compression tests, for isotropic consolidation, but had little effect after anisotropic consolidation.

Lee (1970) reviewed the extensive data that exist comparing drained plane strain active and triaxial compression tests on cohesionless soils. Plane strain conditions generally produced the following effects relative to triaxial compression:

(1) Increased friction angle, the effect being more pronounced as the relative density increased.

(2) Reduced strain at failure and a much more brittle type stress-strain behavior. The larger strain softening effect was accompanied by formation of a failure plane.

5.3 COMPARISON OF $\overline{\text{CK}_\text{o}\text{U}}$ PLANE STRAIN ACTIVE AND PASSIVE TESTS ON BOSTON BLUE CLAY

The various strength parameters and other pertinent information are plotted versus overconsolidation ratio in

Figure 5-1. Average values are summarized in Table 5-2. These data, and the results presented in Section 4, show that rotation of principal planes through 90 degrees causes a substantial change in the stress-strain-strength behavior of Boston Blue Clay at overconsolidation ratios from one to four. Failure in passive shear, relative to an active failure:

(1) Reduces the undrained strength by 30 to 44 percent, the effect being most pronounced with normally consolidated clay. The ratio

$$K_s = \frac{s_u \text{ (Passive)}}{s_u \text{ (Active)}} = \frac{s_u(H)}{s_u(v)}$$

increases from 0.56 at OCR = 1 to 0.705 at OCR = 4.

(2) Greatly increases the strain at failure. The active tests failed at $\varepsilon = 0.4$ to 1.8 percent, while ε_f for the passive tests was 4 to 7 percent.

(3) Increases Skempton's pore pressure parameter A at failure, primarily because of the large difference in the strain at failure. If compared at equal strains, A for passive tests is less than that for active tests with normally consolidated clay; the reverse is true for overconsolidated clay.

The only other data comparing active and passive tests are that by Duncan and Seed (1966) for normally consolidated undisturbed San Francisco Bay Mud (see Table 5-1). This much more plastic clay showed less strength anisotropy (K_s = 0.76 vs 0.56 for Boston Blue Clay). As with Boston Blue Clay, the passive tests showed a larger strain at failure (10.2 vs 3.6 percent); but in contrast both A_f and $\bar{\phi}$ were decreased.

The effect of rotation of principal planes on secant modulus is complex, as summarized below:

		$E_s/\bar{\sigma}_{vc}$		E_s/s_u	
$\Delta q/\Delta q_f$	OCR	Active	Passive	Active	Passive
	1	650	450	2000	2500
0.2	2	470?	550	825?	1500
	4	700	750	750	1100
	1	250	150	750	800
0.5	2	340	200	600	535
	4	450	230	475	350

However, if one compares values of $E_s/\bar{\sigma}_{vc}$ at the same strain as shown in Figure 5-2 for normally consolidated clay, passive tests yield much higher modulii.

5.4 COMPARISON OF $\overline{CK_oU}$ PLANE STRAIN AND TRIAXIAL TESTS ON BOSTON BLUE CLAY

5.4.1 Normally Consolidated Boston Blue Clay

This section compares the results of plane strain and triaxial tests on normally consolidated samples. The appropriate pairs to compare are:

(1) Plane strain active versus triaxial compression where $\sigma_{1f} = \sigma_{vf}$ and there is no rotation of the principal planes.

(2) Plane strain passive versus triaxial extension where $\sigma_{1f} = \sigma_{hf}$ and there is a 90 degree rotation of the principal planes.

In both cases, the only variable is the value of the intermediate principal stress, σ_2.

(a) Plane strain active versus triaxial compression

Stress-strain curves are compared in Figure 5-3 and the stress paths in Figure 5-5; Table 5-3 summarizes consolidation and failure conditions for these tests. The triaxial compression data were obtained from Ladd and Varallyay (1965) and several other tests performed since then (Braathen, 1966, Guertin, 1967, and Research in Earth Physics).

Plane strain active conditions, compared to triaxial compression, produce the following:

(1) A slight increase in $s_u/\bar{\sigma}_{vc}$, although the difference is of little practical significance. This is in agreement with the data on undisturbed San Francisco Bay Mud, remolded Weald Clay (see Table 5-1), and remolded Osaka Clay.

(2) An increase in both A_f and $\bar{\phi}$ at undrained failure. A higher failure envelope was also obtained by others (Table 5-1), whereas there was no change in A_f for the Bay Mud and a decrease in A_f for the Weald Clay. Because A changes rapidly with strain in both tests (see Figure 5-3), one might expect variable trends in A_f depending on the change in strain at failure.

(3) A very slight increase in the maximum obliquity, although it occurs at a much lower strain, as happened for the Weald Clay.

(4) An increase in the excess pore pressures at lower strains, as occurred with the remolded Weald and Osaka clays. The A parameter starts off with a value of about one half compared to one third for triaxial compression, as would be expected for an elastic medium.

(5) An increased rate of strain softening after failure, perhaps due to the formation of a failure plane. Plane strain tests on the Weald Clay also produced more strain softening.

It is difficult to assess differences in Young's modulus prior to failure because of the very small strains at failure. Based on the limited data plotted in Figure 5-6, one concludes that triaxial compression yields a somewhat higher value of Young's modulus. However, the difference is small and will generally be masked by scatter in the data.

(b) Plane strain passive versus triaxial extension

Stress-strain curves are compared in Figure 5-4 and the stress paths in Figure 5-5; Table 5-3 summarizes consolidation and failure conditions for these tests. The triaxial extension data are the strain controlled tests from Ladd and Varallyay (1965).

Plane strain passive tests yield a significantly higher value of $s_u/\bar{\sigma}_{vc}$, primarily because of a lower A_f. One can not reliably compare failure envelopes because of necking in both tests and "friction" in the passive tests. The passive test also failed at a much lower strain.

The stress-strain characteristics from both tests appear to be almost identical up to about one percent strain, except for the lower A parameter of the plane strain tests.(1) At larger strains, the larger value of σ_2 in the extension tests causes a greater reduction in effective stress, and hence a lower undrained strength.

---

(1) Note that K_c was somewhat higher in the extension tests, thereby causing a lower excess pore pressure. For the same value of K_c the extension tests would therefore exhibit a greater $(\Delta u-\Delta\sigma_3)/\bar{\sigma}_{vc}$ than the plane strain passive tests.

The normalized secant modulus data in Figure 5-6 again show a slightly higher value of Young's modulus for the triaxial tests, except near failure. However, the difference is very small.

There are no similar data (to the authors' knowledge) on other clays that can be compared to the trends obtained with Boston Blue Clay.

5.4.2 Overconsolidated Boston Blue Clay

The comparison of plane strain and triaxial tests on overconsolidated Boston Blue Clay is by necessity restricted to triaxial compression tests. Moreover, most of the triaxial compression tests employed isotropic consolidation stresses.

Figure 5-7 plots $s_u/\bar{\sigma}_{vc}$ and A_f versus OCR for $\overline{CK_oU}$ plane strain active and triaxial compression tests. The range in $s_u/\bar{\sigma}_{vc}$ values from $\overline{CIUC}$ tests has been added for comparison*. Plane strain conditions continue to lead to a slight increase in $s_u/\bar{\sigma}_{vc}$ with overconsolidated clay, while the differences in A_f appear to diminish. At an OCR of four, the strain at failure for the active tests was 1.7 - 1.8 percent, while that for the triaxial compression tests equalled 2.5 ± 1 percent. The decrease in ε_f agrees with the trends obtained by Lee and Shubeck (1971) on compacted clay.

5.4.3 Discussion

The preceding data show that the plane strain tests generally yielded stress-strain-strength characteristics that are either in close agreement with those measured in

* For OCR=1, K=1 consolidation yields a lower $s_u/\bar{\sigma}_c$ with higher values of A_f and $\bar{\Phi}_u$ than K_o consolidation (Ladd and Varallyay, 1965).

corresponding triaxial tests, or differ as would be expected based on theoretical considerations. Moreover, differences in behavior between the active and triaxial compression tests generally agreed with the trends obtained by others. These two facts suggest that the M.I.T. plane strain apparatus yields fairly reliable data, or at least data as reliable as obtained by others.

If it is concluded that the plane strain data are reliable, then one can also conclude that:

(1) Triaxial compression tests (after K_o consolidation) yield stress-strain-strength data that are practically identical to plane strain active conditions for undrained shear up to failure.

(2) Triaxial extension tests (after K_o consolidation) yield an underestimate of undrained strength for plane strain passive condition, because the A parameter is too large. However, initial stress difference versus axial strain data are in close agreement.

SOIL DESCRIPTION	TYPE OF TEST	K_c	At $(\sigma_1 - \sigma_3)_{max}$				REMARKS	REFERENCE
			ε_a %	$\frac{q_f}{\bar{\sigma}_{1c}}$	A_f	$\bar{\Phi}_u{}^\circ$		
Undisturbed San Francisco Bay mud $\omega_N = 90\%$ $\omega_L = 88\%$ $\omega_p = 43\%$ $S_t = 8$	$\overline{CIUC}$	1.0	11.6	0.33	1.05	34.5	3 tests	*Duncan and Seed (1965) and (1966)*
	$\overline{CK_oUC}$	0.54	6.2	0.35	1.11	34.3	1 test	
	$\overline{CK_oU}PSA$	0.50	3.6	0.37	1.12	38	6 tests	
	$\overline{CK_oU}PSP^{(3)}$	0.42 $\pm$.05	10.2	0.28	0.70	35	7 tests	
	$\overline{C(1/K_o)U}RC^{(4)}$	1.54	12.9	0.29	0.82	34.5	1 test	
Remolded Weald Clay $\omega_i = 34\%$ $\omega_L = 46\%$ $\omega_p = 20\%$	$\overline{CIUC}$	1.00	-	0.315			For $\bar{\sigma}_{1c} = 60-130$psi PSA showed: $\bar{\sigma}_{2f}/\bar{p}_f = 0.8$	*Henkel and Wade (1966)*
	$\overline{CK_oUC}$	0.59	6 $\pm$	0.26	2.0	$25.9^{(1)}$		
	$\overline{CK_oU}PSA$	0.58	2 $\pm$	0.28	1.7	$27.1^{(2)}$		

(1) Increased to 26.2° at maximum obliquity
(2) " " 27.4° " " "
(3) Employed horizontal K_o consolidation
(4) Consolidated with $\bar{\sigma}_h / \bar{\sigma}_v = 1.54$, followed by failure in triaxial compression.

COMPARISON OF CONSOLIDATED-UNDRAINED PLANE STRAIN AND TRIAXIAL TESTS ON NORMALLY CONSOLIDATED CLAYS

TABLE 5 - 1

OCR	TYPE OF TEST	K_c	At $(\bar\sigma_1 - \bar\sigma_3)_{max}$				At $(\bar\sigma_1 / \bar\sigma_3)_{max}$				REMARKS
			ε %	$q/\bar\sigma_{vc}$	A	ϕ or $q/\bar p$	ε %	$q/\bar\sigma_{vc}$	ϕ or $q/\bar p$	$\bar\sigma_2/\bar p$	
1	Active	0.52 (±.05)	0.4 (±.15)	0.34 (.32-.35)	0.8 (±.15)	29° (27-30)	3.5 (±1.0)	0.29 (±.03)	34° (±1)	0.74 (±.05)	Based on 4 tests
	Passive	0.50 (.45-.52)	4.3 (±1.5)	0.19 (.175-.215)	1.015 (±.05)	40° (Criteria)	Assumed to be the same as at $(\bar\sigma_1 - \bar\sigma_3)_{max}$			0.92 (±.13)	Based on 4 tests and $\bar\sigma_1/\bar\sigma_3$ = 4.60 failure criteria
2	Active	0.72 (±.01)	1.3 (±.1)	0.57 (±.01)	0.34 (±0)	0.57 (±.01)	4 (±1)	0.51 (±.025)	0.605 (±.02)	—	Average from 2 good tests
	Passive	0.71 (.66-.80)	5.5 Estimat.	0.37 (.36-.39)	0.82 (.72-.86)	0.707 (Criteria)	—	—	—	—	Based on 3 tests and $\bar\sigma_1/\bar\sigma_3$ = 5.80 failure criteria
4	Active	0.89 (±0)	1.8 (±0)	0.95 (±.005)	0.14 (±.05)	0.60 (±.05)	1.3 (Est.)	0.94 (.84-.98)	0.62 (.62-.65)	0.65 (±.02)	Based on 2 tests but A-7 judged more reliable
	Passive	0.85 (.80-.89)	7 Est.	0.67 (.64-.72)	0.49 (±.13)	0.715 (Criteria)	—	—	—	—	Based mainly on 2 tests, especially P-12 H

COMPARISON OF $\overline{CK_oU}$ PLANE STRAIN ACTIVE AND PASSIVE TESTS ON BOSTON BLUE CLAY

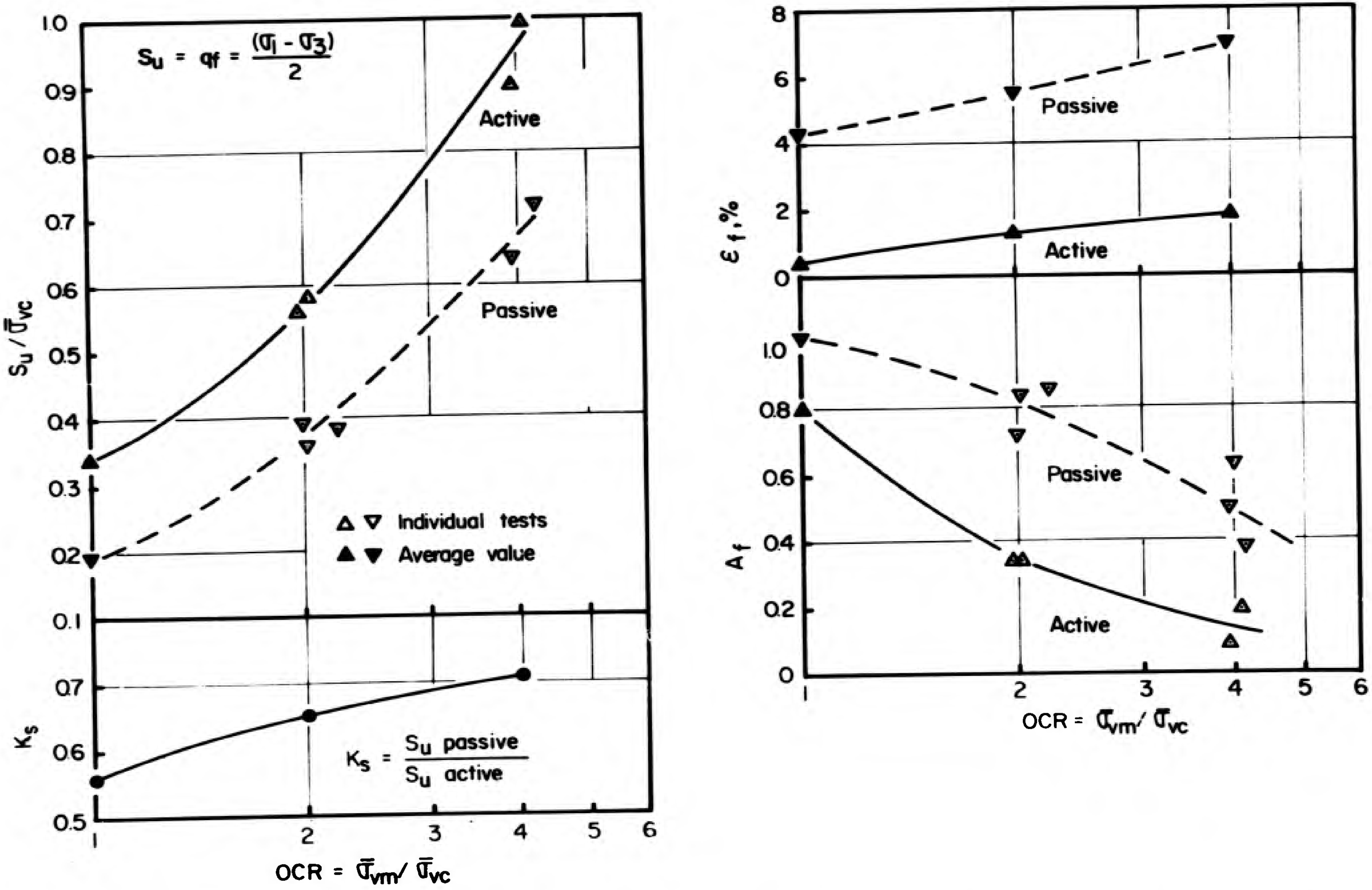
TABLE 5-2

TYPE OF TEST	$\bar{\sigma}_{vc}$ kg/cm^2	K_c	At $(\sigma_1 - \sigma_3)_{max}$				At $(\bar{\sigma}_1 / \bar{\sigma}_3)_{max}$			REMARKS
			ε %	$q/\bar{\sigma}_{vc}$	A	$\bar{\phi}_u$°	ε %	$q/\bar{\sigma}_{vc}$	$\bar{\phi}$ max°	
$\overline{CK_oUC}$ (Triaxial compression)	Mostly 4 - 6	(1) 0.51 (.50-.53)	0.3 (.25-.4)	0.33 (.315-.335)	0.6 (.5-.65)	26.5 (24-27.5)	8 (±2)	0.25 (±.02)	33 (±2)	Based on Ladd and Varallyay (1965) plus 7 other tests
$\overline{CK_oU}$ PSA (Plane strain active)	3.8- 4.0	0.52 (±.05)	0.4 (±.15)	0.34 (.32-.35)	0.8 (±.15)	29 (27-30)	3.5 (±1.0)	0.29 (±.03)	34 (±1.0)	From table 5-2
$\overline{CK_oUE}$ (Triaxial extension)	4 & 6	(2) 0.54 (±0)	(3) 10 (±0)	0.155 (.14-.165)	1.17 (±.05)	38 (36-39.5)	Same as at $(\sigma_1 - \sigma_3)$ max			From Ladd and Varallyay (1965) for 2 ε controlled tests
$\overline{CK_oU}$ PSP (Plane strain passive)	4.0- 4.2	0.50 (.45-.52)	4.3 (±1.5)	0.19 (.175-.215)	1.015 (±.05)	40°	Assumed to be same as at $(\sigma_1 - \sigma_3)$ max			From table 5-2

(1) t_c = 6 - 8 days
(2) t_c = 4 - 6 days
(3) t_c = Problem with necking at $\varepsilon > 6 - 7$ % strain

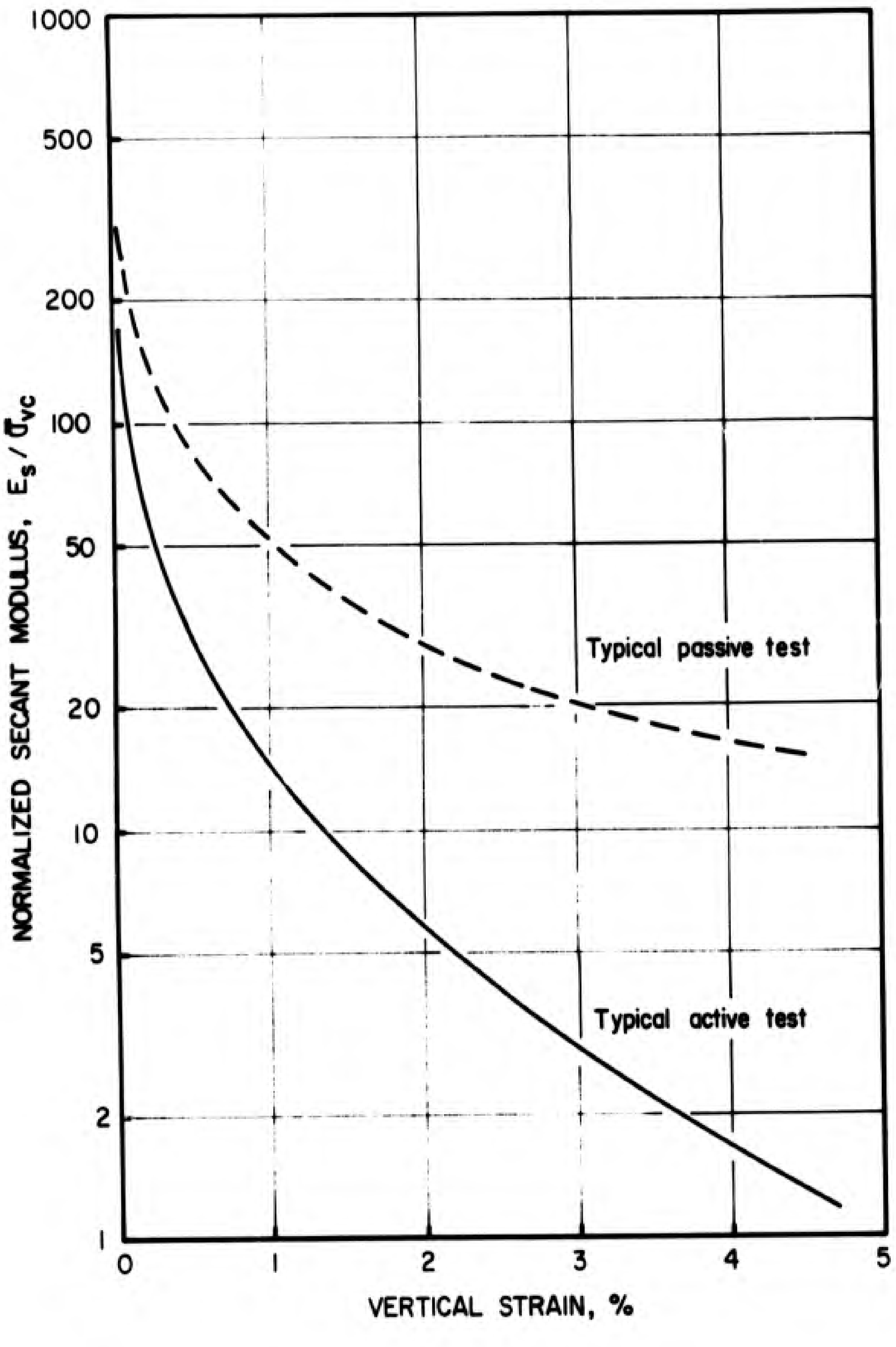
COMPARISON OF $\overline{CK_oU}$ PLANE STRAIN AND TRIAXIAL TESTS ON NORMALLY CONSOLIDATED BOSTON BLUE CLAY

TABLE 5 - 3



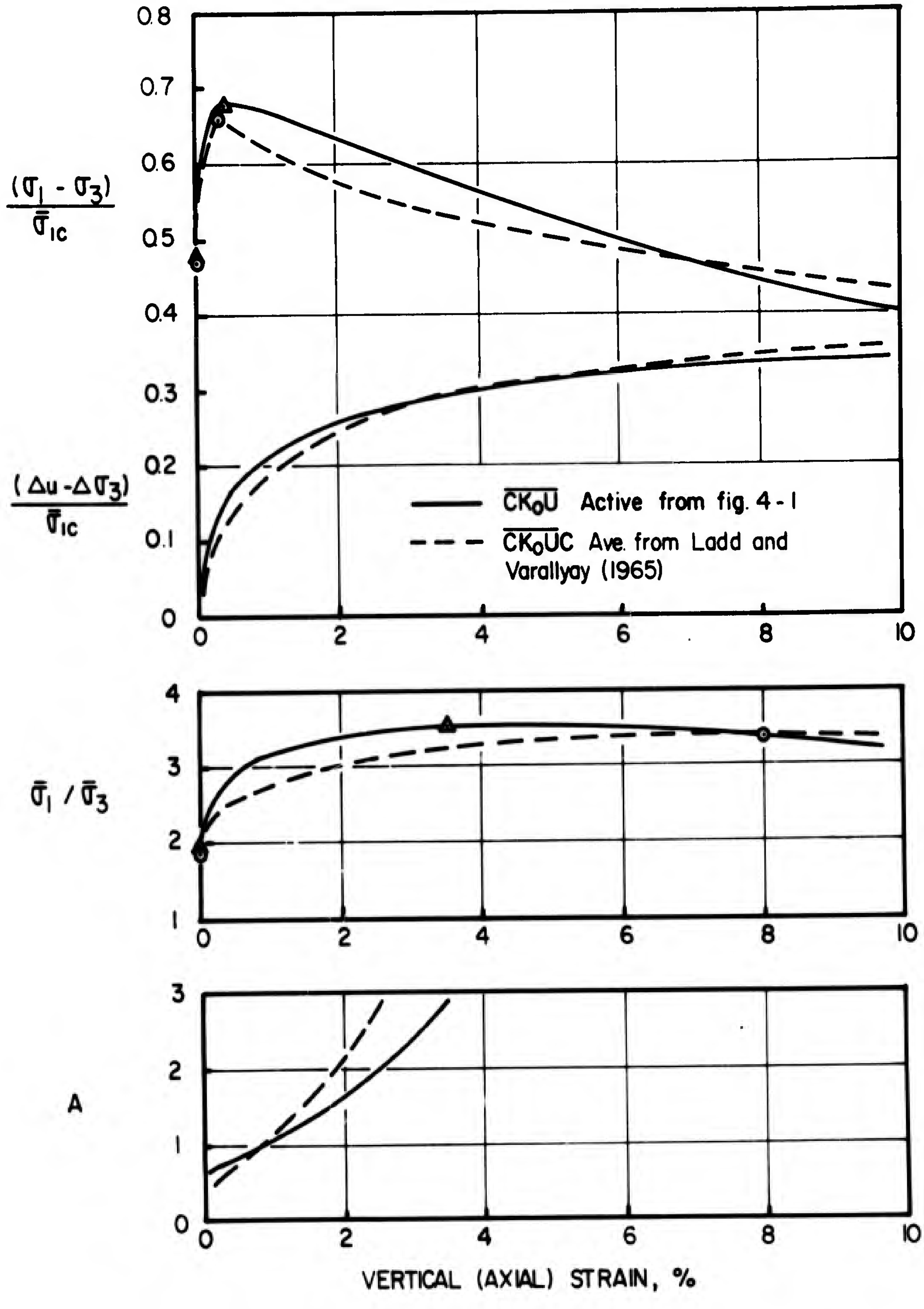
COMPARISON OF $\overline{CK_oU}$ PLANE STRAIN ACTIVE AND PASSIVE TESTS ON BOSTON BLUE CLAY

FIGURE 5-1



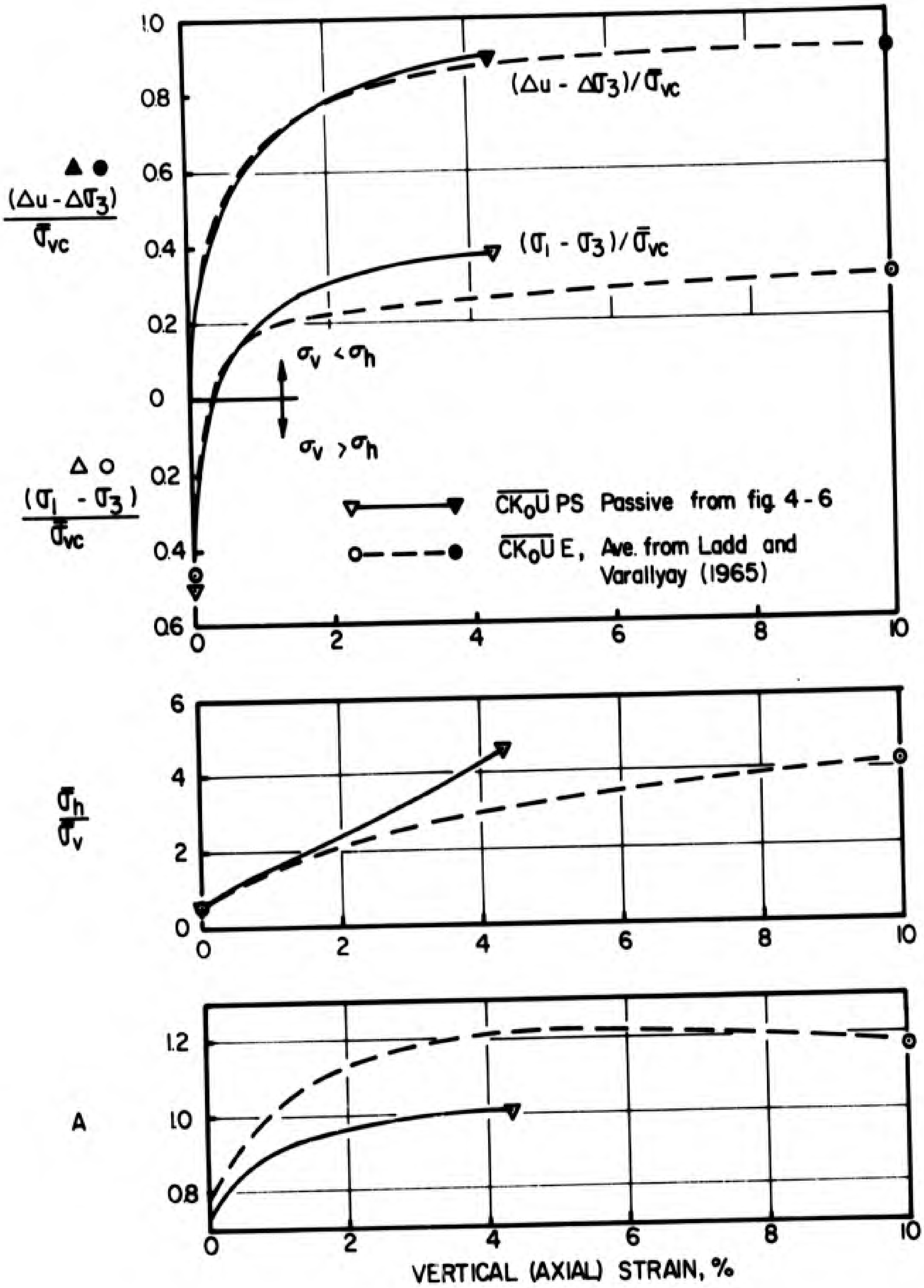
NORMALIZED SECANT MODULUS VS VERTICAL STRAIN FOR $\overline{CK_0U}$ PLANE STRAIN ACTIVE AND PASSIVE TESTS ON NORMALLY CONSOLIDATED BOSTON BLUE CLAY

FIGURE 5 - 2



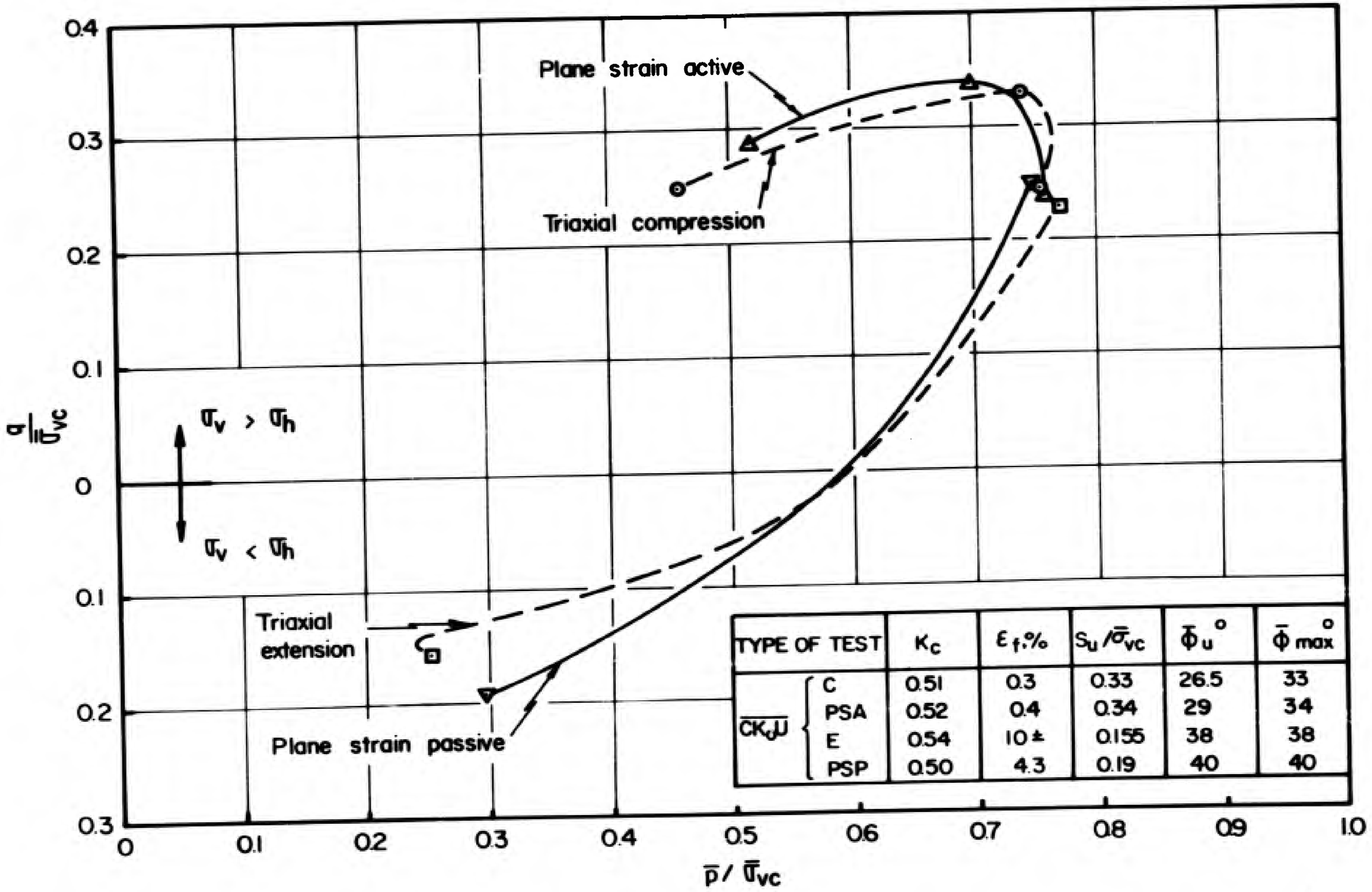
STRESS VS STRAIN FROM $\overline{CK_0U}$ PLANE STRAIN ACTIVE AND TRIAXIAL COMPRESSION TESTS ON NORMALLY CONSOLIDATED BOSTON BLUE CLAY

FIGURE 5 - 3



STRESS VS STRAIN FROM $\overline{CK_0U}$ PLANE STRAIN PASSIVE AND TRIAXIAL EXTENSION TESTS ON NORMALLY CONSOLIDATED BOSTON BLUE CLAY

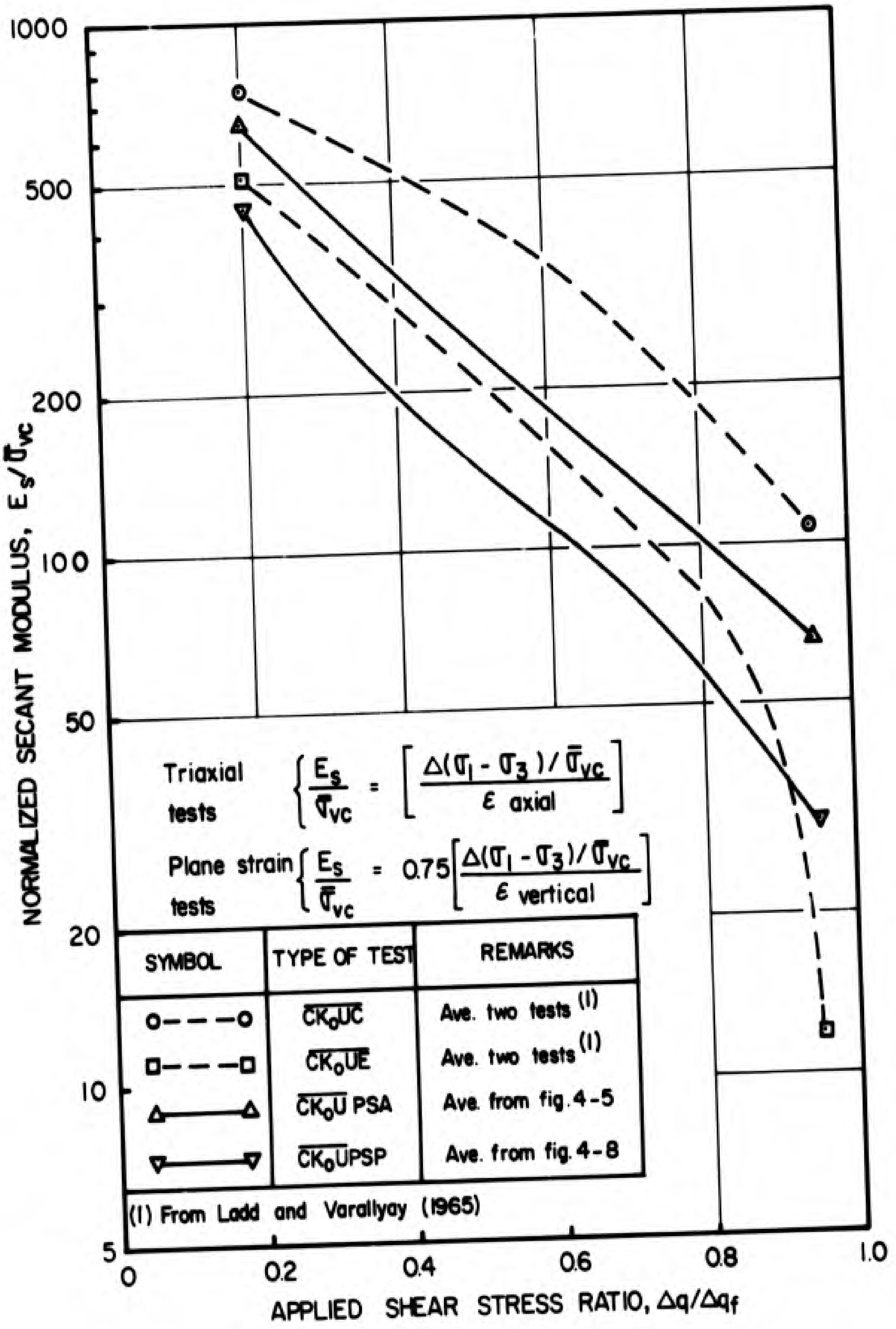
FIGURE 5-4



TYPE OF TEST		K_c	ε_f,%	$s_u / \bar{\sigma}_{vc}$	$\bar{\Phi}_u$ °	$\bar{\Phi}_{max}$ °
$\overline{CK_0U}$	C	0.51	0.3	0.33	26.5	33
	PSA	0.52	0.4	0.34	29	34
	E	0.54	10 ±	0.155	38	38
	PSP	0.50	4.3	0.19	40	40

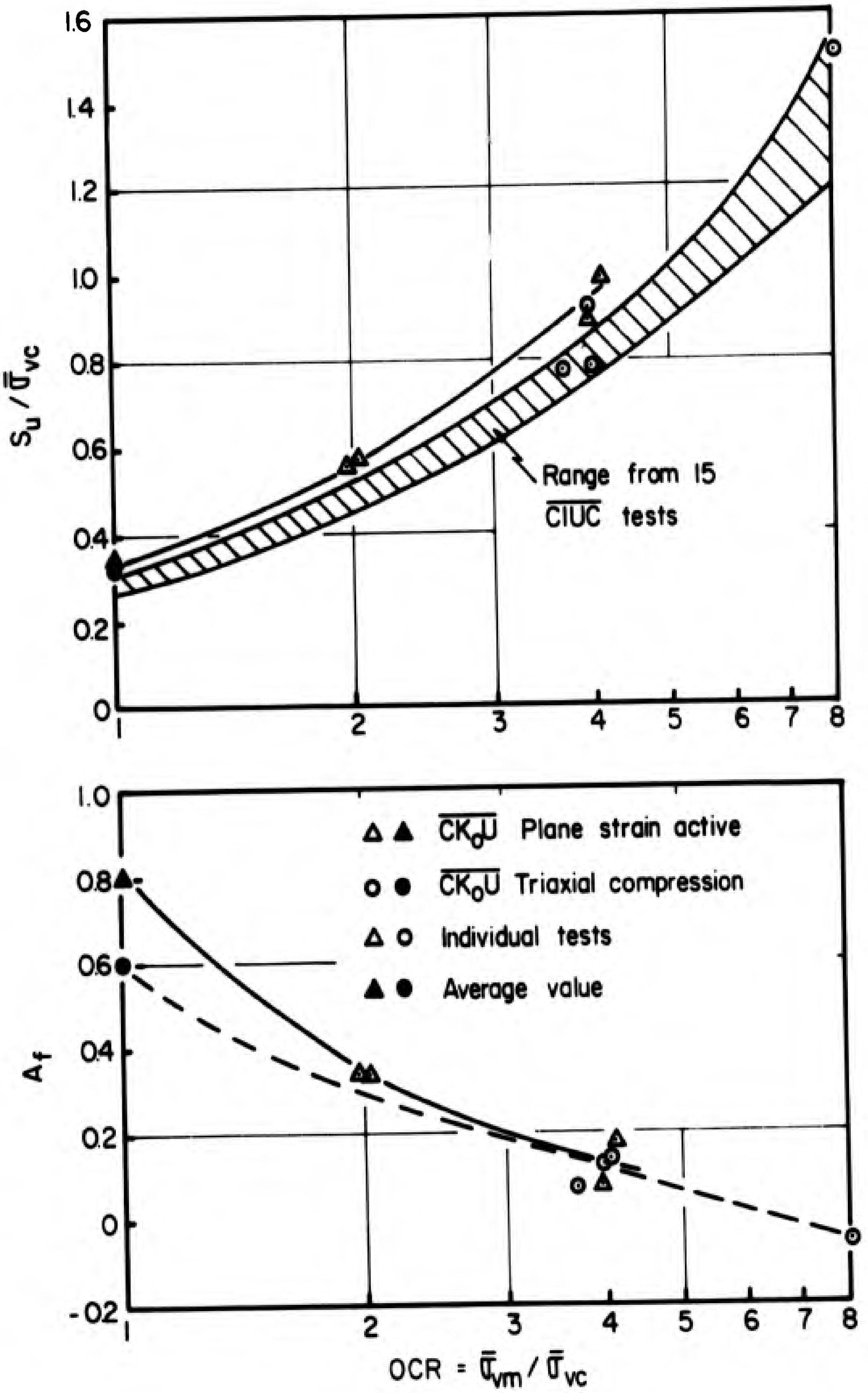
STRESS PATHS FROM $\overline{CK_0U}$ PLANE STRAIN AND TRIAXIAL TESTS ON NORMALLY CONSOLIDATED BOSTON BLUE CLAY

FIGURE 5 - 5



NORMALIZED SECANT MODULUS FROM $\overline{CK_0U}$ PLANE STRAIN AND TRIAXIAL TESTS ON NORMALLY CONSOLIDATED BOSTON BLUE CLAY

FIGURE 5 - 6



COMPARISON OF $\overline{CK_0U}$ PLANE STRAIN ACTIVE AND TRIAXIAL COMPRESSION TESTS ON BOSTON BLUE CLAY

FIGURE 5 - 7

6. SUMMARY AND CONCLUSIONS

1. This research is part of an overall program aimed at generation of normalized stress-strain-strength data versus overconsolidation ratio for a variety of clays for undrained shear conditions simulating several in situ modes of failure. Data are presented from consolidated-undrained plane strain active and passive tests on K_o consolidated samples of resedimented Boston Blue Clay at overconsolidation ratios of one, two and four. The resedimented clay ($w_N = 36\%$, $w_L = 41\%$, $w_p = 20\%$) has engineering properties very similar to those of natural Boston Blue Clay.

2. The plane strain equipment, developed at M.I.T. (see Figure 2-1), uses a sample 3.5 in. high by 3.5 in. wide by 1.4 in. deep (σ_2 plane). K_o consolidation is obtained by using fixed end platens and removable side platens; values of K_o are obtained by several independent methods of messurement. The major principal stress can be applied in either the horizontal or vertical direction, with σ_2 measured at the fixed end platens (see Figures 2-5 and 2-6). A standard active test consists of strained controlled vertical loading. A standard passive test consists of strained controlled vertical unloading. Passive tests were also run by vertical loading after K_o consolidation in the horizontal direction, i.e., $\bar{\sigma}_{1c} = \bar{\sigma}_{hc}$ and $\bar{\sigma}_{3c} = \bar{\sigma}_{vc}$.

3. The apparatus and test procedures yielded reasonably good one-dimensional consolidation conditions. The removable side platens enabled use of much larger consolidation increments than are possible with K_o

interpreted in light of reasonable values of obliquity of the principal stresses.

6. The strength parameters for active and passive undrained shear of Boston Blue Clay at OCR values of one, two and four are presented in Table 5-2 and Figure 5-1 and are summarized below:

OCR	Type of Shear	ε_f, %	$s_u/\bar{\sigma}_{vc}$	A_f
1	A	0.4	0.34	0.8
	P	4.3	0.19	1.02
2	A	1.3	0.57	0.34
	P	5.5	0.37	0.82
4	A	1.8	0.95	0.14
	P	7	0.67	0.49

Thus passive shear, which involves a 90 degree rotation of the principal planes, causes a substantial reduction in undrained strength, a much larger strain at failure, and an increased value of A_f.

7. Undrained model footing tests with a strip load were performed on Boston Blue Clay (Kinner and Ladd, 1970). Measured values of the ultimate bearing capacity are compared below to those predicted from the plane strain tests based on the relationship $q_{ult} = 5.14\ s_u$, where s_u equals the average from the active and passive tests:

OCR	$(s_u)_{ave}/\bar{\sigma}_{vc}$	Predicted $q_{ult}/\bar{\sigma}_{vc}$	Measured $q_{ult}/\bar{\sigma}_{vc}$
1	½(0.34+0.19)=0.265	1.36	1.34
2	½(0.57+0.37)=0.47	2.41	2.42
4	½(0.95+0.67)=0.81	4.15	4.20

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6. SUMMARY AND CONCLUSIONS

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consolidation in a standard triaxial cell. The cell pressure yielded the most reliable values of K_o; pressure transducers inserted in the fixed end platens gave erratic results with an average K_o that was slightly too low for normally consolidated clay and much too low for overconsolidated clay.

4. Results are reported for ten $\overline{CK_oU}$ plane strain active tests. There were generally few experimental problems and the measured stress-strain-strength data show relatively little scatter once the test procedures had been finalized. It is concluded that the apparatus yields reliable data for plane strain active tests.

5. Results are reported for 13 $\overline{CK_oU}$ plane strain passive tests. Of these, eight were consolidated in the usual fashion while five employed horizontal K_o consolidation. Allbut one of the vertical K_o consolidated samples yielded obviously erroneous data at large strains because of various sources of "friction" in the device and/or necking of the specimen. This resulted in measured values of vertical stress that were too low and measured values of $q = 0.5\ (\sigma_h - \sigma_v)$ that were too large. Consequently, undrained failure was defined in terms of when the measured obliquity of effective stresses ($\bar{\sigma}_h/\bar{\sigma}_v = \bar{\sigma}_1/\bar{\sigma}_3$) reached a certain value. This approach yielded a reasonable estimate of the maximum possible undrained strength from passive tests. The resulting stress-strain-strength data for normally consolidated samples were quite consistent, whereas data for overconsolidated samples were more erratic. It is concluded that the apparatus yields reliable stress-strain data for passive shear up to about 3 ± 1 percent strain. Failure conditions must generally be

interpreted in light of reasonable values of obliquity of the principal stresses.

6. The strength parameters for active and passive undrained shear of Boston Blue Clay at OCR values of one, two and four are presented in Table 5-2 and Figure 5-1 and are summarized below:

OCR	Type of Shear	ε_f, %	$s_u/\bar{\sigma}_{vc}$	A_f
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Thus passive shear, which involves a 90 degree rotation of the principal planes, causes a substantial reduction in undrained strength, a much larger strain at failure, and an increased value of A_f.

7. Undrained model footing tests with a strip load were performed on Boston Blue Clay (Kinner and Ladd, 1970). Measured values of the ultimate bearing capacity are compared below to those predicted from the plane strain tests based on the relationship $q_{ult} = 5.14\ s_u$, where s_u equals the average from the active and passive tests:

OCR	$(s_u)_{ave}/\bar{\sigma}_{vc}$	Predicted $q_{ult}/\bar{\sigma}_{vc}$	Measured $q_{ult}/\bar{\sigma}_{vc}$
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2	½(0.57+0.37)=0.47	2.41	2.42
4	½(0.95+0.67)=0.81	4.15	4.20

The excellent agreement between the predicted and measured bearing capacity indicates that the undrained strength ratios listed in paragraph 6 above are reliable.

8. Synthesized stress-strain curves and stress paths were developed for each type of test at each OCR. These relationships are presented in Figures 4-1 through 4-3 for the active tests and Figures 4-6 through 4-8 for the passive tests. Passive tests yielded higher values of Young's secant modulus, E_s, at the same strain, but equal or lower values based on the same factor of safety with respect to the applied shear stress causing failure (i.e., $\Delta q/\Delta q_f$).

9. The plane strain data on normally consolidated clay are compared to $\overline{CK_oU}$ triaxial test data (active vs triaxial compression and passive vs triaxial extension) in Table 5-3 and Figures 5-3 through 5-6. The results show that:

   (a) Plane strain active, versus triaxial compression, causes a very slight increase in s_u (both $\bar{\phi}_u$ and A_f increased) and $\bar{\phi}_{max}$, more strain softening (probably due to formation of a failure plane), and perhaps a slightly lower value of Young's modulus.

   (b) Plane strain passive, versus triaxial extension, causes a significantly higher value of s_u (because of a lower A_f) at a much lower strain at failure, but the initial stress-strain characteristics up to about one percent strain are essentially identical.

   The close agreement between the plane strain active and triaxial compression data agrees with the findings of others. No other data exist comparing plane strain passive and triaxial extension tests.

10. Data on three normally consolidated clays (Boston Blue Clay, Undisturbed San Francisco Bay Mud, remolded Weald Clay), on two compacted clays, and on overconsolidated Boston Blue Clay show that $\overline{CK_oU}$ plane strain active and triaxial compression tests yield either essentially identical stress-strain-strength data, or changes that can be predicted fairly well by the theory of elasticity. The major difference appears to be more strain softening after failure with plane strain conditions. There are some indications that "creep" effects may also be significantly different. However, from a practical viewpoint, it would appear that $\overline{CK_oU}$ triaxial compression tests can yield reasonably close estimates of undrained plane strain active conditions for soft saturated clays.

11. The only data comparing $\overline{CK_oU}$ plane strain passive and triaxial extension tests are for normally consolidated Boston Blue Clay, which showed a significant difference at strains exceeding about one percent. Consequently, similar comparisons should be made for several types of clay and stress histories.

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APPENDIX A - NOTATION

Note: Suffix f indicates a failure condition.
Δ indicates a change
A bar over a stress indicates an effective stress

A	Skempton's A parameter = $(\Delta u - \Delta\sigma_3)/(\Delta\sigma_1 - \Delta\sigma_3)$
A_f	A parameter at failure
A_s	Area of sample
B	Skempton's B parameter = $\Delta u/\Delta\sigma_c$
$\bar{c}$	Intercept of τ_{ff} versus $\bar{\sigma}_{ff}$ envelope
e	Void ratio
e_o	Initial void ratio
E_s	Secant modulus
H	Height of sample
K_c	$\bar{\sigma}_{hc}/\bar{\sigma}_{vc}$
K_o	Coefficient of lateral earth stress at rest, i.e. K_c for no lateral strain
$\bar{p}$	$(\bar{\sigma}_1 + \bar{\sigma}_3)/2$
q	$(\sigma_1 - \sigma_3)/2$
S	Degree of saturation
s_u	q at $(\sigma_1 - \sigma_3)$ max
t_c	Time of consolidation after side platens are removed
u	Pore pressure
u_B	Backpressure

V	Volume
V_o	Initial volume
w_i	Initial water content
w_f	water content at failure
ε	Axial(vertical)strain
σ	Total normal stress
σ_c	Cell pressure
σ_h, $\bar{\sigma}_h$	Horizontal stress
σ_v, $\bar{\sigma}_v$	Vertical stress
$\bar{\sigma}_{hc}$	Horizontal consolidation stress
$\bar{\sigma}_{vc}$	Vertical consolidation stress
$\bar{\sigma}_{hm}$	Maximum past horizontal stress
$\bar{\sigma}_{vm}$	Maximum past vertical stress
σ_1, $\bar{\sigma}_1$	Major principal stress
σ_2, $\bar{\sigma}_2$	Intermediate principal stress
σ_3, $\bar{\sigma}_3$	Minor principal stress
$\bar{\sigma}_{1c}$	$\bar{\sigma}_1$ at consolidation
$\bar{\phi}$	Effective stress friction angle
$\bar{\phi}$ max	$\bar{\phi}$ at (σ_1/σ_3)max
$\bar{\phi}_u$	$\bar{\phi}$ at $(\sigma_1-\sigma_3)$max
$\overline{CK_oUC}$	Undrained triaxial compression test after K_o consolidation
$\overline{CIUC}$	Undrained triaxial compression test after isotropic consolidation
$\overline{CK_oUE}$	Undrained triaxial extension test after K_o consolidation

$\overline{CK_o}$UPSA	Undrained plane strain active test after K_o consolidation
$\overline{CK_o}$UPSP	Undrained plane strain passive test after K_o consolidation
A-	Shorthand for $\overline{CK_o}$UPSA
P-	Shorthand for $\overline{CK_o}$UPSP

APPENDIX B

PREPARATION AND PROPERTIES OF BOSTON BLUE CLAY AND MISCELLANEOUS INFORMATION

LIST OF TABLES

LIST OF FIGURES

B1 Batch Preparation

The Boston Blue Clay used for plane strain tests was obtained in 1966 during construction of the M.I.T. Space Center. The soil was stored in galvanized containers at a water content of from 60 to 80 percent until the fall of 1968. The soil was then sieved through a number 40 sieve to remove the shells and sand found in its natural state. After sieving, the soil has been stored in 20 gallon plastic containers.

Each batch of clay, containing approximately 11 kg of solids, is mixed to a nominal water content of 100 percent at a NaCl concentration of 16 g/l. The as-stored water content and salt concentration is obtained one day before batch preparation. Experience from preparing many batches shows the salt concentration in the storage containers to remain nearly constant. Distilled water and reagent quality NaCl are used to bring the slurry salt concentration up to 16 g/l and the water content to 100 percent. The soil is mixed with a hand electric mixer and spoons.

Prior to assembly of the vacuum chamber, the consolidometer inner surface is liberally coated with silicone grease. The vacuum chamber, having a 12 in. inside diameter and a 3 ft. height, and the consolidometer with the same diameter and a 10 inch height are assembled and evacuated to an absolute pressure of less than 4 centimeters of mercury.*

A vertical three inch diameter tube with a valve, attached above the vacuum chamber, holds the soil prior to insertion into the chamber. Adjustment of the injection valve position and the use of a diffuser atomizes the soil as it enters the chamber. Insertion of the slurry is done

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* See Figure B-1 of Kinner and Ladd (1970) for a picture of the apparatus.

very slowly and in several increments. Even with diffusion it is possible for excessive air to remain in the soil. Therefore, after every second increment, insertion of slurry is stopped until air bubbles cease to escape from the slurry surface. Insertion time for each batch varied from 1.5 to 3 hours.

During insertion of the slurry the valves at the bottom of the consolidometer are closed and the vacuum is drawn only from the valve at the top of the chamber adjacent to the insertion tube. Within thirty minutes after inserting all the slurry, the top vacuum line is closed and a vacuum is then applied to the base of the consolidometer. The soil injection valve at the base of the insertion tube is opened slightly to allow the pressure in the cylinder to gradually increase to atmospheric pressure. The clay slurry consolidates under the resultant seepage force as water is drawn from the base of the consolidometer. This process continues until the soil surface is one half inch below the top surface of the consolidometer.

B2 Consolidation

Following disassembly of the vacuum unit, the consolidometer is transferred to a Conbel loading frame. A rigid consolidation plate is put in place and an initial stress of 0.07 kg/cm^2 is applied for a few hours. This consolidation stress is applied to ensure that the consolidation plate is well seated on the soil before higher stresses are applied.

The increments of stress usually applied to the batch with the consolidation plate were 0.25, 0.50, 1.0 and 1.5 kg/cm^2. The individual increments applied to the various batches are summarized in Table B-1. The final increment of consolidation, usually $\bar{\sigma}_{vc} = 1.5$ kg/cm^2, is left on until the total increment time is twice that required for 90 percent consolidation.

The load is then removed and the consolidometer disassembled. The clay, in the form of a cake 12 inches in diameter and four to six inches high, is removed by lifting the consolidometer ring up from the base plate. The silicone grease placed on the inner surface prior to assembly of the chamber aids in removal of the consolidometer ring. A piece of 3/8 in. lucite is placed on the clay surface and the cake is inverted with the base plate still intact. A wire saw is passed between the clay and the base plate to facilitate its removal.

B3 Storage of Test Specimens

A twelve inch diameter cake yields between 8 and 10 plane strain samples, depending on how the cake is trimmed and whether the proposed test series requires vertically K_o consolidated or horizontal K_o consolidated samples. Since the initial water content of the cake needs to be maintained, the clay is stored in a plastic container filled with transformer oil. The oil minimizes evaporation of the pore water.

B4 Properties of Batches

Information on the eleven batches of clay used over a 3.5 year period is presented in Table B-1.

TABLE B-1

PROPERTIES OF BATCHES OF RESEDIMENTED BOSTON BLUE CLAY

BATCH NO.	w_L (%)	w_P (%)	P.I. (%)	Final w (%)	Slurry w (%)	NaCl Conc. (g/1)	Consolidation Increments (kg/cm^2)	Time Per Increment (hr.)
150	43.5	19.6	23.9	34.1	70	-	0 -0.25 0.25-1.5	24 46
160	38.1	17.8	20.3	34.4	70	~8	- -	- -
300	39.7	21.6	18.1	35.9	100	~10	0 -0.5 0.5 -1.5	24 45
400	39.4	21.3	18.1	36.7	100	~10	0 -0.5 0.5 -1.5	38 48
600					100	~10		
700					100	~10		
1000	41.1	19.5	22.6	37.3	100	16	0 -0.25 0.25-0.5 0.5 -1.5	26 12 47
1100(1)	42.0	20.6	21.4	43.4	100	16	0 -0.5 0.5 -1.0 1.0 -1.5	- 144 96
1200	40.2	18.6	21.6	38.1	100	16	0 -0.5 0.5 -0.9 0.9 -1.5	228 504 72
1300	42.1	22.1	20.0	35.6	100	16	0 -0.25 .25-.5 .5 -1.0 1.0 -1.5	72 24 24 27
1500	43.8	20.6	23.2	37±	100	16	0.02-0.25 0.25-0.5 0.5 -1.0 1.0 -1.5	48 30 67 196

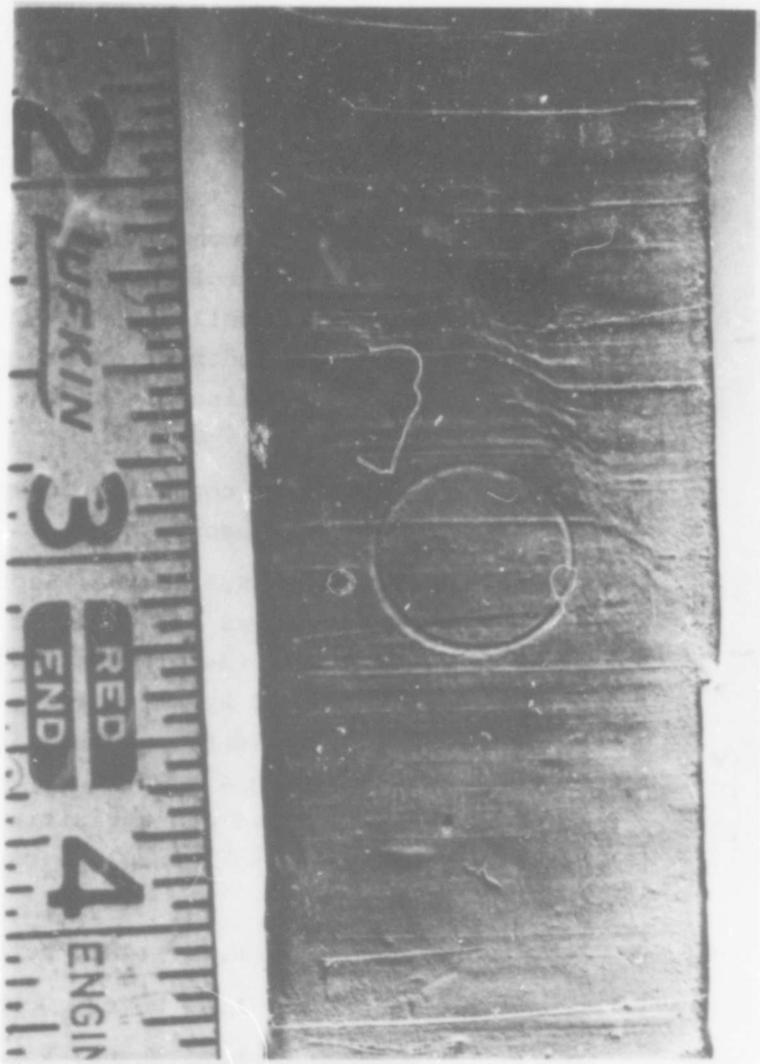
(1) Loading plate jammed so that final consolidation stress was less than 1.5 kg/cm^2

TABLE B-2

MISCELLANEOUS INFORMATION ON PLANE STRAIN TESTS

Test No.	Batch No.	Device	Remarks
A-2	150	P	Conducted by J.W. Dickey, April, 1967.
A-3	160	P	Conducted by J.W. Dickey, June, 1967.
A-4	300	P	Conducted by J.J. Rixner, July, 1967.
A-5	400	P	Conducted by J.J. Rixner, August, 1967. Test developed leak in pore pressure line, recorded less volumetric strain than axial strain.
A-6	700	P	Conducted by J.J. Rixner, April, 1968. Front end pressure plate replaced by two transducers.
A-7	1000	P	Conducted by R.B. Bovee, June, 1969. Test was set up twice due to sample membrane rupturing at $\bar{\sigma}_{vc} = 2.0$ kg/cm^2. Initial set-up resulted to 2.5% axial strain; volumetric strain could not be calculated due to leak. Front end pressure plate replaced by two transducers.
A-8	1200	P	Conducted by R.W. Skellinger, August, 1969.
A-9	1200	B	Conducted by R.B. Bovee, October, 1969.
A-10	1200	B	Conducted by R.B. Bovee, November , 1969.
A-11	1500	B	Conducted by L. Edgers, November, 1970.
P-1	150	P	Conducted by J.J. Rixner, April, 1967.
P-2	160	P	Conducted by J.J. Rixner, April, 1967.

Test No.	Batch No.	Device	Remarks
P-3	400	P	Conducted by J.J. Rixner, July 1967. Test developed leak in pore pressure line, recorded less volumetric strain than axial strain.
P-4H	600	P	Conducted by J.J. Rixner, March, 1968. Horizontal K_o consolidated followed by stress controlled shear by reducing the cell pressure until $q = 0$. Remainder of shear was strain controlled by increasing the vertical load.
P-9H	1200	P	Horizontal K_o consolidated by R.W. Skellinger, August, 1969.
P-10	1100	B	Conducted by R.B. Bovee, September, 1969. Test was set up twice due to ruptured side platen diaphragm at $\bar{\sigma}_{vc} = 0.80$ kg/cm². Initial set-up resulted in 6% axial strain and 8% volumetric strain. Sample from Batch 1100 had a high initial water content due to incomplete consolidation.
P-11	1200	B	Conducted by R.B. Bovee, October, 1969.
P-12H	1200	B	Conducted by R.B. Bovee, October, 1969.
P-13	1300	B	Conducted by R.B. Bovee, November, 1969.
P-17H	1300	B	Conducted by R.B. Bovee, January, 1970. Difficulty in measuring pore pressures during shear resulted in unusual stress-strain behavior.

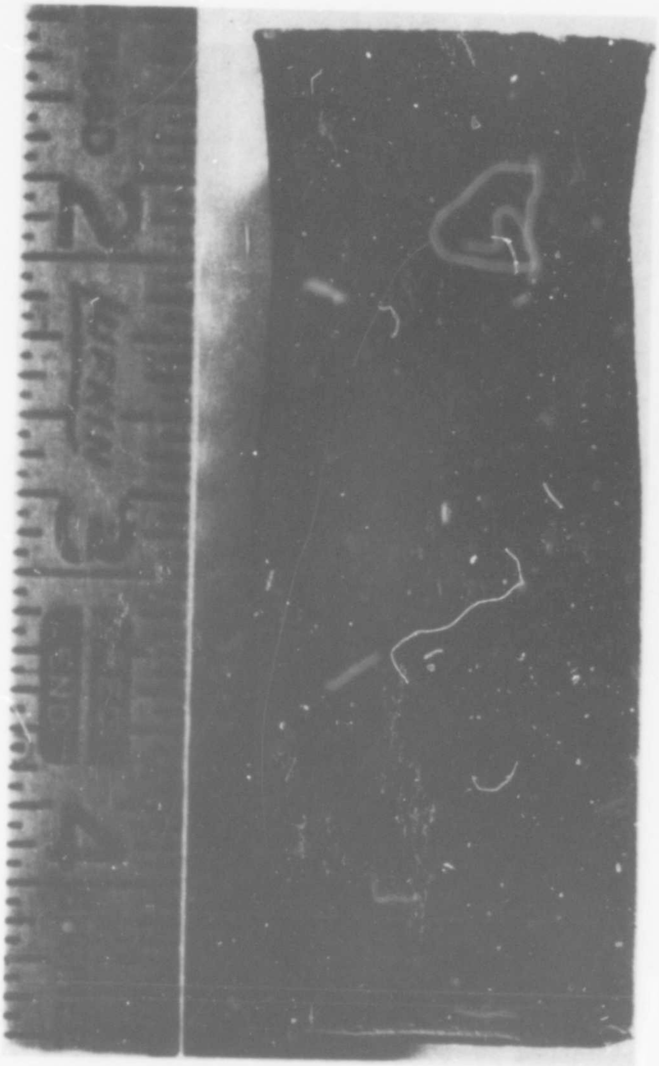


PICTURE OF DRIED SAMPLE
AFTER TESTING, TEST A-7

Figure B-1

PICTURE OF DRIED SAMPLE
AFTER TESTING, TEST A-9

Figure B-2



PICTURE OF DRIED SAMPLE
AFTER TESTING, TEST P-10

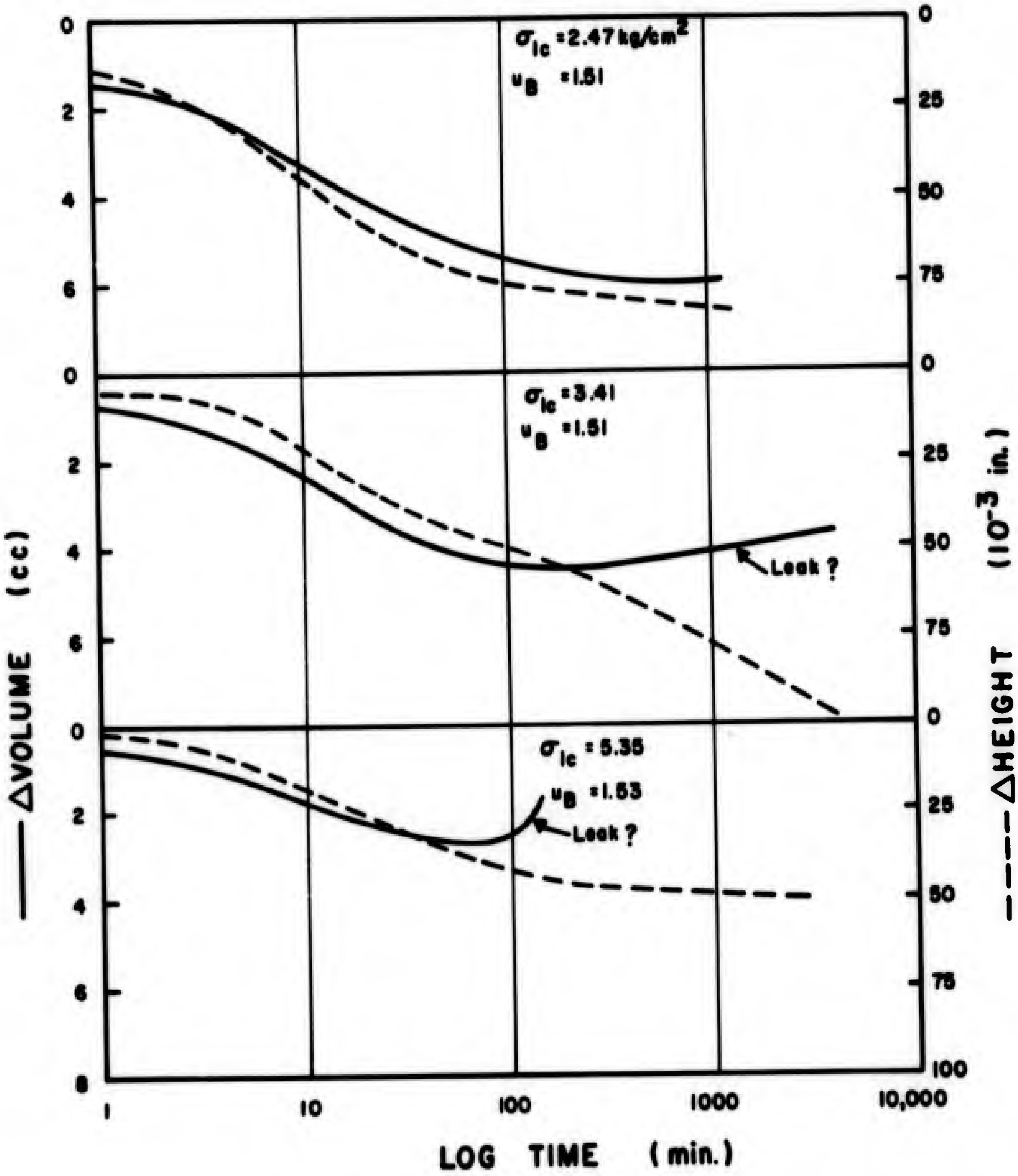
Figure B-3

PICTURE OF DRIED SAMPLE
AFTER TESTING, TEST P-11

Figure B-4

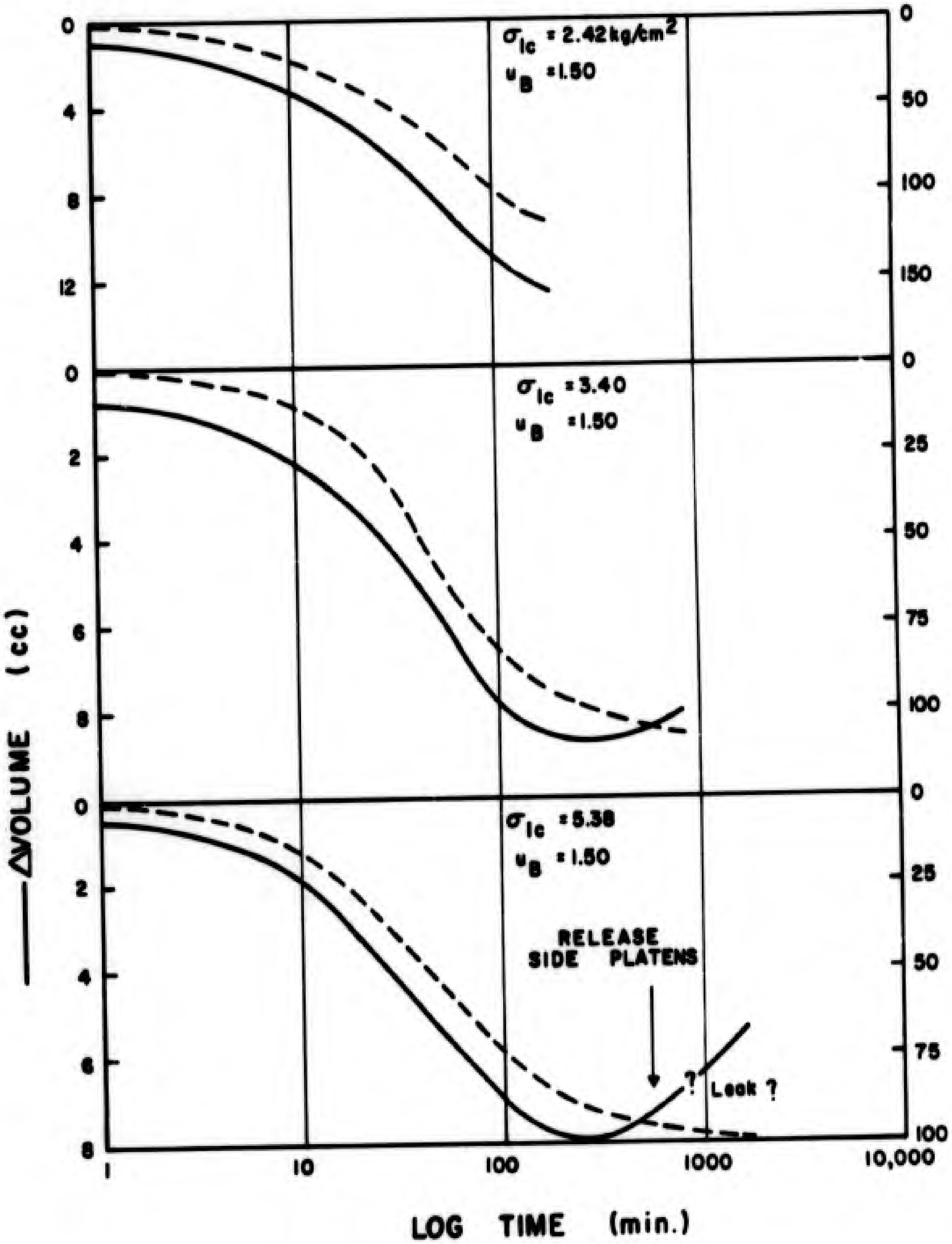
APPENDIX C

AXIAL, VOLUMETRIC AND HORIZONTAL STRESS DATA DURING CONSOLIDATION



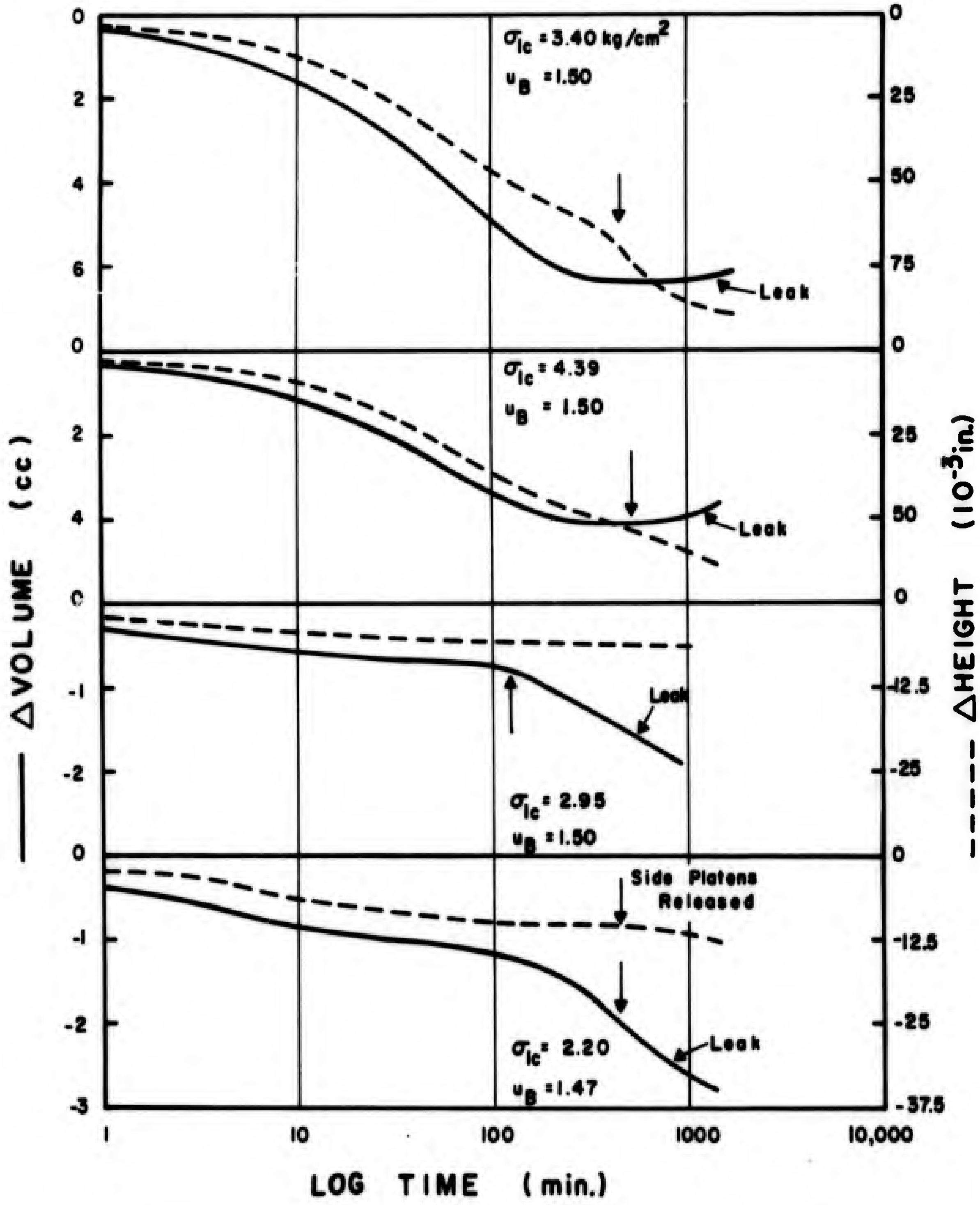
CHANGE IN VOLUME AND HEIGHT VS LOG TIME FOR $\overline{\text{CK}_0\text{UPSA}}$-3, OCR = 1.0

Figure C-1



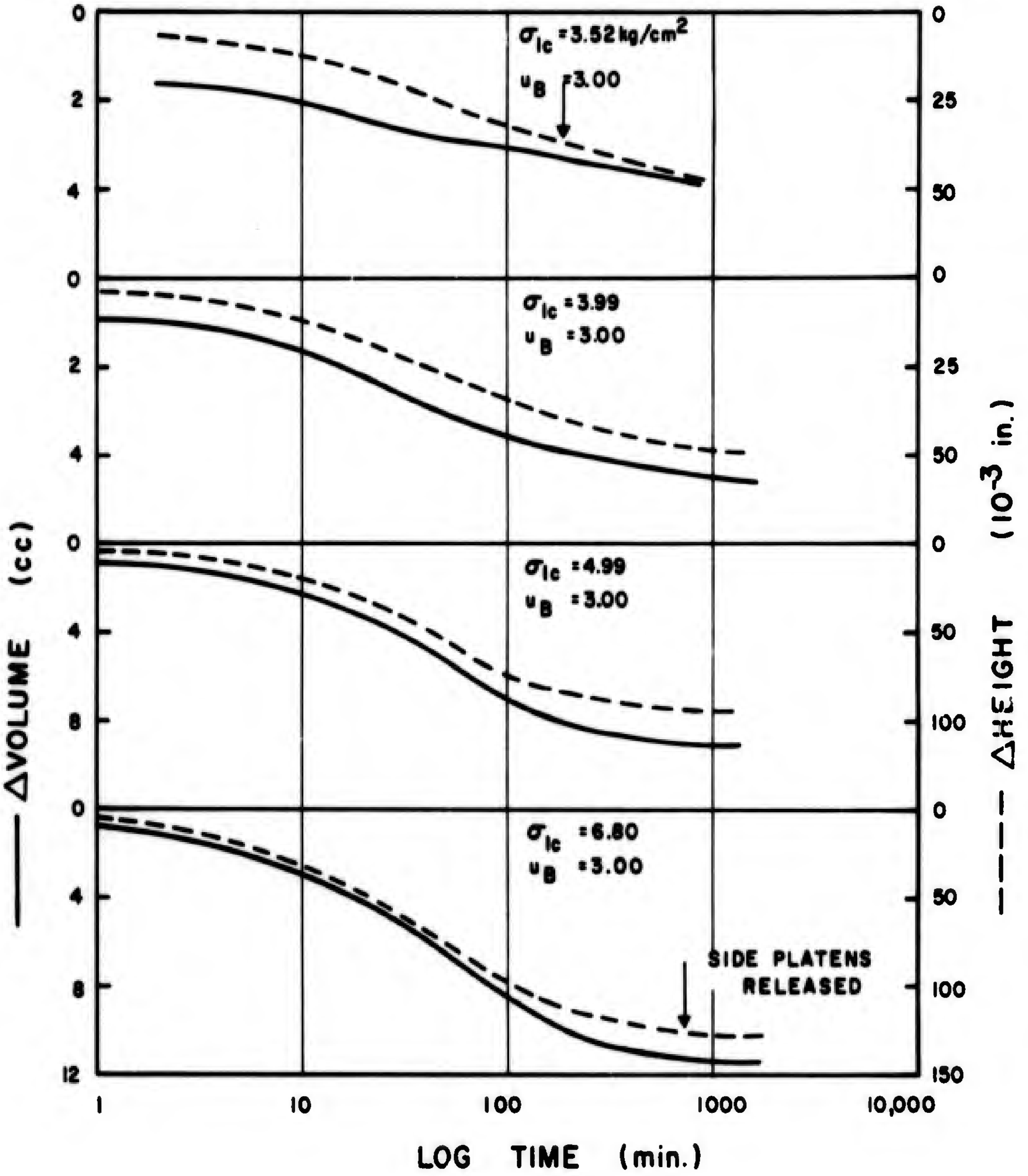
CHANGE IN VOLUME AND HEIGHT VS LOG TIME FOR $\overline{CK_0U}$PSA-4, OCR=1.0

Figure C-2



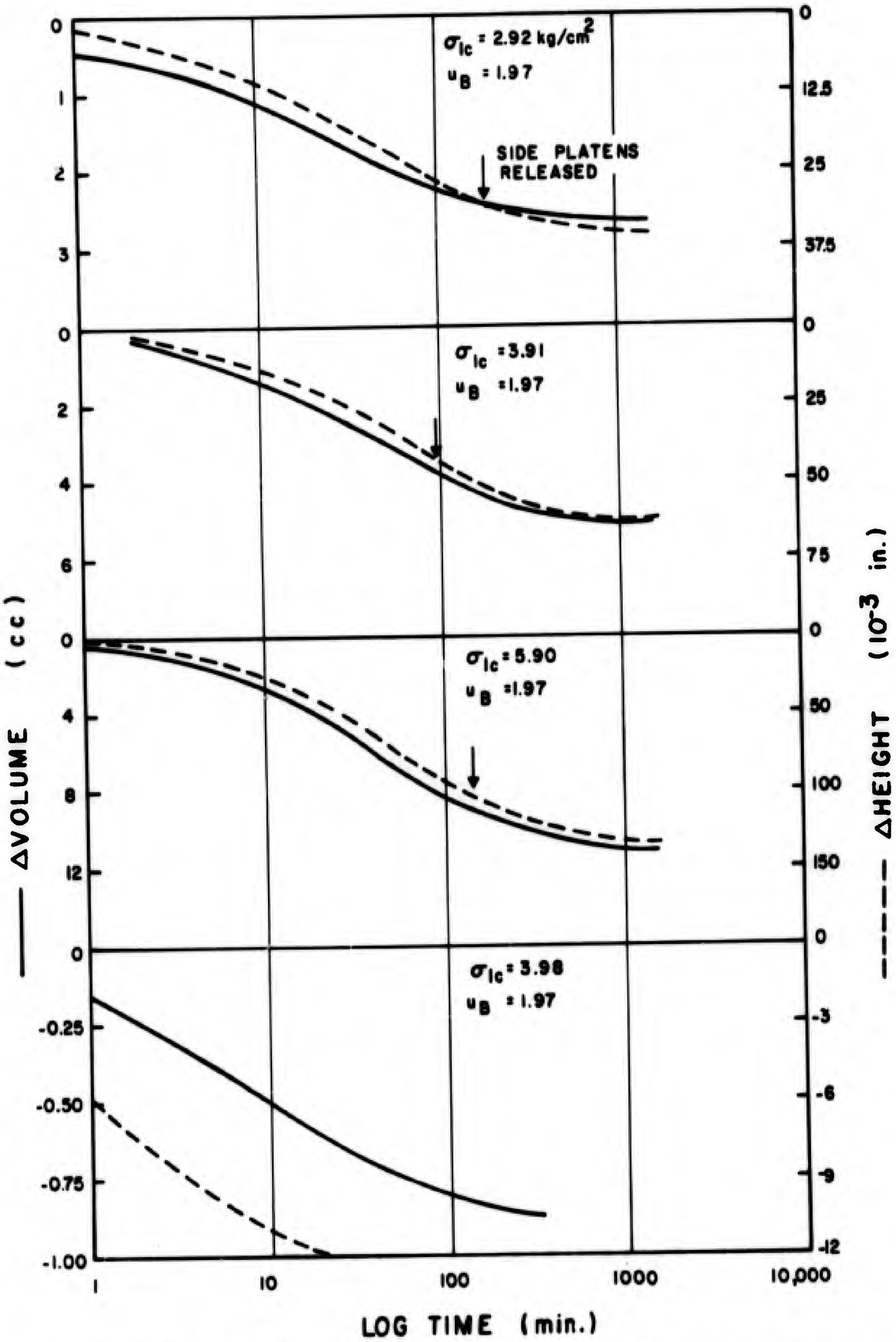
CHANGE IN VOLUME AND HEIGHT VS LOG TIME FOR $\overline{CK_oUPSA}$-5, OCR = 3.94

Figure C-3



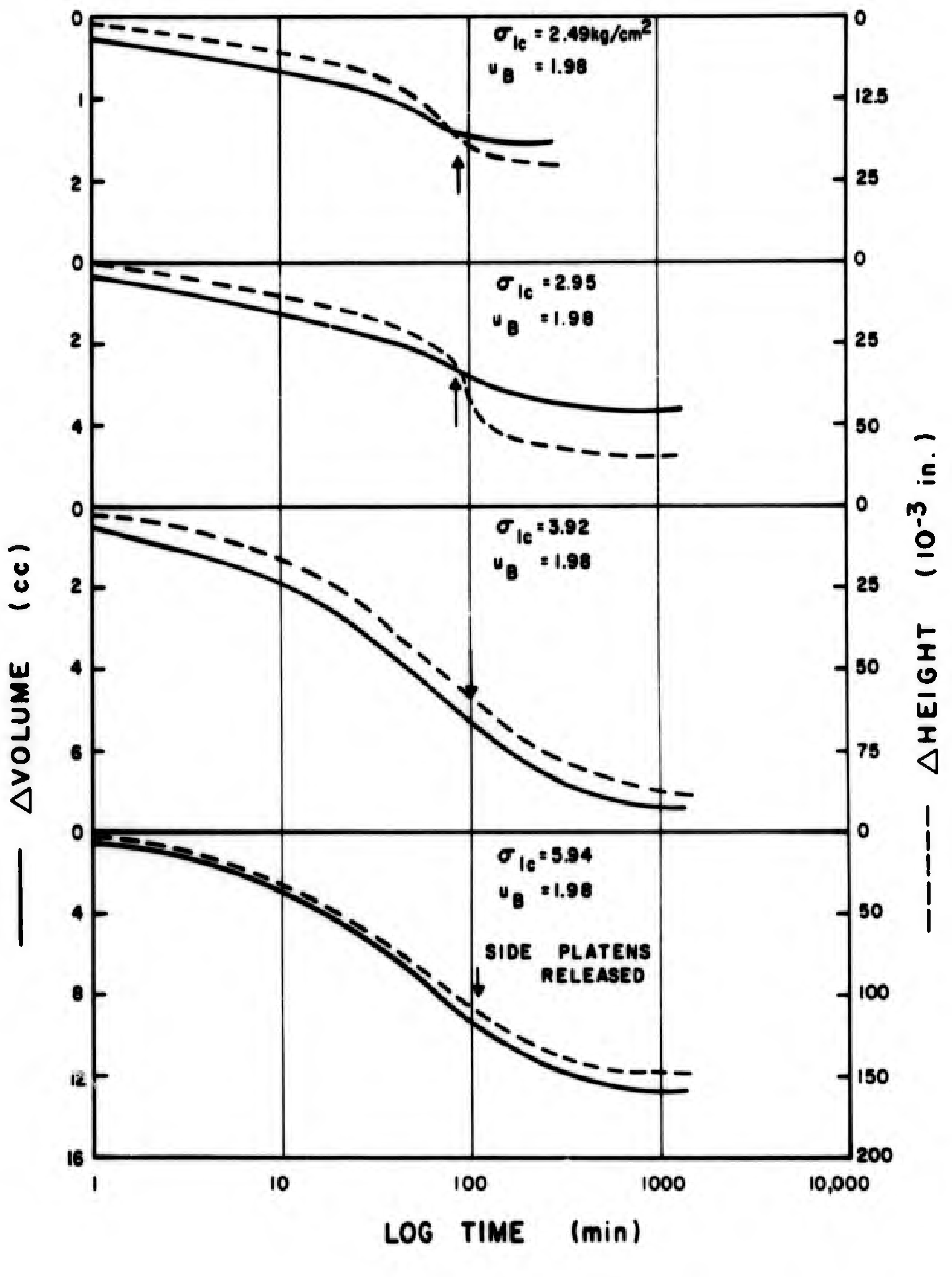
CHANGE IN VOLUME AND HEIGHT VS LOG TIME FOR $\overline{CK_oU}$PSA-6 , OCR=1.0

Figure C-4



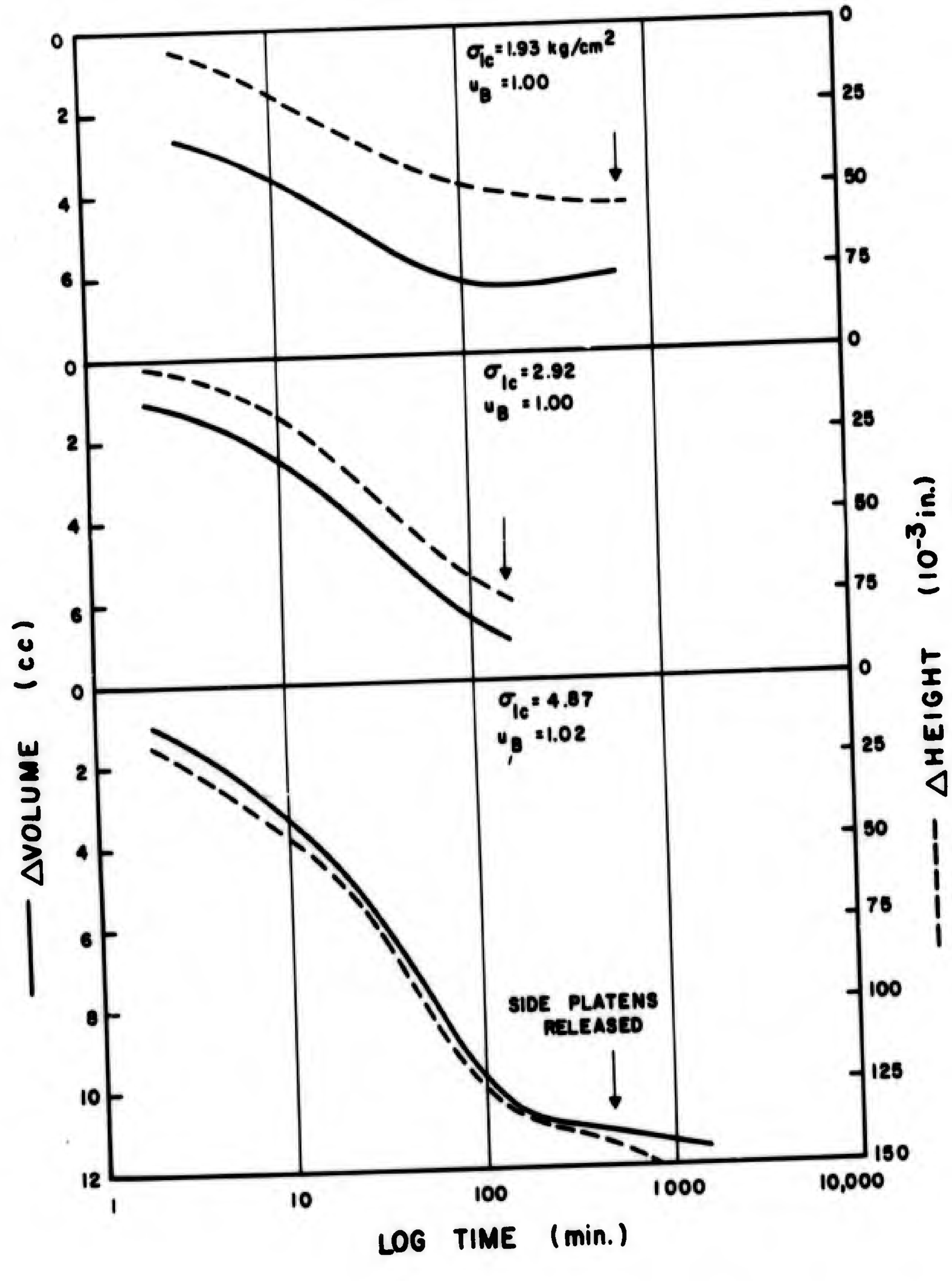
CHANGE IN VOLUME AND HEIGHT VS LOG TIME FOR $\overline{CK_0UPSA}$-9, OCR = 1.96

Figure C-5



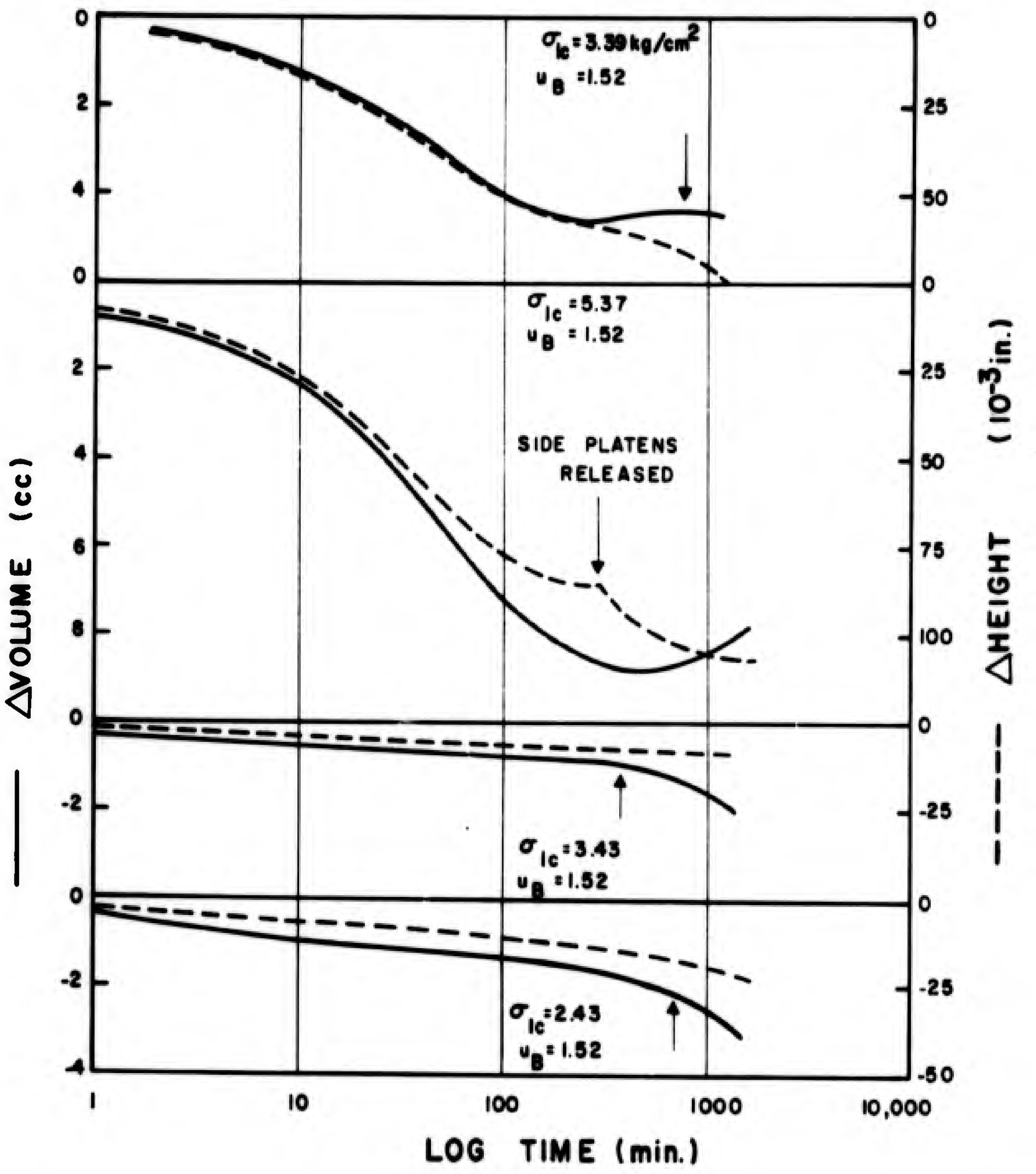
CHANGE IN VOLUME AND HEIGHT VS LOG TIME FOR $\overline{CK_o}$UPSA-10, OCR=1.0

Figure C-6



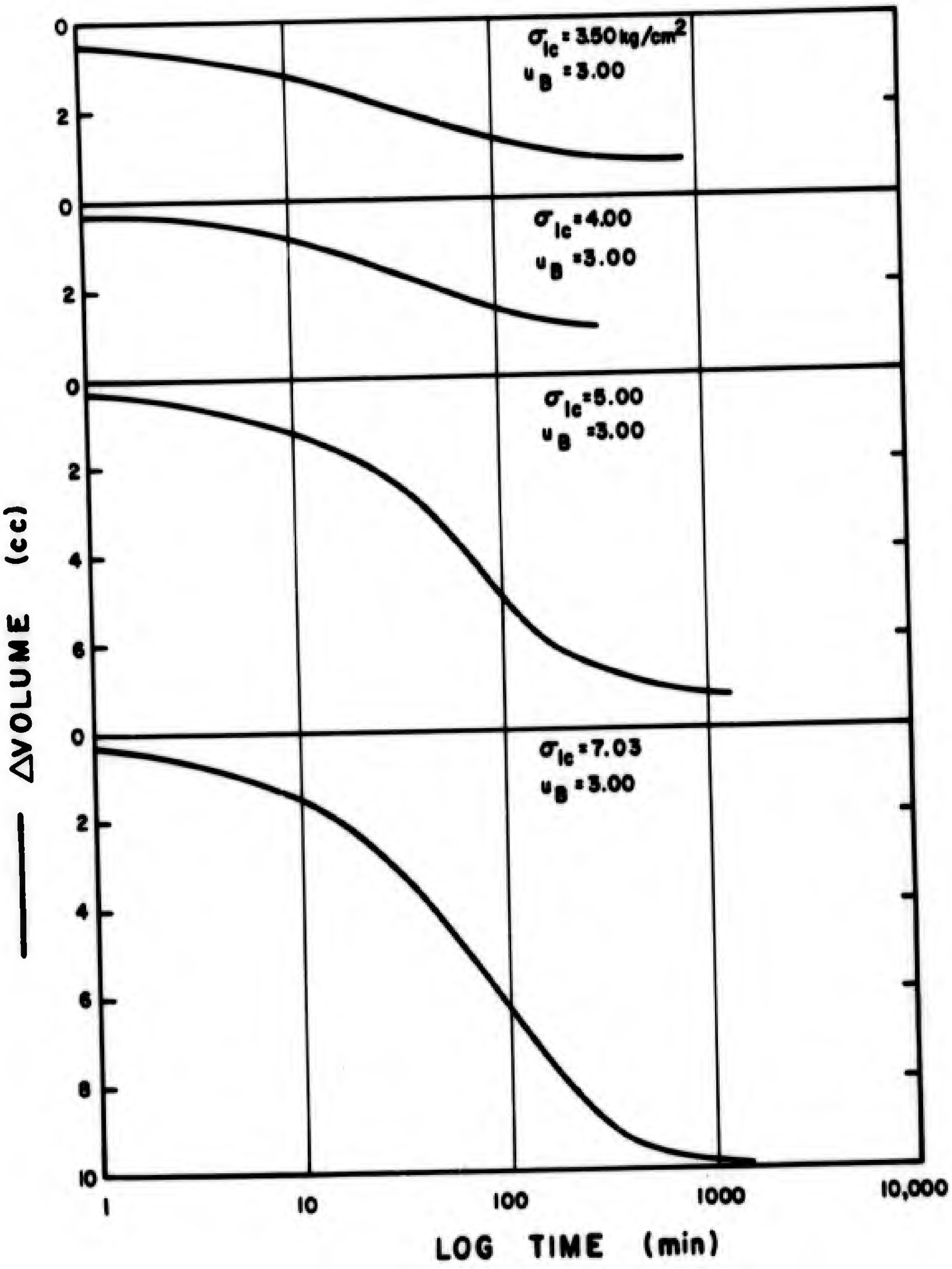
CHANGE IN VOLUME AND HEIGHT VS LOG TIME FOR $\overline{CK_0U}$PSP-2, OCR=1.0

Figure C-7



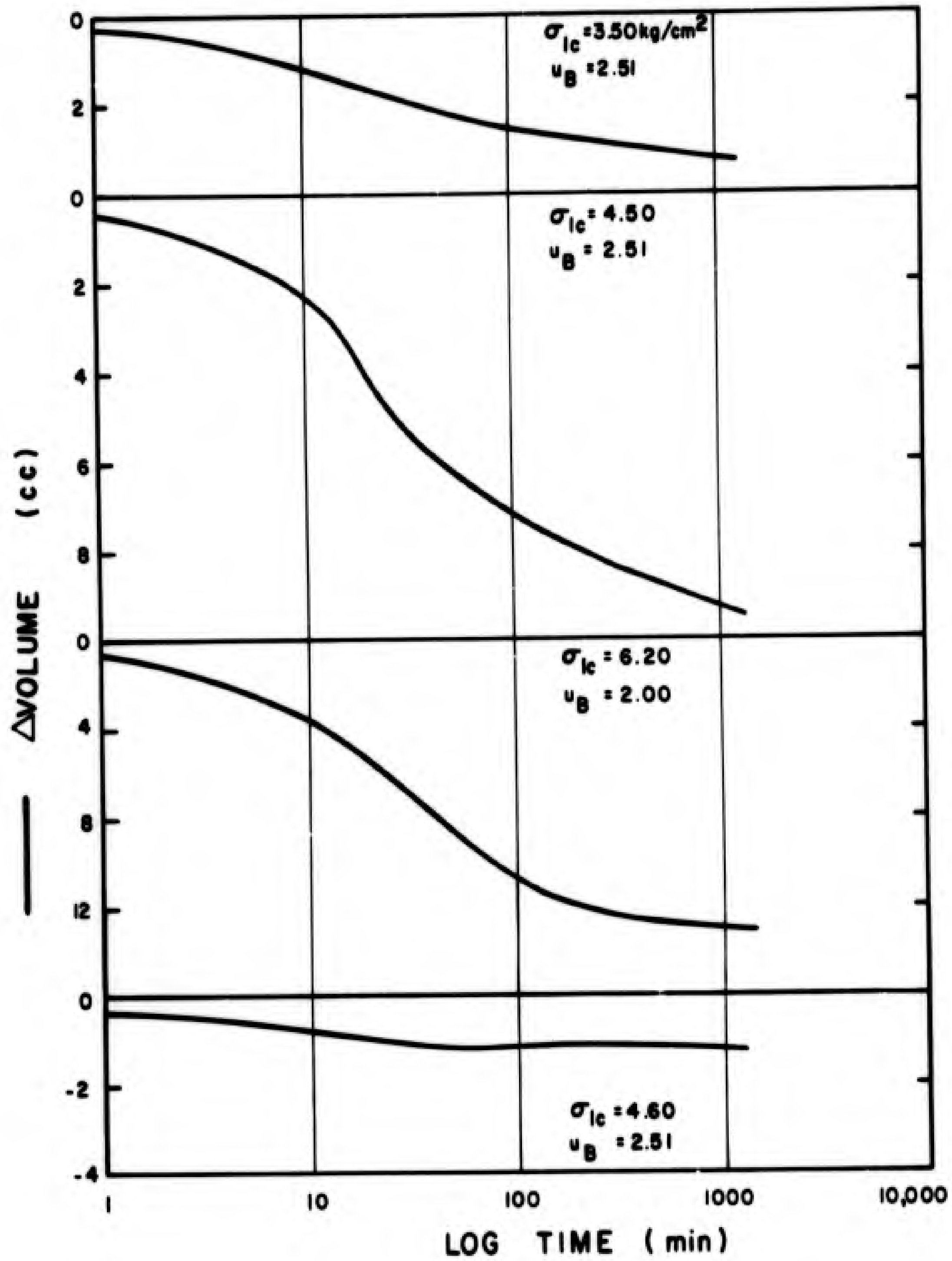
CHANGE IN VOLUME AND HEIGHT VS LOG TIME
FOR $\overline{CK_oU}$PSP-3, OCR=4.25

Figure C-8



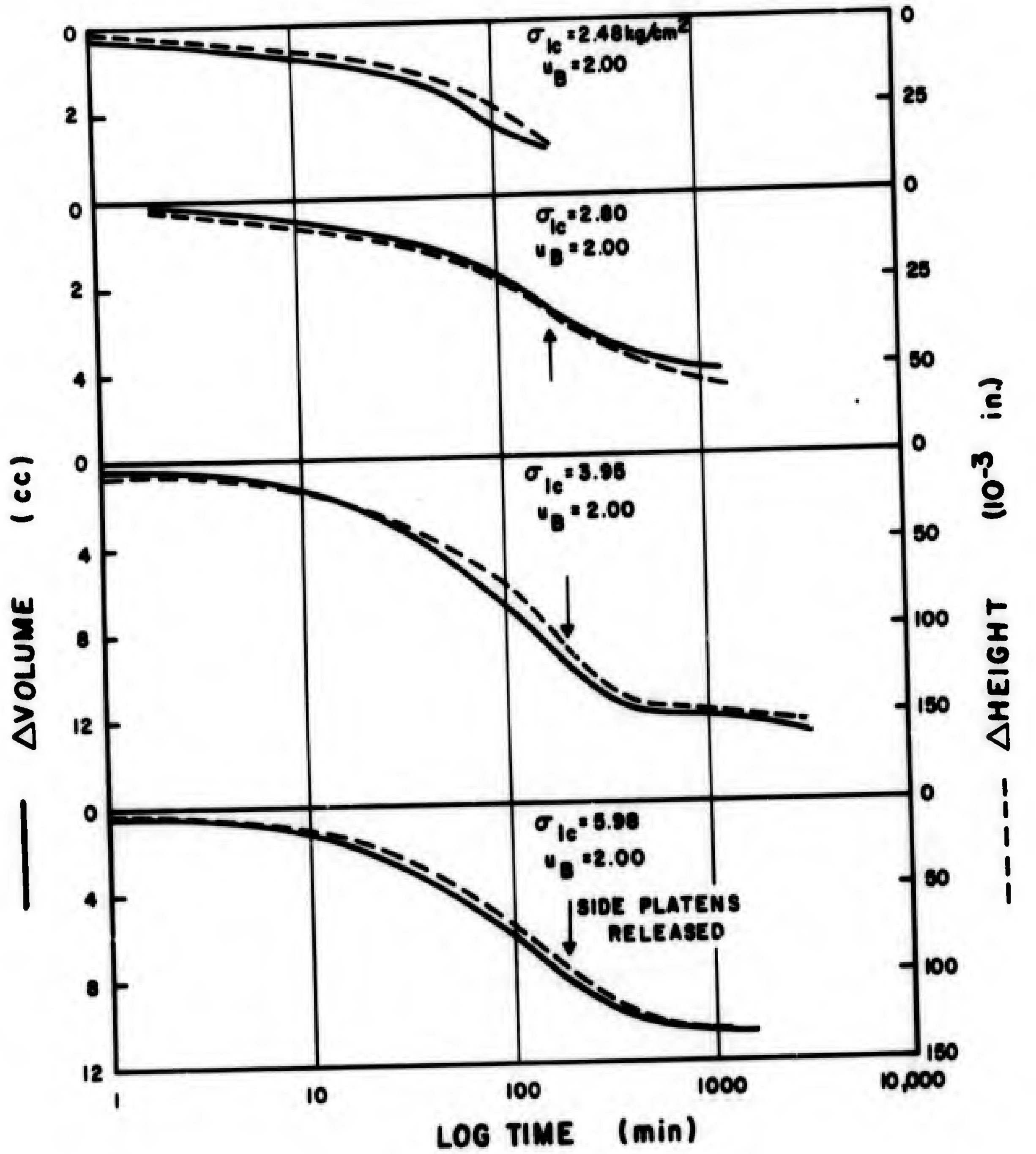
CHANGE IN VOLUME VS LOG TIME
FOR $\overline{CK_0U}$PSP-4H, OCR= 1.0

Figure C-9



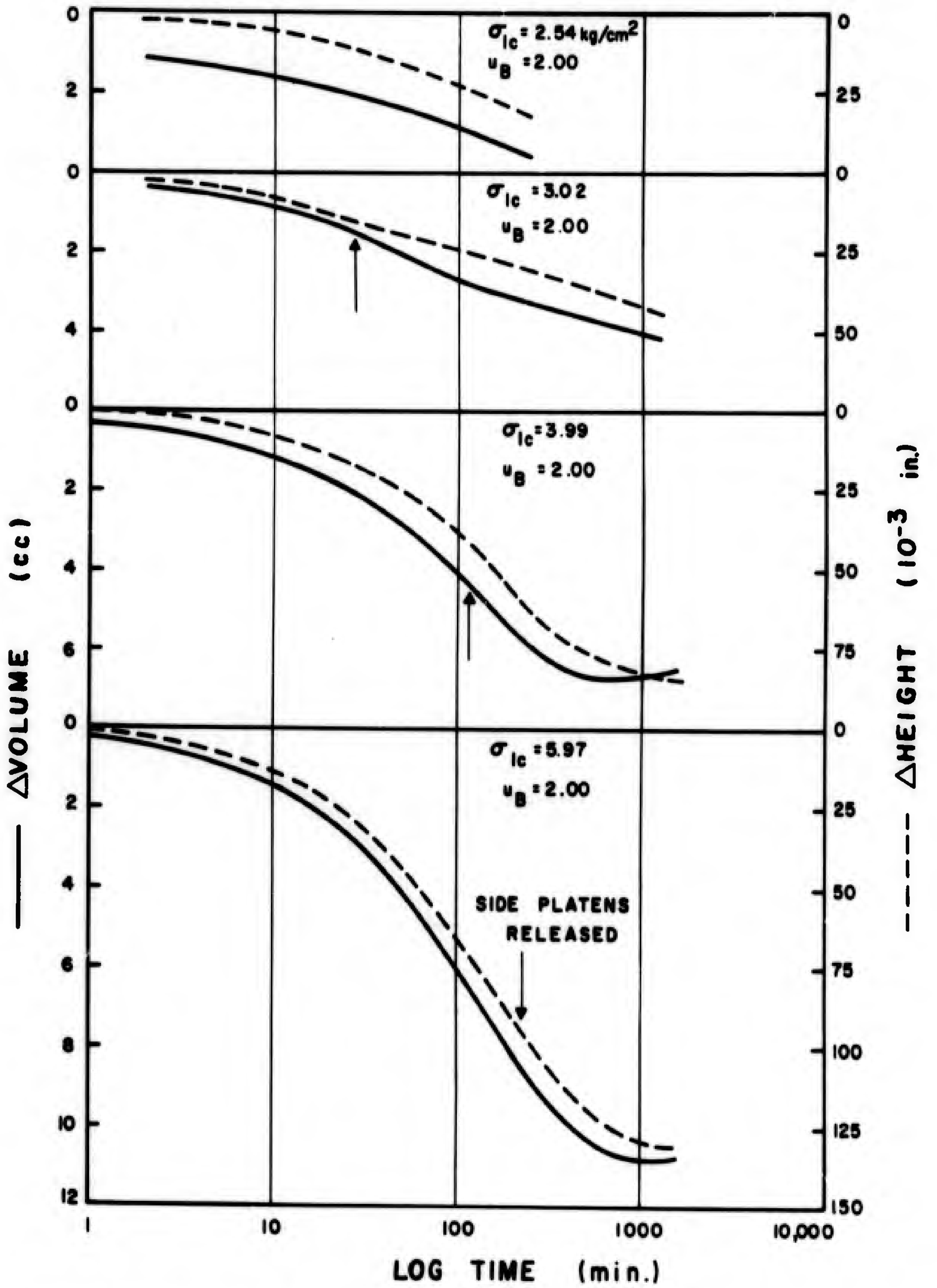
CHANGE IN VOLUME VS LOG TIME
FOR $\overline{CK_0U}$PSP-9H, OCR=2.00

Figure C-10



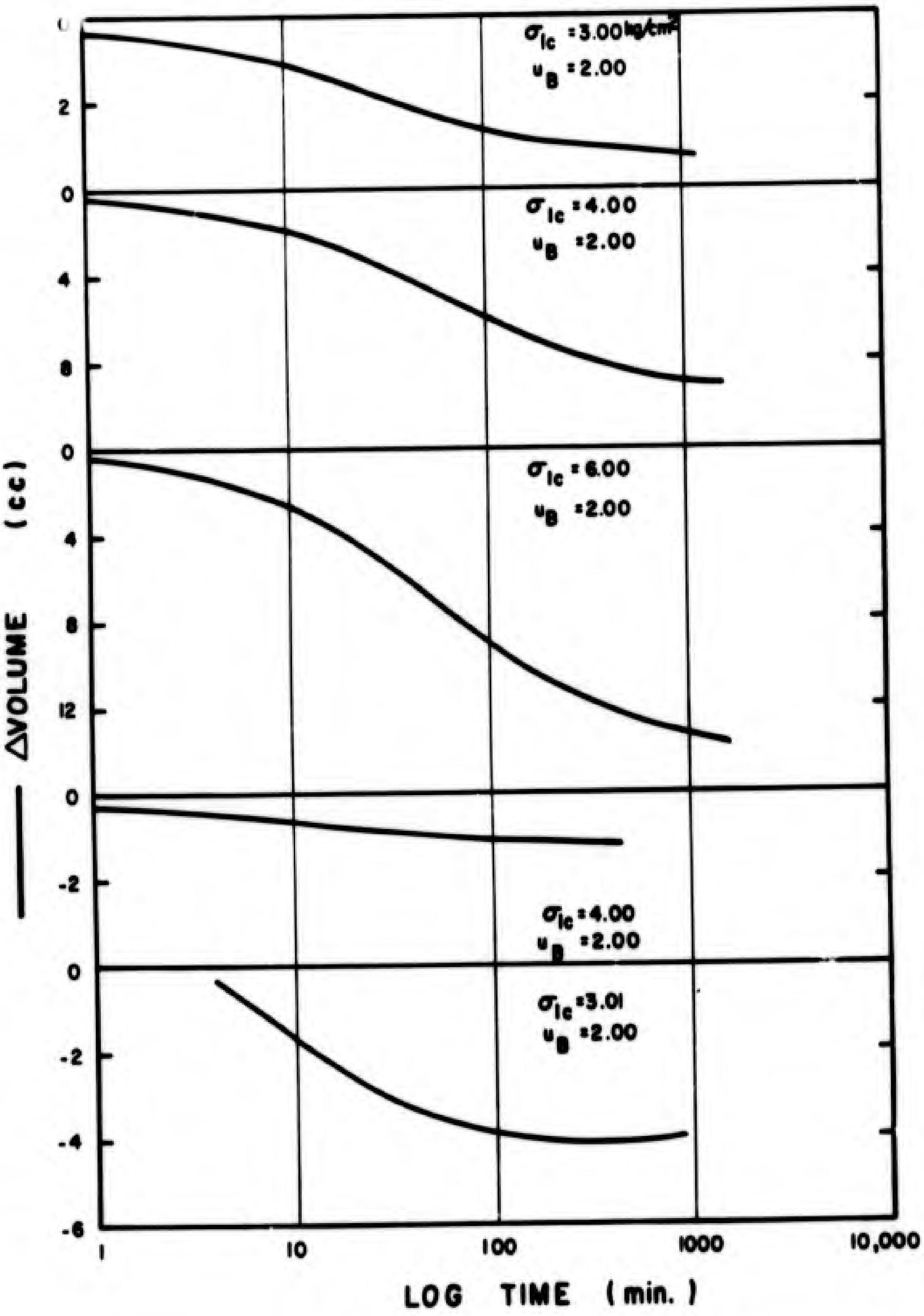
CHANGE IN VOLUME AND HEIGHT VS LOG TIME FOR $\overline{CK_oU}$PSP-10, OCR = 1.0

Figure C-11



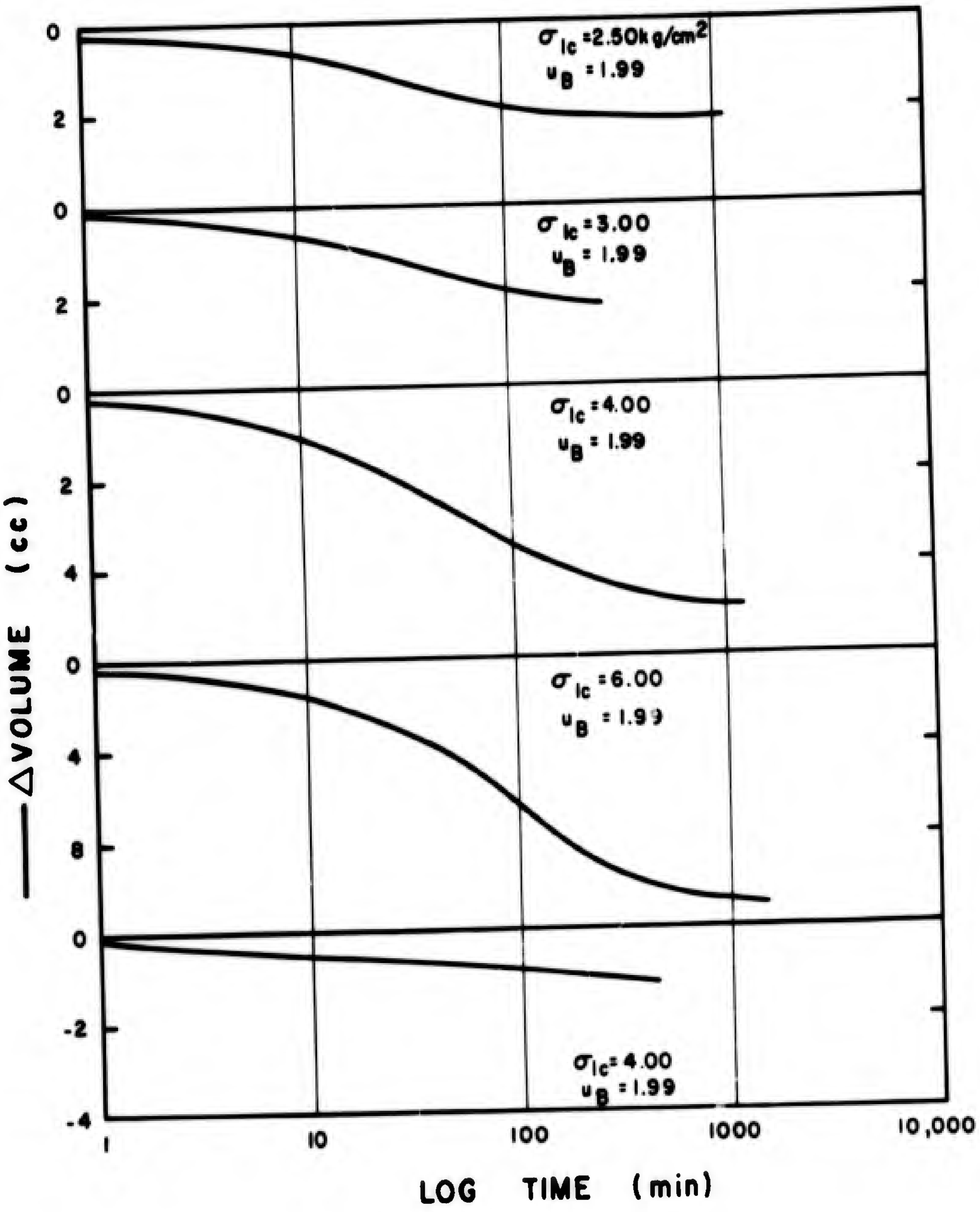
CHANGE IN VOLUME AND HEIGHT VS LOG TIME FOR $\overline{CK_oU}$PSP-11, OCR = 1.0

Figure C-12



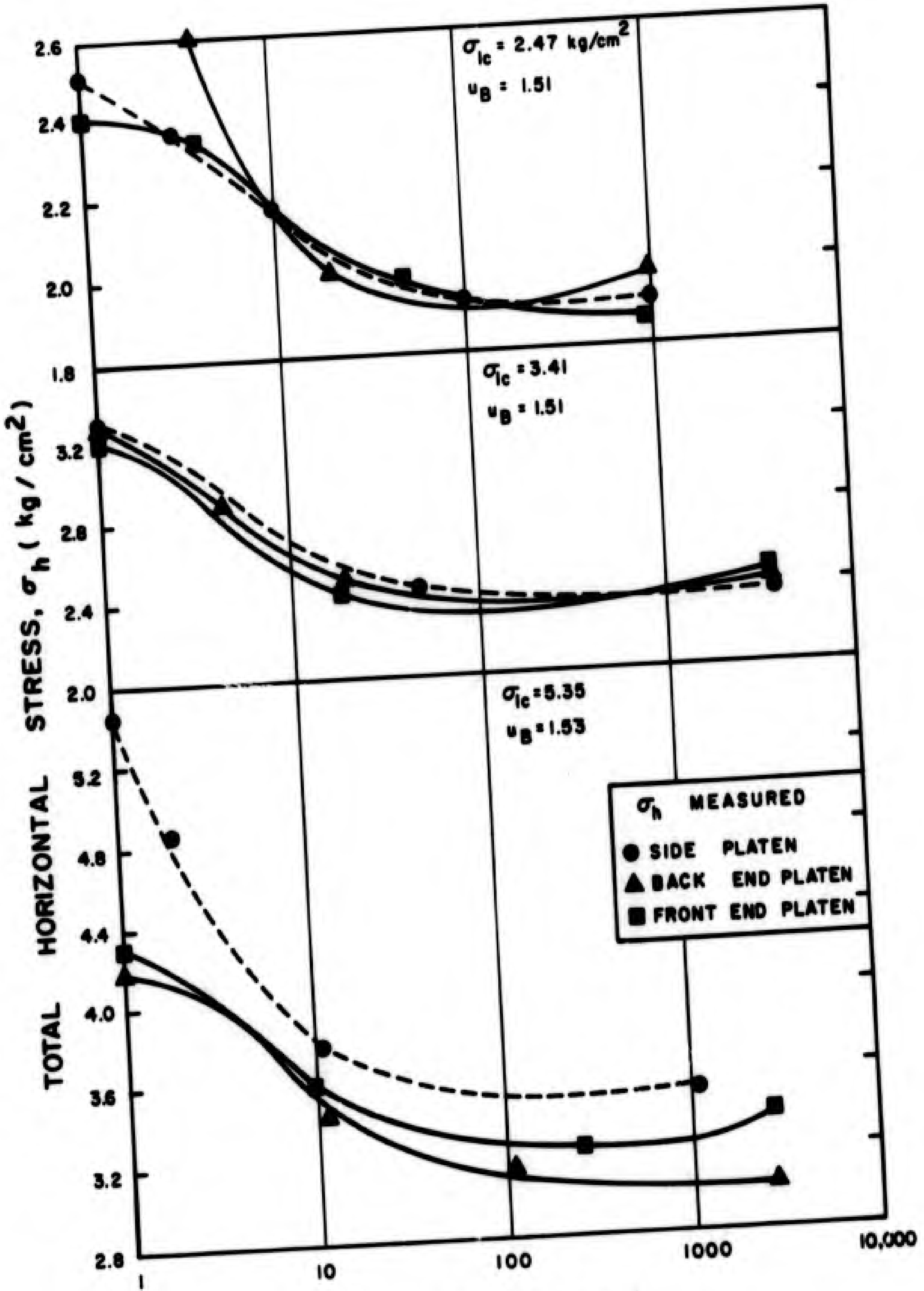
CHANGE IN VOLUME VS LOG TIME FOR $\overline{CK_0U}PSP$-12H, OCR = 3.96

Figure C-13



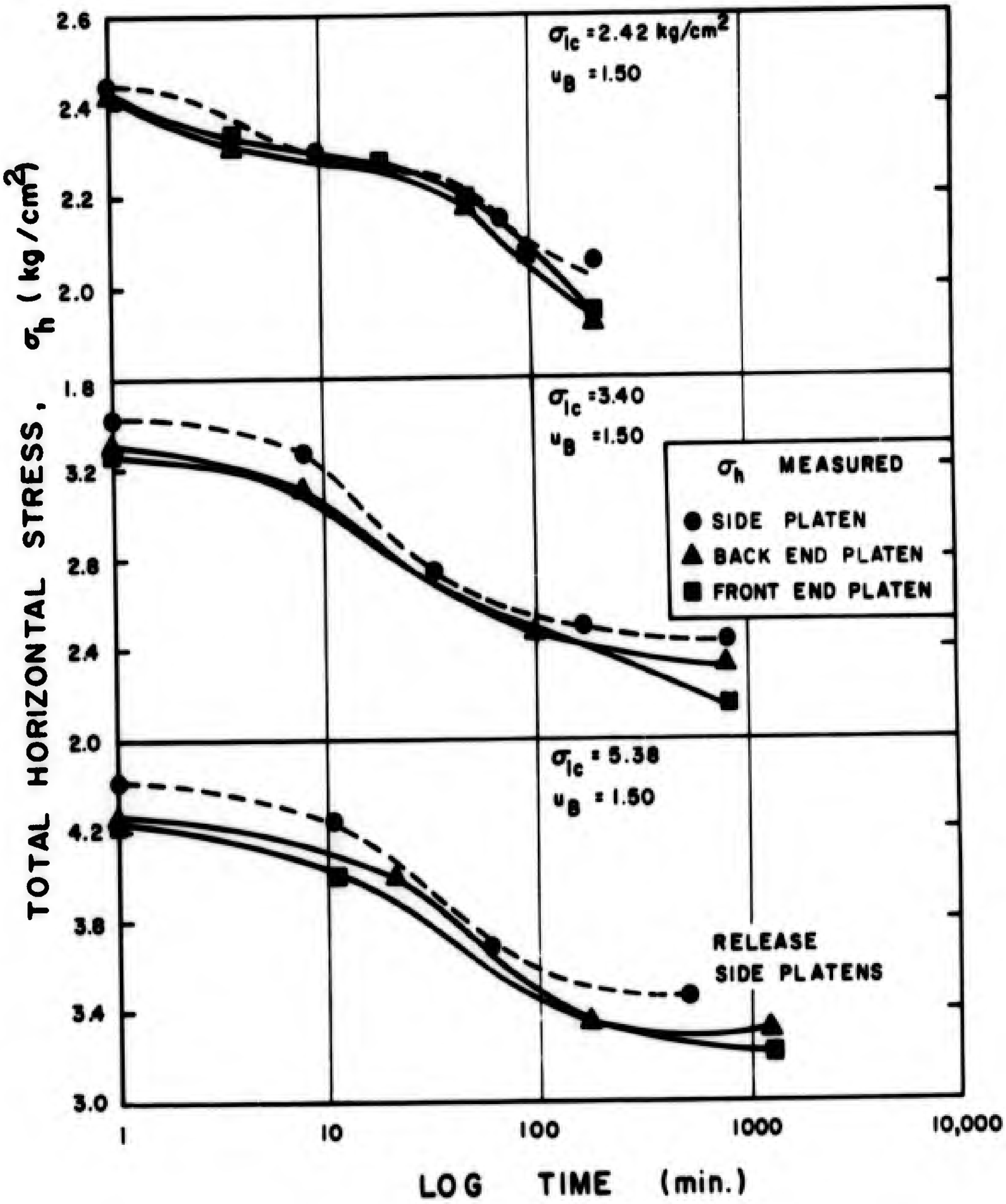
CHANGE IN VOLUME VS LOG TIME FOR $\overline{\text{CK}_o\text{U}}$PSP-17H, OCR=2.00

Figure C-14



TOTAL HORIZONTAL STRESS VS. LOG TIME
$\overline{CK_oU}$PSA - 3, OCR = 1.0

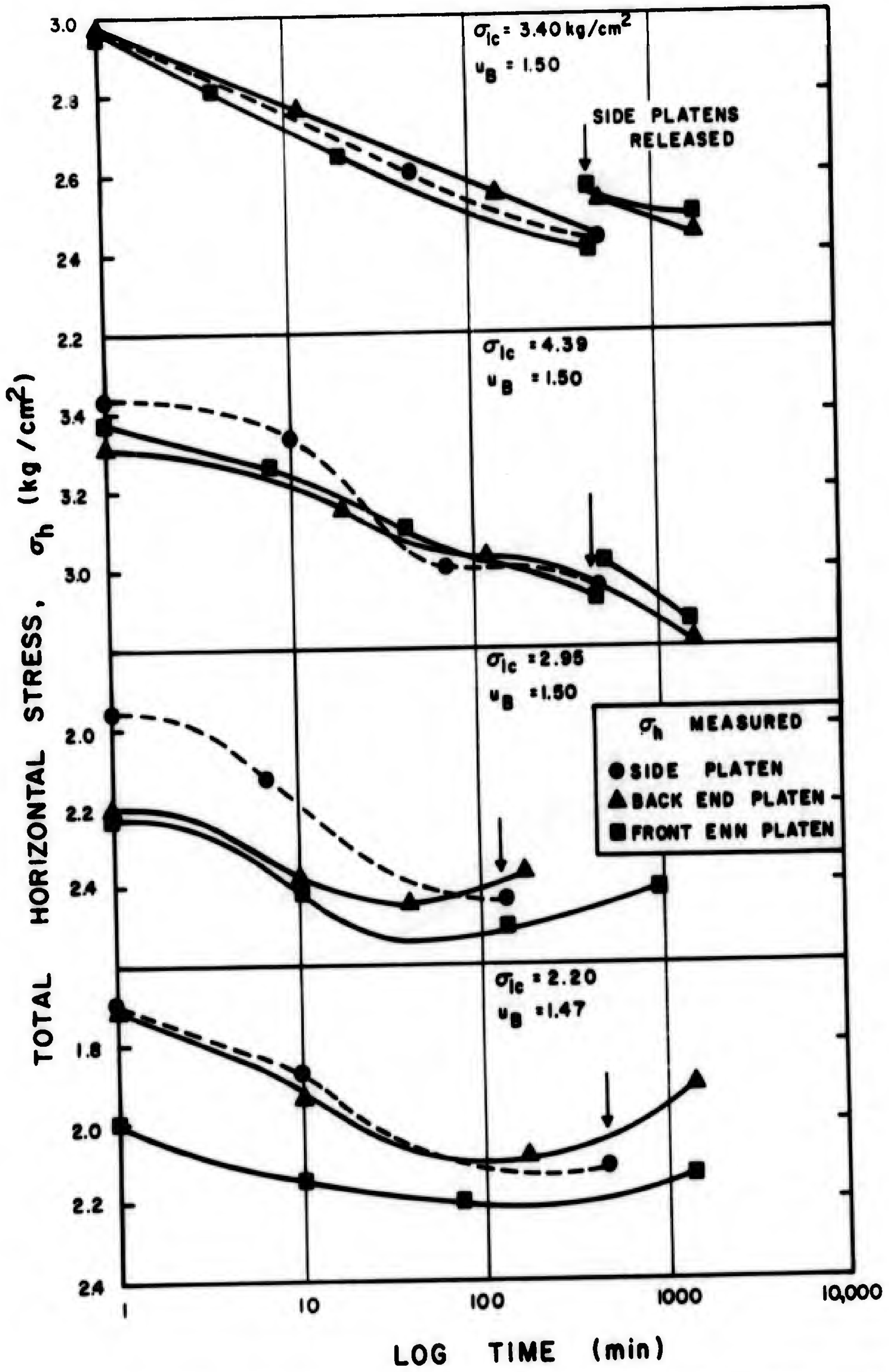
Figure C-15



TOTAL HORIZONTAL STRESS VS LOG TIME

$\overline{\mathrm{CK_0UPSA}}$-4, OCR = 1.0

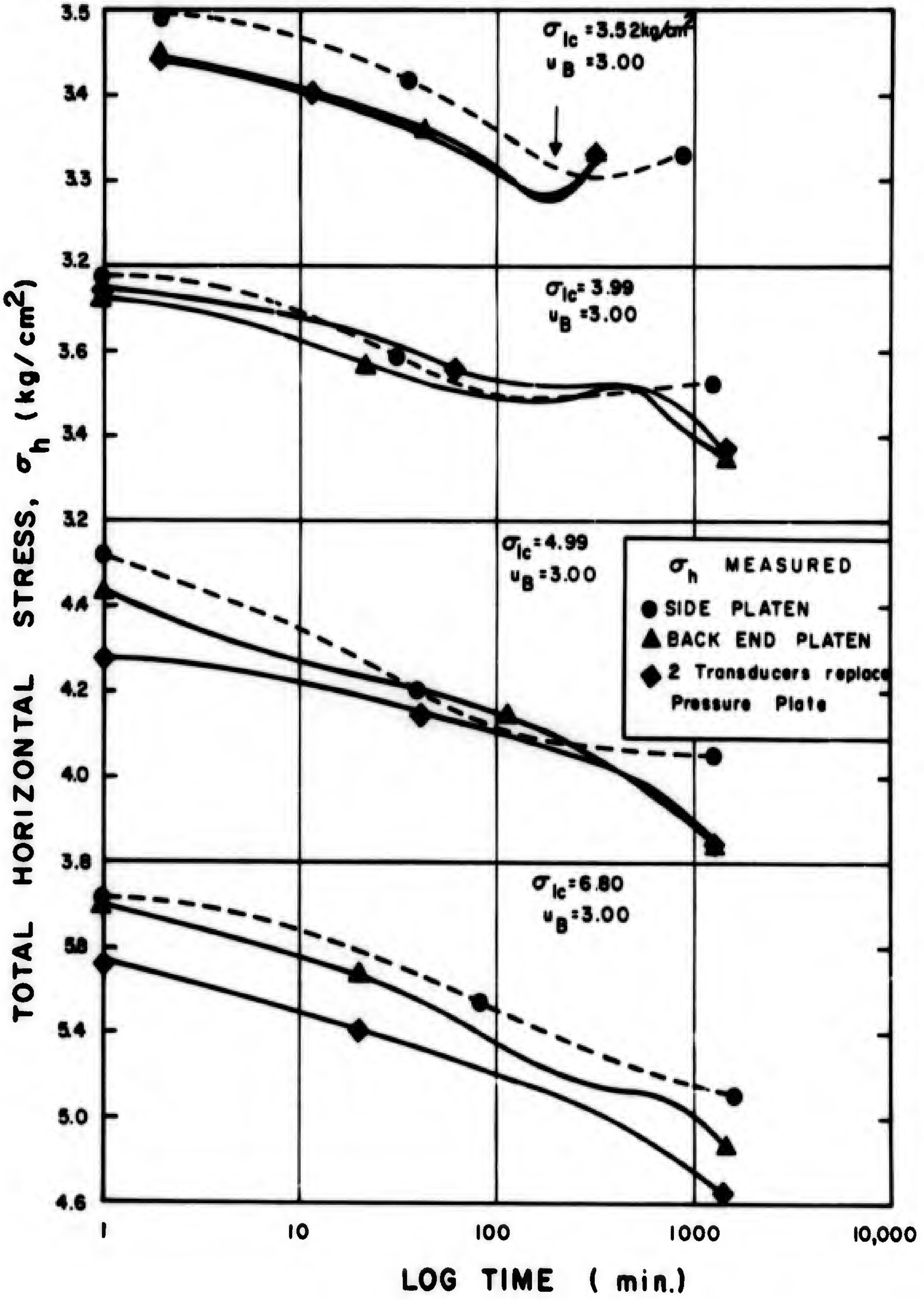
Figure C-16



TOTAL HORIZONTAL STRESS VS LOG TIME

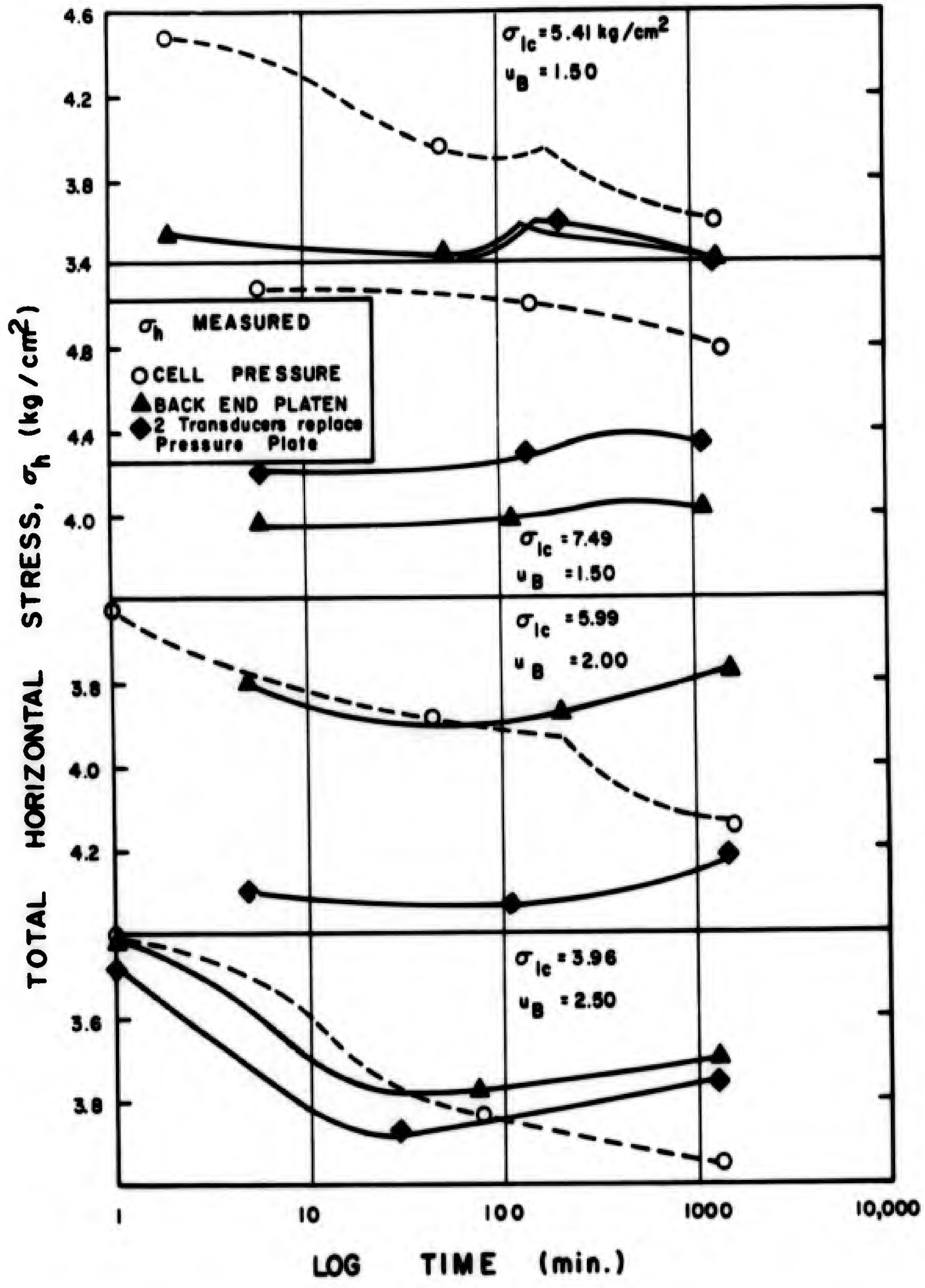
$\overline{CK_oU}$PSA -5, OCR=3.94

Figure C-17



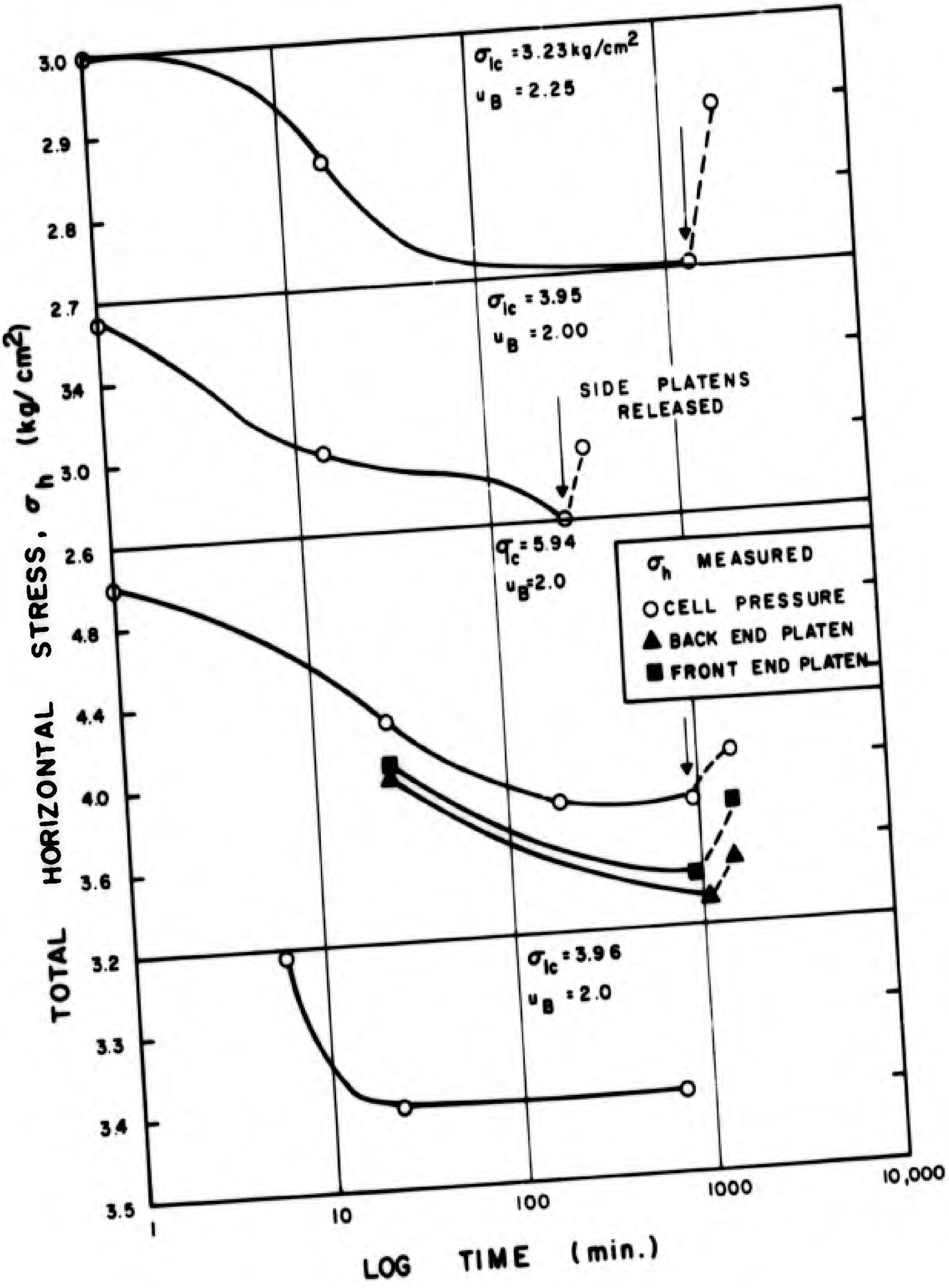
TOTAL HORIZONTAL STRESS VS LOG TIME
FOR $\overline{CK_oU}$PSA-6, OCR = 1.0

Figure C-18



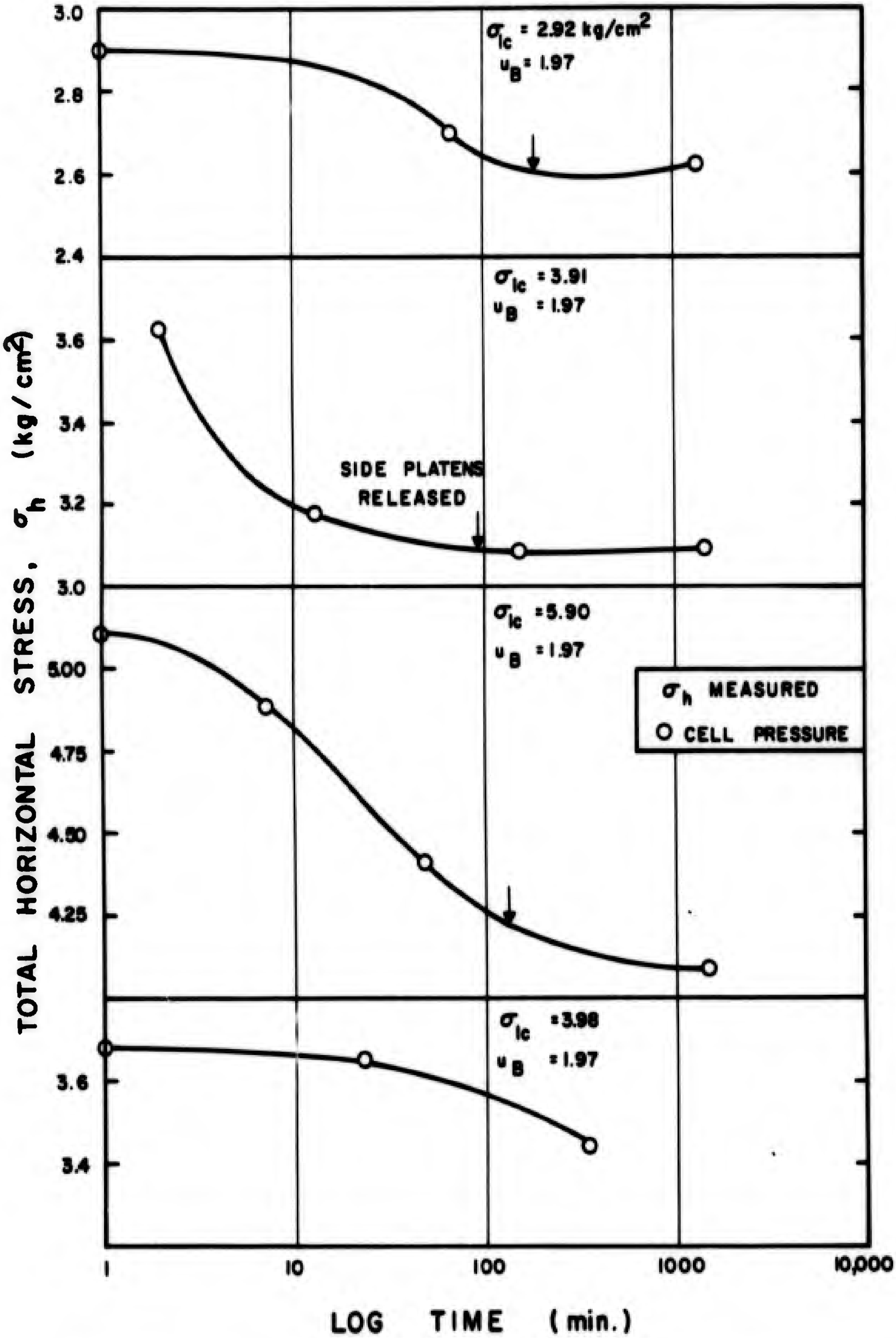
TOTAL HORIZONTAL STRESS VS LOG TIME
CK$_o$UPSA-7, OCR = 4.10

Figure C-19



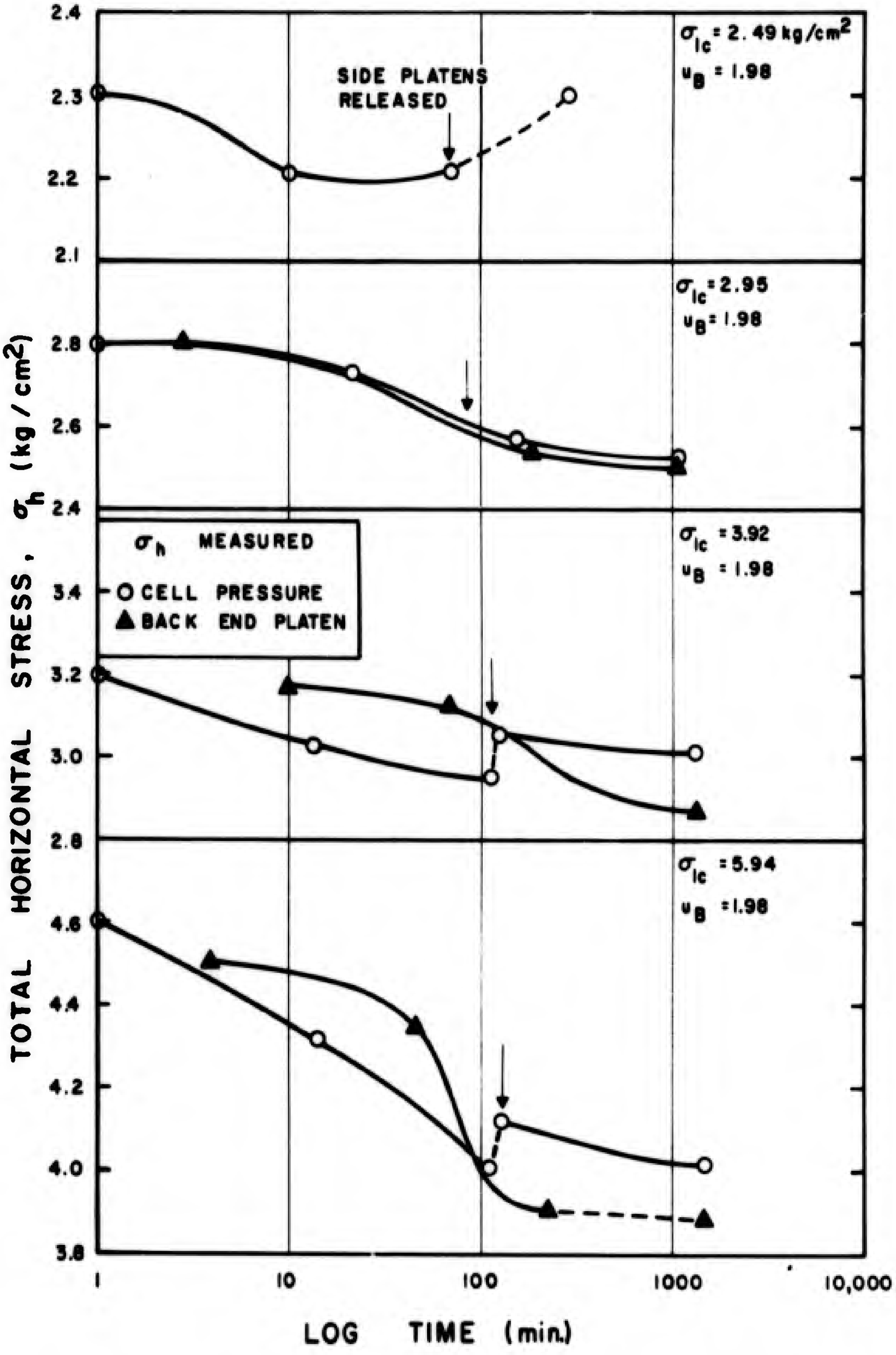
TOTAL HORIZONTAL STRESS VS LOG TIME
$\overline{CK_oU}$PSA -8 , OCR =2.02

Figure C-20



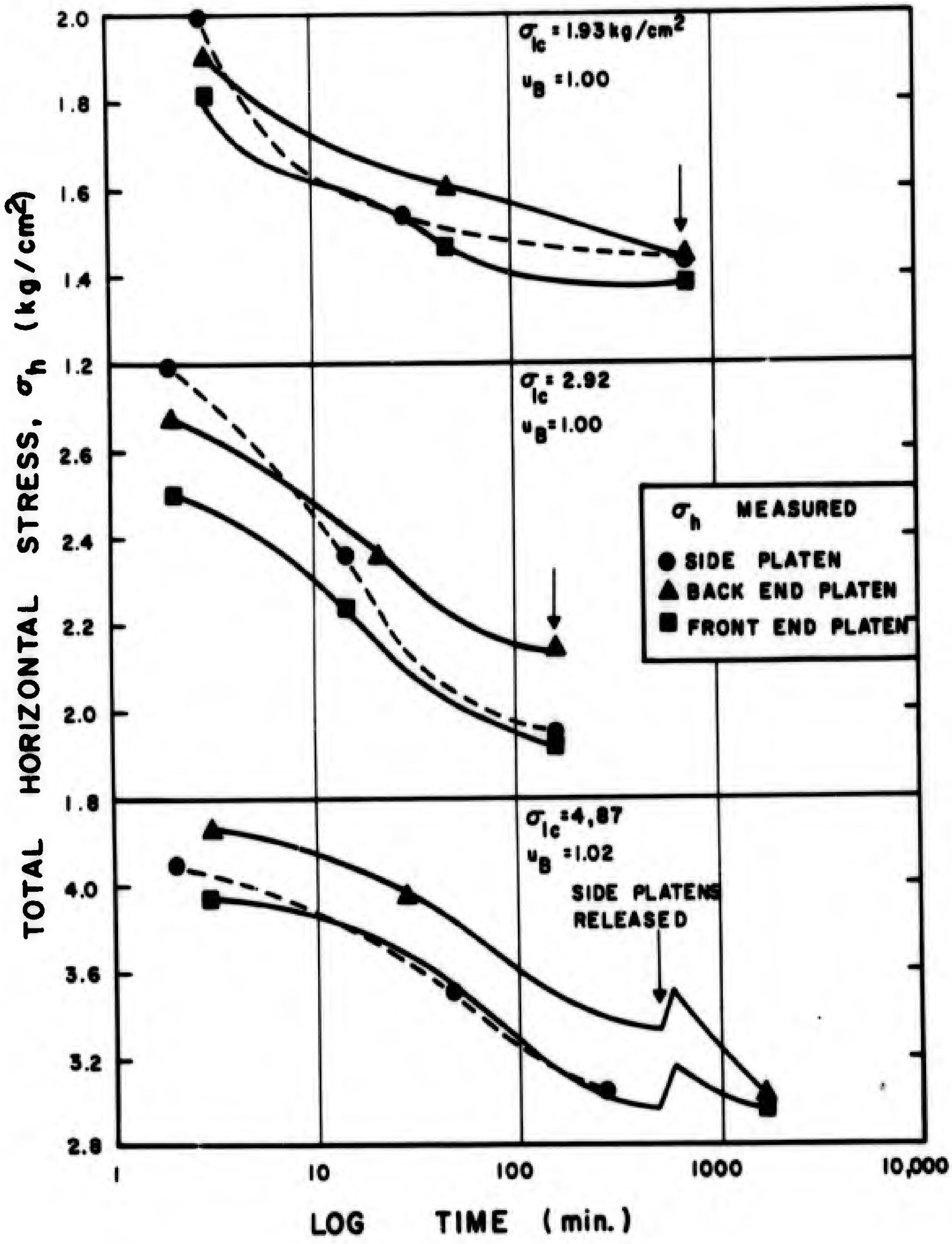
TOTAL HORIZONTAL STRESS VS LOG TIME
$\overline{\text{CK}_0\text{U}}$PSA-9, OCR = 1.96

Figure C-21



TOTAL HORIZOTAL STRESS VS LOG TIME
$\overline{\text{CK}_0}$UPSA-10, OCR = 1.0

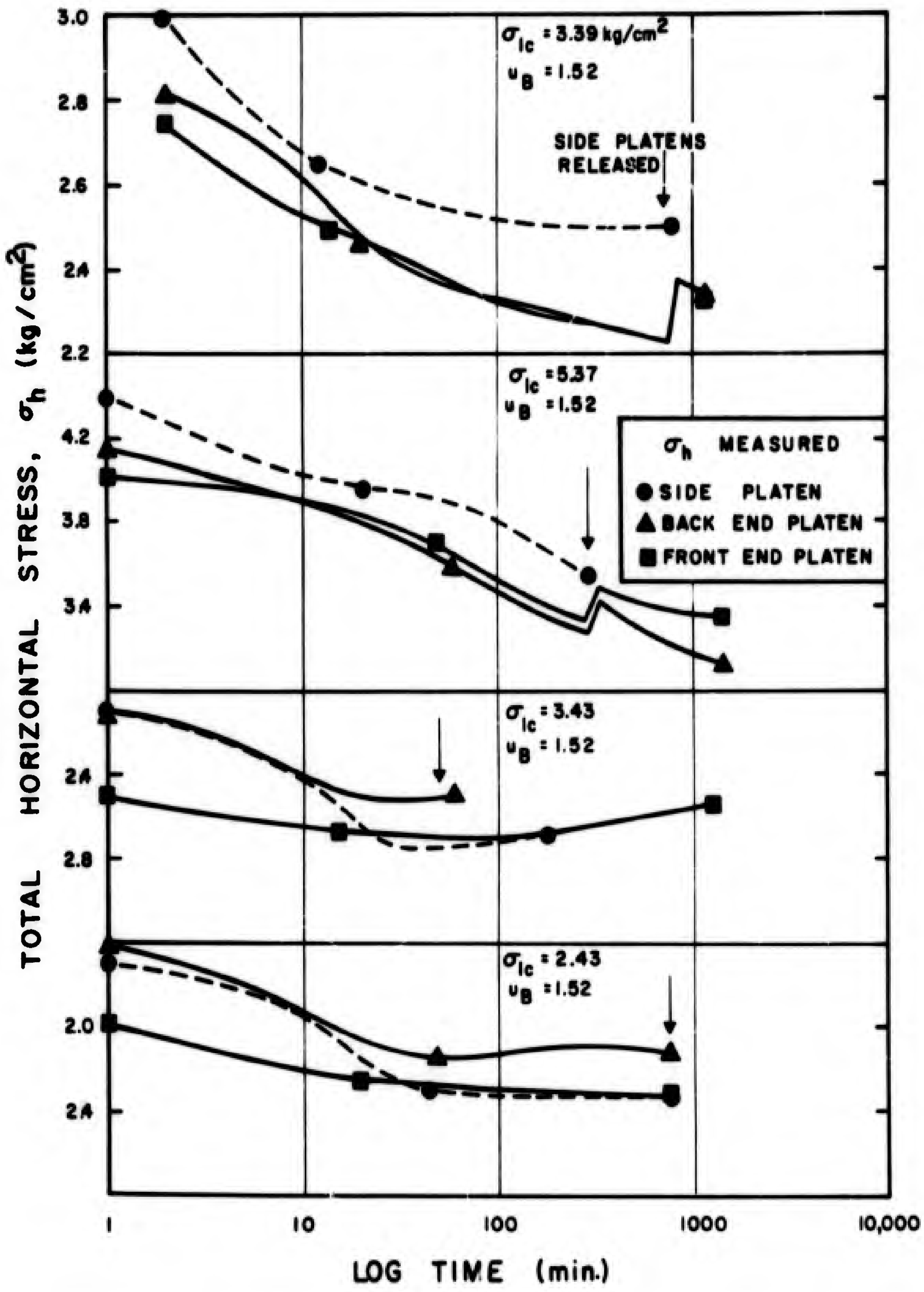
Figure C-22



TOTAL HORIZONTAL STRESS VS LOG TIME

$\overline{CK_oU}$PSP -2, OCR = 1.0

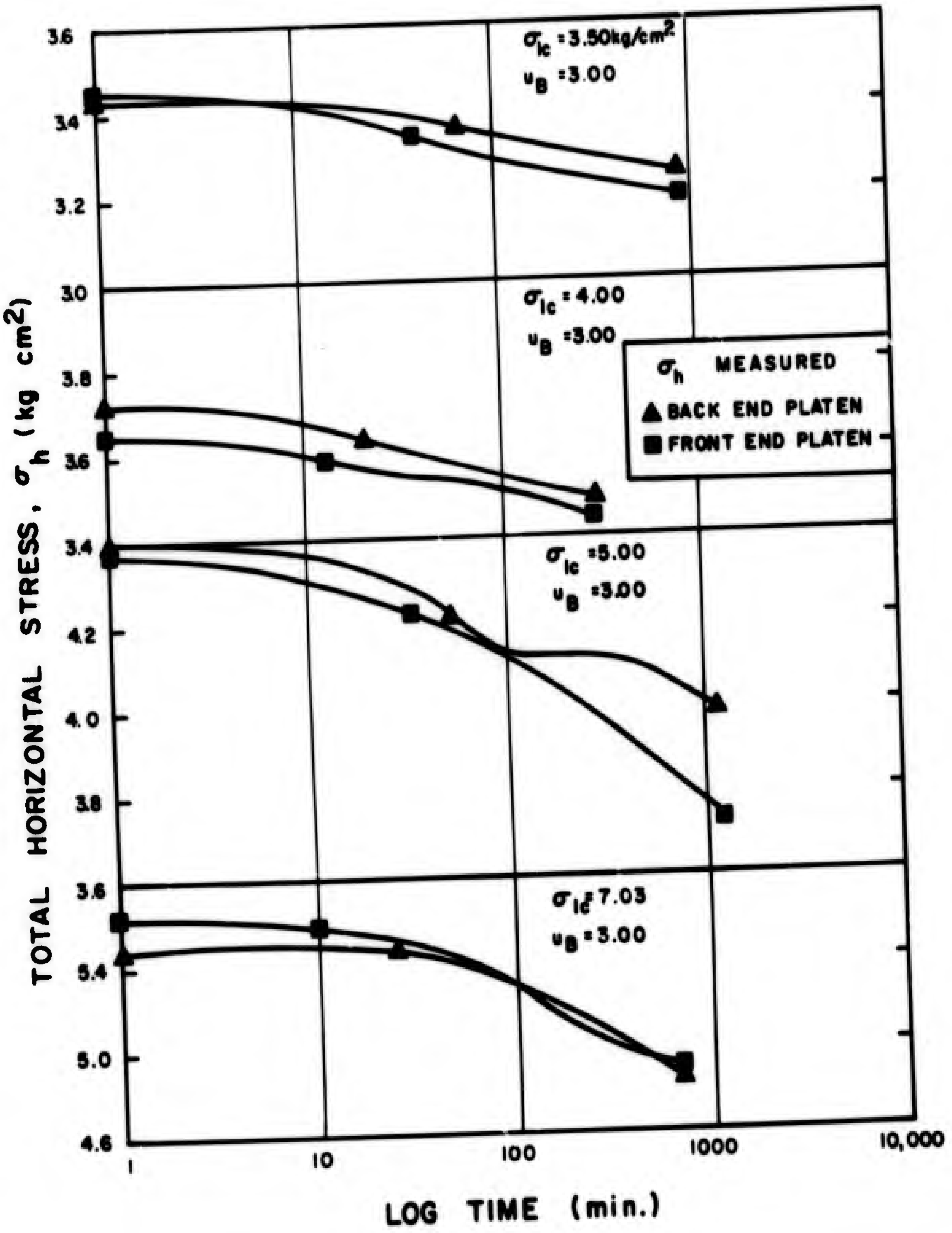
Figure C-23



TOTAL HORIZONTAL STRESS VS LOG TIME

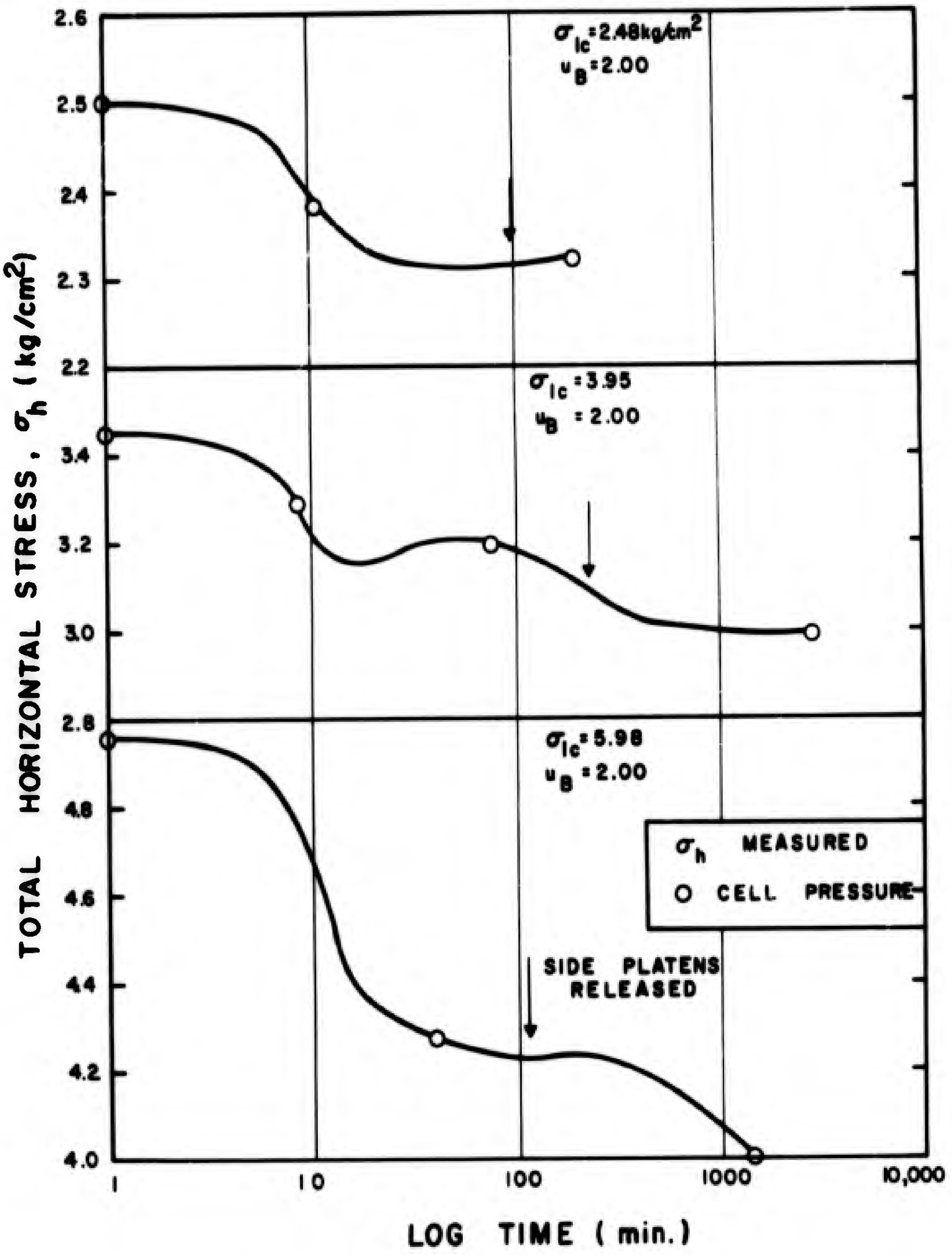
$\overline{\mathrm{CK_0U}}$PSP-3 , OCR = 4.25

Figure C-24



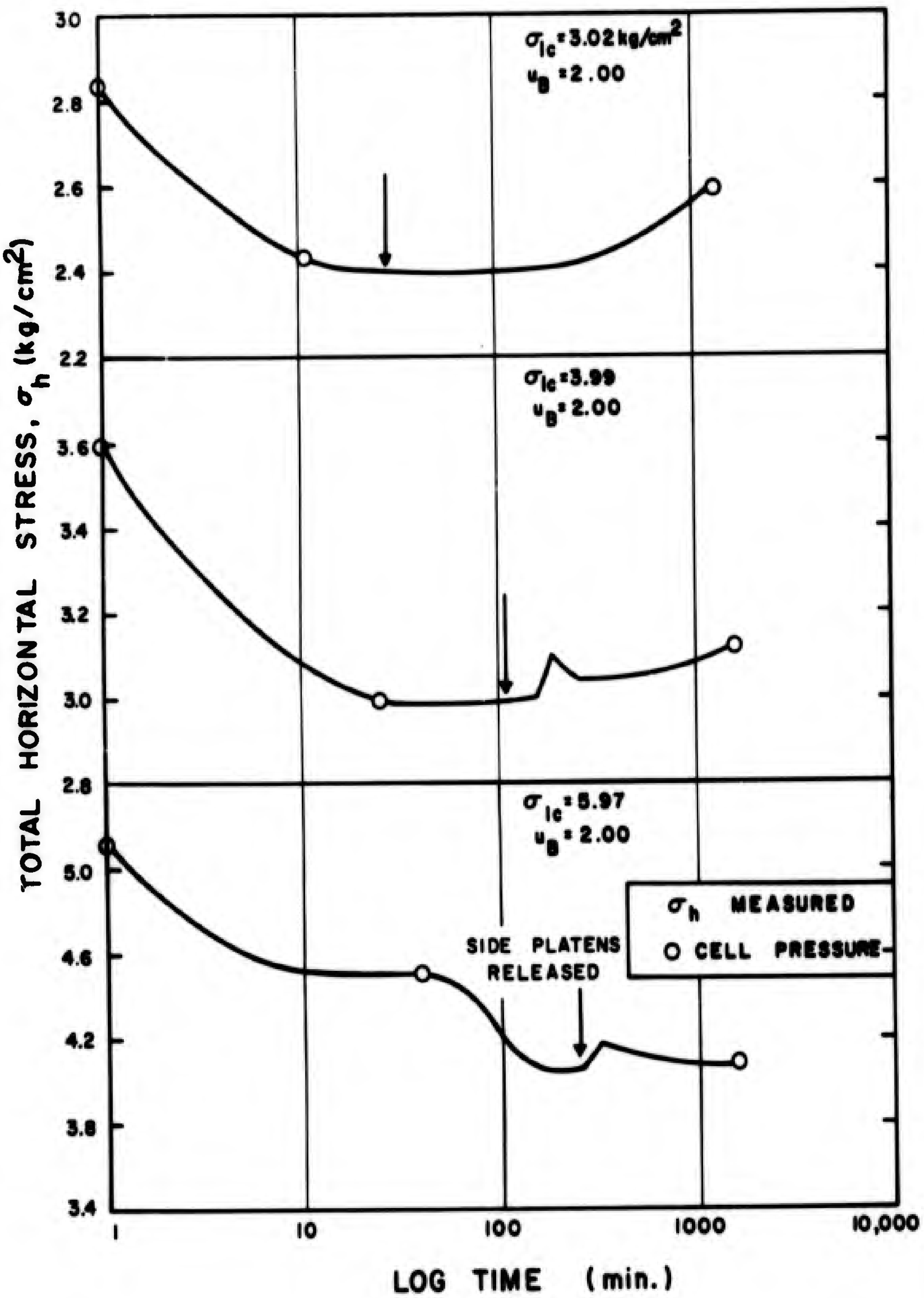
TOTAL HORIZONTAL STRESS VS LOG TIME FOR $\overline{CK_oU}$PSP-4H, OCR=1.0

Figure C-25



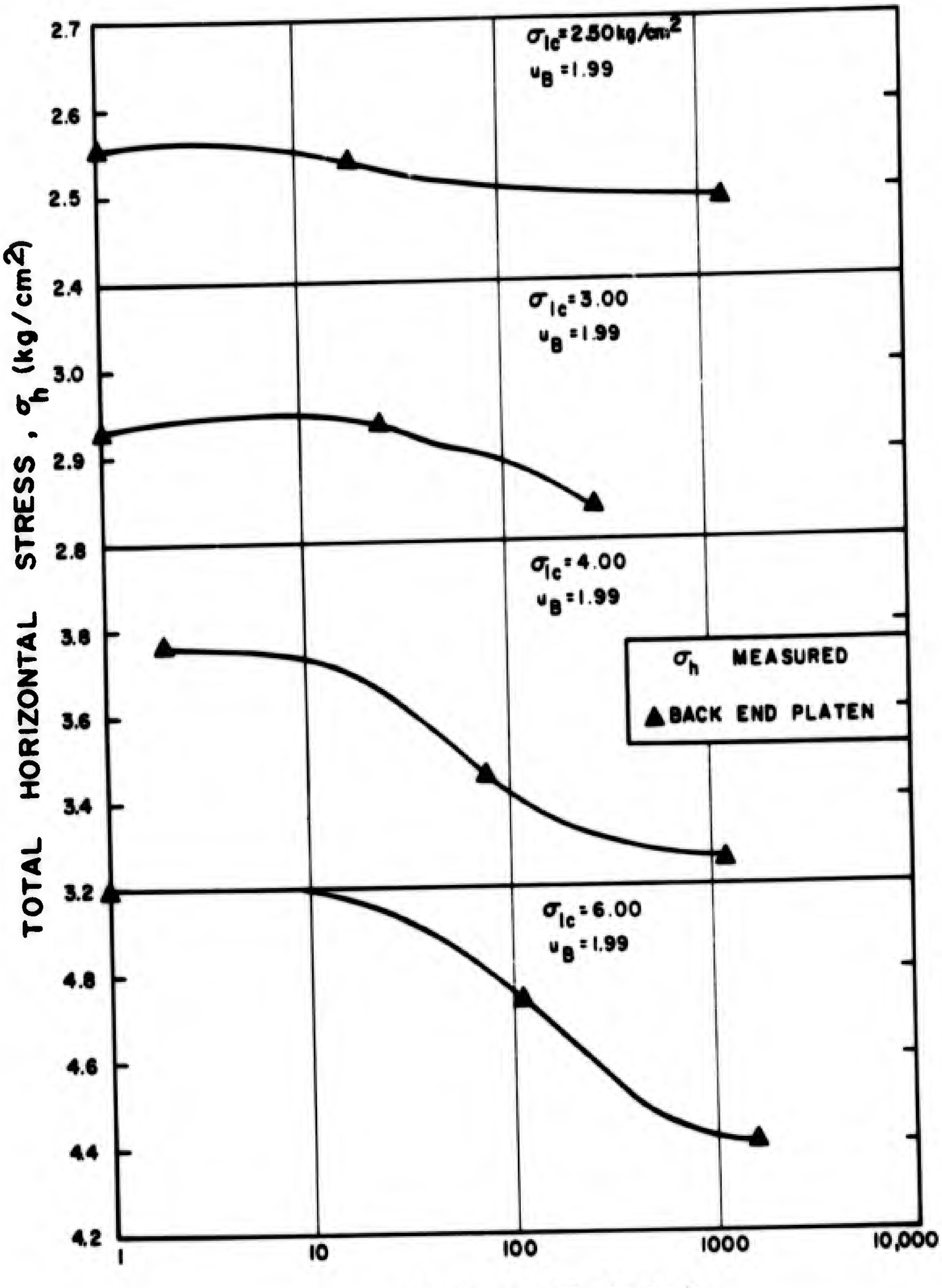
TOTAL HORIZONTAL STRESS VS LOG TIME FOR $\overline{CK_oU}$PSP-10, OCR=1.0

Figure C-26



TOTAL HORIZONTAL STRESS VS LOG TIME FOR $\overline{CK_oUPSP}$-II, OCR=1.0

Figure C-27



TOTAL HORIZONTAL STRESS VS LOG TIME FOR $\overline{\text{CK}_0\text{U}}$PSP-17H, OCR = 2.0

Figure C-28

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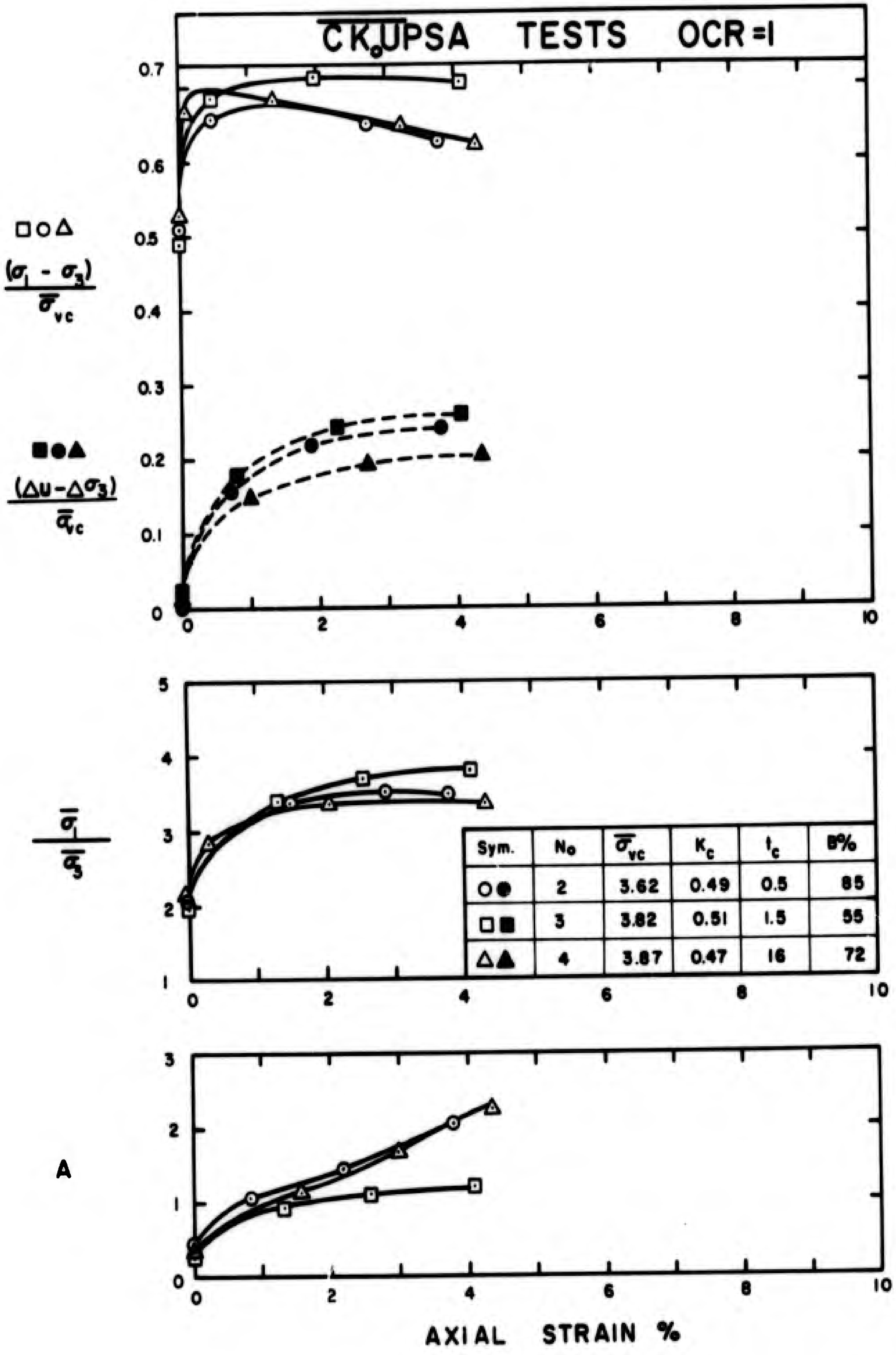
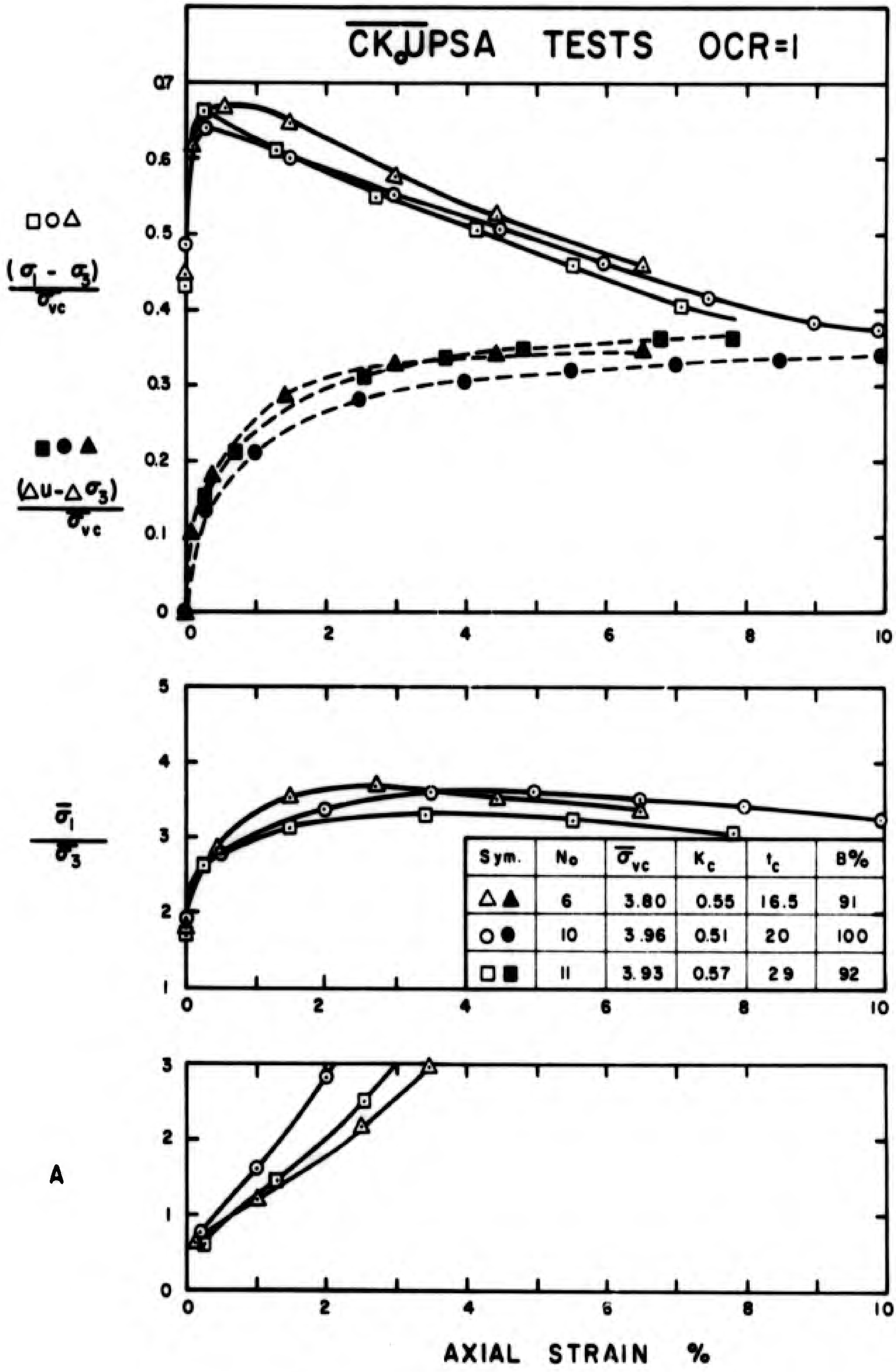
APPENDIX D

STRESS-STRAIN AND STRESS PATH DATA DURING UNDRAINED SHEAR



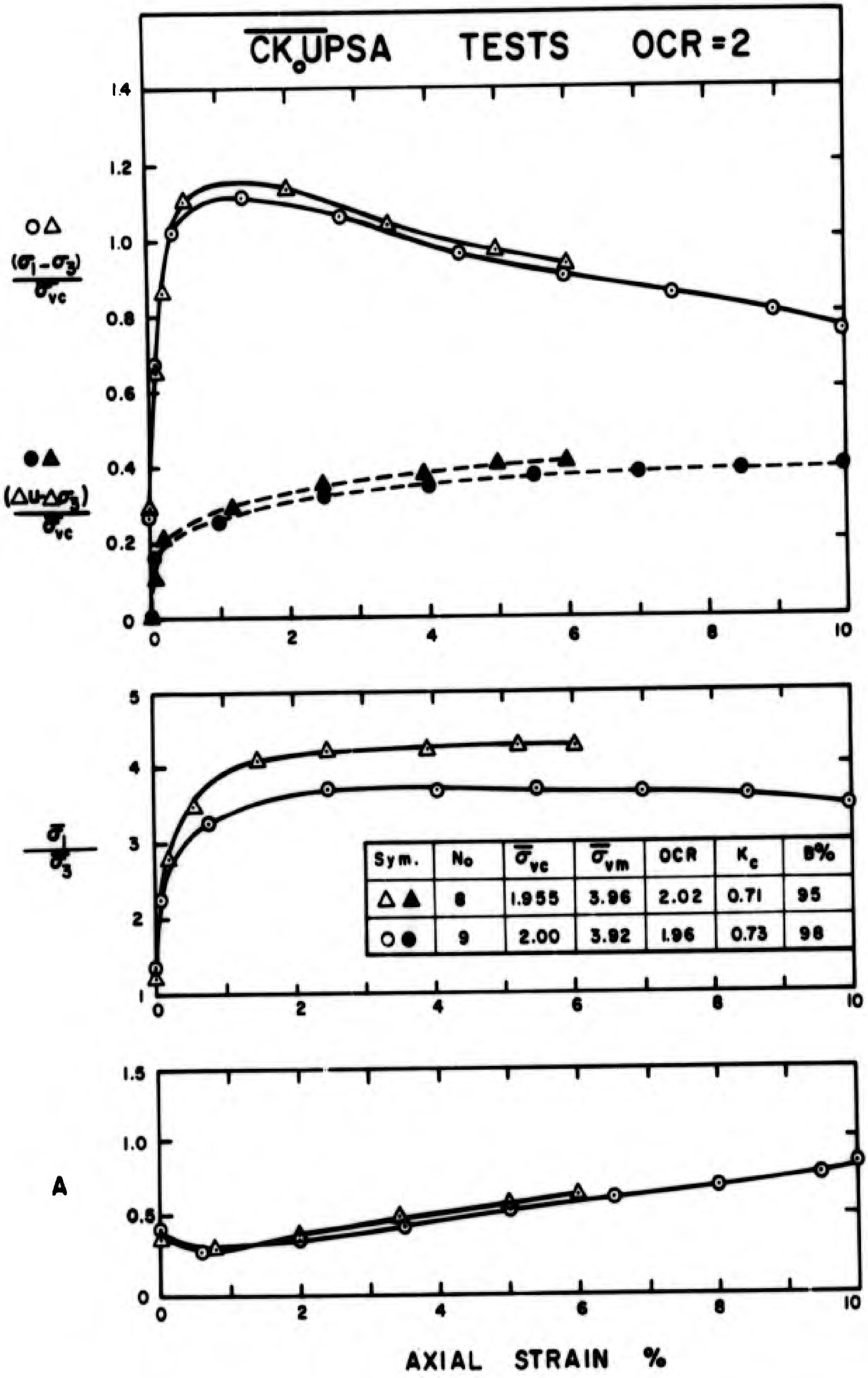
Sym.	No	$\overline{\sigma}_{vc}$	K_c	t_c	B%
○●	2	3.62	0.49	0.5	85
□■	3	3.82	0.51	1.5	55
△▲	4	3.87	0.47	16	72

Figure D-1



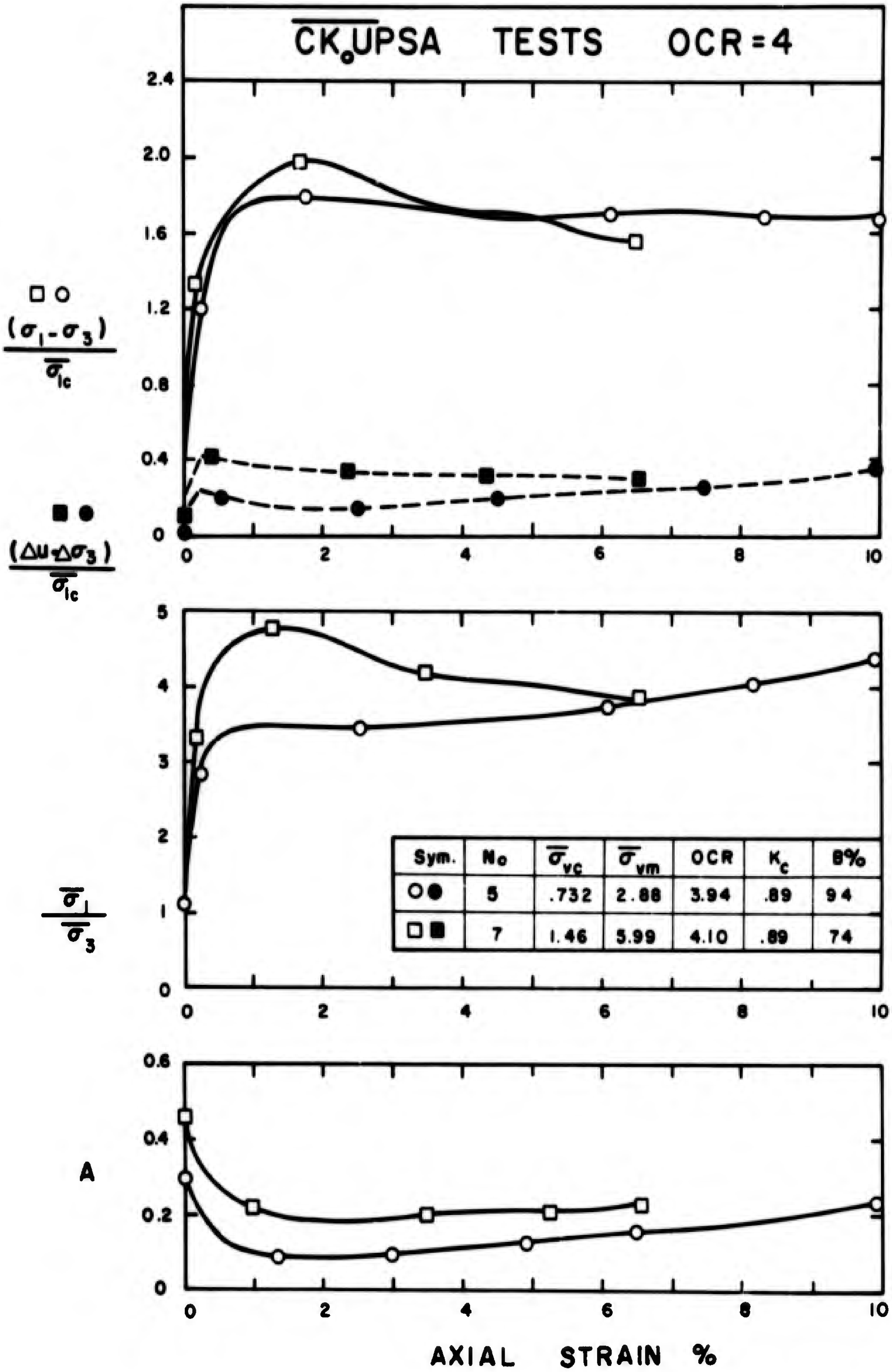
Sym.	No	$\bar{\sigma}_{vc}$	K_c	t_c	B%
△▲	6	3.80	0.55	16.5	91
○●	10	3.96	0.51	20	100
□■	11	3.93	0.57	29	92

Figure D-2



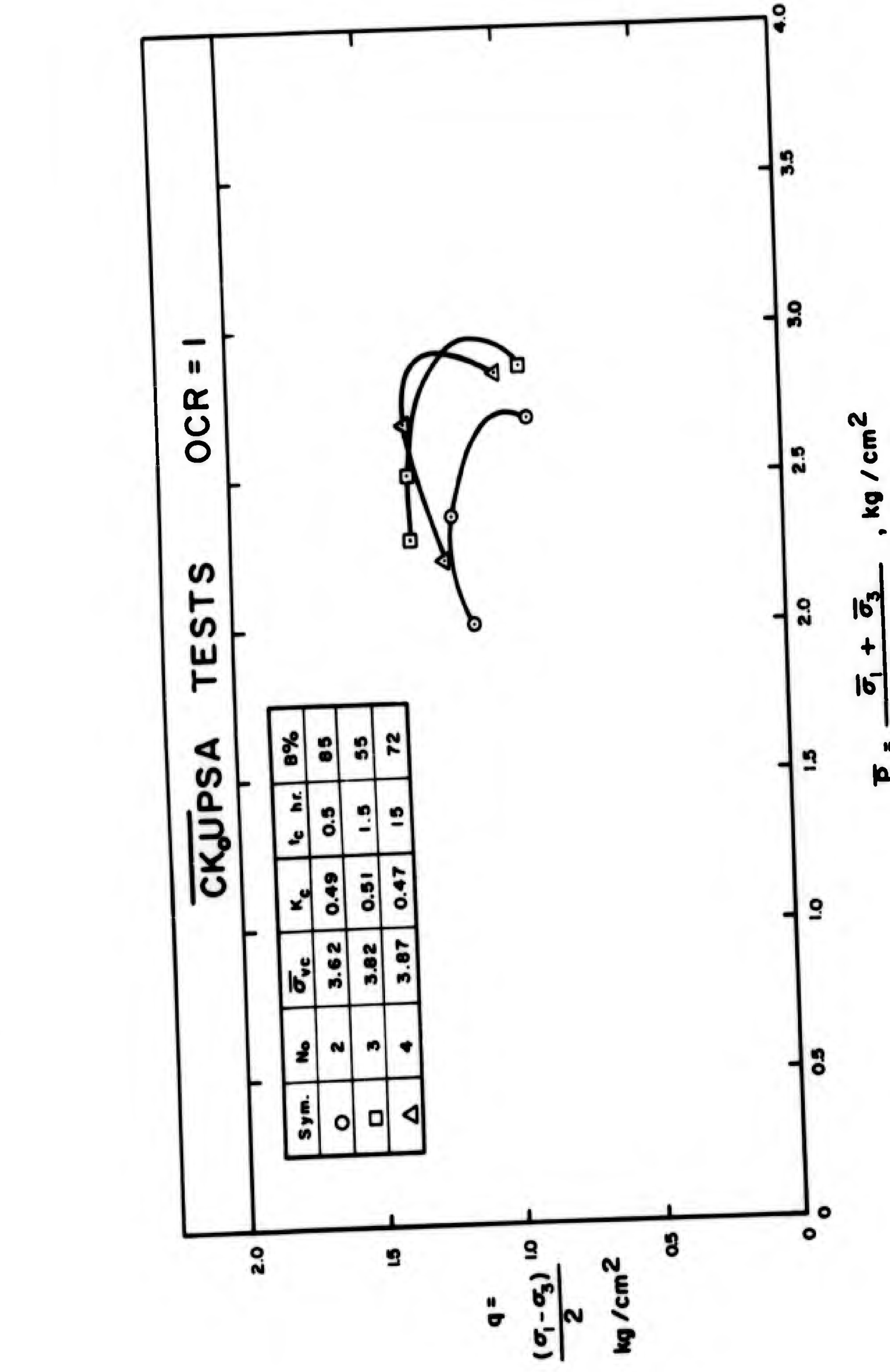
Sym.	No	$\bar{\sigma}_{vc}$	$\bar{\sigma}_{vm}$	OCR	K_c	B%
△ ▲	8	1.955	3.96	2.02	0.71	95
○ ●	9	2.00	3.92	1.96	0.73	98

Figure D-3



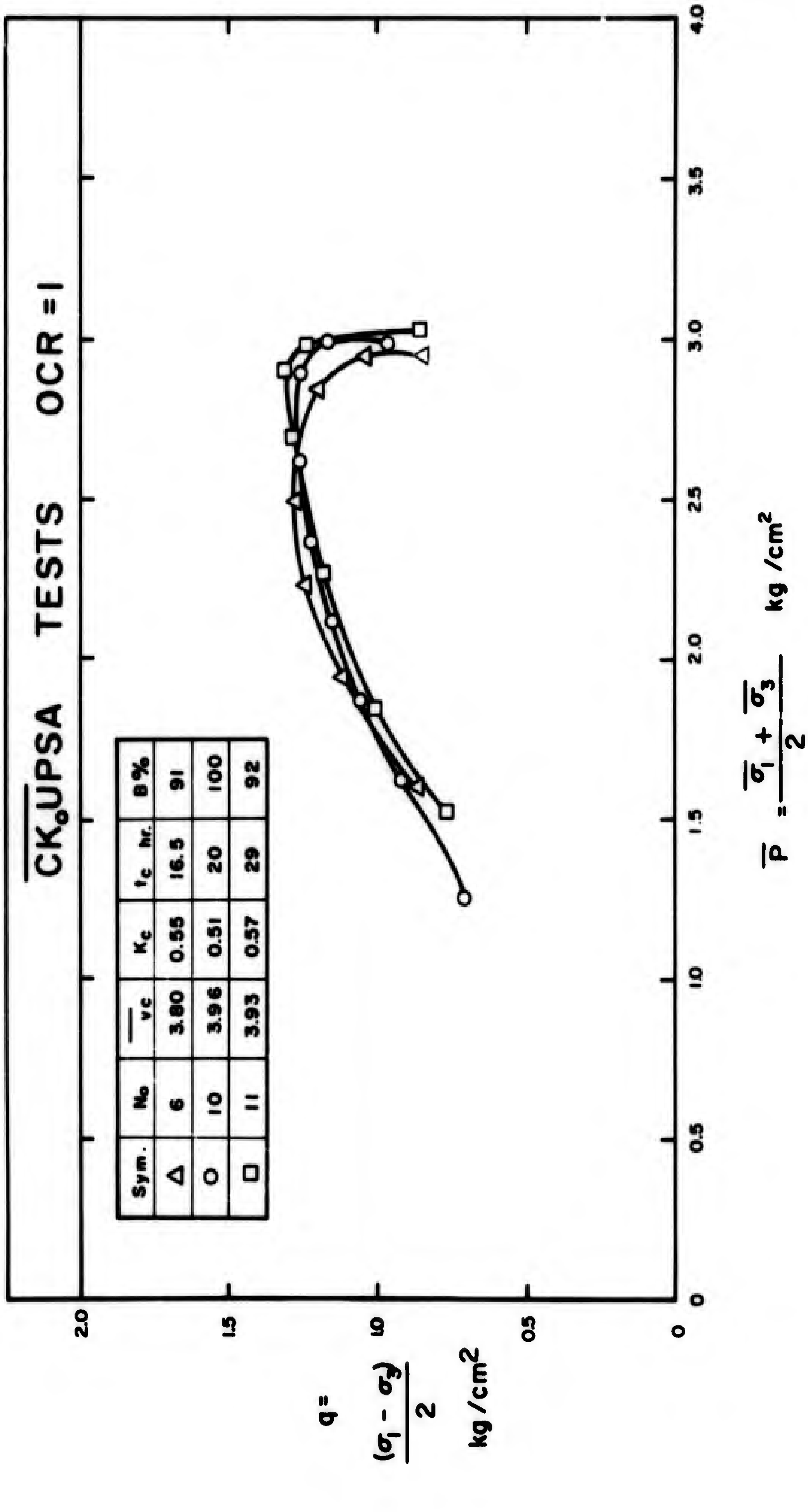
Sym.	No	$\bar{\sigma}_{vc}$	$\bar{\sigma}_{vm}$	OCR	K_c	B%
○●	5	.732	2.88	3.94	.89	94
□■	7	1.46	5.99	4.10	.89	74

Figure D-4



Sym.	No	$\bar{\sigma}_{vc}$	K_c	t_c hr.	B%
○	2	3.62	0.49	0.5	85
□	3	3.82	0.51	1.5	55
△	4	3.87	0.47	15	72

Figure D-5



Sym.	No	$\overline{\ }_{vc}$	K_c	t_c hr.	B%
△	6	3.80	0.55	16.5	91
○	10	3.96	0.51	20	100
□	11	3.93	0.57	29	92

Figure D-6

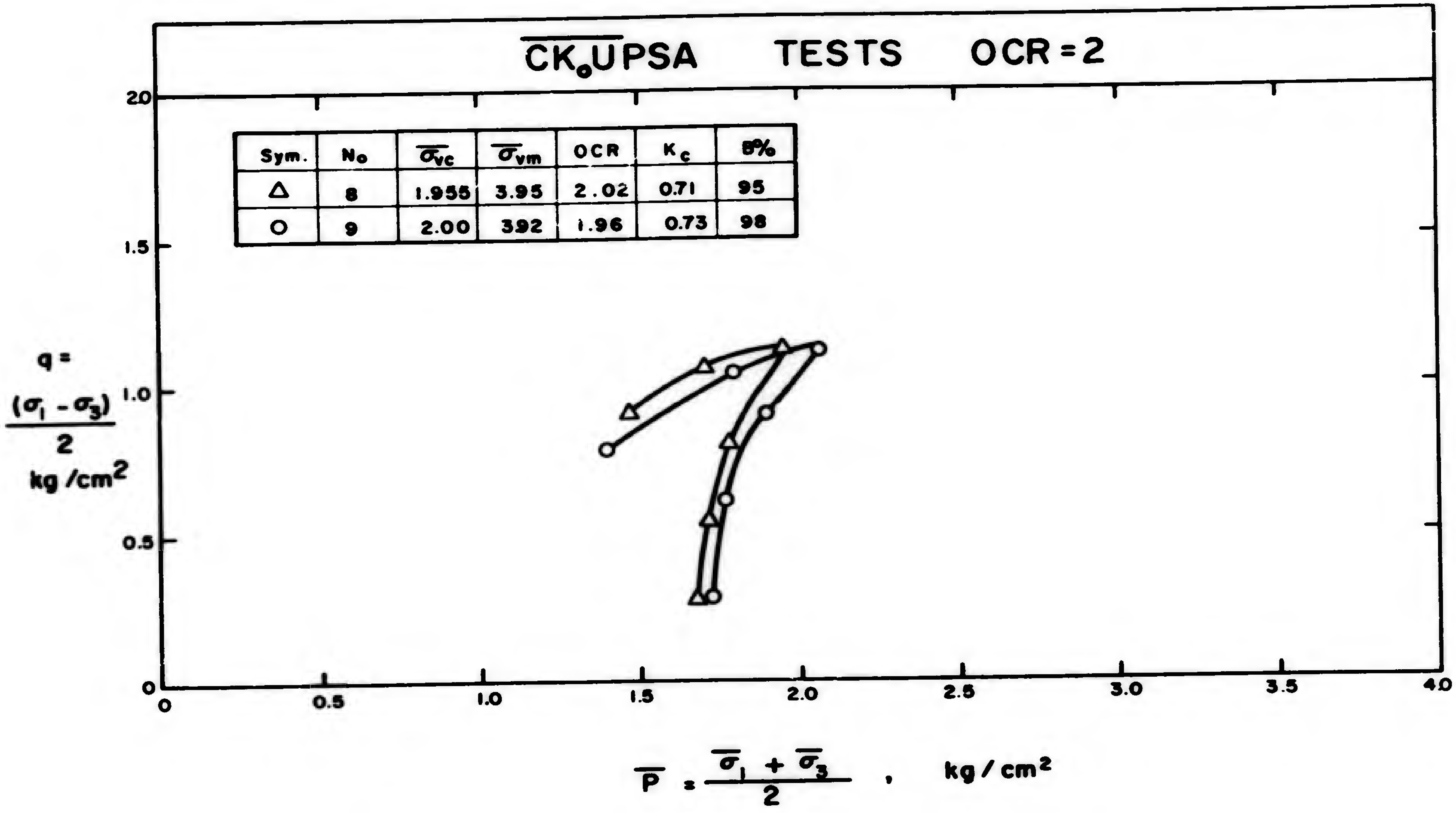
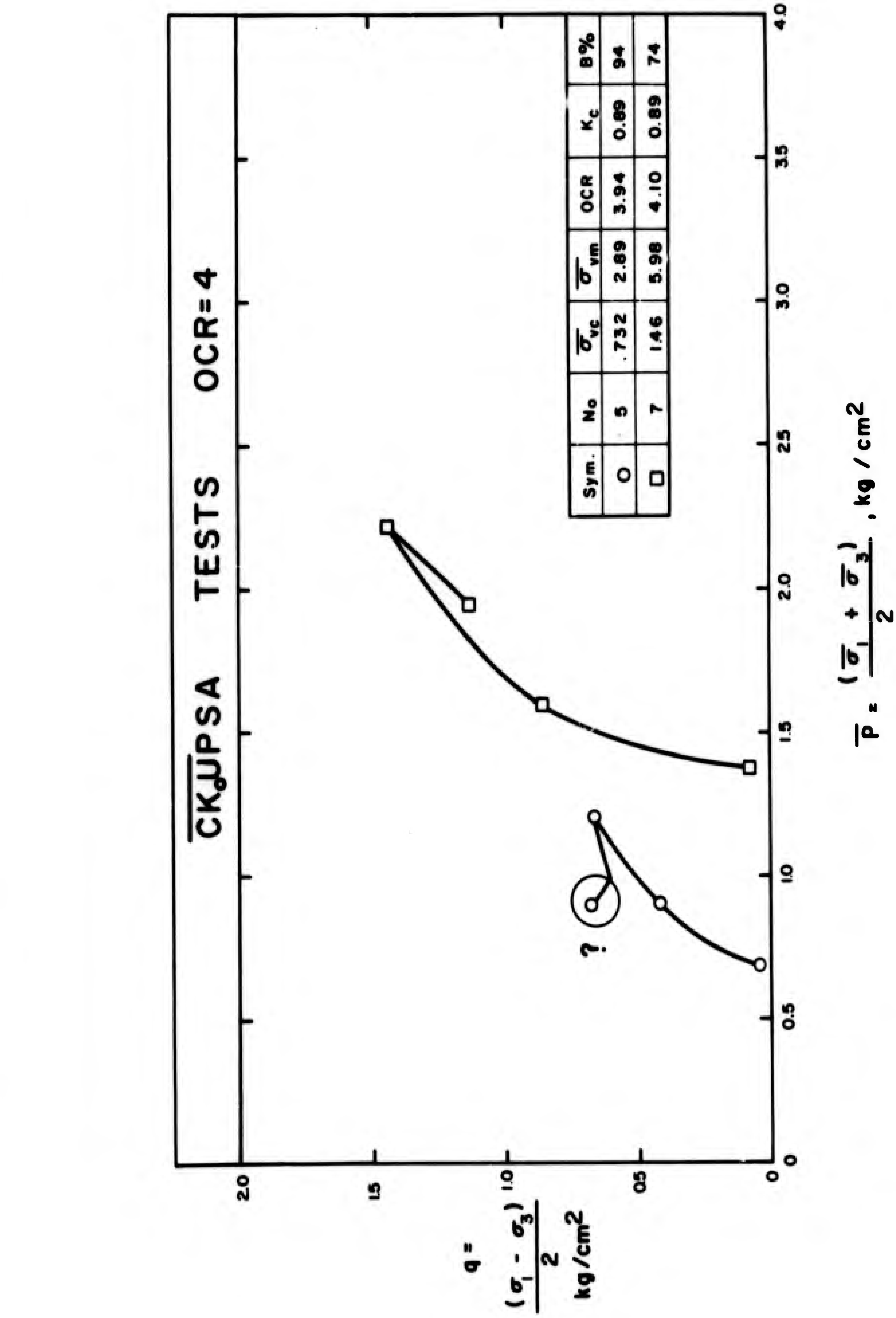

$\overline{CK_oU}PSA$ TESTS OCR = 2
Sym. | No | $\overline{\sigma}_{vc}$ | $\overline{\sigma}_{vm}$ | OCR | K_c | B%
△ | 8 | 1.955 | 3.95 | 2.02 | 0.71 | 95
○ | 9 | 2.00 | 3.92 | 1.96 | 0.73 | 98
$q = \frac{(\sigma_1 - \sigma_3)}{2}$ kg/cm²
2.0
1.5
1.0
0.5
0
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
$\overline{P} = \frac{\overline{\sigma}_1 + \overline{\sigma}_3}{2}$, kg/cm²

Figure D-7



Sym.	No	$\bar{\sigma}_{vc}$	$\bar{\sigma}_{vm}$	OCR	K_c	B%
○	5	.732	2.89	3.94	0.89	94
□	7	1.46	5.98	4.10	0.89	74

Figure D-8

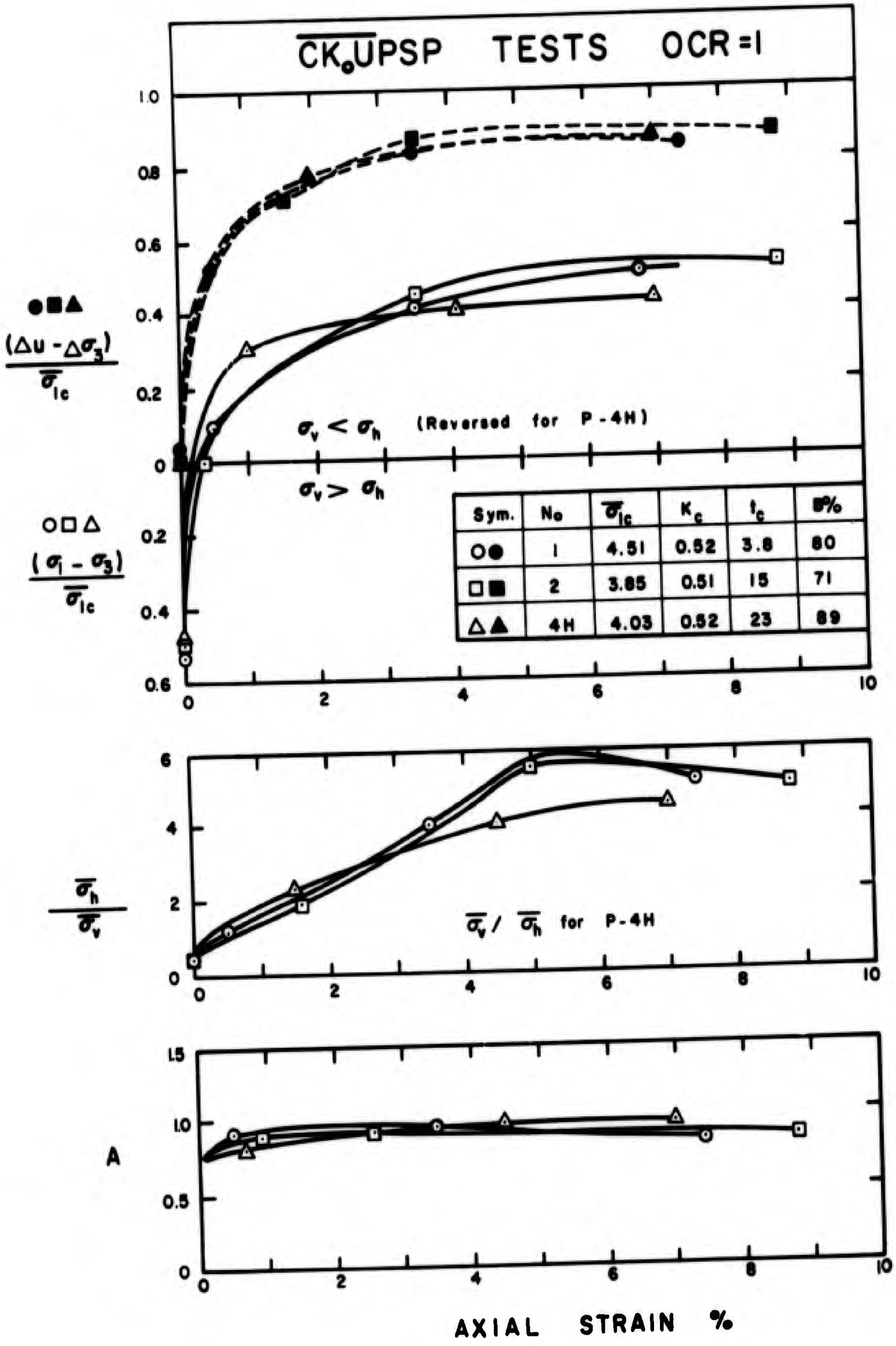
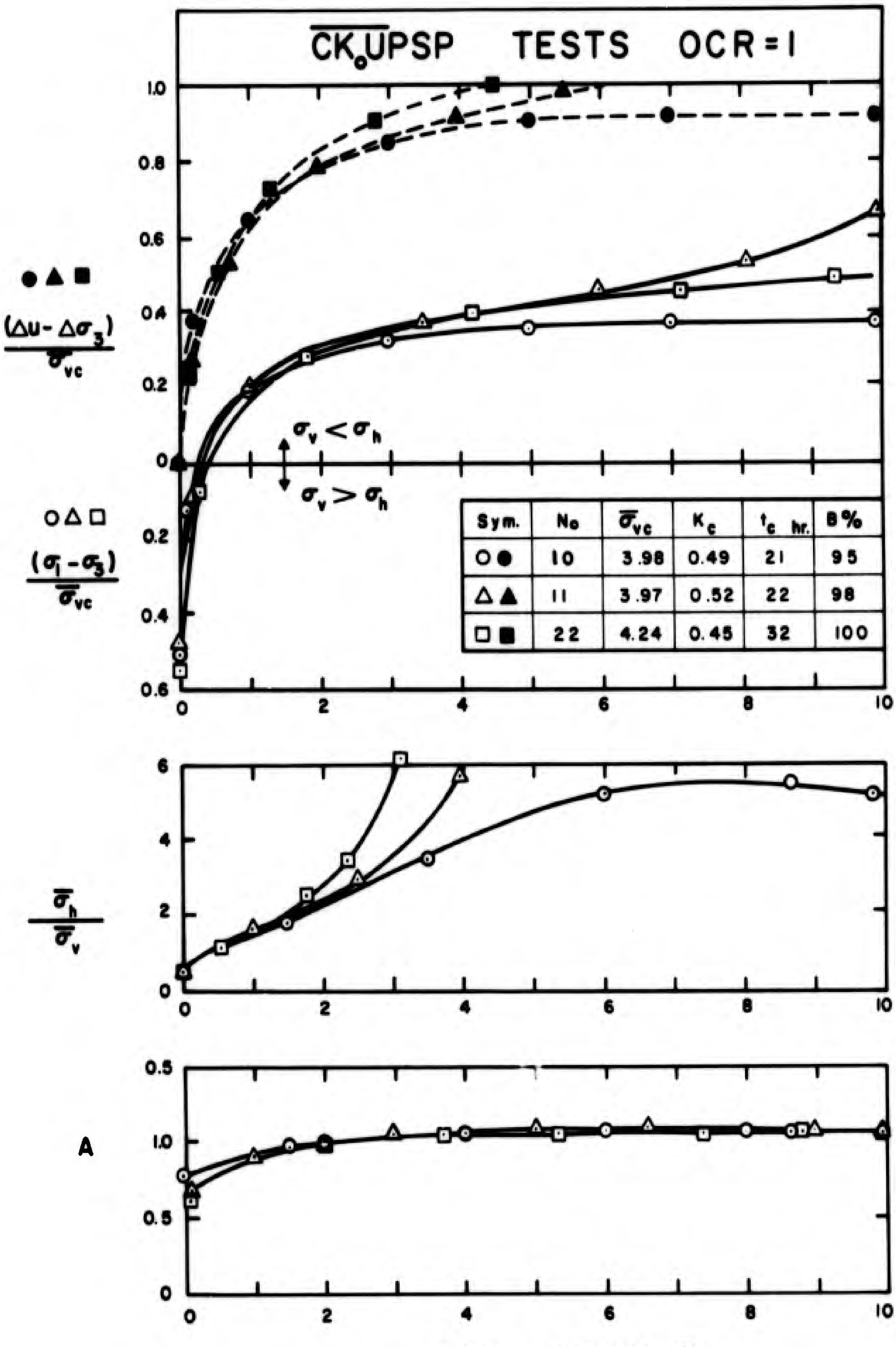
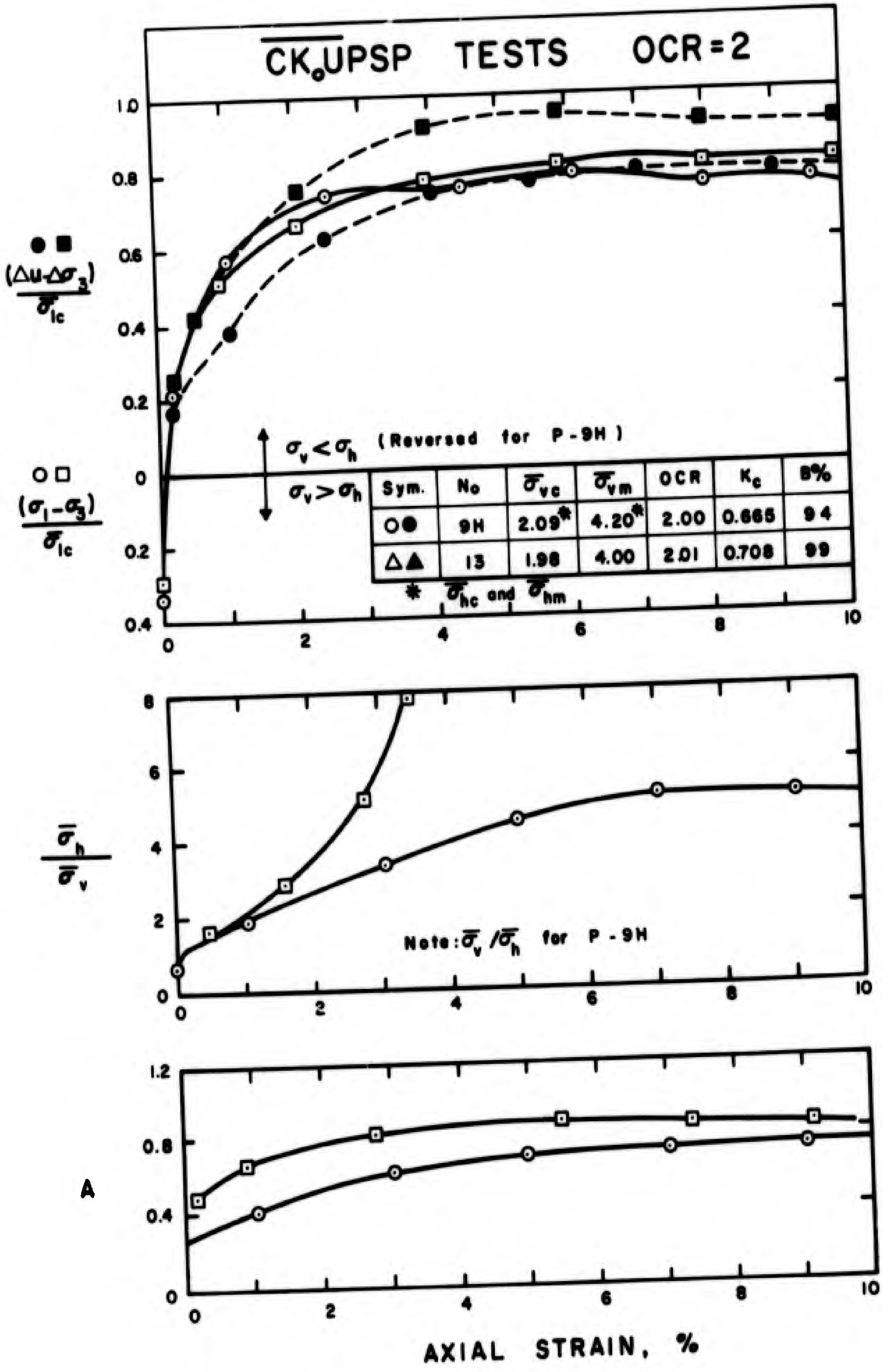

$\overline{CK_o}$UPSP TESTS OCR=1
●■▲
$(\Delta u - \Delta\sigma_3)$
$\bar{\sigma}_{1c}$
○□△
$(\sigma_1 - \sigma_3)$
$\bar{\sigma}_{1c}$
$\sigma_v < \sigma_h$ (Reversed for P-4H)
$\sigma_v > \sigma_h$
Sym. | No | $\bar{\sigma}_{1c}$ | K_c | t_c | B%
○● | 1 | 4.51 | 0.52 | 3.8 | 80
□■ | 2 | 3.85 | 0.51 | 15 | 71
△▲ | 4H | 4.03 | 0.52 | 23 | 89
1.0
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0
2
4
6
8
10
$\bar{\sigma}_h$
$\bar{\sigma}_v$
$\bar{\sigma}_v$ / $\bar{\sigma}_h$ for P-4H
6
4
2
0
0
2
4
6
8
10
A
1.5
1.0
0.5
0
0
2
4
6
8
10
AXIAL STRAIN %

Figure D-9



Sym.	No	$\bar{\sigma}_{vc}$	K_c	t_c hr.	B%
○ ●	10	3.98	0.49	21	95
△ ▲	11	3.97	0.52	22	98
□ ■	22	4.24	0.45	32	100

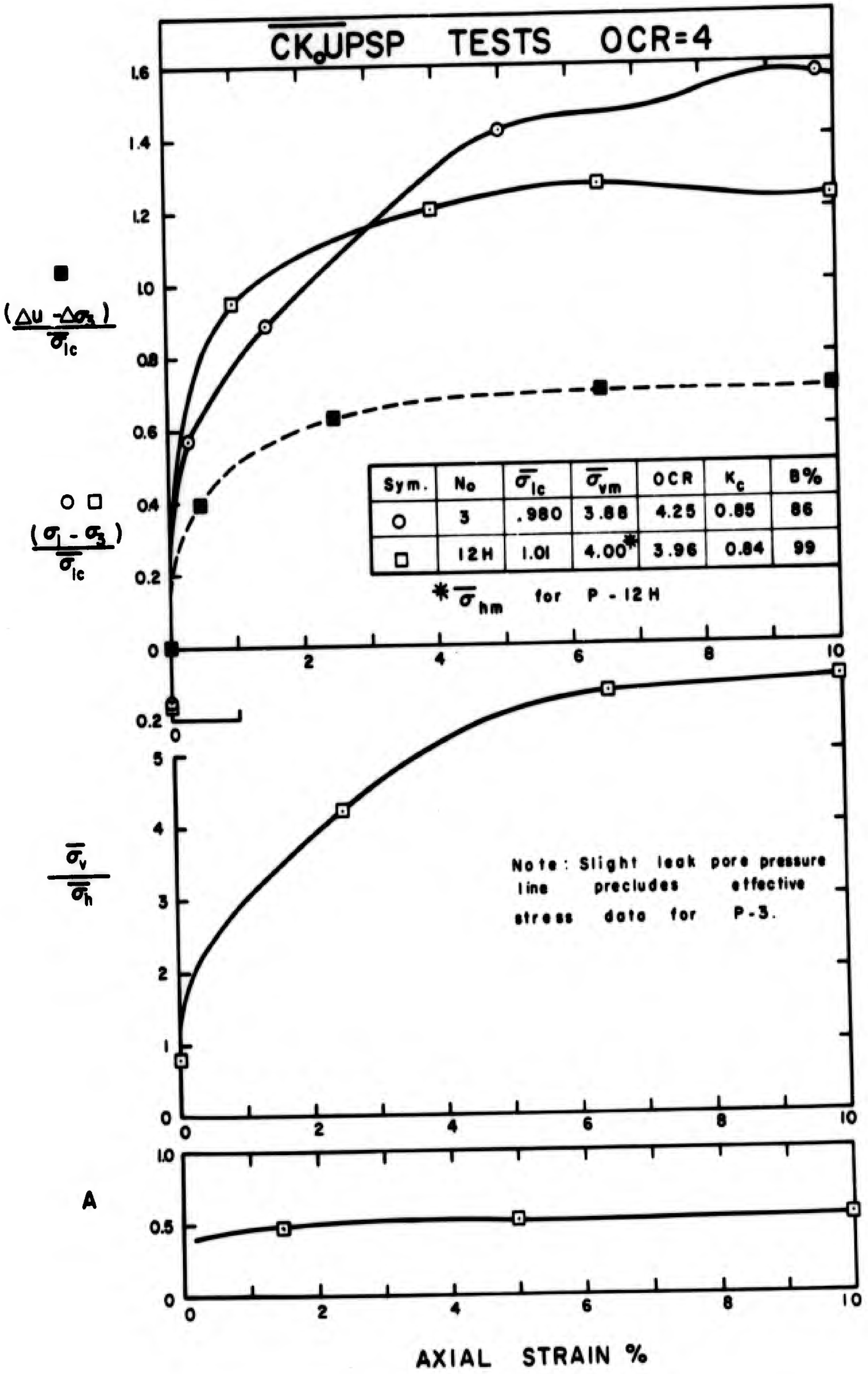
Figure D-10



Sym.	No	$\bar{\sigma}_{vc}$	$\bar{\sigma}_{vm}$	OCR	K_c	B%
○●	9H	2.09*	4.20*	2.00	0.665	94
△▲	13	1.98	4.00	2.01	0.708	99

* $\bar{\sigma}_{hc}$ and $\bar{\sigma}_{hm}$

Figure D-11

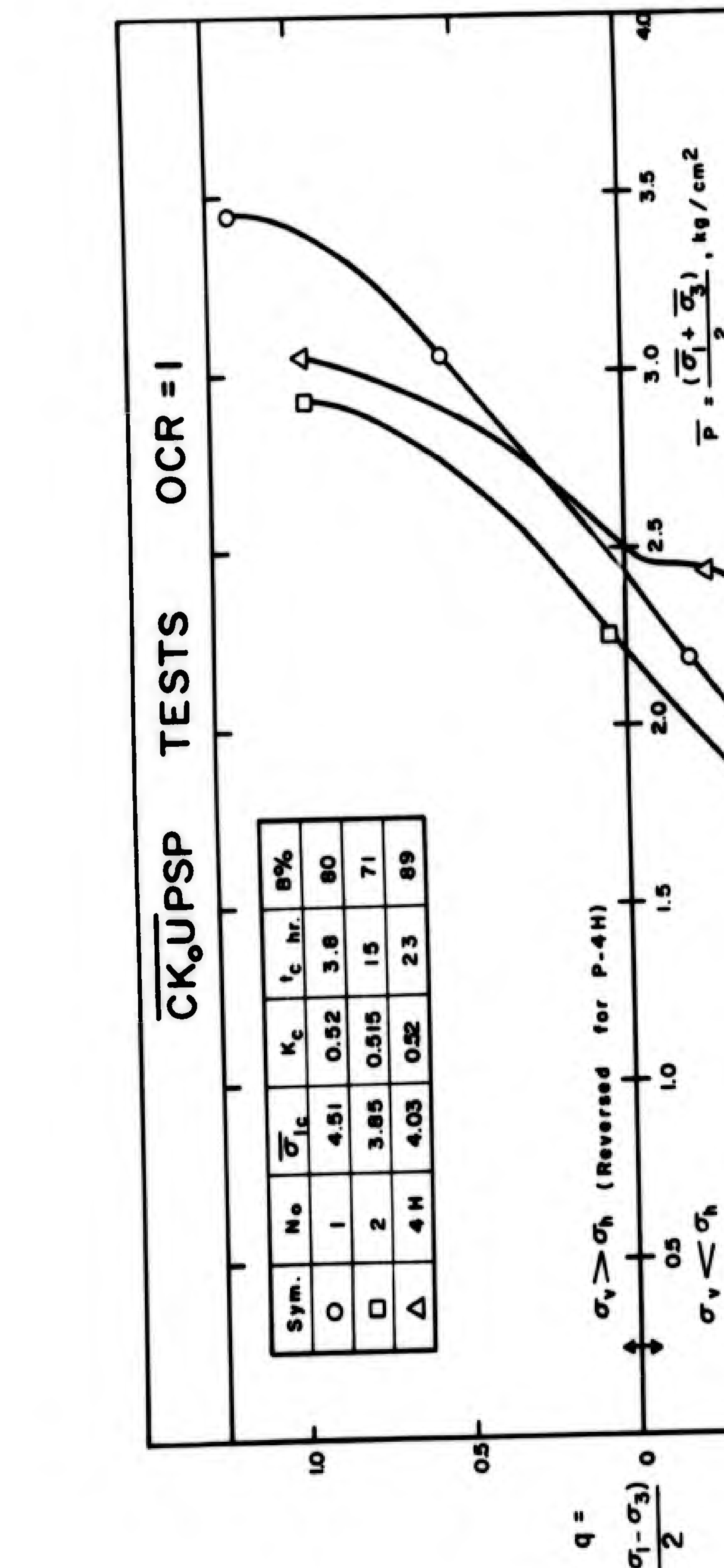


Sym.	No	$\bar{\sigma}_{1c}$	$\bar{\sigma}_{vm}$	OCR	K_c	B%
○	3	.980	3.88	4.25	0.85	86
□	12H	1.01	4.00*	3.96	0.84	99

* $\bar{\sigma}_{hm}$ for P-12H

Note: Slight leak pore pressure line precludes effective stress data for P-3.

Figure D-12



Sym.	No	$\overline{\sigma}_{1c}$	K_c	t_c hr.	B%
○	1	4.51	0.52	3.8	80
□	2	3.85	0.515	15	71
△	4 H	4.03	0.52	23	89

Figure D-13

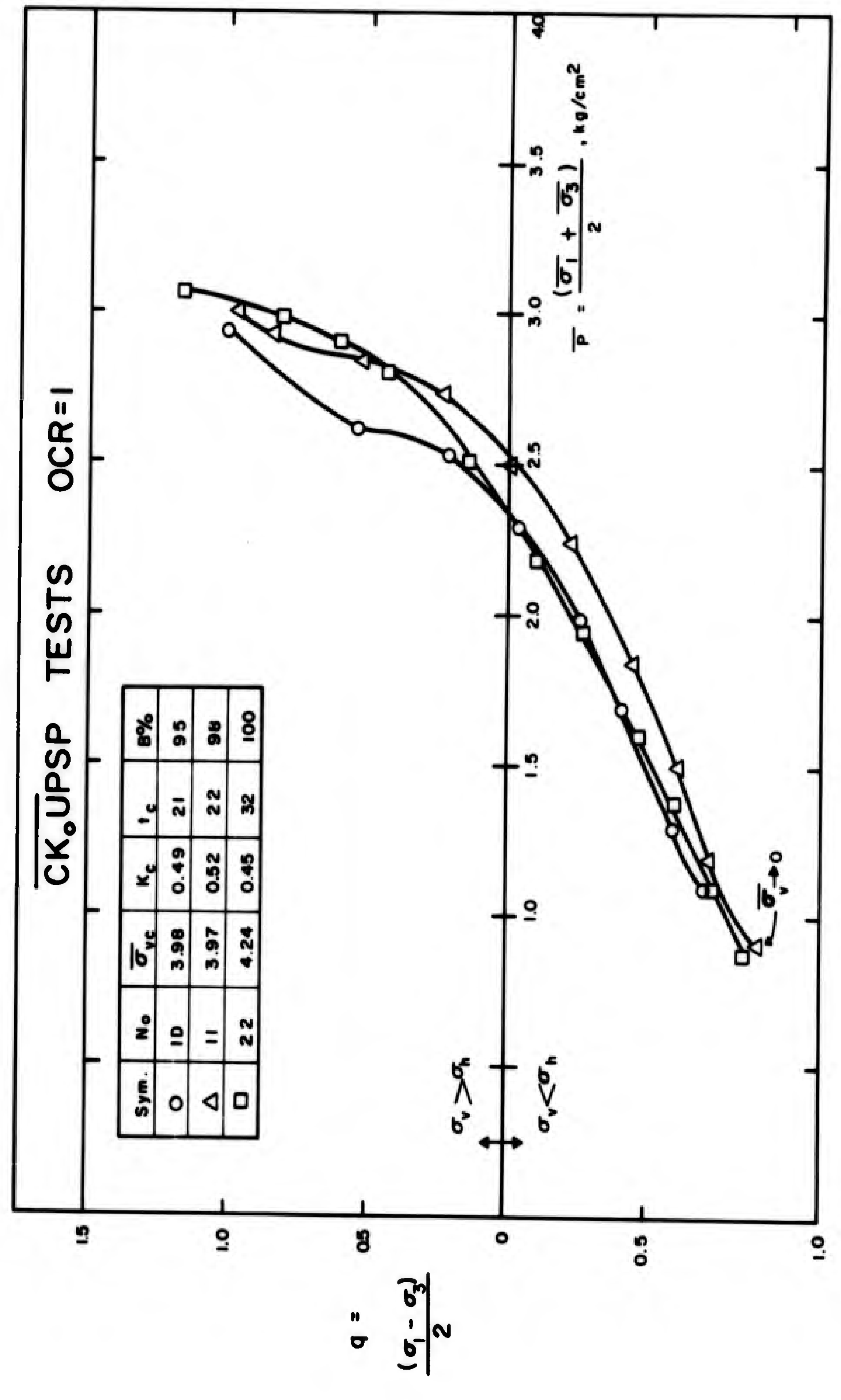

$\overline{CK_oUPSP}$ TESTS OCR=1
Sym. | No | $\overline{\sigma}_{vc}$ | K_c | t_c | B%
○ | 1D | 3.98 | 0.49 | 21 | 95
△ | 11 | 3.97 | 0.52 | 22 | 98
□ | 22 | 4.24 | 0.45 | 32 | 100
$\sigma_v > \sigma_h$
$\sigma_v < \sigma_h$
$\overline{\sigma}_v \to 0$
$\overline{p} = \frac{(\overline{\sigma}_1 + \overline{\sigma}_3)}{2}$, kg/cm^2
$q = \frac{(\sigma_1 - \sigma_3)}{2}$
1.0
1.5
2.0
2.5
3.0
3.5
4.0
1.5
1.0
0.5
0
0.5
1.0

Figure D-14

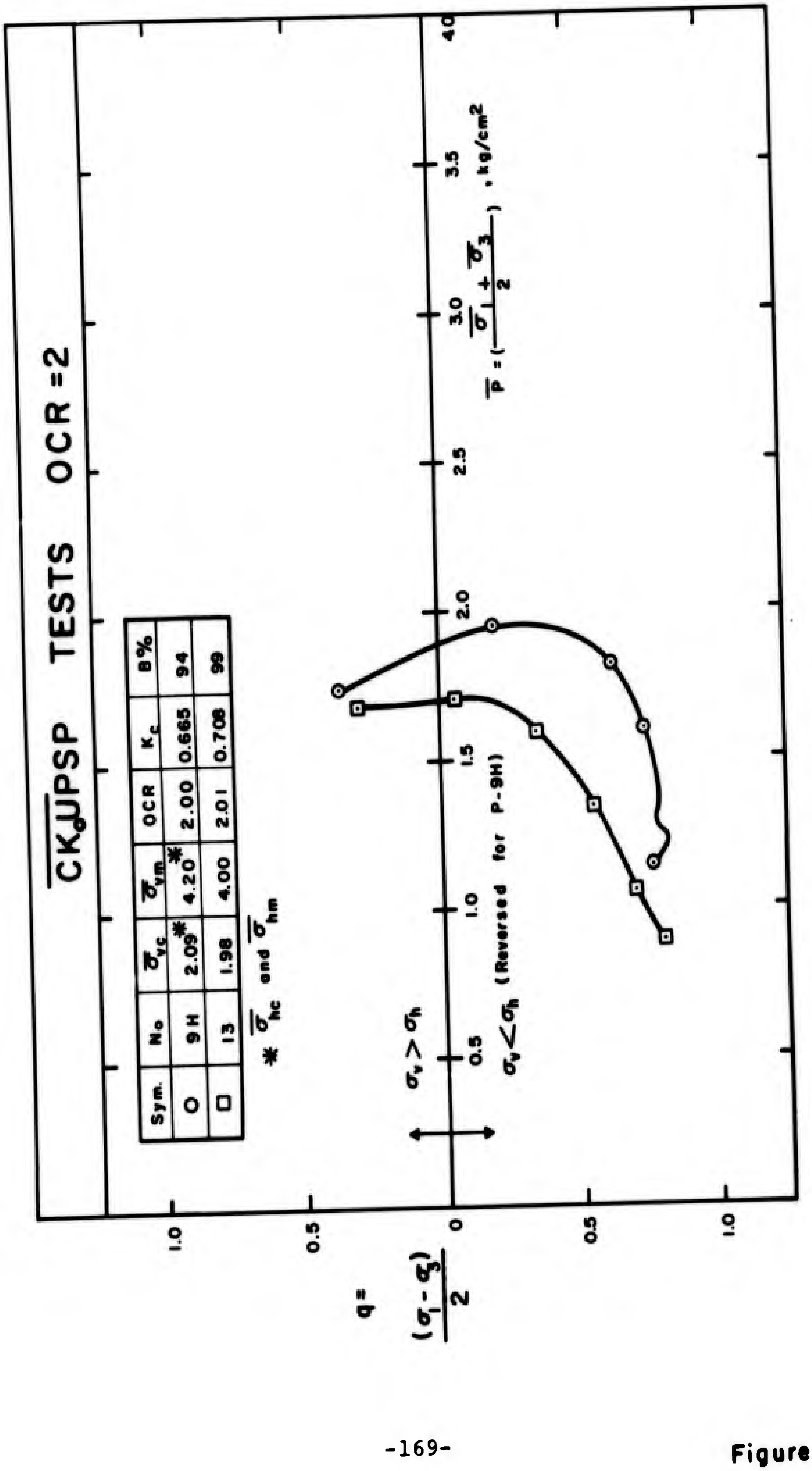

$\overline{CK_0UPSP}$ TESTS OCR = 2
Sym. | No | $\overline{\sigma}_{vc}$ | $\overline{\sigma}_{vm}$ | OCR | K_c | B%
○ | 9H | 2.09* | 4.20* | 2.00 | 0.665 | 94
□ | 13 | 1.98 | 4.00 | 2.01 | 0.708 | 99
* $\overline{\sigma}_{hc}$ and $\overline{\sigma}_{hm}$
$\sigma_v > \sigma_h$
$\sigma_v < \sigma_h$ (Reversed for P-9H)
$q = \frac{(\sigma_1 - \sigma_3)}{2}$
1.0
0.5
0
0.5
1.0
$\overline{p} = (\frac{\overline{\sigma}_1 + \overline{\sigma}_3}{2})$, kg/cm²
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

Figure D-15

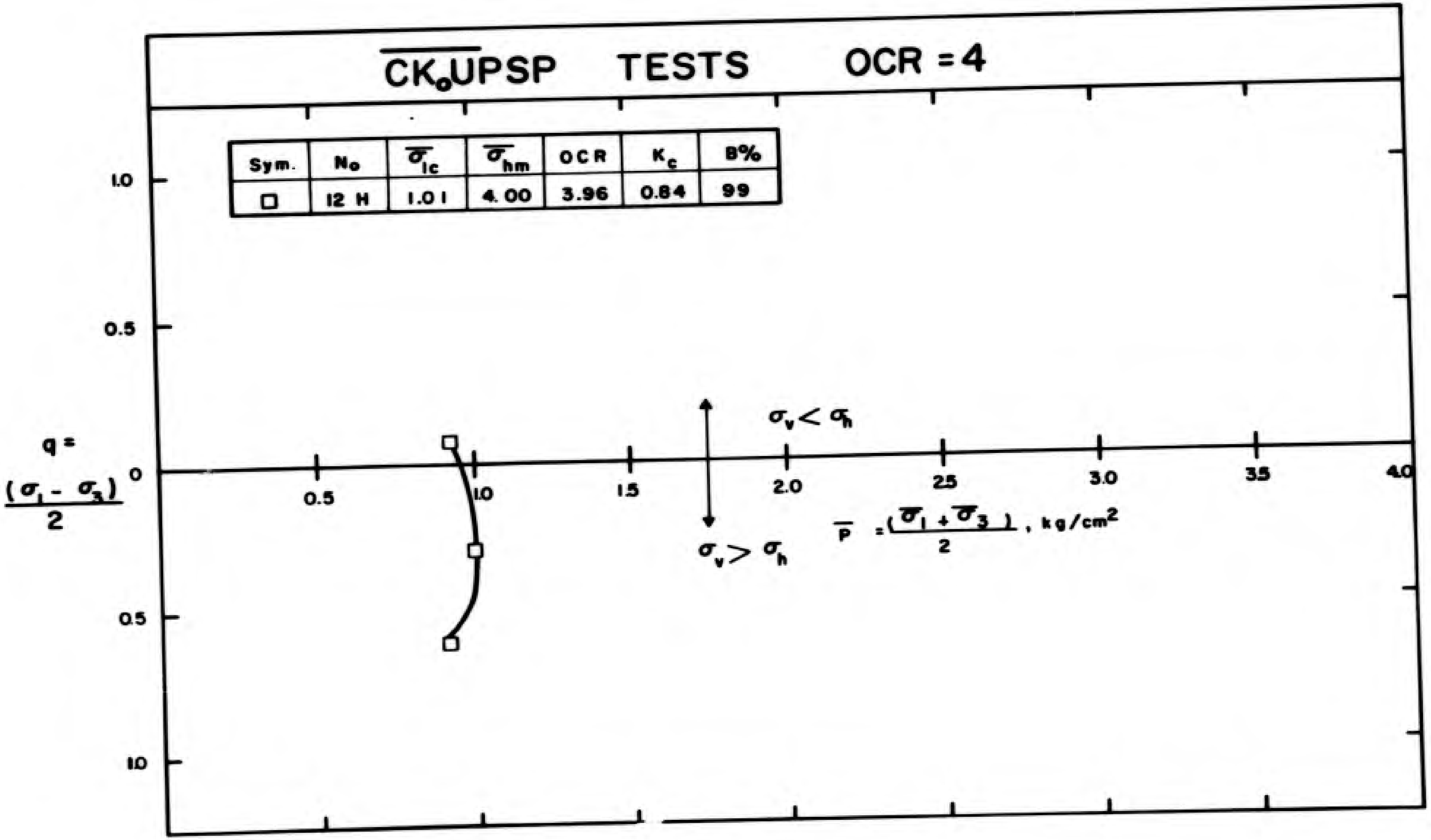

$\overline{CK_oUPSP}$ TESTS OCR = 4
Sym. | No | $\overline{\sigma}_{lc}$ | $\overline{\sigma}_{hm}$ | OCR | K_c | B%
□ | 12 H | 1.01 | 4.00 | 3.96 | 0.84 | 99
$q = \frac{(\sigma_1 - \sigma_3)}{2}$
1.0
0.5
0
0.5
1.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
$\sigma_v < \sigma_h$
$\sigma_v > \sigma_h$
$\overline{p} = \frac{(\overline{\sigma}_1 + \overline{\sigma}_3)}{2}$, kg/cm^2

Figure D-16

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APPENDIX E

TABULATED DATA FOR SELECTED TESTS

Test No.	Summary of Consolidation Data	Consolidation During Increments	Undrained Shear
A-2	See Dickey, Ladd and Rixner (1968)		
A-3	X		X
A-4	X	X	X
A-5	X	X	X
A-6	X	X	X
A-7	X	X	X
A-8	X		X
A-9	X		X
A-10	X		X
P-1	See Dickey, Ladd and Rixner (1968)		
P-2	X	X	X
P-3	X	X	
P-4H	X	X	X
P-9H	X		X
P-10	X		X
P-11	X		X
P-12H	X		X
P-13	X		X
P-22	X		X

CONSOLIDATION DATA

U_B 1.50 kg/cm^2

TEST NO $\overline{CK}_0$UPSA-3

DATE 6-6-67 DEVICE PROTOTYPE TESTED BY JWD

	V_{OL} (cc)	Wgt. (g)	L (in)	ω(%)	S(%)	e
INITIAL	280.43	532.24	3.506	34.6	98.0	0.986
FINAL	264.08	508.44	3.301	29.2	94.0	0.864

$\bar{\sigma}_{1c}$ Corrected kg/cm²	$\Delta H/H_0$ [(1)] %		$\Delta V/V_0$ [(2)] %	
	Δ	Σ	Δ	Σ
0.96	2.12	2.12	0.29	0.29
1.90	2.40	4.52	0.20	1.49
3.82	1.31	5.83	?	—

(1) FROM DIAL DISPLACEMENT READINGS

(2) FROM VOLUME CHANGE DEVICE

PLANE STRAIN TEST ON COHESIVE SOIL **SHEAR DATA**

TEST NO. PSA - 3
DATE 6-5-67
TESTED BY J WD

CONSOLIDATION PRESSURE, $\bar{\sigma}_c$ 3.82 KG/CM²
BACK PRESSURE, u_B 1.51 KG/CM²
PORE PRESSURE RESPONSE IN 1 MINUTES AT u_B = 1.55 KG/CM² 55 %

GAUGE NO. .001
PROVING RING NO. 1889
STRAIN RATE .00012 IN/MIN
MEMBRANE LEAKAGE —

INITIAL LENGTH 3.300 IN.
INITIAL AREA 31.491 CM²
INITIAL Z_3 ($\sigma_3 = \bar{\sigma}_c + u_B$) —

AXIAL STRAIN (%)	$\bar{\sigma}_1$ (1) CORRECTED	AVG $\bar{\sigma}_2$ CORRECTED	$\bar{\sigma}_3$ CORRECTED	$\bar{\sigma}_1/\bar{\sigma}_{1c}$	$\bar{\sigma}_2/\bar{\sigma}_{1c}$	$\bar{\sigma}_3/\bar{\sigma}_{1c}$	$\frac{\sigma_1-\sigma_3}{\bar{\sigma}_{1c}}$	$\bar{\sigma}_1/\bar{\sigma}_3$	q	$\bar{p}$	$\bar{\sigma}_2/\bar{p}$	$\Delta\sigma_1$	Δu	$\frac{\Delta u}{\bar{\sigma}_{1c}}$	A (2)		
0	3.82	1.69	1.95	1.000	.442	.510	.487	1.959	.935	2.885	0.586	—	—	—	—		
.04	4.08	1.69	1.85	1.068	.442	.484	.584	2.205	1.115	2.965	0.570	.36	.10	.026	.277		
.07	4.13	1.71	1.80	1.081	.448	.471	.609	2.294	1.165	2.965	.577	.46	.15	.039	.362		
.12	4.14	1.71	1.71	1.084	.448	.448	.636	2.421	1.215	2.925	.585	.56	.24	.063	.429		
.28	4.14	1.70	1.57	1.084	.445	.411	.673	2.637	1.285	2.855	.595	.70	.38	.099	.543		
.40	4.09	1.68	1.48	1.071	.440	.387	.683	2.764	1.305	2.785	.603	.74	.47	.123	.635		
.55	4.04	1.66	1.40	1.059	.435	.366	.691	2.886	1.320	2.720	.610	.77	.55	.144	.714		
.77	3.97	1.62	1.30	1.039	.424	.340	.699	3.054	1.335	2.635	.615	.80	.65	.170	.812		
.91	3.93	1.59	1.25	1.029	.416	.327	.702	3.144	1.340	2.590	.614	.81	.70	.183	.864		
1.00	3.91	1.58	1.22	1.024	.414	.319	.704	3.205	1.345	2.565	.616	.82	.73	.191	.890		
1.08	3.91	1.58	1.21	1.024	.414	.317	.707	3.231	1.350	2.560	.617	.83	.74	.194	.892		
1.17	3.89	1.57	1.19	1.018	.411	.312	.707	3.269	1.350	2.540	.618	.83	.76	.199	.916		
1.41	3.84	1.55	1.13	1.005	.406	.296	.709	3.378	1.355	2.485	.624	.84	.82	.215	.976		
1.55	3.92	1.54	1.11	1.027	.403	.291	.709	3.441	1.355	2.465	.625	.84	.84	.220	1.000		
1.69	3.91	1.54	1.10	.997	.403	.288	.712	3.464	1.355	2.460	.626	.84	.85	.223	1.012		
1.76	3.81	1.54	1.09	.997	.403	.285	.712	3.495	1.360	2.450	.629	.85	.86	.225	1.012		
1.94	3.80	1.54	1.08	.995	.403	.283	.712	3.518	1.360	2.440	.631	.85	.87	.228	1.024		
1.99	3.77	1.51	1.05	.987	.395	.275	.712	3.590	1.360	2.410	.627	.85	.90	.236	1.059		
2.25	3.74	1.49	1.02	.979	.390	.267	.712	3.667	1.360	2.380	.626	.85	.93	.243	1.094		
2.46	3.72	1.49	1.00	.974	.390	.262	.712	3.720	1.360	2.360	.631	.85	.95	.249	1.118		
2.55	3.71	1.50	1.00	.971	.393	.262	.709	3.710	1.355	2.355	.637	.84	.95	.249	1.131		
2.69	3.71	1.50	1.00	.971	.393	.262	.709	3.710	1.355	2.355	.637	.84	.95	.249	1.131		
2.92	3.71	1.50	1.00	.971	.393	.262	.709	3.710	1.355	2.355	.637	.84	.95	.249	1.131		
2.95	3.71	1.49	.99	.971	.390	.257	.715	3.785	1.365	2.345	.635	.86	.97	.254	1.128		
3.07	3.71	1.49	.98	.971	.390	.257	.715	3.785	1.365	2.345	.635	.86	.97	.257	1.128		
3.14	3.72	1.50	.99	.969	.393	.257	.712	3.775	1.360	2.340	.641	.85	.97	.254	1.141		
3.22	3.70	1.49	.97	.969	.390	.254	.715	3.814	1.365	2.335	.628	.86	.98	.257	1.140		
3.40	3.68	1.49	.96	.962	.390	.251	.712	3.833	1.360	2.323	.642	.85	.99	.259	1.165		
3.59	3.67	1.48	.96	.961	.387	.251	.709	3.823	1.355	2.315	.629	.84	.99	.259	1.179		
3.80	3.66	1.47	.96	.950	.385	.251	.707	3.812	1.350	2.310	.636	.83	.99	.259	1.193		
4.11	3.64	1.47	.96	.953	.385	.251	.702	3.792	1.340	2.300	.631	.81	.99	.259	1.220		

REMARKS: (1) CORRECTED FOR MEMBRANE STRENGTH, FILTER STRIPS & PISTON FRICTION

(2) $A = \frac{\Delta u - \Delta\sigma_3}{\Delta\sigma_1 - \Delta\sigma_3}$

CONSOLIDATION DATA

U_B 1.50 kg/cm^2

TEST NO CK. UPSA-4

DATE 2-9-62 DEVICE PROTOTYPE TESTED BY JJR

	VOL (cc)	Wgt. (g)	L (in)	ω(%)	S(%)	e
INITIAL	286.35	533.0	3.505	36.0	75.0	1.058
FINAL	258.22	492.95	3.172	28.1	92.3	0.820

$\bar{\sigma}_{1c}$ corrected kg/cm^2	$\Delta H/H_0$ [1] %		$\Delta V/V_0$ [2] %	
	Δ	Σ	Δ	Σ
0.1	0.05	0.05	0.46	0.46
0.92	3.38	3.43	4.40	4.86
1.90	2.85	6.28	2.78	7.64
3.88	3.23	9.51	1.93	9.57

[1] FROM DISPLACEMENT DIAL READINGS

[2] FROM VOLUME CHANGE DEVICE

PLANE STRAIN CONSOLIDATION

TEST NO. CK₀UPSA-4 TYPE OF CONSOLIDATION VERT K₀

INCREMENT : 0.1 TO 1.0 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1C} 2.42 kg/cm² u_B 1.50 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATEN σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.0204	0.0	–	–	–
LOAD	0.0179	0.0	2.45	2.44	2.44
OPEN DRAIN	0.0179	0.0	–	–	–
0.5	0.0201	0.75	2.45	2.43	2.42
2	0.0216	1.48	2.45	–	–
4	0.0331	1.92	2.32	2.30	2.33
8	0.0429	2.82	2.32	2.29	2.32
10	0.0483	3.13	2.31	2.28	2.29
15	0.0534	3.91	2.31	2.22	2.32
20	0.0581	4.66	2.31	2.27	2.32
31	0.0637	6.18	2.30	2.26	2.28
49	0.0823	8.01	2.22	2.19	2.16
56	0.0876	8.55	2.22	2.15	2.16
73	0.1011	9.58	2.15	2.08	2.12
86	0.1164	10.41	2.07	2.02	2.07
122	0.1290	11.71	2.06	1.99	1.98
141	0.1322	12.16	2.06	1.95	1.98
172	0.1363	12.68	2.06	1.92	1.94
176	0.1368	12.76	–	–	–
PLATENS	RELEASED				

PLANE STRAIN CONSOLIDATION

TEST NO. $\overline{CK_0}$UPSA-4 TYPE OF CONSOLIDATION Vert. K_0

INCREMENT : 1.0 TO 2.0 kg/cm^2 DEVICE Prototype

CORRECTED σ_{1C} 3.40 kg/cm^2 u_B 1.50 kg/cm^2

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	Side Platen σ_h kg/cm^2	Back End Platen σ_h kg/cm^2	Front End Platen σ_h kg/cm^2
INITIAL	0.1368	0.0	-	-	-
LOAD	0.1307	0.0	3.46	3.32	3.27
OPEN DRAIN	0.1309	0.0	-	-	-
0.5	0.1319	0.39	3.46	3.25	3.26
4	0.1347	1.22	3.40	3.24	3.19
8	0.1388	2.03	3.27	3.12	3.10
14	0.1475	3.05	3.13	2.95	2.93
22	0.1582	3.82	2.91	2.84	2.82
26	0.1674	4.25	-	-	-
34	0.1773	4.88	2.74	2.75	2.69
56	0.1929	6.36	2.75	2.64	2.62
76	0.2039	7.24	2.64	2.56	2.55
100	0.2114	7.96	2.64	2.50	2.49
125	0.2201	9.36	2.51	2.43	2.49
151	0.2248	8.68	2.49	2.42	2.39
804	0.2380	7.98	2.44	2.32	2.15
PLATENS	RELEASED				

PLANE STRAIN CONSOLIDATION

TEST NO. CK₀ UPSA-4 TYPE OF CONSOLIDATION VERT K₀

INCREMENT : 2.0 TO 4.0 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1c} 5.38 kg/cm² u_B 1.50 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATEN σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.2384	0.0	–	2.32	2.15
LOAD	0.2522	0.0	4.43	4.30	4.32
OPEN DRAIN	0.2522	0.0	–	–	–
0.25	0.2533	0.28	4.42	–	–
2	0.2555	0.63	4.42	4.25	4.23
4	0.2579	1.10	–	–	–
11	0.2666	1.19	4.25	4.09	4.03
22	0.2783	3.40	4.07	4.01	3.97
31	0.2926	4.26	4.06	3.83	3.79
45	0.3032	5.26	3.84	3.72	3.65
55	0.3094	5.73	–	–	–
62	0.3134	6.11	3.67	3.59	3.55
81	0.3221	6.73	3.55	3.51	3.49
104	0.3281	7.25	3.54	3.46	3.42
129	0.3321	7.55	3.51	3.39	3.39
149	0.3346	7.70	–	–	–
319	0.3416	7.82	–	–	–
499	0.3434	7.52	3.46	3.23	3.26
CLOSE	DRAIN	RELEASE	PLATENS		
OPEN	DRAIN	[illegible]	PRESSURE	= 3.33 Kg/cm²	
511	0.3448	–	–	–	–
514	0.3448	–	–	3.32	3.36
549	0.3454	–	–	3.35	3.36
1459	0.3515	5.52	–	3.31	3.22

PLANE STRAIN TEST ON COHESIVE SOIL , SHEAR DATA

TEST NO CK_0U- PSA-4
DATE 7-9-67
TESTED BY JJR
CONSOLIDATION PRESSURE, $\bar{\sigma}_c$ 3.876 KG/CM²
BACK PRESSURE, u_B 1.50 KG/CM²
PORE PRESSURE RESPONSE IN 2 MINUTES AT u_B : 72 % 1.50 KG/CM²
GAUGE NO .001
PROVING RING NO 1867
STRAIN RATE .0006 IN/MIN
MEMBRANE LEAKAGE —
INITIAL LENGTH 3.172 IN
INITIAL AREA 32.179 CM²
INITIAL Z_3 ($\sigma_3 = \bar{\sigma}_c + u_B$) —
FINAL Z_3 ($\sigma_3 = 0$) —
FINAL COUNTER ($\sigma_3 = 0$) —

AXIAL STRAIN (%)	$\bar{\sigma}_1$ (1) CORRECTED	AVG $\bar{\sigma}_2$ CORRECTED	$\bar{\sigma}_3$ CORRECTED	$\frac{\bar{\sigma}_1}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_2}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_3}{\bar{\sigma}_{1c}}$	$\frac{\sigma_1-\sigma_2}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_1}{\bar{\sigma}_3}$	q	$\bar{p}$	$\bar{\sigma}_3/\bar{p}$	$\Delta\sigma_1$	Δu	$\frac{\Delta u}{\bar{\sigma}_{1c}}$	A (2)
—	3.876	1.887	1.822	1.000	.487	.485	.530	2.127	1.027	2.849	.662	—	—	—	—
.01	3.968	1.917	1.792	1.024	.495	.462	.561	2.214	1.088	2.880	.666	.122	.03	.007	.246
.02	4.076	1.907	1.732	1.052	.492	.447	.602	2.353	1.172	2.904	.657	.290	.09	.023	.310
.03	4.151	1.932	1.722	1.071	.498	.444	.627	2.410	1.214	2.936	.658	.375	.10	.026	.266
.07	4.173	1.906	1.661	1.077	.492	.424	.648	2.512	1.256	2.917	.653	.457	.16	.041	.350
.11	4.206	1.915	1.610	1.085	.494	.415	.670	2.612	1.298	2.908	.659	.590	.21	.054	.389
.21	4.229	1.933	1.548	1.090	.499	.399	.690	2.667	1.338	2.896	.670	.618	.27	.070	.437
.27	4.178	1.897	1.487	1.078	.489	.384	.694	2.810	1.345	2.832	.670	.632	.33	.085	.522
.36	4.150	1.892	1.447	1.071	.488	.373	.697	2.868	1.352	2.799	.676	.694	.37	.095	.574
.42	4.136	1.871	1.426	1.067	.493	.368	.699	2.900	1.354	2.780	.673	.649	.39	.101	.601
.50	4.095	1.845	1.385	1.057	.476	.357	.699	2.957	1.355	2.740	.673	.649	.43	.111	.663
.58	4.041	1.815	1.335	1.042	.468	.344	.698	3.027	1.353	2.688	.675	.695	.48	.124	.744
.69	4.017	1.824	1.314	1.036	.471	.339	.697	3.057	1.351	2.665	.684	.641	.50	.129	.780
.74	3.963	1.779	1.269	1.022	.459	.326	.696	3.114	1.349	2.613	.691	.637	.55	.142	.863
.82	3.943	1.778	1.253	1.017	.459	.323	.694	3.147	1.345	2.598	.684	.627	.56	.144	.893
.90	3.934	1.788	1.253	1.015	.461	.323	.692	3.140	1.340	2.593	.690	.618	.56	.144	.906
.98	3.906	1.768	1.233	1.008	.456	.318	.690	3.168	1.336	2.569	.688	.610	.58	.150	.951
1.06	3.896	1.777	1.232	1.005	.458	.318	.687	3.162	1.332	2.564	.693	.600	.58	.150	.967
1.13	3.877	1.782	1.222	1.000	.460	.315	.685	3.173	1.327	2.549	.699	.591	.59	.152	.998
1.29	3.841	1.766	1.201	.991	.456	.310	.681	3.198	1.320	2.521	.701	.575	.61	.157	1.061
1.45	3.810	1.766	1.181	.983	.456	.305	.678	3.226	1.314	2.495	.708	.564	.63	.163	1.117
1.61	3.770	1.735	1.150	.973	.448	.297	.676	3.278	1.310	2.460	.705	.559	.66	.170	1.191
1.77	3.760	1.755	1.150	.970	.453	.297	.673	3.270	1.305	2.455	.715	.549	.66	.170	1.213
1.92	3.726	1.729	1.119	.961	.445	.289	.673	3.330	1.303	2.422	.712	.540	.69	.178	1.278
2.08	3.698	1.724	1.109	.954	.445	.286	.668	3.334	1.294	2.403	.717	.522	.70	.181	1.341
2.27	3.679	1.718	1.098	.948	.443	.283	.665	3.346	1.288	2.388	.720	.508	.71	.183	1.398
2.40	3.656	1.713	1.088	.943	.442	.281	.663	3.360	1.284	2.372	.722	.500	.72	.186	1.440
2.59	3.631	1.712	1.077	.937	.442	.278	.659	3.371	1.277	2.354	.727	.485	.73	.188	1.505
2.79	3.590	1.697	1.057	.926	.438	.273	.654	3.396	1.266	2.323	.731	.469	.75	.194	1.616
3.10	3.554	1.696	1.046	.917	.438	.270	.647	3.398	1.254	2.300	.737	.438	.76	.196	1.736
3.42	3.504	1.750	1.025	.904	.452	.264	.640	3.418	1.239	2.264	.773	.408	.78	.201	1.912
3.61	3.477	1.739	1.034	.897	.449	.267	.630	3.362	1.222	2.256	.771	.391	.79	.204	2.020
3.77	3.475	1.759	1.024	.896	.454	.264	.632	3.394	1.225	2.249	.782	.379	.78	.201	2.053
4.15	3.450	1.743	1.023	.890	.451	.264	.626	3.372	1.213	2.236	.782	.354	.78	.201	[illegible]
4.34	3.433	1.712	1.022	.887	.442	.264	.623	3.364	1.205	2.230	[illegible]	.342	.79	.201	[illegible]

REMARKS: (1) CORRECTED FOR MEMBRANE STRENGTH, FILTER STRIPS & PISTON FRICTION

(2) $A = \frac{\Delta u - \Delta\bar{\sigma}_3}{\Delta\bar{\sigma}_1 - \Delta\bar{\sigma}_3}$

CONSOLIDATION DATA

TEST NO $\overline{CK_oU}$ PSA-5 U_B 1.50 kg/cm^2

DATE 8-2-67 DEVICE PROTOTYPE TESTED BY J J R

	V_{OL} (cc)	Wgt. (g)	L (in)	ω (%)	S (%)	e
INITIAL	293.70	546.55	3.50	36.9	97.0	1.056
FINAL	269.44	520.73	3.245	31.2	98.0	0.886

$\bar{\sigma}_{1c}$ Corrected kg/cm^2	ΔH/Ho, % (1)		ΔV/Vo, % (2)	
	Δ	Σ	Δ	Σ
0.1	0.36	0.36	0.74	0.74
0.92	3.07	3.43	1.01	1.75
1.90	2.55	5.98	2.05	3.80
2.89	1.91	7.89	1.21	5.01
2.20	-.05	7.84	-.39	4.62
1.45	-.18	7.66	-.67	3.95
0.73	-.38	7.28	-.95	3.00

(1) FROM DISPLACEMENT DIAL READINGS

(2) FROM VOLUME CHANGE DEVICE

PLANE STRAIN CONSOLIDATION

TEST NO. CK₀UPSA-5 TYPE OF CONSOLIDATION VERT. K₀

INCREMENT : 0.1 TO 1.0 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1C} 2.42 kg/cm² u_B 1.50 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATEN σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.0381	0.0	-	-	-
LOAD	0.0413	0.0	2.45	2.53	2.45
OPEN DRAIN	0.0413	0.0	-	-	-
0.5	0.0430	0.59	2.49	2.50	2.45
2	0.0443	0.89	2.47	2.43	2.40
4	0.0445	1.20	-	-	-
6	0.0490	1.45	2.32	2.36	2.30
8	0.0514	1.74	-	-	-
10	0.0554	1.95	2.26	2.31	2.25
13	0.0601	2.37	2.23	2.30	2.16
18	0.0622	2.75	2.17	2.25	2.14
26	0.0731	3.25	2.17	2.23	2.14
36	0.0782	3.68	2.14	2.20	2.07
[illegible]	0.0834	4.03	2.09	2.15	2.11
62	0.0881	4.41	2.08	2.14	2.05
71	0.0901	4.57	2.07	2.12	2.05
98	0.0940	4.86	2.05	2.09	1.99
119	0.0946	4.95	2.02	2.07	1.98
146	0.0984	4.98	2.02	2.06	1.98
179	0.0998	4.95	2.01	2.06	1.98
206	0.1006	4.87	1.99	2.05	1.99
216	0.1010	4.85	1.99	2.05	1.99
PLATENS RELEASED					
231	0.1218	4.97	2.02[1]	2.10	2.04
236	0.1238	5.03		2.10	2.04
240	0.1249	5.06		2.09	2.03
244	0.1260	5.13		2.09	1.98
251	0.1273	5.18		2.09	1.97
266	0.1295	5.25		2.08	2.02
844	0.1410	5.28		2.08	2.04
(1) CELL	PRESSURE				

PLANE STRAIN CONSOLIDATION

TEST NO. $CK_oUPSA-5$ TYPE OF CONSOLIDATION VERT. K_o

INCREMENT : 1.0 TO 2.0 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1c} 3.40 kg/cm² u_B 1.50 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATEN σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.1455	0.0	–	2.08	2.04
LOAD	0.14[illegible]	0.0	2.98	3.04	2.94
OPEN DRAIN	0.1483	0.0	–	–	–
0.5	0.1486	0.0[illegible]	2.76	–	–
2	0.1502	[illegible]	2.59	2.91	[illegible]
4	0.1512	0.93	–	–	–
6	0.1528	1.14	2.82	2.82	2.81
9	0.15[illegible]2	1.48	–	–	–
12	0.1566	1.71	2.7[illegible]	2.75	2.75
20	0.1615	2.33	[illegible]	[illegible]	[illegible]
30	[illegible]	2.51	[illegible]	[illegible]	2.71
50	[illegible]	3.4[illegible]	[illegible]	[illegible]	[illegible]
62	0.1837	4.30	[illegible]	2.62	2.57
95	0.1874	4.62	2.55	2.60	2.56
123	0.1945	5.[illegible]	2.55	2.50	[illegible]
152	0.1961	5.[illegible]	[illegible]	2.5[illegible]	[illegible]
171	0.2021	5.35	[illegible]	2.51	[illegible]
217	0.2036	6.06	[illegible]	2.49	2.50
240	0.2061	6.12	2.44	2.48	2.38
310	0.2079	6.18	2.44	2.47	2.38
370	0.2094	6.18	2.45	2.42	2.45
425	0.2105	6.10	2.40	2.45	2.41
RELEASE PLATENS		–	–	–	–
438	0.2157	6.15	2.45 (1)	2.53	2.56
[illegible]	0.2172	6.21		–	–
[illegible]	0.2181	6.2[illegible]		2.53	2.56
[illegible]	0.2196	6.30		2.53	[illegible]
502	[illegible]	6.32		–	–
510	0.2225	6.41		2.53	[illegible]
620	[illegible]	6.66		2.52	[illegible]
1044	[illegible]	7.03		2.44	2.49
(1) CELL	PRESSURE				

PLANE STRAIN CONSOLIDATION

TEST NO. CK₀UPSA-5 TYPE OF CONSOLIDATION VERT. K₀

INCREMENT : 2.0 TO 3.0 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1c} 4.39 kg/cm² u_B 1.50 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATEN σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.2349	0.0	-	2.44	2.49
LOAD	0.2369	0.0	3.43	3.34	3.37
OPEN DRAIN	0.2368	0.0	-	-	-
0.5	0.2328	0.23	3.43	-	-
1	0.2382	0.38	3.43	3.31	3.37
4	0.2405	0.67	3.38	3.25	3.27
9	0.2426	1.00	3.38	3.22	3.27
13	0.2447	1.23	3.30	3.20	3.21
16	0.2462	1.38	3.29	3.19	3.14
22	0.2491	1.66	3.17	3.14	3.09
33	0.2537	2.00	3.08	3.10	3.02
41	0.2573	2.19	3.00	3.08	3.06
48	0.2607	2.48	-	-	-
60	0.2636	2.73	3.02	3.05	3.04
70	0.2661	2.92	3.00	3.04	3.00
80	0.2681	3.08	2.99	3.02	2.98
91	0.2700	3.26	3.02	3.02	3.06
110	0.2726	3.47	3.00	3.00	2.96
200	0.2798	4.06	3.02	2.96	3.01
273	0.2846	4.26	2.98	2.90	2.94
474	0.2861	4.11	2.95	2.89	2.92
RELEASE	PLATENS	-	-	-	-
491	0.2882	4.06	2.95$^{(1)}$	2.95	3.02
496	0.2888	4.13		2.95	2.96
501	0.2893	4.15		2.95	2.94
509	0.2900	4.16		2.95	2.95
526	0.2911	4.20		2.95	3.03
546	0.2921	4.25		2.95	3.03
1391	0.3019	3.54		2.80	2.86
(1) CELL	PRESSURE				

PLANE STRAIN CONSOLIDATION

TEST NO. $\overline{I}K_0UPSA$-5 TYPE OF CONSOLIDATION VERT. K_0

INCREMENT : 3.0 TO 2.25 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{IC} 3.70 kg/cm² u_B 1.50 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATEN σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h Kg/cm²
INITIAL	0.3019	0.0	–	2.80	2.86
LOAD	0.3015	0.0	2.18	2.33	2.44
OPEN DRAIN	0.3015	0.0	–	–	–
1	0.3016	-0.14	2.20	2.39	2.44
4	0.3014	-0.25	2.34	2.48	2.67
8	0.3010	-0.34	2.37	2.53	2.70
17	0.3008	-0.36	2.45	2.60	2.75
19	0.3008	-0.40	2.45	2.61	2.75
25	0.3006	-0.43	2.52	2.62	2.68
32	0.3006	-0.44	2.53	2.62	2.66
41	0.3006	-0.44	2.58	2.62	2.66
66	0.3004	-0.45	2.58	2.61	2.69
89	0.3004	-0.52	2.58	2.60	2.25
111	0.3004	-0.54	2.62	2.57	2.64
161	0.3004	-0.64	2.63	2.57	2.70
176	0.3004	-0.64	2.61	2.54	2.64
196	0.3004	-0.69	2.61	2.54	2.70
RELEASE	PLATEAUS	–	–	–	–
201	0.3002	-0.75	2.62(1)	2.57	2.73
211	0.3002	-0.26		2.57	2.25
433	0.3002	-1.15		2.61	2.81
(1) CELL	PRESSURE				

PLANE STRAIN CONSOLIDATION

TEST NO. CK_0UPSA-5 TYPE OF CONSOLIDATION VERT. K_0

INCREMENT : 2.25 TO 1.50 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1C} 2.95 kg/cm² u_B 1.50 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATEN σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.3001^5	0.0	–	2.61	2.81
LOAD	0.2981	0.0	1.96	2.19	2.24
OPEN DRAIN	0.2981	0.0	–	–	–
1	0.2978	-0.28	–	–	–
3	0.2976	-0.49	1.96	2.22	2.26
5	0.2968	-0.52	2.15	–	–
6	0.2966	-0.60	2.15	2.35	2.35
11	0.2962	-0.62	2.20	2.38	2.42
16	0.2960	-0.64	2.26	2.41	2.46
23	0.2956	-0.62	2.34	2.43	2.52
31	0.2952	-0.61	2.45	2.44	2.52
41	0.2952	-0.61	2.41	2.43	2.45
76	0.2951	-0.65	2.41	2.43	2.45
95	0.2951	-0.68	2.47	2.40	2.50
111	0.2950	-0.72	2.41	2.38	2.44
136	0.2950	-0.74	2.44	2.38	2.51
RELEASE	PLATEN'S	–	–	–	–
148	0.2945	-0.82	2.45(1)	2.38	2.42
156	0.2944	-0.87		2.38	2.46
166	0.2943	-0.91		2.38	2.51
181	0.2943	-0.92		2.38	2.45
971	0.2939	-1.97			2.42
(1) CELL	PRESSURE				

PLANE STRAIN CONSOLIDATION

TEST NO. $\overline{CK_0U}$PSA-5 TYPE OF CONSOLIDATION Vert. K_0

INCREMENT : 1.50 TO 0.75 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1c} 2.20 kg/cm² u_B 1.47 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATEN σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.2939	0.0	–	–	2.42
LOAD	0.2927	0.0	1.68	1.67	1.95
OPEN DRAIN	0.2927	0.0	–	–	–
0.5	0.2920	-0.27	1.69	1.71	1.98
3	0.2903	-0.55	1.78	1.80	2.09
6	0.2894	-0.66	1.79	1.86	2.06
10	0.2882	-0.84	1.87	1.94	2.15
16	0.2872	-0.94	1.89	1.97	2.16
26	0.2866	-0.99	1.89	2.01	2.10
31	0.2858	-0.99	1.99	2.04	2.16
38	0.2855	-1.02	2.00	2.07	2.21
45	0.2849	-1.00	2.09	2.10	2.23
60	0.2848	-1.05	2.06	2.10	2.12
76	0.2846	-1.07	2.08	2.11	2.21
77	0.2843	-1.09	2.07	2.11	2.23
100	0.2841	-1.14	2.12	2.11	2.16
115	0.2840	-1.15	2.12	2.10	2.21
142	0.2840	-1.20	2.13	2.10	2.21
184	0.2839	-1.27	2.12	2.08	2.17
210	0.2838	-1.35	2.13	2.08	2.21
490	0.2836	-1.57	2.12	2.05	2.21
RELEASE	PLATENS	–	–	–	–
498	0.2836	-1.57	2.12U	–	–
506	0.2829	-1.73		2.03	2.16
525	0.282[illegible]	-1.81		2.03	2.17
560	0.2822	-1.87		2.03	2.17
582	0.2821	-1.90		2.03	2.15
646	0.2819	-1.98		2.02	2.13
1446	0.2813	-2.79		1.91	2.1[illegible]
U) CELL	PRESSURE				

PLANE STRAIN TEST ON COHESIVE SOIL SHEAR DATA

TEST NO. $\overline{CK_0U}$-PSA-5 (OC)
DATE 8-2-67
TESTED BY JJR

CONSOLIDATION PRESSURE, $\bar{\sigma}_c$ .732 KG/CM²
BACK PRESSURE, u_B 1.47 KG/CM²
PORE PRESSURE RESPONSE IN 5 MINUTES AT u_B = 99 % 1.47 KG/CM²

GAUGE NO. .001
PROVING RING NO. 1867
STRAIN RATE .00036 IN/HR
MEMBRANE LEAKAGE —

INITIAL LENGTH 3.295 IN
INITIAL AREA 33.037 CM²
INITIAL Z_3 ($\sigma_3 = \bar{\sigma}_c + u_B$) —

AXIAL STRAIN (%)	$\bar{\sigma}_1$ (1) CORRECTED	AVG. $\bar{\sigma}_2$ CORRECTED	$\bar{\sigma}_3$ CORRECTED	$\bar{\sigma}_1/\bar{\sigma}_{1c}$	$\bar{\sigma}_2/\bar{\sigma}_{1c}$	$\bar{\sigma}_3/\bar{\sigma}_{1c}$	$(\sigma_1-\sigma_3)/\bar{\sigma}_{1c}$	$\bar{\sigma}_1/\bar{\sigma}_3$	q	$\bar{p}$	$\bar{\sigma}_3/\bar{p}$	$\Delta\sigma_1$	Δu	$\Delta u/\bar{\sigma}_{1c}$	A (2)	
—	.732	.583	.663	1.000	.796	.892	.108	1.121	.039	.692	.842	—	—	—	—	
.025	.861	.563	.603	1.162	.769	.824	.339	1.411	.129	.727	.774	.169	.065	.068	.296	
.058	.988	.493	.563	1.360	.673	.769	.590	1.755	.212	.776	.636	.346	.09	.123	.260	
.074	1.010	.533	.543	1.390	.728	.742	.638	1.960	.233	.776	.687	.389	.11	.150	.294	
.089	1.049	.533	.523	1.426	.728	.714	.712	1.996	.260	.783	.681	.442	.13	.177	.294	
.120	1.111	.523	.503	1.519	.729	.687	.831	2.209	.304	.807	.648	.529	.15	.205	.289	
.151	1.191	.532	.497	1.613	.727	.679	.934	2.376	.342	.839	.634	.614	.155	.212	.257	
.197	1.267	.602	.497	1.731	.822	.665	1.066	2.602	.390	.877	.686	.700	.165	.225	.236	
.228	1.337	.602	.492	1.826	.822	.672	1.159	2.717	.422	.914	.659	.775	.17	.232	.219	
.258	1.382	.601	.491	1.888	.821	.671	1.217	2.915	.445	.936	.642	.820	.17	.232	.207	
.350	1.537	.610	.480	2.100	.833	.656	1.499	3.202	.528	1.008	.605	.936	.17	.232	.182	
.443	1.615	.689	.489	2.206	.941	.668	1.538	3.303	.563	1.052	.650	1.093	.16	.219	.153	
.505	1.649	.709	.489	2.263	.967	.667	1.596	3.379	.580	1.068	.663	1.077	.16	.219	.199	
.596	1.717	.699	.499	2.346	.954	.690	1.665	3.443	.609	1.107	.631	1.135	.15	.205	.132	
.690	1.759	.697	.507	2.403	.952	.693	1.710	3.469	.626	1.133	.615	1.167	.14	.191	.119	
.844	1.809	.735	.525	2.469	1.004	.717	1.747	3.436	.639	1.169	.631	1.192	.12	.164	.101	
1.09	1.820	.723	.523	2.486	.988	.714	1.772	3.492	.648	1.171	.617	1.208	.12	.164	.099	
1.46	1.853	.791	.541	2.520	1.081	.739	1.822	3.436	.659	1.200	.659	1.227	.10	.137	.081	
1.77	1.962	.780	.540	2.544	1.066	.739	1.806	3.449	.661	1.201	.649	1.230	.10	.137	.081	
2.29	1.892	.758	.538	2.516	1.036	.735	1.791	3.424	.652	1.190	.637	1.210	.10	.137	.093	
2.52	1.841	.816	.536	2.514	1.115	.722	1.781	3.433	.652	1.188	.657	1.209	.10	.137	.093	
3.05	1.823	.794	.524	2.490	1.135	.716	1.776	3.479	.649	1.173	.677	1.201	.11	.150	.092	
3.67	1.770	.892	.502	2.418	1.150	.686	1.732	3.526	.639	1.136	.741	1.168	.13	.178	.111	
4.35	1.729	.819	.499	2.362	1.119	.669	1.694	3.536	.620	1.109	.738	1.137	.14	.191	.123	
5.10	1.699	.776	.476	2.321	1.060	.650	1.671	3.569	.611	1.087	.719	1.117	.15	.205	.134	
6.21	1.704	.841	.451	2.327	1.176	.616	1.712	3.779	.626	1.077	.799	1.142	.17	.232	.149	
6.92	1.690	.869	.439	2.309	1.186	.598	1.710	3.858	.626	1.039	.808	1.139	.18	.246	.158	
7.45	1.677	.845	.435	2.290	1.159	.599	1.697	3.855	.621	1.056	.800	1.125	.18	.246	.160	Leakage?
8.29	1.653	.852	.412	2.258	1.164	.563	1.696	4.012	.621	1.033	.825	1.121	.20	.273	.179	
8.95	1.632	.821	.399	2.216	1.122	.531	1.699	4.170	.616	1.015	.817	1.110	.22	.301	.198	
9.56	1.599	.766	.376	2.193	1.060	.514	1.669	4.250	.611	.937	.786	1.135	.23	.314	.210	
10.33	1.603	.833	.333	2.190	1.139	.455	1.736	4.848	.635	.919	.861	1.191	.27	.369	.237	
11.11	1.599	.820	.310	2.177	1.134	.356	1.822	6.131	.667	.927	.895	1.202	.34	.464	.293	
11.49	1.588	.846	.276	2.169	1.156	.309	1.961	7.027	.681	.907	.933	1.226	.37	.505	.302	

REMARKS: (1) CORRECTED FOR MEMBRANE STRENGTH, FILTER STRIPS & PISTON FRICTION
(2) $A = \dfrac{\Delta u - \Delta\sigma_3}{\Delta\sigma_1 - \Delta\sigma_3}$

CONSOLIDATION DATA

TEST NO $\overline{EK_oU}$ PSA-6 U_B 3.00 kg/cm^2

DATE 4-8-68 DEVICE PROTOTYPE TESTED BY J. J. R.

	VOL (cc)	Wgt. (g)	L (in)	ω (%)	S (%)	e
INITIAL	285.22	532.53	3.508	36.5	98.2	1.033
FINAL	252.75	501.00	3.165	29.5	92.3	0.835

σ_{IC} corrected kg/cm^2	$\Delta H/H_o$, % [(1)]		$\Delta V/V_o$, % [(2)]	
	Δ	Σ	Δ	Σ
0.21	0.63	0.63	1.63	1.63
0.52	1.35	1.98	1.34	2.97
0.99	1.42	3.40	1.61	4.58
1.99	2.73	6.13	3.18	7.76
3.80	3.63	9.76	4.03	11.79

(1) FROM DISPLACEMENT DIAL READINGS

(2) FROM VOLUME CHANGE DEVICE

PLANE STRAIN CONSOLIDATION

TEST NO. $\overline{CK_o}$UPSA-6 TYPE OF CONSOLIDATION Vert. Ko

INCREMENT : 0 TO 0.2 kg/cm² DEVICE Prototype

CORRECTED σ_{1C} 3.21 kg/cm² u_B 3.00 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATEN σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.0350	0.0	0.0	–	–
LOAD	0.0385	0.0	3.30	–	–
OPEN DRAIN	0.0385	0.0	3.30	–	–
1	0.0421	1.63	3.30	3.30	3.33
2	0.0424	1.80	3.30	3.29	3.31
3	0.0428	2.00	3.30	3.28	3.31
5	0.0432	2.22	3.20	3.26	3.30
15	0.0460	3.52	3.20	3.25	3.28
29	0.0481	3.65	3.19	3.23	3.25
35	0.0513	4.17	3.19	3.23	3.22
40	0.0524	4.25	3.17	3.22	3.21
80	0.0537	4.37	3.17	3.20	3.17
119	0.0556	4.55	3.17	3.19	3.15
145	0.0562	4.58	3.17	3.17	3.16
255	0.0570	4.65	3.17	3.16	3.12

PLANE STRAIN CONSOLIDATION

TEST NO. CK₀UPSA-6 TYPE OF CONSOLIDATION VERT K₀

INCREMENT : 0.2 TO 0.5 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1C} 3.52 kg/cm² u_B 3.00 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATEN σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.0570	0.0	-	3.16	3.12
LOAD	0.0600	0.0	3.49	-	-
OPEN DRAIN	0.0630	0.0	3.49	-	-
2	0.0635	1.62	3.49	3.44	3.44
7	0.0665	1.92	3.49	3.41	3.41
12	0.0695	2.22	3.49	3.40	3.40
17	0.0727	2.32	3.41	3.39	3.40
22	0.0756	2.34	3.41	3.38	3.38
32	0.0780	2.60	3.41	3.36	3.37
42	0.0803	2.61	3.41	3.35	3.36
52	0.0832	2.62	3.41	3.35	3.32
62	0.0853	2.72	3.41	3.34	—
72	0.0866	2.82	3.41	3.32	3.30
107	0.0894	3.12	3.36	3.31	3.30
142	0.0915	3.17	3.30	3.28	3.29
169	0.0922	3.22	3.30	3.28	3.28
199	0.0928	3.24	3.30	3.28	3.27
RELEASE					
222	0.0990	3.30	3.30[1]	3.35	3.35
PLATES:	[illegible]				
237	0.1000	3.33	3.30	3.33	3.34
242	0.1001	3.47	3.35	3.34	3.34
849	0.1045	3.82	3.33	—	—
(1) CELL	PRESSURE				

PLANE STRAIN CONSOLIDATION

TEST NO. $\overline{CK_0}$UPSA-6 TYPE OF CONSOLIDATION VERT. K_0

INCREMENT : 0.5 TO 4.0 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1c} 3.99 kg/cm² u_B 3.00 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATEN σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h Kg/cm²
INITIAL	0.1045	0.0	–	–	–
LOAD	0.1048	0.0	3.83	–	–
OPEN DRAIN	0.1048	0.0	3.83	–	–
1/4	0.1068	0.75	3.83	–	–
1	0.1083	0.90	3.78	3.75	3.73
2	0.1097	1.05	3.78	3.73	3.71
5	0.1121	1.40	3.78	3.71	3.67
7	0.1138	1.55	3.22	3.66	3.65
11	0.1170	1.85	3.68	3.64	3.62
15	0.1193	1.95	3.63	3.63	3.60
21	0.1222	2.26	3.63	–	–
27	0.1249	2.50	3.60	3.61	3.57
35	0.1275	2.75	3.60	–	–
44	0.1299	2.95	3.57	–	–
50	0.1313	3.05	3.57	3.58	3.55
61	0.1334	3.24	3.53	–	–
75	0.1356	3.36	3.50	3.56	3.54
93	0.1375	3.53	3.50	–	–
162	0.1413	3.85	3.50	3.55	3.51
230	0.1428	4.00	3.50	3.53	3.48
260	0.1433	4.04	3.50	3.53	3.48
320	0.1441	4.08	3.50	3.52	3.46
357	0.1477	4.12	3.50	3.55	3.55
371	0.1480	4.15	3.50	–	–
417	0.1492	4.25	3.50	3.54	3.54
510	0.1505	4.30	3.52	3.53	3.52
770	0.1521	4.42	3.52	3.48	3.44
1340	0.1539	4.59	3.52	3.40	3.37
1505	0.1542	4.60	3.52	3.37	3.36

PLANE STRAIN CONSOLIDATION

TEST NO. CK_oUPSA-6 TYPE OF CONSOLIDATION VERT K_o

INCREMENT : 1.0 TO 2.0 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1C} 4.99 kg/cm² u_B 3.00 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATEN σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN $\overline{T}_h$ kg/cm²
INITIAL	0.1543	0.0	–	3.37	3.36
LOAD	0.1561	0.0	4.52	–	–
OPEN DRAIN	0.1561	0.0	4.52	–	-
1	0.1600	0.75	4.52	4.44	4.38
2	0.1623	1.02	4.47	4.37	4.31
3	0.1643	1.20	4.41	4.35	4.27
4	0.1652	1.30	4.41	4.32	4.23
5	0.1668	1.52	4.41	4.32	4.22
7	0.1698	1.80	4.35	4.29	4.21
11	0.1738	2.28	4.35	4.28	4.20
13	0.1768	2.50	4.29	4.29	4.19
15	0.1791	2.70	4.29	4.28	4.19
20	0.1848	3.17	4.23	4.22	4.18
25	0.1893	3.53	4.23	4.27	4.17
40	0.2011	4.60	4.20	4.25	4.15
54	0.2080	5.25	4.20	4.21	4.14
75	0.2171	6.08	4.13	4.18	4.11
95	0.2321	7.53	4.13	4.16	4.07
360	0.2412	8.46	4.10	4.05	4.02
460	0.2428	8.58	4.05	4.02	3.97
482	0.2444	8.63	4.05	3.95	4.02
540	0.2457	8.71	4.05	4.05	4.04
1285	0.2501	9.06	4.05	3.84	3.84

PLANE STRAIN CONSOLIDATION

TEST NO. CK₀UPSA-6 TYPE OF CONSOLIDATION VERT K₀

INCREMENT : 2.0 TO 4.0 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1c} 2.03 kg/cm² u_B 3.00 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATEN σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.2501	0.0	-	3.84	3.84
LOAD	0.2584	0.0	6.05	-	-
OPEN DRAIN	0.2584	0.0	6.05	-	-
1/4	0.2619	0.50	6.05		-
1	0.2644	0.80	6.05	6.01	5.74
2	0.2670	1.09	6.02	5.92	5.67
3	0.2696	1.40	5.98	5.87	5.62
5	0.2740	1.91	5.98	5.81	5.57
8	0.2808	2.40	5.83	5.77	5.55
9	0.2829	2.61	5.83	-	-
10	0.2848	2.77	5.81	5.76	5.49
15	0.2927	3.50	5.75	5.71	6.46
20	0.2997	4.20	5.75	5.69	5.42
30	0.3098	5.18	5.70	5.60	5.36
45	0.3215	6.32	5.66	5.56	5.34
53	0.3275	6.82	5.59	5.54	5.31
75	0.3381	7.93	5.59	5.48	5.28
90	0.3438	8.43	5.48	5.37	5.21
96	0.3461	8.71	5.43	—	—
110	0.3499	9.01	5.38	—	—
125	0.3530	9.31	5.38	5.30	5.17
167	0.3596	9.96	5.32	5.27	5.15
195	0.3620	10.27	5.32	5.22	5.13
243	0.3653	10.52	5.27	—	—
364	0.3689	10.81	5.27	5.16	5.03
402	0.3694	10.86	5.27	5.14	5.02
RELEASE PLATENS 620	0.3714	11.00	5.21	5.06	4.85
PLATENS RELEASED [illegible]0	0.3730	11.10	5.22 (1)	5.11	4.94
820	0.3741	11.12	5.22	5.09	4.56
1395	0.3759	11.46	5.22	4.88	4.61
1566	0.3766	11.51	5.11	-	—
(1) CELL	PRESSURE				

PLANE STRAIN TEST ON COHESIVE SOIL

TEST NO. CK₀U PSA-6
DATE 4-12-68
TESTED BY JJR

CONSOLIDATION PRESSURE, $\bar{\sigma}_c$ 3.80
BACK PRESSURE, u_B 3.00
PORE PRESSURE RESPONSE IN – MINUTES AT u_B = 91 %

GAUGE NO. 3/1
PROVING RING NO. –
STRAIN RATE 1% PER HR.
MEMBRANE LEAKAGE NONE

INITIAL LENGTH 3.165(in)
INITIAL AREA 32.015 cm²
INITIAL Z_3 ($\sigma_3 = \bar{\sigma}_c + u_B$) –

FINAL Z_3 ($\sigma_3 = 0$) –
FINAL COUNTER ($\sigma_3 = 0$) –

AXIAL STRAIN (%)	$\bar{\sigma}_1$ (1) CORRECTED	AVG. $\bar{\sigma}_2$ CORRECTED	$\bar{\sigma}_3$ CORRECTED	$\frac{\bar{\sigma}_1}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_2}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_3}{\bar{\sigma}_{1c}}$	$\frac{\sigma_1-\sigma_3}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_1}{\bar{\sigma}_3}$	q	$\bar{p}$	$\bar{\sigma}_2/\bar{p}$	$\Delta\sigma_1$	Δu	$\frac{\Delta u}{\bar{\sigma}_{1c}}$	A (2)
0.0	3.80	1.689	2.096	1.000	0.444	0.552	.448	1.813	0.852	2.948	.573	0.0	0.0	0.0	–
0.0	3.84	1.688	2.082	1.012	0.444	0.548	.464	1.847	.881	2.963	.570	0.06	0.014	.004	0.246
0.002	3.884	1.682	2.043	1.022	0.443	0.538	.485	1.841	.921	2.964	.568	0.136	0.062	.014	0.384
.006	3.924	1.682	2.00	1.033	0.443	0.527	.505	1.958	.960	2.964	.568	0.214	0.090	.024	0.422
.015	3.965	1.683	1.956	1.043	0.443	0.515	.529	2.027	1.004	2.96	.569	0.302	0.138	.036	0.457
.028	3.99	1.69	1.89	1.051	0.445	0.498	.553	2.11	1.05	2.94	.575	0.393	0.200	.053	0.508
.041	4.02	1.72	1.85	1.058	0.451	0.487	.571	2.17	1.08	2.94	.584	0.462	0.240	.063	0.520
.058	4.03	1.73	1.79	1.061	0.455	0.473	.588	2.24	1.12	2.91	.593	0.527	0.295	.077	0.560
.088	4.05	1.75	1.73	1.065	0.460	0.456	.610	2.34	1.16	2.89	.604	0.608	0.360	.095	0.591
.117	4.05	1.76	1.67	1.066	0.464	0.442	.624	2.41	1.18	2.86	.615	0.662	0.412	.108	0.622
.161	4.09	1.78	1.61	1.078	0.468	0.424	.654	2.54	1.24	2.85	.623	0.774	0.479	.126	0.618
.227	4.01	1.79	1.53	1.055	0.472	0.402	.652	2.62	1.24	2.77	.647	0.768	0.560	.147	0.728
.395	3.94	1.80	1.40	1.035	0.473	0.370	.666	2.80	1.26	2.67	.673	0.818	0.683	.180	0.835
.490	3.87	1.79	1.33	1.020	0.471	0.362	.668	2.89	1.27	2.60	.687	0.824	0.750	.197	0.910
.562	3.84	1.78	1.29	1.009	0.470	0.340	.669	2.96	1.27	2.56	.697	0.827	0.793	.208	0.958
.644	3.83	1.81	1.29	1.008	0.477	0.340	.669	2.97	1.27	2.56	.707	0.827	0.795	.209	0.962
.847	3.72	1.76	1.18	0.978	0.464	0.312	.666	3.13	1.26	2.45	.720	0.816	0.900	.237	1.103
.982	3.65	1.74	1.13	0.962	0.459	0.299	.663	3.22	1.26	2.37	.729	0.804	0.950	.250	1.181
1.18	3.57	1.71	1.06	0.939	0.451	0.279	.659	3.36	1.25	2.31	.741	0.788	1.021	.269	1.299
1.58	3.42	1.66	0.97	0.901	0.439	0.255	.646	3.53	1.23	2.20	.759	0.709	1.126	.292	1.589
1.81	3.34	1.63	0.94	0.880	0.429	0.246	.634	3.57	1.20	2.14	.763	0.689	1.145	.301	1.662
2.24	3.27	1.61	0.91	0.861	0.425	0.239	.622	3.60	1.18	2.09	.772	0.644	1.171	.308	1.819
2.40	3.18	1.57	0.86	0.836	0.412	0.228	.608	3.67	1.15	2.02	.775	0.591	1.214	.319	2.054
2.76	3.08	1.54	0.84	0.812	0.405	0.220	.592	3.69	1.12	1.96	.787	0.527	1.243	.327	2.357
2.98	3.04	1.53	0.83	0.801	0.402	0.218	.583	3.67	1.11	1.93	.788	0.493	1.248	.328	2.533
3.44	2.94	1.48	0.81	0.776	0.391	0.213	.563	3.64	1.07	1.88	.791	0.414	1.267	.333	3.058
4.02	2.84	1.40	0.79	0.747	0.368	0.208	.538	3.58	1.02	1.81	.776	0.320	1.283	.337	4.010
4.47	2.78	1.35	0.78	0.731	0.365	0.205	.525	3.56	0.99	1.79	.762	0.269	1.293	.340	[illegible]
5.04	2.71	1.30	0.77	0.712	0.341	0.203	.509	3.51	0.97	1.74	.746	0.206	1.300	.342	[illegible]
5.54	2.64	1.27	0.76	0.694	0.334	0.199	.495	3.48	0.94	1.70	.747	0.148	1.312	.345	8.850
6.53	2.48	1.22	0.74	0.653	0.321	0.196	.457	3.33	0.87	1.61	.756	0.062	1.321	.348	–

REMARKS: (1) CORRECTED FOR MEMBRANE STRENGTH, FILTER STRIPS & PISTON FRICTION

(2) $A = \frac{\Delta u - \Delta\sigma_3}{\Delta\sigma_1 - \Delta\sigma_3}$

CONSOLIDATION DATA

TEST NO $\overline{\text{CK}_o\text{UPSA}}$-2(3) U_B 1.5 to 3.0 kg/cm^2

DATE 6-5-69 DEVICE PROTOTYPE TESTED BY R.B.B.

	VOL (cc)	Wgt. (g)	L (in)	ω(%)	S(%)	e
INITIAL	277.18	514.07	3.526	36.5	97.9	1.032
FINAL	255.86	488.5	3.263	29.6	100	0.889

$\bar{\sigma}_{1c}$ corrected Kg/cm^2	ΔH/Ho, % (1)		ΔV/Vo, % (2)	
	Δ	Σ	Δ	Σ
0.56	0.32	0.32	-0.88	-0.88
1.03	0.38	0.70	0.35	-0.53
2.09	1.14	1.84	1.21	0.68
2.99	0.96	2.80	1.06	1.74
3.91	1.17	3.97	0.99	2.73
5.01	1.21	5.18	0.97	3.70
5.99	0.66	5.84	0.37	4.07
6.49	0.03	5.87	-0.13	3.94
3.99	-0.08	5.79	-0.25	3.69
2.48	-0.19	5.60	-0.34	3.35
1.46	-0.41	5.19	-0.40	

(1) FROM DISPLACEMENT DIAL READINGS

(2) FROM VOLUME CHANGE DEVICE

(3) SECOND SET UP ONLY

PLANE STRAIN CONSOLIDATION

TEST NO. $\overline{CK_0U}PSA$-2 TYPE OF CONSOLIDATION Vert. K_0

INCREMENT : 0.0 TO 0.5 kg/cm² DEVICE Prototype

CORRECTED σ_{1c} 2.06 kg/cm² u_B 1.5 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	CELL PRESSURE σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.0154	[illegible]	0.0	–	–
LOAD	0.0154	0.0	2.00	–	–
OPEN DRAIN	0.0154	0.0	2.00	–	–
3	0.0242	–	2.00	–	–
5	0.0263	2.03	2.00	–	–
6	0.0263	2.11	2.00	1.70	1.85
11	0.0265	2.30	1.98	1.80	1.95
15	0.0265	2.43	1.98	1.82	1.92
34	0.0265	2.91	1.98	1.95	1.94
286	0.0265	3.06	1.98	1.95	1.94
1540	0.0265	2.39	1.98	2.15	1.93

PLANE STRAIN CONSOLIDATION

TEST NO. CK₀UPSA-2 TYPE OF CONSOLIDATION VERT. K₀

INCREMENT : 0.5 TO 1.0 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1C} 2.53 kg/cm² u_B 1.5 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	CELL PRESSURE σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.0265	0.0	1.98	2.15	1.93
LOAD	0.0265	0.0	2.49	–	–
OPEN DRAIN	0.0265	0.0	2.49	–	–
1	0.0275	0.05	2.49	–	–
3	0.0280	0.22	2.49	2.30	2.14
5	0.0283	0.26	2.42	–	–
12	0.0295	0.38	2.39	–	–
28	0.0302	0.53	2.33	2.12	1.95
152	0.0312	0.56	2.33	2.15	1.94
RELEASE PLATENS		–	–	–	–
16.5	0.0329	0.57	2.26	2.20	2.09
196	0.0364	0.76	2.31	2.20	2.13
406	0.0385	0.91	2.31	2.12	2.09
1192	0.0395	0.96	2.31	2.15	2.02

PLANE STRAIN CONSOLIDATION

TEST NO. CK₀UPSA-2 TYPE OF CONSOLIDATION VERT. K₀

INCREMENT : 1.0 TO 2.0 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1C} 3.59 kg/cm² u_B 1.5 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	CELL PRESSURE σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.0395	0.0	2.31	2.15	2.07
LOAD	0.0395	0.0	3.31	—	—
OPEN DRAIN	0.0395	0.0	3.31	—	—
1	0.0442	0.38	3.31	2.75	2.74
3	0.0459	0.58	3.31	-	-
5	0.0474	0.70	3.22	2.71	2.69
7	0.0485	[illegible]	3.15	—	—
12	[illegible]	1.04	3.00	2.56	2.56
20	0.0549	1.29	[illegible]	2.54	2.55
83	0.0614	1.91	2.92	2.50	2.51
114	0.0623	2.03	2.93	2.48	2.53
174	0.0632	2.15	2.88	—	—
194	0.0636	2.19	2.83	2.51	2.53
RELEASE	PLATENS	—	—	—	—
212	0.0674	2.30	2.81	2.65	2.62
230	0.0696	2.40	2.83	2.66	2.63
240	0.0712	2.50	2.83	2.66	2.61
PLATENS	RELEASED.	—	—	—	—
251	0.0719	2.54	2.83	2.64	2.60
417	0.0749	2.81	-	—	—
1414	0.0778	3.33	2.79	2.65	2.49
1534	0.0784	3.46	2.71		

PLANE STRAIN CONSOLIDATION

TEST NO. CK_0UPSA-2 TYPE OF CONSOLIDATION VERT K_0

INCREMENT : 2.0 TO 3.0 kg/cm^2 DEVICE PROTOTYPE

CORRECTED σ_{1C} 4.49 kg/cm^2 u_B 1.5 kg/cm^2

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	CELL PRESSURE σ_h kg/cm^2	Back End Platen σ_h kg/cm^2	FRONT END PLATEN σ_h Kg/cm^2
				—	—
INITIAL	0.0784	0.0	2.71	–	–
LOAD	0.0805	0.0	3.71	–	—
OPEN DRAIN	0.0805	0.0	3.71	–	—
6	0.0845	0.33	3.61	3.05	3.04
20	0.0870	0.51	3.61	—	—
40	0.0892	0.75	3.64	2.92	2.89
80	0.0914	0.86	3.58	2.92	2.90
135	0.0932	1.19	3.58	2.90	2.89
PLATENS	RELEASED	-	—	—	—
150	0.0956	1.25	3.50	3.21	3.06
175	0.0986	1.44	3.50	3.13	3.11
256	0.1030	1.76	3.50	3.06	3.01
325	0.1060	2.05	3.47	—	—
633	0.1086	2.38	3.47	—	—
785	0.1095	2.49	3.47	—	—
1333	0.1114	2.92	3.47	3.03	3.03

PLANE STRAIN CONSOLIDATION

TEST NO. $\overline{CK_o}$UPSA-2 TYPE OF CONSOLIDATION VERT. K_o

INCREMENT : 3.0 TO 4.0 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1C} 5.41 kg/cm² u_B 4.5 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	CELL PRESSURE σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN $\overline{\sigma}_h$ kg/cm²
INITIAL	0.1114	0.0	3.47	3.03	3.03
LOAD	0.1134	0.0	4.47	–	–
OPEN DRAIN	0.1134	0.0	4.47	–	–
2	0.1150	0.34	4.47	3.55	3.35
3	0.1154	0.39	4.47	–	–
6	0.1166	0.50	4.47	3.50	3.36
14	0.1177	0.60	4.20	3.49	3.36
23	0.1192	0.70	4.08	3.46	3.37
45	0.1210	0.84	4.00	3.48	3.38
77	0.1229	1.02	4.00	3.46	3.37
89	0.1245	1.12	3.90	3.41	3.36
PLATENS RELEASED		–	–	–	–
151	0.1300	1.20	3.89	3.58	3.60
197	0.1333	1.31	3.98	3.52	3.53
317	0.1387	1.68	3.78	3.51	3.57
715	0.1462	2.31	3.68	3.49	3.43
1300	0.1514	2.74	3.60	3.39	3.37

PLANE STRAIN CONSOLIDATION

TEST NO CK0UPSA-2 TYPE OF CONSOLIDATION VERT. K0

INCREMENT : 4.0 TO 5.0 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1c} 6.51 kg/cm² u_B 1.5 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	CELL PRESSURE σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.1514	0.0	3.60	3.39	3.37
LOAD	0.1539	0.0	4.60	-	-
OPEN DRAIN	0.1538	0.0	4.60	-	-
1	0.1542	0.14	4.60	-	-
4	0.1556	0.24	4.45	3.80	3.85
12	0.1561	0.33	4.45	3.79	3.82
23	0.1599	0.53	4.52	3.78	3.81
65	0.1629	0.72	4.52	3.81	3.86
78	0.1637	0.78	4.52	3.81	3.89
122	0.1671	0.97	4.35	3.85	3.91
192	0.1739	1.33	4.35	3.90	4.04
252	0.1776	1.57	4.30	3.92	4.03
526	0.1853	2.09	4.18	3.90	4.12
1334	0.1915	2.55	4.18	3.72	4.07
1580	0.1928	2.67	4.09	3.71	4.07

PLANE STRAIN CONSOLIDATION

TEST NO. CK_0UPSA-2 TYPE OF CONSOLIDATION VERT. K_0

INCREMENT : 5.0 TO 6.0 kg/cm^2 DEVICE PROTOTYPE

CORRECTED σ_{IC} 7.49 kg/cm^2 u_B 1.5 kg/cm^2

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c)	CELL PRESSURE σ_h kg/cm^2	Back End Platen σ_h kg/cm^2	FRONT END PLATEN σ_h kg/cm^2
INITIAL	0.1928	0.0	4.09	3.71	4.02
LOAD	0.1936	0.0	5.09	–	–
OPEN DRAIN	0.1936	0.0	5.09	–	–
6	0.1971	-0.09	5.09	3.95	4.21
19	0.1980	-0.19	5.09	–	–
39	0.1987	-0.09	5.10	3.92	4.24
55	0.1995	-0.04	5.05	3.95	4.23
152	0.2032	0.31	5.00	3.96	4.28
PLATENS	RELEASED	–	–	–	–
340	0.2057	0.41	4.95	4.06	4.38
403	0.2073	0.51	4.85	4.07	4.40
1149	0.2147	1.00	4.85	4.03	4.33
1299	0.2154	1.03	4.73	–	–

PLANE STRAIN CONSOLIDATION

TEST NO. $\overline{CK_0}$UPSA-7 TYPE OF CONSOLIDATION VERT. K_0

INCREMENT : 6.0 TO 5.5 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1c} 7.49 kg/cm² u_B 2.00 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	CELL PRESSURE σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.2154	0.0	4.78	—	—
LOAD	0.2162	0.0	4.78	—	-
OPEN DRAIN	0.2162	0.0	4.78	—	—
—	0.2162	-0.10	4.78	4.20	4.08
-	0.2162	-0.12	4.85	—	—
150	0.2161	-0.22	4.95	4.25	4.61
1242	0.2165	-0.36	4.95	-	-

PLANE STRAIN CONSOLIDATION

TEST NO. $\overline{CK_0}$UPSA-7 TYPE OF CONSOLIDATION VERT. K_0

INCREMENT : 5.5 TO 4.0 kg/cm^2 DEVICE PROTOTYPE

CORRECTED σ_{1C} 5.99 kg/cm^2 u_B 2.0 kg/cm^2

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	CELL PRESSURE σ_h kg/cm^2	Back End Platen σ_h kg/cm^2	FRONT END PLATEN σ_h Kg/cm^2
INITIAL	0.2165	0.0	4.95	—	—
LOAD	0.2160	0.0	3.58	—	—
OPEN DRAIN	0.2160	0.0	3.58	—	—
1	0.2155	-0.09	3.62	—	—
4	0.2153	-0.14	3.74	—	—
5	0.2150	-0.19	3.80	3.80	4.30
9	0.2147	-0.22	3.80	—	—
27	0.2145	-0.31	3.82	3.91	4.32
66	0.2143	-0.31	3.90	—	—
PLATENS	RELEASED	—	3.90	—	—
207	0.2138	-0.41	3.95	3.85	4.33
264	0.2138	-0.46	4.03	3.84	4.31
314	0.2138	-0.47	4.02	—	—
1356	0.2137	-0.69	4.15	3.77	4.22

PLANE STRAIN CONSOLIDATION

TEST NO. CK₀UPSA-7 TYPE OF CONSOLIDATION Vert. K₀

INCREMENT : 4.0 TO 2.5 kg/cm² DEVICE Prototype

CORRECTED σ_{1C} 4.48 kg/cm² u_B 2.0 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	Cell Pressure σ_h kg/cm²	Back End Platen σ_h kg/cm²	Front End Platen σ_h Kg/cm²
INITIAL	0.2132	0.0	4.15	3.77	4.22
LOAD	0.2132	0.0	2.65	–	–
OPEN DRAIN	0.2132	0.0	2.65	–	–
1	0.2122	-0.12	2.65	–	–
–	0.2120	-0.17	2.80	–	–
–	0.2115	-0.23	2.87	–	–
–	0.2108	-0.32	2.98	–	–
31	0.2098	-0.49	3.08	3.48	3.83
69	0.2094	-0.54	3.15	–	–
126	0.2086	-0.62	3.15	–	–
261	0.2080	-0.74	3.15	–	–
301	0.2079	-0.74	3.42	–	–
1326	0.2073	-0.93	3.49	–	

PLANE STRAIN CONSOLIDATION

TEST NO. CKoUPSA-7 TYPE OF CONSOLIDATION VERT. Ko

INCREMENT : 2.5 TO 1.5 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{IC} 3.96 kg/cm² u_B 2.5 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	CELL PRESSURE σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h Kg/cm²
INITIAL	0.2073	0.0	3.49	—	—
LOAD	0.2053	0.0	3.41	—	—
OPEN DRAIN	0.2053	0.0	3.41	—	—
2	0.2048	-0.04	3.41	3.25	3.57
6	0.2035	-0.22	3.41	3.60	3.75
8	0.2028	-0.26	3.56	3.66	3.78
13	0.2018	-0.35	3.63	3.74	3.85
24	0.2009	-0.44	3.78	3.74	3.84
33	0.2004	-0.49	3.88	3.76	3.80
79	0.1994	-0.54	3.83	3.78	3.85
146	0.1989	-0.62	3.87	3.71	3.77
196	0.1967	-0.71	3.87	3.73	3.78
1158	0.1947	-1.01	3.95	3.71	3.76
	INCREASE	PORE	PRESSURE	TO	3.0 Kg/cm²
102.6 HRS	0.1935	-1.06	4.45	3.75	3.82
106 HRS	0.1931	-1.07	4.35	4.16	4.15
125.6 HRS	0.1931	-1.11	4.32	4.16	4.14

PLANE STRAIN TEST ON COHESIVE SOIL

TEST NO. $\overline{CK_0}$UPSA-7
DATE 5-26-69
TESTED BY R. B. B

CONSOLIDATION PRESSURE, $\bar{\sigma}_c$ 1.46
BACK PRESSURE, u_B 3.0
PORE PRESSURE RESPONSE 94 . %
IN — MINUTES AT u_B :

GAUGE NO. 3 / 11
PROVING RING NO. ALF 44575
STRAIN RATE 0.5% [illegible] 2.6%
MEMBRANE LEAKAGE —

INITIAL LENGTH 3.263 in
INITIAL AREA 30.955 cm²
INITIAL σ_3 —
($\sigma_3 = \bar{\sigma}_c + u_B$)

AXIAL STRAIN (%)	$\bar{\sigma}_v^{(1)}$ CORRECTED	AVG. $\bar{\sigma}_z$ CORRECTED	$\bar{\sigma}_H$ CORRECTED	$\frac{\bar{\sigma}_v}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_z}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_H}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_1-\bar{\sigma}_3}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_v}{\bar{\sigma}_H}$	q	$\bar{p}$	$\bar{\sigma}_3/\bar{p}$	$\Delta\sigma$	Δu	$\frac{\Delta u}{\bar{\sigma}_{1c}}$	$A^{(2)}$
0.0	1.46	1.18	1.31	1.002	0.804	0.893	0.107	1.12	0.078	1.386	0.85	0.0	0.0	0.0	–
0.04	1.76	1.11	1.08	1.203	0.761	0.739	0.464	1.63	0.339	1.421	0.784	0.517	0.221	0.150	0.426
0.08	2.07	1.06	0.88	1.414	0.724	0.601	0.813	2.35	0.595	1.474	0.719	1.024	0.419	0.285	0.409
0.12	2.27	1.06	0.80	1.550	0.721	0.548	1.002	2.82	0.733	1.536	0.687	1.298	0.492	0.336	0.379
0.21	2.66	1.07	0.71	1.813	0.733	0.483	1.330	3.75	0.994	1.681	0.639	1.775	0.584	0.398	0.329
0.41	2.92	1.12	0.68	1.992	0.763	0.463	1.529	4.30	1.119	1.789	0.621	2.062	0.609	0.416	0.296
0.61	3.197	1.17	0.71	2.194	0.805	0.485	1.701	4.52	1.246	1.953	0.600	2.324	0.575	0.394	0.248
0.81	3.37	1.27	0.72	2.308	0.867	0.493	1.810	4.70	1.325	2.043	0.620	2.476	0.561	0.396	0.227
1.03	3.44	1.33	0.73	2.352	0.905	0.499	1.853	4.72	1.357	2.085	0.635	2.531	0.552	0.377	0.218
1.20	3.55	1.39	0.76	2.427	0.952	0.517	1.910	4.90	1.398	2.155	0.647	2.613	0.524	0.358	0.201
1.41	3.61	1.43	0.75	2.463	0.976	0.514	1.954	4.80	1.431	2.184	0.656	2.669	0.527	0.359	0.197
1.62	3.64	1.46	0.77	2.488	0.999	0.526	1.962	4.73	1.436	2.206	0.663	2.687	0.509	0.347	0.189
[illegible]	3.68	1.50	0.78	2.515	1.023	0.535	1.980	4.70	1.450	2.233	0.671	2.713	0.495	0.337	0.182
1.90	3.68	1.51	0.78	2.512	1.032	0.535	1.977	4.69	1.447	2.231	0.677	2.708	0.495	0.337	0.183
2.12	3.66	1.52	0.77	2.517	1.037	0.530	1.987	4.75	1.454	2.230	0.681	2.722	0.501	0.342	0.184
2.20	3.62	1.54	0.81	2.474	1.050	0.552	1.923	4.49	1.408	2.215	0.694	2.628	0.470	0.320	0.179
2.45	3.57	1.54	0.80	2.440	1.049	0.546	1.894	4.46	1.386	2.186	0.702	2.585	0.476	0.325	0.184
2.62	3.54	1.53	0.81	2.416	1.043	0.556	1.860	4.35	1.362	2.175	0.702	2.536	0.463	0.316	0.182
2.96	3.45	1.51	0.81	2.355	1.029	0.554	1.801	4.25	1.319	2.130	0.707	2.449	0.465	0.317	0.190
3.24	3.39	1.497	0.80	2.318	1.022	0.547	1.771	4.24	1.296	2.098	0.714	2.434	0.474	0.323	0.197
3.62	3.36	1.49	0.81	2.292	1.020	0.551	1.743	4.16	1.276	2.083	0.719	2.362	0.462	0.319	0.198
4.076	3.29	1.609	0.81	2.249	1.031	0.555	1.689	4.04	1.236	2.049	0.736	2.282	0.460	0.314	0.202
4.40	3.27	1.502	0.79	2.235	1.026	0.540	1.695	4.137	1.241	2.031	0.740	2.288	0.480	0.328	0.210
4.84	3.30	1.51	0.81	2.255	1.033	0.551	1.704	4.092	1.247	2.054	0.736	2.300	0.463	0.316	0.201
5.06	3.29	1.52	0.81	2.246	1.038	0.554	1.692	4.055	1.239	2.050	0.741	2.282	0.458	0.313	0.200
5.45	3.23	1.54	0.82	2.205	1.049	0.558	1.647	3.954	1.206	2.023	0.759	2.215	0.451	0.308	0.204
5.83	3.15	1.55	0.82	2.151	1.061	0.562	1.590	3.829	1.164	1.986	0.782	2.130	0.444	0.303	0.208
5.99	3.13	1.55	0.81	2.136	1.059	0.555	1.581	3.846	1.157	1.970	0.787	2.116	0.453	0.309	0.214
6.27	3.07	1.55	0.79	2.109	1.057	0.542	1.567	3.840	1.147	1.941	0.797	2.095	0.471	0.321	0.225
6.57	3.07	1.55	0.80	2.097	1.062	0.546	1.551	3.843	1.136	1.935	0.804	2.091	0.465	0.317	0.224

REMARKS: (1) CORRECTED FOR MEMBRANE STRENGTH, FILTER STRIPS & PISTON FRICTION

(2) $A = \frac{\Delta u - \Delta\sigma_3}{\Delta\sigma_1 - \Delta\sigma_3}$

CONSOLIDATION DATA

TEST NO $\overline{CK_0U}$PSA-8　U_B 2.0 TO 3.0 kg/cm^2

DATE 8-19-69　DEVICE PROTOTYPE　TESTED BY R. W. S.

	VOL (cc)	Wgt. (g)	L (in)	W (%)	S (%)	e
INITIAL	263.89	482.30	3.523	38.7	96.9	1.109
FINAL	243.51	460.91	3.251	32.6	95.7	0.942

σ_{1c} corrected kg/cm^2	$\Delta H/H_0$, %[1]		$\Delta V/V_0$, %[2]	
	Δ	Σ	Δ	Σ
0.21	0.24	0.24	-0.61	-0.61
0.51	0.34	0.58	0.63	0.02
0.98	1.42	2.00	2.07	2.09
1.95	1.50	3.50	1.79	3.88
3.94	4.63	8.13	5.12	9.00
1.96	-0.40	7.73	-0.35	8.65

(1) FROM DISPLACEMENT DIAL READINGS

(2) FROM VOLUME CHANGE DEVICE

PLANE STRAIN TEST ON COHESIVE SOIL

TEST NO. CK₀UPSA-8
DATE 8-19-69
TESTED BY RWS

CONSOLIDATION PRESSURE, $\bar{\sigma}_c$ 1.955
BACK PRESSURE, U_B 2.0
PORE PRESSURE RESPONSE IN 2 MINUTES AT U_B = 95 ± 5 % –

GAUGE NO. 3/1
PROVING RING NO. BLH 44525
STRAIN RATE 0.5% PER HR.
MEMBRANE LEAKAGE —

INITIAL LENGTH 3.251 in
INITIAL AREA 29.490 cm²
INITIAL z_3 $(\sigma_3 = \bar{\sigma}_c + U_B)$

AXIAL STRAIN (%)	$\bar{\sigma}_v$ [illegible]	[illegible] $\bar{\sigma}_z$ [illegible]CTED	$\bar{\sigma}_H$ CORRECTED	$\frac{\bar{\sigma}}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_z}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_H}{\bar{\sigma}_{1c}}$	$\frac{\sigma_1-\sigma_3}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_v}{\bar{\sigma}_H}$	q	$\bar{p}$	$\bar{\sigma}_z/\bar{p}$	$\Delta\sigma_1$	Δu	$\frac{\Delta u}{\bar{\sigma}_c}$	$A^{(2)}$		
0.0	1.955	1.15	1.39	1.00	0.59	0.71	0.289	1.406	0.282	1.673	0.685	0.0	0.0	0.0	—		
0.02	2.11	1.12	1.29	1.08	0.57	0.66	0.420	1.686	0.411	1.703	0.659	0.26	0.09	0.05	0.38		
0.10	2.41	1.09	1.07	1.23	0.66	0.55	0.683	2.238	0.667	1.745	0.625	0.76	0.31	0.16	0.40		
0.21	2.67	1.11	0.95	1.37	0.57	0.49	0.878	2.799	0.858	1.811	0.614	1.14	0.43	0.22	0.37		
0.28	2.80	1.14	0.92	1.43	0.58	0.47	0.961	3.090	0.940	1.861	0.611	1.30	0.46	0.23	0.35		
0.54	3.03	1.18	0.87	1.55	0.60	0.45	1.104	3.471	1.080	1.953	0.605	1.58	0.50	0.26	0.32		
1.08	3.07	1.20	0.82	1.57	0.62	0.42	1.153	3.760	1.127	1.944	0.618	1.67	0.56	0.28	0.33		
1.17	3.07	1.20	0.81	1.57	0.62	0.41	1.156	3.804	1.130	1.936	0.621	1.68	0.57	0.29	0.34		
1.25	3.05	1.20	0.79	1.56	0.61	0.41	1.154	3.847	1.128	1.920	0.625	1.67	0.58	0.297	0.35		
1.53	3.03	1.20	0.77	1.55	0.61	0.39	1.158	3.951	1.132	1.899	0.630	1.68	0.61	0.31	0.36		
2.07	2.93	1.17	0.72	1.50	0.60	0.37	1.134	4.103	1.109	1.823	0.645	1.63	0.66	0.34	0.40		
2.43	2.86	1.16	0.69	1.46	0.59	0.35	1.109	4.159	1.084	1.771	0.654	1.58	0.68	0.35	0.43		
2.99	2.76	1.13	0.65	1.41	0.58	0.33	1.079	4.241	1.054	1.705	0.662	1.52	0.72	0.37	0.47		
3.47	2.67	1.08	0.63	1.36	0.55	0.32	1.044	4.262	1.021	1.646	0.658	1.45	0.74	0.38	0.51		
3.91	2.61	1.08	0.62	1.34	0.55	0.32	1.018	4.206	0.995	1.616	0.665	1.40	0.74	0.38	0.53		
4.56	2.53	1.03	0.59	1.29	0.53	0.30	0.991	4.276	0.969	1.560	0.663	1.35	0.77	0.39	0.57		
4.82	2.53	1.03	0.39	1.29	0.53	0.30	0.990	4.277	0.967	1.558	0.659	1.34	0.77	0.39	0.58		
5.22	2.47	1.02	0.57	1.27	0.52	0.29	0.977	4.378	0.955	1.520	0.668	1.31	0.79	0.41	0.61		
5.65	2.45	1.02	0.57	1.25	0.52	0.29	0.957	4.262	0.936	1.509	0.675	1.28	0.79	0.40	0.62		
6.05	2.37	1.01	0.55	1.22	0.52	0.28	0.932	4.299	0.911	1.463	0.690	1.22	0.81	0.41	0.66		

REMARKS: (1) CORRECTED FOR MEMBRANE STRENGTH, FILTER STRIPS & PISTON FRICTION
(2) $A = \frac{\Delta u - \Delta\sigma_3}{\Delta\sigma_1 - \Delta\sigma_3}$

CONSOLIDATION DATA

TEST NO CK.UPSA-9

u_B 2.00 kg/cm²

DATE 10-10-69 DEVICE MODEL B TESTED BY R.B.B.

	VOL (cc)	Wgt. (g)	L (in)	ω (%)	S (%)	e
INITIAL	283.21	529.95	3.519	37.1	99.5	1.040
FINAL	260.85	510.32	3.381	32.2	100	0.829

$\bar{\sigma}_{IC}$ corrected	$\Delta H/H_o$, % (1)		$\Delta V/V_o$, % (2)	
	Δ	Σ	Δ	Σ
0.24	0.48	0.48	0.82	0.82
0.49	1.36	1.84	1.18	2.00
0.95	1.00	2.84	0.94	2.94
1.94	1.76	4.60	1.81	4.75
3.93	3.71	8.31	3.95	8.70
2.01	-0.42	7.89	-0.31	8.39

(1) FROM DISPLACEMENT DIAL READINGS

(2) FROM VOLUME CHANGE DEVICE

PLANE STRAIN TEST ON COHESIVE SOIL

TEST NO. CK₀UPSA-9
DATE 10-16-69
TESTED BY R. B. B.

CONSOLIDATION PRESSURE, $\bar{\sigma}_c$ 2.00
BACK PRESSURE, U_B 1.97
PORE PRESSURE RESPONSE IN 2 MINUTES AT U_B = 98 %

GAUGE NO. 3/1
PROVING RING NO. BLH 44525
STRAIN RATE 0.5 % PER HR.
MEMBRANE LEAKAGE —

INITIAL LENGTH 3.381 IN
INITIAL AREA 31.722 cm²
INITIAL Z_3 —
($\sigma_3 = \bar{\sigma}_c + U_B$)

AXIAL STRAIN (%)	[illegible]	[illegible] $\bar{\sigma}_2$ TOTAL	$\bar{\sigma}_3$ CORRECTED	$\frac{\bar{\sigma}}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_2}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}}{\bar{\sigma}_{1c}}$	$\frac{\sigma_1-\sigma_3}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_1}{\bar{\sigma}_3}$	q	$\bar{P}$	$\bar{\sigma}_2/\bar{P}$	$\Delta\sigma_1$	Δu	$\frac{\Delta u}{\bar{\sigma}_{1c}}$	$A^{(2)}$
0.0	2.00	—	1.46	1.00	—	.729	0.271	1.373	.272	1.733	—	0.0	0.0	0.0	—
0.04	2.15	—	1.33	1.071	—	.664	0.408	1.614	.409	1.740	—	.271	.128	.064	.472
0.08	2.38	—	1.15	1.188	—	.575	.621	2.064	.614	1.768	—	.677	.301	.150	.445
0.10	2.48	—	1.10	1.237	—	.549	.688	2.254	.690	1.792	—	.829	.352	.176	.425
0.20	2.82	—	1.00	1.403	—	.499	.904	2.810	.907	1.908	—	1.258	.449	.223	.357
0.50	3.11	—	.98	1.549	—	.490	1.059	3.164	1.062	2.044	—	1.566	.465	.232	.297
0.74	3.15	—	.95	1.572	—	.473	1.099	3.322	1.102	2.052	—	1.644	.496	.247	.302
1.02	3.15	—	.93	1.572	—	.464	1.108	3.387	1.111	2.042	—	1.661	.513	.256	.309
1.40	3.12	—	.88	1.554	—	.440	1.114	3.532	1.117	1.999	—	1.671	.561	.279	.336
1.70	3.07	—	.85	1.530	—	.426	1.105	3.595	1.108	1.962	—	1.652	.588	.293	.356
2.00	3.04	—	.83	1.514	—	.413	1.101	3.663	1.104	1.933	—	1.643	.611	.305	.372
2.44	2.97	—	.78	1.479	—	.397	1.082	3.722	1.085	1.882	—	1.603	.642	.320	.400
2.89	2.89	—	.76	1.442	—	.380	1.062	3.797	1.065	1.827	—	1.563	.676	.337	.432
3.49	2.81	—	.75	1.403	—	.376	1.027	3.734	1.030	1.738	—	1.489	.682	.340	.458
4.04	2.75	—	.76	1.369	—	.382	.987	3.588	.990	1.756	—	1.409	.669	.333	.475
4.48	2.65	—	.72	1.322	—	.359	.963	3.684	.966	1.685	—	1.358	.713	.355	.525
5.03	2.57	—	.70	1.283	—	.348	.935	3.689	.938	1.635	—	1.300	.733	.366	.564
5.50	2.54	—	.69	1.265	—	.343	.921	3.682	.924	1.613	—	1.271	.740	.369	.582
6.04	2.50	—	.68	1.244	—	.339	.905	3.670	.908	1.588	—	1.236	.747	.372	.604
6.50	2.44	—	.65	1.218	—	.326	.892	3.734	.892	1.548	—	1.207	.770	.384	.638
7.07	2.38	—	.66	1.190	—	.327	.868	3.642	.866	1.521	—	1.179	.769	.382	.668
7.54	2.36	—	.65	1.175	—	.326	.850	3.609	.852	1.505	—	1.119	.767	.382	.685
8.01	2.31	—	.64	1.154	—	.318	.836	3.630	.838	1.476	—	1.089	.781	.389	.717
8.48	2.28	—	.63	1.137	—	.315	.822	3.608	.824	1.456	—	1.059	.784	.391	.740
9.04	2.25	—	.63	1.120	—	.314	.806	3.569	.808	1.437	—	1.024	.784	.391	.766
9.48	2.20	—	.62	1.099	—	.311	.788	3.533	.790	1.414	—	.985	.787	.393	.799
10.00	2.13	—	.62	1.061	—	.310	.751	3.423	.753	1.375		.909	.787	.392	.866

REMARKS: (1) CORRECTED FOR MEMBRANE STRENGTH, FILTER STRIPS & PISTON FRICTION
(2) $A = \frac{\Delta u - \Delta\sigma_3}{\Delta\sigma_1 - \Delta\sigma_3}$

CONSOLIDATION DATA

TEST NO $\overline{C}K_0U$ PSA-10 u_B 2.00 kg/cm^2

DATE 11-3-69 DEVICE MODEL B TESTED BY RBB

	Vol (cc)	Wgt. (g)	L (in)	ω (%)	S (%)	e
INITIAL	281.92	521.90	3.515	39.1	97.9	1.064
FINAL	255.85	494.78	3.190	30.4	96.8	0.873

$\bar{\sigma}_{1c}$ Corrected kg/cm^2	$\Delta H/H_0$, % (1)		$\Delta V/V_0$, % (2)	
	Δ	Σ	Δ	Σ
0.22	0.24	0.24	0.61	0.61
0.51	0.63	0.87	0.55	1.16
0.97	1.70	2.57	1.27	2.43
1.94	2.41	4.98	2.63	5.06
3.96	4.26	9.24	4.46	9.52

(1) FROM DISPLACEMENT DIAL READINGS

(2) FROM VOLUME CHANGE DEVICE

PLANE STRAIN – TEST ON COHESIVE SOIL

TEST NO PSA-10
DATE 11-7-69
TESTED BY R.B.B.

CONSOLIDATION PRESSURE, $\bar{\sigma}_c$ 3.96
BACK PRESSURE, U_B 1.98
PORE PRESSURE RESPONSE 100 %
IN ___ MINUTES AT U_B *

GAUGE NO. 3/1
PROVING RING NO. BLH 44575
STRAIN RATE 0.0006 in/min
MEMBRANE LEAKAGE —

INITIAL LENGTH 3.190 in
INITIAL AREA 31.62 cm²
INITIAL Z_3 —
$^*(\sigma_3 = \bar{\sigma}_c + U_B)$

AXIAL STRAIN (%)	$\bar{\sigma}_v$ (1) CORRECTED	AVG. $\bar{\sigma}_2$ CORRECTED	$\bar{\sigma}_h$ CORRECTED	$\frac{\bar{\sigma}_v}{\bar{\sigma}_{vc}}$	$\frac{\bar{\sigma}_2}{\bar{\sigma}_{vc}}$	$\frac{\bar{\sigma}_h}{\bar{\sigma}_{vc}}$	$\frac{\sigma_1-\sigma_3}{\bar{\sigma}_{vc}}$	$\frac{\bar{\sigma}_1}{\bar{\sigma}_3}$	q	$\bar{p}$	$\bar{\sigma}_3/\bar{p}$	$\Delta\sigma_1$	Δu	$\frac{\Delta u}{\bar{\sigma}_{vc}}$	$A^{(2)}$
0.0	3.96	1.73	2.03	1.00	0.44	0.51	0.49	1.95	0.964	2.773	0.56	0.0	0.0	0.0	—
0.02	4.08	1.74	1.98	1.03	0.44	0.50	0.53	2.06	1.052	3.029	0.57	0.17	0.05	0.013	0.29
0.03	4.12	1.73	1.91	1.04	0.43	0.48	0.56	2.16	1.105	3.016	0.57	0.22	0.12	0.029	0.41
0.12	4.16	1.76	1.82	1.06	0.44	0.46	0.62	2.45	1.227	2.948	0.60	0.52	0.31	0.077	0.56
0.20	4.13	1.76	1.61	1.04	0.45	0.41	0.64	2.57	1.260	2.866	0.62	0.57	0.42	0.106	0.71
0.29	4.04	1.74	1.50	1.02	0.44	0.38	0.64	2.69	1.269	2.791	0.63	0.60	0.52	0.132	0.86
0.39	3.96	1.71	1.44	1.00	0.43	0.37	0.64	2.74	1.259	2.704	0.63	0.58	0.58	0.146	0.99
0.51	3.90	1.68	1.39	0.99	0.42	0.35	0.635	2.81	1.255	2.645	0.64	0.57	0.65	0.160	1.10
0.76	3.76	1.62	1.29	0.95	0.41	0.33	0.62	2.92	1.235	2.522	0.64	0.53	0.73	0.185	1.32
1.00	3.63	1.56	1.17	0.92	0.39	0.30	0.62	3.09	1.226	2.401	0.65	0.52	0.85	0.214	1.64
1.51	3.44	1.47	1.06	0.87	0.37	0.27	0.60	3.25	1.191	2.279	0.66	0.44	0.96	0.245	2.17
2.01	3.26	1.41	0.96	0.83	0.36	0.24	0.58	3.40	1.156	2.117	0.67	0.37	1.05	0.266	2.84
2.47	3.14	1.36	0.90	0.80	0.34	0.23	0.57	3.50	1.125	2.021	0.67	0.30	1.12	0.283	3.48
2.99	3.04	1.32	0.86	0.77	0.33	0.22	0.55	3.55	1.093	1.951	0.68	0.24	1.16	0.292	4.76
3.99	2.88	1.26	0.79	0.73	0.32	0.20	0.53	3.64	1.042	1.853	0.69	0.14	3.20	0.308	8.27
4.51	2.78	1.23	0.77	0.70	0.31	0.19	0.51	3.63	1.008	1.776	0.69	0.07	3.22	0.313	—
5.01	2.72	1.20	0.75	0.69	0.30	0.19	0.50	3.62	0.985	1.737	0.69	—	3.24	0.317	—
5.51	2.64	1.19	0.73	0.67	0.30	0.185	0.48	3.60	0.952	1.684	0.71	—	3.25	0.321	—
6.00	2.54	1.22	0.72	0.64	0.31	0.18	0.46	3.55	0.913	1.629	0.75	—	3.27	0.323	—
6.51	2.46	1.22	0.70	0.62	0.31	0.18	0.44	3.51	0.879	1.580	0.77	—	3.28	0.328	—
7.02	2.40	1.22	0.69	0.61	0.31	0.175	0.43	3.46	0.852	1.543	0.79	—	3.29	0.330	—
7.53	2.34	1.24	0.68	0.59	0.31	0.17	0.42	3.45	0.830	1.512	0.82	—	3.29	0.332	—
8.03	2.29	1.24	0.67	0.58	0.31	0.17	0.41	3.44	0.813	1.479	0.84	—	3.31	0.335	—
8.53	2.24	1.25	0.67	0.57	0.32	0.17	0.40	3.36	0.786	1.454	0.86	—	3.31	0.335	—
9.04	2.17	1.25	0.66	0.55	0.32	0.17	0.38	3.32	0.759	1.414	0.88	—	3.32	0.337	—
9.54	2.14	1.26	0.64	0.54	0.32	0.16	0.38	3.35	0.748	1.359	0.91	—	3.33	0.341	—
10.03	2.11	1.27	0.64	0.53	0.32	0.16	0.37	3.32	0.738	1.377	0.92	—	3.33	0.341	—

NOT REPRODUCIBLE

REMARKS: (1) CORRECTED FOR MEMBRANE STRENGTH, FILTER STRIPS & PISTON FRICTION.
(2) $A = (\Delta u - \Delta\sigma_3)/(\Delta\sigma_1 - \Delta\sigma_3)$

CONSOLIDATION DATA

TEST NO $\overline{CK_oU}$PSP-2 U_B 1.00 kg/cm^2

DATE 7-5-62 DEVICE PROTOTYPE TESTED BY J. J. R.

	VOL (cc)	Wgt. (g)	L (in)	ω (%)	S (%)	e
INITIAL	274.69	522.14	3.425	34.2	97.3	0.982
FINAL	246.11	494.20	3.080	22.8	99.9	0.777

σ_{1c} corrected Kg/cm^2	ΔH/Ho, % (1)		ΔV/Vo, % (2)	
	Δ	Σ	Δ	Σ
0.10	-0.95	-0.95	0.19	0.19
0.93	1.60	0.65	2.19	2.38
1.92	2.19	2.84	2.57	4.95
3.85	7.09	9.93	5.44	10.39

PLANE STRAIN CONSOLIDATION

TEST NO. $\overline{CK_0}$UPSP-2 TYPE OF CONSOLIDATION VERT. K_0

INCREMENT : 0.1 TO 1.0 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1c} 1.93 kg/cm² u_B 1.00 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATEN σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.0385	0.0	—	—	—
LOAD	0.0385	0.0	-	-	-
OPEN DRAIN	0.0442	0.0	2.02	2.00	1.93
3	0.0442	2.72	2.00	—	—
5	0.0469	2.92	1.78	1.82	1.68
8	0.0541	3.40	1.66	1.75	1.64
11	0.0592	3.72	1.60	1.71	1.60
21	0.0691	4.51	1.60	1.67	1.58
28	0.0738	4.93	1.54	1.65	1.53
43	0.0783	5.49	1.53	1.60	1.46
56	0.0818	5.79	1.49	1.56	1.45
74	0.0844	6.01	1.47	1.55	1.42
105	0.0872	6.27	1.47	1.54	1.40
685	0.0911	6.02	1.43	1.44	1.38
RELEASE	PLATENS	—	-	—	-
687	0.0935	—	1.44	1.44	1.36

PLANE STRAIN CONSOLIDATION

TEST NO. CK0UPSP-2 TYPE OF CONSOLIDATION VERT. K0

INCREMENT : 1.0 TO 2.0 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1c} 2.92 kg/cm² u_B 1.00 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATEN σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.0935	0.0	1.44	1.44	1.36
LOAD	0.0935	0.0	–	–	–
OPEN DRAIN	0.0932	0.0	2.94	2.85	2.74
3/4	0.0933	0.67	2.93	–	–
2	0.0966	1.11	2.79	2.67	2.50
6	0.1037	1.84	2.58	2.55	2.40
9	0.1075	2.37	2.48	2.50	2.30
15	0.1164	3.09	2.36	2.43	2.24
20	0.1240	3.55	2.22	2.35	2.15
25	0.1310	3.94	2.08	2.30	2.15
35	0.1397	4.61	2.08	2.25	2.08
45	0.1458	5.24	2.07	2.23	2.02
62	0.1527	5.82	1.99	2.16	1.97
86	0.1580	6.44	1.99	2.15	1.97
98	0.1598	6.54	1.98	2.15	1.92
110	0.1617	6.74	1.96	2.15	1.92
153	0.1654	2.08	1.95	2.14	1.91
RELEASE	PLATENS	–	–	–	–
160	0.1687	–	–	–	–

PLANE STRAIN CONSOLIDATION

TEST NO. CK_0UPSP-2 TYPE OF CONSOLIDATION VERT. K_0

INCREMENT : 2.0 TO 4.0 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1c} 4.82 kg/cm² u_B 1.02 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATEN σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h Kg/cm²
INITIAL	0.1687	0.0	—	—	—
LOAD	0.1687	0.0			
OPEN DRAIN	0.1747	0.0	4.29	4.45	4.25
1/4	0.1796	0.48	4.28	—	—
2	0.1872	1.09	4.10	—	—
3	0.1944	1.43	3.94	4.26	4.02
5	0.2018	2.09	3.94	—	—
9	0.2110	2.78	3.82	—	—
18	0.2291	4.50	3.80	4.10	3.78
24	0.2400	5.32	3.67	3.94	3.67
32	0.2517	6.18	3.50	3.90	3.62
42	0.2645	7.45	3.50	3.85	3.50
62	0.2761	8.43	3.35	3.73	3.41
84	0.2876	9.38	3.21	3.58	3.26
115	0.2959	10.18	3.21	3.55	3.21
154	0.3019	10.65	3.10	3.46	3.10
192	0.3048	10.87	3.10	3.43	3.09
244	0.3073	11.03	3.04	3.38	3.06
RELEASE	PLATENS	—	—	—	—
507	0.3114	11.05	3.05	3.33	2.96
553	0.3537	11.74	—	3.52	3.16
558	0.3544	11.86	—	—	—
573	0.3556	12.04	—	3.47	3.11
593	0.3570	12.17	—	3.49	3.08
1323	0.3631	11.75	—	3.05	2.78
1436	0.3635	11.65	—	3.01	2.75

PLANE STRAIN TEST ON COHESIVE SOIL **SHEAR DATA**

GAUGE NO. .001

TEST NO. CK_0U - PSP - 2
DATE 7-5-67
TESTED BY JJR

CONSOLIDATION PRESSURE, $\bar{\sigma}_c$ 3.851 KG/CM²
BACK PRESSURE, U_B 1.00 KG/CM²
PORE PRESSURE RESPONSE IN 2 MINUTES AT U_B = 1.00 KG/CM² 71 %

PROVING RING NO. 1867
STRAIN RATE .0006 IN/MIN
MEMBRANE LEAKAGE —

INITIAL LENGTH 3.079 IN
INITIAL AREA 31.574 CM²
INITIAL Z_3 ($\sigma_3 = \bar{\sigma}_c + U_B$) —

AXIAL STRAIN (%)	$\bar{\sigma}_v$ (1) CORRECTED	AVG. $\bar{\sigma}_z$ CORRECTED	$\bar{\sigma}_H$ CORRECTED	$\frac{\bar{\sigma}_v}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_z}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_H}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_v - \bar{\sigma}_H}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_H}{\bar{\sigma}_v}$	q	$\bar{p}$	$\bar{\sigma}_z/\bar{p}$	$\Delta\sigma_v$	Δu	$\frac{\Delta u - \Delta\sigma_v}{\bar{\sigma}_{1c}}$	A (2)
—	3.851	2.36	1.990	1.000	.608	.515	.494	.510	.951	2.931	.805	—	—	—	—
.023	3.894	2.35	2.012	1.003	.606	.519	.489	.517	.941	2.953	.796	-.017	-.03	-.003	-.765
.029	3.717	2.34	2.042	.958	.603	.526	.435	.549	.837	2.879	.813	-.229	-.06	+.042	+.732
.050	3.462	2.31	2.122	.892	.595	.547	.348	.613	.670	2.792	.827	-.559	-.14	.108	.750
.120	3.028	2.26	2.246	.780	.582	.579	.203	.742	.391	2.637	.857	-1.093	-.26	.216	.762
.26	2.657	2.12	2.215	.685	.546	.571	.113	.834	.221	2.436	1.035	-1.449	-.22	.318	.898
.33	2.327	2.03	2.200	.510	.523	.567	-.033	.945	.063	2.263	.897	-1.759	-.20	.404	.886
.43	1.996	1.99	2.251	.514	.513	.580	-.066	1.128	.127	2.123	.937	-2.135	-.25	.489	.883
.51	1.778	1.91	2.262	.458	.492	.583	-.126	1.272	.242	2.120	.946	-2.363	-.26	.546	.890
.69	1.734	1.85	2.265	.447	.477	.584	-.139	1.306	.265	1.949	.925	-2.505	-.26	.593	.896
1.11	1.319	1.76	2.272	.340	.453	.585	-.247	1.722	.477	1.796	.980	-2.822	-.26	.665	.908
1.62	1.155	2.01	2.226	.298	.518	.574	-.278	1.927	.535	1.690	1.189	-2.936	-.21	.709	.928
1.79	1.071	2.01	2.257	.276	.518	.582	-.309	2.187	.593	1.669	1.208	-3.050	-.24	.730	.920
2.11	.981	1.67	2.270	.253	.430	.585	-.335	2.319	.644	1.625	1.028	-3.150	-.25	.753	.921
2.43	.824	1.58	2.231	.212	.407	.575	-.365	2.707	.703	1.527	1.035	-3.267	-.21	.799	.936
2.59	.773	1.57	2.262	.199	.405	.583	-.397	2.926	.744	1.517	1.035	-3.349	-.24	.907	.928
3.00	.684	1.58	2.294	.176	.407	.591	-.418	3.353	.805	1.489	1.061	-3.567	-.27	.856	.924
3.32	.628	1.54	2.315	.162	.397	.596	-.438	3.696	.844	1.472	1.046	-3.593	-.29	.845	.918
4.05	.542	1.56	2.317	.140	.402	.597	-.461	4.275	.887	1.429	1.092	-3.629	-.29	.867	.920
4.87	.439	1.54	2.410	.131	.394	.621	-.512	5.490	.985	1.429	1.081	-3.822	-.38	.899	.901
5.16	.435	1.58	2.450	.112	.407	.631	-.523	5.632	1.007	1.442	1.096	-3.866	-.42	.895	.891
5.67	.422	1.57	2.471	.109	.405	.637	-.532	5.855	1.025	1.447	1.085	-3.899	-.44	.898	.887
5.83	.432	1.58	2.482	.113	.407	.640	-.532	5.745	1.025	1.457	1.084	-3.899	-.45	.896	.885
6.66	.459	1.58	2.493	.117	.407	.642	-.529	5.491	1.020	1.474	1.072	-3.897	-.46	.890	.882
6.97	.459	1.58	2.494	.118	.407	.643	-.529	5.434	1.017	1.476	1.071	-3.932	-.46	.899	.882
7.30	.459	—	2.494	.117	—	.640	-.527	5.471	1.015	1.469	—	-3.837	-.45	.890	.899
7.97	.481	1.64	2.505	.124	.423	.645	-.526	5.207	1.012	1.493	1.098	-3.970	-.47	.883	.879
8.11	.481	1.64	2.505	.124	.423	.645	-.526	5.201	1.012	1.493	1.098	-3.972	-.47	.883	.879
8.61	.492	1.61	2.516	.127	.415	.648	-.526	5.119	1.012	1.509	1.071	-3.869	-.48	.890	.876
9.80	.494	1.60	2.516	.121	.412	.648	-.525	5.093	1.011	1.505	1.063	-3.976	-.48	.890	.876

REMARKS: (1) CORRECTED FOR MEMBRANE STRENGTH, FILTER STRIPS & PISTON FRICTION

(2) $A = \frac{\Delta u - \Delta\sigma_v}{\Delta\sigma_H - \Delta\sigma_v}$

NOT REPRODUCIBLE

CONSOLIDATION DATA

TEST NO [illegible] U_B [illegible] kg/cm²

DATE [illegible]   DEVICE [illegible]   TESTED BY J. J. F

	VOL (cc)	Wgt. (g)	L (in)	ω (%)	S (%)	e
INITIAL	284.80	528.97	[illegible]	36.5	96.0	[illegible]
FINAL	255.64	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

σ_{1c} Corrected Kg/cm²	ΔH/Ho, % (1)		ΔV/Vo, % (2)	
	Δ	Σ	Δ	Σ
0.10	[illegible]	[illegible]	[illegible]	[illegible]
0.89	6.77	[illegible]	[illegible]	[illegible]
1.87	2.14	8.04	1.60	6.81
3.65	3.51	11.55	2.77	9.08
[illegible]	[illegible]	11.45	-0.64	8.44
[illegible]	[illegible]	11.82	-0.71	7.73
[illegible]	[illegible]	[illegible]	[illegible]	6.65

(1) FROM [illegible] DISPLACEMENT READINGS

(2) FROM VOLUME CHANGE [illegible]

PLANE STRAIN CONSOLIDATION

TEST NO. [illegible] TYPE OF CONSOLIDATION VERT. Ko

INCREMENT : [illegible] TO [illegible] kg/cm² DEVICE [illegible]

CORRECTED σ_{1c} [illegible] kg/cm² u_B [illegible] kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATES σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.0328	0.0	—	—	—
LOAD	0.0453	0.0	2.50	2.48	2.42
OPEN DRAIN	0.0453	0.0	—	—	—
[illegible]	0.0484	1.14	2.50	2.45	2.46
[illegible]	0.0513	2.24	2.37	2.34	2.37
[illegible]	0.0583	2.84	2.31	2.28	2.24
[illegible]	0.0677	3.47	2.31	2.27	2.24
15	0.0819	4.30	2.24	2.25	2.20
17	0.0915	4.70	2.24	2.22	2.20
25	0.1084	5.65	2.20	2.20	2.13
3[illegible]	0.1173	6.41	2.21	2.17	2.18
[illegible]	0.1454	7.82	2.14	2.11	2.10
[illegible]	0.1576	7.12	2.13	2.08	2.06
[illegible]	0.1674	9.07	2.07	2.06	2.03
[illegible]	0.1874	10.76	2.07	2.02	2.00
150	0.1970	12.24	2.03	1.96	1.92
15[illegible]	0.2026	12.76	[illegible]	1.91	1.93
831	0.2105	12.26	1.96	1.80	1.75
991	0.2112	12.36	1.92	1.76	1.82
RELEASE	PLATENS	—	—	—	—
1011	0.2400	12.79	2.02	—	1.98
1016	0.2422	12.96	—	2.00	1.93
1026	0.2520	13.26		—	—
1033	0.2538	13.41		—	
1051	0.2571	13.74		1.96	1.96
1077	0.2600	13.86		1.95	—
1111	0.2622	14.07		1.94	1.91
1135	0.2627	14.14		—	—
1165	0.2637	14.15		1.92	1.90
[illegible]	0.2641	14.16		1.92	1.90

PLANE STRAIN CONSOLIDATION

TEST NO. CK₀UPSP-3 TYPE OF CONSOLIDATION VERT. K₀

INCREMENT : 1.0 TO 2.0 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1c} 3.38 kg/cm² u_B 1.52 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATEN σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.2743	0.0	—	1.92	1.90
LOAD	0.2758	0.0	3.02	2.88	2.85
OPEN DRAIN	0.2758	0.0		—	—
1/2	0.2732	[illegible]	3.01	—	—
2	0.2793	0.50	3.[illegible]	2.[illegible]	2.74
4	0.2823	0.68	2.83	2.70	2.63
6	0.2844	0.87	—	—	—
8	0.2863	1.10	2.83	2.66	2.59
12	0.2905	1.39	2.65	2.57	2.50
20	0.2970	1.89	2.65	2.54	2.49
23	0.2992	2.06	—	—	—
30	0.3042	2.45	2.58	2.48	2.45
40	0.3080	2.77	2.58	2.46	2.40
50	0.3140	3.26	2.51	2.44	2.40
80	0.3224	3.89	2.51	2.38	2.34
105	0.3256	4.20	2.51	2.36	2.34
166	0.3296	4.54	2.51	2.32	2.32
260	0.3342	4.23	2.50	2.20	2.22
RELEASE	PLATENS				
297	0.3344	—	2.50 (1)	—	—
303	0.3377	4.14	—	—	—
307	0.3391	—		2.39	2.37
312	0.3400	4.24		2.39	2.37
550	0.3434	4.44		2.37	2.36
577	0.3448	4.52		2.37	2.36
714	0.3461	4.55		2.37	2.34
994	0.3479	4.56		2.3[illegible]	2.39
1050	0.3491	4.54		2.35	2.34
(1) CELL	PRESSURE				

PLANE STRAIN CONSOLIDATION

TEST NO. [illegible] TYPE OF CONSOLIDATION [illegible]

INCREMENT : 2.0 TO 4.0 kg/cm² DEVICE Prototype

CORRECTED σ_{IC} 5.32 kg/cm² u_B [illegible]52 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATEN σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.3491	0.0	–	2.35	2.34
LOAD	0.3600	0.0	4.40	[illegible]	[illegible]
OPEN DRAIN	0.3600	0.0	–	–	–
½	0.3661	0.52	4.40	–	–
1	0.3680	0.75	4.40	4.15	4.09
3	0.3752	1.25	4.20	4.05	3.97
6	0.3790	1.75	4.20	4.00	3.95
10	0.3853	2.26	4.06	3.92	3.87
15	0.3928	2.70	4.06	3.89	3.87
20	0.3993	3.41	3.96	3.79	3.85
25	0.4044	3.88		—	—
30	0.4075	4.13	3.96	3.77	3.77
35	0.4152	4.86	3.[illegible]	3.67	3.72
45	0.4186	5.21	—	—	—
60	0.4265	5.77	3.87	3.59	3.67
74	0.4313	6.52	3.86	3.55	3.56
90	0.4354	7.02	3.7[illegible]	3.48	3.57
105	0.4388	7.36	3.8[illegible]	3.4[illegible]	3.5[illegible]
120	0.4415	7.60	3.74	3.40	3.46
153	0.4453	7.76	3.74	3.37	3.48
308	0.4487 0.2538	8.38	3.7[illegible]	3.26	3.33
RELEASE PLATENS		—	—	—	—
335	0.2553	8.47	3.[illegible]	3.42	3.4[illegible]
340	0.2572	8.50		3.38	3.44
345	0.2583	8.54		3.40	3.[illegible]
360	0.2602	8.[illegible]		3.4[illegible]	3.43
395	0.2630	8.74		3.[illegible]	3.44
420	0.264[illegible]	8.81		3.35	3.44
[illegible]	0.272[illegible]	[illegible]		3.18	3.32
1360	0.2736	7.31		3.12	3.34

PLANE STRAIN CONSOLIDATION

TEST NO. CK₀ UPSP-3 TYPE OF CONSOLIDATION Vert. K₀

INCREMENT : 4.0 TO 3.0 kg/cm² DEVICE [illegible]

CORRECTED σ_{1c} 4.49 kg/cm² u_B 1.52 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATEN σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.2749	0.0	–	3.12	3.34
LOAD	0.2738	0.0	2.57	2.68	2.90
OPEN DRAIN	0.2738	0.0	–	–	–
1	0.2739	-0.15	2.51	2.75	2.95
3	0.2736	-0.23	2.81	2.93	3.07
9	0.2732	-0.41	2.94	3.00	3.11
17	0.2730	-0.43	3.08	3.04	3.11
30	0.2725	-0.44	3.07	3.04	3.11
55	0.2725	-0.48	3.07	3.02	3.09
191	0.2723	-0.65	3.06	2.90	3.03
RELEASE	PLATENS				
209	0.2722	-0.71	3.07	2.93	3.01
240	0.2723	-0.73		2.92	3.06
1125	0.2723	-1.83		2.52	2.87

PLANE STRAIN CONSOLIDATION

TEST NO. $\overline{CK_0}$UPSP-3 TYPE OF CONSOLIDATION VERT. K_0

INCREMENT : 3.0 TO 2.0 kg/cm^2 DEVICE [illegible]

CORRECTED σ_{1C} 3.43 kg/cm^2 u_B [illegible].52 kg/cm^2

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATEN σ_h kg/cm^2	Back End Platen σ_h kg/cm^2	FRONT END PLATEN σ_h kg/cm^2
[illegible]	0.2723	0.0	—	2.52	2.87
[illegible]	[illegible]	0.0	2.10	[illegible]	[illegible]
OPEN DRAIN	[illegible]	0.0			
1	[illegible]	-0.26	2.10	2.11	2.50
5	0.2698	-0.46	2.28	2.27	2.60
[illegible]	0.2691	[illegible]	2.39	2.38	2.64
[illegible]	0.2682	-0.58	2.57	2.47	2.70
25	0.2677	-0.59	2.71	2.50	2.70
[illegible]	0.2673	-0.60	2.71	2.52	2.70
[illegible]	0.2670	-0.80	2.70	2.47	2.70
[illegible]	PLATENS	—	—	—	—
181	0.2666	-0.88	2.68	2.50	2.67
195	0.2666	-0.90		2.48	2.67
205	0.2666	-0.91		2.49	2.67
1295	0.2660	-2.03		2.13	2.55

PLANE STRAIN CONSOLIDATION

TEST NO. CK-UPSC-3 TYPE OF CONSOLIDATION VERT. K_o

INCREMENT : 2.0 TO 4.0 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1c} 2.43 kg/cm² u_B 1.52 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	SIDE PLATEN σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.2666	0.0	—	2.13	2.55
LOAD	0.2630	0.0	1.71	1.50	1.93
OPEN DRAIN	0.2630	0.0	—	—	—
1	0.2628	-0.28	1.70	1.63	1.99
3	0.2624	-0.70	—	—	—
5	0.2620	-0.77	1.79	1.78	2.12
8	0.2607	-0.93	1.89	1.90	2.17
14	0.2592	-1.05	2.04	2.00	2.25
19	0.2583	-1.08	2.16	2.07	2.26
28	0.2575	-1.10	2.22	2.12	2.28
35	0.2573	-1.13	2.22	2.12	2.32
44	0.2566	-1.13	2.31	2.14	2.33
56	0.2563	-1.13	2.31	2.14	2.33
70	0.2562	-1.16	2.31	2.14	2.33
84	0.2553	-1.23	2.31	2.13	2.31
92	0.2551	-1.26	—	2.13	2.32
236	0.2538	-1.36	—	2.13	2.32
352	0.2533	-1.38	—	2.10	2.25
460	0.2490	-1.66	—	2.13	2.36
932	0.2477	-2.12	—	2.12	2.32
RELEASE	PLATENS				
990	0.2473	-2.20	2.81	2.52	2.66
994 (1)	0.2473	-2.22	—	2.56	2.67
1430	0.2475	-3.[illegible]3	—	2.40	2.65
1500	0.2444	---	---	---	
(1) [illegible]	1B	TO 2.03	[illegible]	TO [illegible]	

CONSOLIDATION DATA

TEST NO 2K₀ UTEST-2H HORIZ. K₀ U_B 3.00 kg/cm²

DATE 3-4-68 DEVICE PROTOTYPE TESTED BY JJB

	VOL (cc)	Wgt. (g)	L (in)	ω(%)	S(%)	e
INITIAL	280.19	540.63	3.491	33.6	98.7	0.900
FINAL	254.13	512.67	3.491	26.3	100	0.724

σ_{1c} Corrected kg/cm²	ΔH/Ho, % (1)		ΔV/Vo, % (2)	
	Δ	Σ	Δ	Σ
0.20	—	—	0.91	0.91
0.50	—	—	1.14	2.05
1.00	—	—	1.07	3.12
2.00	—	—	2.62	5.74
4.03	—	—	3.55	9.29

[illegible]

[illegible]

PLANE STRAIN CONSOLIDATION

TEST NO. CK₀UPSP-4H TYPE OF CONSOLIDATION HORIZ. K₀

INCREMENT : 0.0 TO 0.2 kg/cm² DEVICE PROTOTYPE

CORRECTED σ_{1C} 3.20 kg/cm² u_B 3.00 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	CELL PRESSURE σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h Kg/cm²
INITIAL	0.1225	0.0	3.20	3.25	3.22
LOAD		0.0		3.25	3.22
OPEN DRAIN		0.0		3.25	3.22
1		0.30		3.25	3.22
2		0.58		3.25	3.22
3		0.62		3.25	3.22
5		0.80		3.25	3.22
9		0.92		3.25	3.21
15		1.13		3.25	3.21
20		1.28		3.25	3.19
30		1.60		3.24	3.18
50		1.84		3.24	3.17
60		1.92		3.22	3.17
90		2.24		3.21	3.15
190		2.54		3.20	3.12
240	0.1225	2.56	3.20	3.20	3.13

PLANE STRAIN CONSOLIDATION

TEST NO. [illegible] TYPE OF CONSOLIDATION [illegible]

INCREMENT : 0.2 TO 0.5 kg/cm² DEVICE [illegible]

CORRECTED σ_{IC} 3.50 kg/cm² u_B 3.00 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	CELL PRESSURE σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.1775	0.0	3.20	3.20	3.13
LOAD		0.0	3.50	3.42	3.44
OPEN DRAIN		0.0		3.42	3.44
1		0.50		3.43	3.45
3		0.70		3.43	3.45
4		0.79		3.43	3.43
6		0.91		3.43	3.42
8		1.03		3.43	3.42
10		1.15		3.42	3.41
15		1.38		3.42	3.40
20		1.57		3.41	3.39
25		1.71		3.41	3.37
40		2.09		3.39	3.34
70		[illegible]		3.36	3.30
90		2.64		3.34	3.28
115		2.77		3.33	3.27
180		2.95		3.32	3.26
815	0.1775	3.20	3.50	3.25	3.19

PLANE STRAIN CONSOLIDATION

TEST NO. CKo UPSP 4H TYPE OF CONSOLIDATION Horiz. Ko

INCREMENT : 0.5 TO 4.0 kg/cm^2 DEVICE Prototype

CORRECTED σ_{1c} 4.00 kg/cm^2 u_B 3.00 kg/cm^2

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	Cell Pressure σ_h kg/cm^2	Back End Platen σ_h kg/cm^2	Front End Platen σ_h Kg/cm^2
INITIAL	0.1775	0.0	3.50	3.25	3.19
LOAD		0.0	4.00	3.72	3.[illegible]
OPEN DRAIN		0.0		3.72	[illegible]
1		0.30		3.72	3.65
2		0.34		3.72	3.65
3		0.43		3.71	3.64
5		0.54		3.71	3.62
8		0.73		3.69	3.61
11		0.87		3.67	3.59
16		1.11		3.65	3.57
20		1.25		3.64	3.56
35		1.68		3.61	3.55
47		1.91		3.58	3.55
[illegible]		2.05		3.57	3.53
[illegible]		2.43		3.55	3.52
[illegible]		2.79		3.52	3.47
330	0.1775	[illegible]	4.00	3.[illegible]	3.44

PLANE STRAIN CONSOLIDATION

TEST NO. CK₀UPSP-4H TYPE OF CONSOLIDATION [illegible]

INCREMENT : 1.0 TO 3.0 kg/cm², DEVICE [illegible]

CORRECTED σ_{1C} 5.00 kg/cm² u_B 3.00 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	CELL PRESSURE σ_h kg/cm²	Back End Platen σ_h kg/cm²	FRONT END PLATEN σ_h kg/cm²
INITIAL	0.1225	0.0	4.00	3.49	[illegible]
LOAD		0.0	5.00	4.40	[illegible]
OPEN DRAIN		0.0		[illegible]	[illegible]
1		0.20		4.41	4.37
2		0.45		4.40	4.35
3		0.56		4.39	4.33
4		0.72		4.38	4.3[illegible]
5		1.05		4.37	4.32
10		1.22		4.36	4.30
15		1.52		4.35	4.28
20		1.88		4.33	4.26
40		3.06		4.26	4.22
60		4.13		4.15	4.16
90		4.60		4.13	4.13
125		[illegible]		4.12	4.10
320		6.26		4.10	3.93
1005	↓	7.27	↓	4.00	3.76
1150	0.1225	7.35	5.00	3.78	3.73

PLANE STRAIN CONSOLIDATION

TEST NO. CK0UPSP-4H TYPE OF CONSOLIDATION Horiz K0

INCREMENT : 2.0 TO 4.0 kg/cm² DEVICE Pressure

CORRECTED σ_{1c} 7.03 kg/cm² u_B 3.00 kg/cm²

Elapsed time (min)	Dial reading (in)	Δ Vol. (c.c.)	Cell Pressure σ_h kg/cm²	Back End Platen σ_h kg/cm²	Front End Platen σ_h kg/cm²
Initial	0.1025	0.0	5.00	3.98	3.93
Load		0.0	7.03	5.48	5.25
Open Cell		0.0		5.48	5.25
				5.48	5.63
1		0.38		5.47	5.63
2		0.52		5.49	5.61
3		0.68		5.49	5.60
4		0.80		5.50	5.59
6		1.05		5.49	5.58
10		1.49		5.48	5.54
15		1.93		5.47	5.49
25		2.77		5.46	5.47
30		3.07		5.40	5.43
53		4.39		5.35	5.34
80		5.19		5.33	5.35
95		5.68		5.15	5.12
160		7.70		5.10	5.04
230		8.62		5.00	5.06
330		9.29		4.85	4.89
655	↓	9.72	↓	—	—
1365	0.1025	9.96	7.03		

PLANE STRAIN TEST ON COHESIVE SOIL

TEST NO. CK0UPSP-4H
DATE 3-7-68
TESTED BY J.J.R

CONSOLIDATION PRESSURE, $\bar{\sigma}_c$ 4.03
BACK PRESSURE, U_B 3.00
PORE PRESSURE RESPONSE 89 %
IN – MINUTES AT U_B = –

GAUGE NO. 3/1
PROVING RING NO. —
STRAIN RATE 1% PER HR
MEMBRANE LEAKAGE —

INITIAL LENGTH 3.49 in
INITIAL AREA 3.46 in²
INITIAL Z_3 ($\sigma_3 = \bar{\sigma}_c + U_B$)

AXIAL STRAIN (%)	$\bar{\sigma}_v$	$\bar{\sigma}_z$ CORRECTED	$\bar{\sigma}_h$ CORRECTED	$\frac{\bar{\sigma}_v}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_z}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_h}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_v-\bar{\sigma}_h}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_v}{\bar{\sigma}_h}$	q	$\bar{p}$	$\bar{\sigma}_3/\bar{p}$	$\Delta\sigma_v$	Δu	$\frac{\Delta u-\Delta\sigma_3}{\bar{\sigma}_{1c}}$	A
0.0	2.09	1.79	4.03	.518	.444	1.00	-.482	.518	.971	3.059	.585	0.0	0.0	0.0	—
0.001	2.17	1.84	3.91	.538	.456	.970	-.432	.554	.871	3.039	.604	-.200	-.080	.029	.600
0.004	2.27	1.84	3.69	.563	.457	.916	-.353	.615	.711	2.980	.618	-.520	-.180	.084	.654
0.007	2.36	1.84	3.46	.585	.456	.859	-.274	.682	.551	2.910	.632	-.840	-.27	.141	.678
0.04	2.44	1.76	3.12	.605	.441	.775	-.169	.781	.341	2.780	.639	-1.26	-.35	.225	.722
0.09	2.48	1.67	2.85	.615	.416	.708	-.092	.869	.186	2.665	.628	-1.57	-.39	.293	.752
0.12	2.51	1.62	2.74	.662	.402	.680	-.058	.915	.117	2.625	.617	-1.71	-.42	.320	.754
0.23	2.39	1.06	2.45	.593	.264	.608	-.015	.976	.030	2.421	.439	-1.89	-.31	.392	.836
												$\Delta\bar{\sigma}_1$			
0.23'	2.53	1.04	2.36	.593	.258	.585	.042	1.072	.085	2.444	.426	.221	-.22	.414	.791
0.32	2.73	1.14	2.14	.677	.282	.530	.147	1.277	.296	2.432	.468	.641	0.0	.469	.747
0.51	2.72	—	1.84	.675	–	.457	.218	1.477	.439	2.282	—	.924	.29	.541	.775
0.59	2.68	1.08	1.73	.666	.268	.430	.236	1.548	.475	2.207	.490	.994	.40	.568	.794
0.78	2.66	1.01	1.54	.659	.251	.382	.288	1.725	.558	2.097	.482	1.157	.59	.615	.814
1.04	2.56	.97	1.32	.636	.241	.327	.309	1.946	.623	1.940	.500	1.385	.81	.670	.850
1.63	2.45	.88	1.02	.607	.220	.254	.353	2.391	.712	1.735	.510	1.459	1.10	.742	.893
1.90	2.40	.86	.93	.595	.212	.231	.365	2.575	.734	1.666	.514	1.502	1.19	.764	.908
2.41	2.32	.78	.79	.575	.193	.196	.378	2.936	.764	1.553	.502	1.560	1.33	.799	.933
3.06	2.28	.75	.70	.565	.186	.173	.392	3.269	.790	1.487	.503	1.610	1.42	.821	.946
3.56	2.24	.71	.62	.556	.177	.155	.401	3.590	.809	1.433	.497	1.644	1.49	.839	.956
4.02	2.23	.70	.58	.653	.173	.145	.408	3.825	.823	1.405	.496	1.671	1.53	.849	.960
4.48	2.19	.69	.54	.544	.172	.134	.409	4.054	.826	1.366	.607	1.674	1.57	.859	.971
5.13	2.19	.69	.51	.542	.122	.126	.416	4.303	.839	1.347	.515	1.698	1.60	.866	.973
5.45	2.20	.71	.51	.547	.175	.126	.421	4.349	.849	1.355	.522	1.716	1.60	.866	.968
5.56	2.19	.70	.50	.545	.175	.123	.422	4.424	.850	1.364	.523	1.719	1.61	.868	.970
5.85	2.22	.71	.50	.551	.176	.123	.428	4.489	.863	1.358	.521	1.744	1.61	.868	.963
5.99	2.22	.71	.49	.551	.126	.122	.428	4.494	.864	1.358	.523	1.744	1.61	.868	.963
6.54	2.20	.70	.48	.545	.173	.119	.426	4.554	.857	1.339	.521	1.728	1.62	.871	.970
6.99	2.18	.69	.48	.541	.170	.119	.422	4.541	.850	1.3[illegible]	.516	1.714	1.62	.871	.974

REMARKS: (1) [illegible]CTED FOR MEMBRANE STRENGTH, FILTER STRIPS & PISTON FRICTION

CONSOLIDATION DATA

TEST NO CK₀UESP- 9H HORIZ K₀ u_B 2.00 kg/cm²

DATE 8 29-69 DEVICE PROTOTYPE TESTED BY RWS

	Vol (cc)	Wgt. (g)	L (in)	ω (%)	S (%)	e
INITIAL	291.35	534.90	3.493	38.2	10[illegible]	[illegible]
FINAL	253.26	506.20	[illegible]	30.7	100	0.818

σ_{1c} corrected kg/cm²	ΔH/Ho,[1] %		ΔV/Vo,[2] %	
	Δ	Σ	Δ	Σ
0.19	—	—	0.36	0.36
0.49	—	—	0.87	1.23
0.99	—	—	1.16	2.39
1.99	—	—	3.37	5.76
4.20	—	—	4.64	10.40
2.09	—	—	−0.44	9.96

[1] [illegible] TEST

[2] [illegible]

PLANE STRAIN TEST ON COHESIVE SOIL

TEST NO. CK₀UPSP-9H
DATE
TESTED BY F D S

CONSOLIDATION PRESSURE, $\bar{\sigma}_c$ 2.09
BACK PRESSURE, U_B 2.51
PORE PRESSURE RESPONSE 94 %
IN ____ MINUTES AT U_B =

GAUGE NO. 3/1
PROVING RING NO. BLH 44505
STRAIN RATE 0.5%/hr
MEMBRANE LEAKAGE —

INITIAL LENGTH 3.499
INITIAL AREA
INITIAL Z_3 —
$(\sigma_3 = \bar{\sigma}_c + U_B)$

AXIAL STRAIN (%)	$\bar{\sigma}_V$	(1) $\bar{\sigma}_2$ CORRECTED	$\bar{\sigma}_h$ CORRECTED	$\frac{\bar{\sigma}_V}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_z}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_h}{\bar{\sigma}_{1c}}$	$\frac{\sigma_V-\sigma_h}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_V}{\bar{\sigma}_h}$	q	$\bar{p}$	$\bar{\sigma}_3/\bar{p}$	$\Delta\sigma_V$	Δu	$\frac{\Delta u-\Delta\sigma_3}{\bar{\sigma}_{1c}}$	A
0.0	1.39	1.27	2.09	.662	.607	1.000	-.338	.662	-.354	1.741	.730	0.0	0.0	0.0	—
.01	1.55	1.26	2.05	.740	.600	.978	-.238	.757	-.249	1.799	.699	.208	.044	.021	.212
.03[3]	1.74	1.24	1.96	.831	.592	.937	-.106	.887	-.111	1.853	.670	.481	.126	.060	.262
.06	1.88	1.24	1.90	.897	.594	.908	-.012	.987	-.012	1.891	.658	.675	.184	.088	.272
.11	2.04	1.25	1.83	.973	.598	.873	.100	1.115	.105	1.934	.648	.907	.255	.121	.281
.19	2.18	1.28	1.73	1.039	.611	.828	.211	1.256	.222	1.955	.655	1.137	.347	.165	.305
.41	2.32	1.22	1.58	1.109	.582	.752	.357	1.474	.374	1.950	.625	1.438	.500	.239	.348
.71	2.42	.96	1.42	1.156	.461	.676	.480	1.710	.503	1.919	.503	1.692	.656	.313	.388
1.02	2.48	.85	1.28	1.182	.405	.612	.570	1.931	.597	1.880	.452	1.878	.787	.376	.419
1.50	2.42	.77	1.04	1.155	.369	.495	.661	2.336	.692	1.729	.447	2.065	1.031	.492	.499
2.06	2.34	.75	.84	1.116	.359	.399	.717	2.797	.751	1.587	.474	2.180	1.228	.586	.563
2.50	2.31	.70	.75	1.101	.336	.360	.741	3.058	.776	1.530	.460	2.228	1.308	.624	.587
3.06	2.25	.67	.66	1.075	.319	.316	.759	3.404	.795	1.457	.459	2.264	1.399	.667	.618
3.53	2.15	.68	.58	1.027	.326	.277	.750	3.704	.785	1.366	.499	2.243	1.478	.705	.659
4.03	2.10	.66	.53	1.000	.316	.255	.745	3.925	.781	1.315	.504	2.233	1.524	.745	.683
4.48	2.08	.63	.50	.992	.300	.237	.755	4.181	.791	1.287	.489	2.250	1.559	.744	.693
5.00	2.06	.60	.46	.984	.287	.218	.766	4.516	.803	1.259	.477	2.273	1.597	.762	.703
5.47	2.05	.60	.44	.979	.284	.210	.769	4.663	.806	1.246	.478	2.277	1.612	.769	.708
6.07	2.08	.59	.42	.991	.281	.200	.791	4.952	.829	1.248	.472	2.319	1.629	.777	.703
6.55	2.04	.59	.41	.975	.284	.194	.781	5.017	.818	1.225	.485	2.296	1.640	.783	.714
7.07	2.01	.60	.39	.961	.286	.187	.774	5.144	.811	1.202	.499	2.280	1.654	.789	.725
7.49	1.99	.62	.40	.950	.295	.189	.760	5.018	.797	1.193	.517	2.250	1.647	.786	.732
8.00	1.97	.62	.39	.939	.296	.185	.755	5.080	.790	1.178	.526	2.236	1.654	.789	.740
8.51	1.99	.62	.38	.948	.296	.182	.766	5.203	.802	1.184	.523	2.256	1.657	.771	.734
9.08	1.99	.64	.39	.949	.306	.186	.764	5.113	.800	1.189	.539	2.249	1.647	.786	.732
9.54	1.97	.65	.38	.942	.311	.183	.759	5.148	.795	1.179	.552	2.237	1.650	.787	.738
10.03	1.93	.66	.38	.919	.316	.182	.736	5.040	.771	1.153	.574	2.188	1.650	.788	.754

REMARKS: (1) CORRECTED FOR MEMBRANE STRENGTH, FILTER STRIPS & PISTON FRICTION

CONSOLIDATION DATA

TEST NO $\overline{CK_0U}$-PSP-10 u_B 2.00 kg/cm^2

DATE 9-26-69 DEVICE MODEL B TESTED BY R.B.B.

	Vol (cc)	Wgt. (g)	L (in)	ω (%)	S (%)	e
INITIAL	284.47	495.53	3.501	43.4	93.7	1.288
FINAL	235.22	452.25	2.895	30.9	96.3	0.892

$\bar{\sigma}_{1c}$ corrected kg/cm^2	ΔH/Ho, % [1]		ΔV/Vo, % [2]	
	Δ	Σ	Δ	Σ
0.22	1.02	1.02	2.44	2.44
0.48	2.64	3.66	3.79	6.23
0.80	2.98	6.64	1.98	8.21
0.48	1.29	7.93	0.98	9.19
0.80	1.47	9.40	1.58	10.77
1.95	4.40	13.80	4.55	15.32
3.98	3.81	17.61	3.79	19.11

(1) FROM DIAL DISPLACEMENT READINGS
(2) FROM VOLUME CHANGE DEVICE

PLANE STRAIN TEST ON COHESIVE SOIL

TEST NO. PSP-10
DATE 1/1/69
TESTED BY R.B.B.

CONSOLIDATION PRESSURE, $\bar{\sigma}_c$ 3.98
BACK PRESSURE, u_B 2.00
PORE PRESSURE RESPONSE 95% %
IN ___ MINUTES AT u_B =

GAUGE NO. 3/1
PROVING RING NO. BLH 44575
STRAIN RATE 0.5%/HR
MEMBRANE LEAKAGE —

INITIAL LENGTH 2.996 IN.
INITIAL AREA 31.97 cm²
INITIAL $\bar{\sigma}_3$ —
($\sigma_3 = \bar{\sigma}_c + u_B$)

AXIAL STRAIN (%)	$\bar{\sigma}_v$ (1) CORRECTED	AVG. $\bar{\sigma}_2$ CORRECTED	$\bar{\sigma}_H$ CORRECTED	$\frac{\bar{\sigma}_v}{\bar{\sigma}_{vc}}$	$\frac{\bar{\sigma}_2}{\bar{\sigma}_{vc}}$	$\frac{\bar{\sigma}_H}{\bar{\sigma}_{vc}}$	$\frac{\sigma_v-\sigma_h}{\bar{\sigma}_{vc}}$	$\frac{\bar{\sigma}_H}{\bar{\sigma}_v}$	q	$\bar{p}$	$\bar{\sigma}_2/\bar{p}$	$\Delta\sigma_v$	Δu	$\frac{\Delta u-\Delta\sigma_3}{\bar{\sigma}_{vc}}$	$\bar{A}$ (2)
0.0	3.98	1.97	1.98	1.000	.495	.498	.502	.498	1.000	2.984	.661	0.0	0.0	0.0	-
.05	3.00	1.76	2.17	.754	.441	.545	.207	.723	.416	2.587	.756	-1.161	-.180	.276	.845
.15	2.64	1.74	2.35	.664	.486	.590	.073	.839	.146	2.497	.776	-1.676	-.356	.336	.790
.26	2.33	1.85	2.36	.578	.465	.592	.006	.989	.013	2.369	.782	-1.961	-.359	.402	.817
.31	2.27	1.81	2.34	.570	.455	.587	-.017	1.030	-.034	2.306	.787	-2.058	-.342	.429	.833
.58	1.89	1.67	2.29	.475	.420	.576	-.101	1.212	-.201	2.026	.799	-2.386	-.294	.526	.877
.80	1.67	1.57	2.23	.420	.394	.559	-.139	1.330	-.277	1.950	.804	-2.525	-.225	.580	.911
1.02	1.41	1.42	2.16	.353	.357	.541	-.188	1.531	-.374	1.781	.799	-2.723	-.152	.647	.944
1.23	1.29	1.36	2.12	.325	.341	.533	-.209	1.647	-.417	1.707	.796	-2.815	-.121	.676	.957
1.46	1.14	1.31	2.09	.287	.329	.525	-.237	1.826	-.473	1.618	.810	-2.925	-.086	.715	.970
2.06	.86	1.21	1.98	.215	.304	.499	-.283	2.314	-.564	1.422	.851	-3.105	.020	.785	1.007
2.53	.72	1.15	1.93	.180	.290	.485	-.304	2.689	-.605	1.321	.875	-3.185	.082	.820	1.026
3.03	.58	1.13	1.89	.147	.284	.475	-.329	3.229	-.651	1.235	.917	-3.276	.174	.853	1.038
3.51	.52	1.10	1.84	.130	.277	.462	-.332	3.538	-.661	1.181	.934	-3.296	.166	.870	1.051
4.05	.44	1.10	1.83	.110	.277	.453	-.349	4.177	-.694	1.131	.972	-3.360	.186	.890	1.055
4.51	.40	1.10	1.80	.100	.277	.451	-.351	4.528	-.700	1.096	1.005	-3.370	.217	.900	1.064
5.03	.38	1.11	1.78	.094	.278	.448	-.354	4.759	-.704	1.079	1.026	-3.378	.231	.906	1.068
5.52	.36	1.12	1.79	.090	.282	.450	-.357	4.969	-.715	1.076	1.043	-3.377	.224	.909	1.066
6.08	.34	1.15	1.79	.087	.290	.451	-.364	5.206	-.726	1.071	1.077	-3.418	.220	.913	1.067
6.56	.32	1.17	1.78	.081	.295	.448	-.367	5.551	-.731	1.052	1.115	-3.428	.234	.917	1.066
7.01	.32	1.21	1.80	.081	.305	.451	-.370	5.577	-.737	1.061	1.144	-3.437	.220	.919	1.064
7.44	.33	1.26	1.80	.082	.317	.452	-.370	5.518	-.737	1.063	1.188	-3.437	.220	.918	1.064
7.65	.34	1.31	1.78	.084	.328	.447	-.362	5.293	-.722	1.053	1.237	-3.406	.241	.916	1.071
8.65	.33	1.36	1.79	.082	.341	.450	-.367	5.474	-.732	1.059	1.283	-3.424	.231	.913	1.067
8.94	.34	1.38	1.79	.085	.348	.451	-.365	5.282	-.728	1.062	1.297	-3.416	.227	.915	1.067
9.54	.33	1.42	1.79	.082	.357	.447	-.367	5.425	-.732	1.057	1.346	-3.424	.224	.916	1.068
10.12	.33	1.46	1.80	.083	.367	.453	-.374	5.440	-.736	1.068	1.368	-3.432	.220	.917	1.064

NOT REPRODUCIBLE

REMARKS: (1) CORRECTED FOR MEMBRANE STRENGTH, FILTER STRIPS & PISTON FRICTION
(2) A = [illegible]

CONSOLIDATION DATA

TEST NO $\overline{\text{CK}_0\text{U}}$-PSP-11 U_B 2.00 kg/cm^2

DATE 10-20-69 DEVICE MODEL B TESTED BY R.B.B.

	VOL (cc)	Wgt. (g)	L (in)	ω (%)	S (%)	e
INITIAL	289.64	540.02	3.557	37.9	98.9	1.065
FINAL	264.90	509.85	3.253	30.78	96.25	0.889

$\bar{\sigma}_{1c}$ corrected kg/cm^2	$\Delta H/H_0$, % [1]		$\Delta V/V_0$, % [2]	
	Δ	Σ	Δ	Σ
0.24	0.56	0.56	0.92	0.92
0.54	0.90	1.46	1.24	2.16
1.02	1.04	2.50	1.45	3.61
1.99	2.36	4.86	2.22	5.83
3.97	3.68	8.54	3.68	9.51

(1) FROM DIAL DISPLACEMENT READINGS

(2) FROM VOLUME CHANGE DEVICE

PLANE STRAIN TEST ON COHESIVE SOIL

TEST NO. PSP-11 *	CONSOLIDATION PRESSURE, $\bar{\sigma}_c$ 3.97	GAUGE NO. 3/1	
DATE 10-24-69	BACK PRESSURE, U_B 2.01	PROVING RING NO. BLH 44575	INITIAL LENGTH 3.253 IN
TESTED BY R.B.B.	PORE PRESSURE RESPONSE 98 % IN — MINUTES AT U_B = 2.00	STRAIN RATE 0.5 %/HOUR	INITIAL AREA 32.048 CM²
		MEMBRANE LEAKAGE —	INITIAL Z_3 — ($\sigma_3 = \bar{\sigma}_c + U_B$)

AXIAL STRAIN (%)	$\bar{\sigma}_v$ (1) CORRECTED	AVG. $\bar{\sigma}_2$ CORRECTED	$\bar{\sigma}_H$ CORRECTED	$\frac{\bar{\sigma}_v}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_2}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_H}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_v-\bar{\sigma}_H}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_H}{\bar{\sigma}_v}$	$\bar{q}$	$\bar{P}$	$\bar{\sigma}_2/\bar{P}$	$\Delta\sigma_v$	Δu	$\frac{\Delta u-\Delta\sigma_v}{\bar{\sigma}_{1c}}$	$\bar{A}$ (2)
0.0	3.97	1.92	2.07	1.000	.485	.521	.479	.521	.951	3.019	.637	0.0	0.0	0.0	—
.02	3.66	1.86	2.16	.921	.469	.545	.376	.591	.777	2.904	.640	-.407	-.093	.079	.772
.05	3.48	1.86	2.29	.875	.468	.576	.300	.658	.595	2.880	.646	-.702	-.213	.125	.699
.10	3.26	1.86	2.42	.821	.469	.609	.212	.743	.420	2.838	.656	-1.055	-.343	.179	.675
.21	2.88	1.81	2.51	.725	.456	.633	.092	.877	.182	2.696	.672	-1.527	-.436	.275	.715
.30	2.56	1.75	2.51	.646	.440	.633	.013	.980	.025	2.537	.689	-1.840	-.432	.354	.745
.49	2.18	1.65	2.51	.550	.416	.632	-.083	1.151	-.164	2.346	.703	-2.217	-.429	.450	.806
.74	1.84	1.54	2.43	.464	.387	.613	-.149	1.320	-.295	2.138	.718	-2.477	-.350	.536	.859
1.02	1.49	1.41	2.35	.375	.356	.593	-.218	1.530	-.432	1.921	.735	-2.722	-.268	.625	.903
1.26	1.31	1.33	2.29	.330	.336	.576	-.245	1.740	-.487	1.773	.741	-2.858	-.199	.669	.930
1.49	1.12	1.26	2.21	.283	.318	.556	-.273	1.966	-.542	1.664	.758	-2.963	-.120	.717	.960
1.76	.98	1.19	2.16	.247	.301	.545	-.298	2.207	-.591	1.572	.761	-3.065	-.076	.753	.975
2.02	.84	1.14	2.10	.212	.288	.529	-.317	2.496	-.629	1.470	.777	-3.140	-.010	.788	.997
2.25	.75	1.11	2.08	.190	.279	.523	-.333	2.755	-.661	1.417	.784	-3.203	.014	.610	1.004
2.51	.69	1.06	2.02	.174	.267	.508	-.334	2.919	-.663	1.354	.783	-3.207	.072	.826	1.022
2.76	.60	1.03	1.99	.150	.260	.501	-.350	3.328	-.695	1.272	.798	-3.270	.103	.847	1.031
3.01	.53	1.00	1.96	.134	.253	.495	-.360	3.685	-.715	1.243	.804	-3.310	.127	.866	1.038
3.24	.47	.98	1.93	.117	.247	.485	-.368	4.130	-.730	1.196	.820	-3.339	.145	.882	1.049
3.49	.43	.97	1.93	.107	.244	.485	-.378	4.522	-.751	1.177	.822	-3.377	.165	.893	1.049
3.74	.37	.95	1.89	.098	.239	.477	-.379	4.337	-.753	1.140	.831	-3.384	.179	.902	1.059
4.10	.30	.93	1.88	.077	.234	.475	-.378	6.204	-.790	1.094	.848	-3.457	.209	.924	1.060
4.45	.26	.91	1.86	.066	.229	.468	-.402	7.070	-.797	1.060	.857	-3.471	.227	.937	1.068
4.70	.21	.90	1.86	.053	.227	.468	-.415	8.891	-.825	1.034	.872	-3.525	.236	.947	1.067
4.94	.19	.89	1.83	.048	.224	.461	-.414	9.708	-.821	1.010	.881	-3.516	.244	.955	1.075
5.41	0.124	0.882	1.951	.031	.222	.463	-.432	—	[illegible]	[illegible]	.519	[illegible]	.257	.969	1.072
6.17	.027	.874	1.837	[illegible]	.220	.460	-.458	—	-.910	.917	.953	[illegible]	.251	[illegible]	1.073
6.63	-.037	.875	1.832	-.009	.220	.461	-.471	—	-.935	.817	.976	-3.740	.267	1.009	1.071
7.13	-.104	.874	1.836	-.026	.220	.457	-.483	—	-.960	.856	1.021	-3.787	.254	1.026	1.075
7.51	-.161	[illegible]	1.834	-.041	.221	.462	[illegible]	—	[illegible]	[illegible]	1.047	[illegible]	.267	1.041	[illegible]
[illegible]	-.271	.882	1.839	-.068	.222	.463	-.531	—	-1.055	.784	1.126	-3.777	.264	1.068	1.066
[illegible]	-.376	.880	1.836	-.095	.222	.463	-.557	—	-1.106	.730	1.206	-4.077	.267	1.095	1.066
1.07	-.415	.874	1.854	-.125	.220	.462	-.587	—	-1.165	.669	[illegible]	-4.195	.271	1.125	1.065
1.54	[illegible]	.882	1.876	-.165	.222	.465	[illegible]	—	-1.250	.516	1.477	[illegible]	.260	1.165	1.060
[illegible]	-.786	.877	1.833	-.192	.221	.462	-.660	—	-1.310	.524	1.673	[illegible]	.274	1.198	1.031
11.21	-1.072	.863	1.864	-.270	.217	.469	-.739	—	-1.465	.396	2.180	-4.745	.247	1.270	1.051

REMARKS: (1) CORRECTED FOR MEMBRANE STRENGTH, FILTER STRIPS & PISTON FRICTION

(2) $A = \frac{\Delta u - \Delta\sigma_v}{\Delta\sigma_h - \Delta\sigma_v}$

NOT REPRODUCIBLE

CONSOLIDATION DATA

TEST NO [illegible]H

U_B 2.00 kg/cm^2

DATE 10-27-69 DEVICE MODEL B TESTED BY S. SS

	VOL (cc)	Wgt. (g)	L (in)	ω(%)	S(%)	e
INITIAL	[illegible].85	[illegible]	[illegible]	38.5	[illegible]	[illegible]
FINAL	[illegible]	497.35	[illegible]	31.9	[illegible]	[illegible]

NOT REPRODUCIBLE

$\bar{\sigma}_{1c}$ Corrected kg/cm²	ΔH/Ho (1)		ΔV/Vo, % (2)	
	Δ	Σ	Δ	Σ
[illegible]	—	—	0.55	0.55
[illegible]	—	—	0.84	1.39
[illegible]	—	—	1.15	2.54
2.00	—	—	3.23	5.77
[illegible]	—	—	4.92	10.69
2.00	—	—	-.39	10.30
1.01	—	—	-1.42	8.88

(1) [illegible]

(2) FROM VOLUME CHANGE DEVICE

PLANE STRAIN TEST ON COHESIVE SOIL

GAUGE NO. 3/1

TEST NO $\overline{\mathrm{CK_0U}}$PSP-12H
DATE 11-2-69
TESTED BY RBB

CONSOLIDATION PRESSURE, $\bar{\sigma}_c$ 1.011
BACK PRESSURE, u_B 2.00
PORE PRESSURE RESPONSE 99 %
IN — MINUTES AT u_B = 3.00

PROVING RING NO BLH 44 575
STRAIN RATE 0.5%/hr
MEMBRANE LEAKAGE —

INITIAL LENGTH 3.499
INITIAL AREA —
INITIAL z_3 —
($\sigma_3 = \bar{\sigma}_c + u_B$)

AXIAL STRAIN (%)	$\bar{\sigma}_v^{(1)}$ CORRECTED	AVG. $\bar{\sigma}_z$ CORRECTED	$\bar{\sigma}_h$ CORRECTED	$\frac{\bar{\sigma}_v}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_z}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_h}{\bar{\sigma}_{1c}}$	$\frac{\sigma_v - \sigma_h}{\bar{\sigma}_{1c}}$	$\frac{\bar{\sigma}_v}{\bar{\sigma}_h}$	q	$\bar{p}$	$\bar{\sigma}_z/\bar{p}$	$\Delta\sigma_v$	Δu	$\frac{\Delta u - \Delta\sigma_h}{\bar{\sigma}_{1c}}$	$A^{(2)}$
0.0	.85	.657	1.011	.842	.650	1.00	-.158	.842	-.080	.931	.706	0.0	0.0	0.0	—
.02	1.04	.65	.92	1.029	.641	.912	.117	1.128	.059	.981	.661	.275	.086	.084	.312
.10	1.24	.64	.76	1.223	.632	.756	.467	1.618	.236	1.000	.638	.625	.240	.237	.383
.25	1.37	.61	.67	1.359	.601	.662	.697	2.053	.352	1.021	.595	.854	.332	.328	.389
.50	1.42	.55	.59	1.403	.540	.586	.817	2.395	.413	1.005	.543	.974	.407	.403	.418
.76	1.44	.51	.53	1.423	.503	.527	.897	2.703	.453	.985	.517	1.053	.465	.461	.442
1.01	1.45	.49	.49	1.436	.488	.485	.951	2.964	.481	.971	.508	1.107	.507	.501	.458
1.51	1.45	.48	.43	1.432	.476	.426	1.006	3.363	.509	.939	.512	1.160	.564	.558	.486
2.02	1.48	.47	.39	1.470	.466	.383	1.086	3.833	.549	.936	.503	1.238	.604	.598	.488
2.51	1.47	.45	.35	1.456	.446	.341	1.115	4.265	.563	.909	.496	1.266	.645	.638	.510
3.02	1.49	.44	.33	1.478	.435	.323	1.155	4.582	.584	.910	.483	1.305	.662	.655	.507
3.50	1.51	.43	.31	1.491	.426	.307	1.183	4.848	.598	.909	.474	1.331	.675	.668	.507
4.03	1.52	.43	.30	1.501	.422	.292	1.209	5.141	.611	.906	.471	1.354	.689	.682	.509
4.49	1.53	.42	.28	1.514	.418	.277	1.237	5.472	.625	.905	.466	1.381	.702	.695	.509
4.73	1.53	.42	.28	1.517	.420	.279	1.238	5.435	.625	.908	.468	1.381	.699	.691	.506
4.96	1.53	.42	.28	1.510	.419	.272	1.238	5.557	.626	.900	.471	1.381	.706	.698	.511
5.18	1.54	.42	.26	1.526	.416	.260	1.265	5.858	.639	.903	.465	1.407	.716	.708	.509
5.25	1.55	.42	.26	1.535	.415	.260	1.275	5.902	.644	.907	.463	1.416	.716	.708	.506
5.62	1.55	.42	.27	1.534	.413	.265	1.269	5.781	.641	.909	.459	1.408	.709	.702	.503
6.07	1.55	.41	.26	1.535	.404	.264	1.272	5.824	.643	.909	.449	1.410	.709	.702	.503
6.51	1.55	.39	.26	1.536	.384	.262	1.275	5.868	.644	.909	.427	1.411	.709	.702	.503
6.97	1.53	.38	.26	1.512	.376	.260	1.252	5.812	.633	.896	.424	1.387	.709	.702	.511
7.44	1.54	.37	.27	1.518	.369	.265	1.254	5.731	.633	.901	.414	1.386	.702	.695	.507
7.90	1.54	.37	.26	1.523	.364	.256	1.267	5.947	.640	.899	.409	1.397	.709	.702	.508
8.59	1.52	.35	.25	1.507	.351	.250	1.257	6.029	.635	.888	.399	1.384	.712	.705	.515
9.04	1.50	.36	.25	1.483	.352	.248	1.234	5.974	.624	.875	.407	1.360	.712	.705	.524
9.48	1.49	.36	.24	1.479	.354	.243	1.236	6.094	.625	.870	.411	1.360	.716	.708	.526
10.14	1.49	.36	.24	1.478	.354	.239	1.239	6.173	.626	.868	.413	1.359	.716	.708	.527

REMARKS: (1) CORRECTED FOR MEMBRANE STRENGTH, FILTER STRIPS & PISTON FRICTION

(2) $A = \frac{\Delta u - \Delta\sigma_v}{\Delta\sigma_h - \Delta\sigma_v}$

CONSOLIDATION DATA

TEST NO CK_oU-PSP-13 u_B 2.0 kg/cm²

DATE 12/69 DEVICE MODEL B TESTED BY R. B. BOVEE

	VOL (cc)	Wgt. (g)	L (in)	ω (%)	S (%)	e
INITIAL	281	534.3	3.462	36.0	101	0.985
FINAL		515				

$\bar{\sigma}_{1c}$ Corrected kg/cm²	ΔH/Ho, % (1)		ΔV/Vo, % (2)	
	Δ	Σ	Δ	Σ
0.2	0.13	0.13	0	0
0.5	0.64	0.77	0.76	0.76
1.0	0.81	1.58	1.12	1.88
2.0	1.36	2.94	1.45	3.33
4.0	3.48	6.42	3.60	6.93
2.0	-0.36	6.06	-0.38	6.55

(1) FROM DIAL DISPLACEMENT READINGS
(2) FROM VOLUME CHANGE DEVICE

PLANE STRAIN TEST ON COHESIVE SOIL

TEST NO CK₀U-PSP-13
DATE 12/69
TESTED BY R.B.B.

CONSOLIDATION PRESSURE, $\bar{\sigma}_c$ 1.98
BACK PRESSURE, U_B 2.01
PORE PRESSURE RESPONSE 99 %
IN ___ MINUTES AT U_B = 2.00

GAUGE NO. 3/1
PROVING RING NO BLH 44575
STRAIN RATE 0.5%/HR.
MEMBRANE LEAKAGE —

INITIAL LENGTH 3.252 in.
INITIAL AREA 31.950 cm²
INITIAL Z_3 —
$(\sigma_3 = \bar{\sigma}_c + U_B)$

AXIAL STRAIN (%)	$\bar{\sigma}_v$ (1) CORRECTED	AVG. $\bar{\sigma}_z$ CORRECTED	$\bar{\sigma}_h$ CORRECTED	$\frac{\bar{\sigma}_v}{\bar{\sigma}_{vc}}$	$\frac{\bar{\sigma}_z}{\bar{\sigma}_{vc}}$	$\frac{\bar{\sigma}_h}{\bar{\sigma}_{vc}}$	$\frac{\sigma_v-\sigma_h}{\bar{\sigma}_{vc}}$	$\frac{\bar{\sigma}_h}{\bar{\sigma}_v}$	q	$\bar{p}$	$\bar{\sigma}_z/\bar{p}$	$\Delta\sigma_v$	Δu	$\frac{\Delta u-\Delta\sigma_v}{\bar{\sigma}_{vc}}$	A		
0.0	1.983	1.255	1.403	1.00	.633	.708	0.292	.708	0.290	1.693	.741	0.0	0.0	0.0	—		
.02	1.809	1.312	1.572	.912	.662	.793	.120	.869	0.119	1.690	.776	-.339	-.165	.088	.512		
.05	1.702	1.349	1.712	.858	.680	.863	-.005	1.005	-.005	1.707	.790	-.584	-.303	.142	.481		
.10	1.619	1.405	1.827	.816	.709	.921	-.105	1.129	-.104	1.723	.815	-.781	-.417	.184	.466		
.15	1.551	1.412	1.876	.782	.712	.946	-.164	1.209	-.162	1.714	.824	-.897	-.465	.218	.481		
.21	1.474	1.413	1.915	.743	.713	.966	-.222	1.299	-.221	1.695	.834	-1.012	-.503	.257	.503		
.25	1.431	1.408	1.930	.722	.710	.973	-.252	1.349	-.249	1.680	.838	-1.069	-.517	.278	.527		
.30	1.376	1.396	1.944	.694	.704	.980	-.286	1.413	-.284	1.660	.841	-1.137	-.530	.306	.534		
.35	1.325	1.384	1.951	.668	.698	.984	-.316	1.472	-.313	1.638	.845	-1.195	-.537	.332	.550		
.40	1.285	1.366	1.945	.648	.689	.981	-.333	1.513	-.330	1.615	.846	-1.228	-.530	.352	.568		
.45	1.215	1.351	1.956	.613	.681	.986	-.374	1.610	-.371	1.585	.852	-1.309	-.540	.387	.587		
.61	1.090	1.306	1.957	.550	.659	.987	-.437	1.795	-.433	1.524	.857	-1.433	-.540	.450	.623		
.81	.971	1.250	1.938	.490	.630	.977	-.488	1.996	-.483	1.454	.859	-1.532	-.520	.510	.660		
1.01	.858	1.196	1.915	.433	.603	.966	-.533	2.232	-.528	1.386	.863	-1.621	-.496	.567	.694		
1.26	.751	1.147	1.885	.379	.578	.950	-.572	2.509	-.567	1.318	.870	-1.697	-.465	.621	.726		
1.51	.659	1.109	1.858	.333	.559	.937	-.605	2.818	-.599	1.257	.881	-1.761	-.438	.668	.752		
2.05	.491	1.051	1.808	.248	.530	.912	-.664	3.681	-.659	1.150	.914	-1.828	-.386	.752	.794		
2.56	.378	1.016	1.755	.190	.512	.885	-.694	4.648	-.689	1.066	.953	-1.936	-.331	.810	.829		
3.15	.252	.993	1.736	.127	.501	.875	-.748	6.896	-.742	.994	.999	-2.041	-.310	.873	.848		
3.48	.219	.988	1.719	.110	.498	.867	-.757	7.666	-.750	.969	1.020	-2.057	-.293	.890	.858		
3.96	.165	.980	1.703	.083	.494	.859	-.776	10.340	-.769	.934	1.049	-2.094	-.276	.917	.868		
4.47	.119	.972	1.694	.060	.490	.853	-.794	14.194	-.788	.907	1.072	-2.122	-.265	.940	.875		
5.01	.104	.973	1.692	.053	.491	.852	-.801	—	-.794	.898	1.084	-2.141	-.262	.947	.878		
5.53	.089	.971	1.690	.045	.490	.852	-.807	—	-.801	.887	1.092	-2.153	-.258	.955	.880		
6.07	.100	.975	1.701	.050	.492	.858	-.808	—	-.801	.900	1.083	-2.152	-.269	.950	.825		
6.60	.110	.978	1.712	.056	.493	.864	-.808	—	-.801	.911	1.074	-2.152	-.279	.944	.820		
7.02	.120	.976	1.776	.060	.502	.895	-.835	—	-.828	.948	1.051	-2.204	-.341	.940	.845		
7.50	.145	.984	1.752	.073	.496	.884	-.811	—	-.804	.946	1.038	-2.155	-.317	.927	.853		
8.00	.163	.960	1.760	.082	.494	.887	-.805	—	-.798	.962	1.019	-2.144	-.324	.918	.849		
8.50	.169	.976	1.767	.085	.492	.891	-.806	—	-.799	.968	1.008	-2.144	-.331	.916	.846		
9.0	.166	.976	1.779	.084	.492	.897	-.813	—	-.806	.972	1.004	-2.158	-.341	.916	.842		
9.51	.162	.976	1.780	.082	.492	.903	-.824	—	-.814	.976	1.000	-2.172	-.351	.918	.838		
10.01	.164	.976	1.794	.083	.492	.905	-.822	—	-.815	.979	.997	-2.174	-.355	.917	.837		
10.63	.108	.974	1.799	.055	.491	.907	-.853	—	-.845	.954	1.021	-2.233	-.358	.945	.840		
11.75	.052	.946	1.777	.026	.474	.896	-.870	—	-.862	.914	1.028	-2.265	-.334	.974	.852		

REMARKS: (1) CORRECTED FOR MEMBRANE STRENGTH, FILTER STRIPS & PISTON FRICTION

CONSOLIDATION DATA

TEST NO $\overline{\text{CK}_0\text{U}}$-PSP-22 U_B 2.00 kg/cm^2

DATE 4/17/69 DEVICE MODEL B TESTED BY R.B. BOVEE

	V_{OL} (cc)	Wgt. (g)	L (in)	ω (%)	S (%)	e
INITIAL	272.06	517.99	3.367	35.5	99.2	0.980
FINAL				30.0		

$\bar{\sigma}_{1c}$ Corrected kg/cm^2	$\Delta L/L_0$, % (1)		$\Delta V/V_0$, % (2)	
	Δ	Σ	Δ	Σ
0.2	0.25	0.25	0.34	0.34
0.5	0.45	0.70	0.65	0.99
1.0	0.97	1.67	0.98	1.97
2.0	1.63	3.30	1.64	3.61
4.24	4.35	7.65	4.07	7.68

(1) FROM DIAL DISPLACEMENT READINGS
(2) FROM VOLUME CHANGE DEVICE

PLANE STRAIN   TEST ON COHESIVE SOIL

TEST NO CK0U-PSP-22
DATE 4/69
TESTED BY R.B.B.

CONSOLIDATION PRESSURE, $\bar{\sigma}_c$ 4.24
BACK PRESSURE, U_B 2.02
PORE PRESSURE RESPONSE 100 %
IN ___ MINUTES AT U_B : 2.00

GAUGE NO 3/1
PROVING RING NO BLH 44575
STRAIN RATE 0.5%/HR
MEMBRANE LEAKAGE —

INITIAL LENGTH 3.110 in.
INITIAL AREA 31.812 cm²
INITIAL Z_3 —
($\sigma_3 = \bar{\sigma}_c + U_B$)

AXIAL STRAIN (%)	$\bar{\sigma}_v$ (1) CORRECTED	AVG $\bar{\sigma}_z$ CORRECTED	$\bar{\sigma}_h$ CORRECTED	$\frac{\bar{\sigma}_v}{\bar{\sigma}_{vc}}$	$\frac{\bar{\sigma}_z}{\bar{\sigma}_{vc}}$	$\frac{\bar{\sigma}_h}{\bar{\sigma}_{vc}}$	$\frac{\bar{\sigma}_v-\bar{\sigma}_h}{\bar{\sigma}_{vc}}$	$\frac{\bar{\sigma}_h}{\bar{\sigma}_v}$	q	$\bar{p}$	$\bar{\sigma}_z/\bar{p}$	$\Delta\sigma_v$	Δu	$\frac{\Delta u-\Delta\sigma_v}{\bar{\sigma}_{vc}}$	A		
0.0	4.244	1.941	1.907	1.000	.457	.449	.551	.449	1.168	3.025	.631	0.0	0.0	0.0	—		
.03	3.801	1.952	2.183	.896	.460	.515	.381	.574	.809	2.992	.652	-.714	-.271	.104	.620		
.07	3.519	1.917	2.310	.829	.452	.544	.285	.656	.605	2.914	.658	-1.119	-.395	.171	.647		
.29	2.661	1.621	2.371	.627	.382	.559	.068	.871	.145	2.516	.644	-2.033	-.451	.373	.778		
.54	2.081	1.396	2.304	.490	.329	.543	-.053	1.107	-.111	2.192	.637	-2.544	-.381	.510	.850		
.80	1.687	1.248	2.231	.398	.274	.526	-.128	1.321	-.271	1.960	.637	-2.862	-.307	.602	.893		
1.32	1.132	1.076	2.093	.267	.253	.493	-.227	1.830	-.481	1.612	.667	-3.279	-.167	.733	.949		
1.59	.939	1.026	2.036	.221	.242	.480	-.258	2.168	-.548	1.487	.690	-3.413	-.108	.779	.968		
1.85	.777	.983	1.985	.183	.232	.468	-.285	2.556	-.604	1.381	.712	-3.524	-.057	.817	.984		
2.10	.657	.948	1.942	.155	.223	.458	-.303	2.955	-.643	1.300	.729	-3.579	-.013	.845	.996		
2.35	.547	.918	1.908	.129	.216	.450	-.321	3.492	-.681	1.22	.748	-3.676	.022	.871	1.006		
2.60	.464	.892	1.879	.109	.210	.443	-.333	4.049	-.707	1.171	.762	-3.728	.052	.891	1.014		
2.86	.359	.872	1.851	.085	.206	.436	-.352	5.158	-.746	1.105	.790	-3.804	.080	.915	1.021		
3.38	.222	.838	1.809	.052	.198	.426	-.374	8.130	-.793	1.026	.825	-3.897	.124	.948	1.032		
3.93	.111	.809	1.780	.026	.191	.419	-.393	—	-.834	.945	.856	-3.978	.154	.974	1.039		
4.47	.005	.791	1.758	.001	.186	.414	-.413	—	-.876	.881	.877	-4.061	.178	.999	1.044		
5.01	-.046	.767	1.742	-.011	.181	.410	-.421	—	-.894	.848	.904	-4.094	.195	1.011	1.048		
5.56	-.054	.785	1.756	-.013	.185	.414	-.427	—	-.905	.851	.922	-4.116	.182	1.013	1.044		
6.08	-.149	.760	1.731	-.035	.177	.408	-.443	-	-.940	.791	.960	-4.184	.208	1.035	1.050		
6.61	-.194	.753	1.728	-.046	.177	.407	-.453	-	-.961	.767	.982	-4.225	.212	1.046	1.050		
7.15	-.212	.738	1.725	-.050	.174	.406	-.456	-	-.968	.757	.975	-4.239	.217	1.050	1.051		
7.69	-.267	.739	1.726	-.063	.174	.407	-.470	-	-.997	.729	1.013	-4.274	.217	1.063	1.050		
8.52	-.304	.742	1.725	-.072	.175	.407	-.478	-	-1.015	.711	1.045	-4.329	.219	1.072	1.051		
9.07	-.338	.745	1.735	-.080	.175	.409	-.489		-1.037	.698	1.066	-4.372	.210	1.080	1.048		
9.61	-.377	.746	1.736	-.089	.176	.409	-.498	-	-1.056	.679	1.097	-4.410	.210	1.089	1.048		
10.15	-.434	.745	1.737	-.102	.176	.410	-.512	-	-1.087	.653	1.142	-4.470	.208	1.102	1.047		
10.87	-.508	.749	1.747	-.120	.177	.412	-.531	-	-1.128	.620	1.209	-4.550	.202	1.125	1.044		

REMARKS: (1) CORRECTED FOR MEMBRANE STRENGTH, FILTER STRIPS & PISTON FRICTION

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Massachusetts Institute of Technology, Department of Civil Engineering, Soil Mechanics Division Cambridge, Massachusetts	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
CONSOLIDATED-UNDRAINED PLANE STRAIN SHEAR TESTS ON BOSTON BLUE CLAY; Research in Earth Physics, Phase Report No. 15

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Phase Report No. 15

5. AUTHOR(S) (First name, middle initial, last name)
Charles C. Ladd, Richard B. Bovee, Lewis Edgers, and Joseph J. Rixner

6. REPORT DATE March 1971	7a. TOTAL NO. OF PAGES 243	7b. NO. OF REFS 17

8a. CONTRACT OR GRANT NO. DA-22-079-eng-457 b. PROJECT NO. 1-V-0-14501-B-52A-01 and 4A061102B52E c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) Research Report R71-13 Soils Publication 273 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) U. S. Army Engineer Waterways Experiment Station Contract Report No. 3-101, Phase Report No. 15

10. DISTRIBUTION STATEMENT
Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES Prepared under contract for U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi	12. SPONSORING MILITARY ACTIVITY U. S. Army Materiel Command, Washington, D. C.; and Office, Chief of Engineers, U. S. Army, Washington, D. C.

13. ABSTRACT

Results of consolidated-undrained plane strain active($\sigma_{1f} = \sigma_{vf}$) and passive ($\sigma_{1f} = \sigma_{hf}$) tests are reported on K_o consolidated samples of resedimented Boston Blue Clay at overconsolidation ratios of one, two, and four. The plane strain equipment, developed at M.I.T., uses a sample with dimensions 3.5 in. high by 3.5 in. wide by 1.4 in. deep. The vertical and horizontal stresses can be independently varied. The magnitude of the cell pressure during consolidation yields values of K_o and pressure transducers in the fixed end platens yield values of K_o and σ_2. The apparatus gives reliable stress-strain data for active tests; for passive tests the data become unreliable beyond 3 ± 1 per cent axial strain due to various sources of "friction" and due to necking. However, a failure criteria based on the maximum obliquity of principal stresses gave fairly reliable undrained strength parameters for passive conditions. The active and passive test data show that Boston Blue Clay has highly anisotropic undrained strength properties. For normally consolidated clay, $s_u/\bar{\sigma}_{vc} = 0.34$ and 0.19 for active and passive conditions; the corresponding ratios at an OCR of four are 0.95 and 0.67. These strength ratios have been verified by undrained model footing bearing capacity tests. A comparison of plane strain and triaxial test data shows that $\overline{CK_oU}$ triaxial compression tests yield results very similar to those obtained by the active tests. However, $\overline{CK_oU}$ triaxial extension tests will underestimate the undrained passive strength.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified
Security Classification

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Boston Blue Clay Earth physics Plane strain shear tests Soil strength Soil stress-strain relations Triaxial tests						

Unclassified
Security Classification