AN INVESTIGATION ON THE SHEAR STRENGTH CHARACTERISTICS OF PEAT

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By

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SCOPE AND CONTENTS: Shear strength characteristics of peat were investigated by a series of consolidated undrained tests with pore pressure measurements. Cubes from the peat samples used for triaxial testing were infiltrated by paraffin and thin sections obtained; these were examined microscopically. A correlation of macroscopic and microscopic investigations was attempted.

ACKNOWLEDGEMENTS

I would like to express my gratitude to Professor N. E. Wilson for his help and encouragement during the course of this work.

I am also indebted to McMaster University for awarding me a research scholarship in the Department of Civil Engineering.

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INTRODUCTION

In an age when overpopulation is predicted to become a serious problem, certain areas on earth can not be indefinitely bypassed by engineering structures because of their economical non-feasibility. Neither can an expanding Canada afford a negligence with her vast lands covered with muskeg. Access and the utilization of organic terrain, which must precede as well as accompany its development, are mainly hindered by the inability of soft organic soils to carry engineering structures and vehicles.

A scientific and rational treatment of organic soils within the domain of present day knowledge of Soil Mechanics is not possible; therefore, only an uneconomical exploitation of the organic terrain is being maintained.

An understanding of the behaviour of the structure of peat under stresses can direct the application of Soil Mechanics principles to peat to a more rational way. The structural similarities of peat to mineral soils, as well as their differences, have been appreciated; though more complex like other soil kinds peat possesses a structure, with particle sizes ranging from colloidal sizes to tree trunks at various degrees of decomposition, all of various but organic origin. Under an apparent cosmos lies organization and perhaps some discipline as implemented by Radforth classifications (Radforth, 1952). Certain

synthesis of information may be necessary before these are revealed.

On a general scale, an understanding of peat requires a knowledge on several related sciences. An application from these related areas to engineering requires an appreciation of some of these principles. On the specific topic of shear strength of peat, although there is an acute shortage of information, any one investigation is limited to the kind of peat that is tested; that is, unless attention is concentrated on some elements common to most kinds of peat. For example, as peat is of organic origin, it is logical to think in terms of cell structure as a common denominator to work on whenever possible. Importance of its water content, fibrous behaviour, tensile strength of its fibres and several different kinds of water held within peat, in relation to its shear strength as well as structural deformations that peat undergoes under stresses have in most cases only been hypothesized. Therefore, this investigation on the shear strength of peat, using conventional tools of Soil Mechanics such as triaxial testing, supplemented by an investigation on the microscopic scale to focus attention on the less apparent but intrinsic structural features of peat, was undertaken. This is one of the series of research projects being conducted at McMaster University on organic terrain, with the cooperation of several departments.

CHAPTER I

LITERATURE SURVEY

Shear Strength Properties of Soils:

Coulomb's equation, introduced in 1776, has been used in determining the shear strength of soils (Coulomb, 1776). The equation:

$$S = c + \sigma \tan \phi$$

states that the shear resistance of a soil is the sum of two components (i) Cohesion, c; and (ii) frictional component which is dependent on the normal pressure acting on the plane under consideration. Hvorslev suggested cohesion as a function of water content while confirming Coulomb's equation (Hvorslev, 1938 and 1960). Both Terzaghi and Hvorslev suggested frictional component to be a function of effective stress whereby the original Coulomb equation could be redefined as:

$$S = \bar{c} + \bar{\sigma} \tan \bar{\phi}$$

where $\bar{c}$ is the true cohesion which is dependent on water content, $\bar{\sigma}$ is the effective normal stress on the plane of failure and $\bar{\phi}$ is the true angle of internal friction.

With the introduction of the triaxial testing equipment where the measurements of pore water pressure were possible, stresses experienced by a sample could be analyzed and varied. The history of stress as experienced by a particular sample is called a stress path when plotted on a stress diagram. While attention was called to the importance of

stress paths by Rendulic especially related with water content, Taylor pointed out the importance of investigation of the stress history on the failure plane (Taylor, 1948). While Hvorslev's contention of shear strength parameters was complicated to apply to the investigation of natural soil samples, the examination of the stress history on the assumed failure plane was shown to be a useful and practical approach by Casagrande (Casagrande and Hirschfield, 1960). This concept, called vector curves, was useful in the understanding of the less permeable soils.

Investigation of volume changes during shearing (Bjerrum, 1954) and introduction of pore pressure parameters (Skempton, 1954) and their applicability to natural soils and practical problems (Bishop, 1954) have also proven to be a useful tool. As the ultimate aim in research is the application of findings to practice, it was necessary to corrolate the behaviour of a soil sample to the behaviour of the same soil under gross field conditions.

The triaxial testing apparatus proved to be useful in examining the behaviour of soil samples, but its limitations are known (Bishop and Henkel, 1957).

Organic Soils:

The engineering characteristics of peat were investigated by Radforth who was able to generalize the surface vegetation of muskeg and devise a system useful in interpreting the strength of peat

qualitatively, especially for highway access through muskeg (Radforth, 1952). Again Radforth classified peat into sixteen categories in relation to its structure.

In running laboratory tests, remoulded samples are desirable for the duplicability of test results in thorough investigations of shear strength. Because remoulding destroys the structure, especially in relation to fibre strength and water holding capacity, generally remoulding of peat has not been attempted in laboratory triaxial testing.

Hanrahan conducted laboratory triaxial testing of peat (Hanrahan, 1954); he came to the conclusion that the shear strength of peat was mainly due to cohesion. However, there were others who seemed to entertain the idea that its strength was mainly due to the frictional component. MacFarlane pointed out this controversy (MacFarlane, 1959). Pioneering work in Canada (Adams, 1961) supports this latter point of view. This, perhaps, has led Wilson and his associates to doubt the applicability of strength theories that have been successful in determining the shear strength of mineral soils to peat; thus they chose to investigate the strength of peat from a rheological point of view (Schroeder and Wilson, 1962; Krzywicki and Wilson, 1964).

Yet as repeatedly pointed out, each investigator was dealing with one kind of peat with a unique structure. Not only should peat be treated as a unique material but also each kind of peat should be

treated the same. While each investigation was useful for the accumulation of information, it was necessary to accept the results cautiously due to the complex biological origin of peat. This was the reason for controversial laboratory test results.

It is logical that, in order to be able to generalize, it is necessary to find out some common structural elements and concentrate the attention on these. In other words, it is necessary to supplement any investigation in shear strength with an investigation on a microscopic scale as the constituents of peat range down to colloidal particles. MacFarlane and Radforth report research where the effect of stressing on peat structure during consolidation is to be examined microscopically although no published results are given (MacFarlane and Radforth, 1964).

Microscopic examination and analysis of peat for purposes other than engineering have been utilized. In almost all cases thin sections of peat were examined. One of the more significant was the work of Eydt (Eydt, 1956 and 1962) where a method was developed for examining in situ arrangement of peat by paraffin infiltration (Radforth and Eydt, 1958). Thaler devised a similar method for peat with considerable mineral content (Thaler, 1964). Stewart made indirect use of cuticles in examination of peat (Stewart, 1960).

Because an understanding of the structure of peat requires a diversified investigation, it is necessary to resort to publications in various other fields related to organic soils. In agriculture,

researchers who dealt with peat mainly from a biochemical point of view are unable to reveal the complex nature of humic acid which is an end product in the humification of peat (Kononova, 1960). This necessity of having to obtain pertinent information from other fields like microbiology (Alexander, 1961) and others (Bear, 1955; Bailey, 1947; Miller and Turk, 1943; Black, 1957; Francis, 1954) strongly suggests the necessity of a synthesis of information pertinent to engineering purposes.

CHAPTER II

MATERIAL AND INVESTIGATION TECHNIQUES

Site Selection:

Peat samples were taken from Copetown Bog which lies about 1/2 mile south of Copetown Village in Wentworth County, Ontario. The organic terrain, confined to an area of about 28 acres, is located at a depression formed during the last glaciation, possibly being the largest of the kettles of a knob and kettle topography. Mineral sublayer is composed of fine sand, silt and clay. The deepest part of organic soil is 7.5 meters near the centre of the bog. In September the water table was about eight inches below the ground level. Its high water table is believed to be due to the adjacent high water table rather than continuous streams being emptied into the depression as no such are visible (for more information see Stewart, 1960).

The surface vegetation is IEF - EIF and BEI according to the Radforth classification. The bog has been bypassed by engineering structures and left undisturbed from human activity.

The site chosen for sampling within the bog was an area where the tree density was less as it was undesirable to have large roots in the samples. The immediate area was covered with mosses, some sedge grasses and low shrubs (Figs. #1 and #2).

Fig. 1 - General View of the Sampling Area

Fig. 2 - Closer View of the Sampling Area

It was desirable to obtain relatively young peat as it is likely that the cell structure is not prominent in humified peat. Therefore, samples were taken from 2 to 3 feet depths. To ensure some uniformity among the samples, all the samples were taken from the same depth and close to each other.

Fig. 3 - A Sampling Hole and Experimental Sampling Pipes.

Holes about 3' X 2' X 2' were dug with spades and were cleared of debris by hand. As an experiment, pipes, of different lengths with diameters ranging from 1.5 to 6 inches, sharpened at one end, were used as samplers (Fig. #3). It was found that the larger diameter pipes not only reduced the friction between the sample and the sampler, but also utilized more cutting action. The degree of disturbance of

the samples was examined in the laboratory by freezing and cutting them into two along their length; the disturbance due to sampling was found to be negligible. Finally, thin-walled pipes like stove-pipes, four inches in diameter, cut to about one foot in length, and sharpened at one end, were used for sampling. The sharpened end was pushed into the peat with very slight turning action utilizing the cutting ability. In most cases, the thin-walled pipes penetrated into the soft peat without necessitating any turning action; this was desirable to avoid pulling and breaking the fibres. Having pushed several pipes into one hole in this manner, they were retrieved with as little water loss as possible. They were then sealed at the ends by quick foam forming chemicals in situ and brought under water to the laboratory where they were resealed by waxing and stored immersed under water in the humid room.

Triaxial Sample Preparation:

For macroscopic analysis, the samples were obtained from the thin-walled pipes by the use of 1.5 inch diameter stainless-steel samplers sharpened to razor edge thickness at one end; the samplers were pushed into the pipes with minimum turning action. The samples were consolidated in these samplers before they were extruded for triaxial testing. The stress used for consolidation was equal to the proposed cell pressure for that sample; this ensured that the samples were not over-consolidated. Using this technique, the consolidation pressure was less than the cell pressure because the sample experienced less stress due to friction between the sample and the sampler; also

the horizontal stress was less than the vertical stress by the ratio of earth pressure at rest.

These consolidated samples were assembled under water so as to minimize the amount of air entrapped between the rubber membrane and the sample. They were consolidated under a predetermined cell pressure.

As the permeability of peat varies considerably with the consolidation pressure, the possibility of consolidating all the samples for the same length of time was discarded because it was necessary to ensure uniformity of samples. At the time a sample consolidating under a high cell pressure is still in the primary consolidation stage, another sample consolidating under a lower cell pressure is way in the secondary consolidation stage; it is known that secondary consolidation effects can not be neglected in organic soils (Wilson, 1963).

The criterion for deciding the end of consolidation was chosen to be the end of primary consolidation. A plot of expelled water versus logarithm of elapsed time was made as the consolidation progressed. It was found that, in many cases, this criterion for the end of primary consolidation was rather arbitrary; and therefore, pore pressures were recorded. When the pore pressures within the sample fell below a certain percentage of the cell pressure, shear testing was started.

A further difficulty was encountered at the consolidation stage; it was found that, because drainage was only from the bottom of the sample, by the time pore pressures fell close to zero within the sample, the bottom of the sample was stronger than the top due to its lower water content; because of the length of drainage path, the bottom of the sample experienced more secondary consolidation than the top. This gave rise to a non-homogeneous sample which promoted failure at the top half of the sample during shearing. To overcome this effect, drainage from the top as well as from the bottom was tried. This procedure was discontinued because the pull by the plastic tubing used to drain the sample from the top gave rise to some eccentricity along the length of the sample before shearing started. The non-homogeneity of this peat was such that eccentricity of the samples was common; during shearing, that same eccentricity grew larger and the sample failed by buckling. This is significant in that it gives a false value of the stress that the sample can carry in the field. Finally, side drains cut from filter paper were used to obtain a relatively uniform sample with regards to its water content after consolidation.

Fig. 4 - Typical Eccentric Sample Before and After Shearing Stage.

Shear testing was performed by a strain controlled type Wykeham Farrance Eng. Ltd. triaxial apparatus.

During all tests, it was intended to use 1.4 X 2.8 inch samples. However, because the dimensions of the samples changed drastically during consolidation, not all samples had these exact dimensions before the start of the shearing stage.

A constant displacement rate of 0.009 in/min. (or about 0.32 %/min.) was used during all tests.

Material description:

The peat used was non-woody, fine fibrous, containing a mound of coarse fibres (Category No. 8 of Radforth Classification). Its colour changed from reddish brown to black upon exposure to atmosphere. The peat samples had a natural water content of about 800%, a specific gravity of 1.57, 96% organics and a pH value of 4.5 determined using water obtained by squeezing out the samples; the loosely held water of the peat gave a pH value of 4.9.

Microscopic Analysis:

To examine the effect of shearing on the structure of peat, first a direct approach was taken. The sheared triaxial samples were cut along desired planes and examined under a microscope capable of utilizing reflected light. However, this approach was discarded because of technical difficulties. Of the available

microscopes, a metallurgical microscope requires a preparation of the sample so that it reflects the light. The surface of peat, being irregular and dark coloured, absorbed the light. An electron microscope has too great a magnification for this purpose and only shows the topography. Therefore, it was decided to conduct examinations using thin sections and transmitted light.

First a freezing technique was tried. The sample was frozen and thin sections were cut using a microtome. The sections crumbled and did not retain their original arrangement. Gelatin embedding, accompanied by quick freezing, was also discarded for similar reasons. In this method, a 1/2" cubic sample was subjected to two changes of 20% gelatin each for 12 hours in an oven at 37°C. It was then embedded in 20% gelatin and was allowed to set at 5°C. The block was trimmed and immersed in 10% formalin solution for 24 hours to harden. It was then quickly frozen and sections were cut by a microtome.

Eydt found that for thin section examination of peat, paraffin infiltration gave satisfactory results (Eydt, 1956 and 1962). 3/4" cubic samples cut from the larger triaxial samples were subjected to changes of 10%-30%-50%-70%-85%-95% and 100% alcohol solutions (see the Appendix). Samples were placed in each solution for four hours except for 10% alcohol solutions in which the samples were kept for two hours. They were then placed in pure tertiary butanol. Three changes of pure tertiary butanol were made, 24 hours each. Then the

samples were placed for one hour in beakers containing equal mixtures of tertiary butanol and paraffin oil. The samples, then, were ready for paraffin infiltration. They were transferred into aluminum cans (the kind used for water content determination) containing melted but slightly cooled paraffin wax. They were just covered by a mixture of tertiary butyl alcohol and paraffin oil and then placed in a ventilated oven at 60°C. After 12 hours they were subjected to two changes of pure paraffin for 24 hours each, after which time the distinctive smell of tertiary butyl alcohol was absent which meant that the alcohol was replaced by paraffin. They were immediately placed in deep freeze for quick cooling. The frozen paraffin containing the peat samples were slightly melted along the walls of the cans and dumped out. The samples were trimmed off the excess paraffin. The paraffin infiltrated samples were sliced by a sliding table microtome. The slices were transferred on the glass slides covered by Haupt's adhesive prepared in accordance with Johansen's recommendations (Johansen, 1948) and flooded with 3% formalin solution. They were slightly heated on a warm plate. After several hours of drying, the slides were put in xylene which removed the paraffin. Canada Balsam was used as the mounting medium.

CHAPTER III

RESULTS

Triaxial Tests:

A series of consolidated undrained tests with pore pressure measurements ($\bar{R}$ tests) was performed.

Stress-Strain:

A typical stress-strain diagram is shown in Fig. #5. Stress-strain diagrams of all the tests are included in the Appendix. Maximum deviator stresses were taken as the failure criterion.

Pore Pressures:

Pore pressures are plotted on the stress-strain diagrams. The pore pressure parameter B was calculated by raising the cell pressure and recording the pore pressures induced. After each increment of cell pressure, ten minutes were allowed for the pore pressures to reach equilibrium. A typical graph of pore pressures versus cell pressures is given in Fig. #6. The values found are in the order of 0.9-1.0. The pore pressure parameter A_f was calculated by dividing the pore pressures (at maximum deviator stresses) by the maximum deviator stresses. The values of A_f range from 0.44 to 0.84.

Mohr Diagrams:

Mohr circles, in terms of total stresses for all the tests, are shown in Fig. #7. An approximate envelope drawn for these circles

indicates a cohesion intercept of 0.05 kg./cm.^{2} and an angle of shearing resistance of 18°.

Fig. #8 shows the results of the tests in terms of effective stresses; the approximate envelope indicates a cohesion intercept of 0.05 kg./cm.^{2} and an angle of shearing resistance of 46°.

Water Contents:

Water contents were obtained after dividing the test specimen into three parts. Water contents versus effective consolidating pressures and logarithm of compressive strengths are given in Fig. #9.

Vector Curves:

Fig. #10 shows the vector curves for all the tests. These curves were obtained by assuming an effective angle of shearing resistance of 46° which gave a failure plane of 68° to the horizontal using the equation:

$$\alpha = 45^\circ + \bar{\phi}/2$$

where α is the assumed failure plane and $\bar{\phi}$ is the effective angle of shearing resistance.

Rendulic Plots:

Rendulic plots are given in Fig. #11.

Microscopic Examination:

Visual examinations of the prepared slides were conducted under microscope at various magnifications ranging from 40X to 1000X. Pictures, taken at appropriate places, are shown from Fig. #12 to Fig. #37.

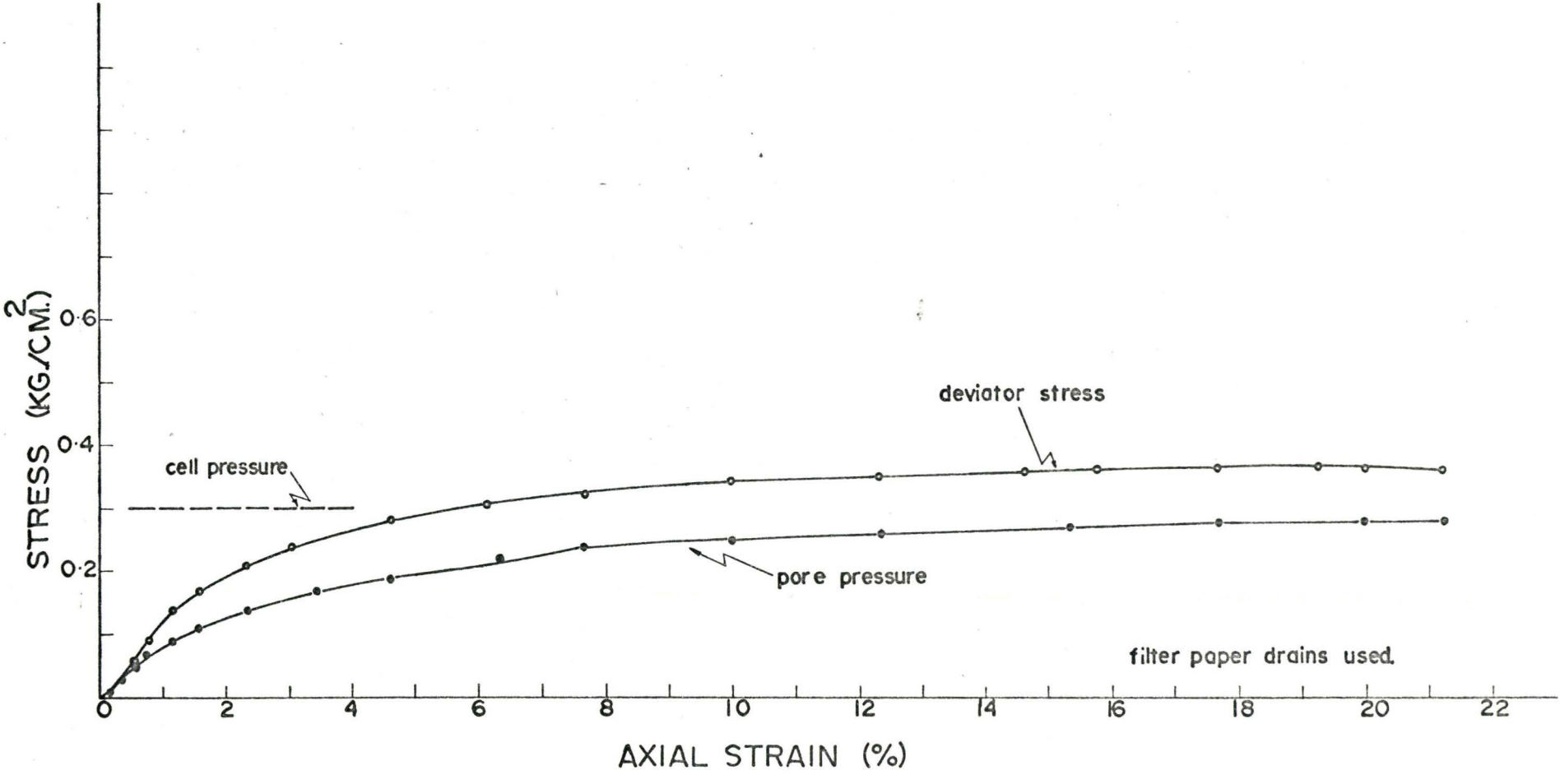

FIG.5 — TYPICAL STRESS-STRAIN CURVE: TEST #7

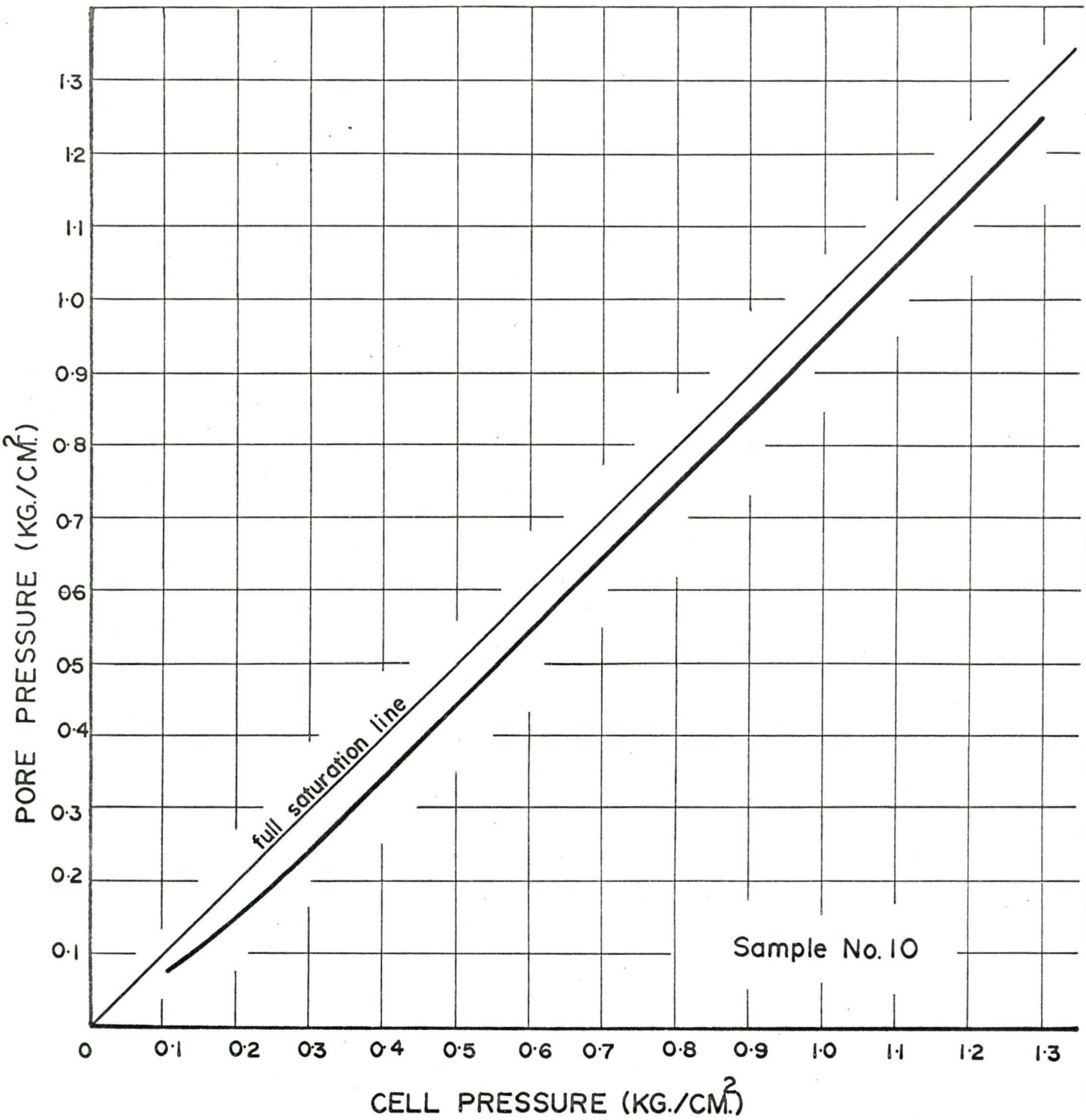

FIG. 6— TYPICAL SATURATION CURVE

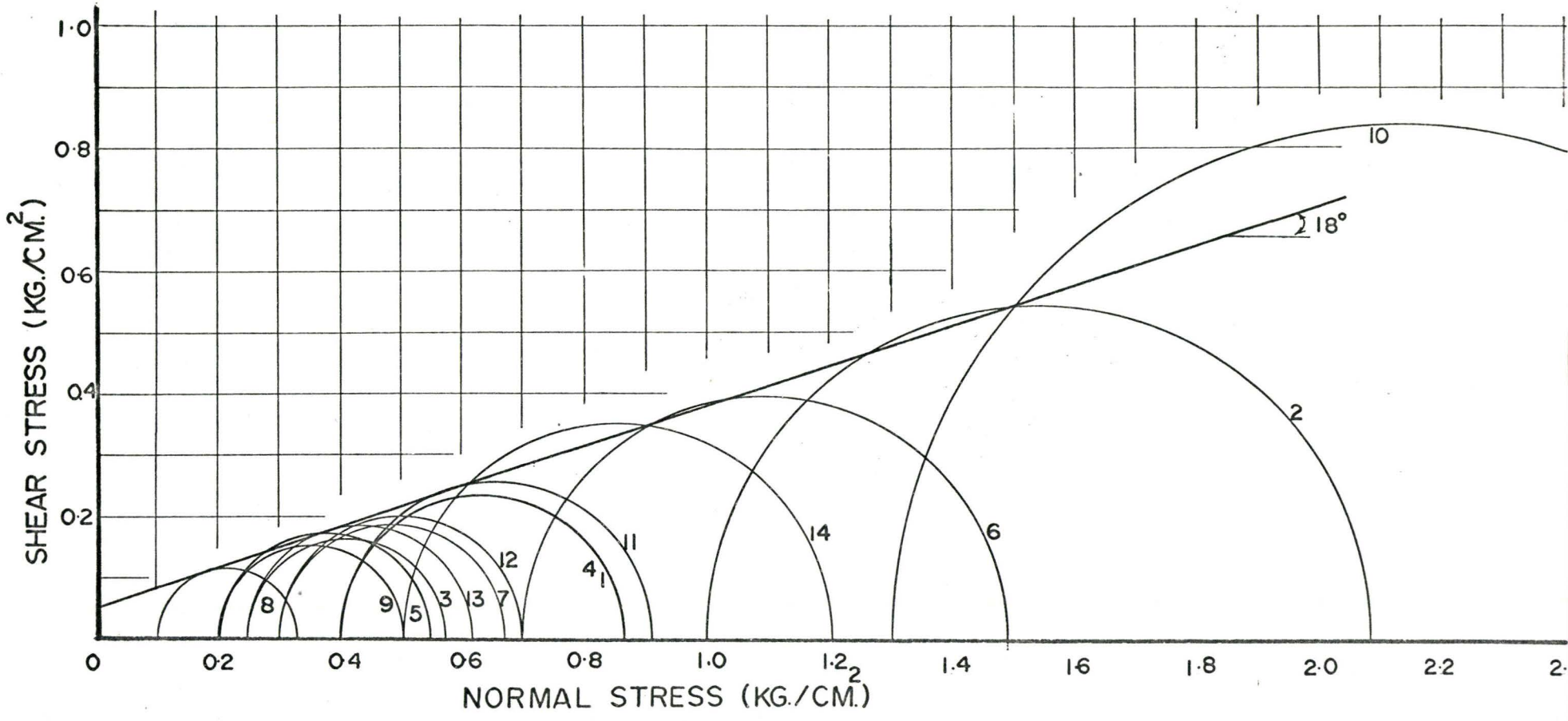

FIG. 7 — MOHR DIAGRAM IN TERMS OF TOTAL STRESSES

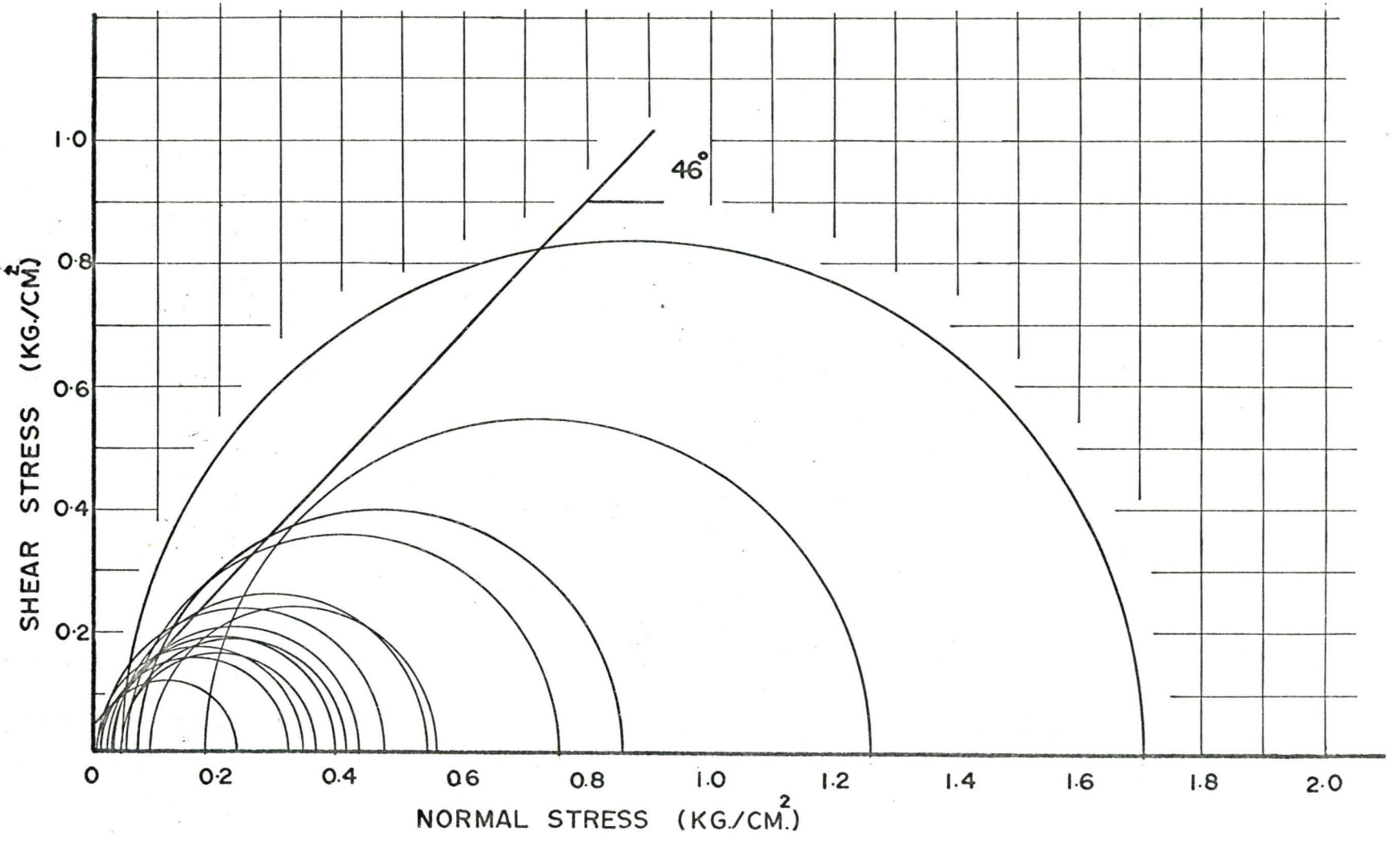

FIG. 8 — MOHR DIAGRAM IN TERMS OF EFFECTIVE STRESSES

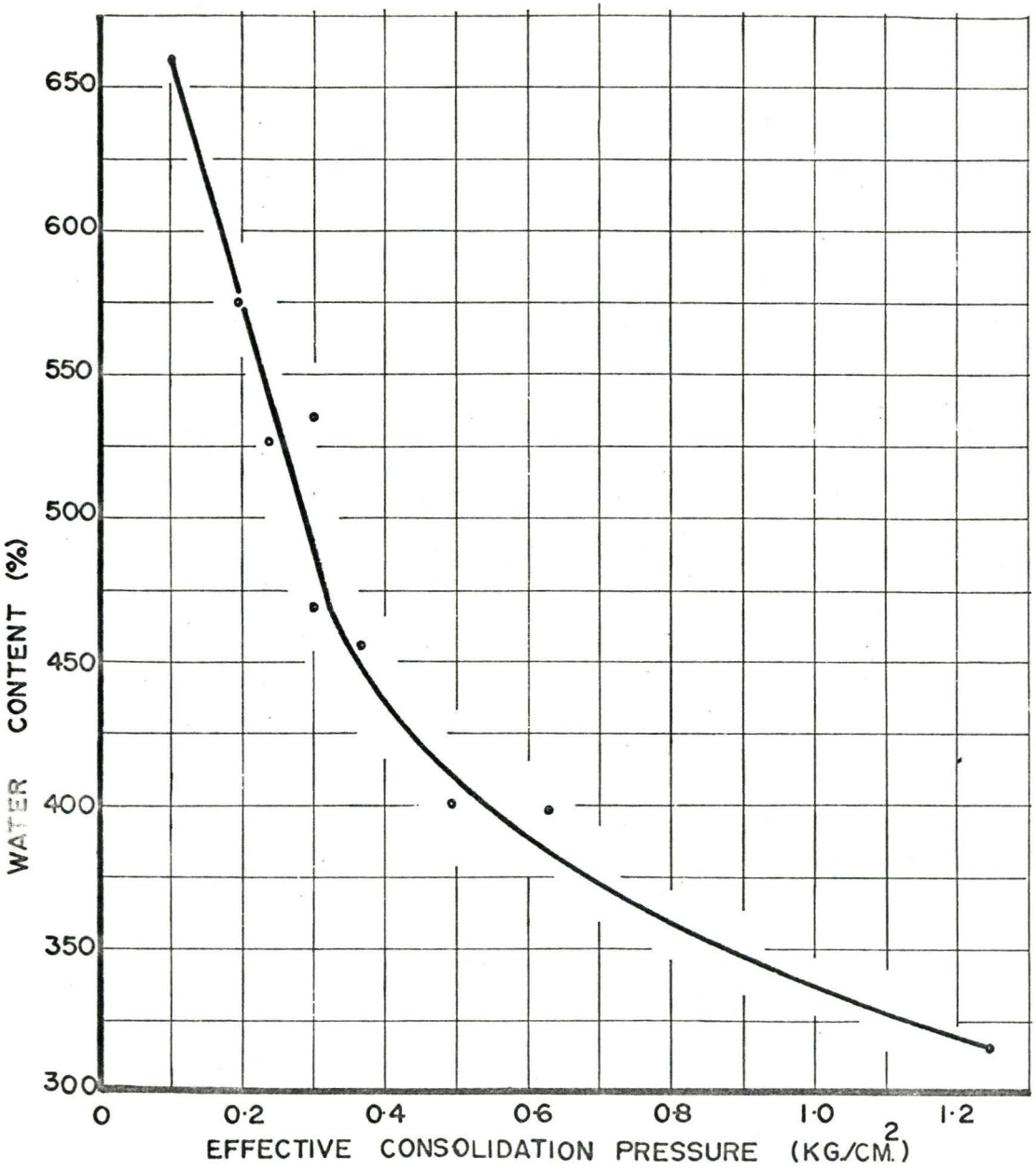

FIG. 9A — RELATIONSHIP BETWEEN WATER CONTENT AND EFFECTIVE CONSOLIDATION PRESSURE.

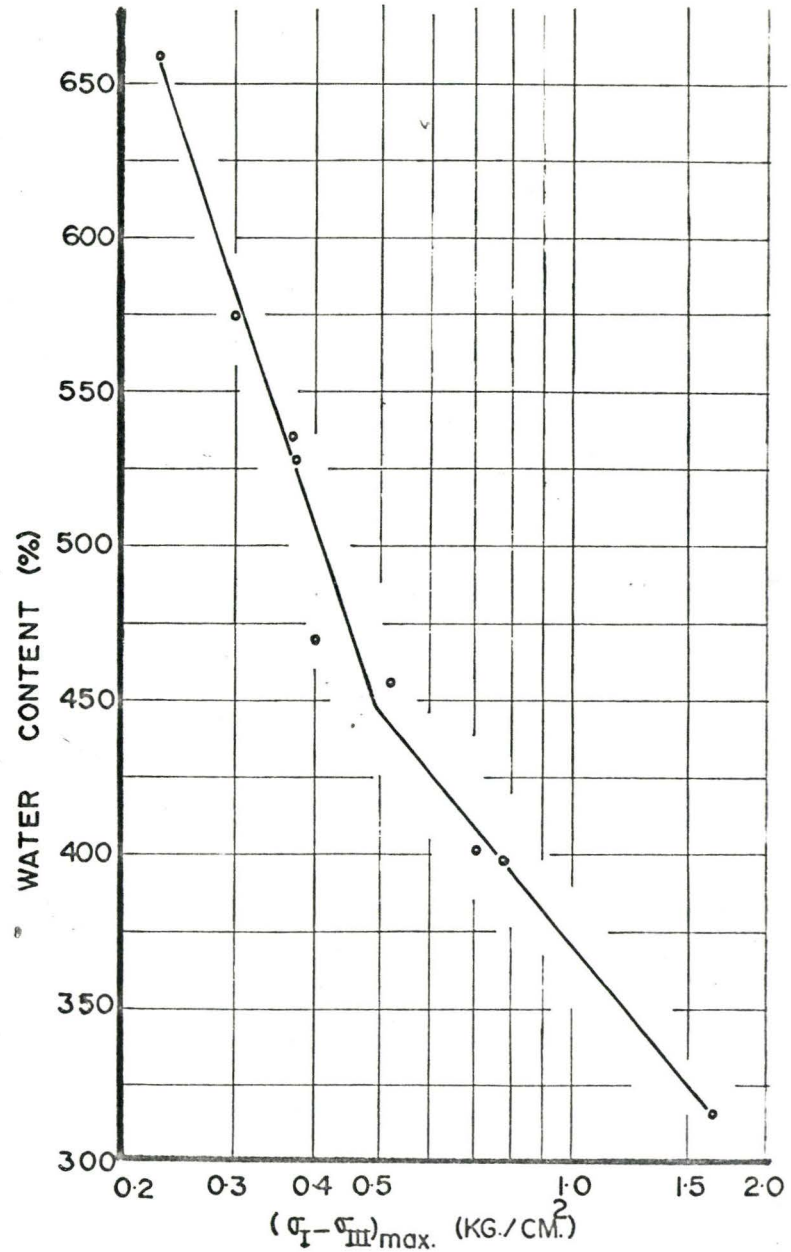

FIG. 9B — RELATIONSHIP BETWEEN WATER CONTENT AND COMPRESSIVE STRENGTH.

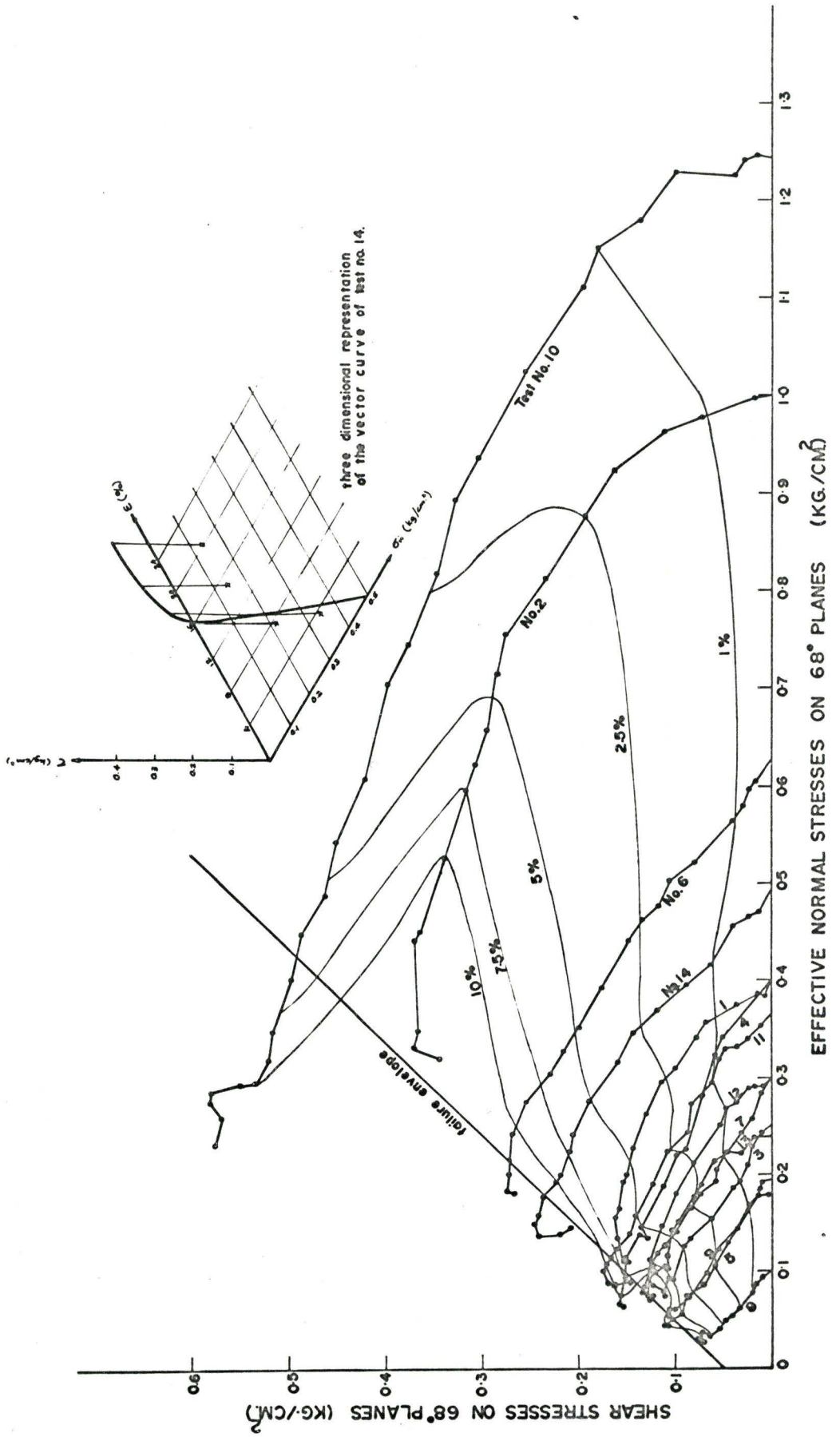

FIG. 10— VECTOR CURVES

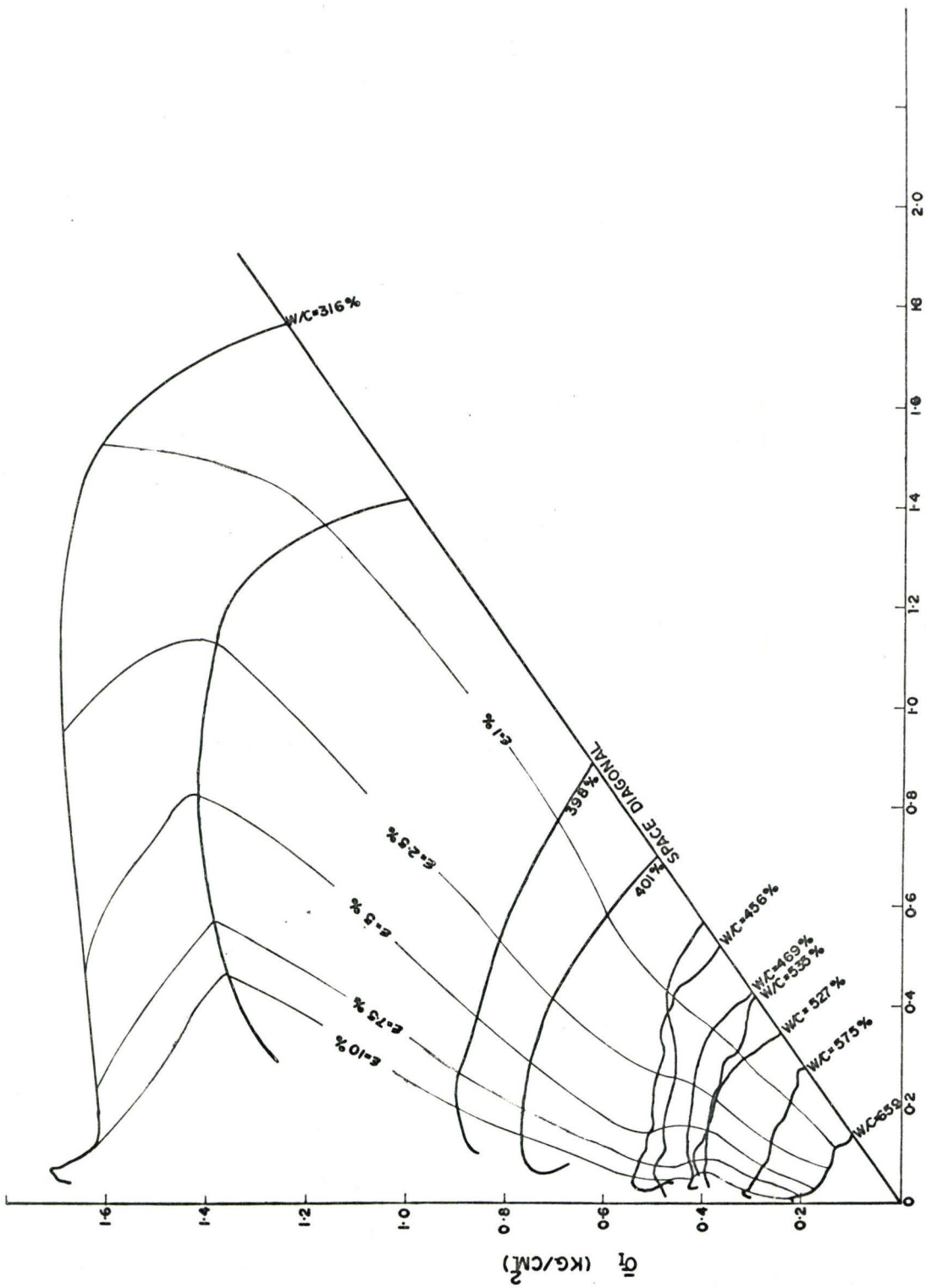

FIG. II—RENDULIC PLOTS

PLATE I A

In Plates I A and I B, microscopic photographs of thin sections cut from the three sides of a peat cube are shown to give a pseudo three dimensional view (top, front and side) of the structure of peat. All magnifications given are approximate.

Fig. 12A - The high density, and the random voids are shown. The colony of round particles is, most probably, not pollen grains. (Mag. 30X; Top view.)

Fig. 12B - (Mag. 30X; Top view.)

Fig. 13A - The voids, especially adjacent to the fibres, are shown; this effect is also shown in later photographs. (Mag. 30X; Front view)

Fig. 13B - The high fibrosity ratio (the ratio of stems to amorphous peat) is shown in this enlarged view. (Mag. 75X; Front view.)

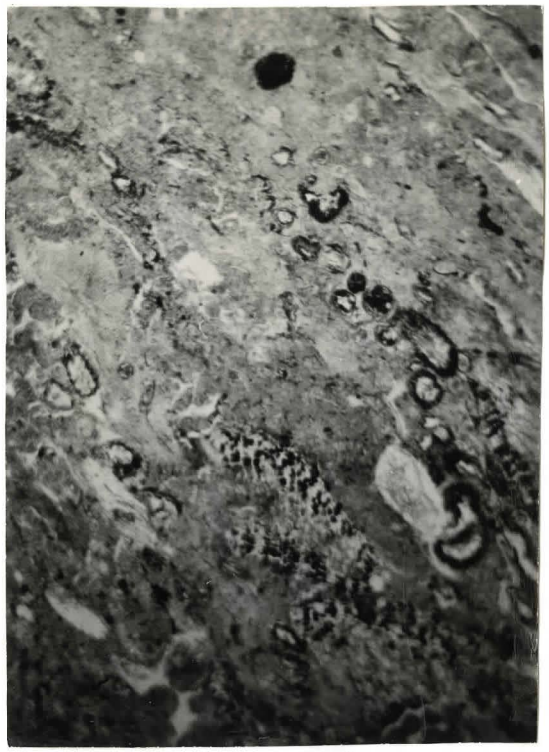

FIG. 12A

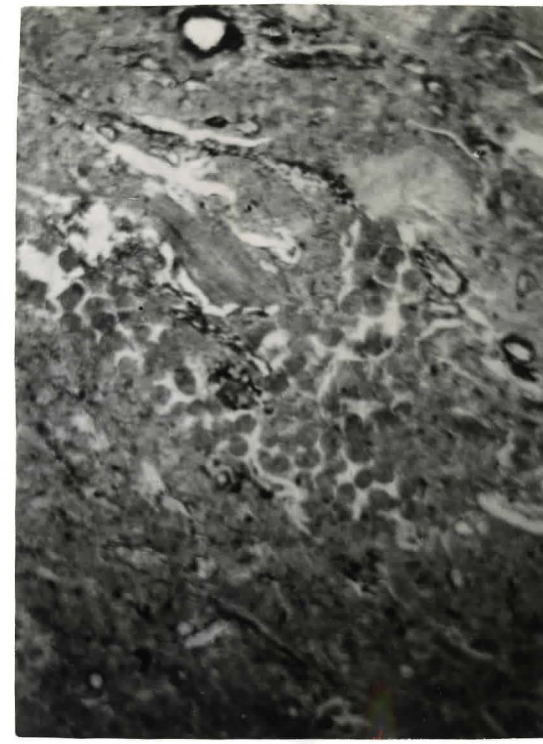

FIG. 12B

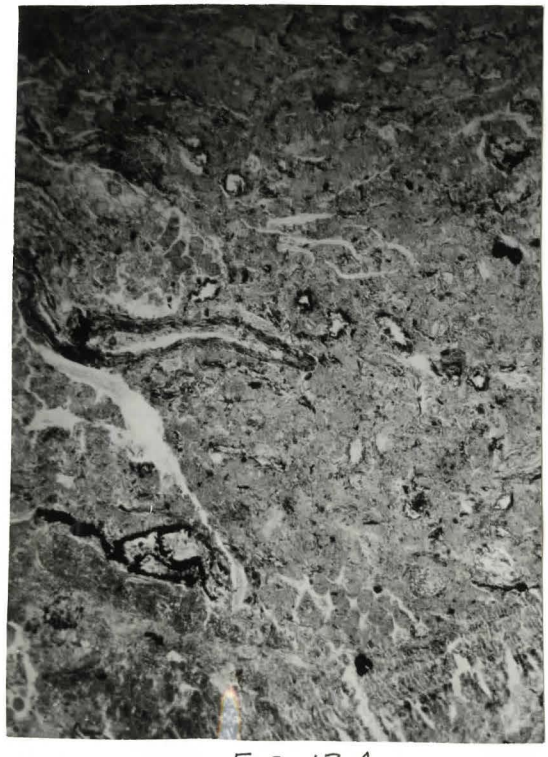

FIG. 13A

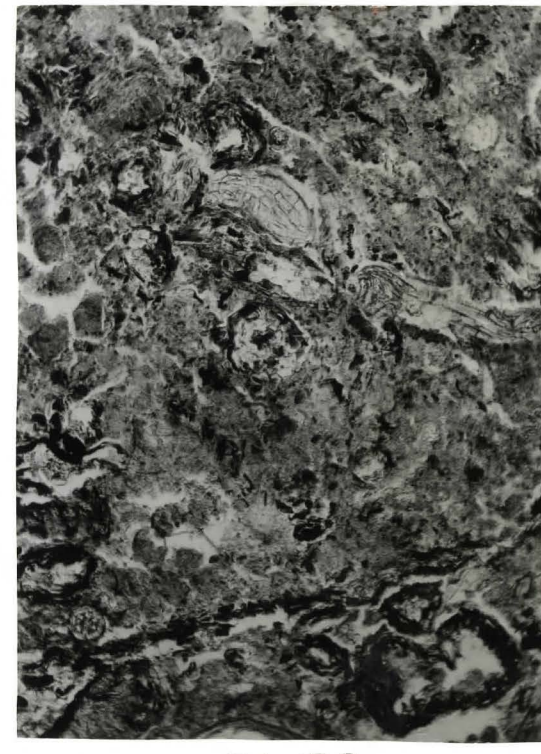

FIG. 13B

PLATE I A

PLATE I B

Fig. 14A - The longitudinal section of a sedge-like tissue is shown. The blending of the sedge-like tissue, the amorphous peat and the fibres into each other to form a unity is noted. The voids, in general, are capable of holding large quantities of water. The random voids around the fibres and the sedge-like plant tissue have been shown in Fig. 13A. (Mag. 30X; Side view.)

Fig. 14B - An enlarged view shows the blending of the sedge tissue into amorphous peat. The voids adjacent to the tissue are clearly shown in this photograph. (Mag. 75X; Side view.)

Fig. 14C - Details of the sedge-like tissue with its typical rectangular cell structure are shown. The volume of water that is capable of being stored in these cells should be noted. (Mag. 300X; Side view.)

Fig. 14D - Details of the cell structure are shown. (Mag. 750X; Side view.)

FIG. 14 A

FIG. 14 B

FIG. 14 C

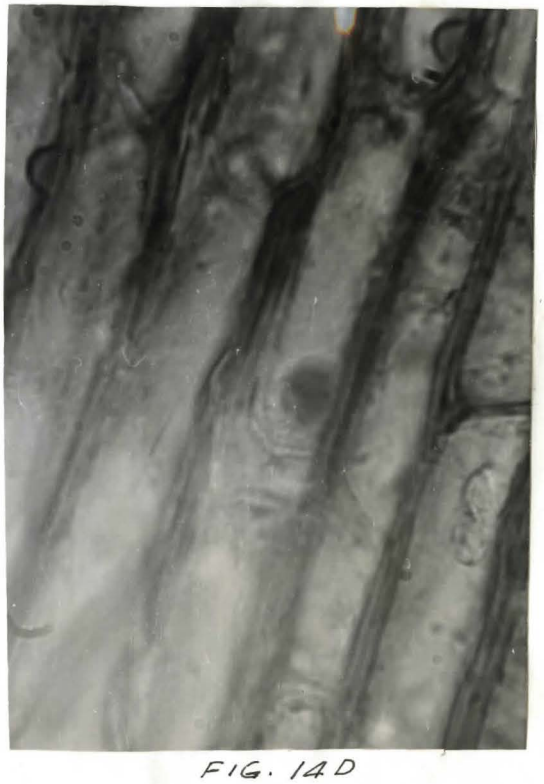

FIG. 14 D

PLATE I B

PLATE II

This plate exhibits the water holding capacity of peat.

Fig. 15 - Cross-section through two non-woody fibres, amorphous granular material and several fungal hyphae is shown. While the hollow sections within the fibres have a large capacity for water storage, the main volume of water is held around the amorphous material. Water held within the cells constitutes another kind of water. (Mag. 300X.)

Fig. 16 - Sedge roots in cross and longitudinal sections are shown. In the hollow parts of the root and in the cavities large quantities of water can be contained. (Mag. 300X.)

Fig. 17 - Another root in cross and longitudinal sections is shown. Note that water can be held both within the hollow fibres and the cells that constitute the fibres (Mag. 300X.)

Fig. 18 - The cavities between the materials, especially around the suberized tissue, are shown in this cross-section through hollow stems (fibres). (Mag. 75X.)

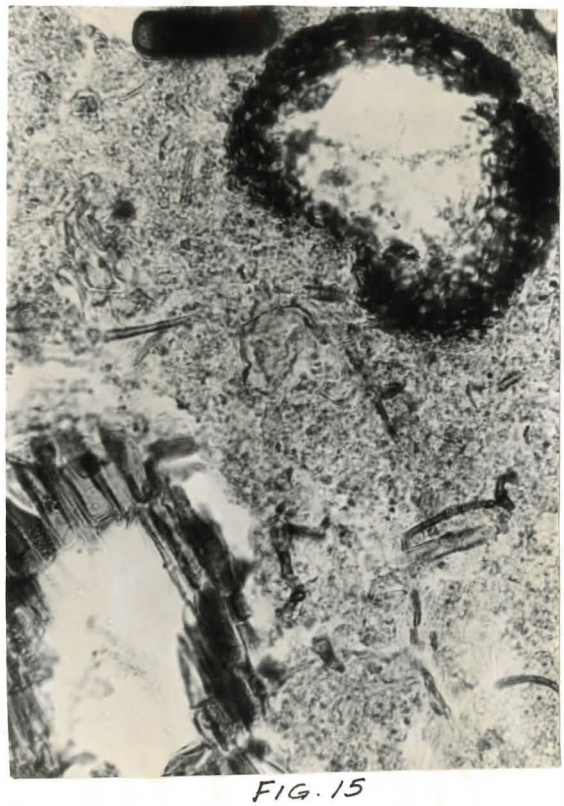

FIG. 15

FIG. 16

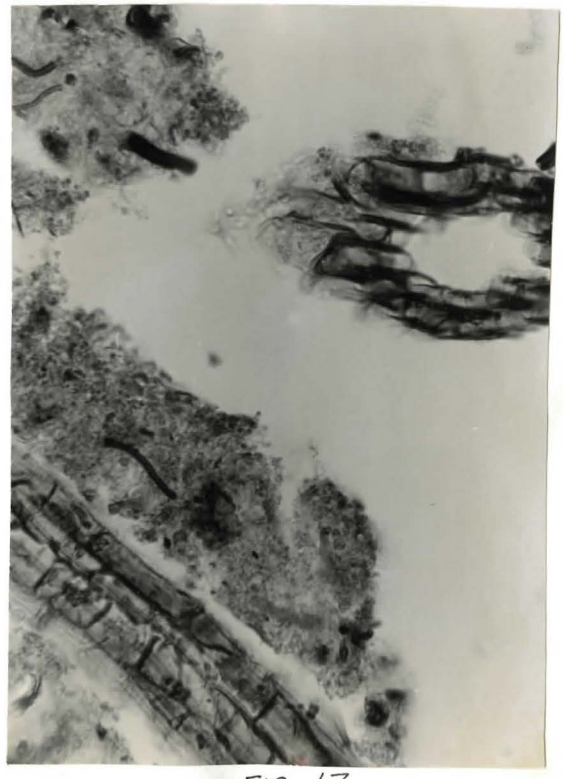

FIG. 17

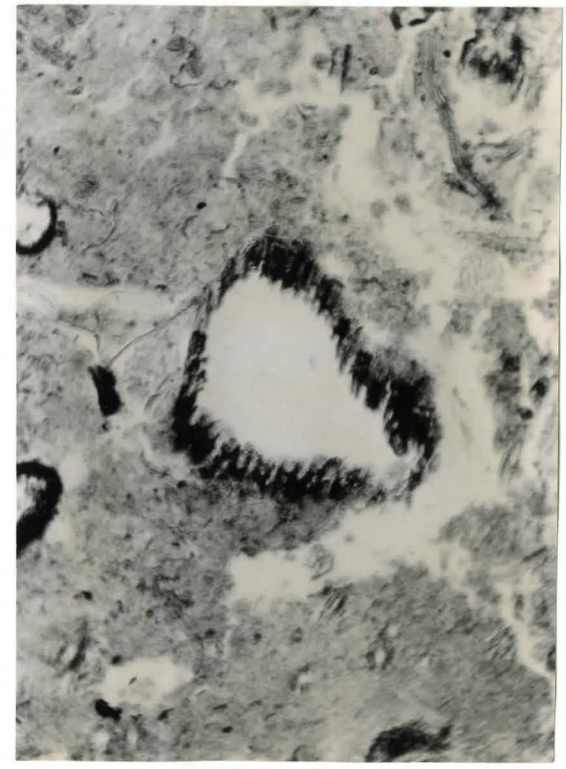

FIG 18

PLATE II

PLATE III A

Plates III A and III B show the structure of peat in general.

Fig. 19 - A large and several smaller fibres which indicate a fairly high fibrosity ratio are shown. (Mag. 30X.)

Fig. 20 - An amorphous section is shown. Note the blending of fibrous material and leafy sections into amorphous material. In this figure and in the next seven figures, note the fungal hyphae; this indicates a dynamic state of breakdown of the cellular material which forms the cells. (Mag. 75X.)

Fig. 21 - A fibre at the top, a cell structure at the right and a spore in the lower right corner are shown. Main body of material is amorphous. Note the active breakdown of the material to form amorphous granular. (Mag. 300X.)

Fig. 22 - Blending of plant tissues into amorphous granular is shown. Note the abundance of fungi and tissues broken down to single cell-size. (Mag. 300X.)

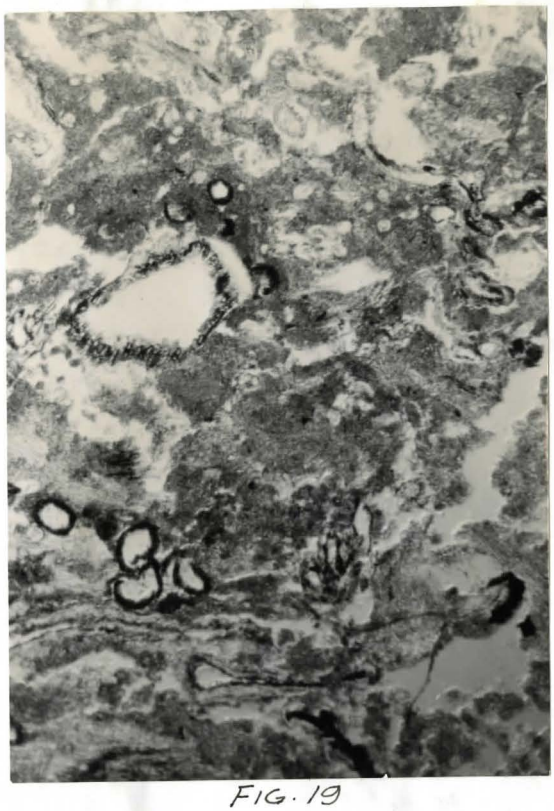

FIG. 19

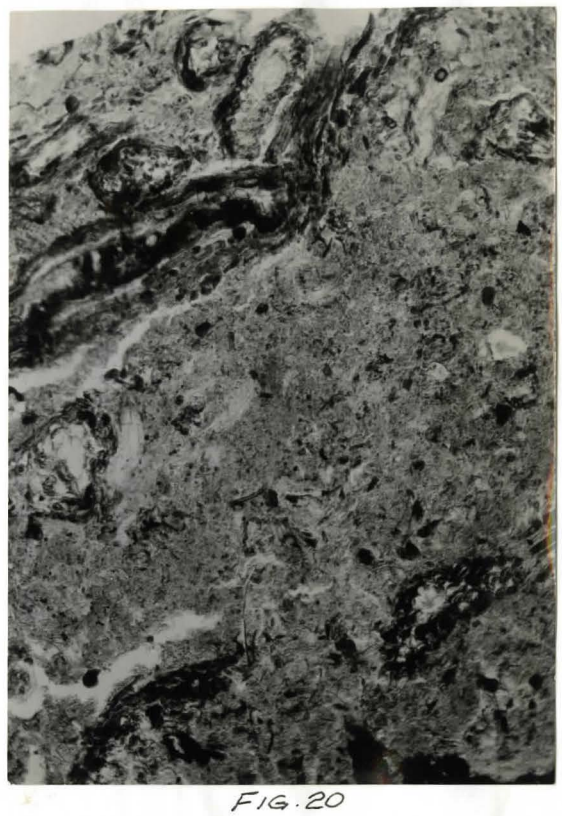

FIG. 20

FIG. 21

FIG. 22

PLATE III A

PLATE III B

Fig. 23 - Amorphous peat is shown with a root (top left) and a spore (bottom right). (Mag. 300X.)

Fig. 24 - Amorphous section with various non-humified tissue structures is shown. (Mag. 75X.)

Fig. 25 - In this photograph the amount of water that can be stored around the plant tissues should be noted. (Mag. 300X.)

Fig. 26 - Another typical amorphous-granular section is shown with some tissue structure as yet undecomposed at lower left corner. (Mag. 300X.)

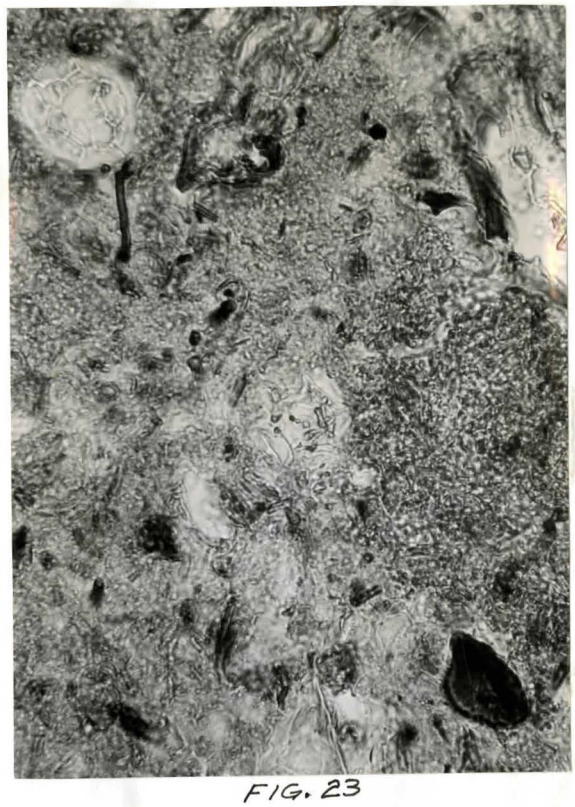

FIG. 23

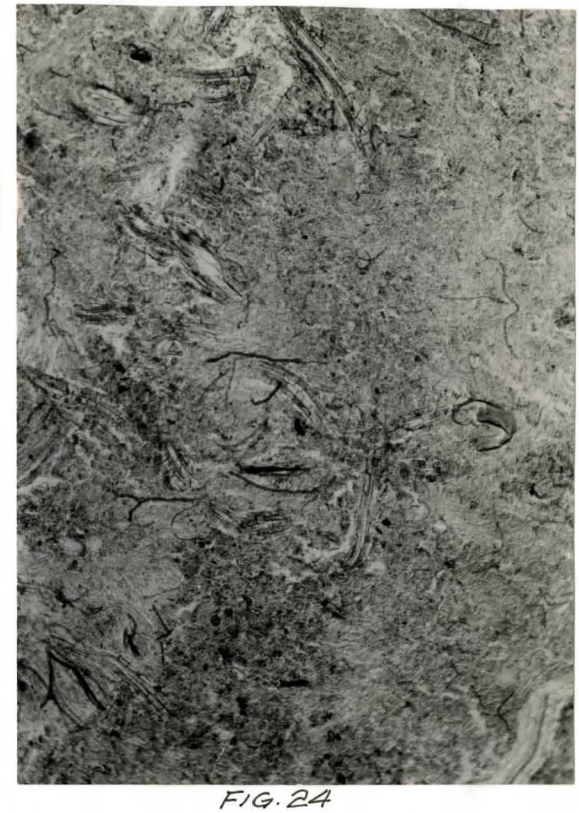

FIG. 24

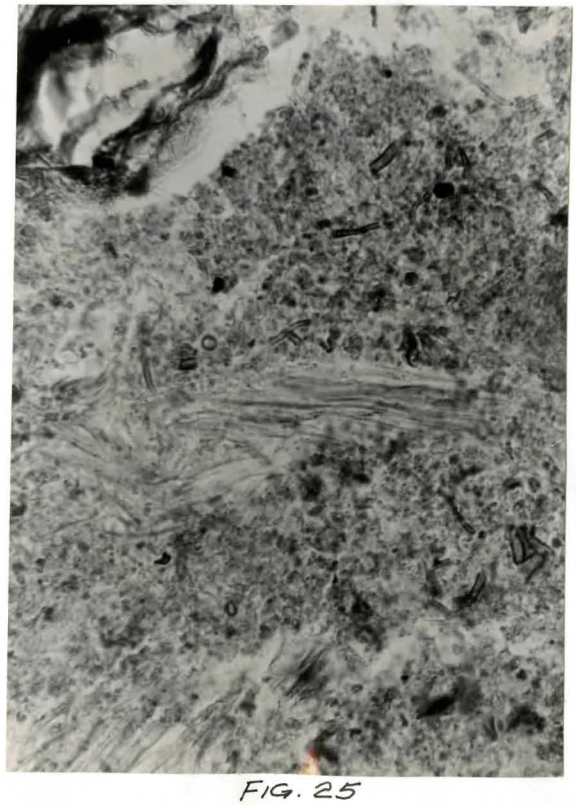

FIG. 25

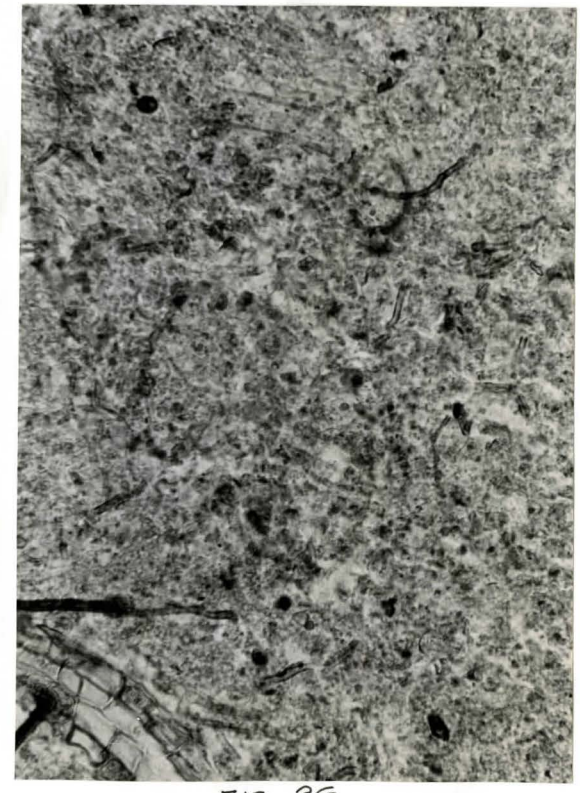

FIG. 26

PLATE III B

PLATE IV A

Plates IV A and IV B show various larger components that form the structure of peat.

Fig. 27 - Amorphous peat with a root in cross-section is shown. (Mag. 75X.)

Fig. 28 - Amorphous peat section with granules is shown. (Mag. 75X.)

Fig. 29A - Cross-section of several large and small roots are shown. Note the voids between the roots. (Mag. 30X.)

Fig. 29B - A further enlarged view of the cross-section of the large root is shown. (Mag. 75X.)

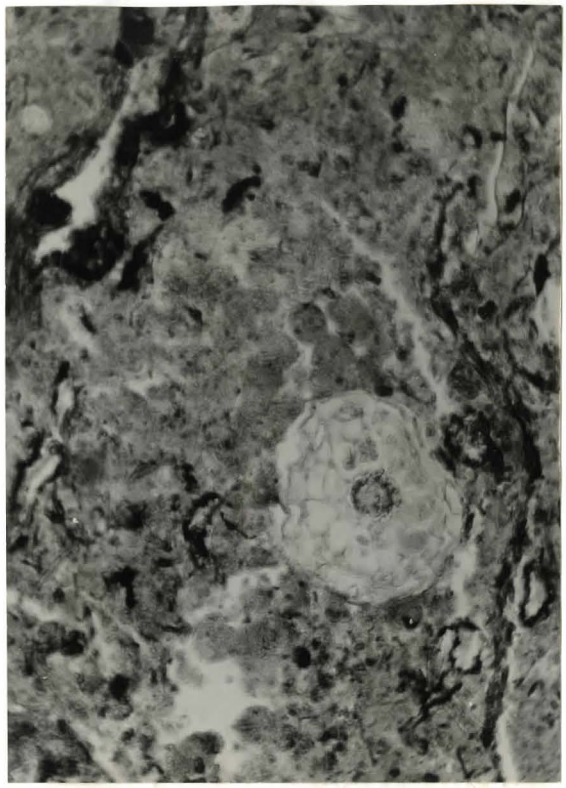

FIG. 27

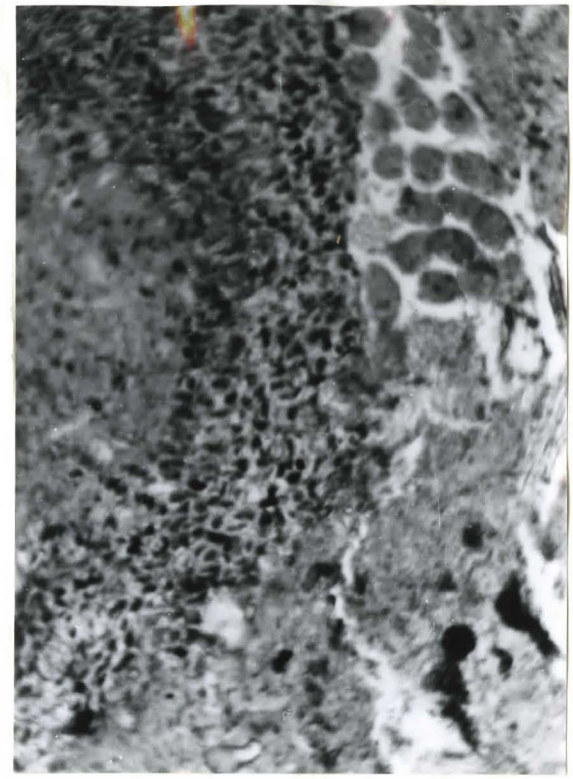

FIG. 28

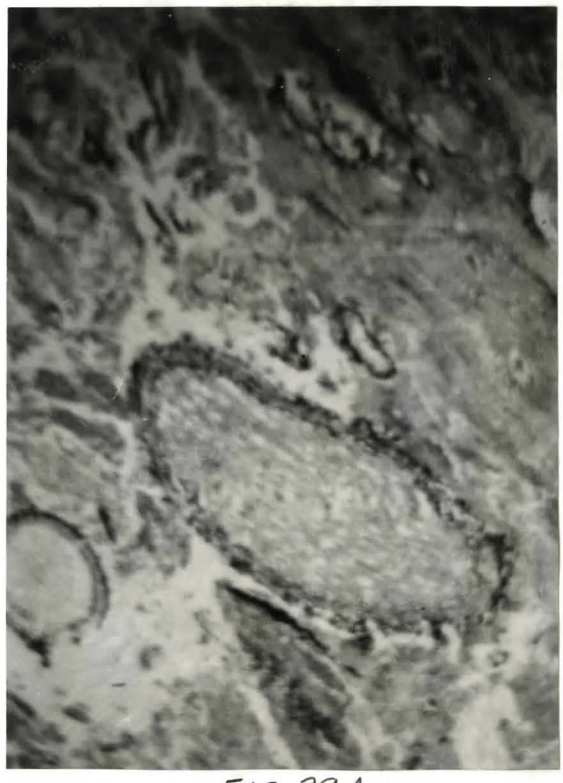

FIG. 29 A

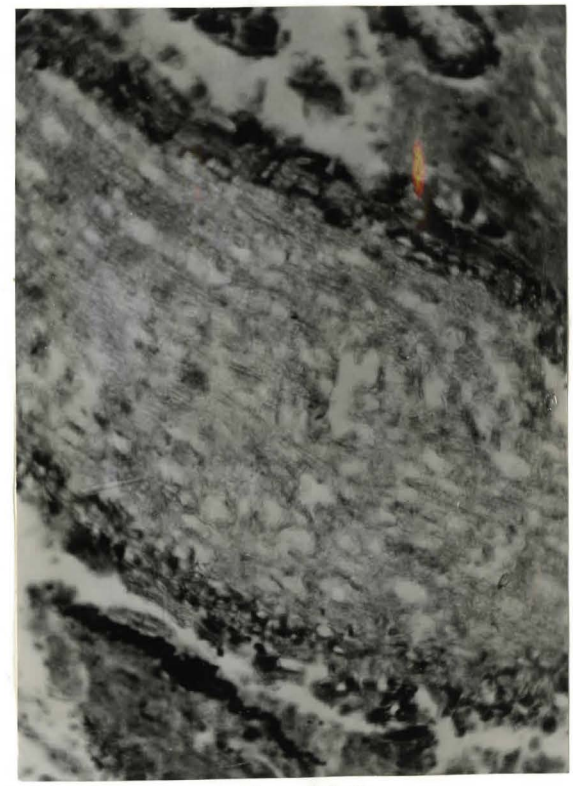

FIG. 29 B

PLATE IV A

PLATE IV B

Fig. 30A - In this cross-section of a woody root note the outer suberized tissue (cork like) and the middle cortex which is typical of roots. (Mag. 75X.)

Fig. 30B - An enlarged detail of the same root is shown. (Mag. 300X.)

Fig. 31 - A large fibre, about 2/3 mm. in width in actual size, is shown in longitudinal section. (Mag. 30X.)

Fig. 32 - Longitudinal section of a smaller fibre is shown. Note the spaces inside the fibre which can hold water. (Mag. 75X.)

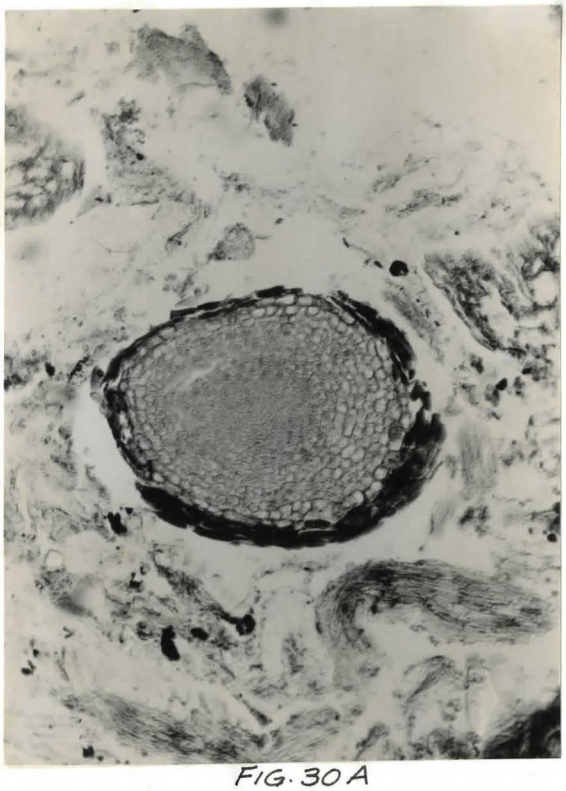

FIG. 30 A

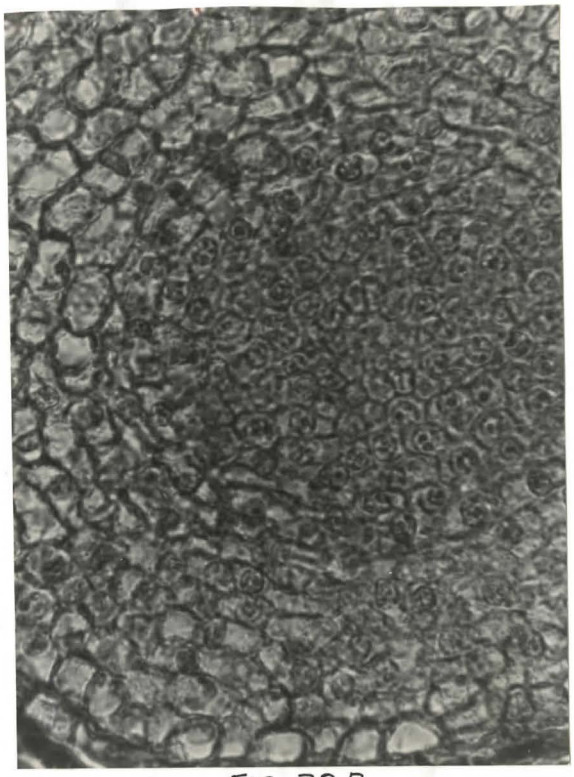

FIG. 30 B

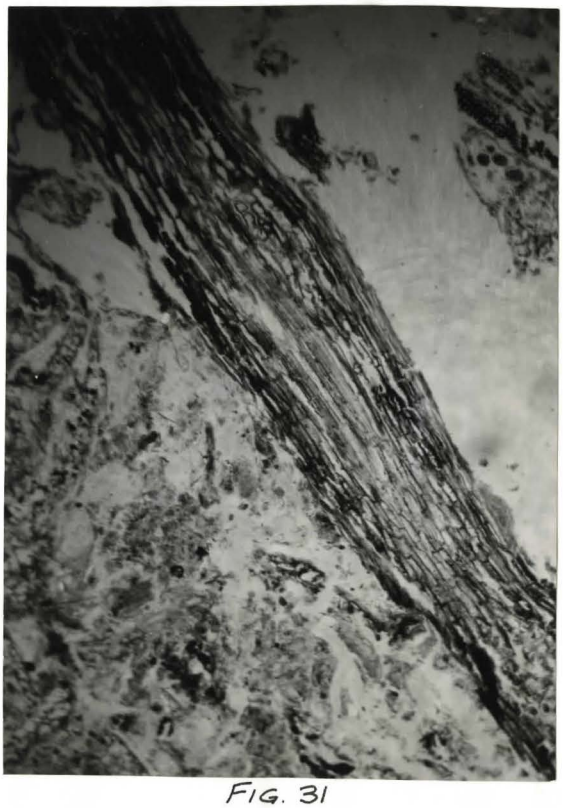

FIG. 31

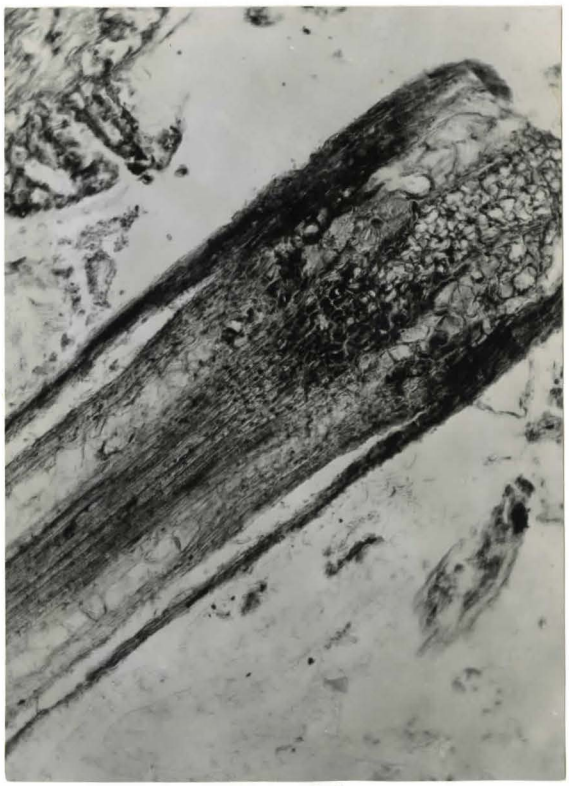

FIG. 32

PLATE IV B

PLATE V

This plate shows various cell structures in detail.

Fig. 33A - A root section, identified from the central position of conducting tissue and the suberized tissue, is shown. Note the effect of the cutting action of the microtome blade due to improper microtoming. (Mag. 75X.)

Fig. 33B - An enlarged view of the tissue with its empty cells is shown. (Mag. 300X.)

Fig. 33C - Further enlarged detail of the same cell structure is shown. (Mag. 750X.)

Fig. 34 - Two different cell structures are shown; above are rectangular cells of sedge - below are typical cells of *Sphagnum* moss which have a very high capacity to store water. (Mag. 300X.)

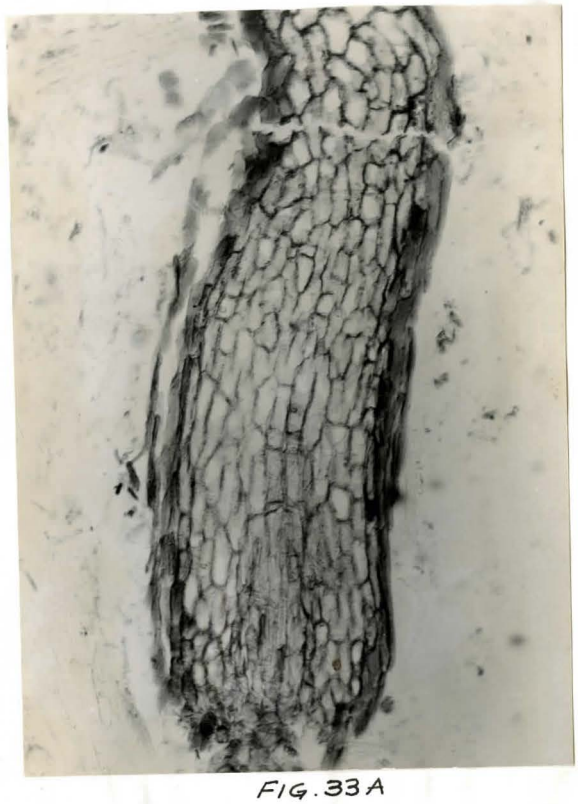

FIG. 33 A

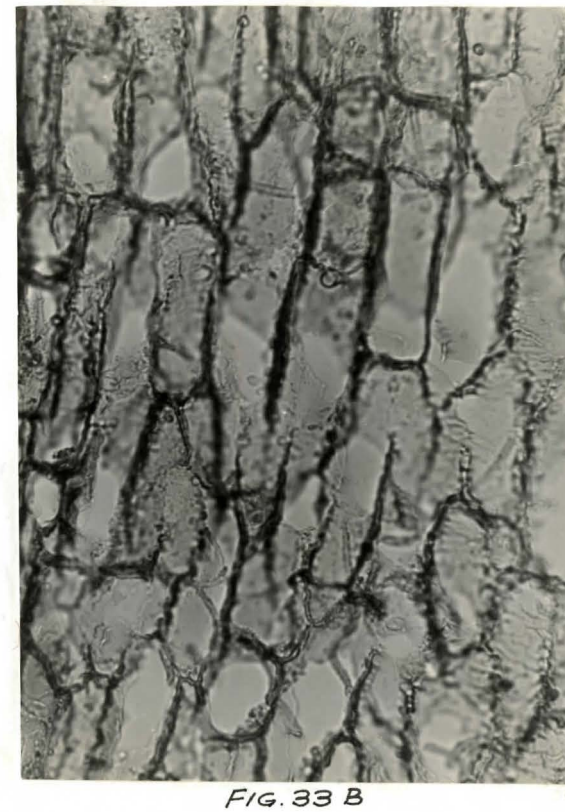

FIG. 33 B

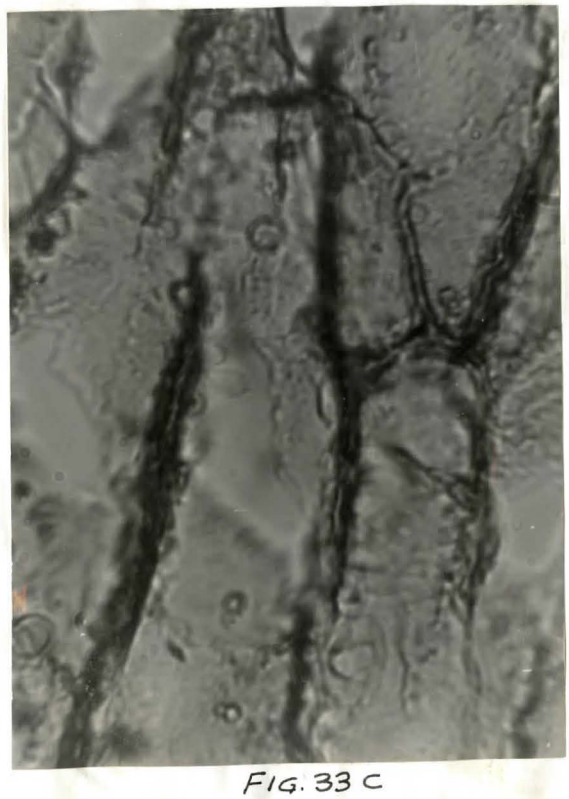

FIG. 33 C

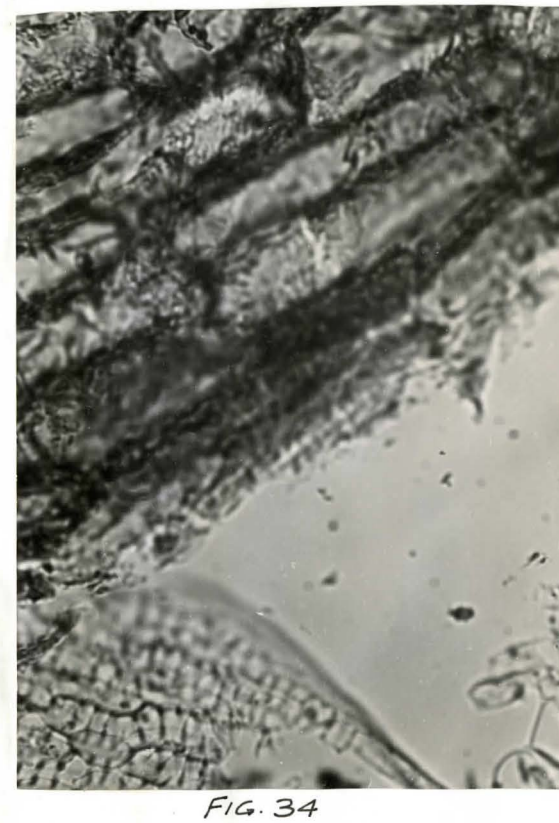

FIG. 34

PLATE IV

PLATE VI

Fig. 35 - Roots in cross and longitudinal sections are shown. (Mag. 75X.)

Fig. 36 - Structure of peat subjected to stress is shown. The peat, obtained from about 6" depth where living cover blended into dead material, was stressed under a load of 0.6 kg./cm.^{2} for ten days. A low density was obtained from the structure formed under stress in this artificial way as shown in this microscopic photograph. Note the lack of amorphous granular material although Sphagnum moss is already experiencing a mechanical breakdown. (Mag. 75X.)

Fig. 37 - The effects of blade action and folding by faulty microtoming are shown. Note that such artificial disturbances can easily be identified. (Mag. 30X.)

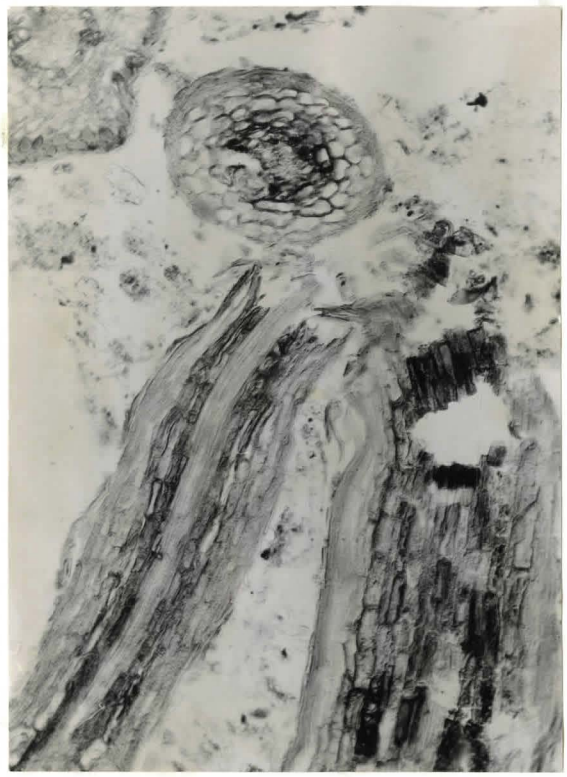

FIG. 35

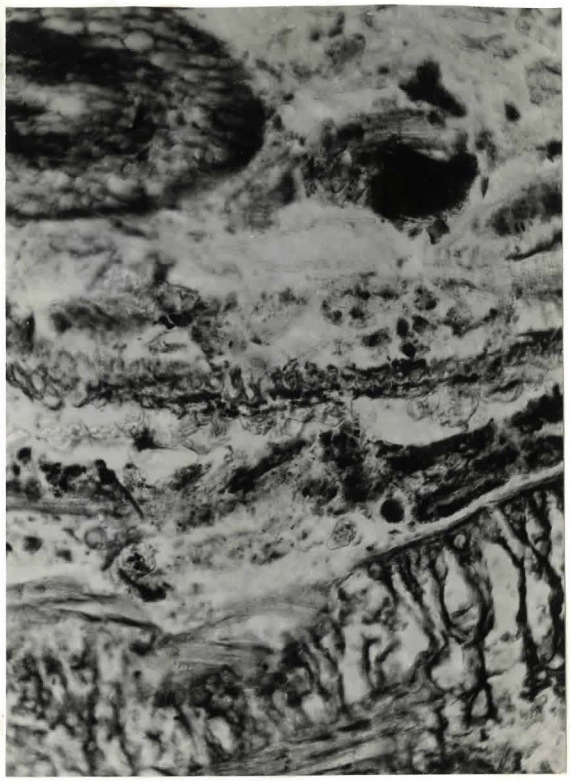

FIG. 36

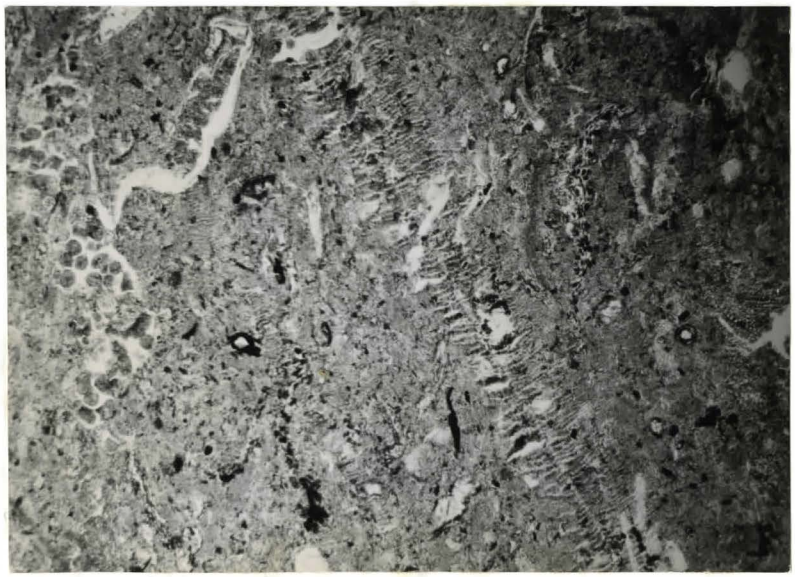

FIG. 37

PLATE VI

CHAPTER IV

DISCUSSION OF TECHNIQUES USED

Sampling:

Thin-walled pipes, used for obtaining peat samples, minimized disturbance to the samples. A few shortcomings of this method, however, should be cited.

Some loss of the gravitational water could not be prevented. This may be achieved by an automatic catcher that closes the bottom of the sampler.

Gases escaping from the peat samples due to pressure release and temperature change could not be prevented. To minimize this effect, ends of the pipes were immediately sealed and samples were immersed in water. Apparently some of the gases lost were replaced by water during transportation; this explains the high saturation values obtained. For permanent storing, great care was taken to seal the pipes. When gases were able to find a way out of the samplers, these were released in the form of bubbles because samplers were immersed in water, and they were replaced by the water.

Preparation for Triaxial testing:

Preparation of peat samples for triaxial testing and executing successful triaxial shear tests are exceptionally difficult operations. If the samples are put into a triaxial

chamber for consolidation without previous treatment, they take distorted shapes during consolidation. Therefore, some treatment of the samples before putting into the triaxial chamber was necessary. Consolidating the samples in 1.5" stainless-steel samplers provided the K_o condition while avoiding this problem of shape.

The samples were softer at the bottom than at the top when extruded from these samplers due to the friction during initial consolidation in the samplers between the samples and the samplers. This caused more water to be expelled from the bottom of the samples during final consolidation in the triaxial chamber. What is more, these samples experienced more pressure at the bottom than at the top when consolidated in triaxial chambers due to a head difference of about 7 cm. (height of the samples) of water. This head difference is 7% of a chamber pressure of 0.10 kg./cm.^{2}. These produced slightly smaller diameters at the bottom of the samples than at the top. These differences in diameters were small and did not effect the results and average of the diameters were used in calculations.

The stresses chosen for consolidating samples in 1.5" ID stainless-steel samplers were equal to the predetermined cell pressures, ignoring the friction between the sample and the sampler. This choice, besides preventing the possibility of working with overconsolidated samples, was such that at the end of consolidation in the triaxial chambers, the diameters of the samples were in the order of 1.4". In this way, the shortening of the samples

in length was also reduced. It was, nevertheless, necessary to measure the dimensions of the samples at the end of final consolidation.

Slight disturbances and, sometimes, their own weight caused samples to acquire eccentricity along the vertical axis. This eccentricity, difficult to detect at the start, became conspicious at the end of consolidation. If this was disregarded, the eccentricity became critical at around 9% strain during shear testing. Therefore, in cases of eccentricity, it was necessary to correct this effect by taking out the sample at the end of consolidation stage. This can perhaps be avoided by using a straight cap attached to the rim of the loading piston. Then the sample will be forced to straighten itself.

It was found that side drains not only decreased consolidation time and ensured some uniformity in connection with water content, but also helped in dealing with eccentricity. They are desirable aids in triaxial shear testing of peat.

To represent natural conditions, the choice of low chamber pressures was necessary. Because the last glaciation scraped the organic terrain on its way, present muskeg is, geologically speaking, recently formed. Therefore, peat is a surficial soil. What is more, peat has a specific gravity of about 1.5, but because water table is almost always near the ground surface, its effective specific

gravity is in the order of 0.5. Therefore, peat experiences relatively small stresses due to its own weight. These factors made the choice of low chamber pressures necessary as in a practical problem chamber pressure represents the confining effect of the soil mass around the sample. Again, because muskeg has been recently formed, it was necessary to work with normally-consolidated samples.

Choice of low chamber pressures meant that small errors in readings of either cell or pore pressures could cause large errors in the results. Care was taken to ensure reliability of both readings. Low chamber pressures impaired the possibility of saturating samples by back pressure. It was not possible to have readings of 0.002 kg./cm.^{2} accuracy at pressures in the order of 6 kg./cm.^{2}. Saturation by back pressure was discarded as a possible aid not only due to the above effect but also due to the fact that it would not be representative of field conditions.

When measuring pore pressures to judge the end of consolidation period, it was found that, although the readings within the first minutes of any one measuring were in the order of zero, by the progress of time they went up; it took as much as 50 minutes to reach a constant final value. Therefore, when measuring the pore pressures only from the bottom this stabilization of pore pressures within the samples was taken into account. Side drains somewhat reduced

this time lag. It was also found that pore pressures were sensitive to temperature changes within the laboratory. For the choice of strain rate, all of these above factors as well as the permeability of peat should be considered.

No attempt was made to vary the strain rate with the variations in chamber pressures in order to keep the number of variables at a minimum.

Discussion of Microscopic Techniques:

No previous records of a microscopic investigation on the structure of peat for engineering purposes were available. Therefore, several methods were tried. At the start, a direct approach seemed appropriate. Each triaxial test sample would be examined for the effects of shearing on the structure before and after shear testing in relation to the effect of stressing on the cell structure, fibre behaviour, water holding capacity and water movement. This would be accomplished by moving the objective lens of a microscope with built in light source along the desired planes of peat sample. This would give at least a two dimensional view of the structure before and after shear. It was abondoned due to non-availability of a microscope fit for the purpose. The only other choice was to resort to thin section methods. Using thin sections, neither the fibre behaviour nor the water movement relations could be investigated. But a better picture of the structure of peat with respect to its water holding capacity could be obtained.

Gelatin infiltration into peat was incomplete, and the method gave unsatisfactory results. As in quick-freezing, components of peat did not retain their original arrangement after slicing.

Radforth and his associates had already developed several techniques for the investigation of the structure of peat under microscope. Stewart's method was not suitable for the purpose as it was devised for cuticle observations (Stewart, 1960) and Thaler's method was much too coarse in that there was a potential danger of disrupting peat tissues (Thaler, 1964). Eydt's method seemed appropriate (Eydt, 1956).

Paraffin infiltration was complete and the components of peat retained their in-situ positions.

As one of the aims of this investigation was to be able to analyze the effect of stressing on cell structures, distortion of the cells during the process of preparation could not be tolerated. Therefore, Eydt's method had to be modified. Instead of subjecting peat cubes directly to 50% alcohol, a gradual increase of alcohol concentration starting from 10% was used in order to avoid any shrinkage of the tissues during the dehydration process. Johansen recommended the use of pure tertiary butyl alcohol as a pre-infiltration medium instead of normal butyl alcohol (Johansen, 1940). According to his experience, normal butyl alcohol, but not tertiary butyl alcohol,

caused distortion of the tissues in some cases. No attempt was made to use vacuum to help remove air as this could disrupt the tissues.

Paraffin infiltration was preceeded by a change of an equal mixture of paraffin oil and tertiary butyl alcohol. This avoided damage to the tissue that could be caused by the heat of the oven while the sample sank into the paraffin. The slow sinking of the peat cube into paraffin insured the complete infiltration of paraffin into the peat tissues. It was learned that, if several changes of paraffin were made, the one week period in the oven recommended by Eydt was not necessary as paraffin and tertiary butyl alcohol proved to be rapidly miscible; all of the tissues that were previously soaked in tertiary butyl alcohol were completely penetrated by paraffin within a couple of days and it was not necessary to add chips of paraffin as recommended by most textbooks on botanical microtechnique.

Optimum thickness for the sections was found to be 15 μ. 15 μ sections were superior to 20 μ sections as better quality pictures could be taken using this thickness. In some cases mechanical injury to the tissue due to the cutting action of microtome blade could not be prevented, but injured sections could be differentiated. No disarrangement of the tissues occured during slide preparation as Haupt's adhesive caused peaty material to stick to the glass slides.

Paraffin infiltration method may be somewhat long and tedious for engineering purposes, but it seems that as of now, it is the only successful thin section method for the examination of peat structure in its in-situ arrangement.

CHAPTER V

DISCUSSION OF THE RESULTS

Reliability of the results:

When examining the results, it must be borne in mind that there were non-homogeneities within the individual samples as well as differences among the samples because peat varies within a bog horizontally as well as vertically. Furthermore, various testing procedures imposed some differences among and within the samples with respect to geometry and water content. Samples which were consolidated with drainage from the bottom only showed a gradation of strength increasing from top to the bottom; other samples showed uniform strength with height.

There was no definite failure pattern of the samples during shear testing. Some failed by buckling due to an initial eccentricity; around 12% strain, eccentricity became critical and the samples were unable to take further load. As the areas were assumed to be increasing, the deviator stresses were calculated to be decreasing. Samples that acquired no eccentricity reached maximum deviator stresses in excess of 15% strain; these samples generally showed bulging. In two cases, it was found that shearing had taken place through disintegrated wood within the samples.

Calculations of the test results were made assuming no volume changes of the samples. Measuring the volume change by the volume of water expelled from the triaxial chamber during testing indicated possible volume changes up to 4% of the original volume of the samples during tests with chamber pressures less than 0.25 kg./cm.^{2}. Therefore, test results calculated for tests with the lower chamber pressures may be slightly below the actual values. Another point that must be kept in mind when analyzing the results is that some samples had small initial pore pressures at the start of the shearing stages.

Stress-strain Relationships:

Fig. #5 shows the general trend for stress-strain relationships. It is noticed that deviator stress reaches a plateau after certain strain and remains fairly constant for a certain range of strain; the curve does not show a pronounced peak value. The deviator stresses rise beyond the cell pressures in all cases.

Mohr Diagrams:

The discrepencies explained are believed to be the reasons for the differences in Mohr circles of the tests run at the same cell pressures (Fig. #7). Using the approximate envelope in this figure, the shearing strength of this peat in terms of total stresses can be expressed as:

$$s = 0.05 + \sigma \tan 18^{\circ}$$

in accordance with Coulomb's Equation where s, c, and σ are in kg./cm.2.

The strength, in terms of effective stresses, can be given as:

$$s = 0.05 + \bar{\sigma} \tan 46^{\circ}$$

Although at a first glance, the exceptionally high angle of shearing resistance indicates a strong material, due to the high pore pressures induced, $\bar{\sigma}$ is very small and therefore, the strength mobilized is very small. In cases of complete drainage a high strength is obtained. But then excessive deformations result due to great volume of water that is expelled. The expelled water can be generalized into four categories:

The first category is the loosely held water in the voids enclosed by what can be considered as the solid constituents of peat.

The second category water is within voids in the solids. For example, water within the void portions of roots, hollow stems, etc. This water is more firmly held than the water in the voids in between the solid constituents.

The third category is the water that constitutes the material itself. The constituents of peat, being of biological origin, are composed mainly of water. Therefore, water forms an integral part of what is considered to be the solid constituents. This water, held in the cells, for instance, can be expelled under certain ranges of stress.

The fourth category of water is the colloidal water.

The first two categories of water can be seen on Plate II in Fig. #15 to Fig. #18.

In the sense explained, as opposed to the solid constituents of mineral soils, the materials that form peat change under stresses. Thus peat should be considered as a unique material when treating it within the range of knowledge of Soil Mechanics.

When this investigation was undertaken, it was expected that, as the materials which form peat change under stresses, the Mohr envelope would not be a straight line. The slope of the envelope, it was expected, would increase after a certain stress range because water of the second and the third categories would be expelled out of the solid constituents and the material dealt would get stronger. This would continue up to a certain stress range where the material could no longer get stronger. Then the individual constituents would yield, causing the envelope to decrease in slope. The increase of strength of the individual constituents of peat would be accompanied by a phenomenon best described as 'fibrous interlock' where fibres would assemble themselves in a form where their total strength would be much higher than the total strength that can be obtained by summing the individual strengths of fibres. This can be visualized if it is thought to be similar to the strength of a rope which is composed of individual fibres.

An examination of the envelope in Fig. #7 shows that such behaviour was not fully realized during this investigation, except for the influence of the last circle. If the results of the tests with the lower cell pressures are considered to be somewhat less than their true value due to volume changes, this effect is slightly more pronounced. Nevertheless, no generalizations can be made using the results obtained. A more thorough investigation is necessary. Such an investigation may prove Coulomb's equation, which assumes a straight line relationship, not to be applicable to peat within certain stress ranges.

Pore Pressures:

Pore pressures induced during any one test follow, in general, the shape of the deviator stress curve. In many cases, the induced pore pressures are in excess of 90% of the cell pressures. Similar results are reported elsewhere (Adams, 1961; Hanrahan, 1954); therefore, this seems to be a general trend in peat.

Pore pressures at maximum deviator stress during any one test are very close in magnitude to the induced maximum pore pressures.

The induced high pore pressures at failure have the influence of plotting the effective stress circles very close to the origin on the Mohr diagram. This influence renders the assignment of an effective angle of shearing resistance and cohesion a rather arbitrary choice.

Pore Pressure Parameters:

The high values obtained for the pore pressure parameter B are not believed to be representative of in-situ conditions. Some saturation during sampling and possibly during storage of the samples may have occured.

The A_f values are in the range commonly associated with normally consolidated clays.

Whereas induced pore pressures are high, they are limited by the magnitude of cell pressures. As compressive strengths are in excess of cell pressures within the stress ranges used during this investigation, relatively low values for the pore pressure parameter A_f are obtained. In spite of high pore pressures, these relatively low A_f values indicate a stable structure. This aspect is further substantiated by the fact that both the deviator stresses and the pore pressures retain their values without substantial decrease with an increase of strain.

The Unique Relationship Between Water Content and Strength:

The importance of water content on shearing strength of peat has been indicated. Radforth conducted cone penetration tests on peat to measure strength. There was no definite tendency for an increase in strength with depth as in clays; this was accompanied by a variation in strength horizontally. However, the strength of peat could qualitatively be guessed with respect to drainage. For example, more

strength can be utilized on peat closer to a drainage face. This relationship between water content and strength observed in the field was also realized during this laboratory investigation. For example, test results of samples run at cell pressures of 0.50 kg./cm.^{2} and 0.70 kg./cm.^{2} indicated closer compressive strengths than was expected (0.71 kg./cm.^{2} and 0.79 kg./cm.^{2} respectively) as can be seen from the Mohr circles in Fig. #7. It was found that their water contents were almost the same (401% and 398% respectively).

Fig. #9B shows the relationship between water contents and compressive strengths. If the data plotted is represented by a curve that decreases in slope with the increase in compressive strength, this means that less water need be expelled to increase the strength (after a certain stress range) than clayey soils in which case the same relationship is a straight line (Henkel, 1960; Casagrande and Rivard, 1959). This can be used to further the point that different water-solid phase relationships govern the structure of peat under stress than mineral soils in that water is an integral part of what is considered to be the solid phase in peat.

Vector Curves:

Fig. #10 shows the results of the tests on a single plot in terms of vector curves. These vector curve shapes are indicative of normally consolidated soils with compressive behaviour during shear when applied to clayey soils. It is shown that the same relationships hold for peat.

When strain contours are superimposed on vector curves, these can be used to predict approximate strains expected during loading as these curves show the stress history on the plane of failure. This feature is useful with peat as it was shown that peat has a stable structure over long ranges of strains which renders the possibility of including strains as a design criterion even in short term loading conditions.

Fig. #11 shows the influence of water contents on stress paths taken by the samples.

Microscopic Analysis:

The microscopic examination showed the amorphous granular material to be the most commonly encountered element that formed the structure of this peat. These generally ranged from 0.1 to 5 microns. Therefore, a high colloidal activity is probable. A unique property of colloidal particles is their large surface areas. As, in general, organic colloids have a high affinity for water, the colloidal phenomenon may be the chief cause of the high water content of peat.

In general, the microscopic examination showed a high density as well as a fairly high fibrosity ratio. The fibrous axes were mostly nonwoody. These fossilized organs formed an important part of the structure of the peat and may act as the supporting media for the structure.

Main body of the cells were identified as being sedges. The lack of moss cells are probably due to their being less resistant than sedge type cells and not due to their original absence. There was a general absence of leafy tissues which may also be due to mechanical breakdown as well as bacterial action.

The large number of fungi encountered were generally associated with tissues in a state of disintegration. Apparently at that level in the bog, cellulose was dynamically being broken down. In general, during early stages, mainly living tissues are decomposed. Usually lignified tissues are preserved for a much longer time. In grass roots, where the pericycle, the phloem and the parenchyma are decomposed during early stages of humification, lignified cells of the cortex and the xylem vessels are preserved. The general rapid humification observed in this peat obtained only from 2 to 3 foot depth indicated the significance of colloidal activity in general, which may be expected to increase with depth. Additional loads may help the breakdown and thus increase the amount of colloidal sized particles. The chemical nature of these micronodules is a determining factor in their colloidal activity. Nevertheless as these are, in general, at various stages of humification, a generalization may be difficult. The general behaviour of the structure will not be only colloidal. Above mentioned fossilized plant organs determine the fibrous activity. The behaviour of the fibres in turn is partly determined by the behaviour of their cell structure. For instance, the strength of the fibres is influenced by the amount of water expelled from these cells under stresses. In any case, significant

changes in the structure can be expected (both in relation to colloidal activity and the behaviour of macro-organisms) as water is expelled from peat under stresses.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Acceptance of peat as just another kind of soil and application of the knowledge and the experience gained from investigations on mineral soils without any questioning is far from rational; before any application of the principles of Soil Engineering to peat is undertaken, their applicability must be questioned. During this investigation, the applicability of Coulomb's equation, which has been successful in expressing the strength of mineral soils since 1776, was questioned. Although there was no definite deviation from the straight line relationship, some indications were observed. Because this could have been due to the variability of peat samples, as with other results no definite conclusions could be drawn. A more thorough investigation is needed in this respect.

The triaxial compressive test results indicated water content to be a key issue to the estimation of strength and the understanding of peat. In addition, there was some indication that different water content relationships governed the strength of peat than those for clayey soils. Therefore, further investigations should give precedence to this aspect. For instance, a research on the contributions of the various kinds of water held in peat to measured high pore pressures may be of assistance in the

understanding of the behaviour of peat structure under stresses.

In an investigation of the shear strength of peat by triaxial testing, some deviation from standard procedures are necessary such as the anisotropic consolidation to precede the isotropic consolidation in the triaxial chamber; otherwise shearing stage is conducted with a distorted sample. Use of larger samples than 1.4 in. by 2.8 in. may help reduce the effects of non-homogeneity. A continuous check against an initial eccentricity is necessary. Time lag can be expected when measuring pore pressures. Side drains cut from good quality filter paper are of practical assistance. More sensitive pressure measuring devices than used during this investigation will be of great assistance. This aspect can not be overemphasized.

The microscopic investigation of the structure of the peat which accompanied the macroscopic investigation was useful in examining the structure of peat per se. It is improbable that the influence of stressing on the structure of peat can be investigated using thin sections due to great variability of the components of peat. A uniform element upon which attention could be concentrated was lacking. Even within this relatively young peat, the cell structure is seldom encountered; and when cells are encountered not only do the cells that belong to various plant organs vary, but also cells within any one tissue may vary. Therefore, no single element could be identified which occured all along within different samples so that thin sections of unstressed

and stressed samples could be compared on this basis.

Examination of thin sections enabled a very objective estimate of fibrosity and density; however, behaviour of fibres during shearing, though hypothesized, could not be observed.

Although by thin section method an estimation of the various kinds of water held within peat structure could be assessed rather than simply hypothesized, a three dimensional view of the structure and the means of an estimation of colloidally held water are lacking.

The microscopic investigation of the structure of peat can be conducted more successfully by combining an examination of the structure by using a microscope capable of utilizing reflected light on the desired planes of peat with an examination using thin sections by the modified paraffin infiltration method which was shown to be the only method available with no disturbance of the original arrangement of peat samples. Even for examination with transmitted light, a better quality microscope than that which this examination was conducted will be of great help especially for higher magnifications.

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APPENDIX

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 1

Cell Pressure = 0.4 kg./cm.^{2}, Sample Dimensions = 2.6 in. x 1.4 in.

Area = 9.73 cm.^{2}

Proving Ring Sensitivity: 0.0001 in. = 0.125 lbs.

Pore Pressure (kg./cm.^{2})	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress (kg./cm.^{2})
0.00	0.000	0.0000		
0.01	0.010	0.0002	0.38	0.013
0.02	0.020	0.0004	0.75	0.023
0.02	0.030	0.0008	1.12	0.046
0.04	0.040	0.0021	1.46	0.121
0.05	0.050	0.0028	1.82	0.160
0.07	0.060	0.0036	2.17	0.205
0.09	0.070	0.0041	2.53	0.233
0.11	0.080	0.0048	2.89	0.270
0.13	0.090	0.0052	3.26	0.293
0.14	0.100	0.0057	3.63	0.320
0.15	0.110	0.0061	3.99	0.341
0.16	0.120	0.0064	4.38	0.356
0.18	0.130	0.0067	4.74	0.372
0.19	0.140	0.0070	5.12	0.387
0.21	0.150	0.0072	5.49	0.396
0.22	0.160	0.0075	5.86	0.411
0.23	0.170	0.0076	6.25	0.415

(Continued....)

TRIAXIAL COMPRESSION TEST DATA: NO. 1 (Continued)

Pore Pressure ($kg./cm.^2$)	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress ($kg./cm.^2$)
0.24	0.180	0.0079	6.62	0.423
0.25	0.190	0.0080	7.00	0.434
0.26	0.200	0.0082	7.38	0.442
0.27	0.210	0.0083	7.76	0.451
0.28	0.220	0.0085	8.13	0.455
0.29	0.230	0.0086	8.52	0.458
0.30	0.240	0.0087	8.90	0.462
0.31	0.280	0.0089	10.43	0.465
0.32	0.300	0.0089	11.96	0.457
0.33	0.340	0.0090	12.73	0.458
0.34	0.380	0.0091	14.26	0.455
0.35	0.400	0.0091	15.03	0.452
0.35	0.440	0.0091	16.57	0.443
0.35	0.460	0.0091	17.34	0.438

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 2

Cell Pressure = 1.00 kg./cm.^{2}, Sample Dimensions =2.4 in. x 1.4 in.,

Area = 9.73 cm.^{2}

Pore Pressure (kg./cm.^{2})	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress (kg./cm.^{2})
0.00	0.000	0.0000	0.00	0.000
0.00	0.010	0.0004	0.40	0.023
0.01	0.020	0.0010	0.79	0.058
0.02	0.025	0.0027	0.93	0.156
0.05	0.030	0.0040	1.08	0.230
0.06	0.035	0.0051	1.25	0.294
0.08	0.040	0.0060	1.42	0.345
0.11	0.050	0.0077	1.76	0.439
0.14	0.055	0.0083	1.94	0.474
0.16	0.060	0.0089	2.12	0.508
0.20	0.070	0.0103	2.49	0.585
0.24	0.080	0.0114	2.73	0.646
0.26	0.085	0.0118	3.00	0.668
0.28	0.090	0.0122	3.25	0.688
0.31	0.100	0.0129	3.62	0.724
0.34	0.110	0.0136	4.01	0.761
0.36	0.120	0.0141	4.41	0.786
0.38	0.125	0.0143	4.61	0.795
0.39	0.130	0.0146	4.81	0.810

(Continued....)

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 2 (Continued)

Pore Pressure ($kg./cm.^2$)	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress ($kg./cm.^2$)
0.40	0.135	0.0148	4.92	0.820
0.42	0.140	0.0149	5.21	0.823
0.44	0.150	0.0153	5.61	0.842
0.46	0.160	0.0156	5.85	0.856
0.47	0.170	0.0160	6.41	0.873
0.50	0.180	0.0165	6.81	0.896
0.53	0.200	0.0172	7.62	0.926
0.56	0.220	0.0179	8.42	0.955
0.61	0.260	0.0189	10.04	0.991
0.67	0.300	0.0198	11.67	1.018
0.70	0.350	0.0207	13.72	1.041
0.79	0.400	0.0215	15.77	1.055
0.80	0.450	0.0221	17.83	1.058
0.82	0.500	0.0232	19.86	1.083
0.82	0.550	0.0223	21.99	1.014
0.82	0.560	0.0222	22.40	1.004
0.82	0.580	0.0224	23.23	0.998
0.82	0.600	0.0226	24.05	1.000

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 3

Cell Pressure = 0.25 kg./cm.^{2}, Sample Dimensions = 2.8 in. x 1.4 in.

Area = 9.93 cm.^{2}

Pore Pressure (kg./cm.^{2})	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress (kg./cm.^{2})
0.01	0.005	0.0005	0.18	0.0285
0.02	0.010	0.0007	0.36	0.0398
0.03	0.015	0.0010	0.54	0.0568
0.05	0.020	0.0013	0.71	0.0738
0.06	0.025	0.0016	0.89	0.0905
0.07	0.030	0.0018	1.07	0.1017
0.07	0.035	0.0020	1.25	0.1128
0.08	0.040	0.0022	1.43	0.1238
0.10	0.050	0.0026	1.78	0.1458
0.10	0.060	0.0029		
0.12	0.070	0.0032	2.50	0.1781
0.14	0.100	0.0039	3.57	0.2147
0.15	0.115	0.0045	4.11	0.2464
0.15	0.120	0.0045	4.29	0.2460
0.16	0.140	0.0049	5.00	0.2658
0.17	0.150			
0.17	0.160			
0.18	0.170			
0.19	0.180			
0.20	0.190			

(Continued....)

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 3 (Continued)

Pore Pressure ($kg./cm.^2$)	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress ($kg./cm.^2$)
0.20	0.200	0.0056	7.14	0.2969
0.20	0.210	0.0059	7.50	0.3116
0.20	0.220	0.0060	7.86	0.3157
0.20	0.230	0.0061		
0.20	0.250	0.0062	8.92	0.3201
0.21	0.300	0.0063	10.71	0.3216
0.21	0.420	0.0067	15.60	0.3229
0.22	0.560	0.0071	20.00	0.3224

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 4

Cell Pressure = 0.40 kg./cm.^{2}, Sample Dimensions = 2.65 in. x 1.35 in.

Area = 9.24 cm.^{2}

Pore Pressure (kg./cm.^{2})	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress (kg./cm.^{2})
0.00	0.000	0.0000		
	0.005	0.0006	0.19	0.037
	0.010	0.0011	0.38	0.067
	0.020	0.0020	0.75	0.122
0.08	0.025	0.0025	0.94	0.152
0.10	0.030	0.0028	1.13	0.170
0.15	0.040	0.0034	1.51	0.206
0.18	0.050	0.0039	1.89	
0.21	0.060	0.0044	2.26	0.264
0.22	0.070	0.0049	2.64	0.292
0.24	0.080	0.0053	3.02	0.315
0.26	0.090	0.0056	3.40	0.332
0.27	0.100	0.0060	3.80	0.354
0.28	0.110	0.0062	4.15	0.364
0.30	0.120	0.0064	4.53	
0.31	0.130	0.0066	4.90	0.385
0.32	0.140	0.0067	5.28	0.387
0.32	0.150	0.0070	5.66	0.405
0.33	0.160	0.0072	6.04	0.415
0.33	0.170	0.0073	6.42	0.419

(Continued....)

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 4 (Continued)

Pore Pressure ($kg./cm.^2$)	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress ($kg./cm.^2$)
0.34	0.180	0.0076		
0.35	0.190	0.0079	7.17	0.450
0.37	0.200	0.0080	7.55	0.454
0.38	0.220	0.0082	8.30	0.461
0.39	0.240	0.0083	9.06	0.463
0.39	0.260	0.0083	9.81	0.460
0.40	0.280	0.0083	10.57	0.456
0.40	0.300	0.0083	11.32	0.452
0.40	0.320	0.0084	12.08	0.453
0.40	0.340	0.0086	12.83	0.460

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 5

Cell Pressure = 0.2 kg./cm.^{2}, Sample Dimensions = 2.8 in. x 1.4 in.

Area = 9.93 cm.^{2}

Sample drained from top and bottom.

Pore Pressure (kg./cm.^{2})	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress (kg./cm.^{2})
0.02	0.000	0.0000		
0.02	0.005	0.0004	0.18	0.023
0.03	0.010	0.0008	0.36	0.046
0.04	0.015	0.0011	0.54	0.063
0.05	0.020	0.0014	0.71	0.080
0.06	0.025	0.0016	0.89	0.090
0.07	0.030	0.0018	1.07	0.101
0.08	0.040	0.0021	1.43	0.118
0.09	0.050	0.0025	1.78	0.140
0.10	0.060	0.0028	2.14	0.156
0.12	0.070	0.0031	2.50	0.173
0.13	0.080	0.0034	2.86	0.189
0.14	0.090	0.0036	3.21	0.200
0.14	0.100	0.0038	3.57	0.209
0.15	0.110	0.0040	3.93	0.219
0.16	0.120	0.0043	4.29	0.235
0.17	0.130	0.0045	4.64	0.245
0.17	0.140	0.0047	5.00	0.255
0.17	0.150	0.0048	5.36	0.260

(Continued....)

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 5 (Continued)

Pore Pressure ($kg./cm.^2$)	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress ($kg./cm^2$)
0.18	0.160	0.0049	5.71	0.264
0.18	0.180	0.0050	6.43	0.268
0.19	0.200	0.0052	7.14	0.276
0.19	0.220	0.0055	7.86	0.289
0.19	0.240	0.0056	8.57	0.292
0.20	0.260	0.0059	9.28	0.306
0.20	0.280	0.0061	10.00	0.314
0.20	0.300	0.0065	10.71	0.331
0.20	0.320	0.0067	11.43	0.339
0.20	0.340	0.0068	12.14	0.341
0.20	0.360	0.0067	12.86	0.333
0.20	0.380	0.0066	13.57	0.325
0.20	0.420	0.0065	15.00	0.316

TRIAXIAL COMPRESSION DATA: TEST NO. 6

Cell Pressure = 0.70 kg./cm.^{2}, Sample Dimensions = 2.65 in. x 1.3 in.

Area = 8.56 cm.^{2}

Sample Drained from Top and Bottom

Pore Pressure (kg./cm.^{2})	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress (kg./cm.^{2})
0.07	0.000	0.0000	0.00	0.000
0.09	0.005	0.0006	0.19	0.039
0.10	0.010	0.0008	0.38	0.053
0.11	0.015	0.0009	0.57	0.059
0.11	0.020	0.0010	0.76	0.066
0.13	0.025	0.0015	0.94	0.098
0.15	0.030	0.0023	1.13	0.120
0.21	0.040	0.0035	1.51	0.228
0.24	0.050	0.0048	1.89	0.312
0.27	0.055	0.0053	2.08	0.344
0.29	0.065	0.0061	2.45	0.394
0.32	0.075	0.0067	2.83	0.431
0.34	0.085	0.0073	3.21	0.468
0.38	0.100	0.0080	3.77	0.510
0.39	0.110	0.0084	4.15	0.533
0.42	0.120	0.0088	4.53	0.566
0.43	0.130	0.0092	4.91	0.579
0.44	0.140	0.0096	5.28	0.602
0.46	0.150	0.0099	5.66	0.619

(Continued....)

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 6 (Continued)

Pore Pressure ($kg./cm.^2$)	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress ($kg./cm.^2$)
0.47	0.160	0.0102	6.04	0.635
0.49	0.180	0.0107	6.79	0.661
0.52	0.200	0.0112	7.54	0.686
0.53	0.210	0.0117	7.92	0.713
0.53	0.220	0.0120	8.30	0.729
0.55	0.240	0.0125	9.06	0.753
0.57	0.260	0.0128	9.81	0.764
0.57	0.280	0.0130	10.57	0.770
0.59	0.300	0.0131	11.32	0.770
0.60	0.320	0.0134	12.08	0.780
0.61	0.340	0.0136	12.83	0.785
0.61	0.360	0.0137	13.58	0.785
0.63	0.400	0.0140	15.09	0.788
0.63	0.440	0.0142	16.60	0.785

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 7

Cell Pressure = 0.30 kg./cm.^{2}, Sample Dimensions = 2.6 in. x 1.35 in.

Area = 9.23 cm.^{2}

Pore Pressure (kg./cm.^{2})	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress (kg./cm.^{2})
0.00	0.000	0.0000		
0.01	0.005	0.0002	0.19	0.012
0.02	0.010	0.0005	0.38	0.031
0.05	0.015	0.0010	0.58	0.061
0.07	0.020	0.0015	0.77	0.091
0.09	0.025	0.0020	0.96	0.122
0.09	0.030	0.0023	1.15	0.140
0.10	0.035	0.0026	1.35	0.158
0.11	0.040	0.0028	1.54	0.169
0.13	0.050	0.0032	1.92	0.193
0.14	0.060	0.0035	2.31	0.210
0.15	0.070	0.0038	2.69	0.227
0.16	0.080	0.0040	3.08	0.238
0.17	0.090	0.0042	3.46	0.250
0.18	0.100	0.0044	3.84	0.260
0.19	0.120	0.0048	4.61	0.281
0.20	0.140	0.0051	5.38	0.295
0.22	0.160	0.0053	6.15	0.306
0.23	0.180	0.0055	6.92	0.314
0.24	0.200	0.0057	7.69	0.323

(Continued....)

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 7 (Continued)

Pore Pressure ($kg./cm.^2$)	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress ($kg./cm.^2$)
0.24	0.220	0.0059	8.46	0.334
0.24	0.240	0.0060	9.23	0.336
0.25	0.260	0.0062	10.00	0.343
0.25	0.280	0.0063	10.77	0.345
0.26	0.300	0.0064	11.54	0.348
0.26	0.320	0.0065	12.31	0.350
0.26	0.340	0.0067	13.08	0.358
0.27	0.380	0.0068	14.62	0.358
0.27	0.400	0.0069	15.38	0.360
0.27	0.410	0.0070	15.77	0.362
0.28	0.420	0.0071	16.15	0.366
0.28	0.460	0.0072	17.69	0.364
0.28	0.470	0.0072	18.08	0.365
0.28	0.500	0.0073	19.23	0.368
0.28	0.520	0.0074	20.00	0.364
0.28	0.560	0.0074	21.54	0.360

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 8

Cell Pressure = 0.10 kg./cm.^{2}, Sample Dimensions = 2.8 in. x 1.4 in.

Area = 9.93 cm.^{2}

Filter Paper Drains Used

Pore Pressure (kg./cm.^{2})	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress (kg./cm.^{2})
0.00	0.000	0.0000	0.00	
0.01	0.005	0.0002	0.18	0.011
0.01	0.010	0.0004	0.36	0.023
0.01	0.015	0.0004	0.54	0.024
0.01	0.020	0.0005	0.71	0.030
0.02	0.025	0.0008	0.89	0.045
0.02	0.030	0.0008	1.07	0.046
0.03	0.035	0.0010	1.25	0.055
0.03	0.040	0.0011	1.43	0.062
0.04	0.050	0.0014	1.78	0.078
0.05	0.060	0.0016	2.14	0.089
0.05	0.070	0.0018	2.50	0.100
0.06	0.080	0.0020	2.86	0.111
0.06	0.090	0.0021	3.21	0.117
0.07	0.100	0.0023	3.57	0.127
0.07	0.110	0.0024	3.93	0.133
0.07	0.120	0.0025	4.29	0.137
0.08	0.150	0.0029	5.36	0.157
0.08	0.170	0.0031	6.07	0.167
0.09	0.200	0.0035	7.14	0.185
0.09	0.220	0.0036	7.86	0.190

(Continued....)

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 8 (Continued)

Pore Pressure ($kg./cm.^2$)	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress ($kg./cm.^2$)
0.09	0.240	0.0038	8.57	0.198
0.09	0.260	0.0039	9.28	0.203
0.09	0.280	0.0040	10.00	0.206
0.10	0.300	0.0041	10.71	0.210
0.10	0.320	0.0042	11.43	0.213
0.10	0.360	0.0045	12.86	0.224
0.10	0.400	0.0045	14.28	0.222
0.10	0.420	0.0046	15.00	0.223
0.10	0.460	0.0047	16.43	0.224
0.10	0.500	0.0048	17.86	0.225
0.10	0.520	0.0049	18.57	0.228
0.10	0.560	0.0049	20.00	0.224
0.10	0.600	0.0049	21.43	0.220
0.10	0.660	0.0049	23.57	0.214
0.10	0.700	0.0049	25.00	0.210

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 9

Cell Pressure: 0.20 kg./cm.^{2}, Sample Dimensions = 2.9 in. x 1.4 in.

Area = 9.93 cm.^{2}

Pore Pressure (kg./cm.^{2})	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress (kg./cm.^{2})
-0.01				
+0.00½	0.000	0.0000	0.00	
0.01	0.005	0.0003	0.17	0.017
0.02	0.010	0.0003	0.34	0.017
0.02	0.015	0.0004	0.51	0.023
0.03	0.020	0.0006	0.69	0.034
0.04	0.025	0.0010	0.86	0.056
0.05	0.030	0.0013	1.03	0.073
0.06	0.035	0.0016	1.21	0.090
0.07	0.040	0.0018	1.38	0.101
0.08	0.050	0.0022	1.72	0.123
0.09	0.060	0.0025	2.07	0.140
0.10	0.070	0.0029	2.41	0.156
0.11	0.080	0.0031	2.76	0.173
0.12	0.090	0.0033	3.10	0.183
0.13	0.100	0.0035	3.45	0.193
0.14	0.110	0.0036	3.79	0.198
0.14	0.120	0.0038	4.14	0.208
0.15	0.130	0.0040	4.48	0.218
0.15	0.140	0.0041½	4.83	0.225

(Continued....)

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 9 (Continued)

Pore Pressure ($kg./cm.^2$)	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress ($kg./cm.^2$)
0.15	0.160	0.0044	5.52	0.237
0.16	0.180	0.0047	6.21	0.251
0.17	0.200	0.0049	6.90	0.260
0.17	0.220	0.0051	7.59	0.269
0.18	0.240	0.0053	8.28	0.278
0.18	0.260	0.0055	8.97	0.286
0.18	0.280	0.0056	9.66	0.289
0.18	0.300	0.0058	10.34	0.297
0.18	0.320	0.0059	11.03	0.300
0.19	0.360	0.0061	12.41	0.305
0.19	0.400	0.0062	13.79	0.305
0.19	0.440	0.0063	15.17	0.305
0.19	0.450	0.0061	15.52	0.294
0.19	0.460	0.0060½	15.86	0.287

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 10

Cell Pressure = 1.30 kg./cm.^{2}, Sample Dimensions = 2.6 in. x 1.4 in.

Area = 10.00 cm.^{2}

Filter Paper Drains Used.

Pore Pressure (kg./cm.^{2})	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress (kg./cm.^{2})
0.05½	0.000	0.0000		
0.06	0.005	0.0006	0.17	0.034
0.06½	0.010	0.0011	0.38	0.062
0.07	0.015	0.0014	0.52	0.079
0.09	0.020	0.0029	0.65	0.107
0.11	0.025	0.0052	0.77	0.293
0.17	0.030	0.0075	0.87	0.422
0.22	0.035	0.0092	0.99	0.516
0.26	0.040	0.0108	1.12	0.605
0.38	0.050	0.0132	1.42	0.738
0.49	0.060	0.0154	1.72	0.858
0.54	0.070	0.0169	2.04	0.939
0.62	0.080	0.0183	2.37	1.013
0.71	0.090	0.0194	2.72	1.070
0.76	0.100	0.0205	3.06	1.126
0.86	0.120	0.0223	3.83	1.216
0.94	0.140	0.0238	4.47	1.289
1.00	0.160	0.0248	5.20	1.333
1.05	0.180	0.0261	5.84	1.394

(Continued....)

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 10 (Continued)

Pore Pressure ($kg./cm.^2$)	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress ($kg./cm.^2$)
1.10	0.200	0.0268	6.66	1.419
1.13	0.220	0.0276	7.40	1.449
1.18	0.240	0.0284	8.14	1.479
1.19	0.260	0.0290	8.88	1.498
1.22	0.290	0.0300	10.00	1.531
1.22	0.300	0.0302	10.38	1.537
1.23	0.340	0.0313	11.88	1.566
1.24	0.380	0.0329	13.35	1.616
1.25	0.400	0.0336	14.08	1.639
1.25	0.420	0.0342	14.84	1.654
1.25	0.440	0.0347	15.58	1.661
1.26	0.480	0.0355	16.73	1.675
1.27	0.520	0.0358	18.61	1.655
1.27	0.540	0.0364	19.38	1.664
1.30	0.580	0.0371	20.89	1.665
1.29	0.610	0.0374	22.03	1.666
1.28½	0.620	0.0373	22.42	1.641
1.27	0.630	0.0362	22.85	1.583
1.26	0.660	0.0345	23.99	1.487

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 11

Cell Pressure = 0.40 kg./cm.^{2}, Sample Dimensions = 2.8 in. x 1.4 in.

Area = 9.93 cm.^{2}

Filter Paper Drains Used.

Pore Pressure (kg./cm.^{2})	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress (kg./cm.^{2})
0.03	0.000	0.0000		
0.05	0.005	0.0005	0.18	0.029
0.07	0.010	0.0013	0.36	0.074
0.08	0.015	0.0019	0.54	0.108
0.09	0.020	0.0025	0.71	0.142
0.10	0.025	0.0029	0.89	0.164
0.13	0.030	0.0033	1.07	0.186
0.14	0.035	0.0037	1.25	0.209
0.16	0.040	0.0040	1.43	0.225
0.19	0.050	0.0046	1.78	0.258
0.21	0.060	0.0051	2.14	0.285
0.22	0.070	0.0056	2.50	0.312
0.23	0.080	0.0059	2.86	0.328
0.24	0.090	0.0062	3.21	0.343
0.26	0.100	0.0066	3.57	0.363
0.29	0.120	0.0072	4.29	0.393
0.30	0.140	0.0077	5.00	0.418
0.32	0.160	0.0080	5.71	0.431
0.33	0.180	0.0085	6.43	0.454
0.34	0.200	0.0088	7.14	0.467

(Continued....)

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 11 (Continued)

Pore Pressure ($kg./cm.^2$)	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress ($kg./cm.^2$)
0.35	0.220	0.0091	7.86	0.479
0.36	0.240	0.0094	8.57	0.491
0.36	0.260	0.0096	9.28	0.497
0.36	0.280	0.0098	10.00	0.504
0.37	0.320	0.0101	11.43	0.511
0.38	0.360	0.0101	12.86	0.505
0.38	0.400	0.0100	14.28	0.490
0.38	0.440	0.0098	15.72	0.474
0.38	0.480	0.0098	17.14	0.469
0.37	0.520	0.0096	18.56	0.446
0.37	0.560	0.0094	20.00	0.429

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 12

Cell Pressure = 0.30 kg./cm.^{2}, Sample Dimensions = 1.4 in. x 2.8 in.

Area = 9.93 cm.^{2}

Filter Paper Drains Used.

Pore Pressure (kg./cm.^{2})	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress (kg./cm.^{2})
0.00	0.000	0.0000		
0.00	0.005	0.0002	0.18	0.011
0.01	0.010	0.0004	0.36	0.023
0.01	0.015	0.0008	0.54	0.045
0.02	0.020	0.0013	0.71	0.074
0.04	0.025	0.0018	0.89	0.102
0.05	0.030	0.0022	1.07	0.125
0.06	0.035	0.0026	1.25	0.147
0.07	0.040	0.0029	1.43	0.163
0.08	0.050	0.0034	1.78	0.191
0.10	0.060	0.0038	2.14	0.212
0.12	0.070	0.0042	2.50	0.234
0.14	0.080	0.0046	2.86	0.255
0.15	0.090	0.0049	3.21	0.271
0.16	0.100	0.0052	3.57	0.286
0.17	0.110	0.0054	3.93	0.296
0.19	0.120	0.0056	4.29	0.308
0.20	0.140	0.0061	5.00	0.331
0.22	0.160	0.0064	5.71	0.345

(Continued....)

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 12 (Continued)

Pore Pressure ($kg./cm.^2$)	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress ($kg./cm.^2$)
0.23	0.180	0.0067	6.43	0.356
0.24	0.200	0.0069	7.14	0.367
0.25	0.220	0.0071	7.86	0.374
0.26	0.240	0.0073	8.57	0.382
0.27	0.260	0.0075	9.28	0.388
0.27	0.280	0.0076	10.00	0.391
0.27	0.300	0.0077	10.71	0.393
0.27	0.320	0.0077	11.43	0.391
0.27	0.340	0.0079	12.14	0.396
0.27	0.360	0.0080	12.86	0.401
0.27	0.380	0.0080	13.57	0.398
0.27	0.390	0.0080	13.93	0.393
0.27	0.400	0.0080	14.28	0.391
0.27	0.420	0.0079	15.00	0.384
0.27	0.440	0.0079	15.71	0.380

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 13

Cell Pressure = 0.25 kg./cm.^{2}, Sample Dimensions = 2.8 in. x 1.4 in.

Area = 9.65 cm.^{2}

Filter Paper Drains Used.

Pore Pressure (kg./cm.^{2})	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress (kg./cm.^{2})
0.01	0.000	0.0000	0.00	
0.01	0.005	0.0003	0.18	0.017
0.02	0.010	0.0008	0.36	0.047
0.04	0.015	0.0015	0.54	0.088
0.04	0.020	0.0023	0.71	0.134
0.07	0.030	0.0029	1.07	0.170
0.08	0.040	0.0033	1.43	0.194
0.10	0.050	0.0037	1.78	0.216
0.11	0.060	0.0041	2.14	0.236
0.12	0.070	0.0044	2.50	0.252
0.13	0.080	0.0046	2.86	0.265
0.14	0.090	0.0049	3.21	0.279
0.15	0.100	0.0051	3.57	0.289
0.16	0.120	0.0055	4.29	0.311
0.17	0.140	0.0059	5.00	0.333
0.18	0.170	0.0063	6.07	0.347
0.19	0.200	0.0065	7.14	0.349
0.19	0.220	0.0065	7.86	0.355
0.20	0.240	0.0066	8.57	0.357
0.20	0.260	0.0067	9.28	0.360

(Continued....)

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 13 (Continued)

Pore Pressure ($kg./cm.^2$)	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress ($kg./cm.^2$)
0.20	0.280	0.0068	10.00	0.362
0.21	0.300	0.0070	10.71	0.371
0.21	0.340	0.0072	12.14	0.372
0.21	0.350	0.0071	12.40	0.369
0.21	0.360	0.0070	12.86	0.357
0.21	0.380	0.0069	13.57	0.350
0.21	0.425	0.0069	15.18	0.343

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 14

Cell Pressure = 0.50 kg./cm.^{2}, Sample Dimensions = 2.8 in. x 1.4 in.

Area = 10.00 cm.^{2}

Filter Paper Drains Used.

Pore Pressure (kg./cm.^{2})	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress (kg./cm.^{2})
0.00	0.000	0.0000		
0.02	0.005	0.0002	0.18	0.014
0.03	0.010	0.0005	0.36	0.028
0.04	0.015	0.0012	0.54	0.067
0.06	0.020	0.0021	0.71	0.118
0.11	0.030	0.0034	0.96	0.191
0.14	0.040	0.0046	1.25	0.257
0.16	0.050	0.0055	1.61	0.307
0.18	0.060	0.0063	1.93	0.350
0.18	0.070	0.0068	2.25	0.377
0.21	0.080	0.0076	2.57	0.420
0.23	0.090	0.0082	2.93	0.451
0.25	0.100	0.0086	3.25	0.474
0.26	0.110	0.0090	3.61	0.495
0.28	0.130	0.0096	4.29	0.523
0.30	0.150	0.0102	5.00	0.549
0.31	0.160	0.0104	5.36	0.560
0.32	0.180	0.0109	6.04	0.581

(Continued....)

TRIAXIAL COMPRESSION TEST DATA: TEST NO. 14 (Continued)

Pore Pressure ($kg./cm.^2$)	Vertical Deflection Dial Reading (in.)	Proving Ring Deflection (in.)	Strain (%)	Deviator Stress ($kg./cm.^2$)
0.34	0.200	0.0113	6.75	0.600
0.36	0.220	0.0116	7.43	0.611
0.37	0.240	0.0119	8.14	0.622
0.37	0.260	0.0122	8.86	0.633
0.39	0.280	0.0125	9.54	0.643
0.40	0.300	0.0128	10.25	0.654
0.41	0.320	0.0131	10.82	0.663
0.42	0.340	0.0134	11.68	0.670
0.42	0.360	0.0136	12.36	0.676
0.43	0.380	0.0138	13.07	0.681
0.44	0.400	0.0140	13.78	0.686
0.44	0.420	0.0143	14.50	0.695
0.45	0.440	0.0146	15.18	0.700
0.45	0.460	0.0148	15.89	0.706
0.45	0.480	0.0149	16.61	0.706
0.45	0.500	0.0149	17.32	0.702
0.46	0.520	0.0149	18.04	0.698
0.46	0.540	0.0148	18.75	0.684
0.45	0.560	0.0145	19.46	0.663
0.45	0.580	0.0142	20.21	0.637
0.44	0.600	0.0141	20.93	0.614
0.44	0.620	0.0140	21.64	0.611
0.44	0.660	0.0139	23.07	0.606

Test Results in Tabular Form

Sample No.	σ_c (kg.cm.$^{-2}$)	$(\sigma_I - \sigma_{III})_{max}$ (kg./cm.^{2})	$\bar{\sigma}_{If}$ (kg./cm.^{2})	$\bar{\sigma}_{IIIf}$ (kg./cm.^{2})	ϵ_f (%) ϵ_{max} (%)	u_f u_{max} (kg./cm.^{2})	A_f	Initial Pore Pressure (kg./cm.^{2})	Water Content (%)
1	0.40	0.465	0.55	0.09	10.45 17.34	0.31 0.35	0.67		
2	1.00	1.083	1.26	0.18	19.86 24.05	0.82 0.82	0.76		
3	0.25	0.323	0.36	0.04	15.60 20.00	0.21 0.22	0.65		
4	0.40	0.463	0.47	0.01	9.06 12.83	0.39 0.40	0.84		
5	0.20	0.341	0.34	0.00	12.14 15.00	0.20 0.20	0.59		
6	0.70	0.788	0.86	0.07	15.09 18.11	0.63 0.63	0.80	0.07	384 405 398% 406
7	0.30	0.368	0.39	0.02	19.23 21.54	0.28 0.28	0.76	0.00	519 528 535% 558
8	0.10	0.228	0.23	0.00	18.57 25.00	0.10 0.10	0.44	0.00	616 638 659% 724

(Continued....)

(Continued)

Sample No.	σ_c (kg./cm.^{2})	$(\sigma_I-\sigma_{III})_{max}$ (kg./cm.^{2})	$\bar{\sigma}_{If}$ (kg./cm.^{2})	$\bar{\sigma}_{IIIf}$ (kg./cm.^{2})	ϵ_f (%) ϵ_{max} (%)	u_f u_{max} (kg./cm.^{2})	A_f	Initial Pore Pressure (kg./cm.^{2})	Water Content (%)	
9	0.20	0.305	0.31½	0.01	12.41 15.86	0.18½ 0.19	0.61	0.00½	570 466 690	575%
10	1.30	1.675	1.71	0.04	16.73 23.99	1.26 1.27	0.76	0.05½	315 312 320	316%
11	0.40	0.511	0.54	0.03	11.43 20.00	0.37 0.38	0.76	0.03½	443 469 456	456%
12	0.30	0.401	0.43	0.02½	12.86 15.71	0.27½ 0.27½	0.68	0.00	467 471 470	469%
13	0.25	0.372	0.41	0.04	12.14 15.18	0.21 0.21½	0.57	0.01	519 544 519	527%
14	0.50	0.706	0.76	0.05	15.89 23.07	0.45 0.46	0.64	0.00½	399 394 409	401%

Where:

σ_c = Cell pressure

$(\sigma_I-\sigma_{III})_{max}$ = Maximum deviator stress

$\bar{\sigma}_{If}$ Effective Maximum Principal Stress at Failure

(Continued....)

(Continued)

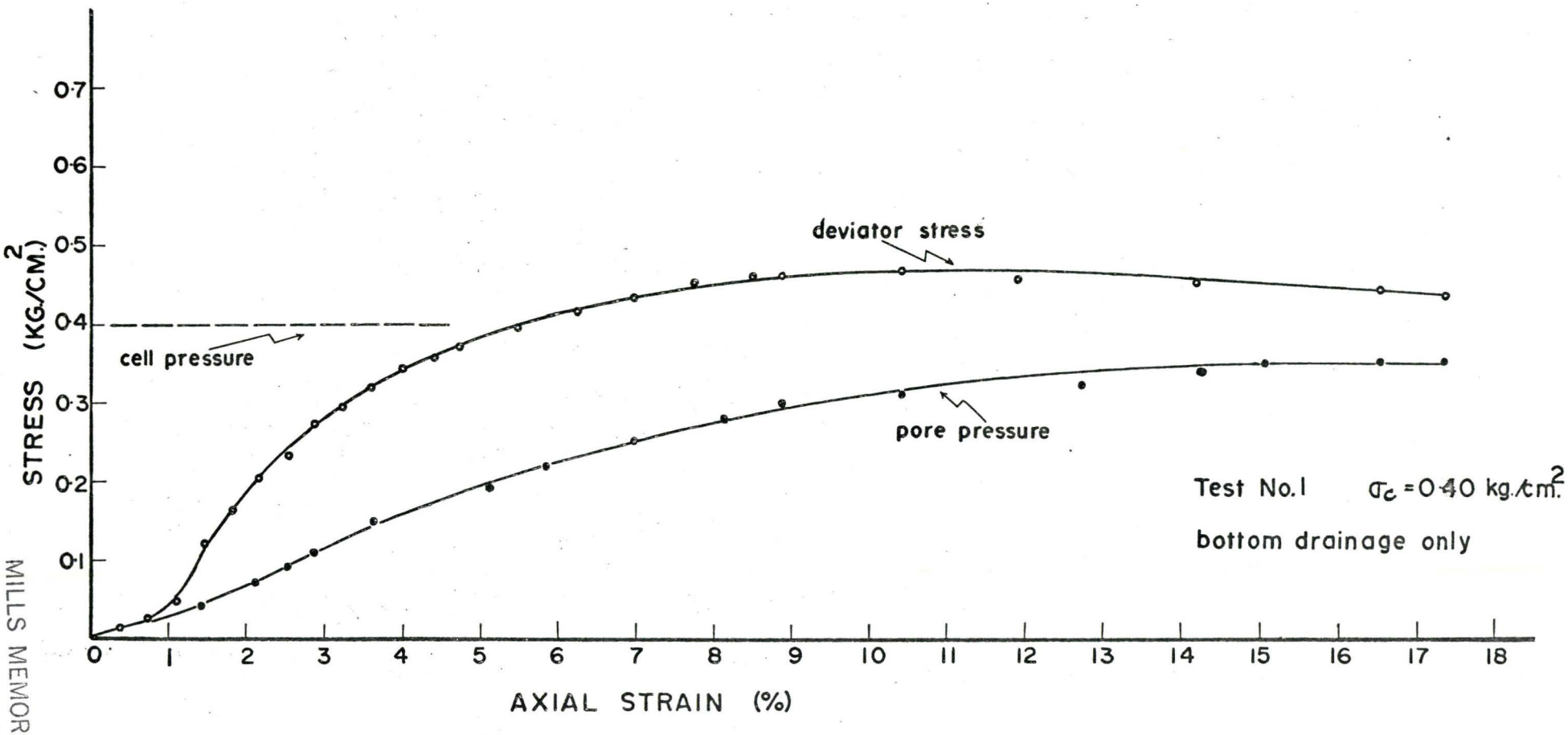
$\bar{\sigma}_{III_f}$ = Effective Minimum Principal Stress at Failure

ϵ_f = Strain at Failure

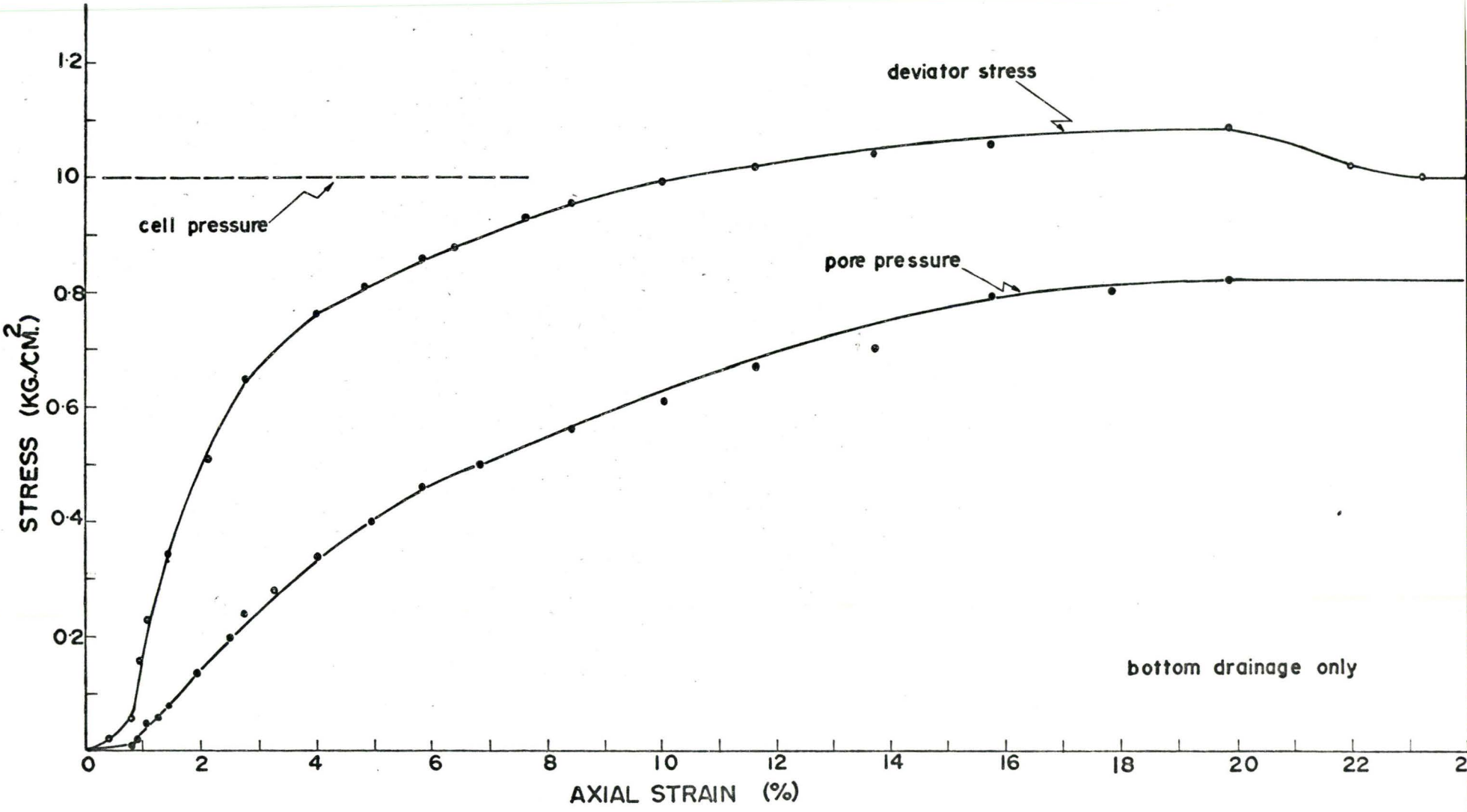
ϵ_{max} = Maximum Strain that the test was taken

u_f = Pore Pressure at Failure

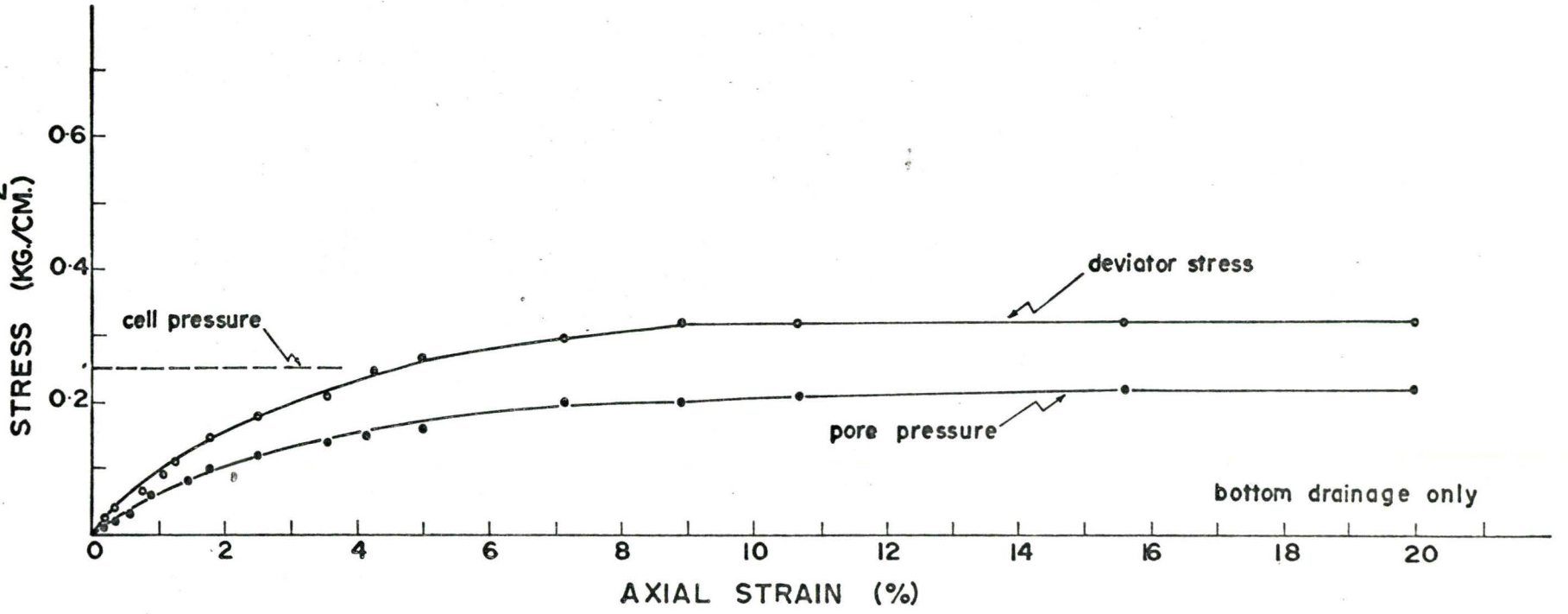
u_{max} = Maximum Pore Pressure induced during the test.



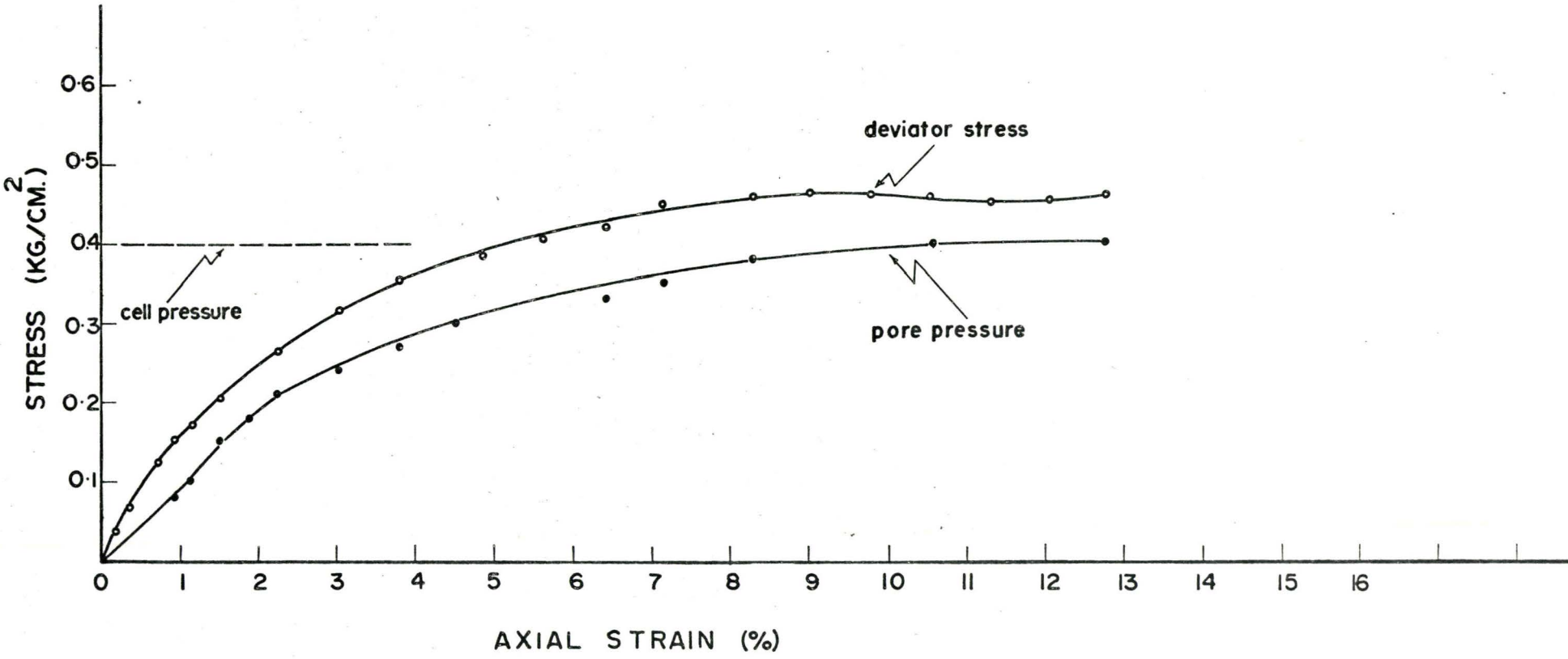
STRESS–STRAIN CURVE : TEST #1



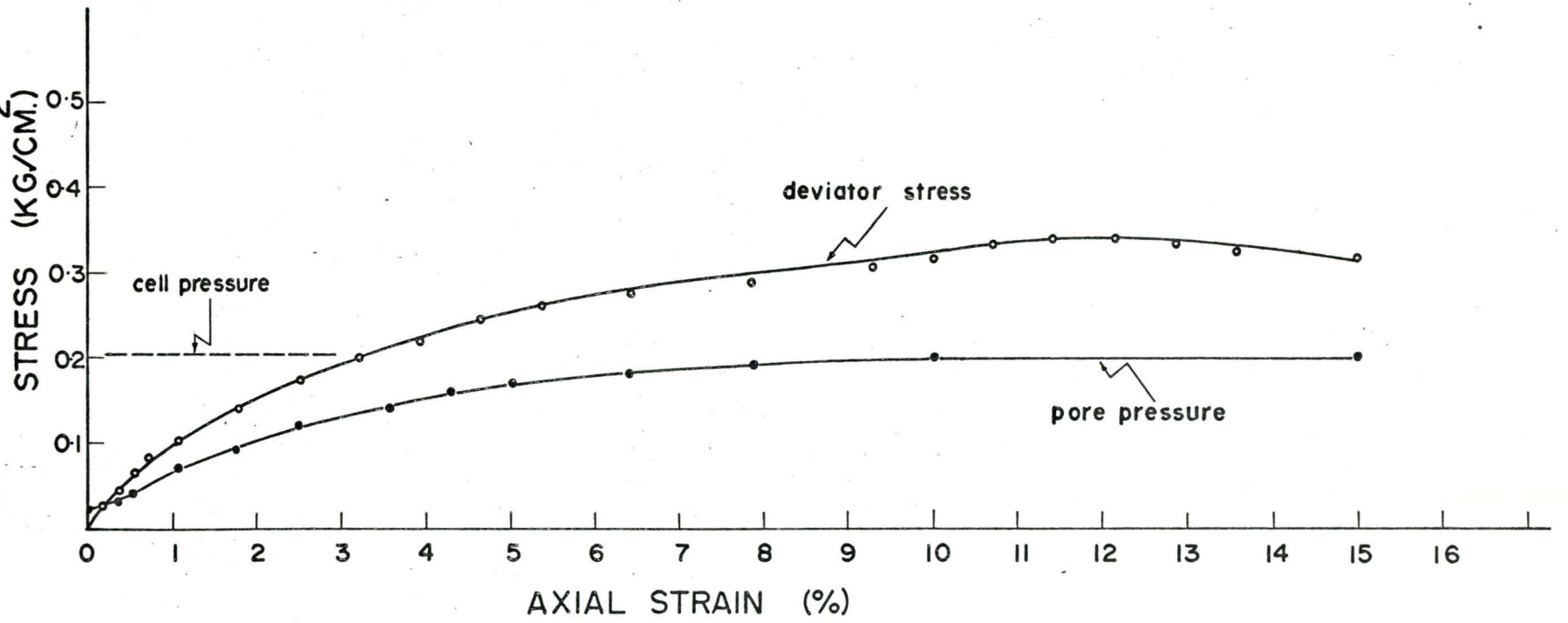
STRESS–STRAIN CURVE: TEST #2



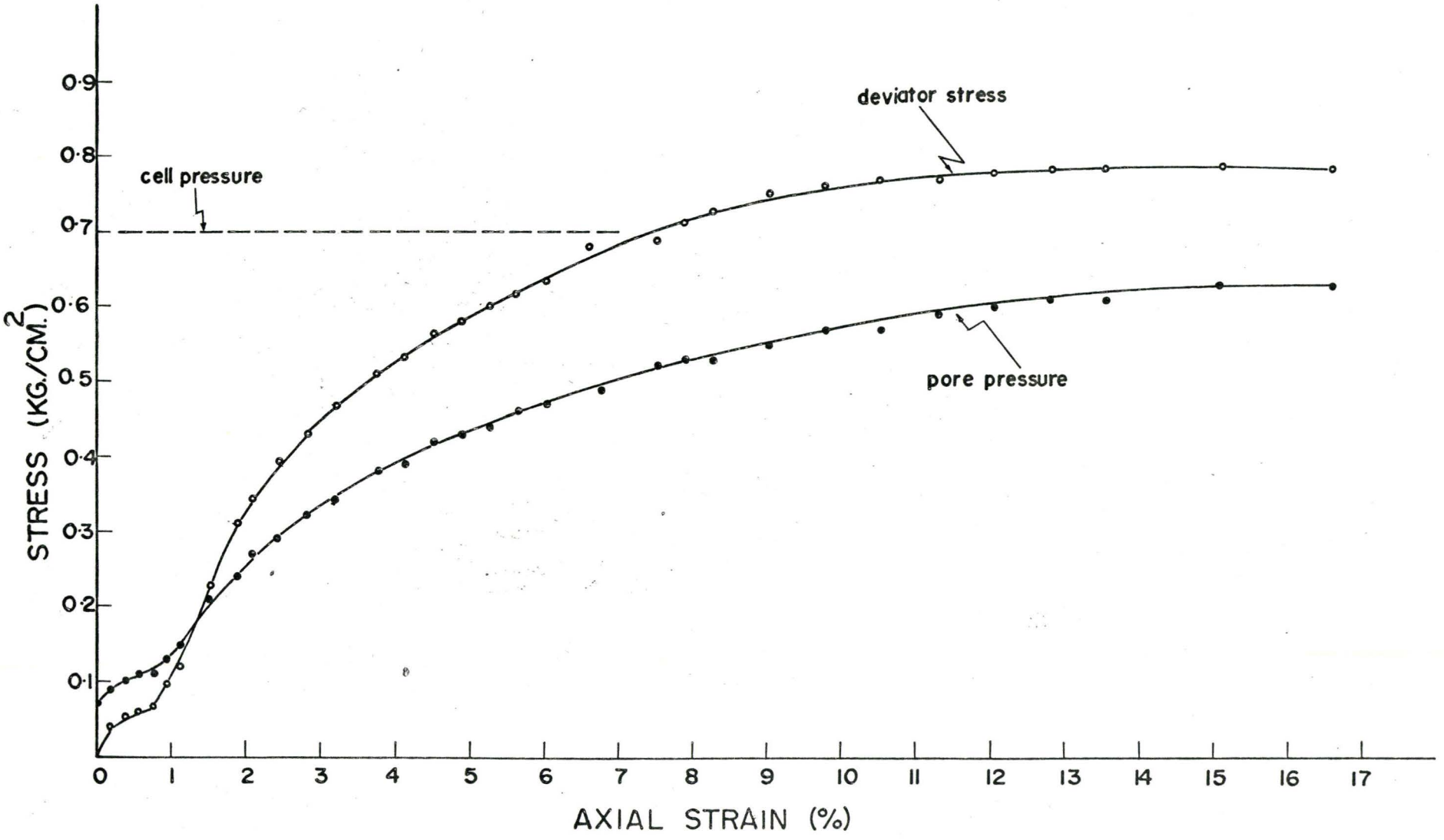
STRESS-STRAIN CURVE: TEST #3



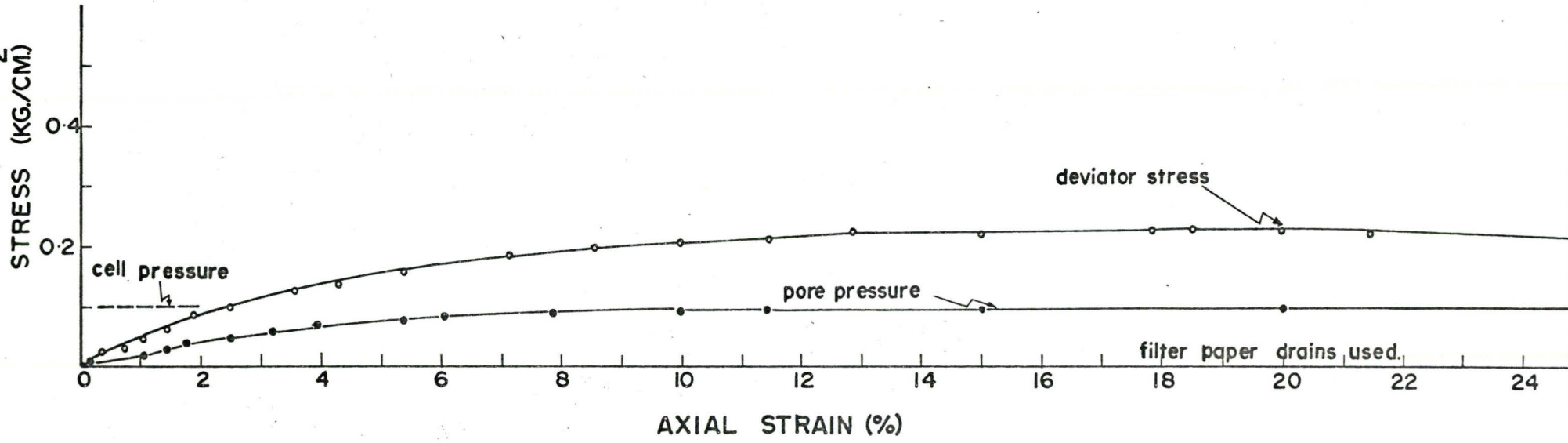
STRESS–STRAIN CURVE: TEST #4



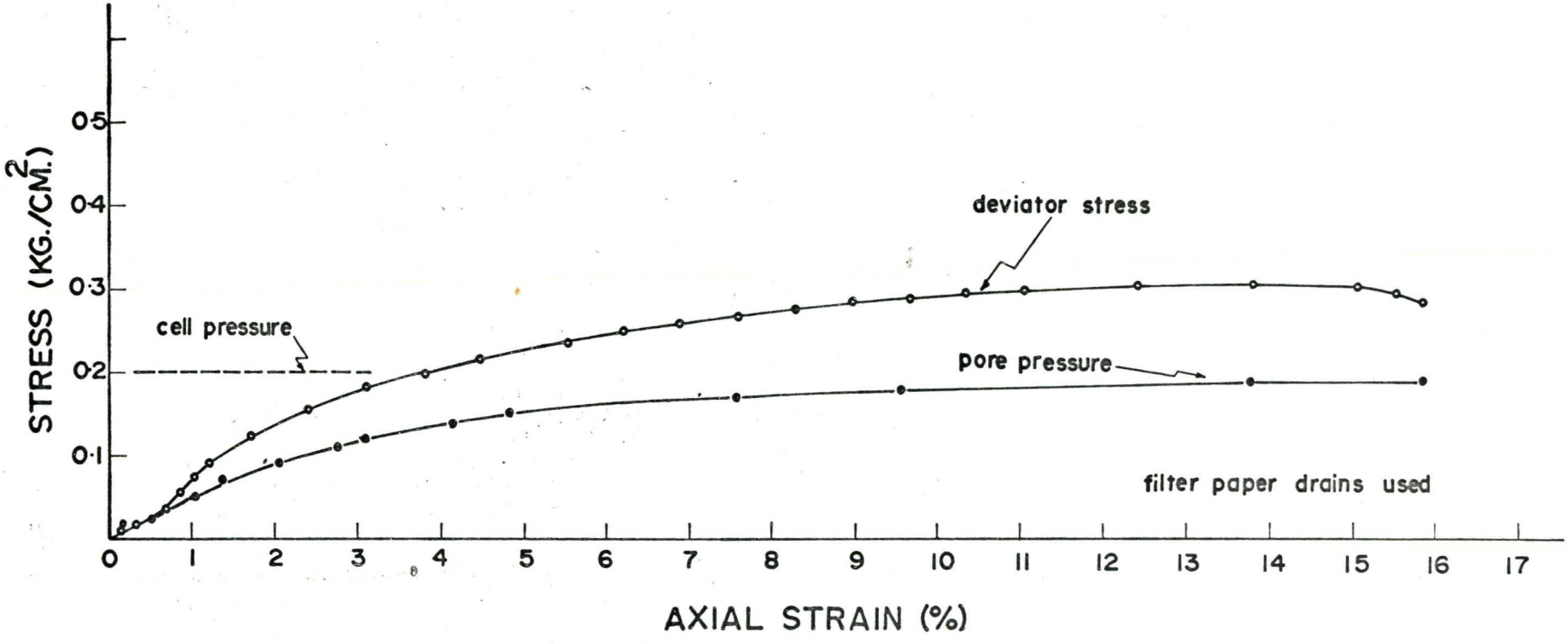
STRESS–STRAIN CURVE: TEST #5



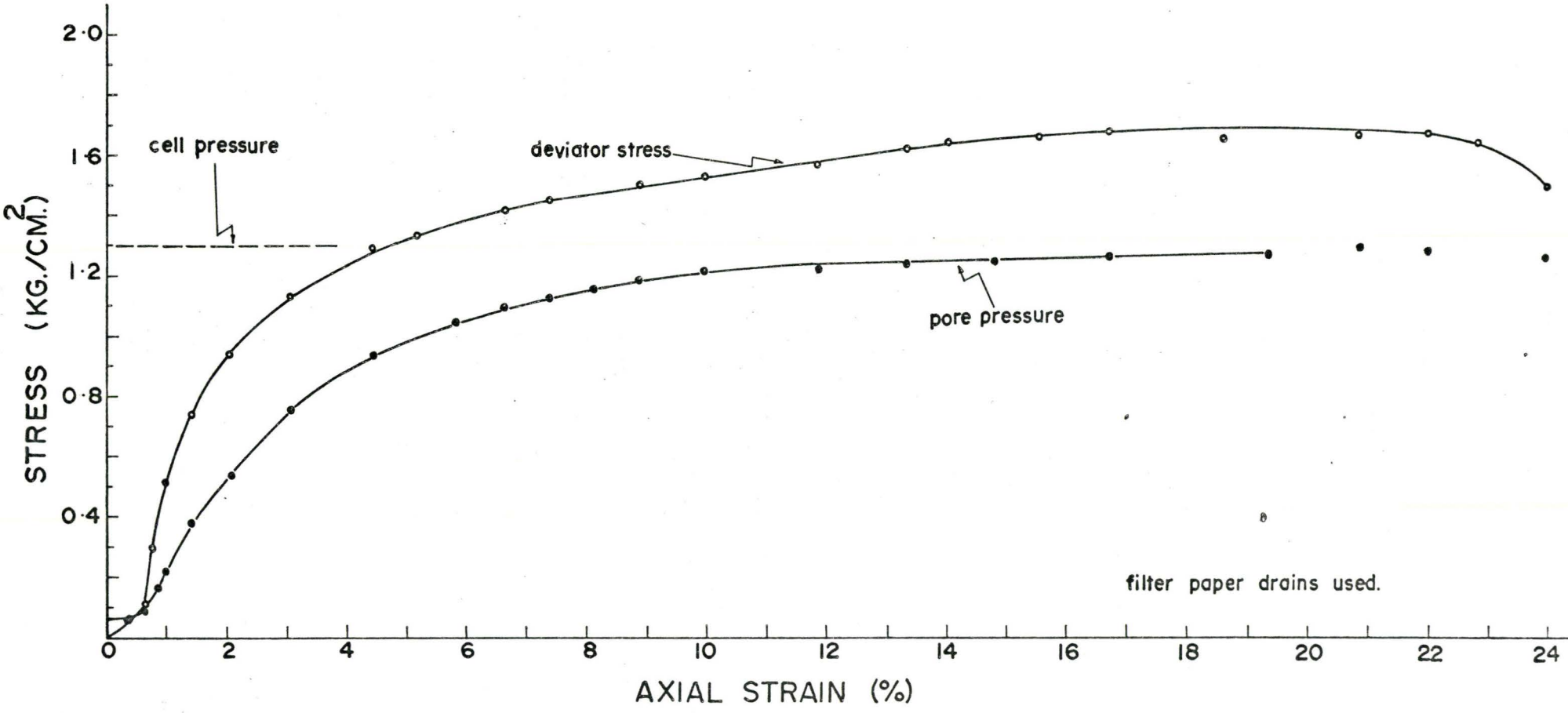
STRESS–STRAIN CURVE: TEST #6



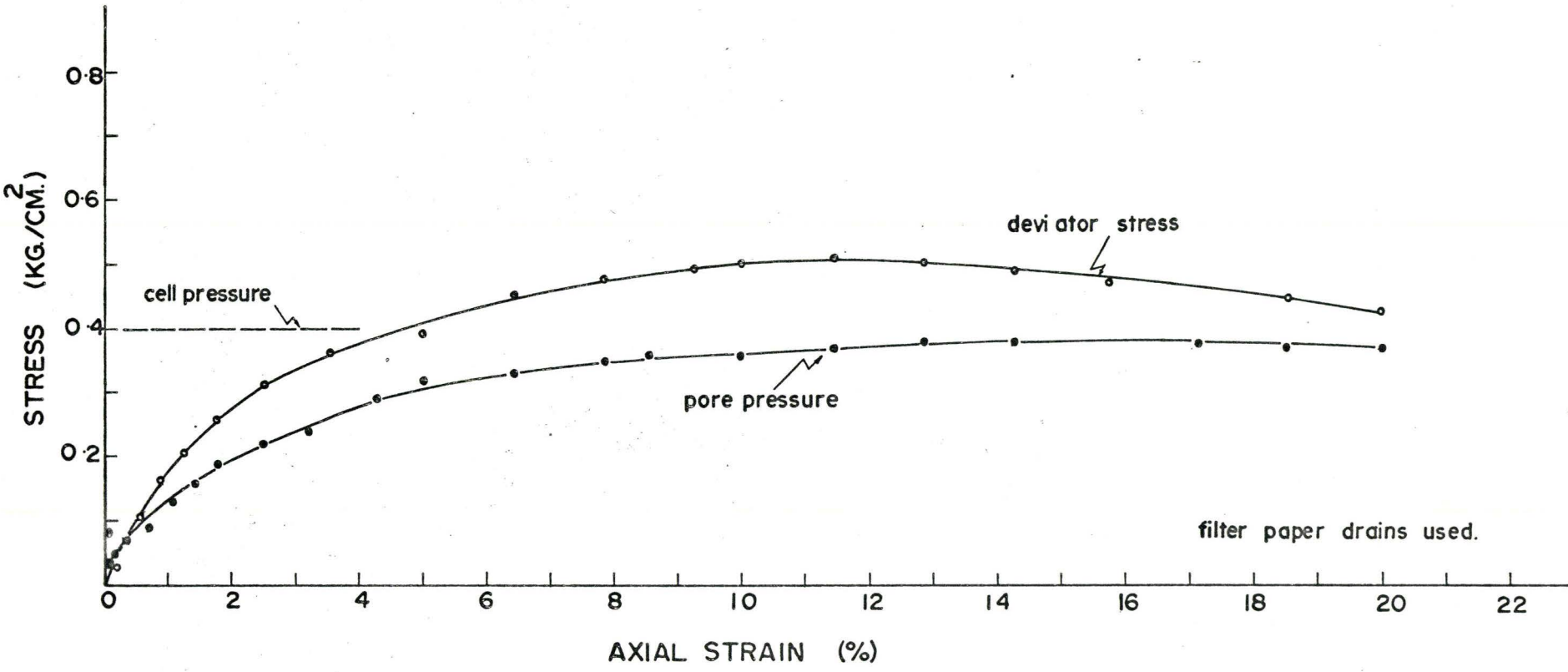
STRESS-STRAIN CURVE: TEST #8



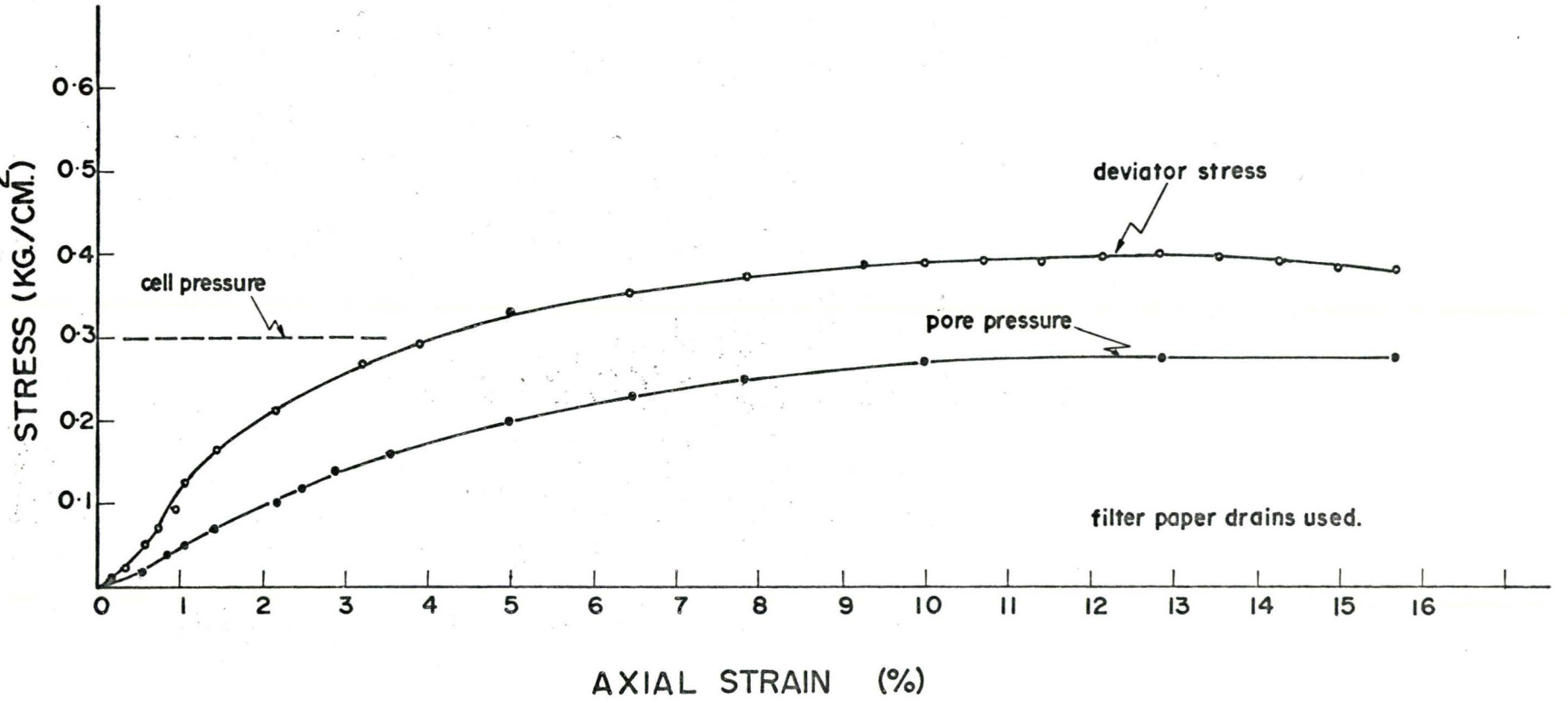
STRESS-STRAIN CURVE : TEST #9



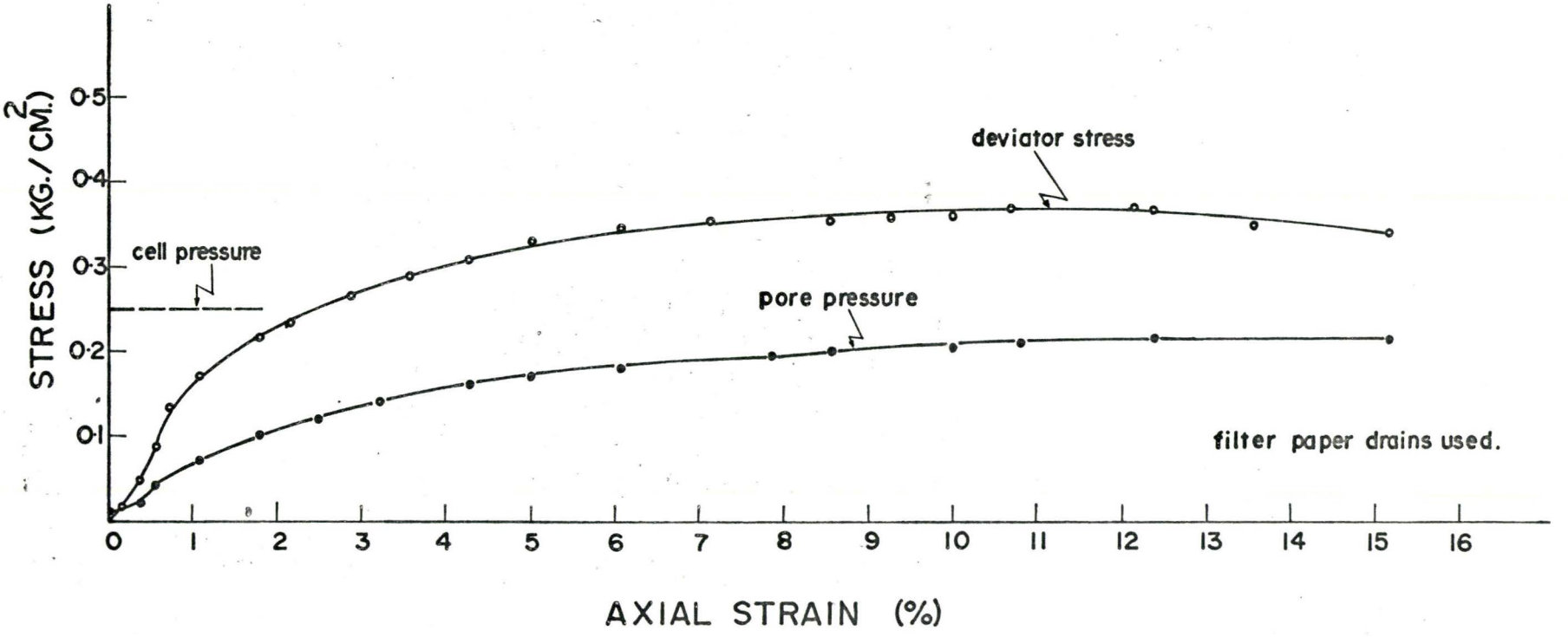
STRESS-STRAIN CURVE: TEST #10



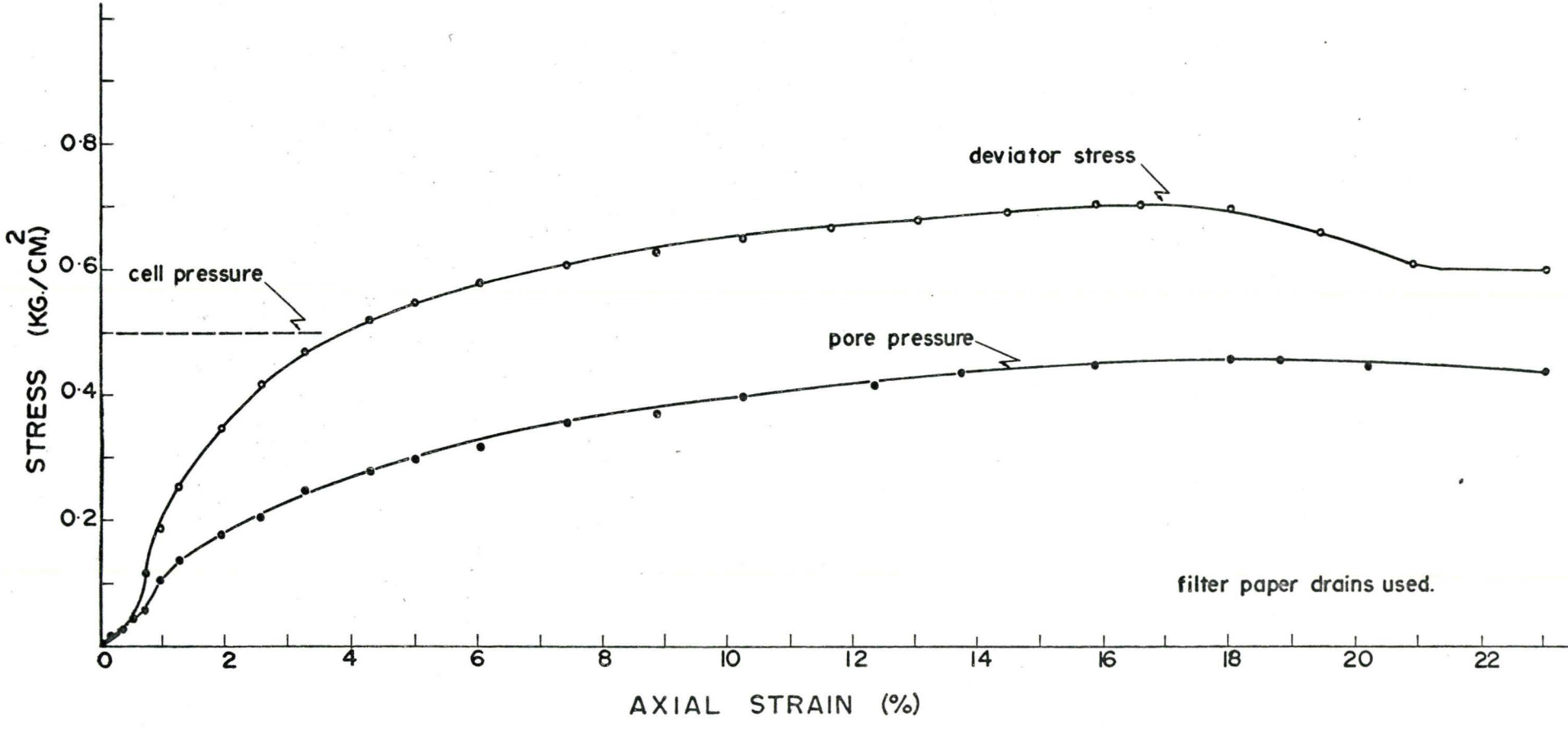
STRESS-STRAIN CURVE TEST #11



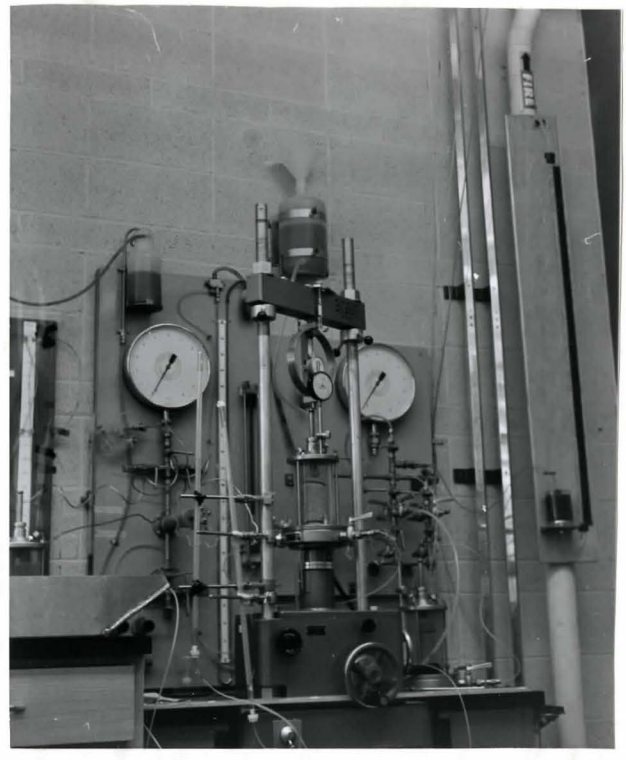
STRESS-STRAIN CURVE: TEST #12



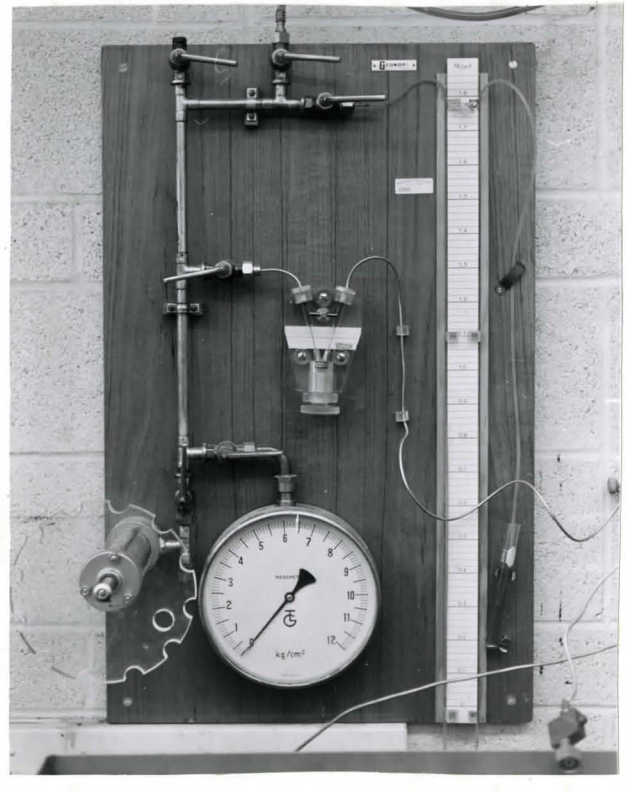
STRESS–STRAIN CURVE TEST #13



STRESS-STRAIN TEST: #14



Triaxial Testing Equipment



Pore Pressure Measuring Device

Preparation of Alcohol Solutions:

10% Alcohol - 10% Ethanol (95%)
90% Distilled water

30% Alcohol - 30% Ethanol (95%)
70% Distilled water

50% Alcohol - 40% Ethanol (95%)
10% Pure Tertiary Butanol
50% Distilled Water

70% Alcohol - 50% Ethanol (95%)
20% Pure Tertiary Butanol
30% Distilled Water

85% Alcohol - 50% Ethanol (95%)
35% Pure Tertiary Butanol
15% Distilled Water

95% Alcohol - 45% Ethanol (95%)
55% Pure Tertiary Butanol

100% Alcohol - 25% Ethanol (100%)
75% Pure Tertiary Butanol

HAUPT'S ADHESIVE:

- 1 gm. plain knox gelatin is dissolved in 100 cc. distilled water at 30°C.
- 2 gms. of Phenol crystals and 15cc. glycerin is added, stirred and filtered.