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# A study of stress distribution and measurement of axial strain around a pilot hole during overboring

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A STUDY OF STRESS DISTRIBUTION AND MEASUREMENT OF AXIAL STRAIN AROUND A PILOT HOLE DURING OVERCORING

BY

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## ABSTRACT

Stress distribution around a pilot hole during overcoring was investigated. A study of axial strain on the borehole surface was undertaken. Two-dimensional epoxy resin models were prepared and stress frozen in a centrifuge. The stress-frozen models were examined under a direct-viewing polariscope. The magnitude of axial strain and the effect of strain relaxation on the pilot hole were measured on blocks of brittle materials. Factors contributing to discing of core during the overcoring operation were investigated and a mechanism of failure postulated. The loading conditions simulating in situ, core and bit pressures were applied individually to the brittle models and axial strain readings were noted. Axial strain was found to be at a significant value and radical differences in stress levels were found within the overcored zone.

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# CHAPTER I

## INTRODUCTION

Relief techniques are commonly used to find the inherent stresses in highly loaded metal plates. In Rock Mechanics, the direction and magnitude of inherent techtonic forces in the strata can be measured by stress-relief techniques. Knowledge of stress distribution in the undisturbed rock is of prime importance to a design engineer as his concern is to increase the stability of the mine and reduce the risk of subsidence.

Considerable advances have been made towards establishing the effect of various parameters in calibrating the stress by overcoring relief techniques.* However, in the past, correlations between the various controlling factors were not thoroughly established. Therefore the purpose of this investigation is to determine the following:

(1) The effect of *in situ*, core load, and cutting tool pressure* on the amount of strain in the axial direction. This helps in designing a better and more accurate strain-measuring cell.

(2) The direction and magnitude of the stress field within and around a vertical core ring under the influence of body forces.

* See Appendix III for definitions.

(3) The distance and angle from the bottom of the overcore slot to a point reading zero axial strain on the surface of the pilot hole.

(4) The mechanism of failure causing core discing* during overcoring in highly stressed zones.

The mathematical solution of the stress distribution within and around the overcore bit was considered, but abandoned due to the complex configuration around core ring. A photoelastic method was applied to study the relative magnitude, direction, and nature of the stress pattern. Electrical foil strain gages were mounted on brittle models to measure axial strain.

* See Appendix III for definition.

# CHAPTER II

## REVIEW OF LITERATURE

During the past three decades numerous methods have been developed to determine magnitude and direction of *in situ* stress in strata by stress-relief techniques. Even today measurement of absolute *in situ* rock pressure in a strict sense is not possible. The moment an opening is created to insert a strain-measuring device, relaxation of the ground takes place, thus affecting strain readings.

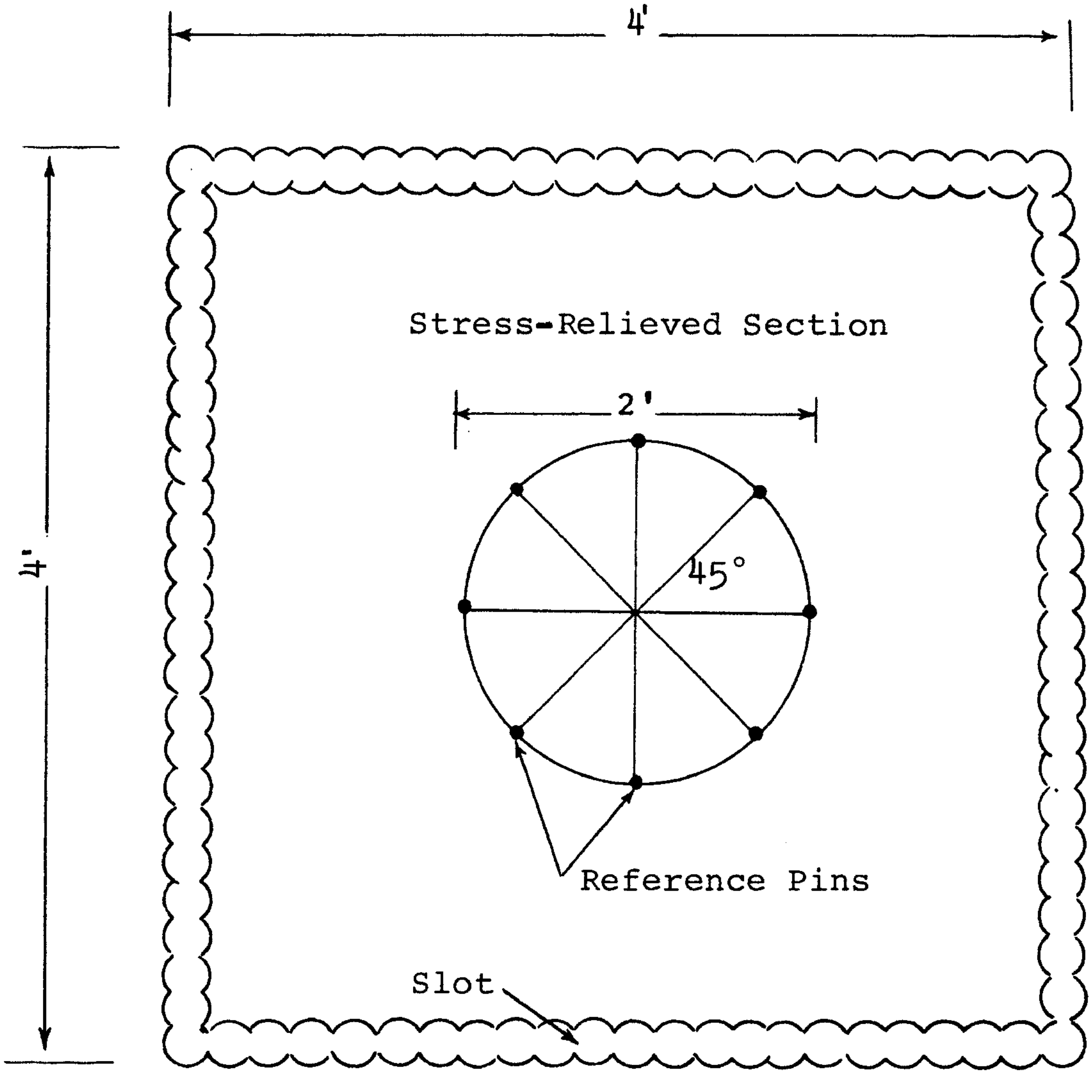
Merrill[1] says, "Stress relief techniques are methods or procedures of wholly or partially isolating a specimen of rock from the stress field . . ." In most of the experiments, *in situ* stress was relieved in the rock by isolating a rectangular or cylindrical specimen by drilling an annular ring of overlapping drill holes, by cutting the top of a pillar free from the roof, by isolating rock with a series of cuts with the cutting machine, and by overcoring the rock with diamond drilling.

Earlier stress-relief experiments were conducted in the United States by the Bureau of Reclamation. From the observations on the wall of a tunnel in the foundation of Boulder (Hoover) Dam, Lieurance[2] in 1933 reported that absolute strain measurement had been achieved by drilling a ring of overlapping holes around an area on which a mechanical strain-gage rosette was mounted as shown in the Figure 1.

Reference pins were placed in the wall of a tunnel and the distance between the pins was measured with a commercial extensometer calibrated in units of strain. The stress in the rock around the pins was relieved by cutting a slot with overlapping drill holes. The drill holes were 30 inches deep around all four sides of the section of rock containing the pins. The changes in distance between the reference pins was measured as the slot was cut. The modulus of elasticity was found in the laboratory from 3-inch diameter cores obtained from the relieved section of rock. Conventional strain rosette formulas were used to compute the stress in the rock. The main features of this study are the corrections made for stress concentrations around the tunnel and the determination of the ratio between the vertical and horizontal stress.

Obert[3] in 1938 produced strain-relief by cutting a mine pillar free from the roof. His investigations were confined to a large pillar instead of a localized small area as in the case of stress-relieving by overcoring.

In 1949 Olsen[4&5] improved Lieurance's stress-relief method by using resistance wire strain gages and relieving



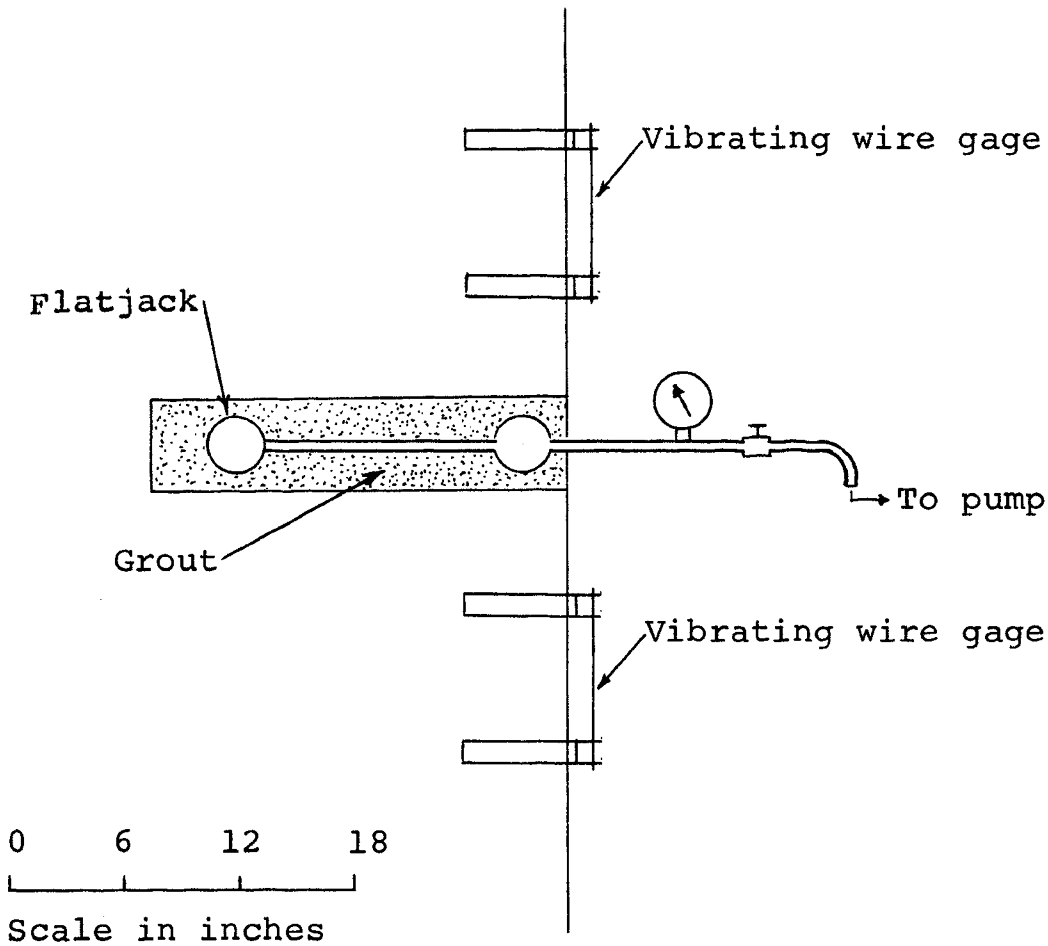

Relieved Section of Rock and Instrumented Points

Figure 1

the rock by overcoring with a relatively large diameter diamond core bit. However, the method applied by Lieurance was used to compute the stresses. The experiments were conducted in Prospect Mountain Tunnel and Gorge Tunnel in the Pacific north-west. Olsen tested his techniques by stress-relieving a large block of rock under uniaxial load in the laboratory. The results of this test showed good agreement between the computed and the applied stress. Later this method was applied in many stress-relief investigations.

A different approach to the problem of determining stress by relief techniques was first used extensively in France and Morocco by Tincelin[6], Mayer, Marchand, and Habib[7] in 1951. This approach consists of measuring the displacements in the rock created by cutting a nearby slot. A flatjack was cemented into the slot, and pressure applied to the hydraulic fluid in the cell until the displacements created by cutting the slot were cancelled by the pressure in the flatjack. The instrumentation layout is shown in the Figure 2. The pressure in the cell required to cancel the deformation in the rock is presumed to be equal to the stress in the rock before the slot was cut.

More recently[8,9,10,&11] the flatjack method has been used in the United States and Australia. Various instruments have been used to measure the deformation




Section of Flatjack and Instrumentation

Figure 2

in the rock as the slot was cut and the pressure at which the changes were candelled. Panek[12] used an embedded resistance wire strain gage. Tincelin and Mayer used reference pins and extensometers.

In 1958, Hast[13] reported a method of producing stress relief by concentrically overdrilling a one-inch diameter borehole in which a gage had been placed. The transducer in the gage was a nickel cell which varied in magnetostrictive properties with differences in applied stress. The changes in these properties in the cell were related to the stresses in rock through formulas, laboratory determined moduli of elasticity, and various calibration techniques.

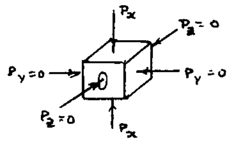
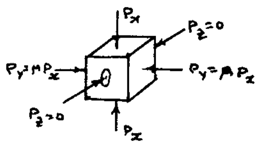
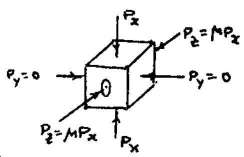
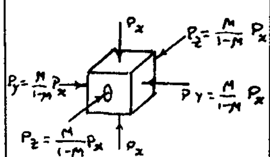
During the overcoring operation, Hast observed that the strain cell began to record changes in the stress when the bottom of the channel was 45° past the cell position. The stress concentrations at the bottom of the stress-release channel are thus distributed at an angle of about 45° to the axis of the hole.

Hast further states that during overcoring, core rings separated in places of extremely high rock pressure (1,000 to 1,500 Kg. per square centimeter) and where the rock was hard. The thickness of the core rings formed was between 0.5 and 5 centimeter and their surfaces were plain and smooth.

In 1957 Leeman[14&15] adopted the same technique as Hast but used a Maihak strain cell developed by H. Maihak, A. G. of Hamburg, Germany. He tabulated a group of formulas as shown in Figure 3 based on the theory of elasticity to calculate the changes in stress in solid rock from the change in borehole measurements for different stress orientations.

In 1958 and 1959 the United States Bureau of Mines[16,17,&18] developed a technique similar to Hast's. The change in deformation of the borehole, measured as the rock was overcored, was related to the stress in the rock by deformation rosette formulas and the laboratory-determined modulus of elasticity.

From the Bureau of Mines overcoring investigations, Obert[19,20,21,&22] reported that in moderately stressed rocks, the cores broke or fractured at comparatively regularly spaced intervals. However, thinner discs were obtained from higher-stress zones and thicker discs were produced in comparatively low-stress zones. These breaks occur on a plane normal to the axis of the core, and radial stresses required for discing are shown in Figure 4. It is evident from this figure that even at zero axial load, discing can be obtained with only radial stresses; contrary to this, axial stress alone cannot produce discing. He further states that by

| Case | Description | Stress | Strain | $P_x$ Vs U |
|---|---|---|---|---|
|  | Vertical stress with no lateral constraint | $P_x \neq 0$<br>$P_y = 0$<br>$P_z = 0$ | $e_x \neq 0$<br>$e_y \neq 0$<br>$e_z \neq 0$ | $P_x = \frac{1}{3 - 2\mu^2} \cdot \frac{Eu}{D}$ |
|  | Vertical stress with lateral constraint normal to borehole axis | $P_x \neq 0$<br>$P_y = \mu P_x$<br>$P_z = 0$ | $e_x \neq 0$<br>$e_y = 0$<br>$e_z \neq 0$ | $P_x = \frac{1}{(1+\mu)(3-4\mu+2\mu^2)} \cdot \frac{Eu}{D}$ |
|  | Vertical stress with lateral constraint parallel to borehole axis | $P_x \neq 0$<br>$P_y = 0$<br>$P_z = \mu P_x$ | $e_x \neq 0$<br>$e_y \neq 0$<br>$e_z = 0$ | $P_x = \frac{1}{3(1-\mu^2)} \cdot \frac{Eu}{D}$ |
|  | Vertical stress with lateral constraint in both lateral directions | $P_x \neq 0$<br>$P_y = \frac{\mu}{1-\mu} P_x$<br>$P_z = \frac{\mu}{1-\mu} P_x$ | $e_x \neq 0$<br>$e_y = 0$<br>$e_z = 0$ | $P_x = \frac{1}{(1+\mu)(3-4\mu)} \cdot \frac{Eu}{D}$ |

$P_x$ = Vertical pressure, normal to the axis of the borehole

$P_y$ = Horizontal pressure, normal to the axis of the borehole

$P_z$ = Horizontal pressure, parallel to the axis of the borehole

U = Change in borehole diameter in the vertical direction

V = Change in borehole diameter in the horizontal direction

$\mu$ = Poisson's ratio of rock

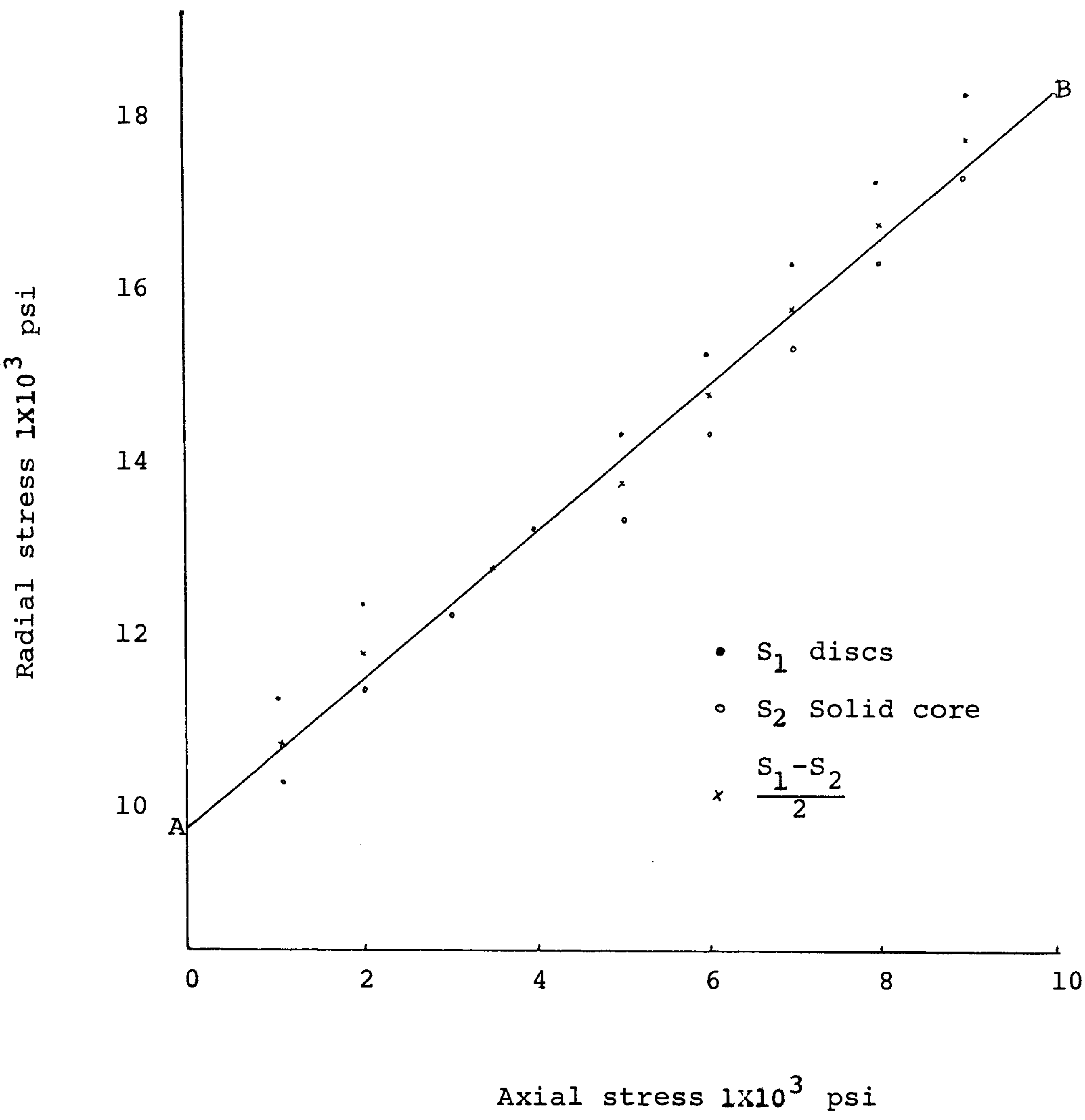
E = Young's modulus

D = Borehole diameter

$e_x$, $e_y$ & $e_z$ = Components of strain in 3 directions

Leeman's Stress Formulas

Figure 3




Radial and Axial Stress for Discing[21]

Georgia Granite

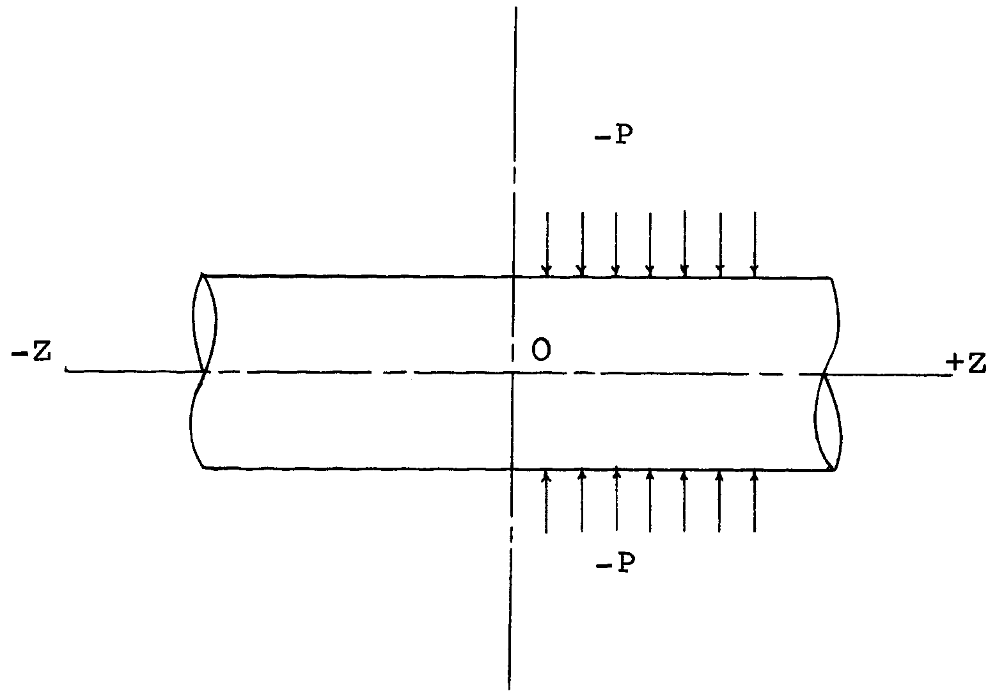
Figure 4

decreasing the pilot hole diameter, the 'OA' intercept in the figure decreases and the slope of the line AB increases. However, at zero axial load, intercept OA for various rocks has a linear relationship with the shear strength. This suggests that discing is initiated by shearing action.

Theoretical investigations conducted by Thanter and Craggs[23] indicate that the stress distribution in an infinite cylinder subjected to hydrostatic pressure from Z=0 to Z=+∞ and no load from A=0 to Z=-∞ are of tensile nature at a point just outside of the loaded zone. This tensile stress develops on the surface of the cylinder and is maximum on the axis of the cylinder.

Jaeger and Cook[24]experimentally investigated the discing mechanism by biaxially loaded cores in a pressure jacket sealed at the ends by 0-rings. Discing took place at random within the pressurized zone.

Experiments conducted by Obert, Jaeger, and Cook show that discing is produced by shear forces. However, according to Tranter and Craggs a tensile zone exists across the core.




Infinite Cylinder[23]

Figure 5

# CHAPTER III

# PHOTOELASTIC STUDIES

## A. INTRODUCTION

Photoelastic studies were used to determine the nature of the complicated stress pattern existing around an overcored borehole. Both qualitative and quantitative stress analyses were done on two-dimensional epoxy resin models simulating the borehole with a projection of overcore channel slots. The models were stress-frozen in a centrifuge under various loads and then examined in a direct-viewing polariscope.*

## B. EARLIER EXPERIMENTS

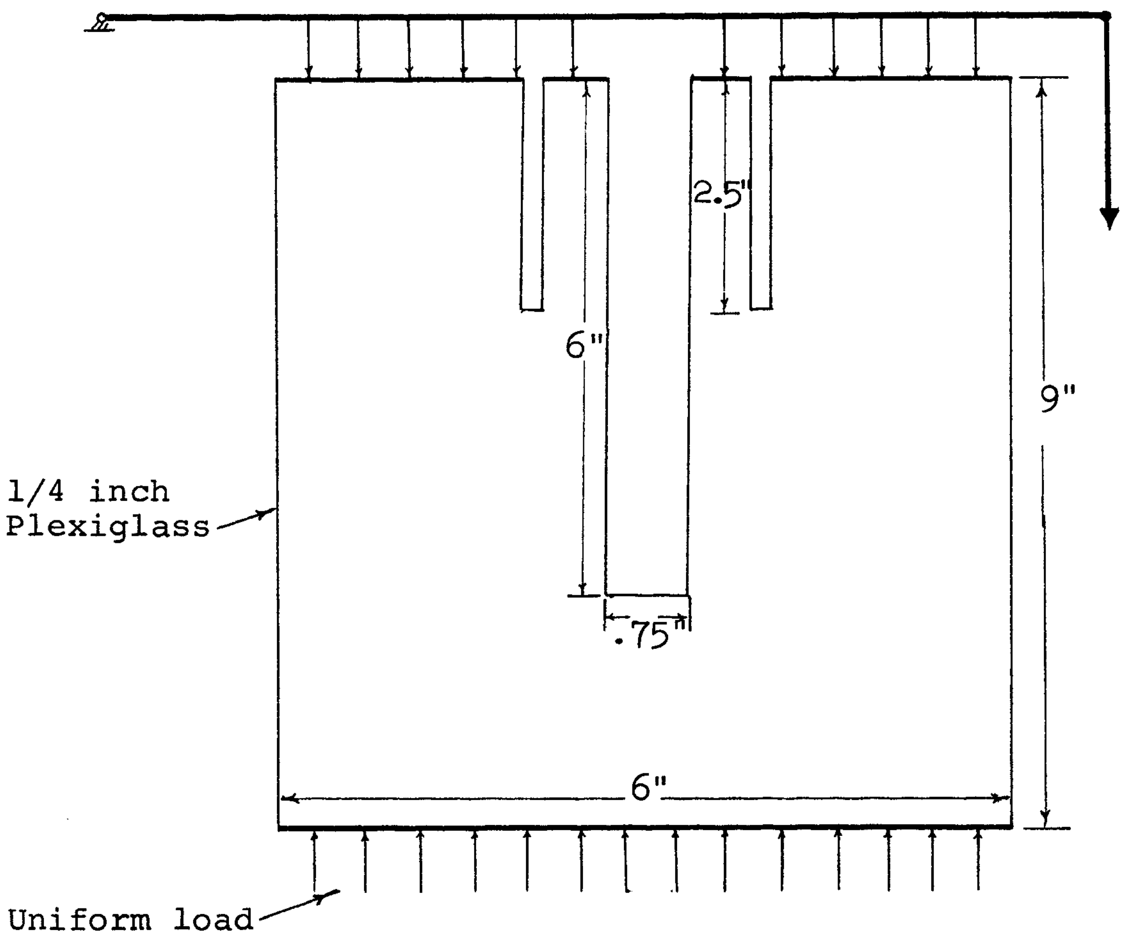
### 1. Plexiglass Sheet Model.

A quarter-inch thick plexiglass sheet was used to contruct a model. The model was cut into the shape shown in Figure 6 and was loaded to provide uniform pressure on each side of the model. However, this did not give sufficient fringes at a low load, and the model began to bend as the load was increased.

### 2. Three-Dimensional Epoxy Resin Model.

Subsequently, a three-dimensional epoxy resin model was cast to stress-freeze in the centrifuge. Four hours after casting the model developed cracks due to shrinkage.

* See Appendix III for definition.




Plexiglass Sheet Model

Figure 6

3. Two-Dimensional Epoxy Resin Model.

Finally, a two-dimensional model of cast resin was successfully developed. Results obtained from this model will be presented.

C. EXPERIMENTAL PROCEDURE FOR STRESS-FROZEN MODELS

1. Materials.

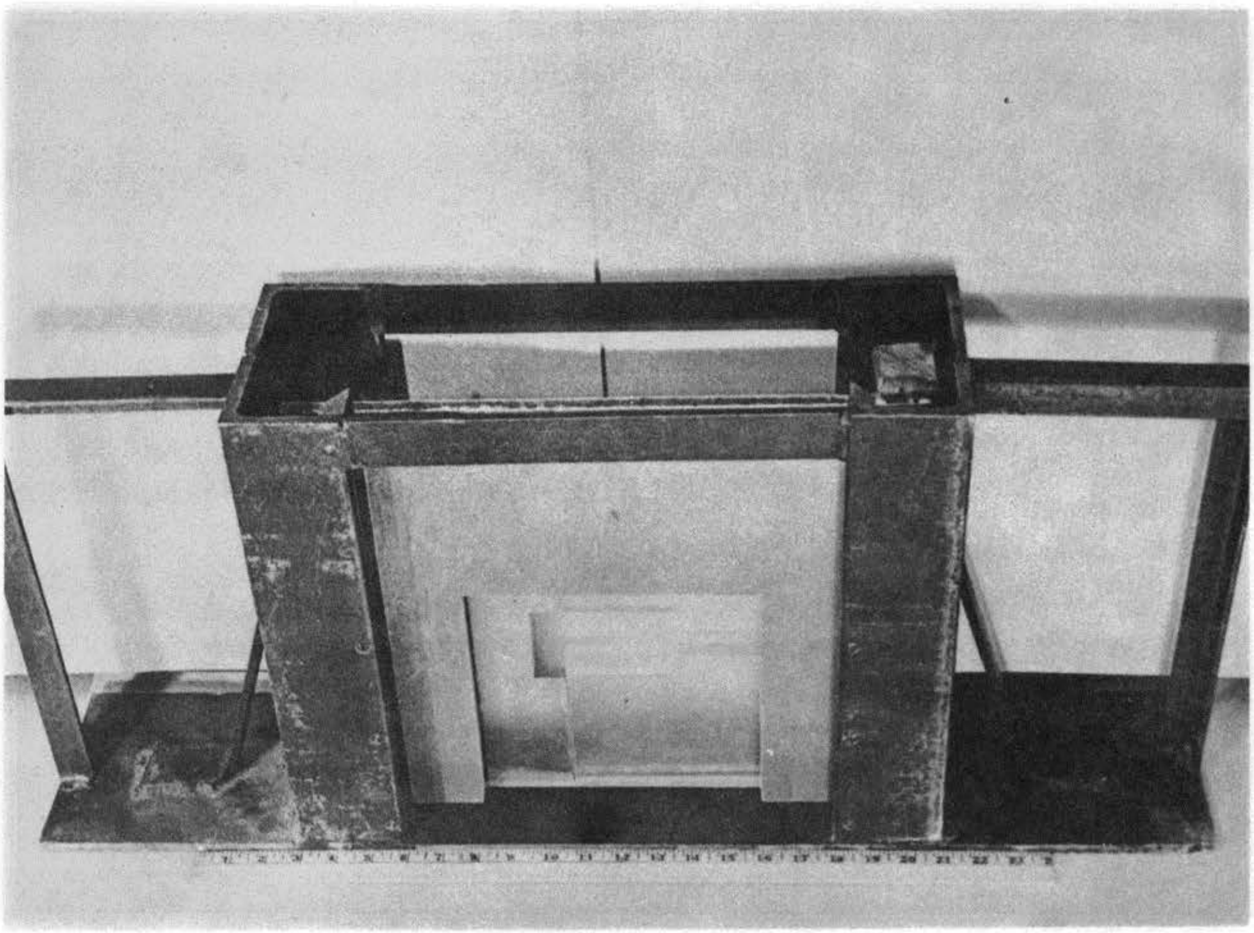
The photoelastic material used for the models was a clear organic epoxy resin, commercially called Araldite 502. This was mixed with a plasticiser (dibutyl phthalate) and a hardener (HN-951). The resultant mixture solidified into a soft plastic within 12 to 20 hours. As an exothermic reaction took place during curing, care was taken to provide adequate cooling. A standard mixture was used for all models. The material ratio by weight was:

| | | |
|---|---|---|
| Araldite 502 | -- | 72 parts |
| Dibutyl phthalate | -- | 20 parts |
| Hardener HN-951 | -- | 8 parts |

The mix was stirred for ten minutes and poured into a lucite mold, to make a 1/2-inch thick plate. The spoxy resin was allowed to cure for eleven hours and then it was cut to the required shape with a circular saw and a band saw.

2. Loading Of Model.

The model was placed in a general-purpose model holder for the centrifuge as shown in Plate 1. An inverted 'U'-shape steel plate was placed on the model during loading, and lucite plates were placed on each



Model Holder for Centrifuge

Plate 1

side of the model.

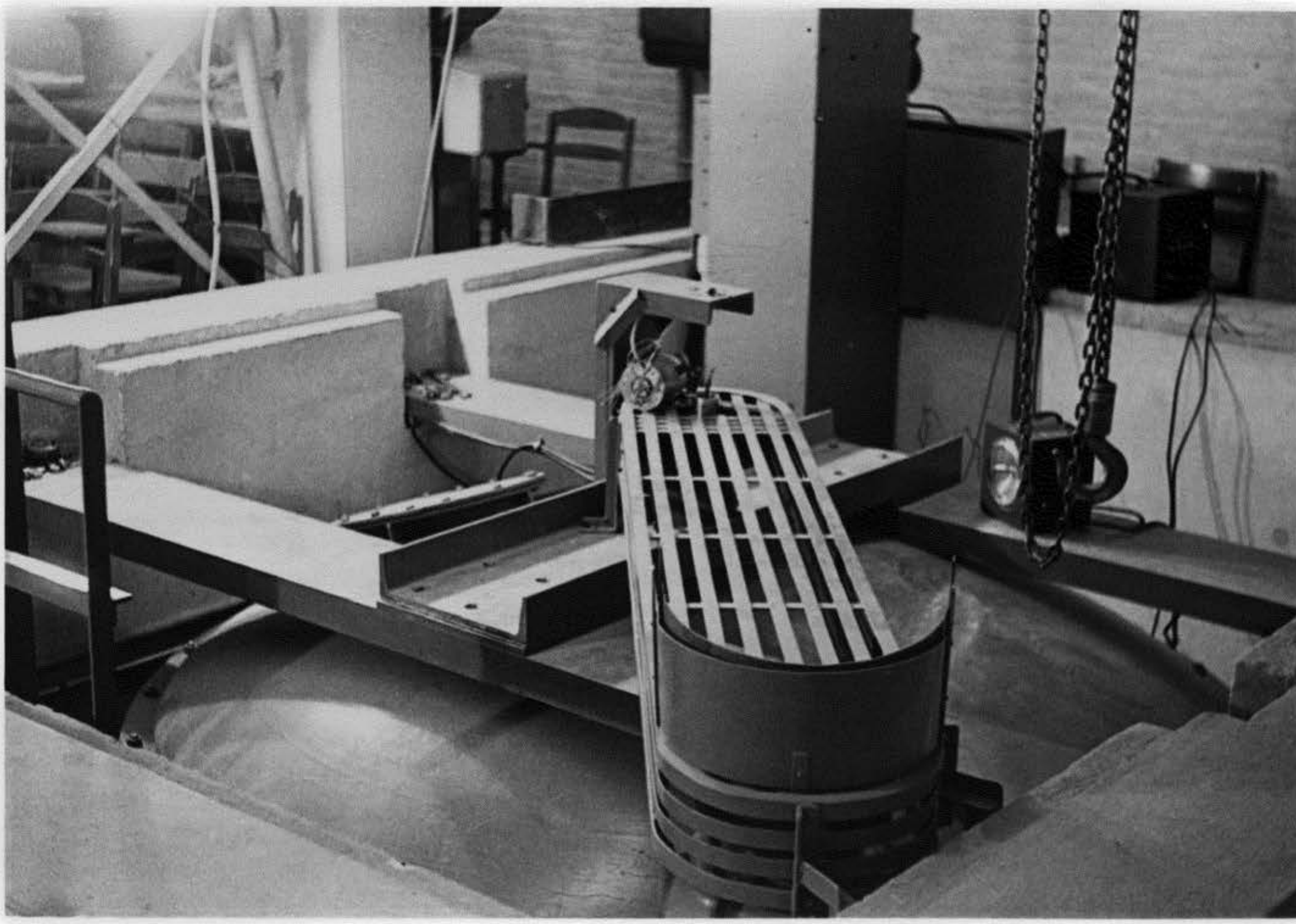
The model holder was balanced against a counterweight. Model holder and counterweight were placed on opposite ends of the centrifuge rotor. The manhole cover of the centrifuge was tightly bolted. A vacuum pump was connected to create a vacuum of 26 inches of mercury and this minimized air resistance on the rotor. The centrifuge is shown in Plate 3.

D. POLARISCOPE

After running for six hours the model was removed and examined in a standard polariscope as shown in Plate 3. Monochromatic light was used to photograph the fringes. The polariscope arrangement is shown in the Figure 7.

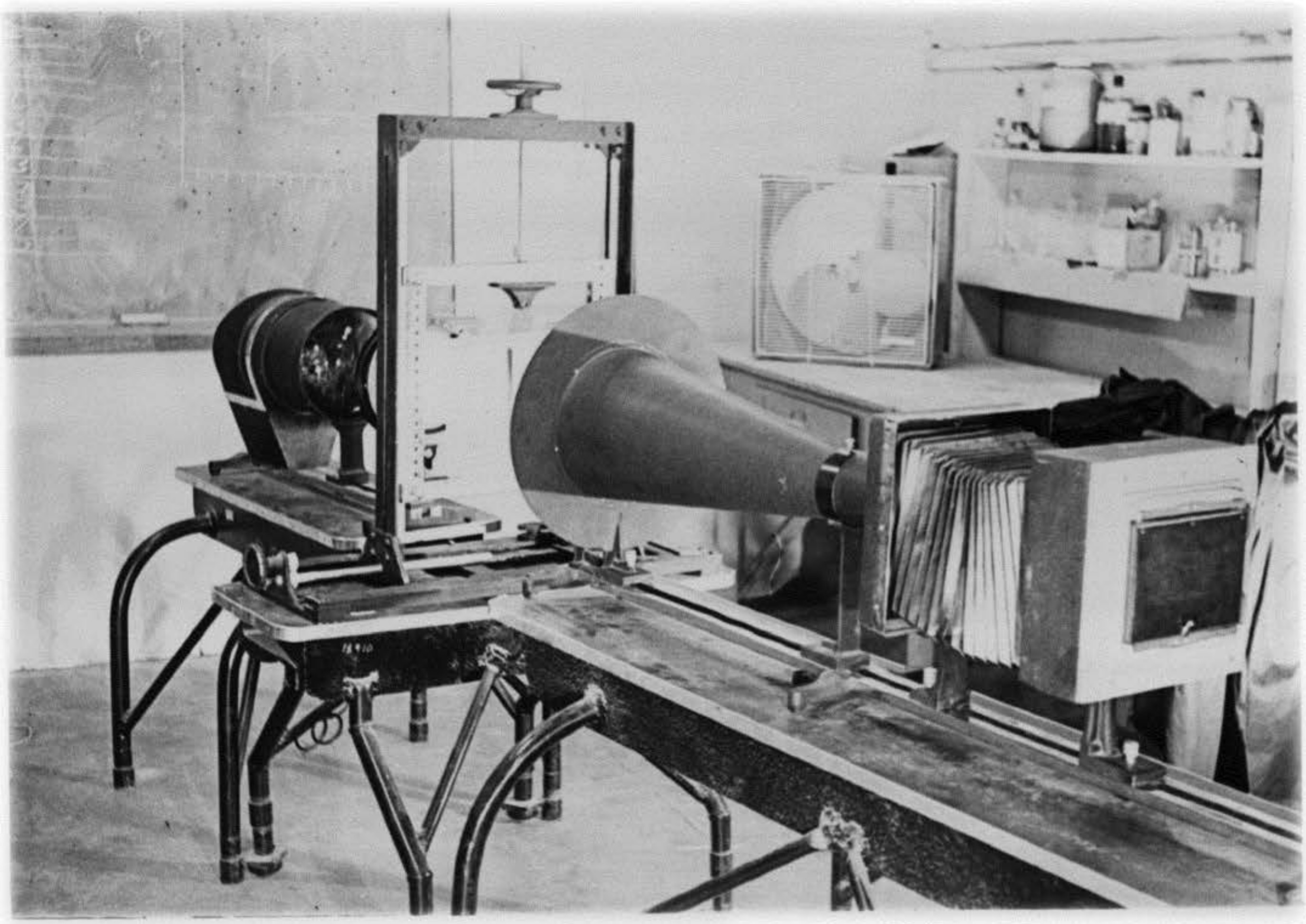
The isoclinics were plotted at 15° intervals by turning the polarizer and analyzer axes simultaneously in the same direction. The polariscope arrangement for obtaining isoclinics is shown in the Figure 8. The stress trajectories were drawn for each model tested.

Four models were tested under various loadings and times of cure. One model was made to run at 400 rpm and others at 300 rpm to simulate the deformed and elastic conditions respectively.



Centrifuge

Plate 2



Model in Polariscope

Plate 3

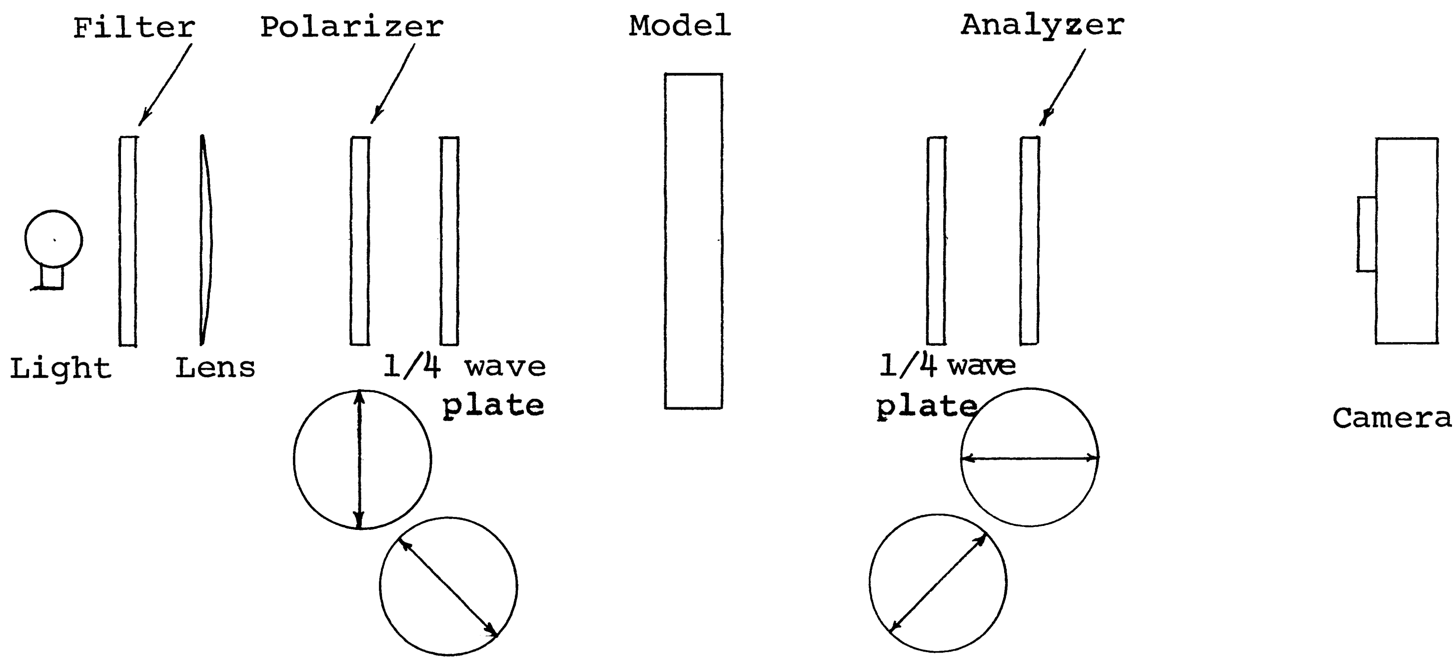
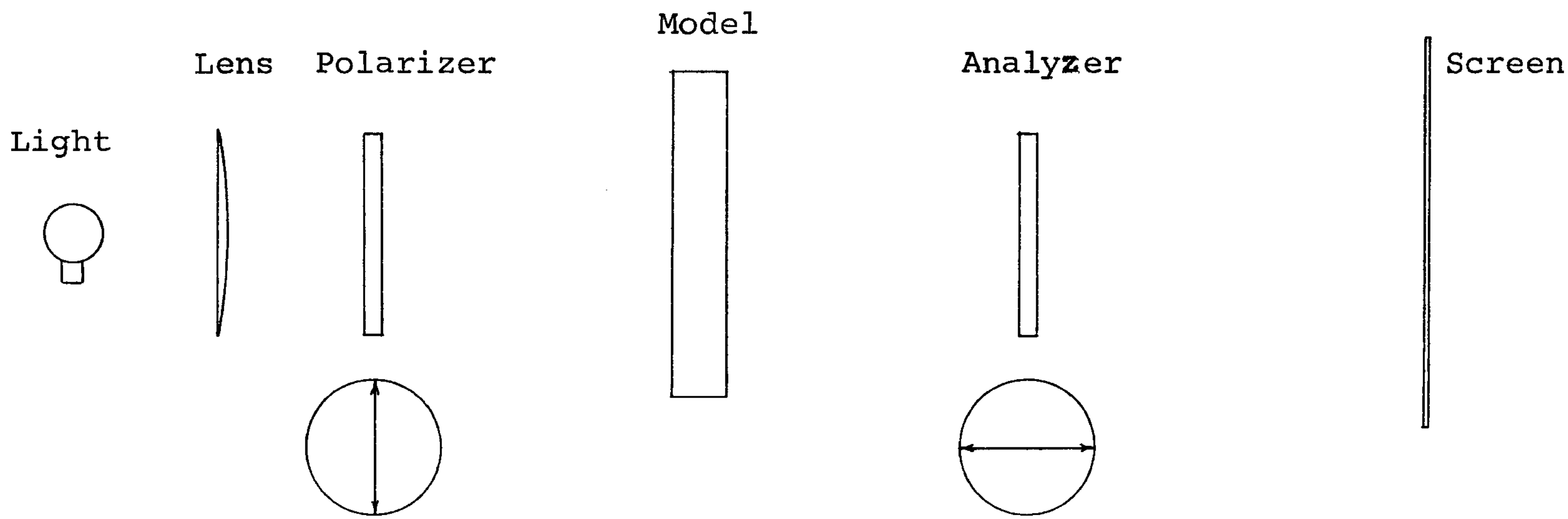



Figure 7

Arrangement for Recording Fringes




Arrangement for Recording Isoclinics

Figure 8

# CHAPTER IV

# BRITTLE MODEL STUDIES

## A. INTRODUCTION

The present chapter deals with the actual measurement of longitudinal strain, during simulated overcoring under *in situ* loads, cutting bit loads, and core loads. Hydrostone and plaster of paris models were selected to represent strata, assuming rocks to be elastic, isotropic, homogeneous, and infinite in extent when subjected to varying conditions of loading. It is worthwhile to imagine the properties of hypothetical bodies which do possess perfect characteristics in order to understand the parts of a total action of an imperfect material.

## B. EARLIER EXPERIMENTS

Two rectangular concrete blocks 12x12x6 inches with a semicirular channel of one-half-inch diameter were cast in a wooden mold. These two blocks when placed together formed a 12-inch cube with a central hole of one-half-inch diameter. Strain gages were mounted in the central portion of the block. A flatjack of 13x13x1/2-inch dimensions was prepared. Concrete block and flatjack were inserted in a rectangular bottomless box of one-inch thick steel plate. The flotjack was pressurized to obtain readings. The faces of the lbock were uneven, this caused the block to fail in tension. Because tools were not available to polish the faces in the laboratory, the experiments were abandoned.

## C. EXPERIMENTAL PROCEDURE

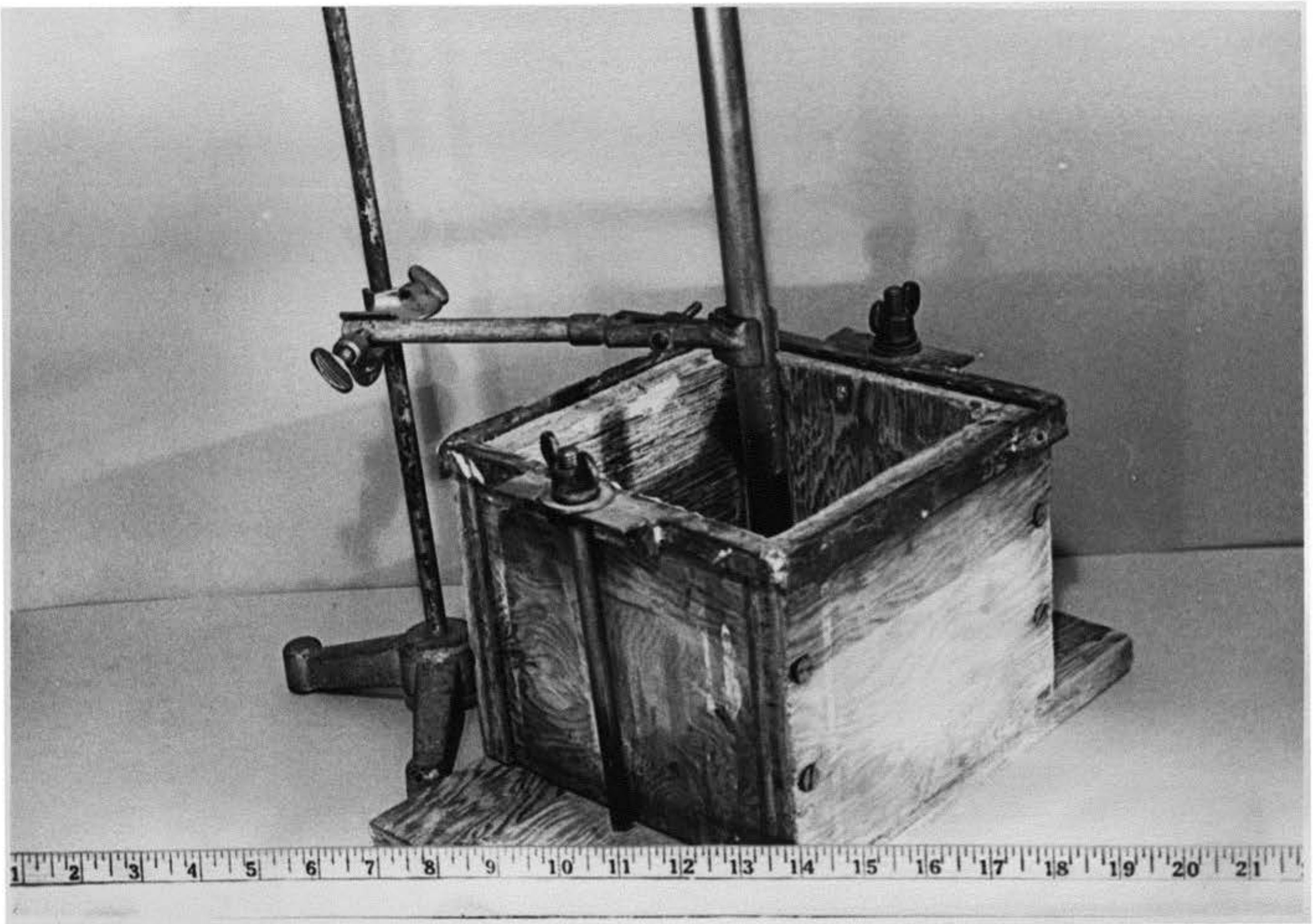
### 1. Model Preparation.

Brittle models of hydrostone and plaster of paris of six-inch cubes with 3/4-inch-diameter central hole were prepared. Electrical strain gages were mounted to measure the axial strain under different loading conditions.

#### a. Hydrostone Models

Hydrostone strength, hardness, and density depend upon the amount of water used in the mixture for a suitable working mix. Thirty-three parts of hydrostone were distributed evenly in a hundred parts of water by weight. The material was allowed to soak for four minutes and then mixed vigorously. The mix was allowed to cream, then was remixed slightly before casting. It was difficult to jar the model to avoid pinholes. Hydrostone hardens and heats rapidly after the initial set. The setting time was 20 to 30 minutes.

Thin lubricating oil was applied to the inner surface of a six-inch cubical wooden mold as shown in Plate 4. A smooth 3/4-inch-diameter steel rod was clamped in the center of the wooden frame. Possible leaking points were covered by masking tape. Hydrostone was mixed and poured into the mold. After setting for 30 minutes the wooden frame was dismantled and the steel



Mold for Casting Brittle Models

Plate 4

road was removed. The hydrostone block was allowed to cure for one week. The rough surface on the top was smoothed by wet grinding. The finished block was dried for three days, before electrical foil strain gages were mounted.

b. Plaster of Paris Models

A mixture of 40 parts water to 60 parts by weight of plaster of paris was used. The same procedure as used in hydrostone models was used to cast plaster of paris blocks.

D. MOUNTING OF ELECTRICAL STRIN GAGES

Fine 180-grit emery tape was wound over a 1/2-inch diameter steel rod. This rod covered with the emery paper was used for cleaning the pilot hole of the model. Compressed air was used to blow out the dust particles. Grease marks were removed by acetone. SR-4 paper-type strain gages were soldered to 10-inch length wire leads and the gages were glued to the interior of the middle portion of the pilot hole in an axial direction. Two such gages were mounted on the opposite sides of the pilot wall to measure axial strain only.

Catalyst 'A' made by Eastman Chemical Products was used as a precoat. The catalyst was dried for 15 minutes with an electric dryer. The paper-type strain gage was trimmed and cleaned with acetone. Two drops of Eastman 910 adhesive were applied to the paper back of the strain gage, and, using the middle finger, the gage was placed halfway between the two ends of the pilot hole. A nominal pressure was applied for 20 minutes. This technique was developed after considerable experimentation. After mounting the strain gages, the adhesive was allowed to dry for three days before any experiments were conducted.

E. DRILLING AND LOADING THE MODEL

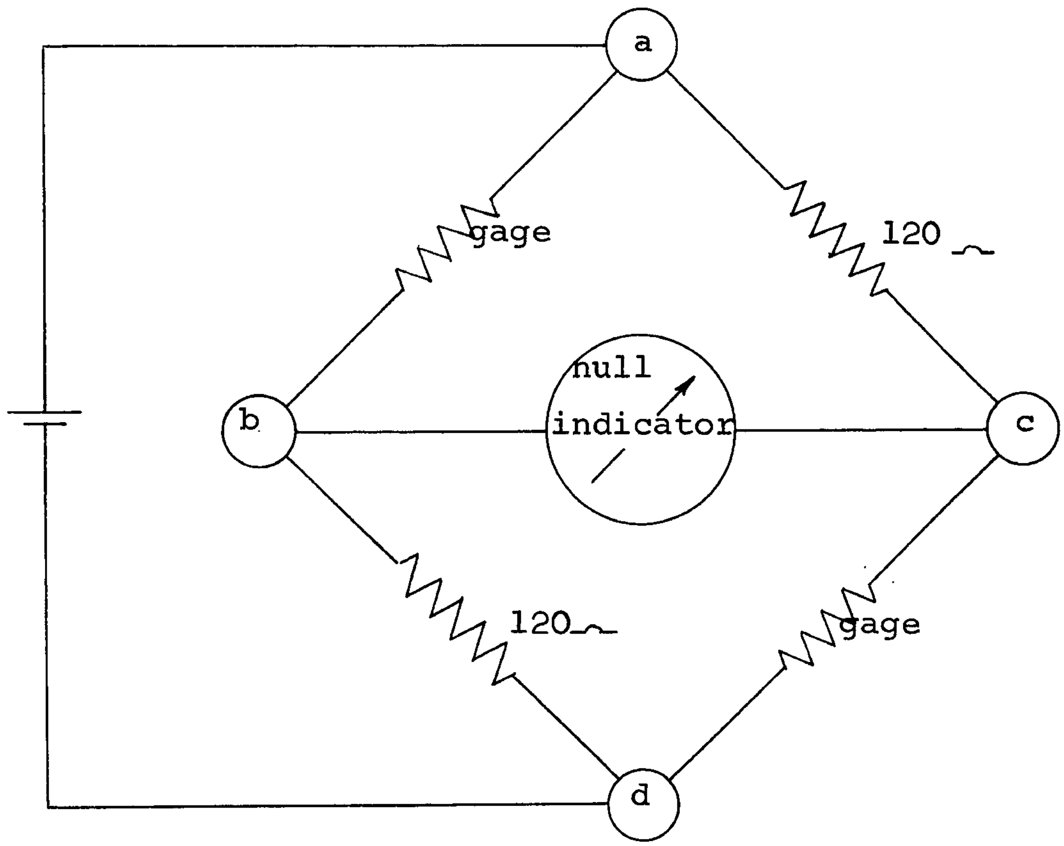
Step (1) The model was placed between the platens of a 60-ton universal hydraulic testing machine with the pilot hole vertical. The strain gage leads were connected to a Hathaway Strain Indicator. The electrical circuit is shown in Figure 9.

Step (2) A six-inch-square by one-inch-thick steel plate was placed over the model, and the load was applied with the hydraulic machine. The strain readings were noted while increasing and decreasing the load. All the readings were kept within the elastic range.

Step (3) Strain readings were noted while using a six-inch-square steel plate with a central hole of 2.35-inch diameter over the model.

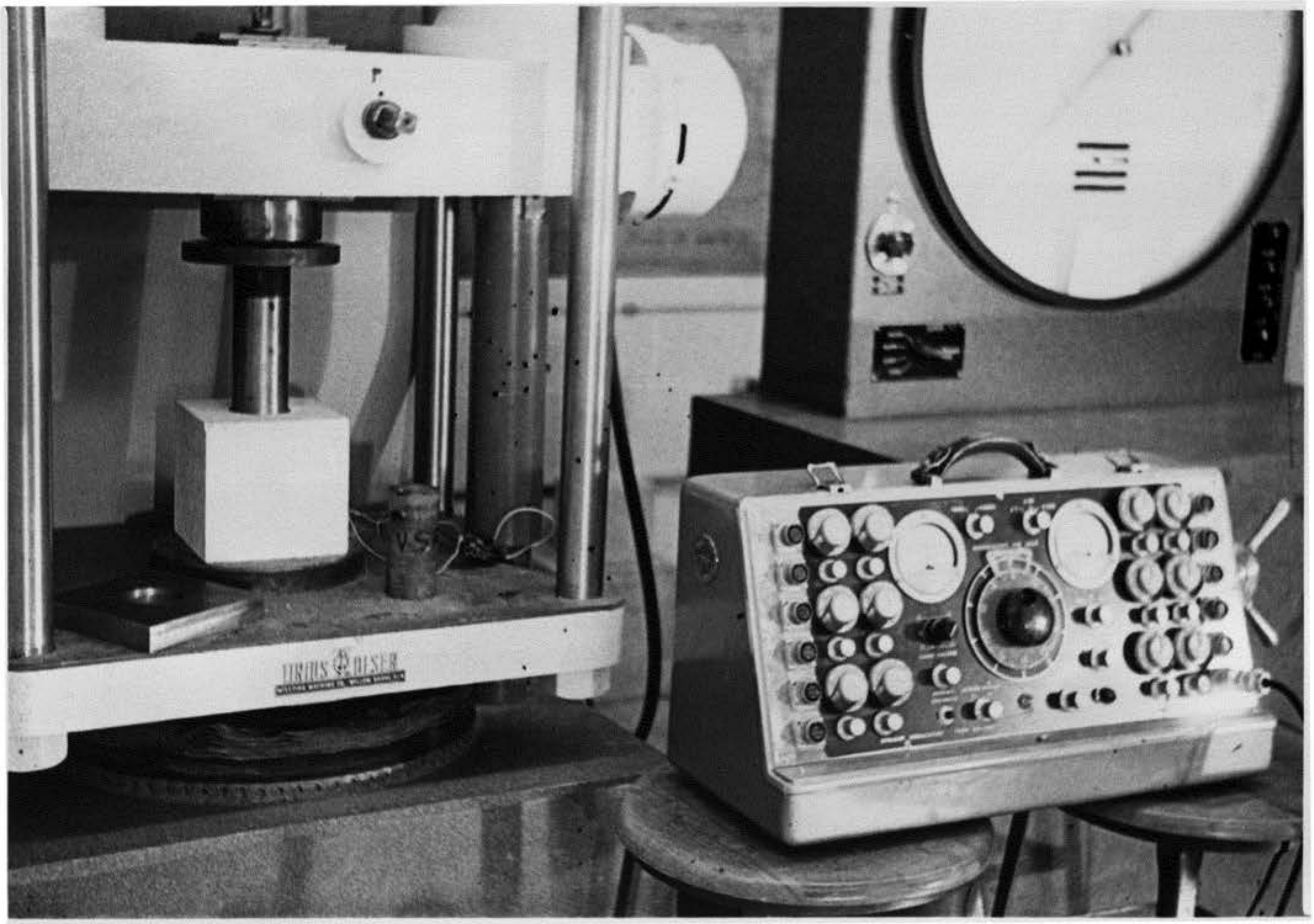
Step (4) Strain readings, as above, were noted using a steel pipe around the pilot hole as shown in Plate 5. The dimensions are as follows:

| | |
|---|---|
| External diameter | 2.350 inches |
| Internal diameter | 2.142 inches |
| Length | 10.000 inches |




Wheatstone Bridge Circuit

Figure 9



Loading Apparatus

Plate 5

Step (5) Similarly, strain readings were again noted by placing a solid greenstone core on the pilot hole. The dimensions of the core are as follows:

Diameter 2.1 inches

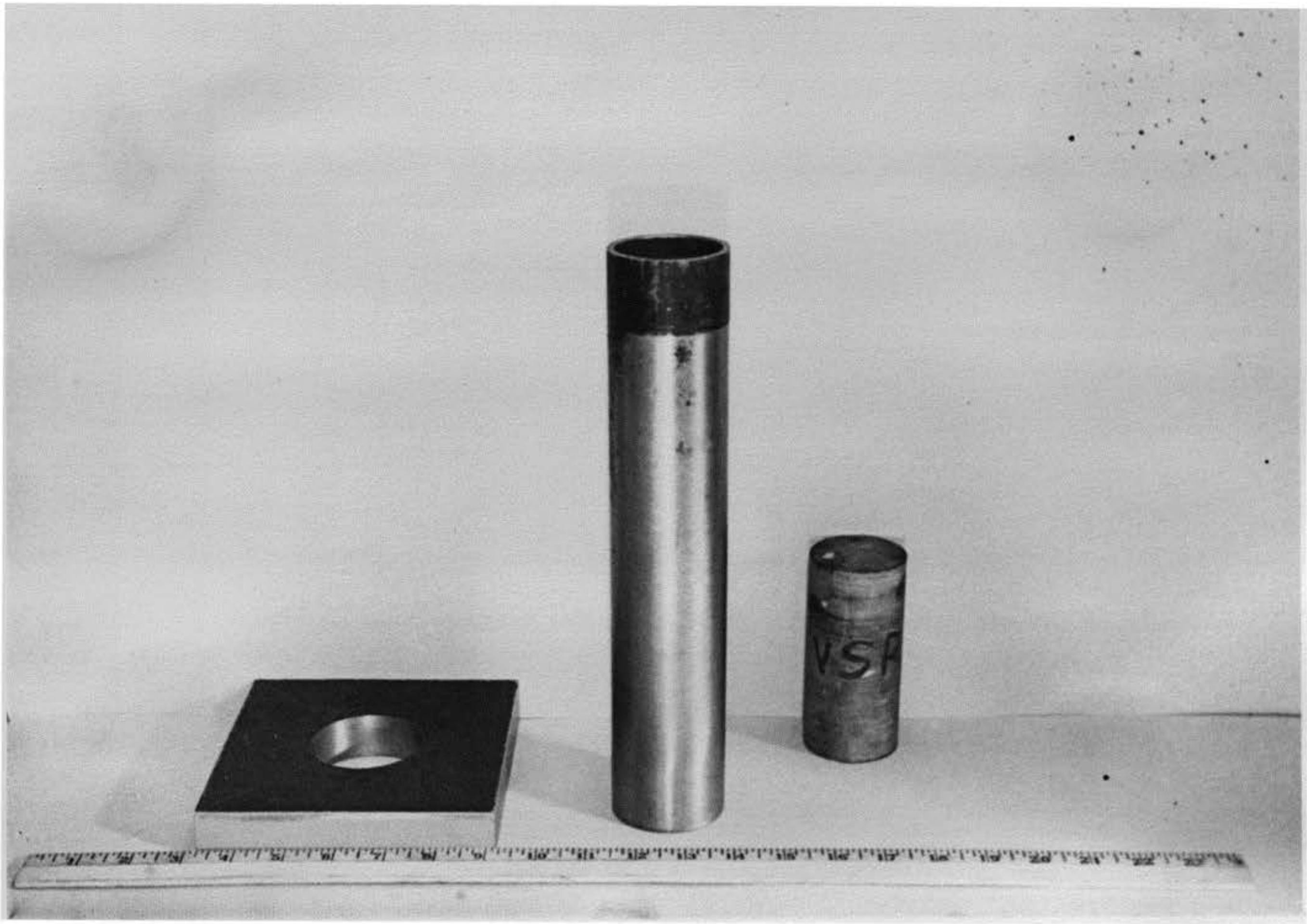
Length 5.0 inches

Note: The steel plate with central hole was used to represent in situ loading conditions while overcoring. The steel pipe was used to simulate bit pressure. The greenstone core was used to represent core load in the drill barrel while overcoring. The strain readings were recorded at $70° \pm 2°F$. Plate 6 shows various items used as loading devices.

Step (6) The model was placed under a vertical drilling machine and clamped with a wooden cross-piece. One-half to one-inch-deep overcoring holes were drilled successively.

After each step of overcoring, steps 3, 4, and 5 were repeated until a complete six-inch core ring was obtained.

Out of nine brittle test models, five were hydrostone and the rest were plaster of paris. One of each type model was tested to determine Poisson's ratio. Four strain gages were mounted on the surface of opposite sides of the block with two gages measuring longitudinal strain and two measuring lateral strain.




Specimen-Loading Devices

Plate 6

# CHAPTER V

# PHOTOELASTIC EXPERIMENTAL RESULTS

## A. INTRODUCTION

The following discussion presents the experimental data observed. Out of a variety of experiments conducted, only representative and meaningful data of the investigation are taken into consideration.

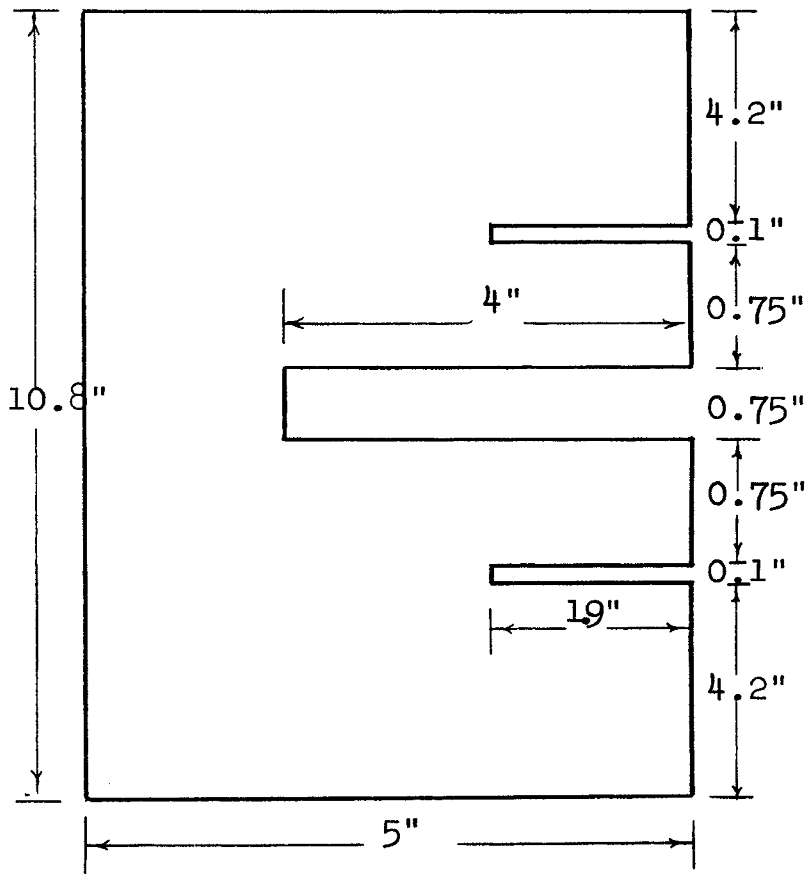
## B. PHOTOELASTIC MODELS

### 1. Model No. 1 with No Superimposed Load.

The model as shown in Figure 10 was stress-frozen with the load induced due to its own body forces in the centrifuge. No superimposed weight was added to this model and isochromatics were not formed in this area around the pilot hole and overcore slot. This indicated that the body forces developed due to the weight of the model were not sufficient to develop isochromatics at the base of the overcore slot.

Data:

| | |
|---|---|
| Weight of the model | 1.04 lbs. |
| Total time of experiment | 57 hours |
| Thickness of model | 1/2 inch |
| Rotational speed | 300 rpm. |




Model No. 1

Model with No Superimposed Load

Figure 10

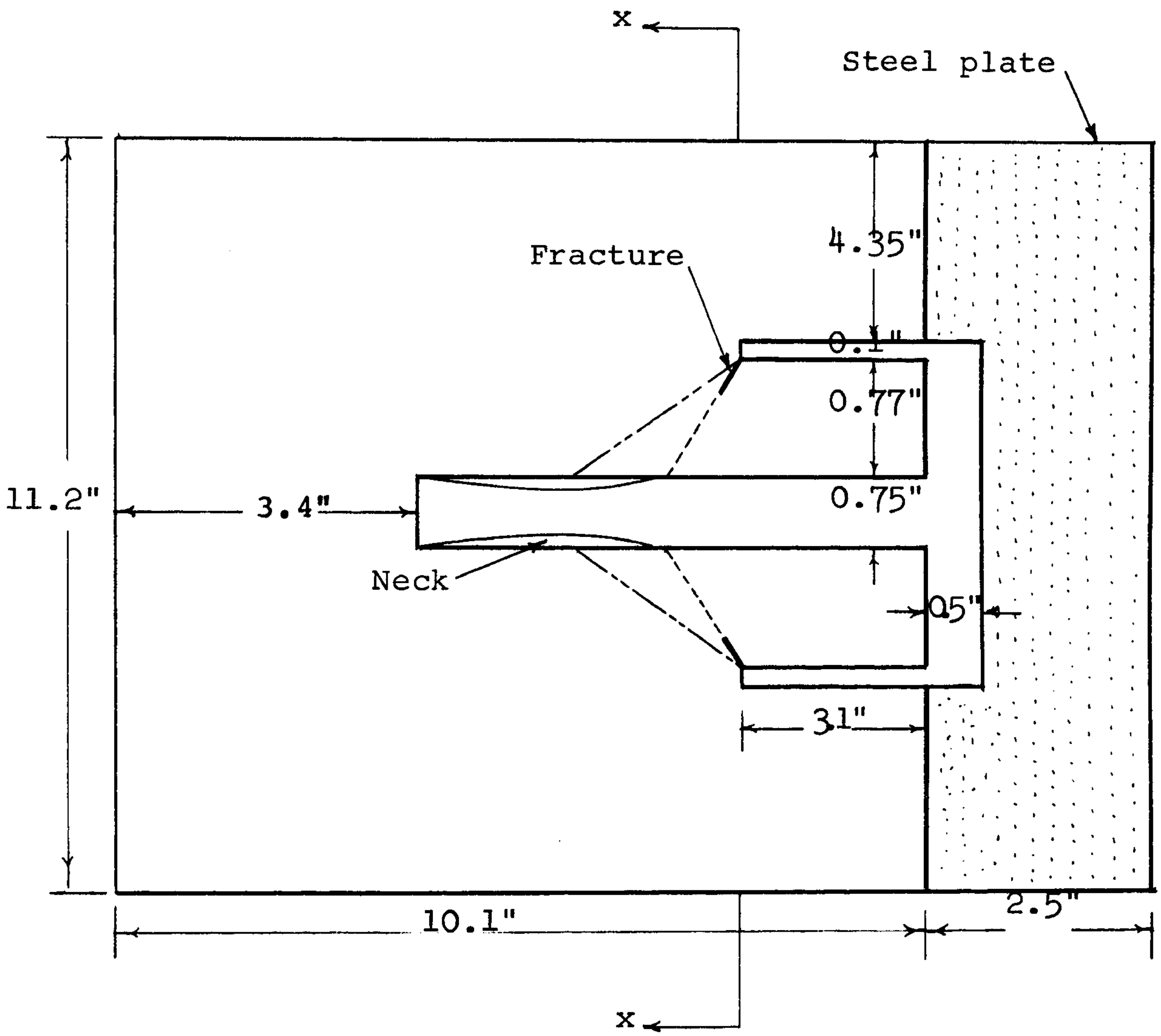
2. Fractured Model No. 2.

The model shown in the Figure 11 was stress-frozen in the centrifuge at 300 rpm. This model was loaded to fracture before complete curing had taken place and Youngs' modulus of the material was thus low. Extra weight was superimposed by a steel plate to simulate a condition of high stress. The fracture plane at the base of the overcore made an angle of 51° to the axis of the pilot hole. The sides of pilot hole formed a neck due to stress concentration in the position shown in the Figure 11. The line joining the maximum deflection point and the slot made an angle of 35° to the original plane of the pilot hole wall.

Data:

| | |
|---|---|
| Weight of model | 2.1123 lbs. |
| Total time of experiment | 18 hours |
| Thickness of the model | 1/2 inch |
| Rotational speed | 300 rpm |
| Steel plate weight | 3.5022 lbs. |
| Stress acting on --xx plane* | 67.3 psi |

*Note: Formulas used in these calculations are adopted from USBM Report of Investigations 4883, Centrifugal Testing Apparatus for Mine-Structure Stress Analysis, by Louis A. Panek. Calculations are shown in Appendix II.




Model No. 2

Fractured Model

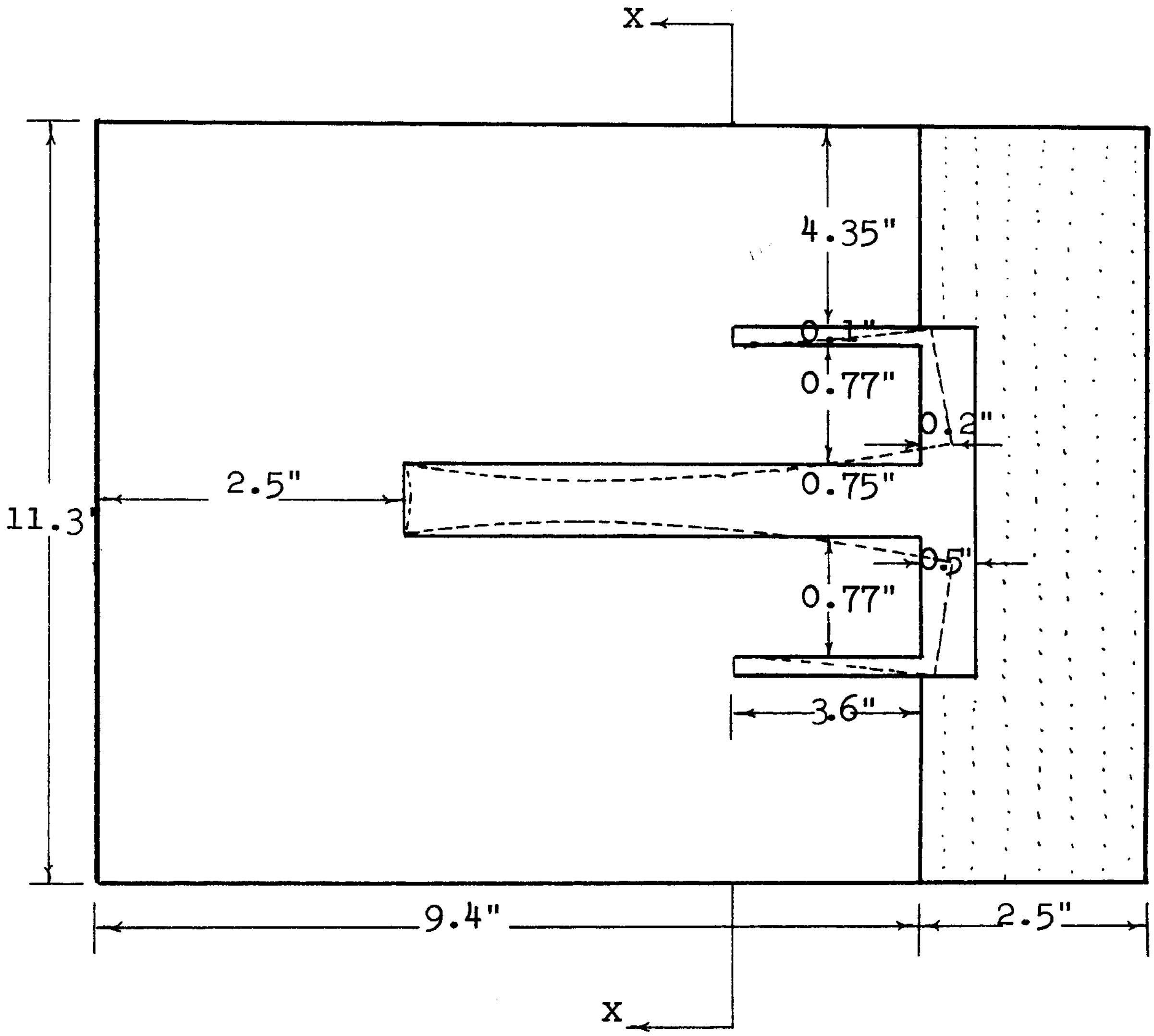
Figure 11

3. Deformation Model No. 3.

The model shown in the Figure 12 resulted due to loading in the cure cycle and stress-freezing in the centrifuge. The pilot hole 6 1/2 inches long was deformed 0.2 inches at the collar and stretched sideways closing the overcore slot towards the loading surface. The hole was necked down in the vicinity of the dead end of the hole. The grid lines shown in the Figure 13 indicate the pattern of movement which took place in the model. The general direction of grid lines around the overcore slot indicate a movement from A to C and C to B. The central core E-F moved sideways and elongated towards loading direction. Due to the shape of the model the load applied to the model acted on the zone ahead of the overcore slot. This caused 'necking' of the borehole at 'D'. Plate 7 shows the fringes obtained due to loading in the centrifuge. Fringes show the contours of constant shear stress. Plate 8 shows the deformation model on the left and the model with no superimposed load on the right.

Data:

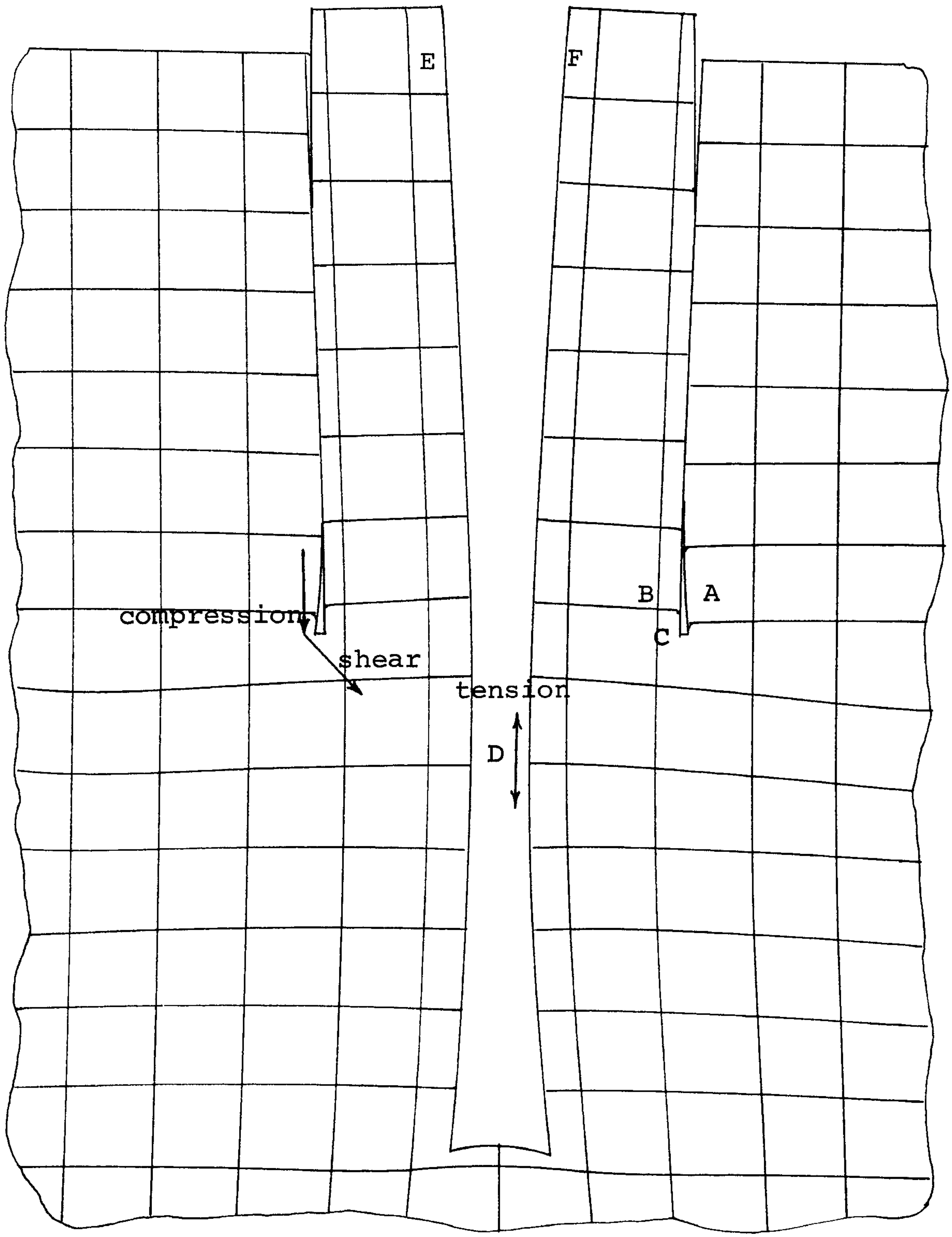
| | |
|---|---|
| Weight of the model | 2.1586 lbs. |
| Total time of experiment | 28 hours |
| Thickness of model | 1/2 inch |
| Rotational speed | 300 rpm. |
| Steel plate weight | 3.5022 lbs. |
| Stress acting on --xx plane | 65.33 psi. |




Model No. 3

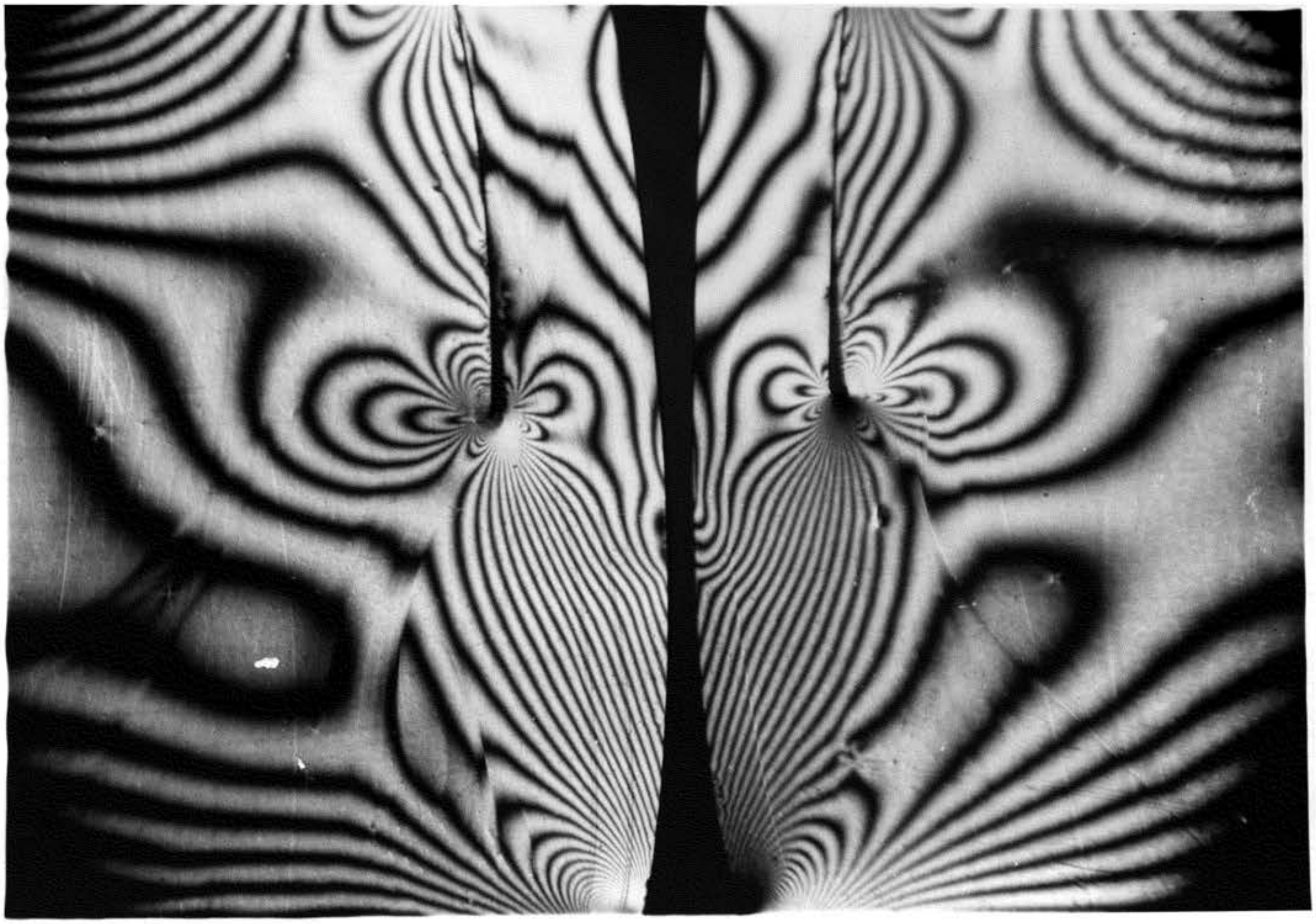
Deformation Model

Figure 12



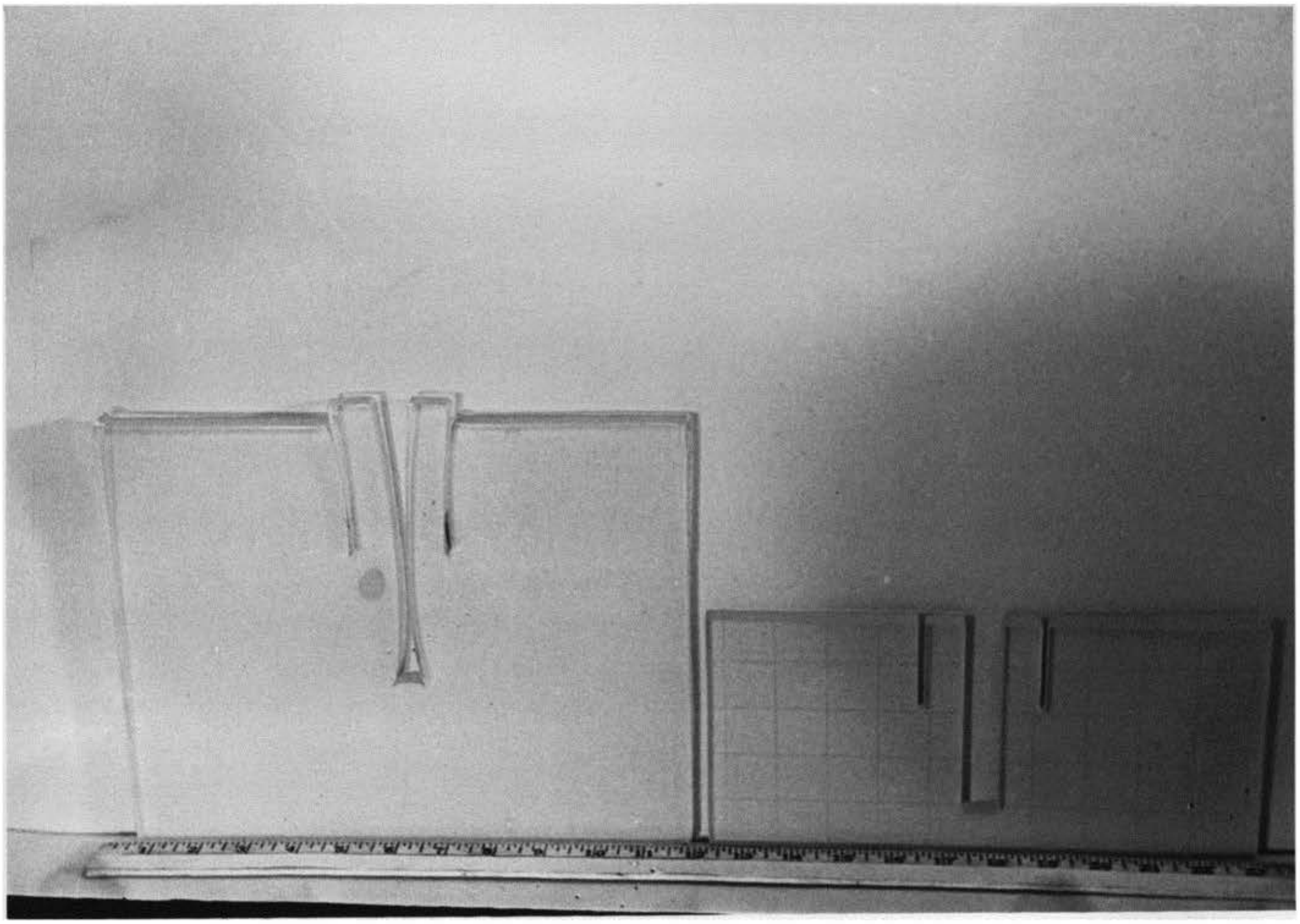

Actual Size of Model No. 3

Figure 13



Fringes in Deformation Model

Plate 7



Deformation Model (left) and No-Load Model (right)

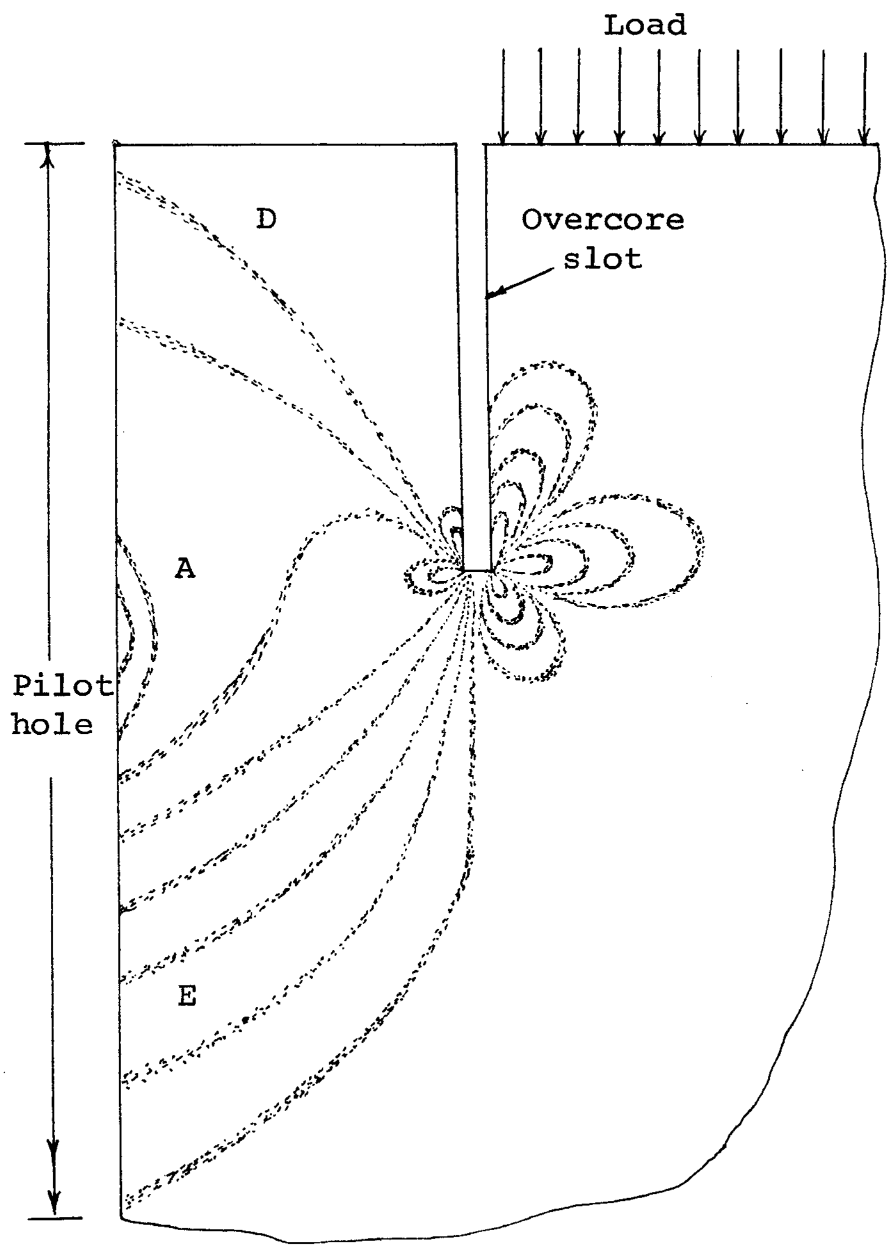
Plate 8

4. Elastic Model No. 4

This model was comparatively elastic. The fringes of the stress-frozen model are shown in Figure 14 and Plate 9 and the stress trajectories are shown in Figure 15. The stress trajectories for deformed and elastic models were similar. From Figure 14 it is evident that a tensile zone 'A' exists at the bottom of the overcore slot towards the pilot hole. An intense compressive zone exists near the free end between overcore slot and pilot hole. Noticeable deformation has taken place in the area 'E', causing a necked area to form. The stress trajectories in the Figure 15 show the direction of principal stresses in the model. The unit elements A, B, and C show the direction of stress at various places in the model. Figure 16 shows the actual dimensions of the model.

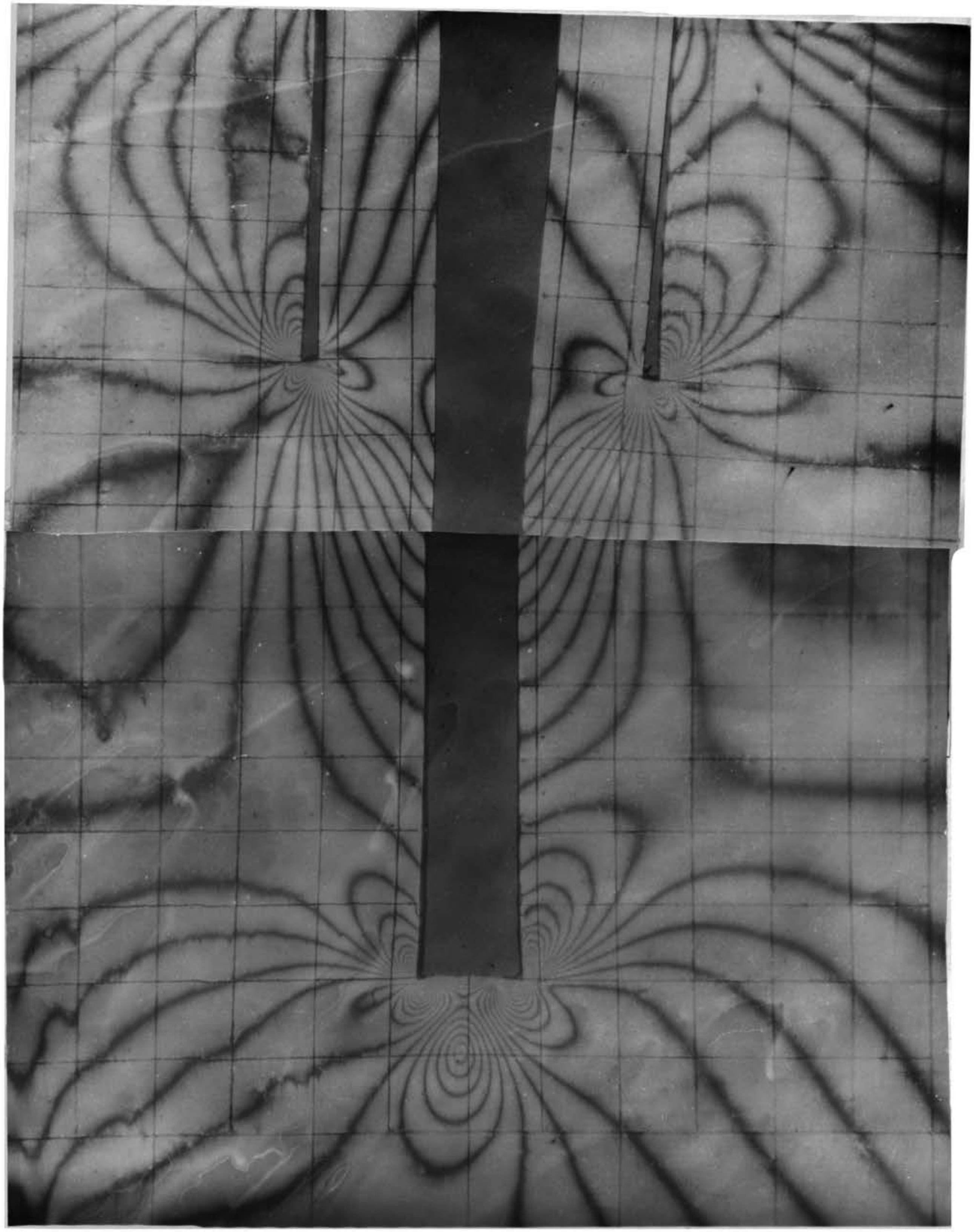
Data:

| | |
|---|---|
| Weight of the model | 2.0529 lbs. |
| Total time of experiment | 28 hours |
| Thickness of model | 1/2 inch |
| Rotational speed | 300 rpm. |
| Steel plate weight | 3.2269 lbs. |
| Stress acting on --xx plane | 49.97 psi. |



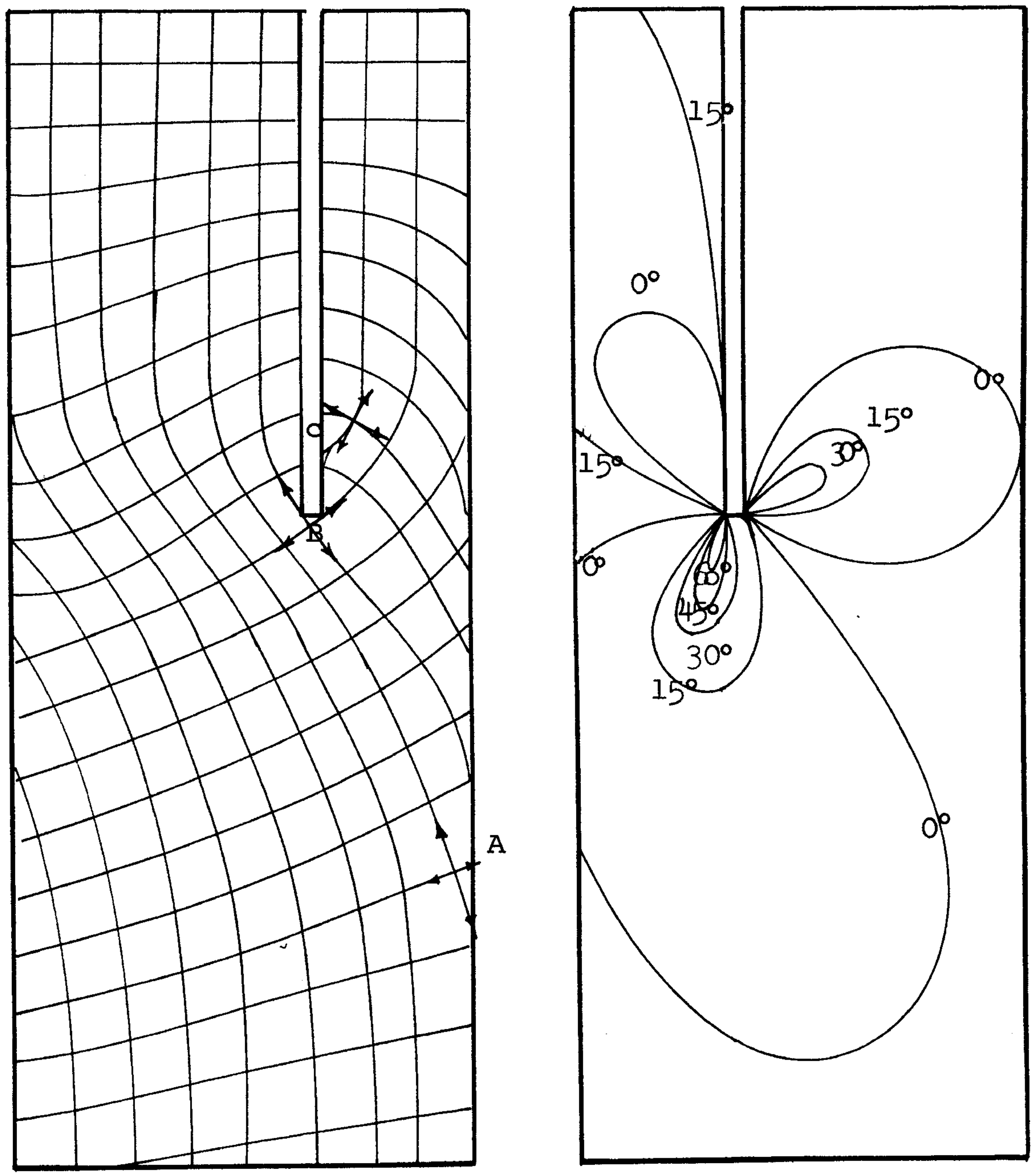

Fringes Around Core

Figure 14



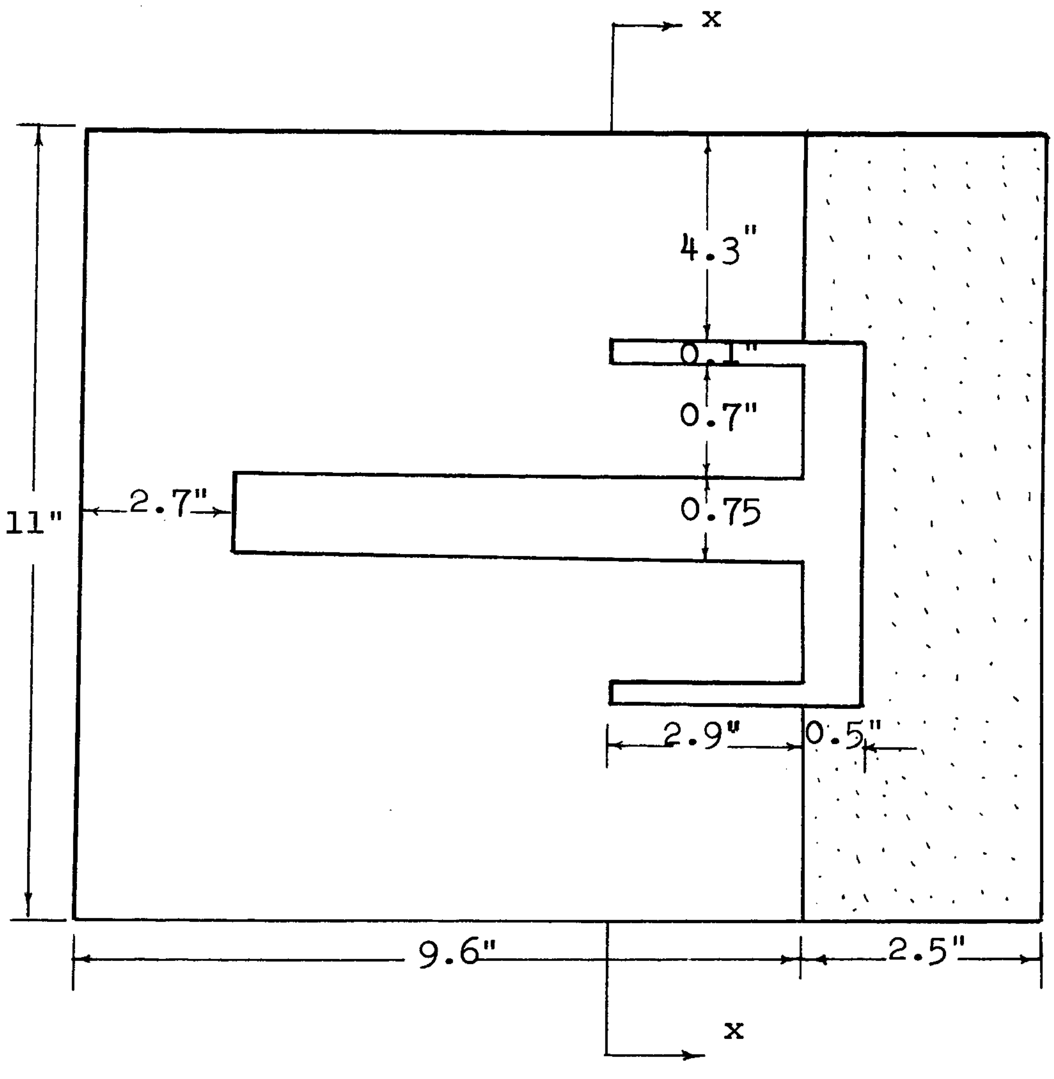
Fringes in Comparatively Elastic Model

Plate 9




Stress Trajectories and Isoclinics

Figure 15




Model 4

Elastic Model

Figure 16

# CHAPTER VI

## EXPERIMENTAL RESULTS OF STUDIES USING BRITTLE MODELS

### A. INTRODUCTION

The following discussion presents the experimental data observed. Physical properties of the brittle models used in the experiments were uniform. Properties did not vary from model to model. The pattern of stress-strain curves obtained from plaster of paris and hydrostone models were the same.

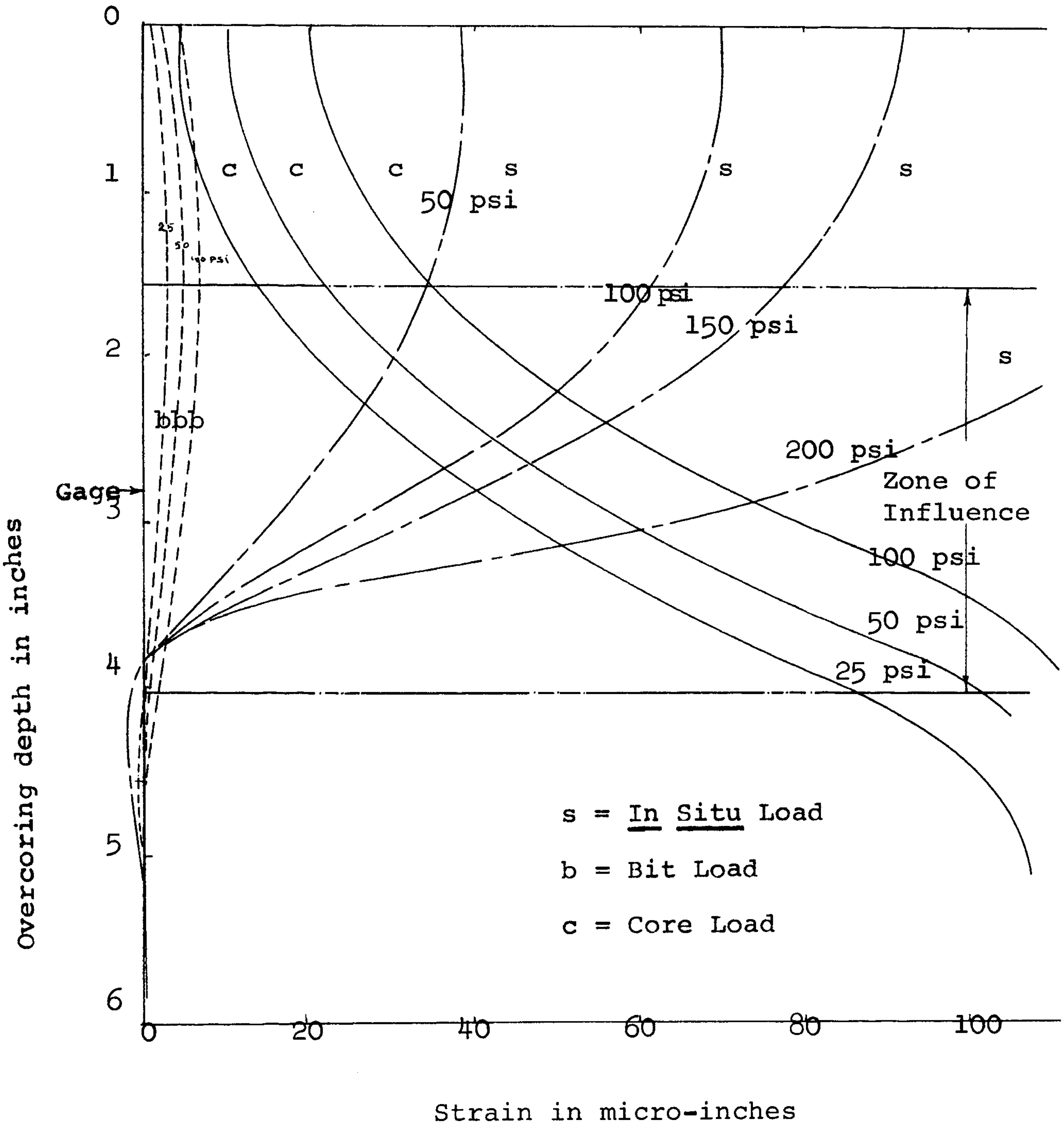
### B. BRITTLE MODELS

The axial strain readings for hydrostone and plaster of paris models were plotted in Figures 20 to 30 as shown in Appendix I. All readings thus obtained were in the elastic region of the stress-strain curve. *In situ*, bit, and core load curves are shown in each curve for regular intervals of overcore drilling depths. Figures 24, 25, and 26 are the stress-strain curves for plaster of paris, Figure 30, the stress-strain curve for hydrostone, indicates a negative variation in the *in situ* and bit load curves. This indicates that a tensile zone exists on the surface of the pilot hole ahead of the overcore slot and extends to some distance towards the free end of the core.

1. Cumulative Strain Curves.

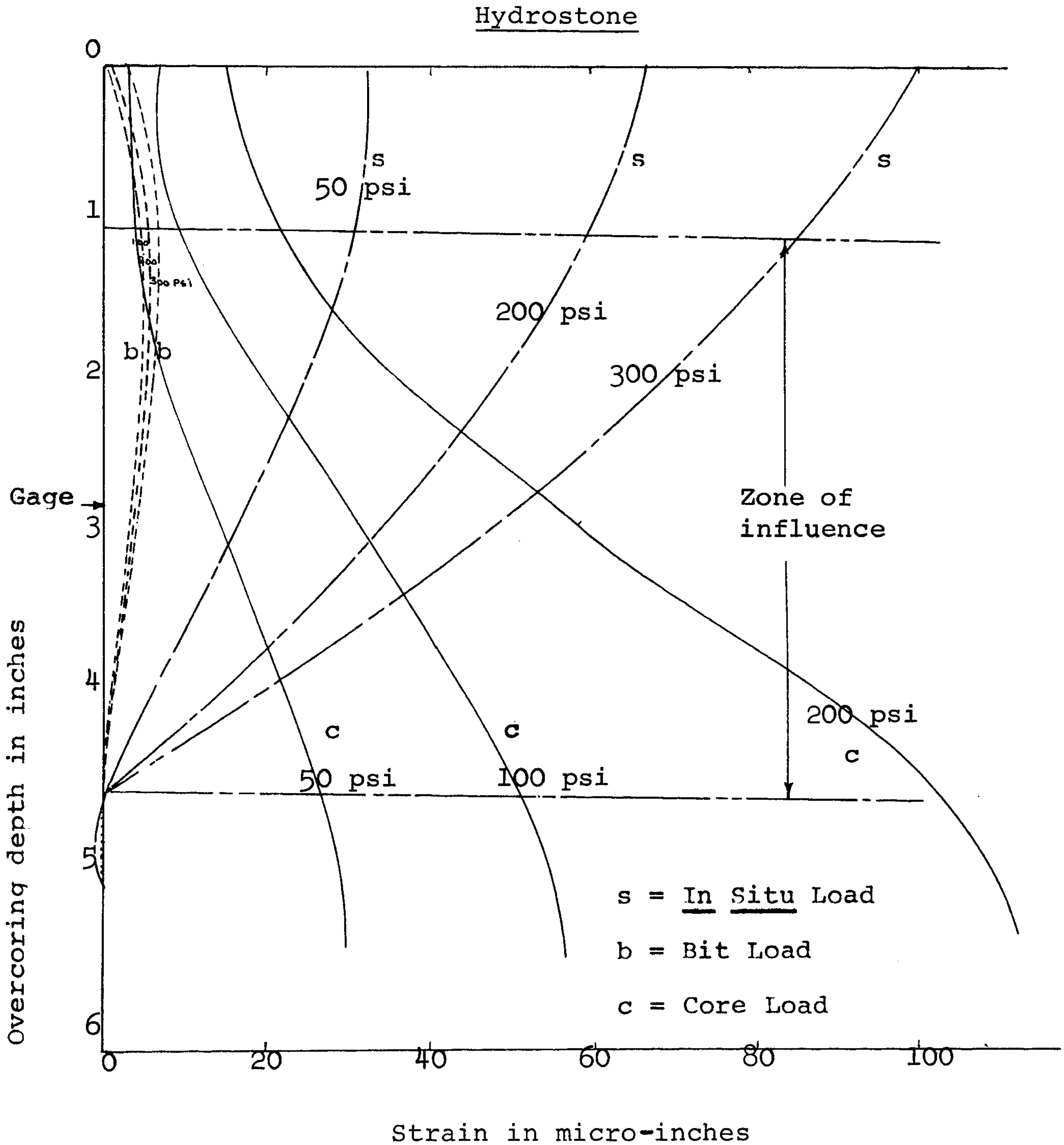
Figures 17 and 18 were drawn for depth of overcore versus axial strain for *in situ*, bit, and core loads. A

Plaster of Paris




Strain Curve For Plaster Of Paris

Figure 17




Strain Curve For Hydrostone

Figure 18

marked deviation in the path of the curves indicates the existence of an intense zone of influence ahead of and within the overcore.

In Figures 17 and 18, bit load curves indicate that for certain stress levels the strain on the survace of the pilot hole gradually increases towards the free end of the core, falls to zero on the opposite side, and then becomes negative, indicating the existence of a tensile zone. In situ stress curves also behave in a similar manner. Core load curves indicate that strain on the surface of the pilot hole gradually increases from the free end of the core until it passes a zone of influence and then achieves a steady level of strain. Vectorially, the in situ and bit load curves act in one direction and core load acts in the opposite direction.

2. Physical Properties.

Young's modulus for hydrostone and plaster of paris was found to be 1,575,000 and 850,000 psi respectively, Poisson's ratio for hydrostone and plaster of paris was found to be 0.13 and 0.162, respectively.

# CHAPTER VII
# DISCUSSION

It was found that there is a definite effect due to *in situ*, bit, and core loads on the axial strain of the borehole. Before designing any strain-measuring gage it is necessary to investigate these effects. The significance of axial strain is well understood from the graphs in Figures 20 to 30. Figures 17 and 18 show that for a particular stress due to *in situ* and bit loads the axial strain is high towards the free end of the core and becomes zero ahead of the overcore slot. A small amount of tensile strain was also observed. The axial strain due to core load constantly increases from the free end of the core and finally attains a steady state of strain on the interior of the core. In the overcoring technique, high loads are not found due to core and bit pressure. However, in areas of high stress there will be considerable axial strain during overcoring due to *in situ* stresses.

In all the brittle model tests a definite zone of influence existed around the strain gages. The zone of influence of axial strain is shown by the marked change in slope of the strain curves as indicated in the graphs of Figures 17 and 18. A borehole strain gage used to measure changes in diameter in this zone of influence may move along with the core in the direction of axial strain. In many of the borehole strain measuring gages, a separate anchor point and transducer points are provided. Due to the effects of axial strain, anchor point and transducer point movements will be different. This may result in slipping of the strain-measuring mechanism. The differential movement of anchor point and transducer point may result in erroneous readings of strain.

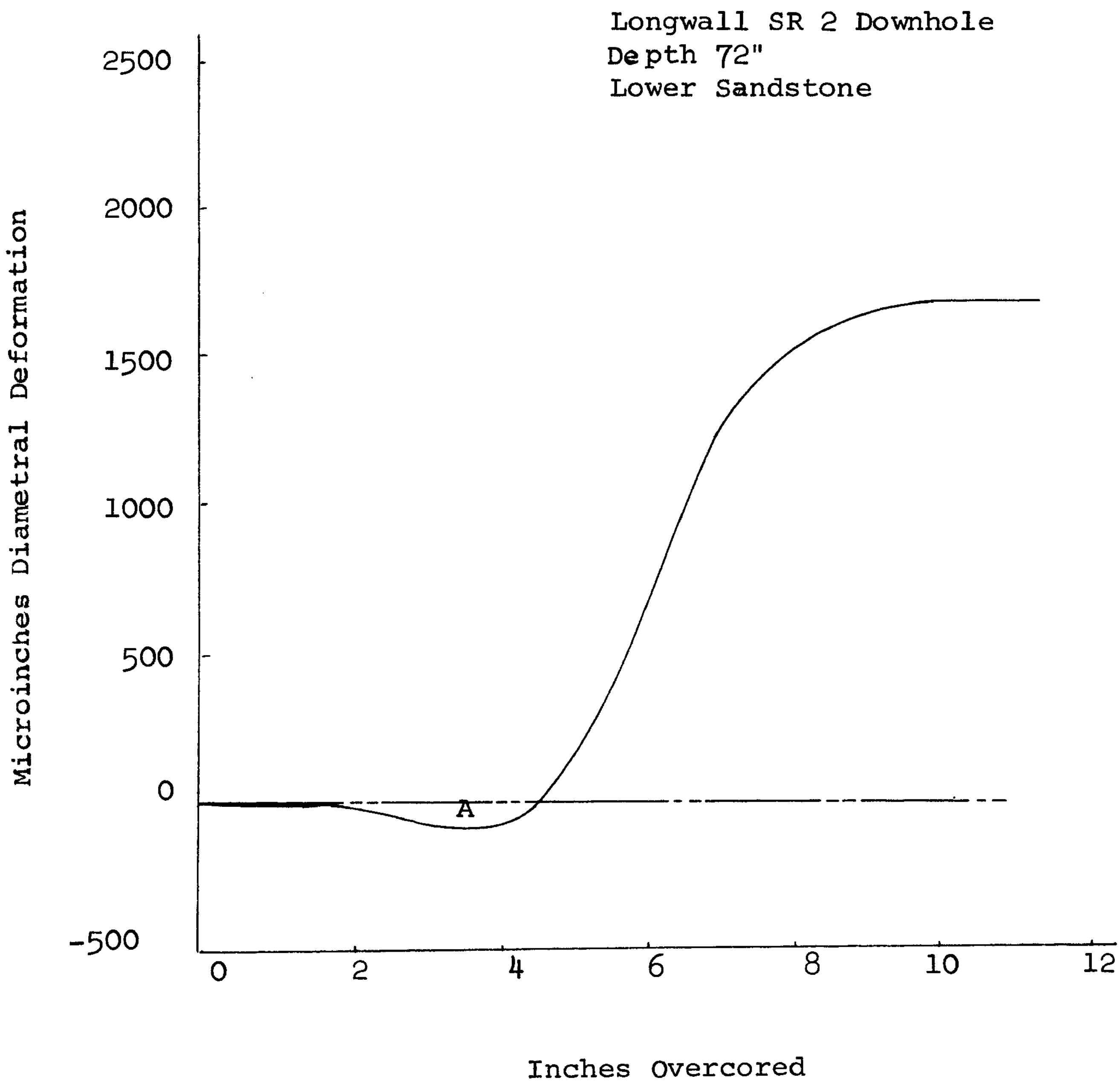
Knowledge of axial strain of a borehole can be utilized to calculate the principal stress. From readings taken with a borehole strain gage, which measures radial and axial strain in a direction of one of the principal stresses, a complete stress ellipsoid can be developed. This will allow a complete definition of the in situ stress with only one overcoring operation.

In the models subjected to centrifuge loading a closure of the borehole took place ahead of the overcore slot. It is clearly shown in the Figure 11. This 'necking' is due to the yielding of material caused by the forces acting due to the superimposed load. In Figure 11 a fracture plane was observed at an angle of 51 degrees to the axis of the borehole. In Figure 14 a tensile zone 'S' exists at the bottom of the overcore slot towards the pilot hole. An intensive compressive zone exists at 'B' causing a shearing action which may propagate a crack, depending on the intensity of stress.

Failure of material in this manner is called 'discing'. Shear cracks developed at the base of the overcore slot due to the high stress differential at this point. They progress through the core into the tensile zone and the final fracture is completed in a direction perpendicular to the axis of the borehole. This conclusion is supported by the characteristic shape of the fracture observed in field work. The fracture planes in the discing phenomena are always concave upward indicating shear at the outer edges and tension at the surface of the inner borehole.

Brittle rocks are more apt to 'disc' than are plastic materials. Plastic rocks will deform and relieve the stress concentration while brittle rocks fracture.

The formation of the neck on the borehole causes a considerable variation in strain readings. In the experiments conducted by Scott and Perrin[30] at White Pine Copper Mine a deviation of strain was observed at 'A' as shown in Figure 19. The curve shows the radial borehole deformation in overcoring experiments. The neck formation zone of the borehole causes negative readings at the transducer points and as soon as the overcore advances it relaxes the transducer. This phenomenon causes a negative anomaly in the radial strain curve.




Typical Stress Relief Curve[30]

Figure 19

# CHAPTER VIII

# CONCLUSIONS AND RECOMMENDATIONS

## A. CONCLUSIONS

(1) As *in situ* stress increases, axial strain relaxation increases.

(2) In actual field overcoring, bit pressure and core load will have little effect upon axial strain.

(3) Core pressure acts against the *in situ* stress and bit pressure, but is probably of an insignificant magnitude in practice.

(4) Only one borehole in the direction of one principal stress is needed to draw a complete stress ellipsoid, provided axial and radial strain are measured from the same unit.

(5) A diameter-measuring transducer should move along the axial direction to an extent equal to the amount of axial strain.

(6) A radical difference in the magnitude of stress exists in the core near the end of the overcoring bit. This is the contributing factor to failure of the core by discing.

(7) The mechanism of failure of highly stressed core is initially shear, which is followed by tension.

(8) The neck formation in the borehole during overcoring causes considerable variation of strain readings.

## B. RECOMMENDATIONS

(1) Construction of a borehole strain gage to measure radial and axial strain is possible. Efforts to construct such a gage should be undertaken to simplify *in situ* stress measurements.

(2) In the case of radial-strain measuring gages, a clearance equivalent to the axial strain should be allowed around the collar of the transducers to allow them to move along with the overcore, thus avoiding any differential movement between the transducer tips and the overcore.

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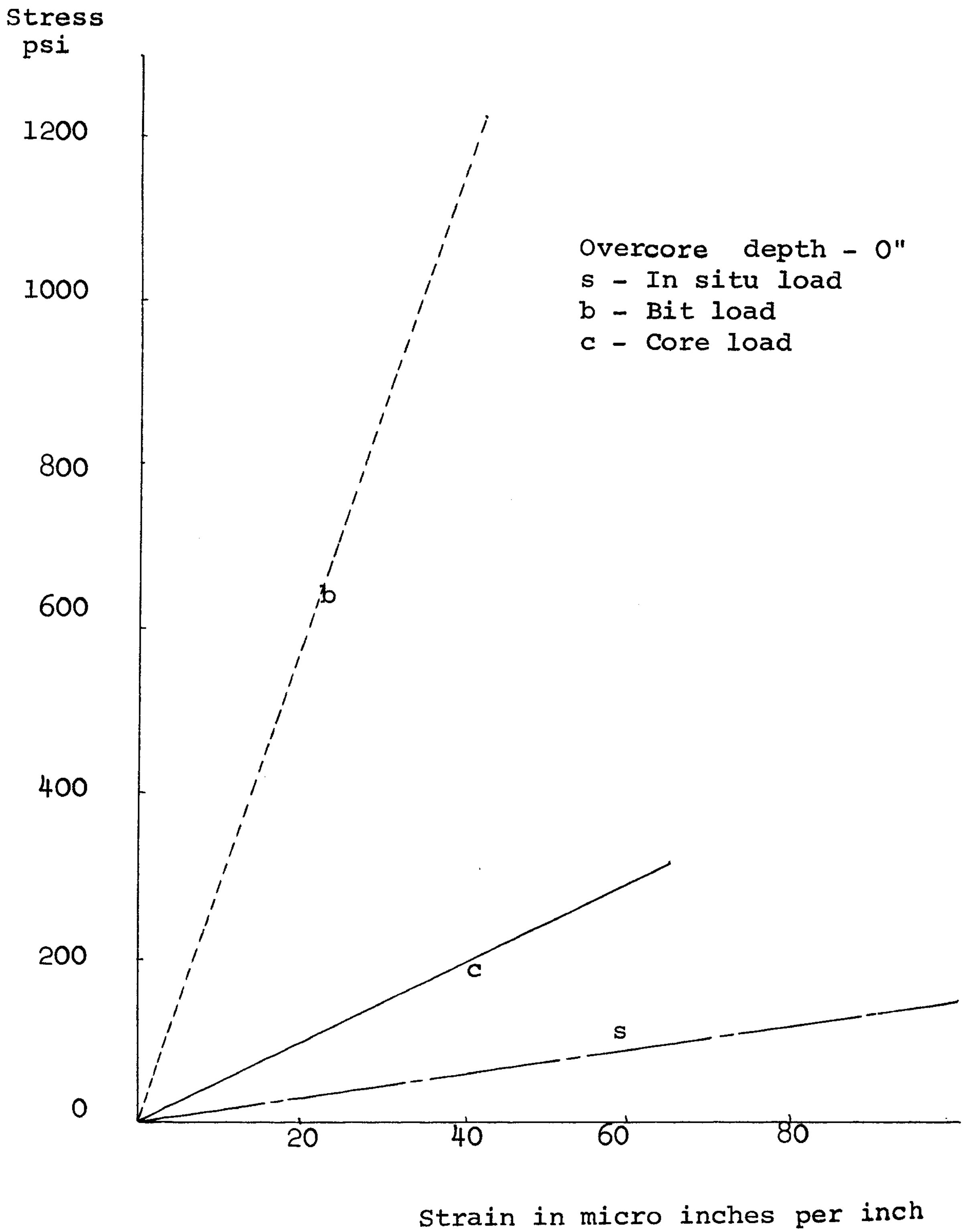
# APPENDIX I

PAGE

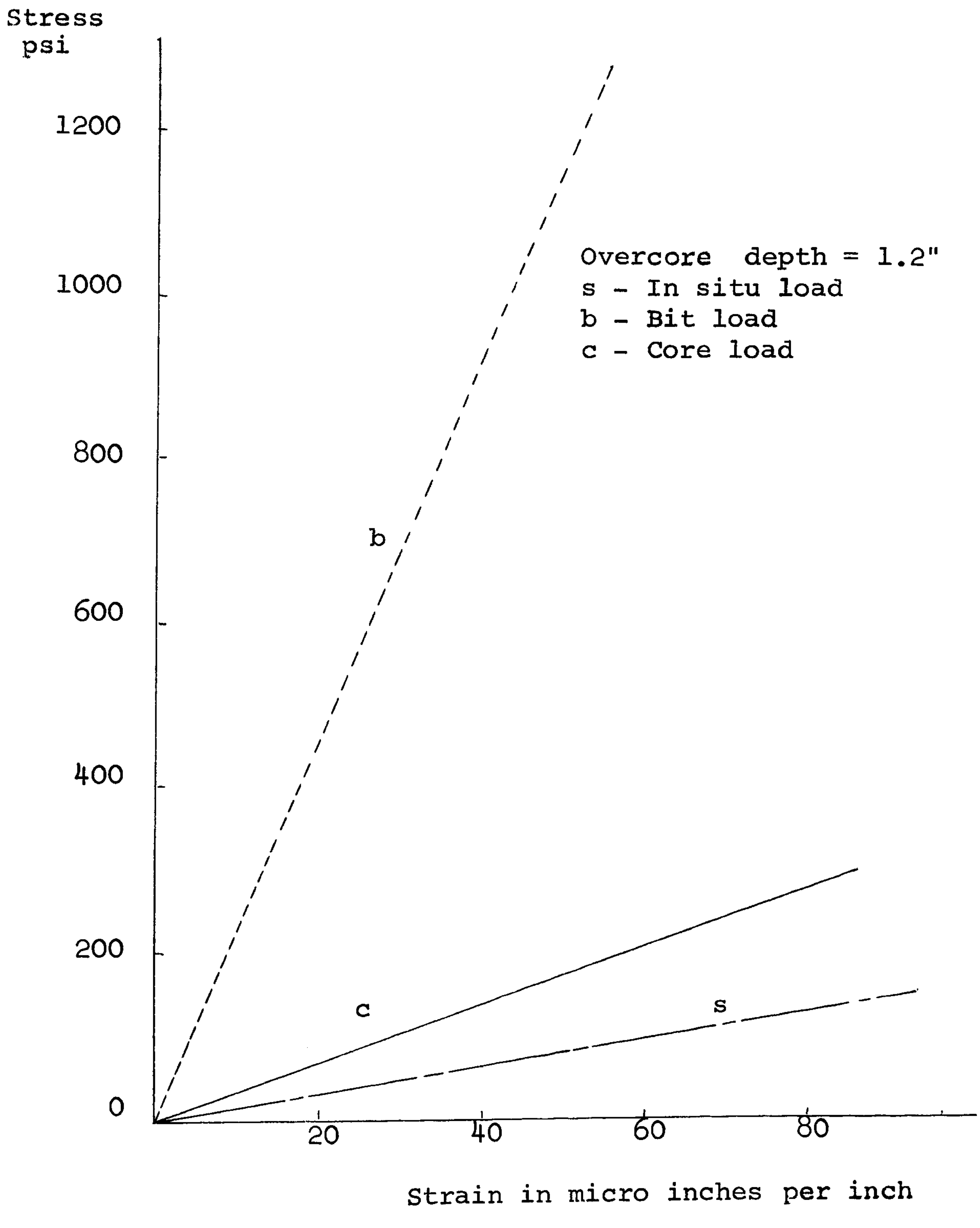
Figures 20 to 26 Stress-Strain Curves for Plaster of Paris 62-68

Figures 27 to 30 Stress-Strain Curves for Hydrostone 69-72



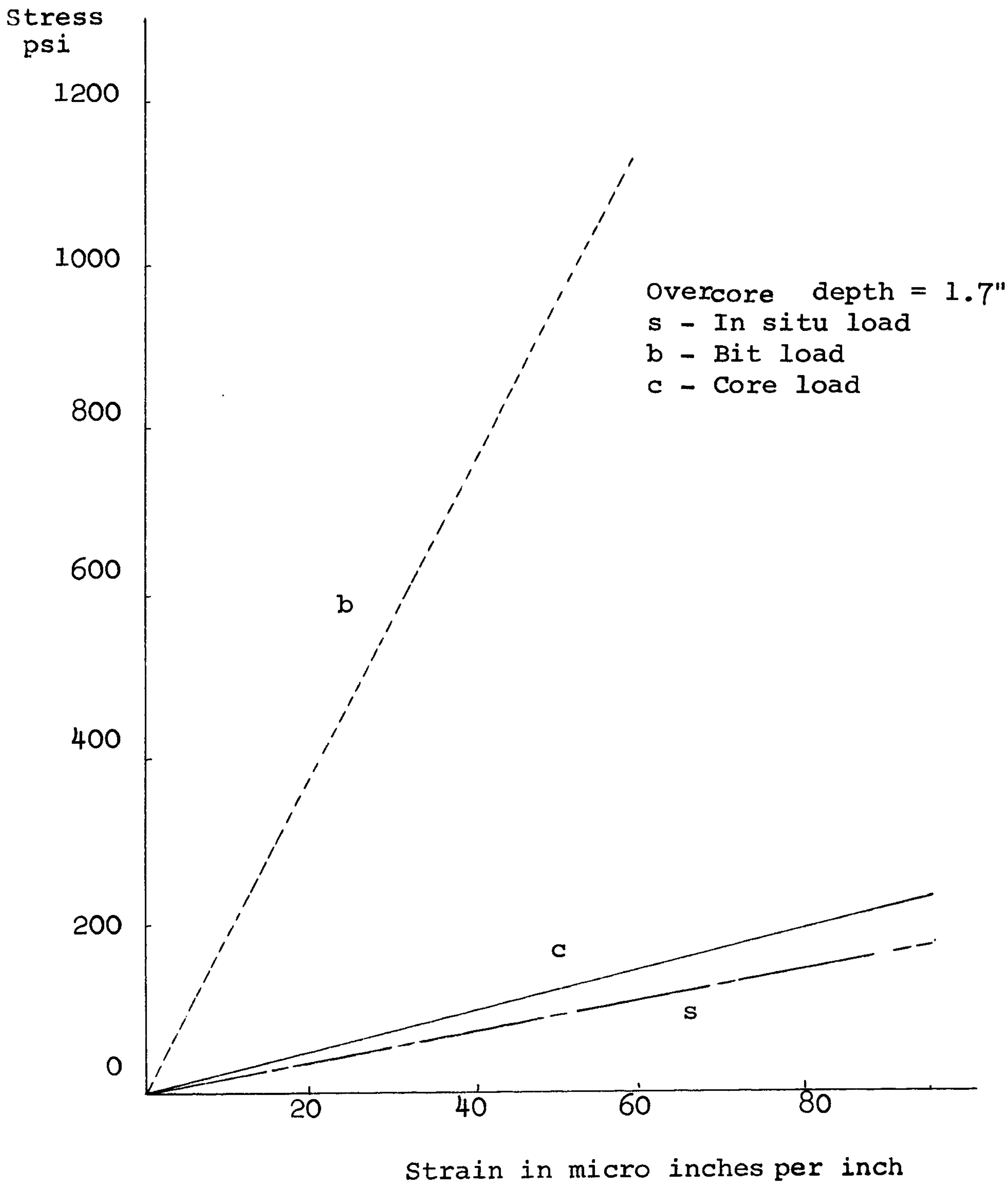

Stress-Strain Curves for Plaster of Paris

Figure 20



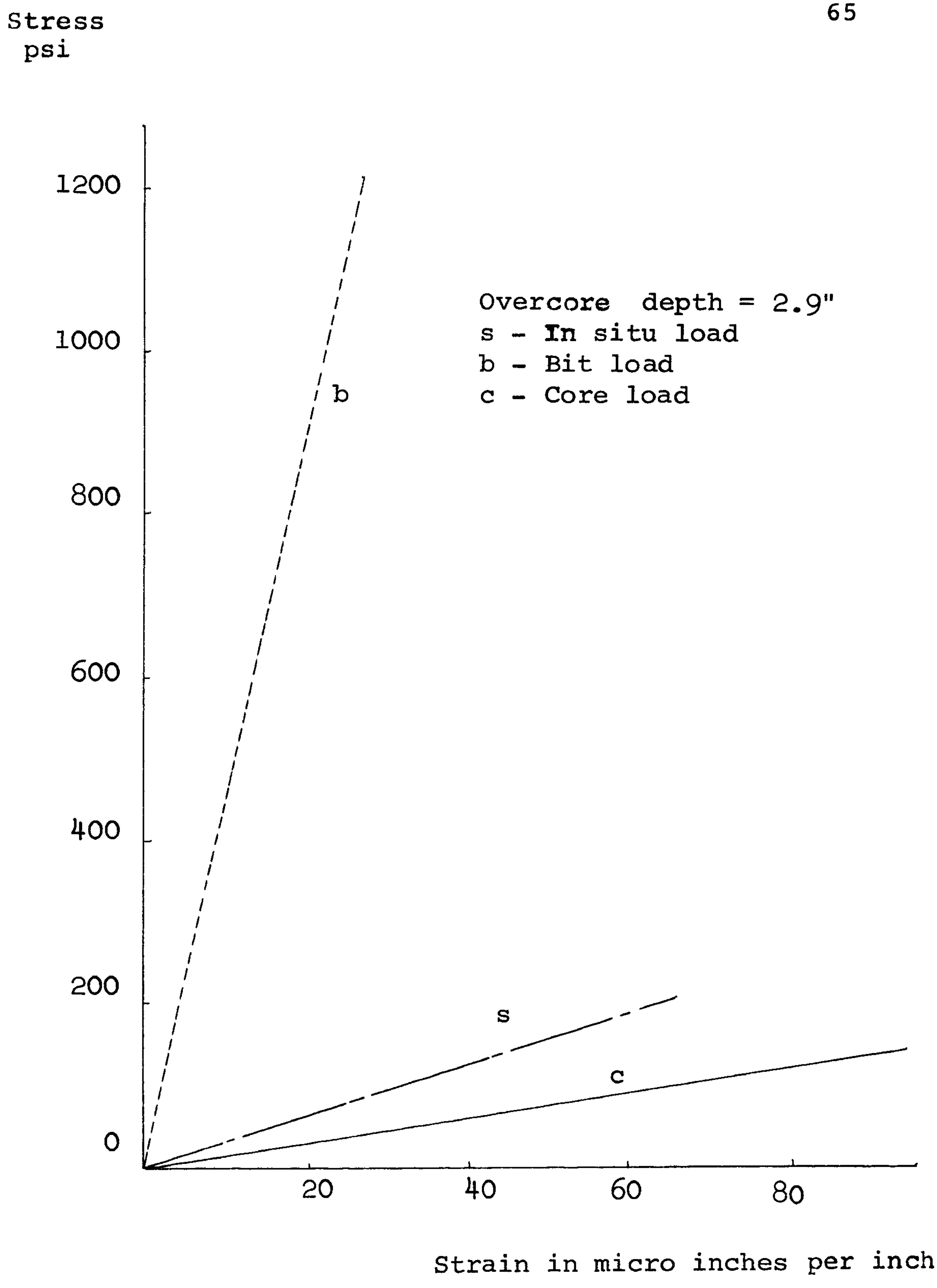

Stress-Strain Curve for Plaster of Paris

Figure 21



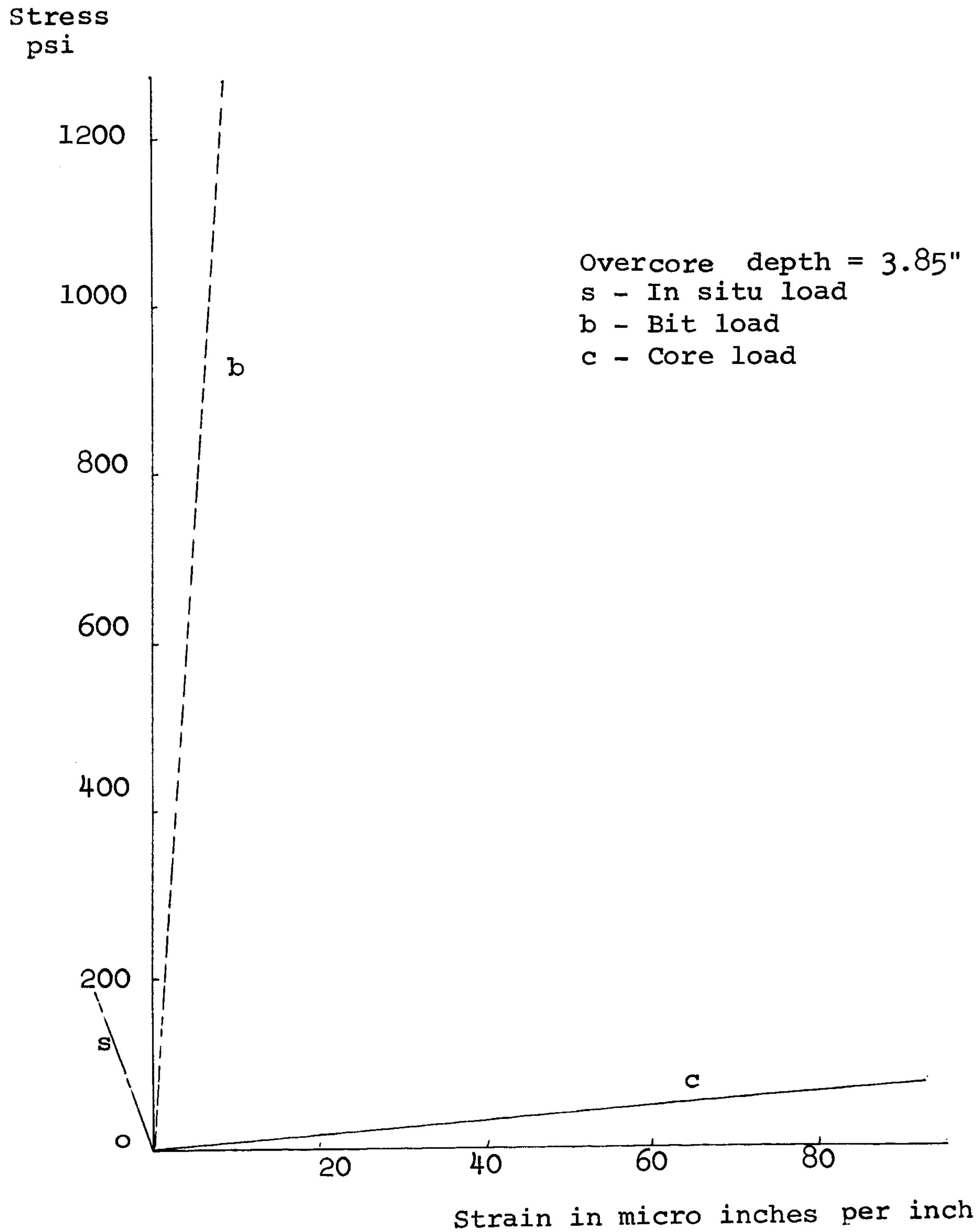

Stress-Strain Curve for Plaster of Paris

Figure 22



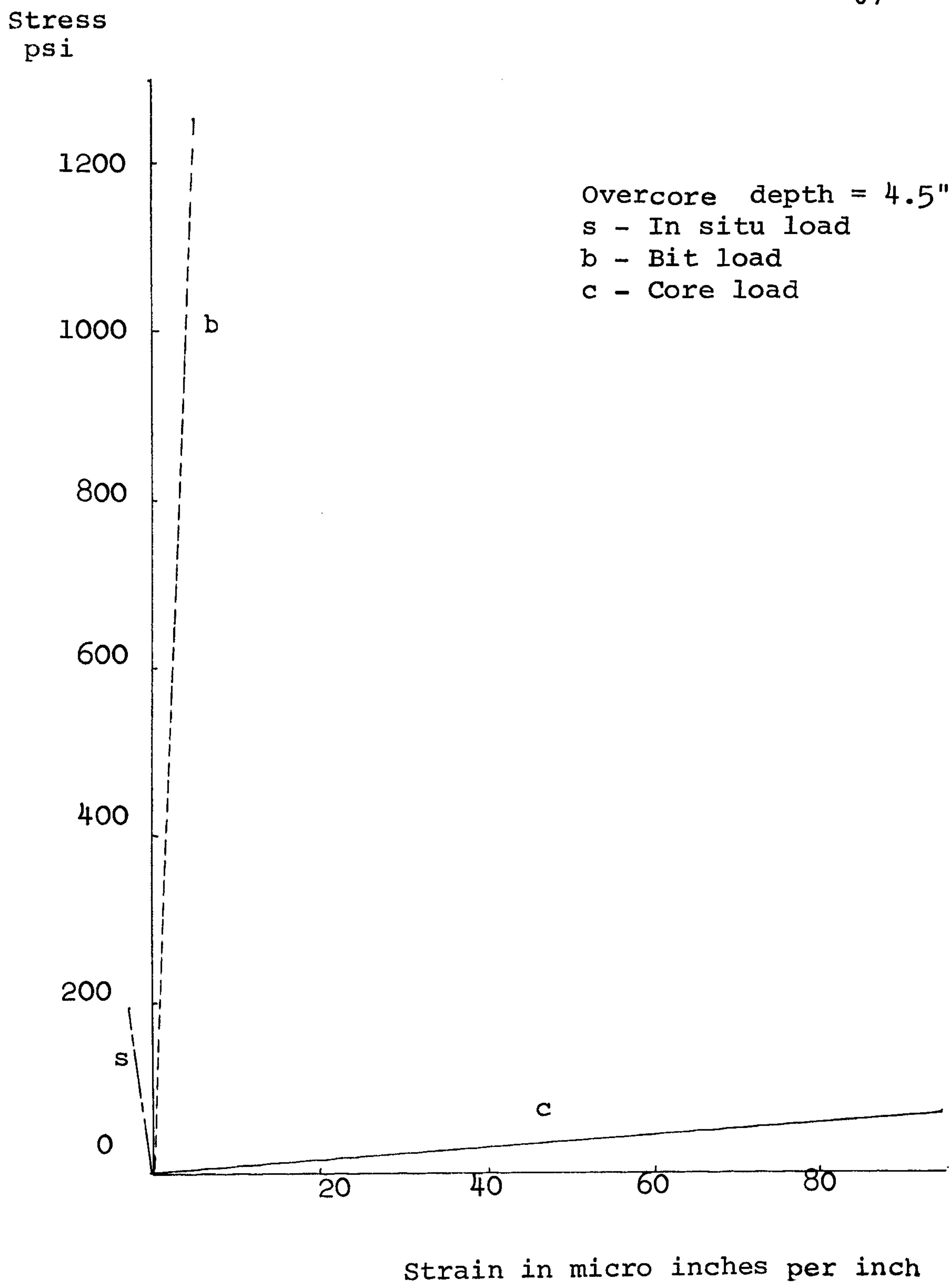

Stress-Strain Curve for Plaster of Paris

Figure 23



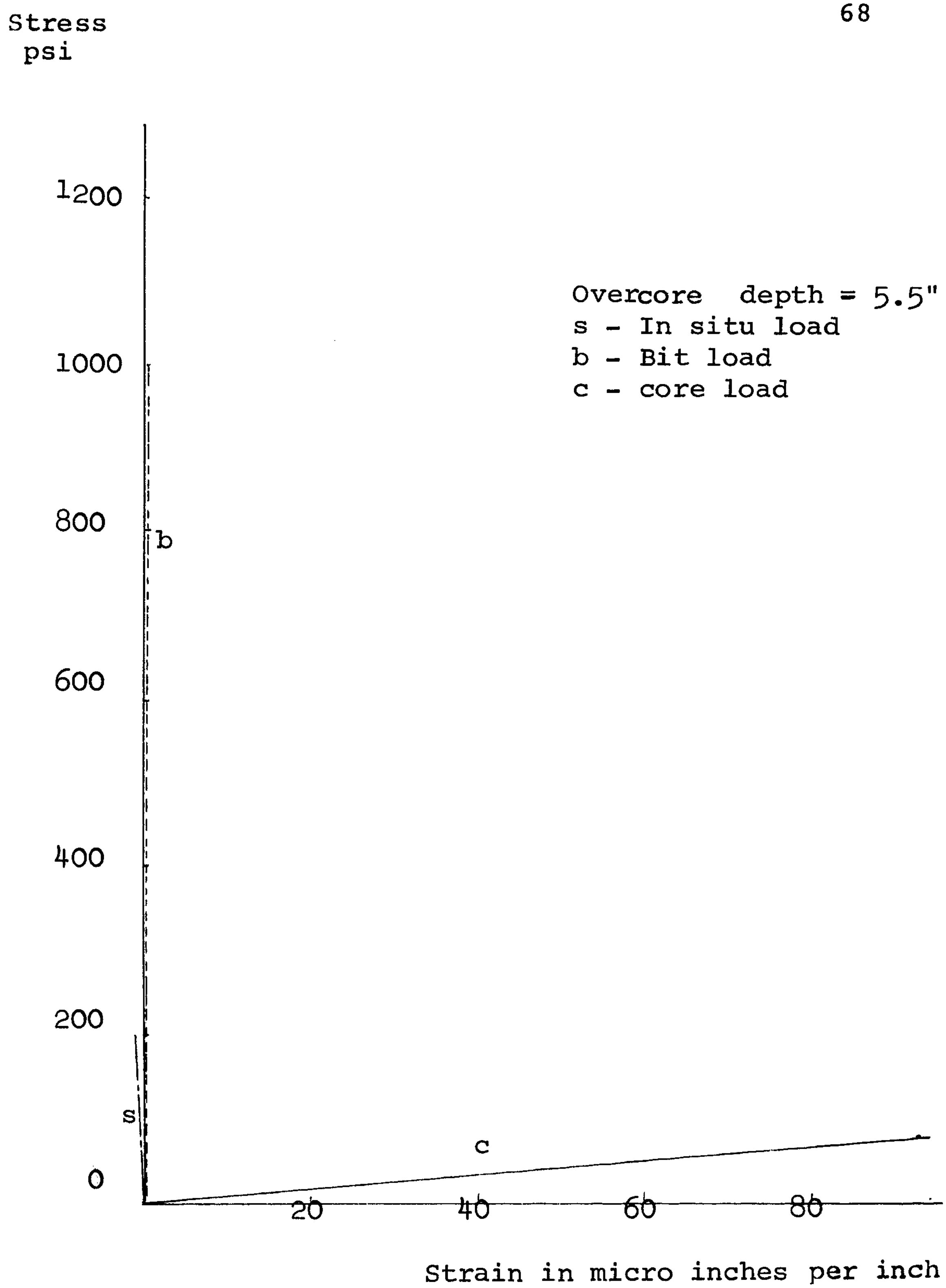

Stress-Strain Curve for Plaster of Paris

Figure 24



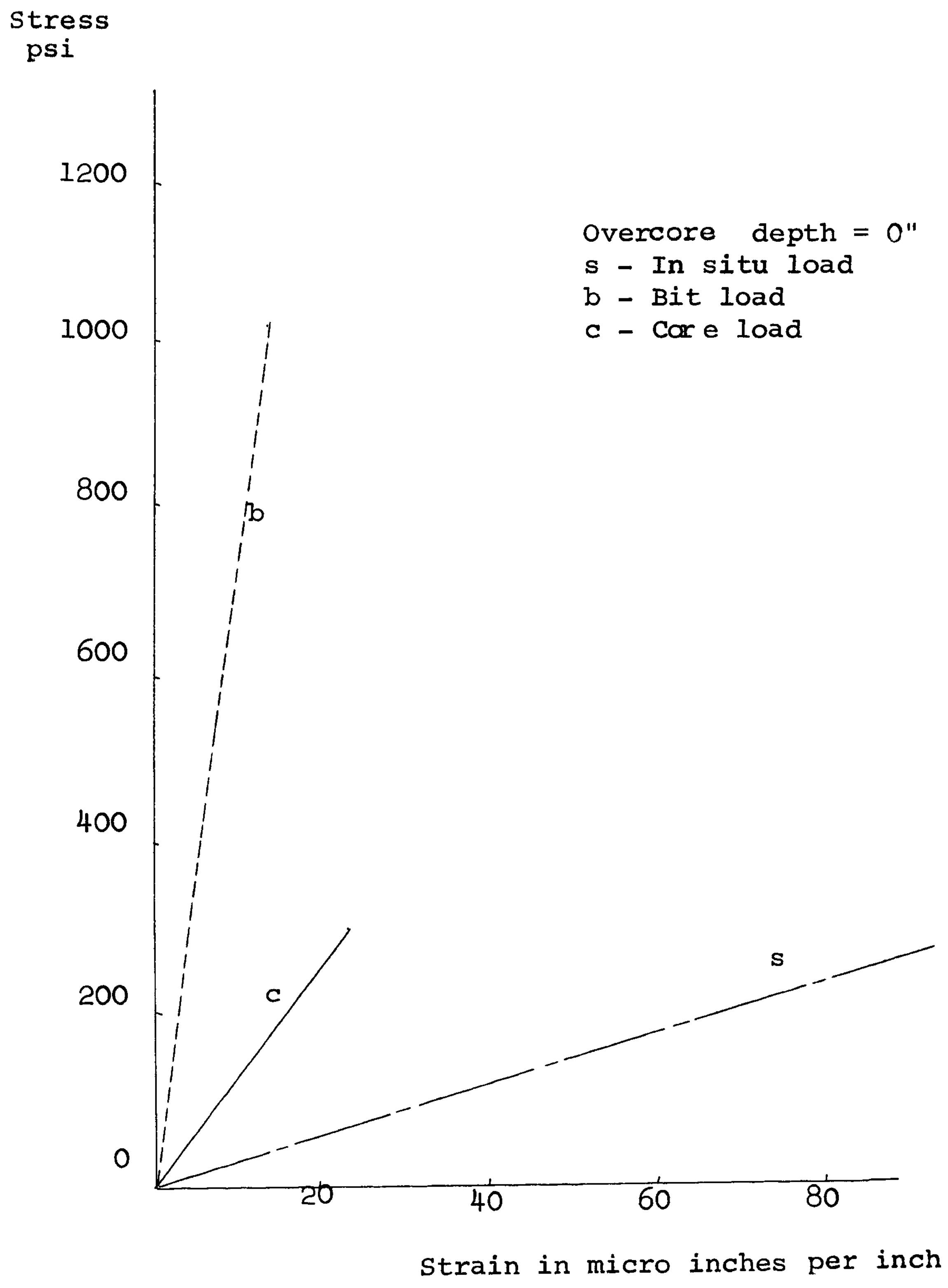

Stress-Strain Curve for Plaster of Paris

Figure 25



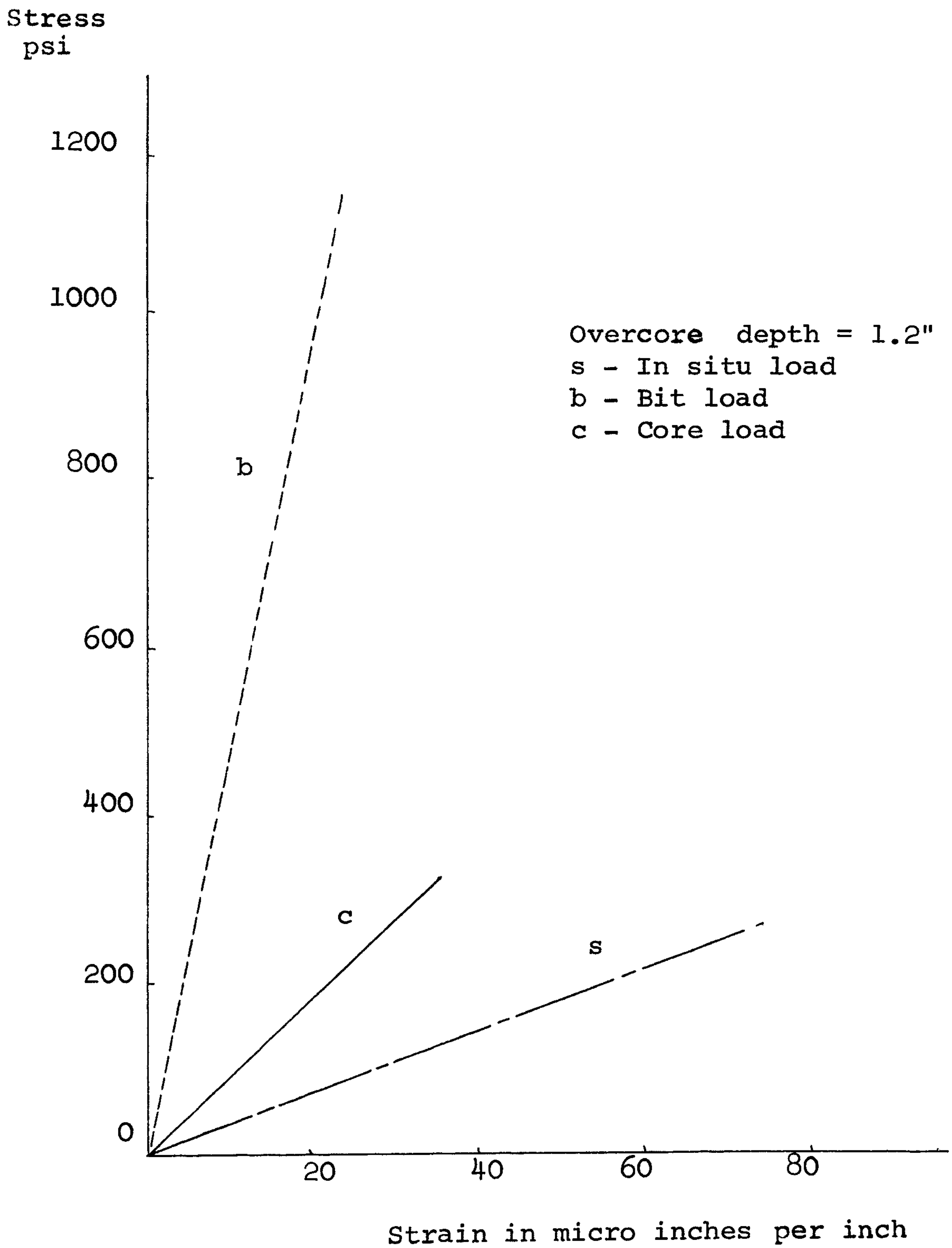

Stress-Strain Curve for Plater of Paris

Figure 26



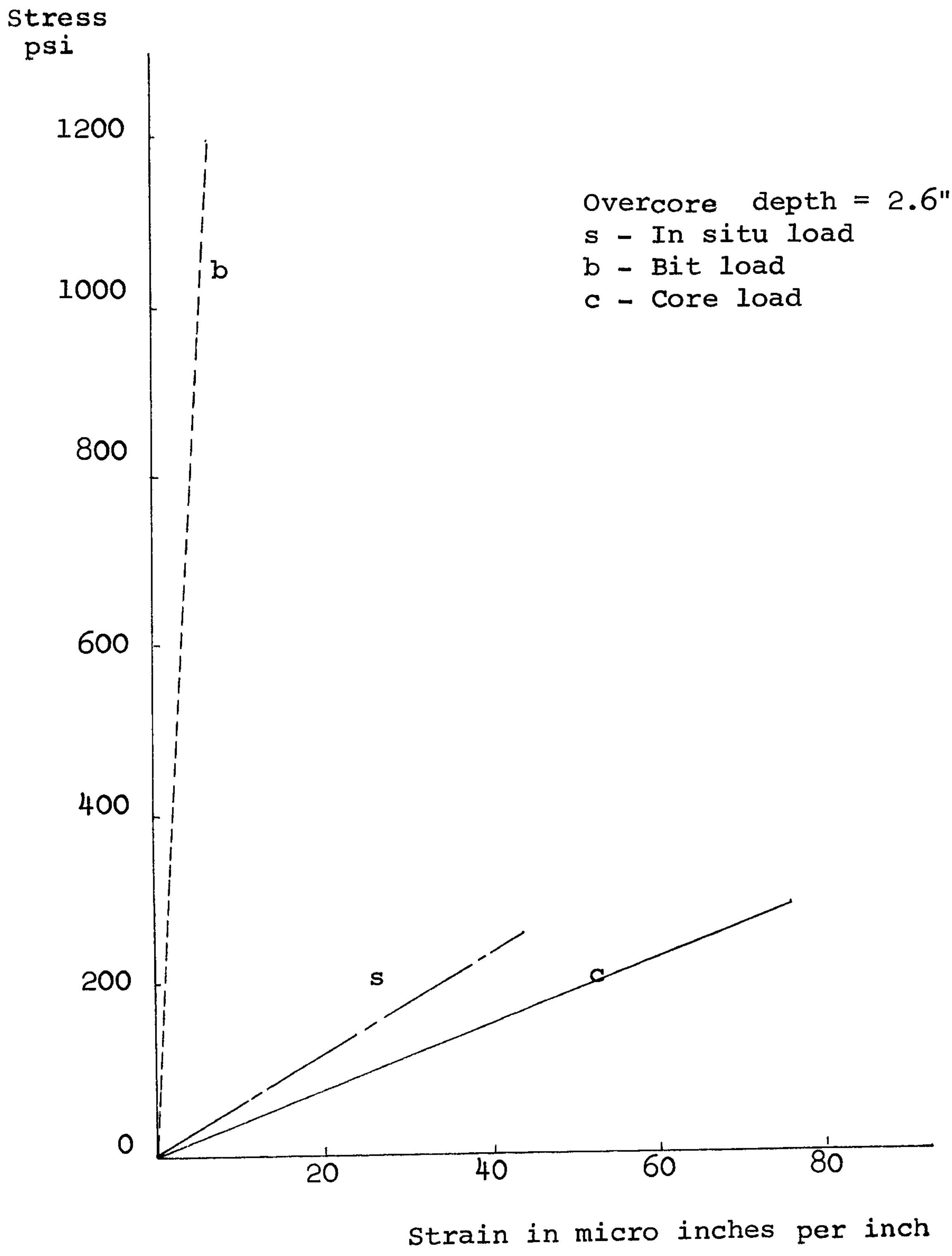

Stress-Strain Curve for Hydrostone

Figure 27



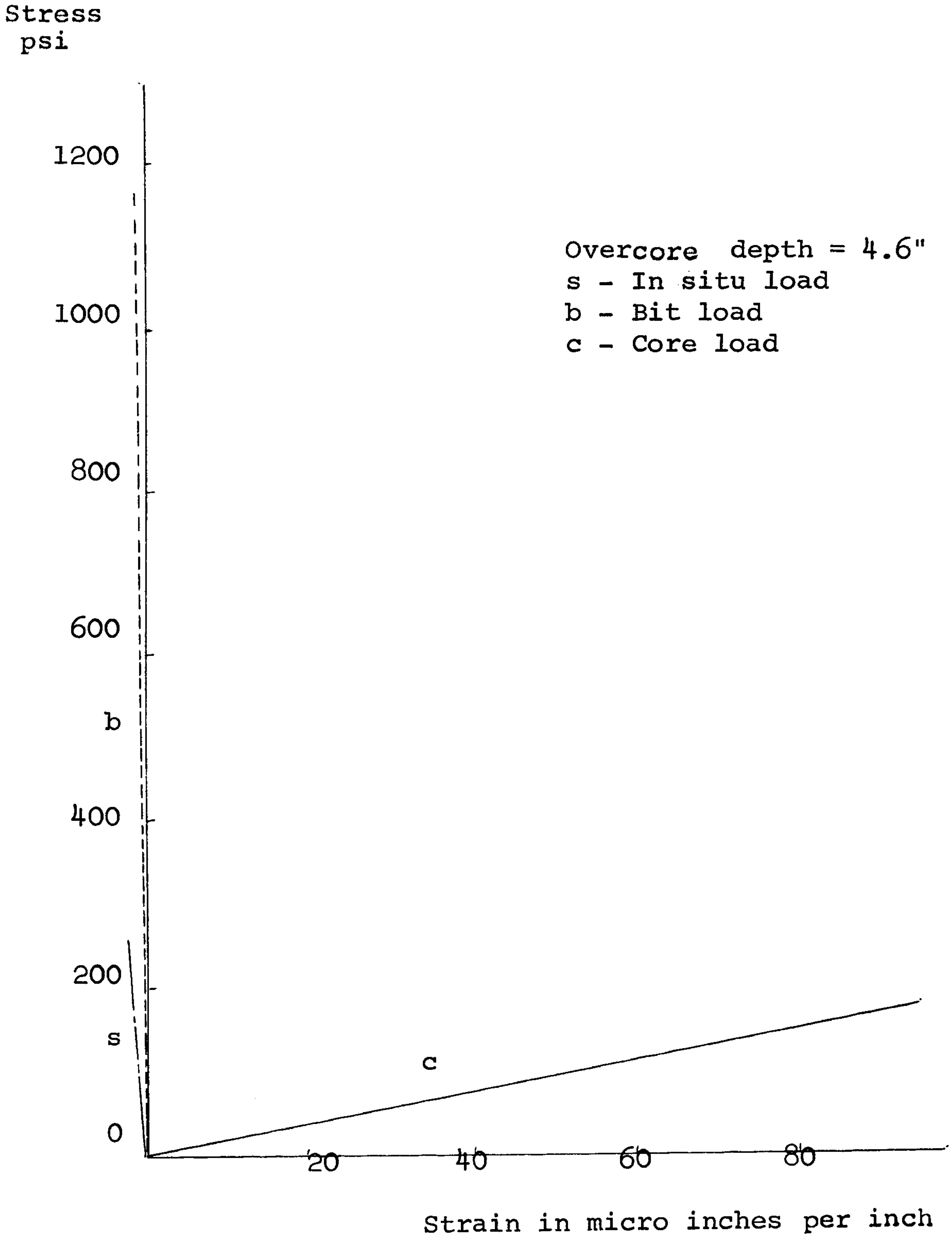

Stress-Strain Curve for Hydrostone

Figure 28




Stress-Strain Curve for Hydrostone

Figure 29




Stress-Strain Curve for Hydrostone

Figure 30

# APPENDIX II

Stress Calculations for Fracture Model No. 2

Data:

Weight of steel plate Wg = 3.5022 lbs.

Weight of resin plate up to xx-- plane Wp = 0.6245

Load bearing area A = 4.35 Sq. In.

Acceleration due to gravity G = 32.2 ft. per sec.$^2$

Distance in feet from the center of centrifuge to the center of gravity of the mass λ.

Rotational speed N = 5 rev. per sec.

The ratio of the centrifugal force to the force of gravity $K = \frac{4\pi^2 rn^2}{G}$

Force due to steel plate K x Wg =

$$\frac{4 \times 3.14 \times 3.14 \times 2.288 \times 5 \times 5 \times 3.5022}{32.2} = 243 \text{ lbs.}$$

Force due to its own weight of plastic up to the xx-- plane K x Wg =

$$\frac{4 \times 3.14 \times 3.14 \times 2.583 \times 5 \times 5 \times 0.6245}{32.2} = 49.5 \text{ lbs.}$$

Total weight = 243 + 49.5 = 292.5 lbs.

$$\text{Stress} = \frac{292.5}{4.35} = 67.3 \text{ psi.}$$

# APPENDIX III

## DEFINITIONS

1. Overcoring Relief Techniques: are procedures for stress-relieving material around a small pilot hole from the stress field by overdrilling with a large size thin walled diamond bit.
2. In Situ Load: is the pressure at any point in the mass due to body forces.
3. Cutting Bit Load: is the pressure applied on the rock surface due to the weight and the cutting action of the drilling tool.
4. Core Load: is the pressure at the bottom of the hole due to the weight of core in the drill barrel.
5. Discing: is the phenomena of slabbing of drilled rock core into small discs due to intense strata pressure.
6. Stress Freezing: is a method to permanently extablish stress patterns in a photoelastic material.

# VITA

Varakantham Sreedhar Reddy was born in Hyderabad, India, on September 22, 1936. His high school and intermediate college education was received at Hyderabad. Later, he enrolled at Banaras Hindu University, India, and received a Bachelor of Science degree in Mining Engineering in the year 1961.

During his training program during and after studies at the university he was assigned to a number of coal and metal mines. In September, 1961, he joined the Mining Department of Osmania University, India, as lecturer.

In September, 1963, he enrolled at the Missouri School of Mines and Metallurgy to work toward the degree of Master of Science in Mining Engineering.