DETERMINATION OF IN SITU STRESS BY THE OVERCORING TECHNIQUE

1. Scope

1.1 The equipment required to perform in situ stress tests using the U. S. Bureau of Mines' three-component borehole deformation gage is described.

1.2 The test procedure and method of data reduction are described, including the theoretical basis and assumptions involved in the calculations. A section on troubleshooting equipment malfunctions is included.

1.3 The procedure herein described was taken from the Bureau of Mines Information Circular No. 8618 dated 1974 [8.1] as were many of the figures. Some modifications based on field experience are incorporated. This test method can be used from the surface or from underground openings. Good results can be expected using this technique in massive or competent rock. Difficulties will be encountered if tests are attempted in fissile or fractured rock.

2. Test Equipment

2.1 Instrumentation

2.1.1 The three-component borehole deformation gage (BDG) is shown in Fig. 1. It is designed to measure diametral deformations during overcoring along three diameters 60 deg apart in a plane perpendicular to the walls of a 1-1/2-in.-diameter borehole. The measurements are made along axes referred to as the U_1, U_2, and U_3 axes. Accessories required with the gage are special pliers, 0.005- and 0.015-in.-thick brass piston washers, and silicone grease (Fig. 1).

2.1.2 Three Vishay P350A or equal strain indicators are required. (Alternatively, one indicator with a switching unit may be used or one unit may be used in conjunction with manual wire changing to obtain readings from the three axes.) These units have a full range digital readout limit of 40,000 indicator units. A calibration factor must be obtained for each axis to relate indicator units to microinches deflection. The calibration factor for each axis will change proportionally with the gage factor used. Normally, a gage factor of 0.40 gives a good balance between range and sensitivity. Figure 2 shows a strain indicator, calibration jig, and a switching unit.

2.1.3 The shielded eight-wire conductor cable transmits the strain measurements from the gage to the strain indicators. The length of cable required is the depth to the test position from the surface plus about 30 ft to reach the strain indicators.

2.1.4 The orientation and placement tools consist of:

(a) The placement tool or "J slot" shown in Fig. 3.

(b) Placement rod extensions as shown in Fig. 3.

(c) The orientation tool or "T handle," also shown in Fig. 3.

(d) The scribing tool is used to orient the core for later biaxial testing. It consists of a bullet-shaped stainless steel head attached to a 3-ft rod extension. Projecting perpendicular from the stainless steel head is a diamond stud. The stud is adjusted outward until a snug fit is achieved in the EX hole so that a line is scratched along the borehole wall as the scribing tool is pushed in.

(e) The Pajari alignment device is inserted into the hole to determine the inclination. It consists of a floating compass and an automatic locking device which locks the compass in position before retrieving it.

2.1.5 The calibration jig (Fig. 2) is used to calibrate the BDG before and after each test.

2.1.6 The biaxial chamber is used to determine Young's Modulus of the retrieved rock core. A schematic of the apparatus is shown in Fig. 4.[8.2]

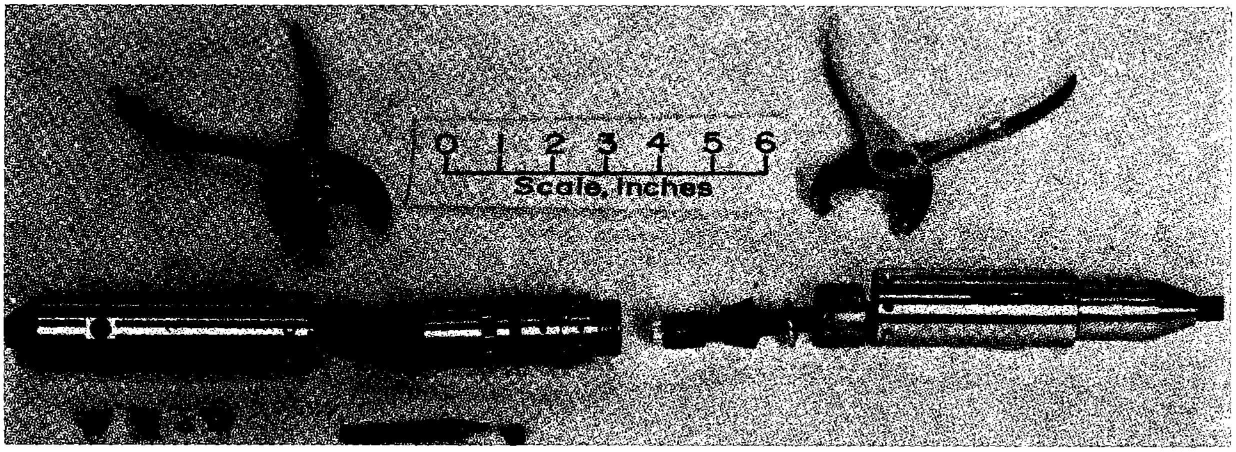


Fig. 1. Special pliers, the Bureau of Mines' three-component borehole gage, a piston, disassembled piston and washer, and a transducer with nut.

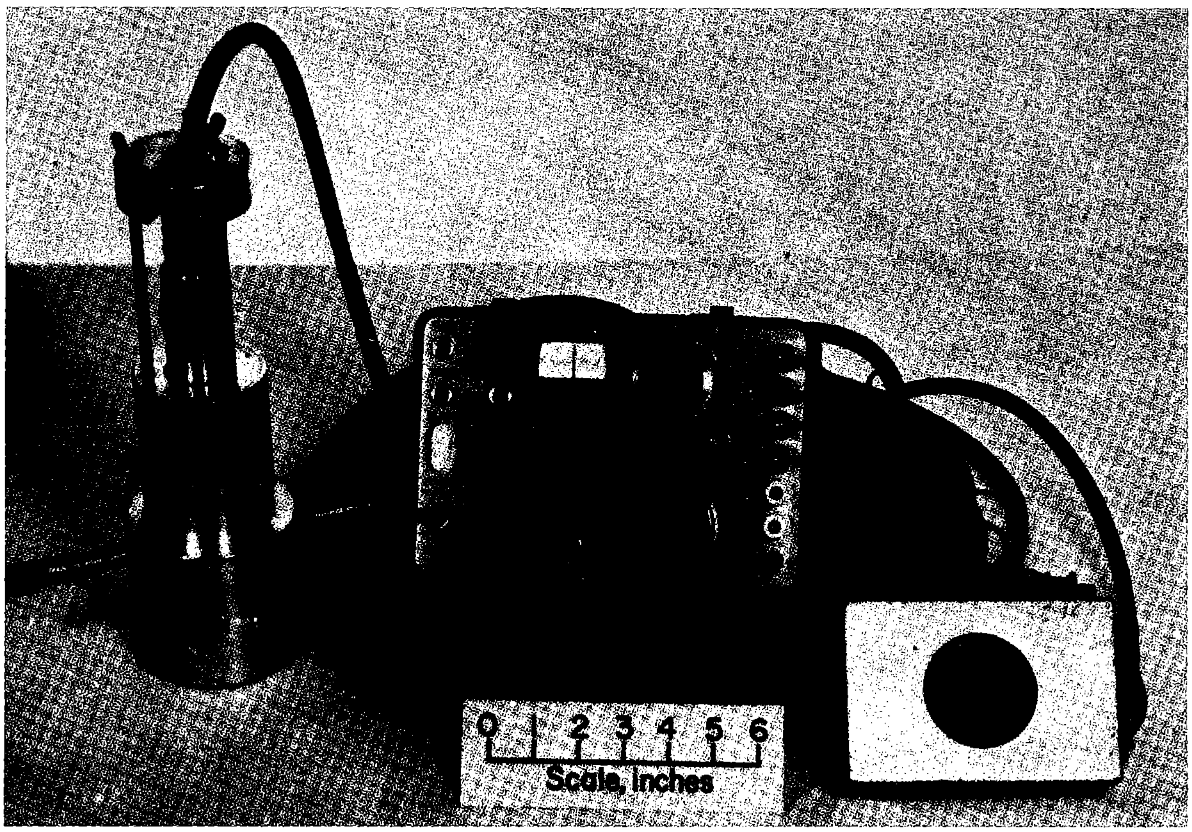


Fig. 2. The calibration device (left side) and a switching unit (right side).

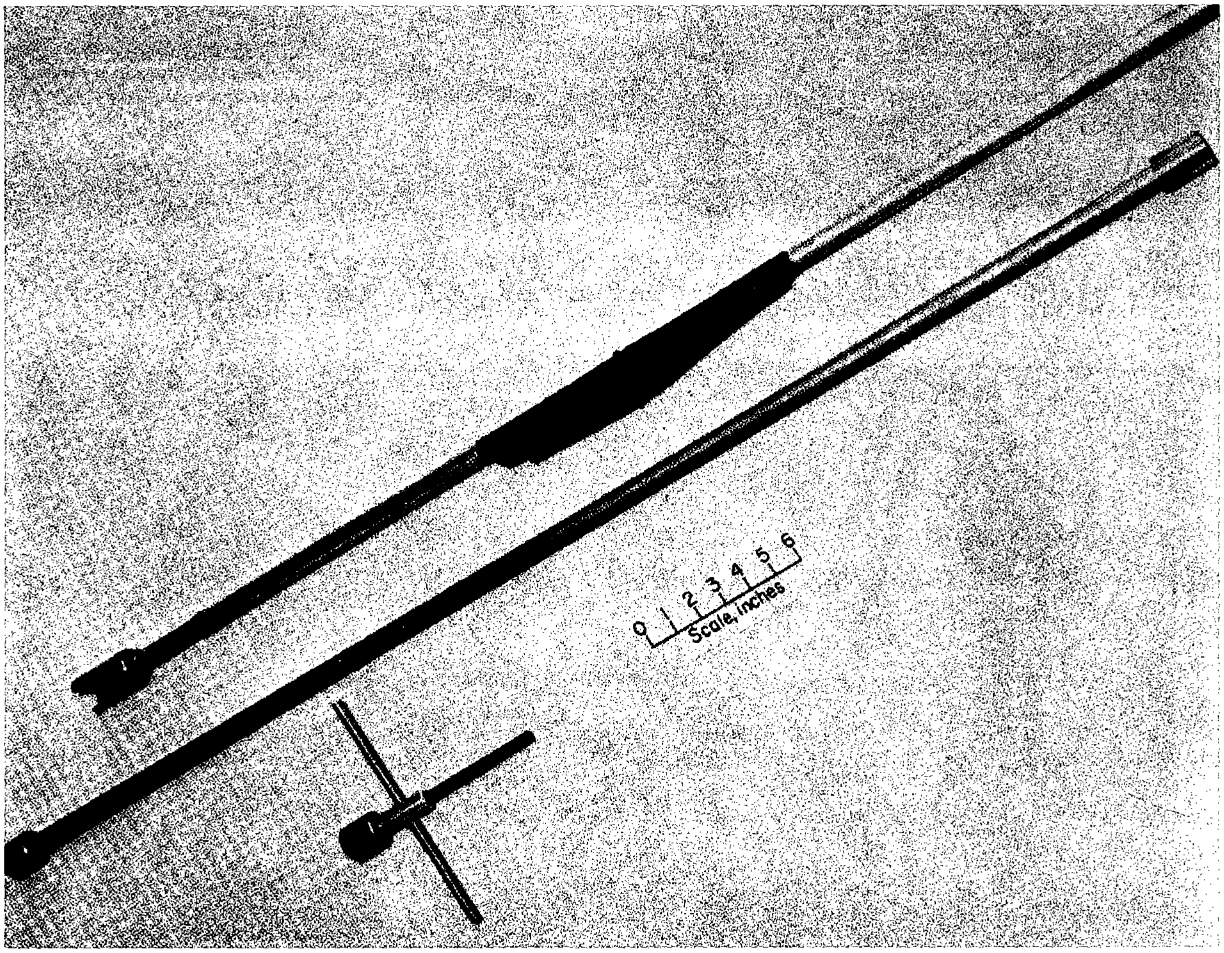


Fig. 3. Placement and retrieval tool.

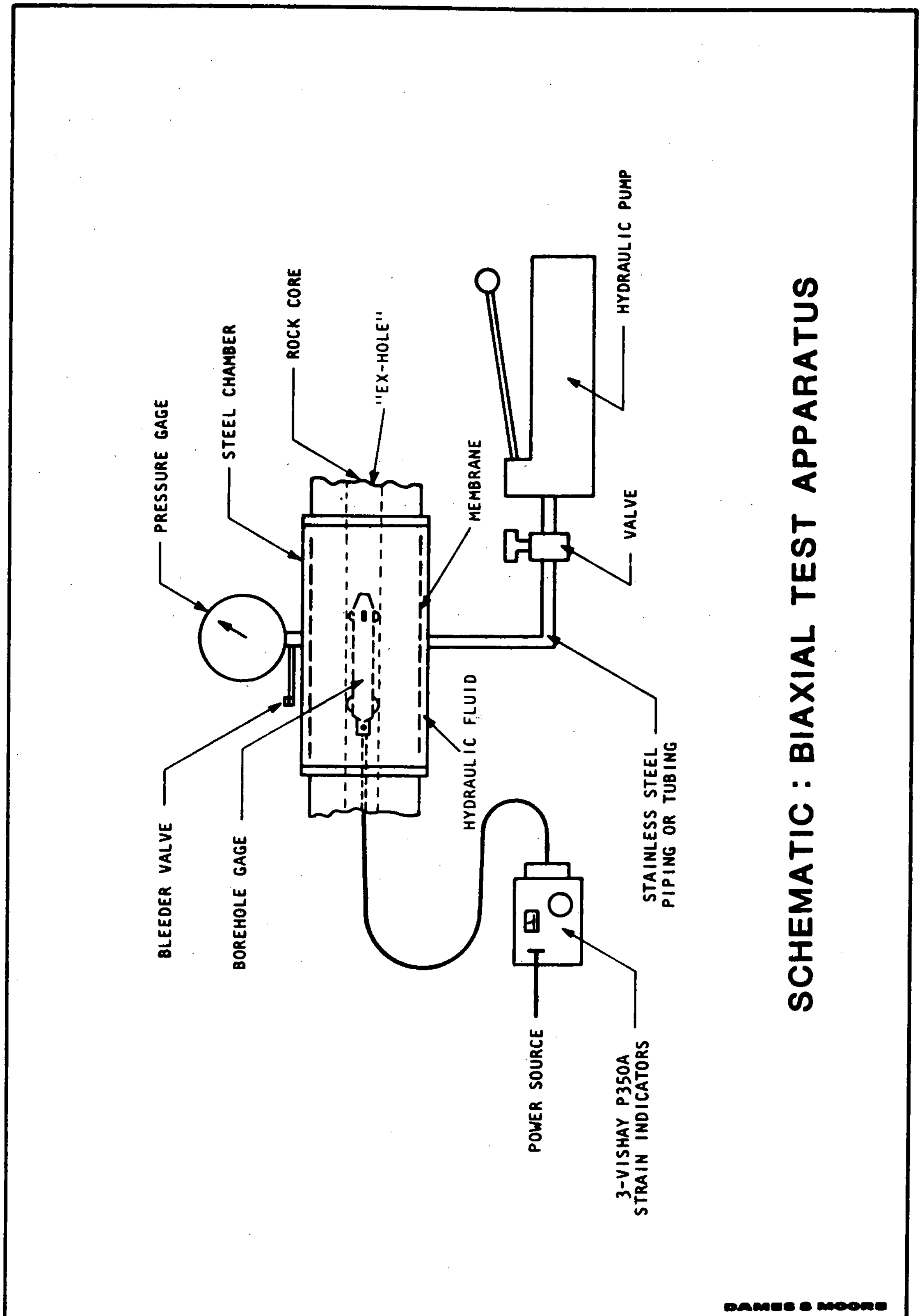

SCHEMATIC : BIAXIAL TEST APPARATUS
PRESSURE GAGE
STEEL CHAMBER
ROCK CORE
"EX-HOLE"
MEMBRANE
HYDRAULIC PUMP
VALVE
BLEEDER VALVE
BOREHOLE GAGE
HYDRAULIC FLUID
STAINLESS STEEL PIPING OR TUBING
POWER SOURCE
3-VISHAY P350A STRAIN INDICATORS

Fig. 4

2.2 Drilling Equipment

2.2.1 A drill with a chuck speed ranging down to 50 rpm should be used. Achievement of this lower end speed will usually require a gear reduction.

2.2.2 An EWX single-tube core barrel, 2 ft long, is required (Fig. 5).

2.2.3 An EX diamond bit is required (Fig. 5).

2.2.4 A reamer is used with the EX bit for the 1-1/2-in.-diameter pilot gage hole (Fig. 5).

2.2.5 Two stabilizers are required. One should be 5-1/2 in. OD by 4 in. long and one should be 2-3/4 in. OD by 4 in. long. Each should have an inner concentric hole slightly larger than the OD of AX casing. Grooves should be cut into the stabilizers to allow water to pass through. The stabilizers are slipped over opposite ends of a 6 ft length of AX flush joint casing and secured with set screws. The stabilizer can be made from hard plastic stock. This assembly fits inside the 5-ft-long, 6-in.-diameter core barrel with the larger stabilizer at the bottom and the smaller stabilizer projecting into the NW casing. As overcoring proceeds, the stabilizer assembly is pushed upward into the NW casing.

2.2.6 An EWX rod stabilizer should be made that will slide over the EWX rod and fit inside the NW casing to align the EX bit with the hole in the center of the stabilizer in the 6-in. core barrel. Cut grooves along the outer edges of the stabilizer to allow water to flow through.

2.2.7 EW drill rods are used with the EX bit. The required length is dependent on the test depth.

2.2.8 NW casing is used with the 6-in. core barrel and bit. The required length will depend on test depth. An adapter is required to couple the NW casing to the 6-in. core barrel.

2.2.9 A water swivel (Fig. 6) is required with a 1/2-in. hole for the conductor cable to pass through and a plug is required to fit the hole when the gage is not being used.

2.2.10 A 6-in.-diameter starter barrel 1 ft long with a detachable 1-1/2-in.-diameter pilot shaft in the center (Fig. 7) is required. The pilot shaft should extend about 5 in. beyond the diamonds of the starter barrel. This barrel is used to center the 6-in.-diameter hole over an initial 1-1/2-in.-diameter hole at the face. The barrel and pilot shaft are not needed for vertical or near vertical holes.

2.2.11 An EW core barrel to replace the pilot shaft should be cut to extend 1 in. beyond the starter barrel. When the bit and reamer are attached, the unit is used to drill a 1-1/2-in.-diameter starter hole 4 in. deep at the end of a 6-in. horizontal hole. This piece of equipment is not needed in vertical holes.

2.2.12 A standard 6-in. diamond drill bit or a 6-in. thin wall masonry bit is used for overcoring.

2.2.13 A core breaker, at least 2-1/2 in. wide and hardened, to fit the EW rod (Fig. 8) is required.

2.2.14 A 6-in. core shovel (Fig. 8) to fit an EW rod is needed for retrieving core from horizontal holes.

2.2.15 A 6-in. core puller (Fig. 8) approximately 18 in. long to fit an EW drill rod is sometimes needed for retrieving core from vertical holes. The core puller is made from a used 6-in. core barrel. A 5/8-in.-thick steel plate is welded to the end of the barrel with an EW rod welded in the center. Three 1-1/2-in.-diameter holes on 120-deg centers are drilled into the plate to allow water to pass through. Four U cuts 90 deg apart are made on the front of the barrel. The rectangular pieces of metal inside the U cuts are pushed in slightly to grip the core. This is an optional piece of equipment. Normally, the core can be retrieved inside the 5-ft barrel.

2.2.16 A 6-in.-diameter core barrel 5 ft long is required.

2.2.17 A high-capacity water pump and hose are required.

Fig. 5. EX size bit with core spring, reamer, and 2-ft EWX core barrel.

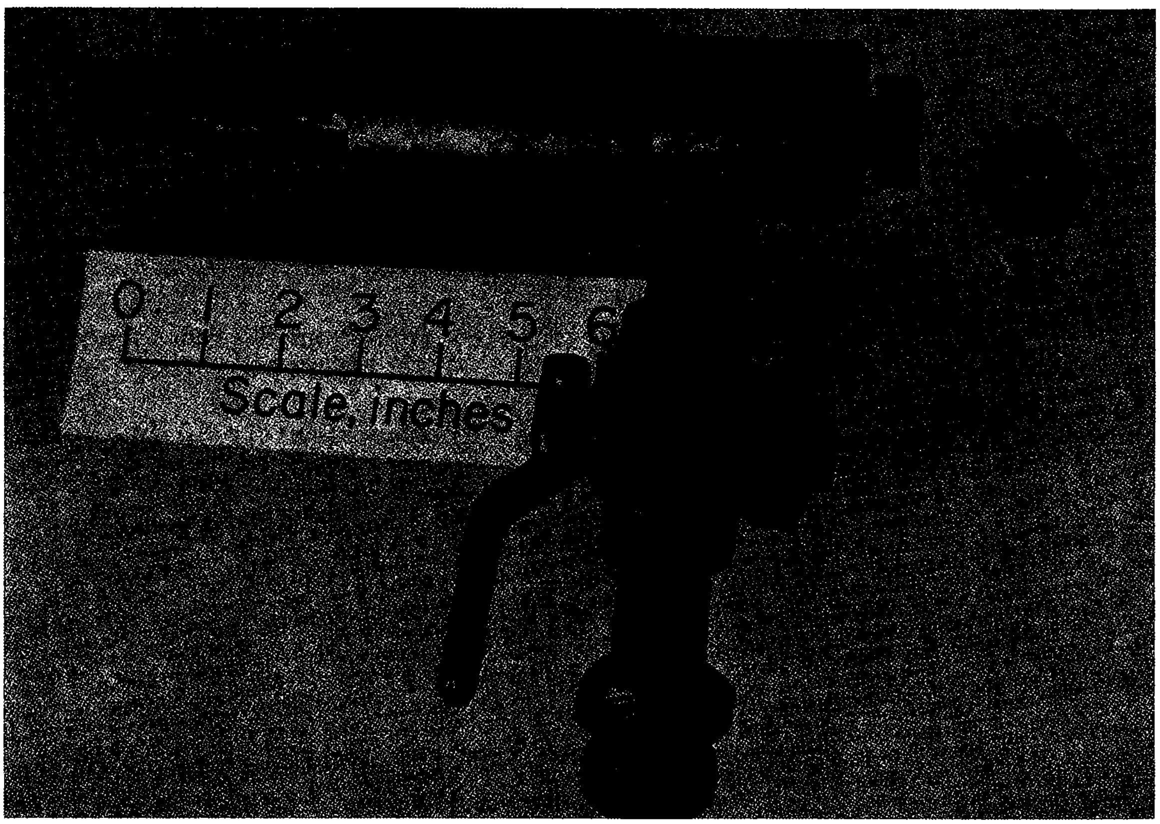


Fig. 6. Water swivel with solid plug. Plug at right used during overcoring.

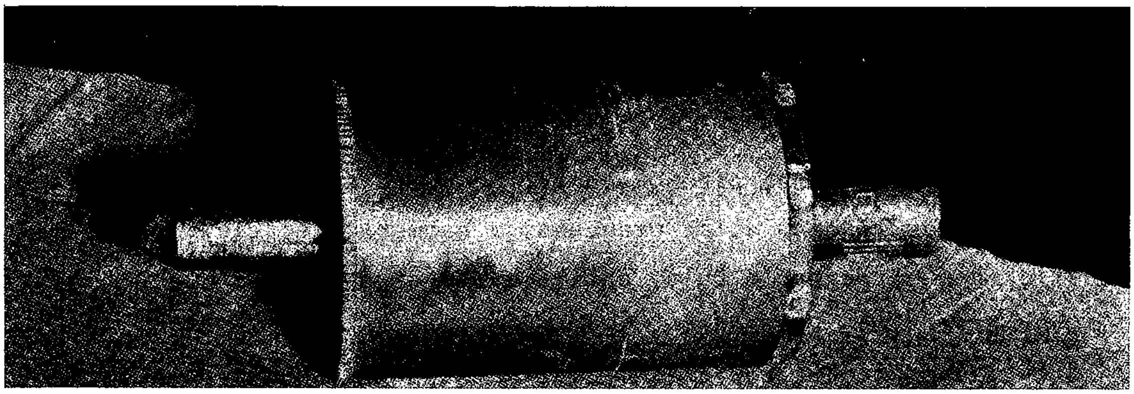


Fig. 7. Six-inch-diameter starter barrel with pilot and expander head adapted for EW drill rod.

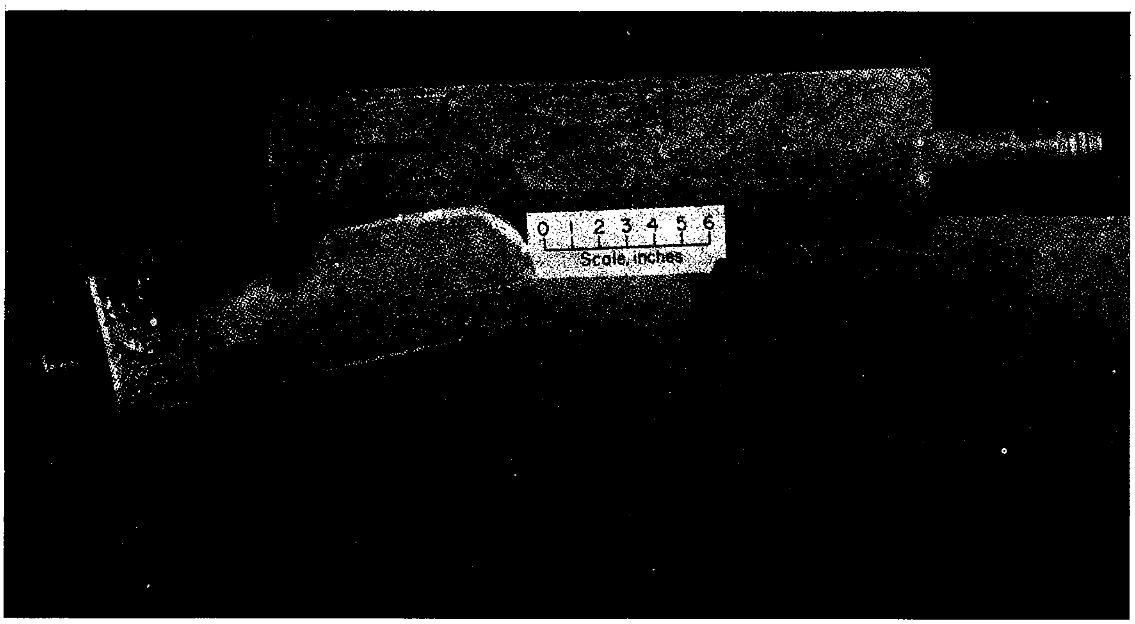


Fig. 8. Core breaker (lower right), core shovel (lower left), and core puller (center).

2.2.18 One clothesline pulley is required.

2.3 Miscellaneous Equipment - This field operation requires a good set of assorted hand tools which should include a soldering iron, solder and flux, pliers, pipe wrenches, adjustable wrenches, end wrenches, screwdrivers, allen wrenches, a hammer, electrical tape, a yardstick and carpenter's rule, chalk, and a stopwatch.

3. Overcoring Test Procedure

3.1 The procedure for determining in situ stress can be divided into three phases: (a) strain relief measurements in situ, (b) determination of Young's Modulus of the rock by recompression in a biaxial chamber, and (c) computation of stress.

3.2 Reliable information on subsurface rock conditions is essential for good test results. For this reason it is advisable to drill an exploratory NX size hole within a few feet of the desired test location.

3.3 Horizontal holes should be started 5 deg upward from horizontal to facilitate removal of water and cuttings. An EX pilot hole is first drilled about 4 in. into the rock. Attach the 6-in. starter barrel and pilot shaft and start the 6-in. hole. Remove the starter barrel, attach the regular 6-in. bit and barrel, and extend the 6-in. hole to within 12 in. of the desired test depth. Proceed to step 3.6.

3.4 When testing in vertical holes, first wash bore through the overburden and core about 5 ft into bedrock. Case the hole with 8-in. casing and grout in place.

3.5 Drill a 6-in.-diameter hole to within 12 in. of the desired test depth. Retrieve the core and go back down the hole with the stabilizers in place in the core barrel.

3.6 Insert the EX bit and reamer coupled to the 2-ft EX core barrel and EWX rods with the EWX stabilizer in place. Drill 2 ft of EX hole.

3.7 Retrieve the EX core and inspect. Insert the scribing tool coupled to the rod extensions. When the scribing tool reaches the stabilizers, it will have to be shoved through. It will then be at the top of the EX hole. Attach the orientation handle and orient the scribe mark as desired. Shove the scribe straight down the hole. (Note: If the scribe cannot be pushed down the hole, the diamond stud is projecting too far; adjust it inward. If the scribe feels loose the stud must be adjusted to project further.) When the scribe hits the bottom of the EX hole, slowly pull it back up along the same scribe mark. If joints or fractures intersect the borehole walls, they can often be detected by a subtle vibration as the diamond stud crosses them. If joints or fractures are detected, extend the hole and try again.

3.8 When the EX hole has been scribed, remove the scribing tool.

3.9 The BDG must now be calibrated. It should be calibrated before and after each test.

3.9.1 Grease all gage pistons with a light coat of silicone grease and install them in gage.

3.9.2 Place the gage in the calibration jig as shown in Fig. 2 with the pistons of the U_1 axis visible through the micrometer holes of the jig. Tighten the wing nuts.

3.9.3 Install the two micrometer heads and lightly tighten the set screws.

3.9.4 Set the strain indicators on "Full Bridge", center the balance knob, and set the gage factor to correspond to the anticipated in situ range and sensitivity requirements. (If high stress conditions are anticipated, sensitivity will have to be compromised to gain the required range.) A lower gage factor results in higher sensitivity. The gage factor used should be the same for calibration, in situ testing, and modulus tests.

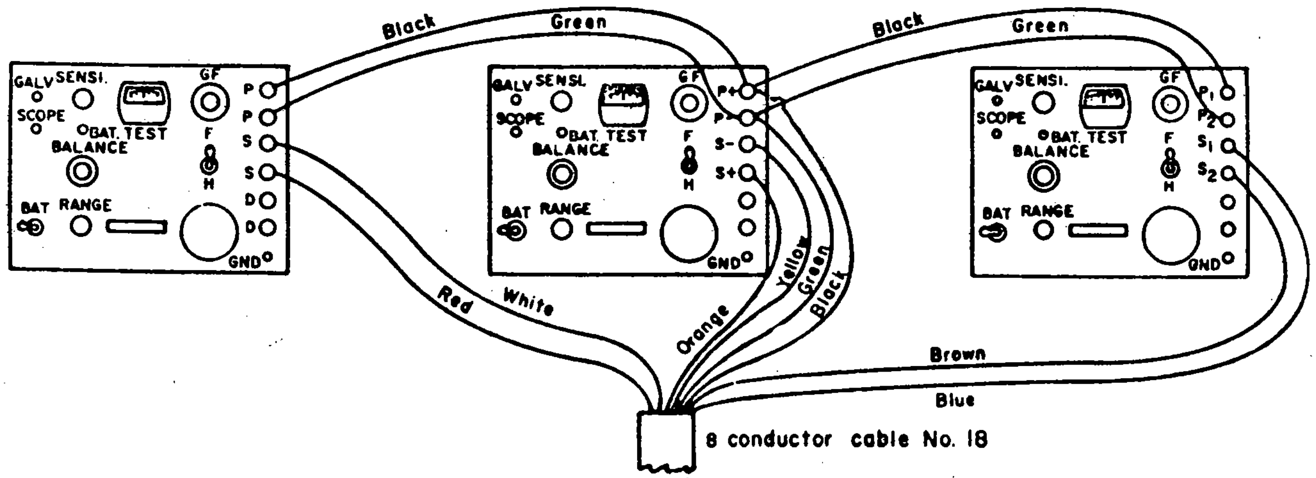
3.9.5 Wire the gage to the indicators as shown in Fig. 9 or to a switching and balance unit and one indicator.

3.9.6 Balance the indicator using the "Balance" knob.

3.9.7 Turn one micrometer in until the needle of the indicator just starts to move. The micrometer is now in contact with the piston. Repeat with the other micrometer.

3.9.8 Rebalance the indicator.

Sensitivity knob turn full clockwise.
Balance knob: put mid-range (5 turns of the 10-turn potentiometer).
Bridge switch: Switch to full (F).



Note. Hook black and green wires to indicator No. 2 and use two other wires (No. 18 or No. 20) to common P+ and P- (or P_1 and P_2) of all three indicators.

Fig. 9. Wire hookup to model P-350 strain indicators.

3.9.9 Record this no load indicator reading for the U_1 axis.

3.9.10 Turn in each micrometer 0.0160 in. (a total of 0.0320-in. displacement).

3.9.11 Balance the indicator and record the reading and the deflection.

3.9.12 Wait two minutes to check the combined creep of the two transducers. Creep should not exceed 20 μ in./in. in two minutes.

3.9.13 Record the new reading.

3.9.14 Back out each micrometer 0.0040 in. (a total of 0.0080 in.).

3.9.15 Balance and record.

3.9.16 Continue this procedure with the same increments until the initial point on the micrometer is reached. This zero displacement reading will be the zero displacement reading for the second run.

3.9.17 Repeat steps 3.9.10 through 3.9.16.

3.9.18 Loosen the wing nuts and rotate the gage to align the pistons of the U_2 axis with the micrometer holes.

3.9.19 Retighten the wing nuts.

3.9.20 Repeat steps 3.9.6 through 3.9.17.

3.9.21 Loosen wing nuts and align pistons of U_3 axis with micrometer holes. Repeat the calibration procedure followed for the U_1 and U_2 axes.

3.9.22 To determine the calibration factor for each axis:

(a) Subtract the zero displacement strain indicator readings (last reading of each run) from the indicator readings for each deflection to establish the differences.

(b) Subtract the difference in indicator units at 0.0080-in. deflection from the difference in indicator units at 0.0320-in. deflection.

(c) Divide the difference in deflections (0.0240 in.) by the corresponding difference in indicator units just calculated to obtain the calibration factor for that axis.

(d) Repeat for the second cycle and take the average as the calibration factor.

(e) The following is an example of the calibration for one axis, calibrated at a gage factor of 0.40.

CALIBRATION OF AXIS U_1

	Displacement in.	Indicator Reading	Difference μin./in.
Run 1	0	-693	---
	0.0320	+30,140	Wait 2 minutes
	0.0320	30,055	30,535
	0.0240	21,920	22,400
	0.0160	14,040	14,520
	0.0080	6,380	6,860
	0	-480	---
Run 2	0	-480	---
	0.0320	+30,034	Wait 2 minutes
	0.0320	29,980	30,430
	0.0240	21,914	22,364
	0.0160	13,975	14,425
	0.0080	6,335	6,785
	0	-450	---

$$\text{Calibration Factor} = K_1 = \frac{\text{Displacement}}{\text{Indicator Units}}$$

$$\text{For Run 1, } K_1 = \frac{32{,}000 - 8{,}000}{30{,}535 - 6{,}860} = \frac{24{,}000}{23{,}675} = 1.014$$

$$\text{For Run 2, K1} = \frac{32{,}000 - 8{,}000}{30{,}430 - 6{,}785} = \frac{24{,}000}{23{,}645} = 1.015$$

Use K_1 = 1.01 μ inches per indicator unit

3.10 Remove the BDG from the calibration jig and disconnect the wires from the strain indicators. Tape the ends of the wires together.

3.11 Thread the conductor cable through the chuck and water swivel and over the clothesline pulley attached to the top of the derrick if testing from ground surface. Reconnect the wires to the strain indicators exactly as during calibration.

3.12 Take zero deformation readings for each axis and record on the Field Data Sheet (Fig. 10) in the row labeled "zero" and in the three columns labeled U_1, U_2, and U_3. If just one indicator is being used, use a switching unit. If a switching unit is not available, the wires must be changed for each axis. Check each axis by applying slight finger pressure to opposing pistons and releasing. The balance needle should deflect, then return to the balanced position. Make sure the correct axis is connected to the correct strain indicator.

3.13 Engage the orientation pins of the BDG with the placement tool using a clockwise motion. Secure the conductor cable with the wire retainer clip on the placement tool. Make sure the orientation pins of the BDG are aligned with the U_1 axis. Push the gage through the stabilizer tube and about 9 in. into the EX hole. With the gage at test depth, orient the U_1 axis along the scribe mark by turning clockwise. If the BDG feels too loose or too tight in the EX hole, it must be removed. If too tight, remove one washer from one piston of each axis and try again. If too loose, add one washer to one piston of each axis. To add or remove washers, pull the piston out with the special pliers, unscrew the two piston halves with two pairs of special pliers, add or remove washers, and screw piston halves back together. Be careful not to damage the O ring. Regrease O ring and reinstall piston in gage. Do this to only one piston in each diametral pair initially. If gage is still too tight or loose, repeat with remaining pistons.

3.14 With the gage installed at test depth and correctly oriented, check the bias of the gage on the strain indicators. The bias set on each component should be between 10,000 and 15,000 indicator units

Hole No. __________ Date __________ Orientation: U_1 __________

Gage No. __________ Calibration Factor U_1 __________

Gage factor __________ U_2 __________

True Bearing of Hole __________ U_3 __________

DEPTH			DEFORMATION			TIME			TEMP.		REMARKS
			INDICATOR READING								
Gage	Hole (+)		U_1	U_2	U_3	Gage Set	Overcore Start	Deformation Read	Rock	Water	
		Zero									
9"	Face	Bias									
	1/2"										
	1"										
	1 1/2"										
	2"										
	2 1/2"										
	7"										
	7 1/2"										
	8"										
	8 1/2"										
Pistons	9"										
	9 1/2"										
	10"										
	10 1/2"										
	11"										
	13"										
	13 1/2"										
	14"										
	14 1/2"										
	15"										
	15 1/2"										
	16"										
	16 1/2"										
	17										
	17 1/2"										
	18										

Note. Next relief would start at 18 inches and go to 36 inches and gage would be orientated at a depth of 27 inches.

Fig. 10. Field data sheet.

with a gage factor of 0.40 for overcoring strain relief tests. For recompression tests in the biaxial chamber, the bias should be between 4,000 and 8,000 indicator units with a gage factor of 0.40. With a gage factor of 1.50, the bias should be between 2300 and 3400 indicator units for overcoring tests and between 900 and 1800 indicator units for recompression tests. Care must be taken to avoid overloading the transducers. Maximum load on any component should not exceed 20,000 indicator units with a gage factor of 0.40 and 4560 units with a gage factor of 1.50.

3.15 Turn the placement tool counterclockwise approximately 60 deg to disengage it from the BDG and remove the tool. (When retrieving the BDG, the tool is lowered onto the orientation pins and turned 60 deg clockwise.)

3.16 Pull the slack conductor cable through the chuck and over the clothesline pulley. Avoid excess tension in the cable or the gage may be pulled out of the EX hole. Tie off the cable and close the drill. Couple the NW casing to the chuck adaptor.

3.17 Turn on water. Allow approximately 10 minutes for gage, water, and rock to reach temperature equilibrium. Obtain new zero readings for each axis.

3.18 With the 6-in. bit resting on the bottom of the hole, tape a yardstick to the drill stand with the end flush with the bottom of the truck bed. As overcoring proceeds, check the advance rate by timing the descent of the yardstick with a stopwatch. Alternatively, the exposed casing may be marked at 1/2-in. increments to regulate the advance rate.

3.19 Start overcoring at a penetration rate of 1/2 in. per 40 seconds and a chuck speed of 50 rpm. The stopwatch is used to calibrate the drill to this rate. Each 1/2-in. penetration should be signaled to the recorder who records the indicator readings for each axis on the field data sheet. Overcore approximately 12 to 18 in. at this rate. If the core breaks during overcoring, the needles on the strain indicators will fluctuate erratically or the cable will twist. If either happens, stop overcoring immediately and retrieve the gage and core. If overcoring is successfully completed, stop the drill and continue to take periodic readings, with the water still running, until no appreciable changes in readings are occurring. This may take only a few minutes or it may take 2 or 3 hours depending on the rock.

3.20 Disconnect the wires from the strain indicators and tape the end of the cable so the drill can be uncoupled and raised without applying excess tension to the cable.

3.21 Pull the cable end back through the water swivel and chuck.

3.22 Secure the cable to the placement tool with the retainer clip and insert the tool over the BDG. When the placement tool engages the pins on the BDG, turn the tool 60 deg clockwise to secure the BDG. Pull the BDG and cable out of the hole.

3.23 Remove the core barrel and NW casing.

3.24 Retrieve the core (if it was not brought up inside the barrel) using the core breaker and core puller (or shovel in horizontal holes).

3.25 Plot the change in indicator units versus inches overcored for each test as shown in Fig. 11.[8.2] Compare this plot with the plot of an idealized overcore test (Fig. 12[8.2]) to determine if the test was successful.

3.26 Repeat this procedure for each additional test.

4. <u>Procedure for Determining Young's Modulus of Elasticity of the Rock Core</u>

4.1 The retrieved rock core should be tested in a biaxial chamber (Fig. 4) as soon as conveniently possible after recovery to determine the modulus of elasticity.

4.2 Place the calibrated BDG in the EX hole in the core at the same point and orientation where the in situ test was performed (align the U_1 axis of the BDG with the scribe mark).

4.3 Slide the rubber membrane over the rock core and place in the biaxial chamber.

4.4 Record initial or zero readings for all axes.

4.5 Increase hydraulic pressure in increments up to the measured in situ strain level and unload in identical increments.

4.6 Record deformation readings for each axis at each loading and unloading increment.

4.7 Repeat steps 4.4 through 4.6 for a second cycle.

4.8 Plot the applied pressure versus diametral deformations for each axis as shown in Fig. 13.[8.2] To calculate the average modulus value, E, obtain the differences in deflections corresponding to the differences in applied pressures on the second unloading cycle and use Equation 5 in the calculations section (see paragraph 6).

4.9 This test procedure requires an intact piece of core at least 10-1/2 in. long.

4.10 Alternatively, the modulus may be obtained by testing the NX core from the same depth in the nearby exploratory NX hole in uniaxial compression using standard procedures described in ASTM Standard Method of Test for Elastic Moduli of Rock Core Specimens in Uniaxial Compression, ASTM Designation D3148-72. This test method is described in Section 201-80 of this handbook.

5. <u>Troubleshooting Equipment Malfunctions</u>

5.1 If balance on one or more indicators cannot be achieved.

5.1.1 Check wiring hookup against wiring diagram (Fig. 9). Make sure all connections are tight.

5.1.2 Check cable connector plug in BDG. Remove screws from placement end of gage, slide the end off, unscrew the knurled retaining cap, and check the plug connection. Push in firmly if loose.

5.1.3 Nonbalance may occur when too much tension has been applied to the conductor cable during gage retrieval. Sometimes in a vertical hole, cuttings or rock fragments drop into the 1-1/2-in. hole on top of the gage, making it impossible to hook the placement and retrieval tool onto the gage pins. A tendency always exists to try to retrieve the gage by pulling on the cable. Do this only as a last resort. Instead, snap the core off and bring it up with the gage inside if overcoring has been successfully completed.

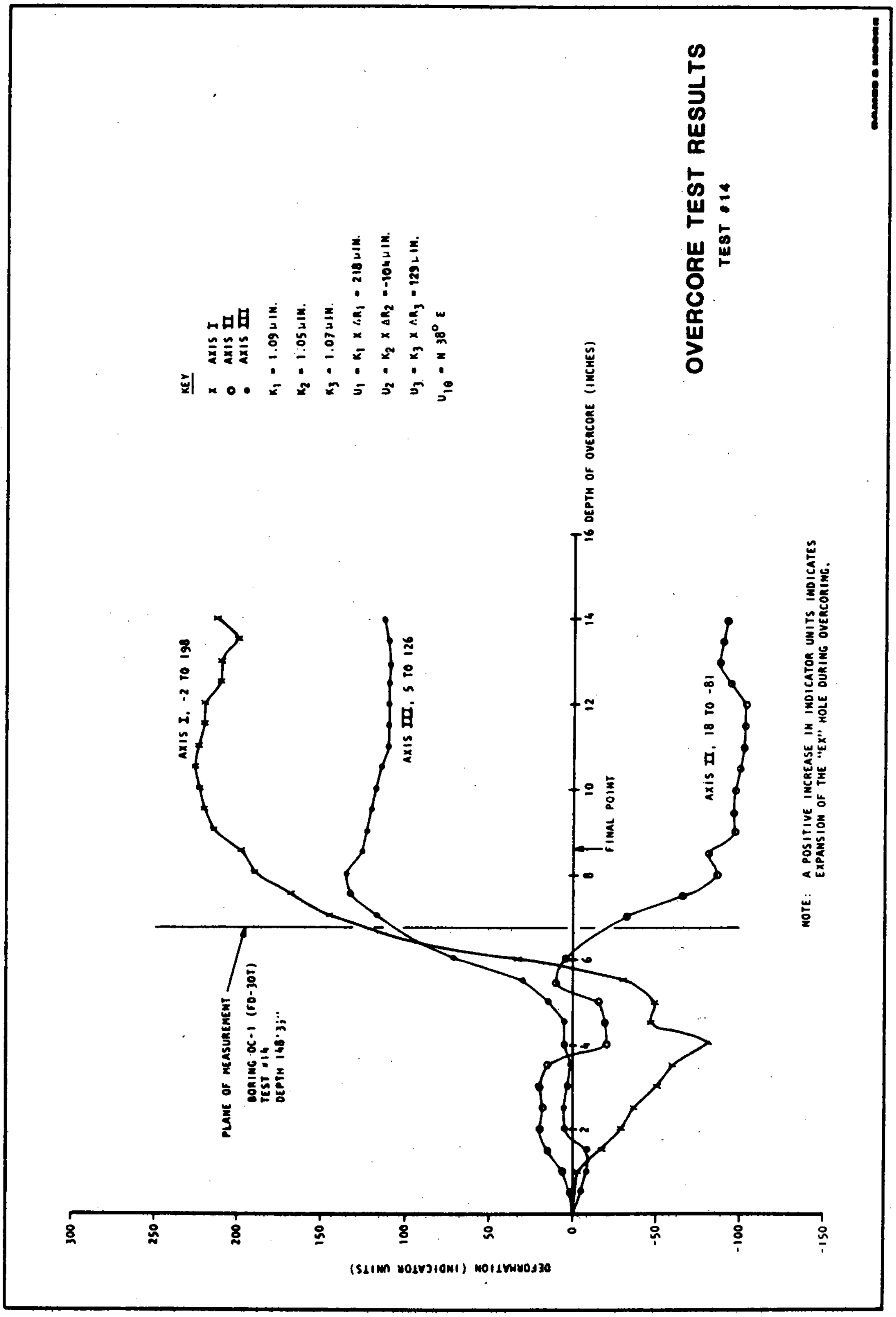

OVERCORE TEST RESULTS
TEST #14
KEY
X AXIS I
O AXIS II
● AXIS III
K1 = 1.09 µIN.
K2 = 1.05 µIN.
K3 = 1.07 µIN.
U1 = K1 X ΔR1 = 218 µIN.
U2 = K2 X ΔR2 = -104 µIN.
U3 = K3 X ΔR3 = 129 µIN.
U18 = N 38° E
AXIS I, -2 TO 198
AXIS III, 5 TO 126
AXIS II, 18 TO -81
FINAL POINT
PLANE OF MEASUREMENT
BORING OC-1 (FD-30T)
TEST #14
DEPTH 148'3½"
DEPTH OF OVERCORE (INCHES)
DEFORMATION (INDICATOR UNITS)
300
250
200
150
100
50
0
-50
-100
-150
2
4
6
8
10
12
14
16
NOTE: A POSITIVE INCREASE IN INDICATOR UNITS INDICATES EXPANSION OF THE "EX" HOLE DURING OVERCORING.

Fig. 11

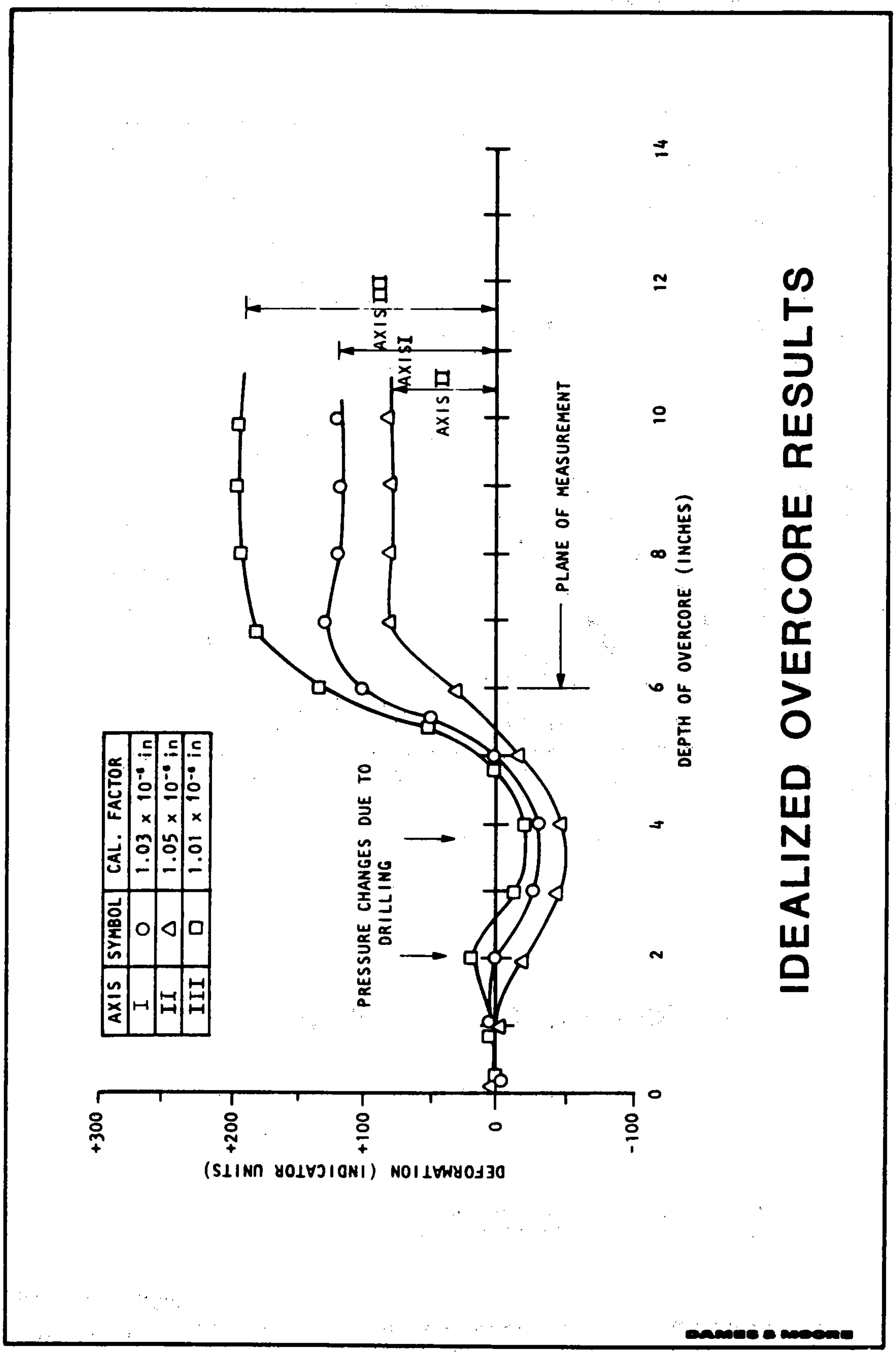
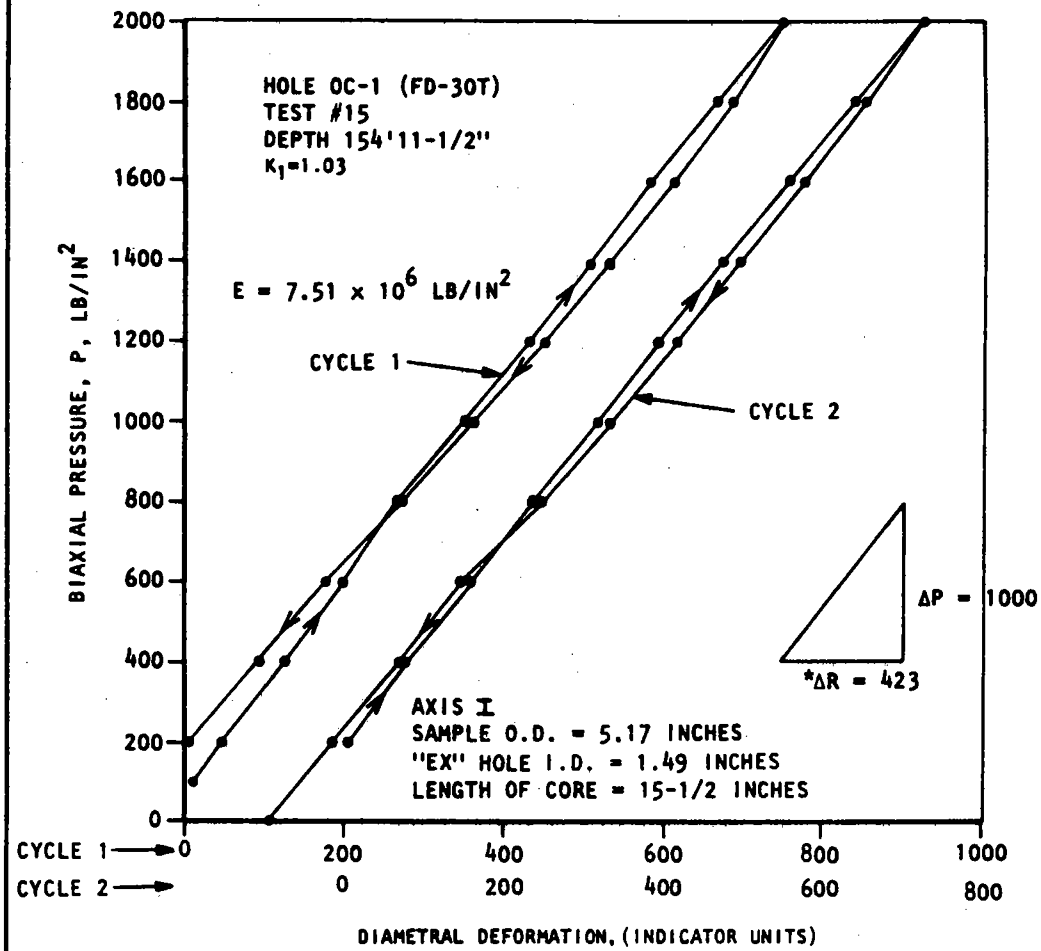

IDEALIZED OVERCORE RESULTS
DEFORMATION (INDICATOR UNITS)
+300
+200
+100
0
-100
DEPTH OF OVERCORE (INCHES)
0
2
4
6
8
10
12
14
AXIS | SYMBOL | CAL. FACTOR
I | ○ | 1.03 x 10⁻⁶ in
II | △ | 1.05 x 10⁻⁶ in
III | □ | 1.01 x 10⁻⁶ in
PRESSURE CHANGES DUE TO DRILLING
PLANE OF MEASUREMENT
AXIS III
AXIS I
AXIS II
DAMES & MOORE

Fig. 12



BIAXIAL TEST RESULTS

TEST #15

AXIS I

*ΔR = CHANGE IN INDICATOR UNITS CORRESPONDING TO CHANGE IN APPLIED PRESSURE ΔP.

DAMES & MOORE

Fig. 13

5.2 If core breaks during overcoring:

5.2.1 If the indicators suddenly start to fluctuate erratically or the needles indicate maximum deflection, the core has probably broken. This situation may also be indicated by twisting of the conductor cable. If this situation occurs, stop the test immediately.

5.2.2 Disconnect the NW casing from the chuck and insert the retrieval tool, but leave the 6-in. bit on the bottom. If retrieval tool will slide over BDG pins, retrieve the BDG. If the retrieval tool will not slide over the pins a piece of rock has probably fallen in on top of it.

5.2.3 If overcoring has proceeded past the end of the gage, snap the core off below the gage and bring core and gage up inside the core barrel. Keep light tension on conductor cable as gage is brought up. If the core does not come up with the barrel, use the core puller.

5.2.4 If overcoring has not proceeded past the end of the gage, try gently tugging on the cable to free the BDG. If this fails, tug sharply on the cable. It will snap off, usually at the connector plug. Retrieve the cable and resume overcoring several inches past the gage (Note 3).

NOTE 3—Snapping the cable off is a drastic measure but is a necessary trade-off to retrieve the gage in working condition. Never raise the 6-in. bit until you are certain that the bit has overcored past the gage. Then snap off core and bring the bit, core, and gage up.

5.3 If one or more elements become insensitive on indicators:

5.3.1 If elements become insensitive to deflection of the pistons or unresponsive to turning of the indicator dial, or the needles drift, water has probably caused a short at the strain gage connections or at the cable connector plug.

5.3.2 Remove the pistons with the special pliers and check for moisture. If moisture is present, dry area thoroughly, check O rings for damage, and replace them if necessary. Apply thin coat of silicone grease to O rings before reinserting pistons.

5.3.3 Check the cable connector plug by removing the upper gage case. Unscrew the retaining cap and check for moisture on plug. Dry plug and surrounding area and grease cable where it passes through retainer cap and rubber grommet. Reassemble gage.

5.4 If one component does not balance anywhere on the indicator dial or balances intermittently:

5.4.1 This situation indicates a disconnected wire or a cold solder joint. Remove the borehole gage case and check all wires and connections, including the cable connector plug. Solder where needed and reassemble gage.

5.5 If indicators are sensitive to touch:

5.5.1 If indicator needles deflect when the units are touched, it is usually a result of prolonged use in a damp environment. Use plastic or other insulating material underneath the indicators as a moisture barrier. Store indicators in a dry place when not in use to allow them to dry out.

6. Calculations

6.1 To determine the secondary principal stress magnitudes and directions it is usually convenient to assume the rock is a linearly elastic isotropic material.

6.2 The diametric deflections are obtained for each of the three axes of measurement by multiplying the indicator reading differences by the appropriate calibration factor. These values, U_1, U_2, and U_3, along with the calculated modulus of elasticity, form the basis for evaluating the maximum and minimum stresses acting in a plane perpendicular to the borehole walls. These stresses are principal stresses only when the borehole is parallel to the third principal stress, which is not always the case for vertical boreholes. However, under the conditions of more or less homogeneous, gently dipping rocks of low relief, it can be assumed that the third principal stress is vertical and equal to the overburden stress and that the maximum and minimum stresses perpendicular to the borehole walls are in fact principal stresses. For other conditions and different borehole orientations this assumption would be invalid, so consideration must be given to the special features and conditions appropriate to the individual site. Fairhurst[8.3] presents a solution for the state of stress in a transversely isotropic medium, that is, one for which the elastic properties are constant in any direction in a given plane but change in directions that intersect the plane. Fairhurst states that the assumption of elastic isotropy can result in errors in the computed stresses of as much as 50 percent in cases where the rock is anisotropic or "transversely isotropic" (typical of rocks such as shale and gneiss).

6.3 The overburden stress, σ_v, is equal to the average density of the overlying material, γ, multiplied by the depth of overburden, H, or

$$\sigma_v = \gamma H \tag{1}$$

6.4 The secondary principal stresses are calculated as shown below, using equations based on a plane stress analysis of an elastic, isotropic thick-walled cylinder as discussed by Obert and Duvall.[8.4]

$$P_c = \frac{E}{6d}\left[U_1 + U_2 + U_3 + \frac{\sqrt{2}}{2}\left\{(U_1 - U_2)^2 + (U_2 - U_3)^2 + (U_3 - U_1)^2\right\}^{1/2}\right] \tag{2}$$

$$Q_c = \frac{E}{6d}\left[(U_1 + U_2 + U_3) - \frac{\sqrt{2}}{2}\left\{(U_1 - U_2)^2 + (U_2 - U_3)^2 + (U_3 - U_1)^2\right\}^{1/2}\right] \tag{3}$$

where U_1, U_2, U_3 are measurements of diametral deformations along three axes 60 deg apart. Deformation is positive for increasing diameter during overcoring.

P_c is the maximum normal stress, psi.*

Q_c is the minimum normal stress, psi.*

E is the modulus of elasticity, psi, and d is the "EX" hole diameter.

6.5 The orientation of the principal stress axis is given by

$$\theta_p = 1/2 \text{ arc tan } \frac{\sqrt{3}\,(U_2 - U_3)}{2U_1 - U_2 - U_3} \qquad (4)$$

where θ_p is the angle from the U_1 axis (positive in a counterclockwise direction) to the major principal stress.

U_1, U_2, U_3 are the diametral deformations.

The angle θ_p could have two values 90 deg apart. The correct angle can be determined using the following rules. For a 60 deg rosette (angular measurements positive in the counterclockwise direction and all angles measured from U_1 to P_c):

6.5.1 If $U_2 > U_3$, θ_p lies between 0° and $+90^\circ$ or -90° and -180°.

6.5.2 If $U_2 < U_3$, θ_p lies between 0° and -90°.

6.5.3 If $U_2 = U_3$, and if: (a) $U_1 > U_2 = U_3$, $\theta_p = 0°$
(b) $U_1 < U_2 = U_3$, $\theta_p = \pm 90°$.

6.6 The modulus of elasticity is calculated using the biaxial test results in the equation

$$E_i = \frac{(4ab^2)\,(\Delta Pi)}{(b^2 - a^2)\,\Delta Ui} \qquad (5)$$

---

* Positive values of P_c and Q_c indicate compressive stresses.

where E_i is the modulus of elasticity, psi

a is the diameter of the "EX" hole, inches

b is the radius of the core, inches

ΔPi is the change in applied pressure, psi

ΔUi is the diametral deformation, in inches corresponding to the change in applied pressure

i is the direction of the axis

7. Reporting Results

7.1 The report shall include:

7.1.1 A description of the test site, including a general area map, characteristic features, and the type and depth of rock at which tests were performed.

7.1.2 The test procedure and apparatus used in the field should be described, including any innovations in procedure or apparatus. The assumptions and equations used in calculating stresses should be presented.

7.1.3 For each test the sample should be described, including depth and rock type and description of joints present. Young's Modulus should be tabulated and a plot of the biaxial test should be presented, as in Fig. 13, along with a plot of the overcoring test results, as in Fig. 11. Calibration factors should be tabulated for each test. The maximum and minimum secondary principal stresses and the orientation should be tabulated for each test.

7.1.4 Any difficulties or unusual circumstances encountered should be noted.

8. References

8.1 Hooker, Verne E., and Bickel, David L., "Overcoring Equipment and Techniques Used in Rock Stress Determination," U. S. Bureau of Mines Information Circular 8618, Denver Mining Research Center, Denver, Colorado, 1974.

8.2 Nataraja, Mysore, "In Situ Stress Measurements, Park River Project," Miscellaneous Paper No. S-77-22, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1977.

8.3 Fairhurst, Charles, "Methods of Determining In Situ Rock Stresses at Great Depths," Technical Report No. 1-68, U. S. Army Corps of Engineers, Missouri River Division, Omaha, Nebraska, 1968.

8.4 Chert, L., and Duvall, W. I., "Rock Mechanics and the Design of Structures in Rock," John Wiley and Sons, Inc., New York, 1967.