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TRIAXIAL TESTING OF SOILS

by

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INTRODUCTION

The triaxial compression machine appears to have been developed from an earlier machine designed at the Prussian Waterway Experimental Station (1). The purpose of the earlier machine was for studying the consolidation of clays under conditions of negligible side friction. In this first apparatus the surrounding liquid was entirely confined, and temperatures and leakage had to be closely controlled to obtain consistent results. Several investigations recognized that the apparatus could be used to measure the ratio of axial and lateral pressures both prior to and at failure. The first results of this investigation appear to be those of T. C. Stanton and F. M. Hveem (1). Positive control over the lateral pressure was later developed independently by L. Redulic working in Vienna and W. S. Housel (1) at the University of Michigan.

PURPOSE OF THE STUDY

Recently, the Department of Civil Engineering at Kansas State University purchased a triaxial testing machine. The machine was inoperative due to the breakdown of the gear box and some electrical problems. The operating techniques needed to be confirmed so that the machine could be used for instruction in laboratory classes. This report deals with the operation of the machine and the experiments on blow sand and silty clay in order to find the unit cohesion and friction angle of these soils.

SCOPE OF THE STUDY

In testing any sample of natural soil, the most important factor is the preparation of the undisturbed sample to determine the characteristics of the soil. However, it is extremely difficult to obtain and to prepare for a laboratory experiment any sample undisturbed from its natural state. The two tests performed for this investigation were on remolded samples. The samples were an oven-dried sand and a silty-clay compacted to the standard Proctor density. Two different samples were chosen to observe the difference in testing procedures and data results.

The sand was difficult to test in the triaxial machine because it would not stand alone when left without chamber pressure or a vacuum within the sample. The situation was corrected by placing the sample on the platen and vacuuming the sample between two porous stones.

The silty clay was difficult to prepare for testing because the Proctor mold and the soil adhered to each other and cracking of the sample resulted. With extreme caution one can obtain a sample without damaging the soil.

The testing was done under drained conditions. Research done by Wesley G. Holtz and Harold J. Gibbs (7) shows that only a small difference in results occurs between the drained and undrained cases. Exceptions are in the testing of clays and clay-dominated silts. The amount of time it takes to equalize pore water pressure would also allow creep action which affects the desired results.

REVIEW OF LITERATURE

Concept of Triaxial Testing

In actual triaxial testing we consider σ_1 which is the major principal stress, σ_3 which is the minor principal stress, and σ_2 which is the intermediate principal stress. The condition imposed by the nature of the testing is that $\sigma_2 = \sigma_3$. The quantity $(\sigma_1 - \sigma_3)$ is called the deviator stress.

An analysis of triaxial stress is best made by the use of Mohr's stress circle (6). This is a graphical representation of the state of stress in the soil. For instance, Fig. 1a is the physical representation of the stressed sample, and Fig. 1b is the corresponding Mohr circle representation. Note that the normal stress at a point is a function of the orientation of the plane chosen to define the stress. Also, when using Mohr's circle to analyze stresses in soils, normal stress is considered positive when compressive.

Any point A on the circle of Fig. 1b represents the stress on a plane whose normal is oriented at an angle θ with the direction of the major principal stress. Thus, σ_θ, the normal stress on the plane is

$$\sigma_\theta = \sigma_1 \cos^2 \theta + \sigma_3 \sin^2 \theta$$

$$= \frac{\sigma_1 + \sigma_3}{2} + \frac{\sigma_1 - \sigma_3}{2} \cos 2\theta$$

The shear stress on the plane located by the angle θ is

$$\tau_\theta = (\sigma_1 - \sigma_3) \sin \theta \cos \theta$$

$$= \frac{(\sigma_1 - \sigma_3)}{2} \sin 2\theta$$

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

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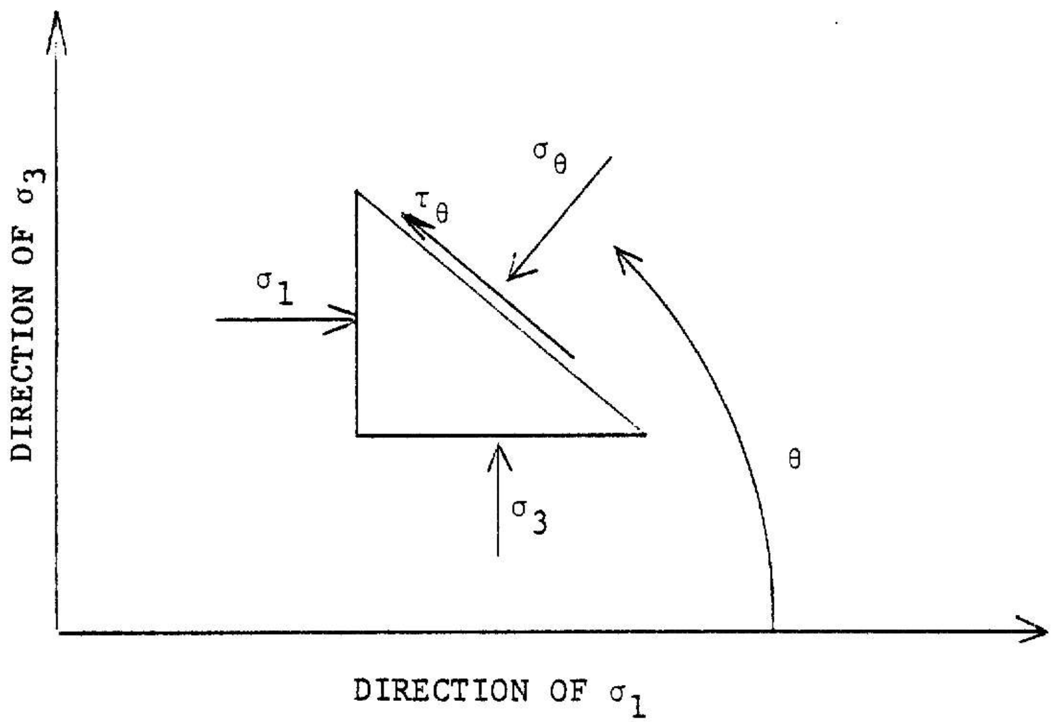
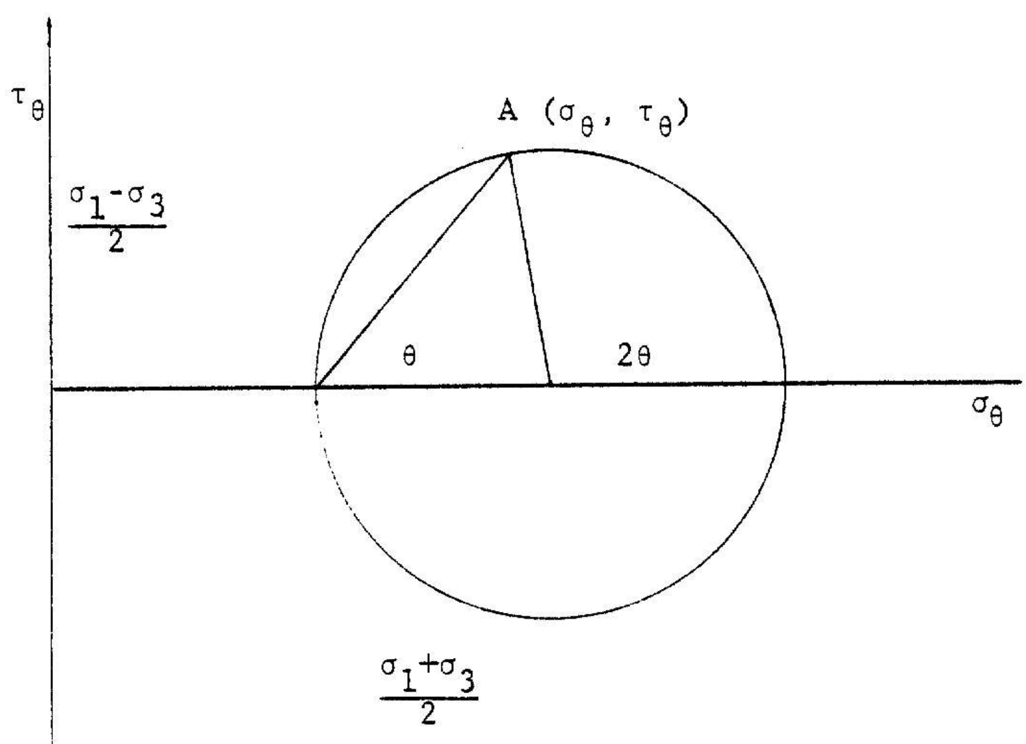


Fig. 1a



MOHR CIRCLE

Fig. 1b

In many problems it is desirable to represent many states of stress for a given specimen of soil on a single diagram. When many Mohr circles are plotted on a single diagram, it becomes confusing and difficult to follow the diagram. An alternative method for plotting the state of stress is to plot p and q (6). p is the stress represented by the distance to the center of the Mohr circle from the origin and q is the stress represented by the radius of the Mohr circle. Thus, p and q are computed as follows:

$$p = \frac{\sigma_1 + \sigma_3}{2}$$

$$q = \pm \frac{\sigma_1 - \sigma_3}{2}$$

q is positive if σ_1 is inclined at an angle equal to or less than ± 45° to the vertical. q is negative if σ_1 is inclined at an angle less than ± 45° to the horizontal.

For the stress point representation, the principal stresses act on vertical and horizontal planes. The above equations simplify to

$$p = \frac{\sigma_v + \sigma_h}{2} \qquad q = \frac{\sigma_v - \sigma_h}{2}$$

A series of values of p and q is plotted representing the successive states of stress that exist in a specimen as the specimen is loaded. Then a series of stress points are plotted. A line is drawn connecting these points using p and q (See Fig. 2). K_f line drawn on Fig. 2 is defined as σ_h/σ_v at failure and is called coefficient of lateral stress at failure.

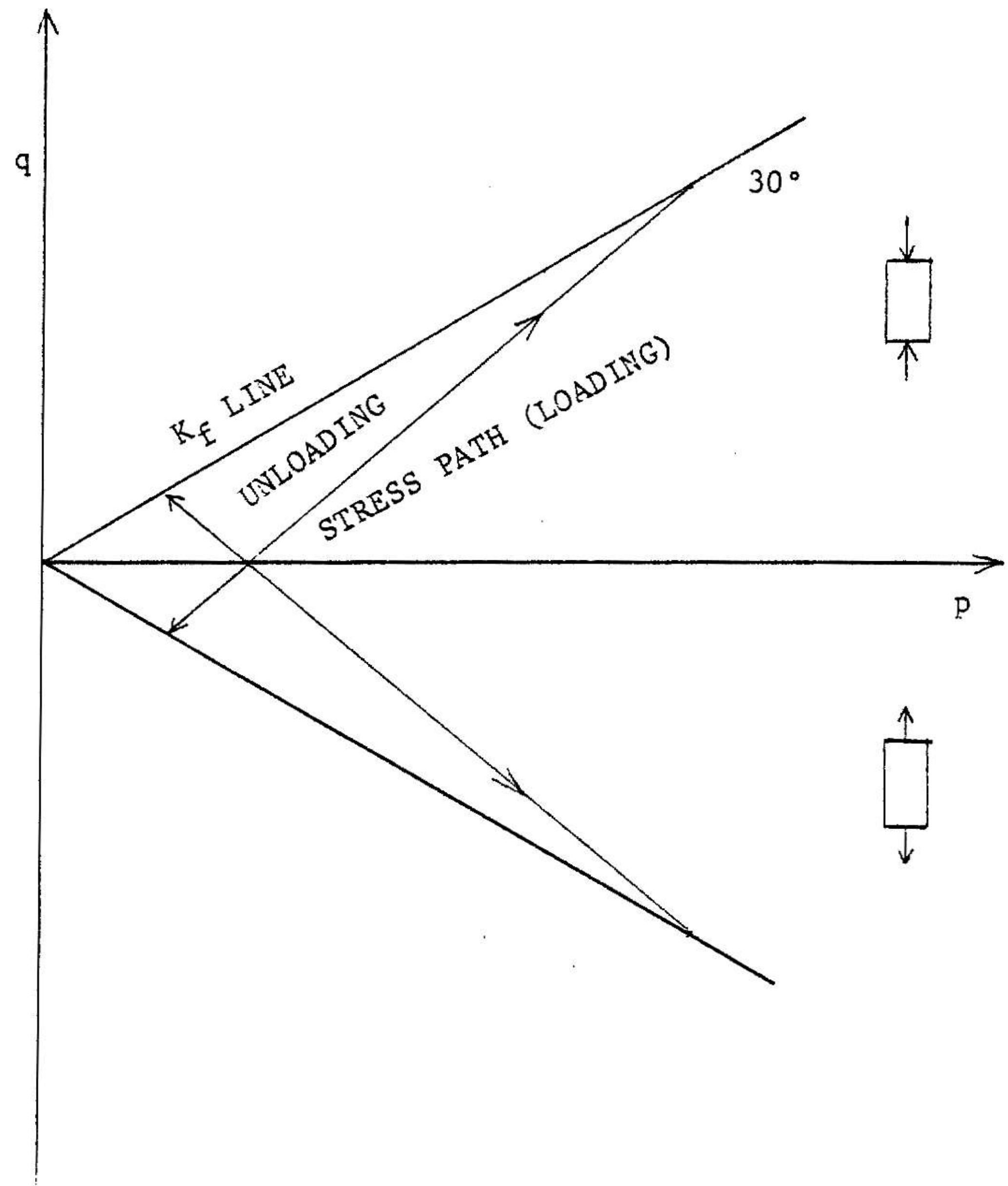


Fig. 2

Advantages and Limitations of Triaxial Testing

Soil samples were tested by the use of the direct shear machine before the triaxial compression machine came into use. The triaxial test and the direct shear test are compared for pointing out the advantages of each method (5). The triaxial test has a smaller progressive effect. During the triaxial test control of drainage is possible. The measurement of specimen volume changes are more accurate in the triaxial test. The complete state of stress is known at all stages during the triaxial test, and the pore water pressure can be measured. The direct shear machine is simpler and faster to operate. A thinner soil sample is used in the direct shear test. The direct shear test can only measure stresses at failure.

A discussion of the limitations of the triaxial test follows (2): One limitation is that the intermediate principle stress can not be varied. In the cylindrical compression test the intermediate principle stress σ_2 is equal to the minor principle stress σ_3. In many practical problems the value of σ_2 will be higher than σ_3. This will influence both the cohesion and the friction angle of the soil sample. Changes in the principle direction are limited as the principle plane is fixed in relation to the axis of the specimen during the test. This restriction is important in problems involving active or passive pressure in zones with a horizontal boundary. The friction between ends of the specimen and the rigid end caps which transmit the axial load restricts lateral deformation adjacent to these surfaces (8). This leads to a departure from the condition of uniform stress and strain. The strength characteristics are limited due to end restraints. When the stresses, σ_1 and σ_3 are increased simultaneously throughout a drained test so that no lateral yield occurs, then no shear is mobilized across the ends of the sample. The result is that axial strain and volume change are uniform throughout its length. However, in the standard test, the cell pressure is generally applied first. A decrease in diameter results from the applied cell pressure. The reduction in volume is resisted locally by end restraints (See Fig. 3a). As the deviator stress is applied, the diameter tends to increase. This again is opposed by end restraint (See Fig. 3b). Nonuniformity of volume change and axial strain becomes noticeable at large strains in loose sand.

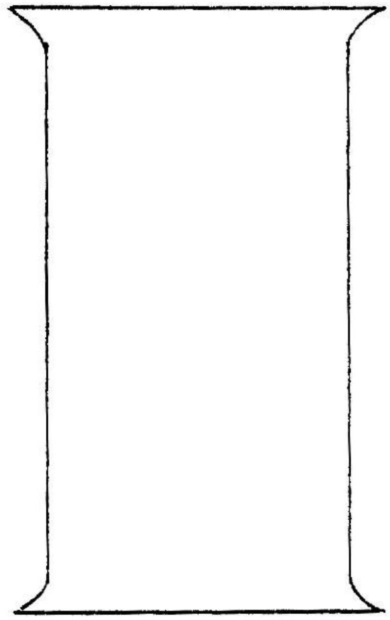


Fig. 3a

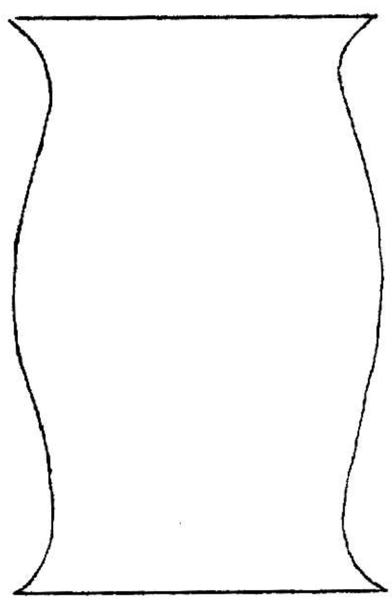


Fig. 3b

DESCRIPTION OF THE TRIAXIAL TESTING APPARATUS

The load was applied by the Wykeham Farrance strain-control machine to the sample within the triaxial pressure cell (See Figs. 4 & 5). The approximate dimensions of the Wykeham Farrance machine are as follows:

Overall height	51.18 in.
Overall width	20.47
Overall depth	16.93
Horizontal clearance between strain rods	12.20
Maximum vertical clearance	29.92
Platen travel	3.937
Net weight	250.8 lbs.

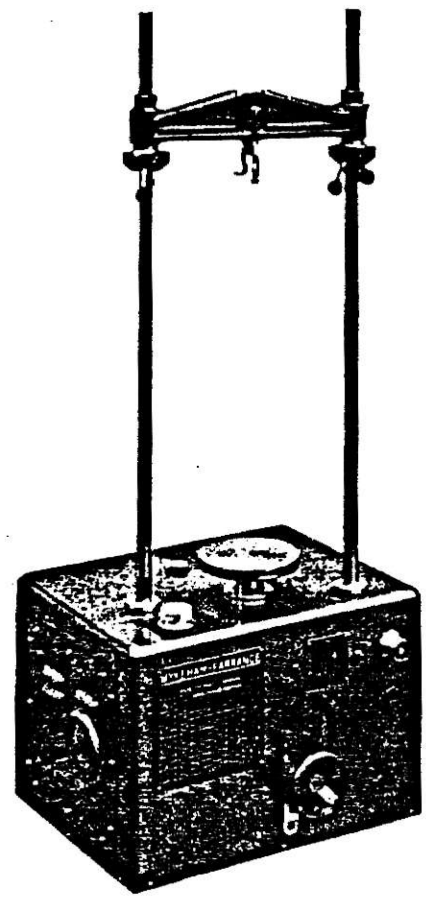


Fig. 4

The Wykeham Farrance strain control machine (4) utilizes a variable speed motor which is operated in conjunction with a sensitive controller. These drive a five speed gear box which is provided with a simple gear selector, operated through the hand knob on the control on the right hand side of the facia. Any required feed can be obtained. The indicator light positioned beside the on/off switch indicates the direction of platen travel.

Triaxial cells for samples up to 100 mm diameter can be accommodated.

The speed chart attached to the left hand front cover shows the rate of feed obtained with combinations of gear settings and motor percentage speeds.

To prevent accidental over-run of the platen travel, a visual indicator is fixed to the pedestal and micro-switches are located inside the machine to switch the machine off if the safe limit of travel is reached.

Coarse and fine feed hand wheels are provided for manual movement of the platen, selection of which is obtained using the lever on the front facia.

This machine is wired for 110/115 volt single phase 60 cycles.

The main features of the pressure cell (See Fig. 5) are the base, the removable cylinder and top cap, the loading ram, the loading cap, and a rubber membrane (3). The base contains three pressure connections. The chamber valve applys an all-round pressure to the sample. The saturation valve provides the water to the sample. The vacuum valve provides vacuum to the sample. The removable cylinder and top cap retains the pressure. The loading ram provides the load to the sample inside the cylinder. The loading cap distributes the point load from the loading ram to the sample. The rubber membrane stabilizes the sample and retains the moisture content of the sample.

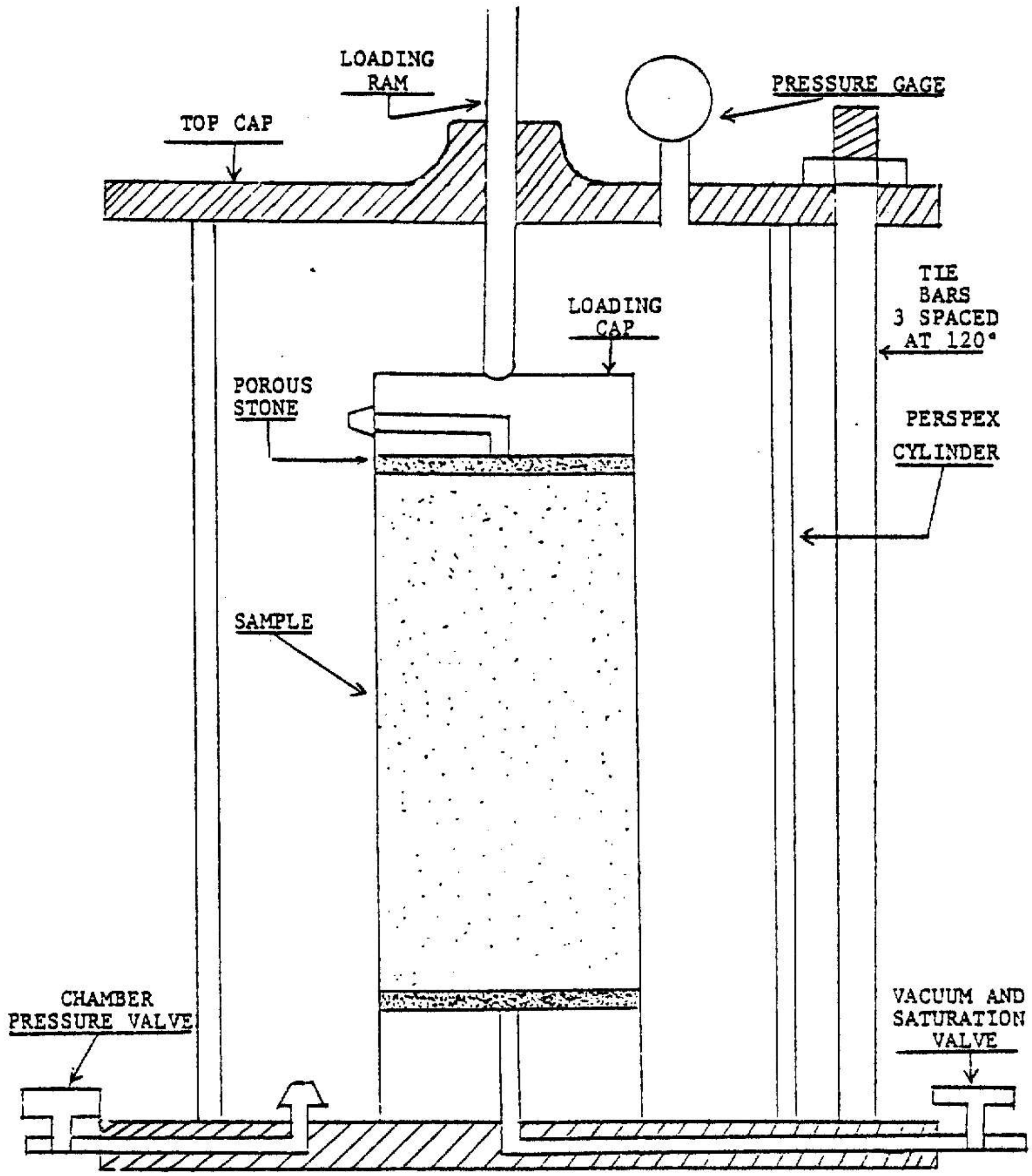

LOADING RAM
TOP CAP
PRESSURE GAGE
TIE BARS 3 SPACED AT 120°
LOADING CAP
POROUS STONE
PERSPEX CYLINDER
SAMPLE
CHAMBER PRESSURE VALVE
VACUUM AND SATURATION VALVE

Fig. 5

PROCEDURES FOR THE TRIAXIAL TESTING OF SOILS

The triaxial testing apparatus has two parts. The loading was done using the Wykeham Farrance strain controlled machine. The sample was tested within the pressure cell. The applied load was measured using a Schaevitz load cell which was connected to a strainsert load indicator. The load cell was calibrated in the structures laboratory. With the diagram relating the load vs. strain, the load applied on the sample was calculated. The procedure using this apparatus is outlined as follows:

1. Attach Schaevitz load cell to the top beam.

2. Connect wires 1, 3, 5 and 6 to a strainsert load indicator Model HW1-D.

3. Set the strainsert gage to a full bridge (+) circuit.

4. Balance the bridge to zero.

Procedure Used for Blow Sand (5)

1. Obtain the thickness of the membrane. This thickness is best obtained by measuring the membrane doubled and then halving the measurement.

2. Roll up the membrane and slide it on the dowel with about 1/2 inch of it projecting from one end of the dowel.

3. Moisten this projecting end and place it over the base of the apparatus which contains the lower porous stone.

4. Bind the membrane to the base with a rubber strip and remove the dowel.

5. Clamp the mold around the membrane and turn the top end of the membrane over the top of the mold.

6. Weigh to 0.1 g a dish with the dry soil which is to be tested. Place the sand within the membrane by tamping each spoonful of soil, taking care not to pinch the membrane with the tamper. Scarify the top of each layer before placing the next one, to reduce stratification. The amount of tamping depends on the denseness of soil desired.

7. Again weigh the dish of soil. The difference in weight is the weight of soil used.

8. Put the upper porous stone and cap on top of the specimen and level by means of the level bubble.

9. Moisten the upper end of the membrane, roll up over the sides of the cap, screw in one vertical rod, attach a clamp from the cap to the rod, thus lining up and supporting the cap, and carefully bind the membrane to the cap with a rubber strip.

10. Close all valves.

11. Vacuum of 5 psi is applied to the specimen.

12. With the specimen under this 5 psi of vacuum, remove the cap clamp, and remove the sample mold.

13. After the mold is removed, increase the vacuum to 10 psi by opening vacuum valve.

14. Measure the length of the specimen to 0.1 mm and measure the circumference of the specimen at the top, midpoint, and bottom to 0.1 mm by means of a tape.

15. Remove the level and clamp, and then screw the remaining vertical rods in the base.

16. Next, grease the bottom rubber gasket, center the lucite cylinder on this gasket, grease the upper rubber

gasket, and place it on top of the lucite cylinder.

17. Carefully put the upper assembly of the machine in place, then check to see that the plunger contacts the sample cap at its center.

18. Tighten all the top nuts on the vertical rods until they just begin to bind, and then give each one-fourth of a revolution turn. Keep giving each nut one-fourth turn until two complete turns have been given.

19. Admit air or pressure source to the chamber by opening chamber valve.

20. Apply the pressure to desired level.

21. Record initial readings of Strainsert, rate of speed of strain, and then start loading.

22. Time needs to be recorded along with the Strainsert readings.

23. Remove the axial force and check for membrane damage.

24. Release the vacuum and remove the specimen.

<u>Procedure Used for Silty Clay</u> (5)

1. Prepare a sample with Proctor Density.

2. Use miter box and wire saw to trim enough clay to make the ends parallel to each other.

3. Place the sample in the lathe or trimmer and trim it to a circular cross section.

4. Measure the length and circumference.

5. Weigh the membrane-enclosed specimen to 0.1 g.

6. Moisten the upper end of the membrane, and roll it over the sides of the cap.

7. Screw in one vertical rod, attach a clamp from the cap to the rod, thus lining up and supporting the cap, and carefully bind the membrane to the cap with a rubber strip.

8. Remove the clamp, then screw the remaining vertical rods in the base.

9. Next, grease the bottom rubber gasket, center the lucit chamber on this gasket, grease the upper rubber gasket, and place it on top of the lucite cylinder.

10. Put the upper assembly of the machine in place, then check to see that the tip of the plunger contacts the center of the cap.

11. Tighten all the top nuts of the vertical rods until they just begin to bind, and then give each one-fourth revolution turn. Keep giving each nut one-fourth turn until two complete turns have been given.

12. By means of a length gage as a check, further tighten any nuts as far as necessary to make the upper plate parallel to the base.

13. Close all valves.

14. Admit air to the chamber by opening chamber valve.

15. Set the desired chamber pressure.

16. Record the initial Strainsert reading, the rate of strain, and start loading.

17. Stop the compression and release the axial load.

18. Release the chamber pressure.

PRESENTATION OF DATA

TRIAXIAL COMPRESSION TEST FOR BLOW SAND

Rate of Strain: 0.06 in/min.

Length of Sample: 5.91 in.

Circumference at Start — top: 9.06 in.; middle: 9.33 in.; bottom: 8.66 in.

Circumference at End — top:; middle:; bottom:

σ_3: 15 psi

Average Area: 6.47 in^2

Elapsed time (sec)	Corrected area (in^2)	Strainsert gage ($\mu\varepsilon$)	Load (lbs/in^2)
0	6.47	0	
15	"	0	
30	"	0	
45	"	0	
60	6.481	1450	35.20
75	"	1660	40.29
90	"	1805	43.80
105	"	1885	45.74
120	6.48	1945	47.20
135	"	1990	48.29
150	"	2000	48.53
165	"	2000 *	48.53
180	"	1988	48.24
195	"	1980	48.04
210	"	1950	47.32
225	"	1920	46.59
240	"	1890	45.86
255	"	1830	44.41
270	"	1800	43.68
285	"	1770	42.96

*Point at which failure of sample occurred.

TRIAXIAL COMPRESSION TEST FOR BLOW SAND

Rate of Strain: 0.060 in/min.

Length of Sample: 14.8 cm

Circumference at Start	top:	9.02 in.
	middle:	9.06 in.
	bottom:	9.25 in.
Circumference at End	top:	10.33 in.
	middle:	10.82 in.
	bottom:	9.45 in.

σ_3: 30 psi

Average Area: 6.60 in^2

Elapsed time (sec)	Corrected area (in^2)	Strainsert gage ($\mu\varepsilon$)	Load (lbs/in^2)
0	6.60	60	1.43
15	6.60	70	1.67
30	6.61	1760	41.87
45	6.62	2610	62.04
60	"	3060	72.71
75	"	3390	80.52
90	"	3570	84.78
105	6.63	3740	88.80
120	"	3850	91.41
135	"	3920	93.06
150	"	3960	94.01
165	"	3980	94.48
180	"	3985 *	94.60
195	"	3968	94.20
210	"	3915	92.94
225	"	3830	90.93
240	"	3700	87.86
255	6.62	3600	85.49
270	"	3390	80.52
285	"	3270	77.68
300	"	3200	76.03

*Point at which failure of sample occurred.

TRIAXIAL COMPRESSION TEST FOR BLOW SAND

Rate of Strain: 0.060 in/min.

Length of Sample: 15 cm

Circumference at Start	top:	9.02 in.
	middle:	9.06 in.
	bottom:	9.25 in.
Circumference at End	top	9.65 in.
	middle	10.24 in.
	bottom	9.25 in.

σ_3: 45 psi

Average Area: 6.60 in^2

Elapsed time (sec)	Corrected area (in^2)	Strainsert gage ($\mu\varepsilon$)	Load (lbs/in^2)
0	6.60	50	1.192
15	6.61	2060	49.00
30	6.62	3136	74.51
45	6.63	3776	89.65
60	"	4320	102.52
75	"	4600	109.13
90	"	5020	117.04
105	6.64	5266	124.85
120	"	5482	129.94
135	"	5640	133.66
150	"	5755	136.37
165	"	5840	138.34
180	"	5860	138.84
195	"	5890 *	139.55
210	"	5774	136.81
225	"	5468	129.56
240	"	5052	119.70
255	"	4792	113.53
270	"	4694	111.22

*Point at which failure of sample occurred.

TRIAXIAL COMPRESSION TEST FOR BLOW SAND

Rate of Strain: 0.036 in/min.

Length of Sample: 15 cm

Circumference at Start — top: 8.66 in.; middle: 9.06 in.; bottom: 9.25 in.

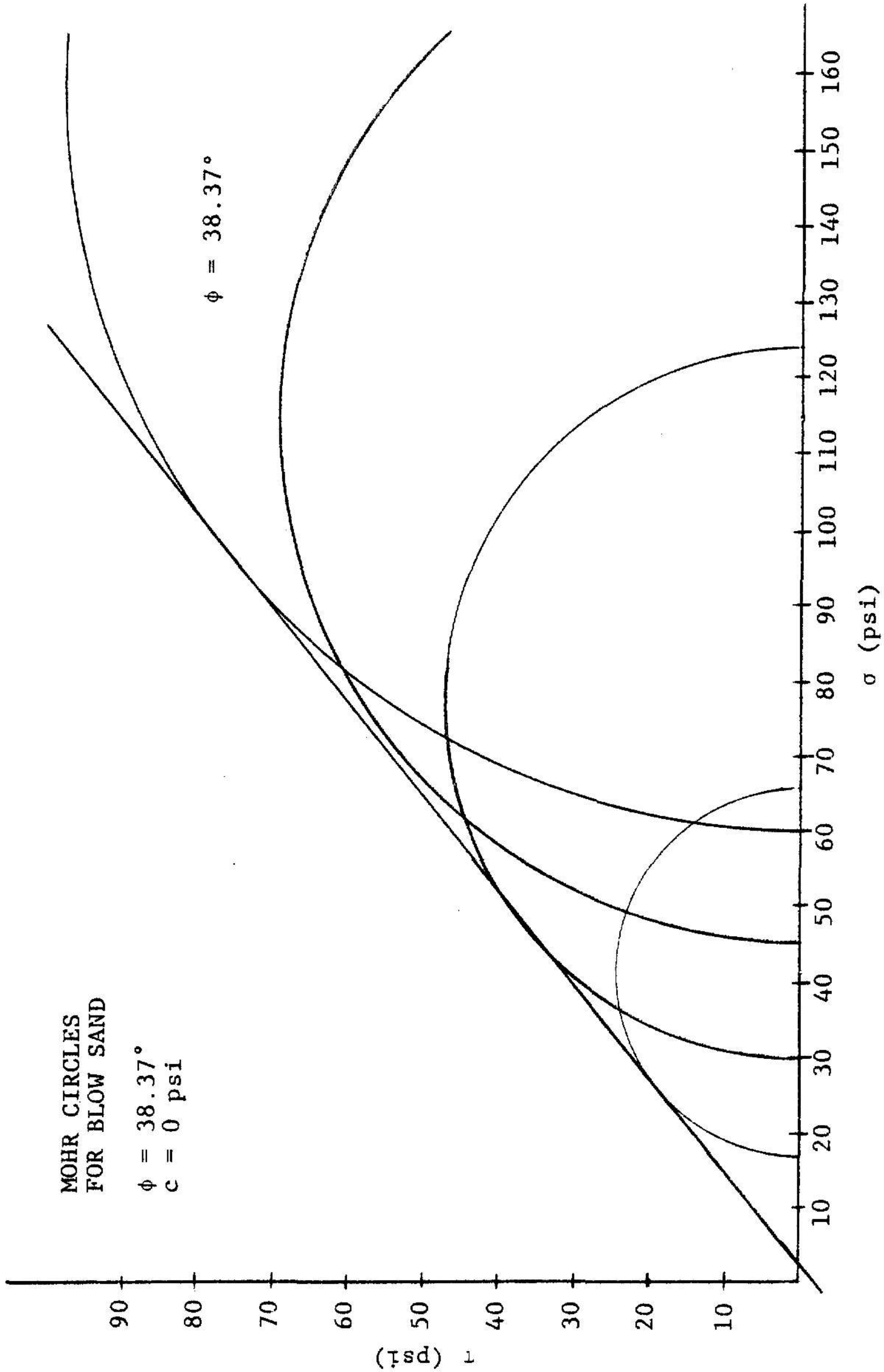
Circumference at End — top: 10.08 in.; middle: 10.63 in.; bottom: 10.04 in.

σ_3: 60 psi

Average Area: 6.43 in^2

Elapsed time (sec)	Corrected area (in^2)	Strainsert gage ($\mu\varepsilon$)	Load (lbs/in^2)
0	6.43	67	1.64
15	6.44	870	21.26
30	6.45	3350	81.68
45	6.46	5090	123.89
60	6.47	6040	146.87
75	6.47	6760	164.26
90	6.48	7312	177.57
105	"	7654	185.81
120	"	7890	191.49
135	"	8045	195.23
150	"	8115	196.91
165	"	8130 *	197.27
180	"	8114	196.87
195	"	8085	196.17
210	"	8055	195.44
225	"	7986	193.77

*Point at which failure of sample occurred.


MOHR CIRCLES
FOR BLOW SAND
ϕ = 38.37°
c = 0 psi
ϕ = 38.37°
τ (psi)
σ (psi)
10 20 30 40 50 60 70 80 90
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160

TRIAXIAL COMPRESSION TEST FOR SILTY CLAY

Rate of Strain: 0.060 in/min.

Length of Sample: 18 cm

Average Circumference: 9.17 in.

σ_3: 15 psi

Average Area: 6.70 in^2

Elapsed time (sec)	Corrected area (in^2)	Strainsert gage ($\mu\varepsilon$)	Load (lbs/in^2)
0	6.70	0	0
15	"	32	0.7513
30	"	238	5.59
45	"	384	9.02
60	"	514	12.07
75	"	675	15.85
90	"	754	17.70
105	"	865	20.31
120	"	975	22.89
135	"	1098	25.78
150	"	1186	27.84
165	"	1280	30.05
180	"	1366	32.07
195	"	1432	33.62
210	"	1506	35.36
225	"	1546	36.30
240	"	1552 *	36.44 *
255	"	1506	35.36
270	"	1466	34.42

*Point at which failure of sample occurred.

TRIAXIAL COMPRESSION TEST FOR SILTY CLAY

Rate of Strain: 0.060 in/min.

Length of Sample: 18 cm

Average Circumference: 9.45 in.

σ_3: 30 psi

Average Area: 7.11 in^2

Elapsed time (sec)	Corrected area (in^2)	Strainsert gage ($\mu\varepsilon$)	Load (lbs/in^2)
0	7.11	128	2.83
15	"	330	7.30
30	"	580	12.83
45	"	800	17.70
60	"	1014	22.43
75	"	1230	27.21
90	"	1455	32.19
105	"	1656	36.64
120	"	1855	41.04
135	"	2005	44.36
150	"	2110	46.68
165	"	2192	48.50
180	"	2220	49.11
195	"	2246	49.69
210	"	2268	50.18
225	"	2282	50.49
240	"	2305	51.00
255	"	2324	51.42
270	"	2350	52.00
285	"	2375	52.54
300	"	2405	53.21
315	"	2426	53.67
330	"	2433	53.83
345	"	2450	54.20
360	"	2457	54.36
375	"	2550 *	55.53

*Point at which failure of sample occurred.

TRIAXIAL COMPRESSION TEST FOR SILTY CLAY

Rate of Strain: 0.060 in/min.

Length of Sample: 12.5 cm

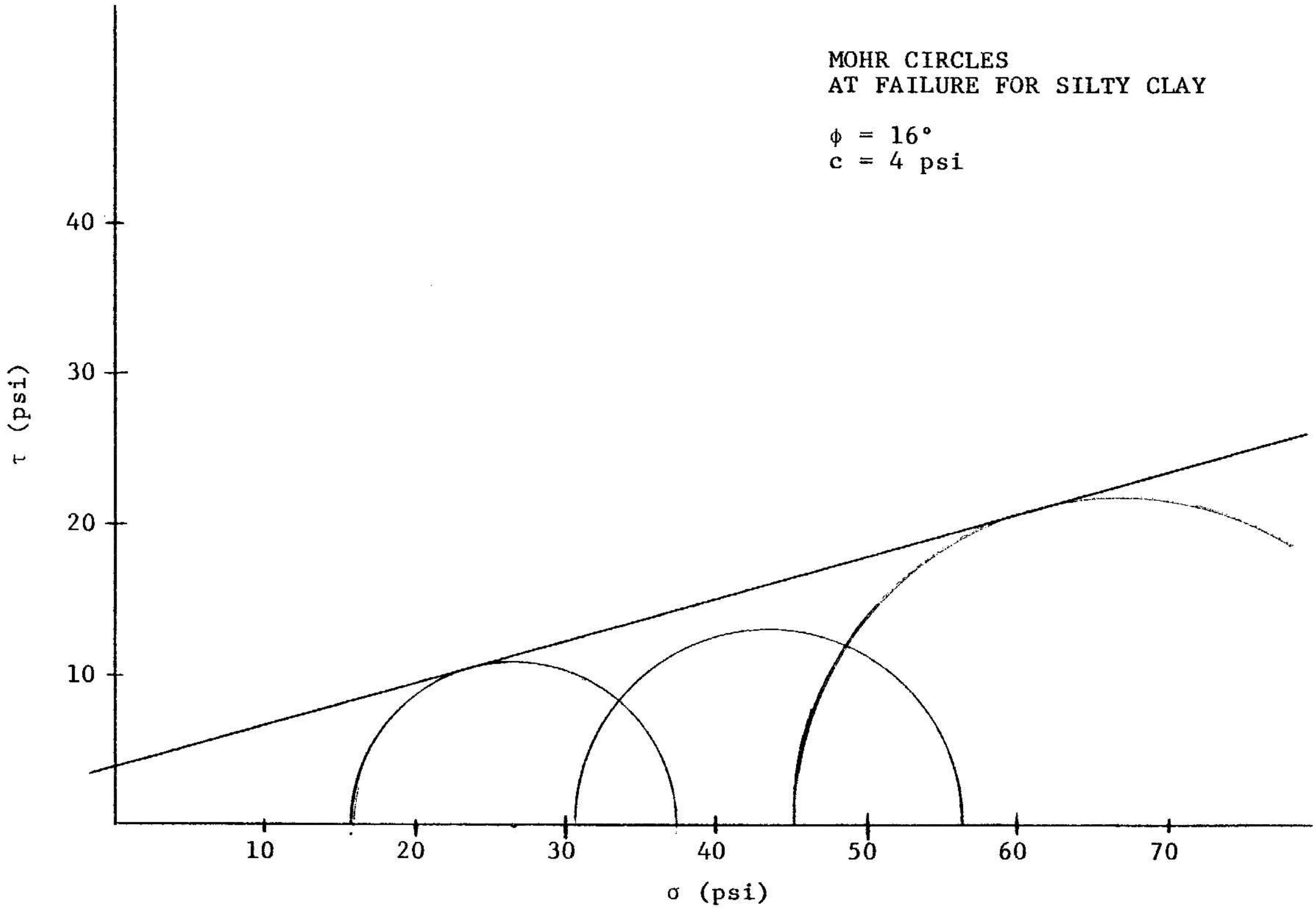
Average Circumference: 9.06 in.

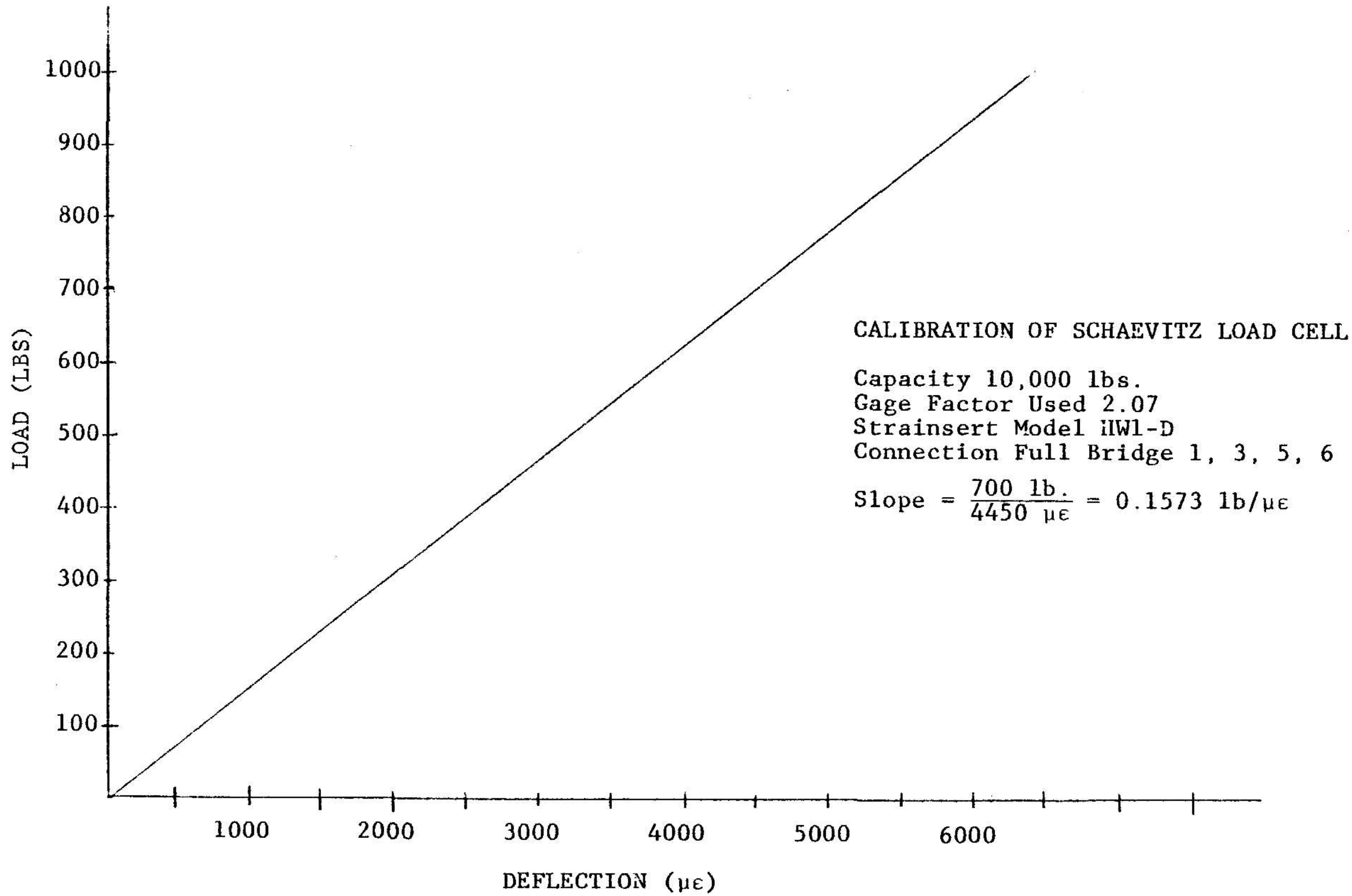
σ_3: 45 psi

Average Area: 6.52 in^2

Elapsed time (sec)	Corrected area (in^2)	Strainsert gage ($\mu\varepsilon$)	Load (lbs/in^2)
0	6.52	90	2.17
15	"	235	5.67
30	"	602	14.52
45	"	1155	27.87
60	"	1654	39.90
75	"	2022	48.78
90	"	2328	58.16
105	"	2562	61.81
120	"	2776	66.97
135	"	2954	71.27
150	"	3115	75.15
165	"	3268	78.84
180	"	3402	82.08
195	"	3530	85.16
210	"	3614	87.19
225	"	3660 *	88.30
240	"	3560	85.89
255	"	3504	84.54
270	"	3474	83.81

*Point at which failure of sample occurred.


MOHR CIRCLES
AT FAILURE FOR SILTY CLAY
φ = 16°
c = 4 psi
τ (psi)
10
20
30
40
σ (psi)
10
20
30
40
50
60
70


CALIBRATION OF SCHAEVITZ LOAD CELL
Capacity 10,000 lbs.
Gage Factor Used 2.07
Strainsert Model HW1-D
Connection Full Bridge 1, 3, 5, 6
Slope = $\frac{700 \text{ lb.}}{4450\ \mu\varepsilon}$ = 0.1573 lb/$\mu\varepsilon$
LOAD (LBS)
1000
900
800
700
600
500
400
300
200
100
1000
2000
3000
4000
5000
6000
DEFLECTION ($\mu\varepsilon$)

CONCLUSIONS

Results obtained from the triaxial testing of both the silty clay and the blow sand were good. The unit cohesion and the friction angle obtained for the silty clay were 4 psi and 16°, respectively. The friction angle for the blow sand was found to be 38°, and it was found to be cohesionless (unit cohesion was equal to zero). These values are in agreement with typical values found in Table 11.3 of Lamb and Whitman (6). Because of these satisfactory results of testing, it is concluded that the triaxial machine is operable and ready for class use and future experiments.

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TRIAXIAL TESTING OF SOILS

by

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AN ABSTRACT OF A MASTER'S REPORT

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ABSTRACT

The friction angle and the unit cohesion of a soil are fundamental in the analysis and design of soil-based structures. The triaxial compression machine can simulate the conditions imposed on a soil mass in its natural environment. Thus, the friction angle and the unit cohesion obtained by the use of this machine approximate the true values of these properties. It can be argued that these results are better than those obtained by the use of the direct shear machine.

The new triaxial machine bought by Kansas State University was assembled, and triaxial tests on two soils were performed. The results compared favorably to the expected values. It is concluded that the machine is now operable and ready for classroom instruction.