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Overcoring Equipment and Techniques Used in Rock Stress Determination (An Update of IC 8618)

By David L. Bickel

UNITED STATES DEPARTMENT OF THE INTERIOR
Donald Paul Hodel, Secretary

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Robert C. Horton, Director

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	pct	percent
hp	horsepower	psi	pound per square inch
in	inch	rpi	revolution per inch
min	minute	rpm	revolution per minute
μin	microinch	s	second
μin/in	microinch per inch		

OVERCORING EQUIPMENT AND TECHNIQUES USED IN ROCK STRESS DETERMINATION (AN UPDATE OF IC 8618)

By David L. Bickel[1]

ABSTRACT

Stress-relief techniques and instrumentation have been developed through many years of research in the Bureau of Mines and successfully used to determine the in situ state of stress in rock. This report describes the Bureau's three-component borehole deformation gauge and the drilling equipment and accessories used with it. Operation and calibration procedures for the deformation gauge are discussed in detail, along with site selection and overcoring procedures. Information and references included in this publication provide a guide to the Bureau's overcoring method for determining rock stress.

[1]Physical scientist, Denver Research Center, Bureau of Mines, Denver, CO.

INTRODUCTION

This publication updates some of the overcoring procedures described in IC 8618 (6).[2] It also includes the field biaxial testing procedure used for determining the modulus of elasticity, as well as additional references not previously available.

The Bureau of Mines three-component borehole deformation gauge (9), which measures three diameters 60° apart and has all sensing elements in the same plane, is designed to measure diametral deformations of a 1-1/2-in borehole during stress relief by overcoring. The process essentially consists of (1) drilling a 1-1/2-in-diam gauge hole (pilot hole) with a diamond bit and reamer, (2) positioning the gauge in the gauge hole, and (3) drilling over the gauge with a 6-in-diam thin-walled diamond masonry bit. The 6-in core is cut in one continuous run, and the deformation readings are taken at the start, during, and at the end of the run. After overcoring is completed, the gauge is removed and the core is freed from the bottom of the hole and retrieved. The core orientation and the position of the gauge are marked on the core.

The marked core is then tested in a biaxial chamber (4) to determine the physical properties of the rock. The physical properties and the deformation measurements from each overcore are used to calculate the stress distribution in the plane normal to the axis of the borehole. The core can then be prepared and tested in a triaxial chamber (10) at the same stress level it experienced in situ (which is not always possible during biaxial testing) to determine Poisson's ratio and a more accurate modulus of elasticity. The effects of anisotropy can be included in these calculations (1). If borehole deformation measurements are obtained from at least three nonparallel holes, the three-dimensional representation of the average ground stress components can be determined (11). A least squares method of calculating the average rock stress components from more than three diametral deformation measurements in a borehole has been developed (3).

ACKNOWLEDGMENT

Acknowledgment is extended to Verne E. Hooker, senior author of the previous edition of this report. Mr. Hooker was with the Bureau's Denver Research Center before his retirement.

DRILLING EQUIPMENT

The following drilling equipment should be employed for in situ stress measurements:

1. A drill with a chuck speed ranging down to 120 rpm and a penetration rate of 1/2 in per 30 to 50 s using a 6-in-diam overcoring bit; the chuck and quill must be large enough to accomodate EW[3] drill rod (fig. 1). Since drills do not normally have chuck speeds as low as 120 rpm, a change in gear ratio may be necessary. For a typical 20-hp air drill, the recommended rotation speed is 0 to 1,000 rpm and the feed ratios are 200, 300, 500, and 800 rpi.

2. Two EWX[4] double-tube swivel-type core barrels, one 5 ft and one 7 ft in length, and an EWX single-tube core barrel 2 ft in length (fig. 2).

3. EX (1-1/2-in diam) diamond bits.

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[2]Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

[3]E, EW, B, and N denote diameter or size.

[4]X denotes manufacturer's series of equipment.

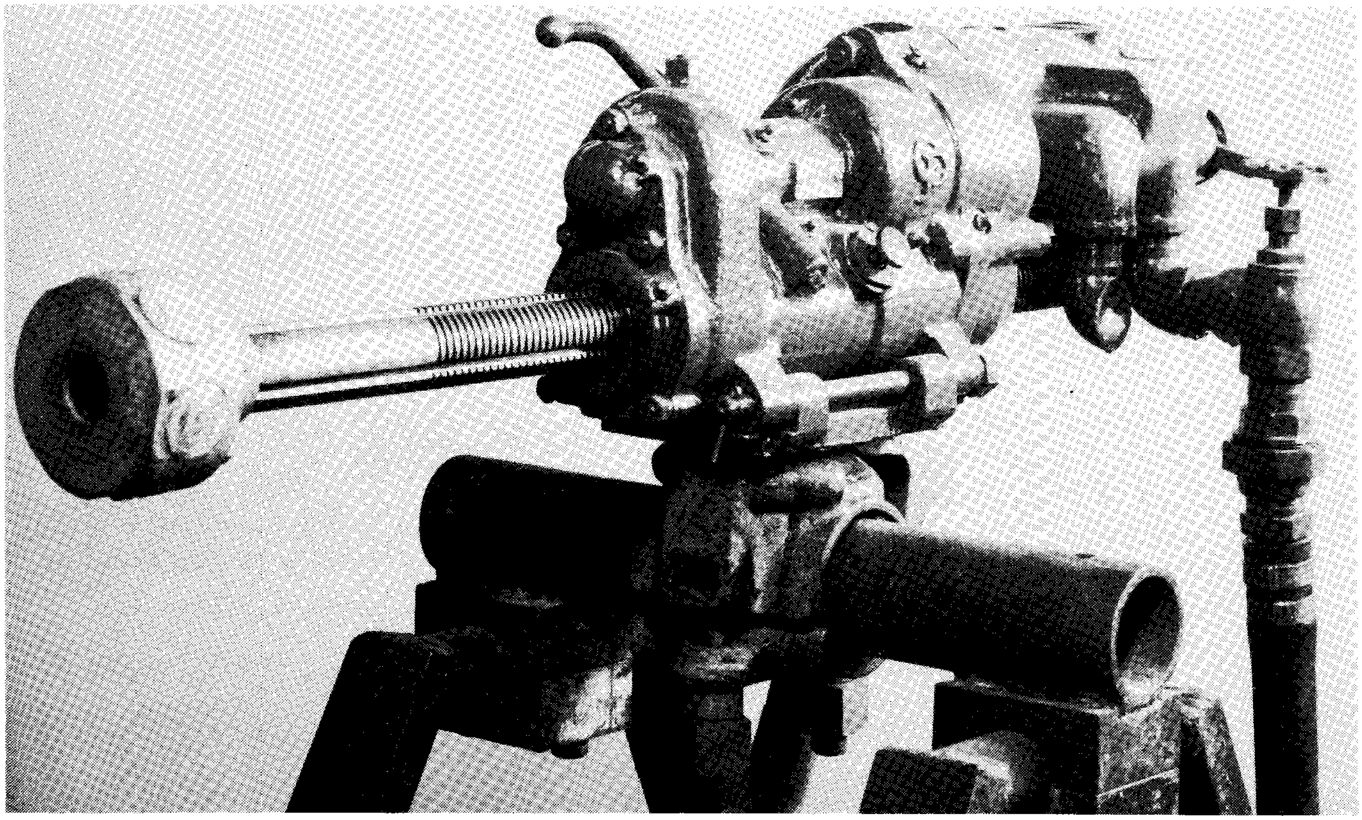


FIGURE 1. - Type CP-65 air drill.

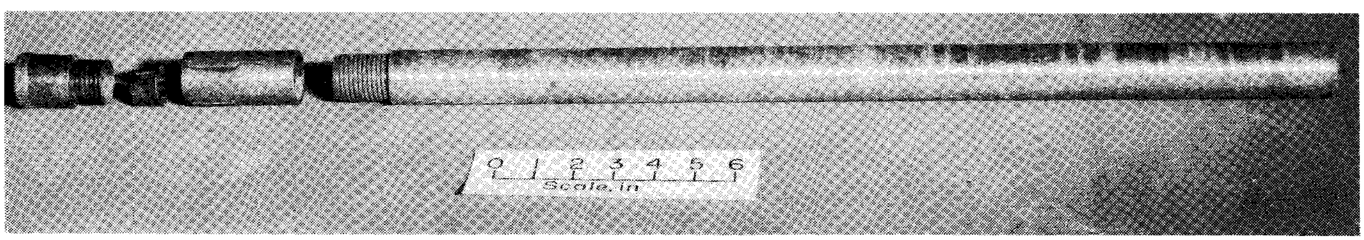


FIGURE 2. - EX-size bit with core spring, reamer, and 2-ft EWX core barrel.

4. A reamer for use with the EX bit in the EX pilot gauge hole.

5. EW drill rod in the following lengths: six 5-ft pieces, four 2-ft pieces, and two 1-ft pieces.

6. Two stabilizers (5-7/8 in. in diam by 8 in long) on a 2-ft length of EW drill rod (fig. 3). (Note.--The stabilizer can be made from a used 6-in-diam core barrel cut 8 in long.)

7. BX wire line drill rod (fig. 3) in the following lengths: three 5-ft pieces, four 2-ft pieces, and two 1-ft pieces. BX wire line drill rod has been found best for overcore drilling. The inside diameter of this drill rod is large enough for the borehole gauge and placement tool to pass through. Also, the wire line drill rod is lightweight yet has the necessary strength for overcore drilling requirements. The rod has four threads per inch, which is desirable to provide fast coupling.

8. Two stabilizers (5-7/8 in. in diam by 8 in long) on a 2-ft length of BX wire line drill rod.

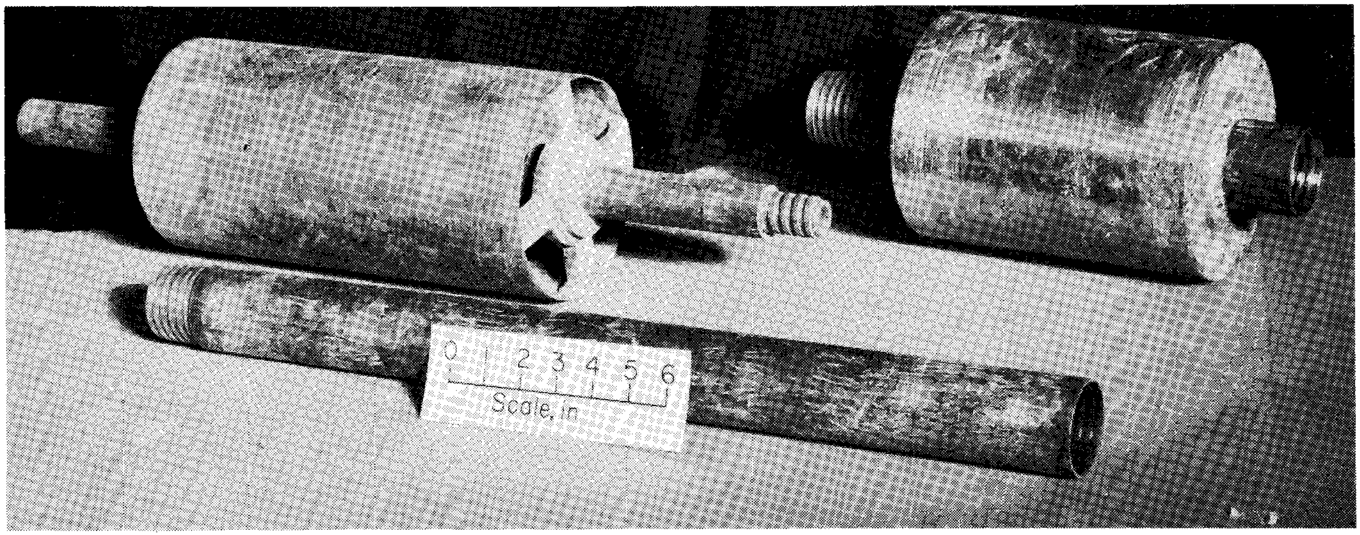


FIGURE 3. - Stabilizer on 2-ft section of EW drill rod (upper left), stabilizer on 1-ft section of BX wire line drill rod (upper right), and 2-ft piece of BX wire line drill rod (foreground).

9. An adapter sub (EW box to BX wire line pin) for connecting the EW drill rod in the chuck and quill to the BX wire line drill rod.

10. A water swivel having a plug with a 1/2-in hole to allow threading of the gauge cable when it is in use and an additional solid plug to fit when the cable is not in use (fig. 4). The water swivel connects to the EW drill rod in the drill. (Note.--The EW pins at the water swivel and at the chuck must be drilled out to at least 9/16 in ID to allow cable and drilling water to pass through.)

11. An expander head for connecting the BX wire line drill rod to the 6-in-OD diamond overcoring bit (figs. 5-6).

12. Thin-wall masonry overcoring bits 6 in. in diam and long enough to obtain 18 in of overcore 5-5/8 in. in diam (fig. 6).

13. A 6-in-diam starter barrel 1 ft in length, equipped with a detachable 1-1/2-in-diam pilot shaft in the center that extends approximately 5 in beyond the diamonds of the starter barrel. This barrel is used to center the 6-in-diam hole over the initial EX hole (figs. 7-8).

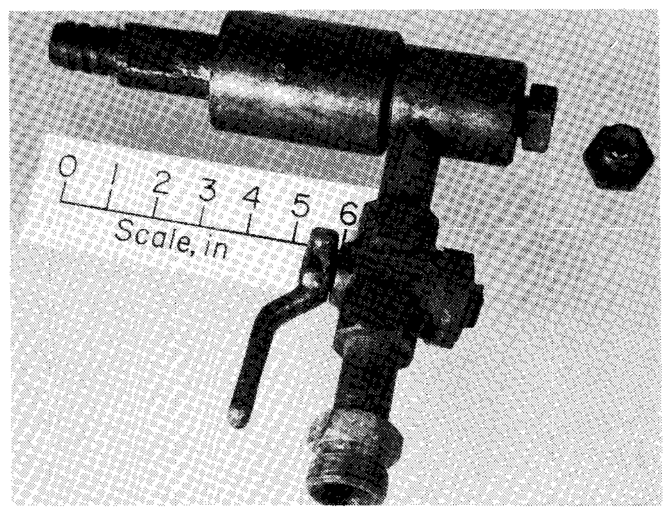


FIGURE 4. - Water swivel with solid plug and plug (right) used during overcoring.

14. An EW core barrel to replace the detachable pilot shaft, sized to extend 1 in beyond the starter barrel. With the bit and reamer attached, this unit is used to drill an EX starter hole 4 in deep in the bottom of the 6-in-diam horizontal or vertical hole.

15. A 6-in-diam centering stabilizer for starting the 5- or 7-ft EWX core barrel into the 4-in-deep horizontal starter hole or for centering the EWX core barrel in the bottom of a 6-in-diam vertical hole (fig. 9).

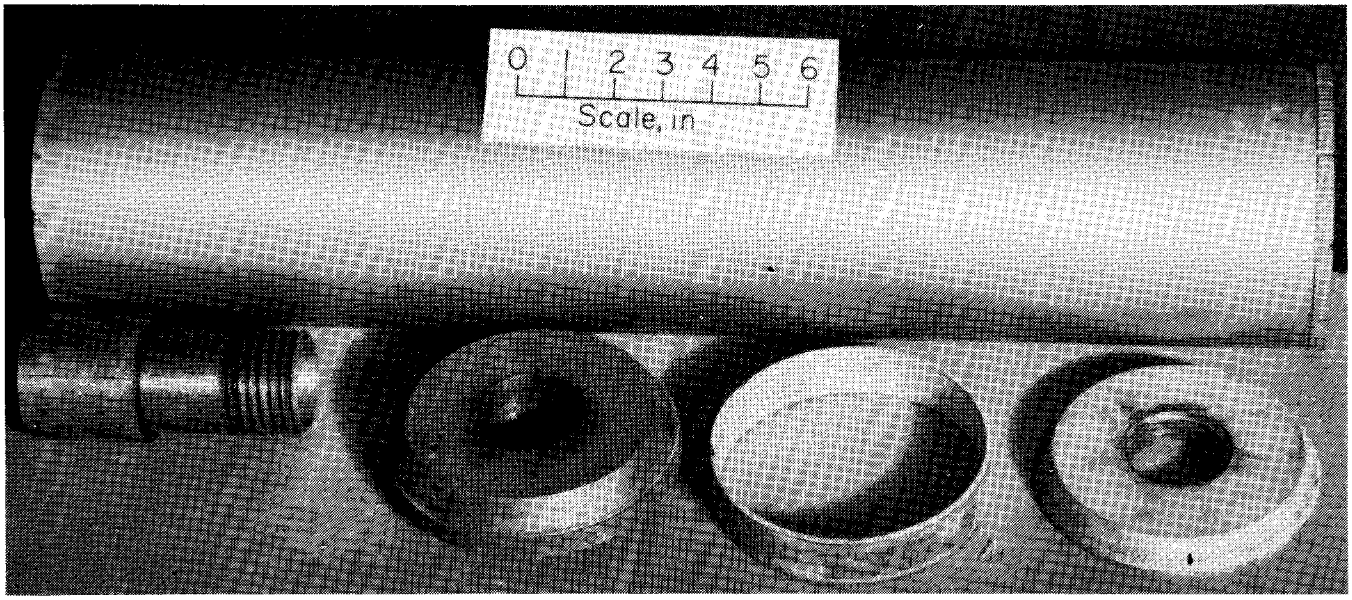


FIGURE 5. - Core barrel, 6 in. in diam by 27 in long (referred to as a 2-ft core barrel), and disassembled expander head.

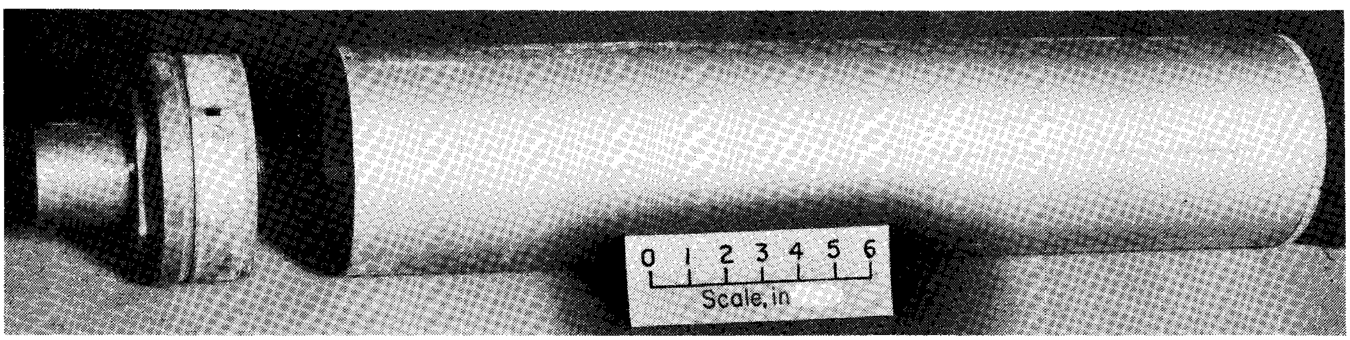


FIGURE 6. - Expander head assembled (adapted for BX wire line drill rod) and 6-in-diam core barrel.

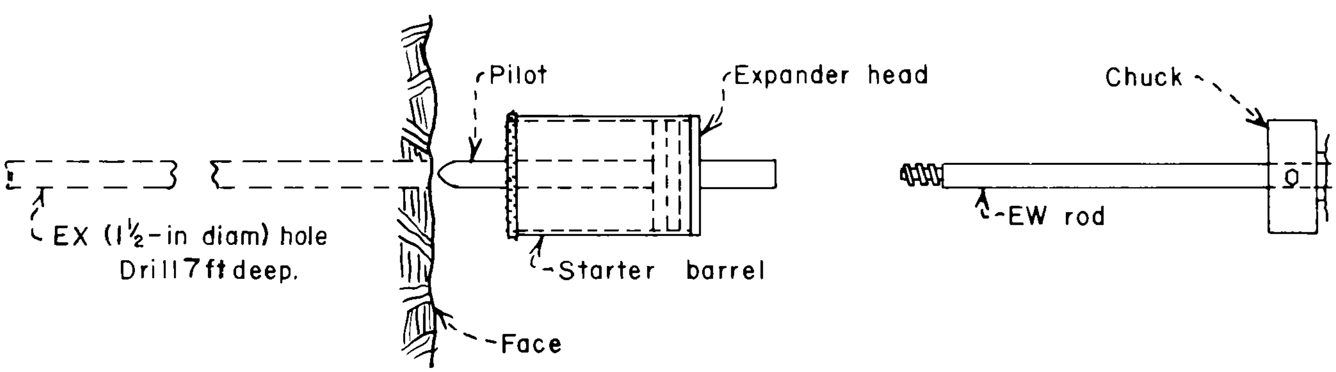


FIGURE 7. - Starting the 6-in-diam overcoring hole.

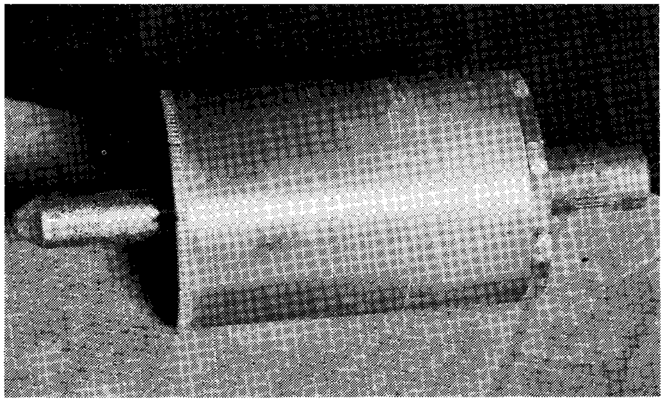


FIGURE 8. - Starter barrel, 6 in. in diam by 1 ft long, with pilot and expander head adapted for EW drill rod.

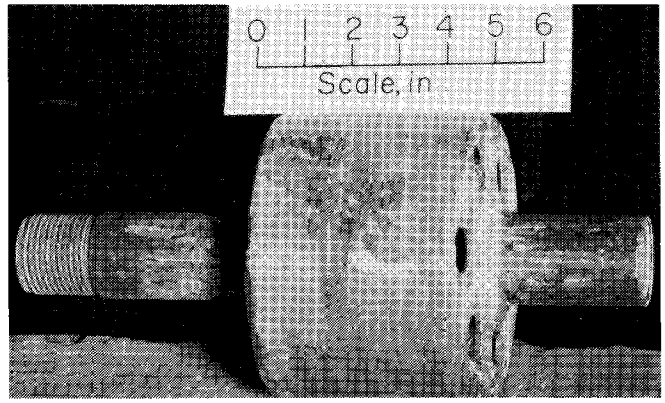


FIGURE 9. - Centering stabilizer.

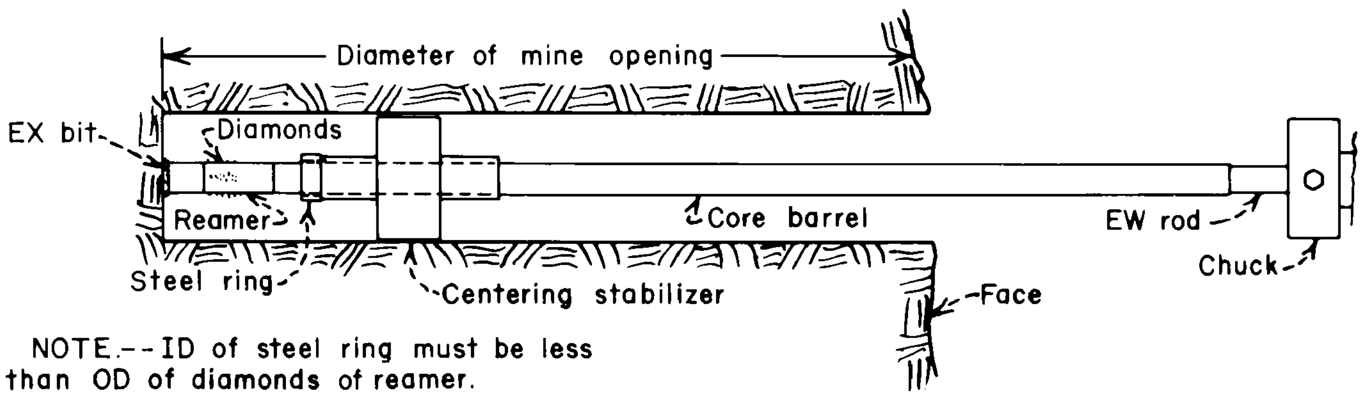


FIGURE 10. - Starting the EX hole in the bottom of the 6-in-diam hole.

16. A steel retriever ring 2 in. in OD, 1.448 in. in ID, and 3/4 in wide placed on the EWX core barrel in front of the centering stabilizer for retrieving the centering stabilizer (fig. 10).

17. A core breaker to fit the EW rod. The core breaker, constructed of steel, should be at least 2-1/2 in wide and hardened (fig. 11).

18. A 6-in core shovel to fit an EW rod for retrieving the core from a horizontal hole (fig. 11).

19. A 6-in core puller approximately 18 in long to fit an EW drill rod for retrieving the core from a vertical hole (fig. 11). The attachment end of the barrel should have an approximately 5/8-in-thick steel plate welded around its circumference to the barrel, with an EW box welded in the center of the plate. Three 1-1/2-in-diam holes on 120° centers are drilled through the plate to allow water to pass when the core puller is lowered into the 6-in-diam hole. The downhole end of the barrel has four U-cuts 90° apart. The remaining rectangular sections of metal are bent in toward the center slightly to hold the 6-in core in the barrel when lifting it out of the vertical hole. The core puller must be marked and kept from rotating as it is lowered into the 6-in-diam hole, to ensure orientation of the core. (Note.--The shovel and core puller should be made from a used 6-in-diam core barrel.)

An alternate means of retrieving an intact 6-in core having an EX-size hole in it from a vertical hole is by means of a roof bolt anchor. A diamond shaped steel point must be welded on the front of the anchor (fig. 12). A section of threaded

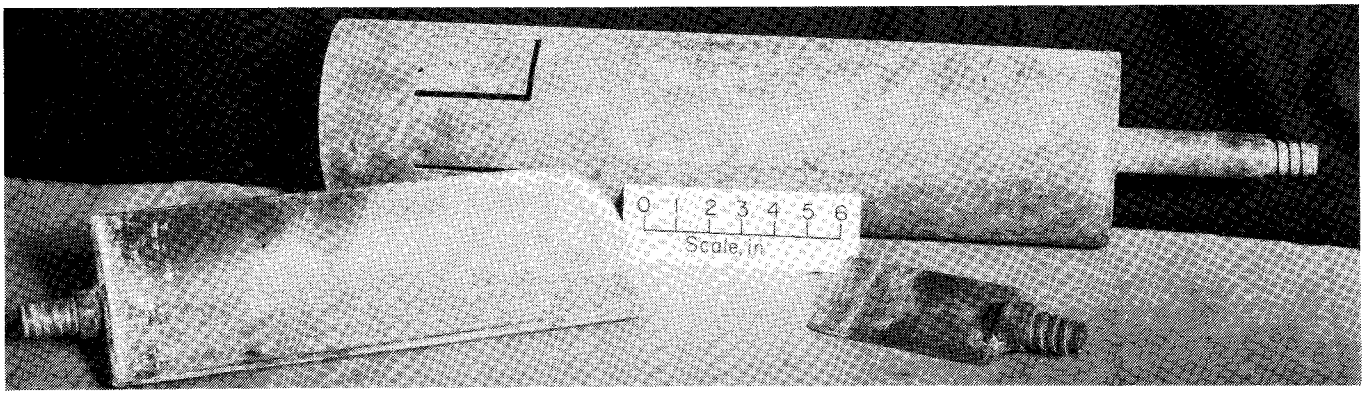


FIGURE 11. - Core breaker (lower right), core shovel (lower left), and core puller (center).

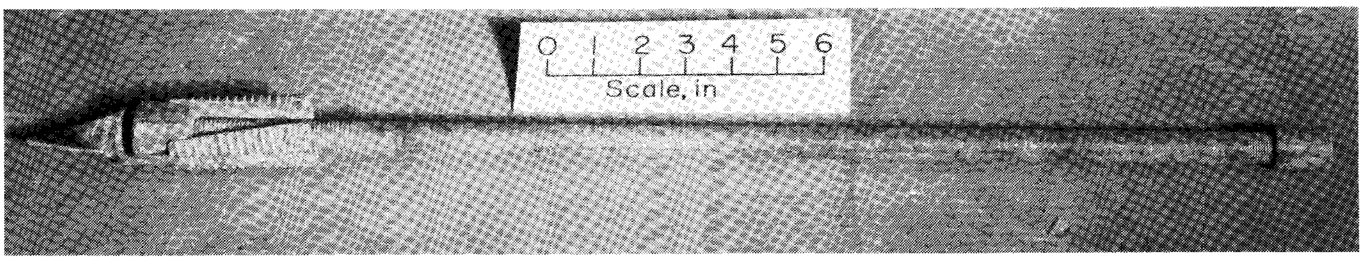


FIGURE 12. - Retrieval tool used in place of core puller to retrieve 6-in-diam core from a vertical hole that has an EX hole through the core.

rod is then screwed into the anchor, and sections of 3/8-in pipe, 5 ft in length, are used to extend this tool into the hole.

INSTRUMENTATION

The following instruments are required for calibrating, testing the drilled core, and measuring the deformations during the overcoring:

1. Three-component (3-D) borehole gauge and accessories (including special pliers, 0.005- and 0.015-in-thick brass washers, and silicone grease) (fig. 13). A report on the assembly and wiring of the gauge is available (2). This information is useful when minor repairs on the gauge are required.

2. Three Vishay model P-350[5] or equivalent strain indicators (fig. 14). (Note.--Normally, a gauge factor (G.F.) of 0.40 is used so that an indicator unit (1 μin/in) represents approximately 1 μin displacement. If other indicators are used and a G.F. of 0.40 cannot be obtained, then calibration at a G.F. suitable to the indicator used is necessary.) If only one indicator is available, a switching and balancing unit or a switching unit must be used.

3. Orientation and placement tool for the gauge (fig. 15).

4. A calibration device for the gauge (fig. 14).

5. A biaxial chamber for determining the modulus of elasticity of the rock (fig. 16).

[5]Reference to specific products does not imply endorsement by the Bureau of Mines.

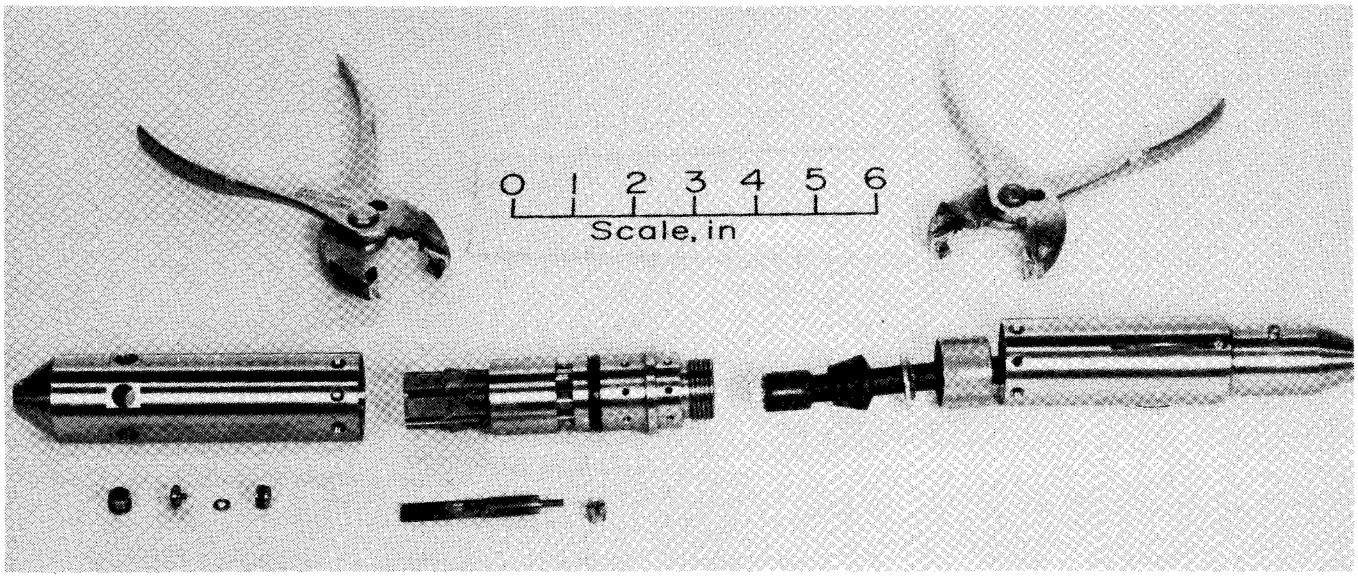


FIGURE 13. - Special pliers, Bureau of Mines three-component borehole gauge, piston, disassembled piston and washer, and transducer with nut.

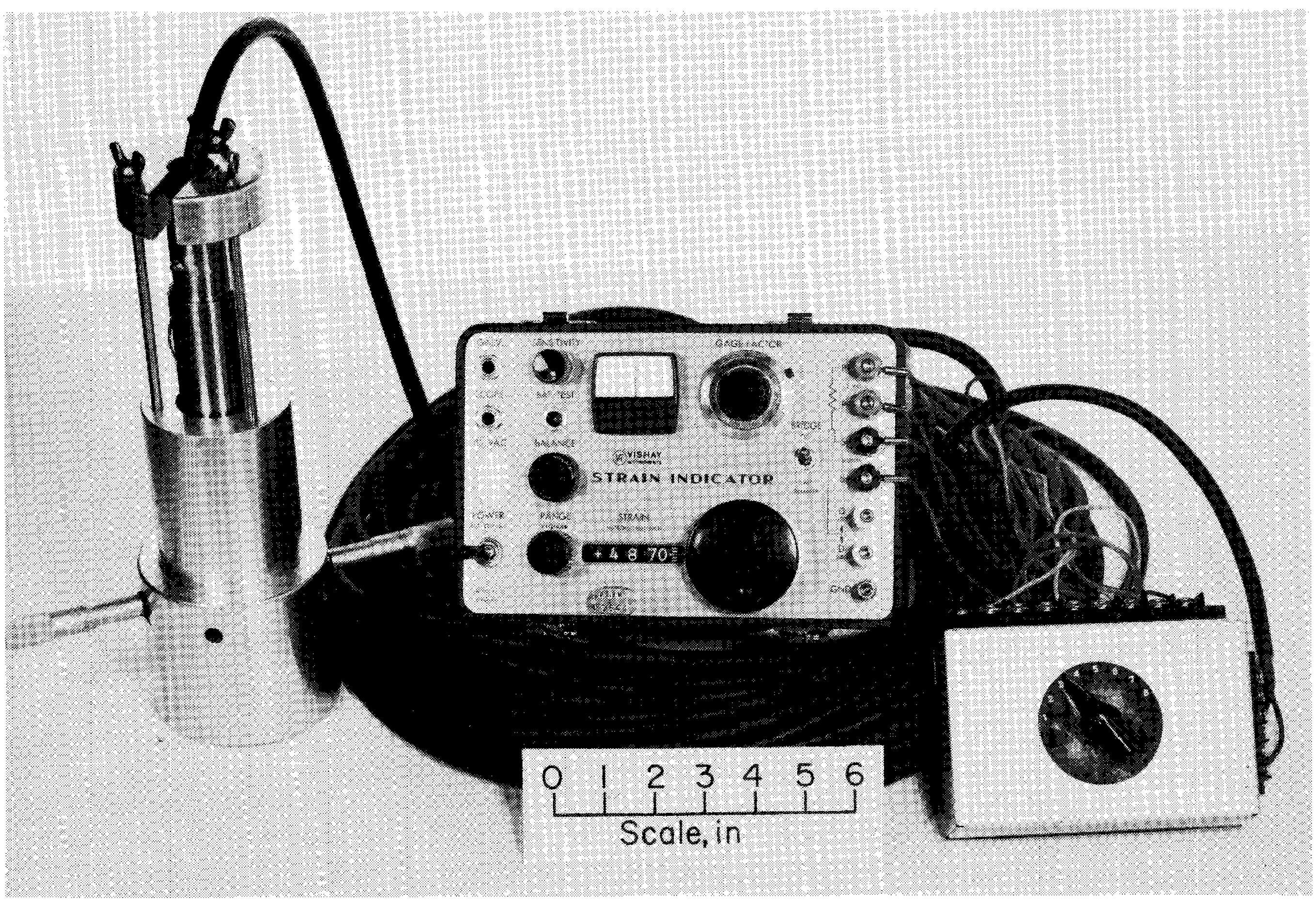


FIGURE 14. - Strain indicator with calibration device (left) and switching unit (right).

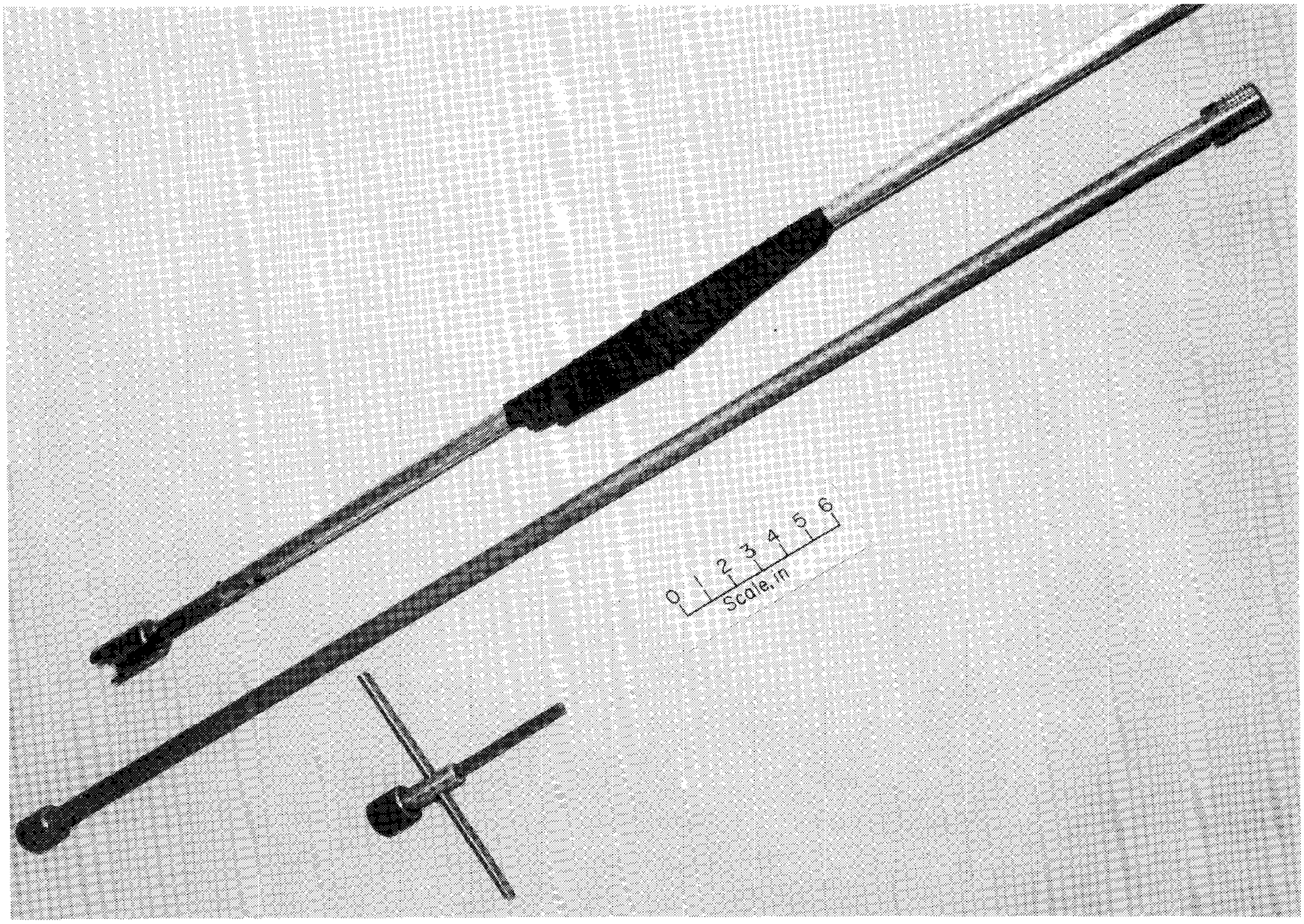


FIGURE 15. - Placement and retrieval tool.

SITE SELECTION

To calculate the complete stress ellipsoid, deformation measurements must be obtained in at least three nonparallel holes. Typical layouts of boreholes and directions of measurement are shown in figure 17. Three orthogonal boreholes provide the best configuration of three boreholes for determining all six stress components with uniform precision (fig. 17*A*). It is possible to obtain very good results from configurations 17*B*, *C*, and *D*, where the angle between the horizontal holes has been decreased from 90° to not less than 60°. Deformation measurements should be made outside the zone of influence of the mined opening. This distance is usually taken to be one diameter of the mine opening. Borehole configurations 17*A*, *B*, and *C* require only one drill setup. Geologic or structural conditions may require that the zone of stress measurement be confined to a small area. The configuration 17*D* will provide good engineering estimates of the stress components, but a high standard deviation will exist for any calculated principal stress component with an orientation parallel or subparallel to the axis of any of the boreholes. This configuration also requires three drill setups.

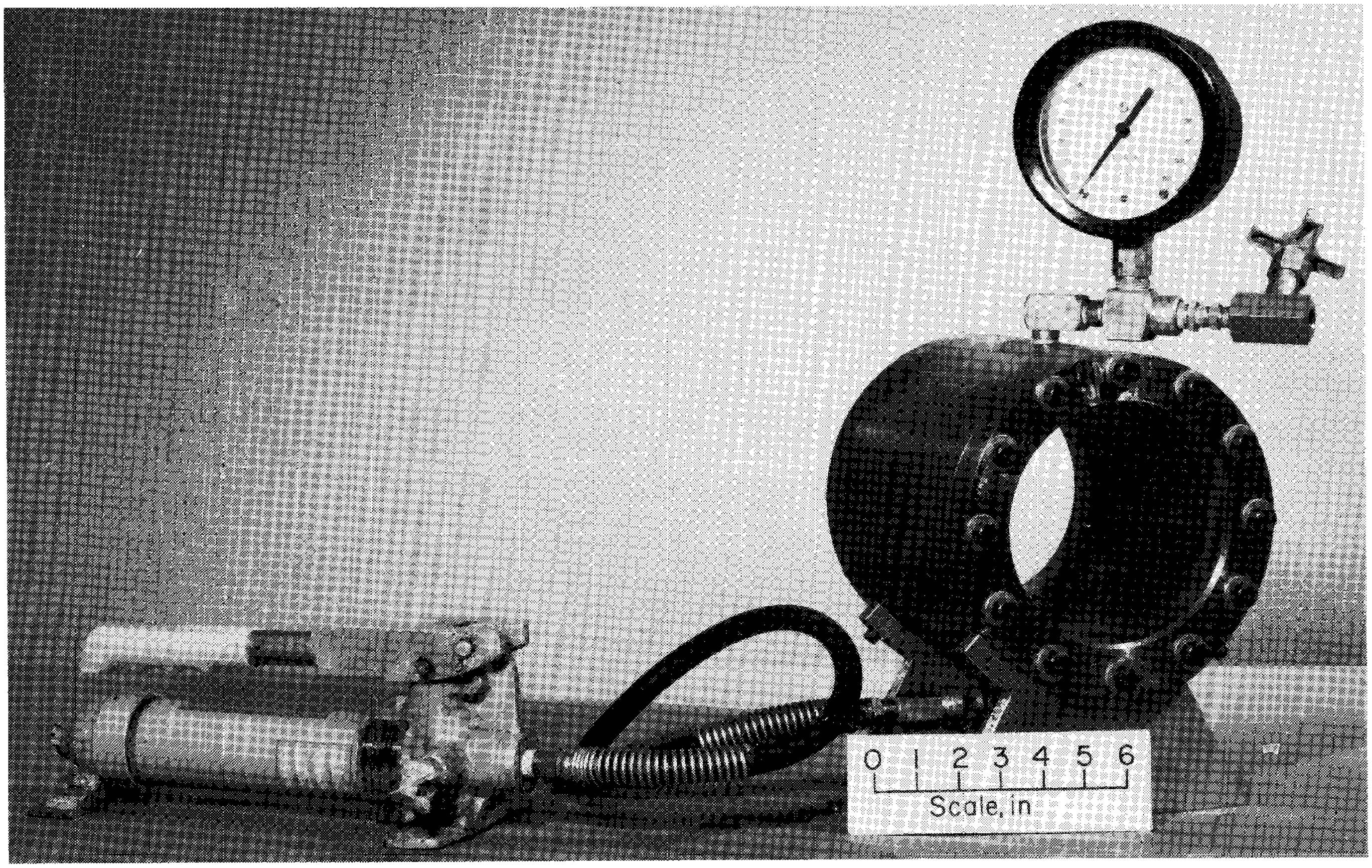


FIGURE 16. - Biaxial chamber and pump.

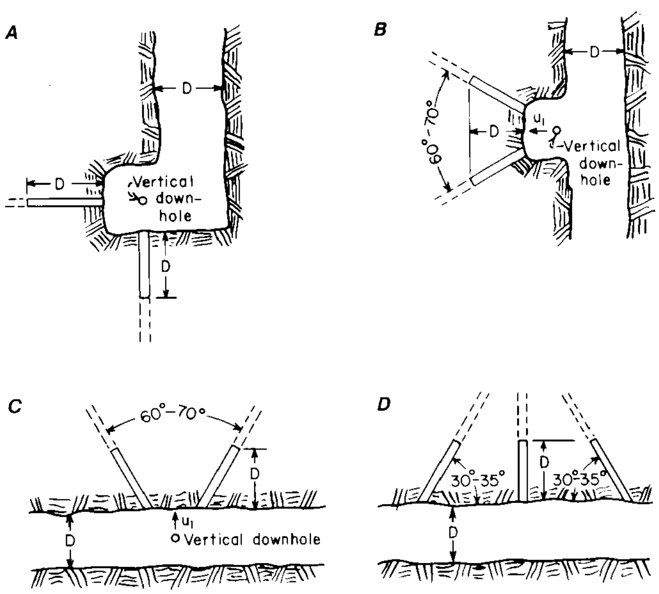


FIGURE 17. - Drill hole configurations. (D indicates diameter of mine opening.)

Horizontal holes should be started 3° upward from horizontal to facilitate removal of water and drill cuttings from the hole. For holes longer than 25 ft, a 5° up-angle is necessary. The drill site should be located in competent rock where core lengths of at least 1 ft can be obtained. Sometimes it may be advisable to drill NX holes at the proposed overcoring location prior to beginning the actual overcoring operation to determine if cores of sufficient length can be obtained.

Recent improvements (5) to the borehole gauge now allow for a complete stress relief in cores of 6-in length. At the present time, the minimum length of core required to perform a biaxial test in the field for the modulus of elasticity is 6 in.

OVERCORING PROCEDURE

For determining stress distribution near the mine opening, overcoring is started at the face and the following procedures apply:

1. Drill 7 ft of EX pilot hole. This distance is the usual limit of pilot-hole depth because overcoring in longer holes off-centers the pilot hole to such a degree that the cores cannot be tested for Young's modulus. However, the deformation readings will not be affected if the pilot hole becomes nonconcentric with the 6-in-diam hole. For the test to determine Young's modulus, the pilot hole must be at least 1-1/4 in from the circumference of the 5-5/8-in-diam core cut by the 6-in-diam thin-wall diamond bit.

2. Use the 6-in-diam starter barrel to drill approximately 1/4 in of kerf so that the overcoring barrel can be started (fig. 7).

3. Uncouple the starter barrel from the drill rod near the chuck and remove the starter barrel.

4. Open the drill to provide clearance for the borehole gauge placement and retrieval tool.

5. String the taped end of the gauge cable through the adapter sub, EW drill rod, and water swivel (fig. 18).

6. Remove the tape from the gauge cable and connect the cable to the three strain indicators as shown in figure 19. Then remove the pistons with the special pliers, grease with silicone grease, and replace in their proper place in the gauge. (If a piston is accidentally dropped, foreign materials can be removed from the O-ring with a toothbrush and the piston wiped clean with a cloth. The O-ring is then greased and the piston replaced into the gauge.) To assure that the transducers across the diameters are properly connected to the strain indicators, apply a slight pressure with the thumb on each piston in turn while watching the indicator. The respective indicator needles will move as the pressure is applied to the piston.

Examine the case screws of the gauge and tighten them if necessary.

Then pull the six pistons about halfway out of the gauge using the special pliers, to ensure they are not touching the transducers. Take a zero reading for each diametral component and record them on the field data sheet (fig. 20) in the row labeled "Zero," in the three columns labeled "U_1," "U_2," and "U_3." Push the pistons back to their original position.

If only one indicator is available, a switching and balancing unit or a

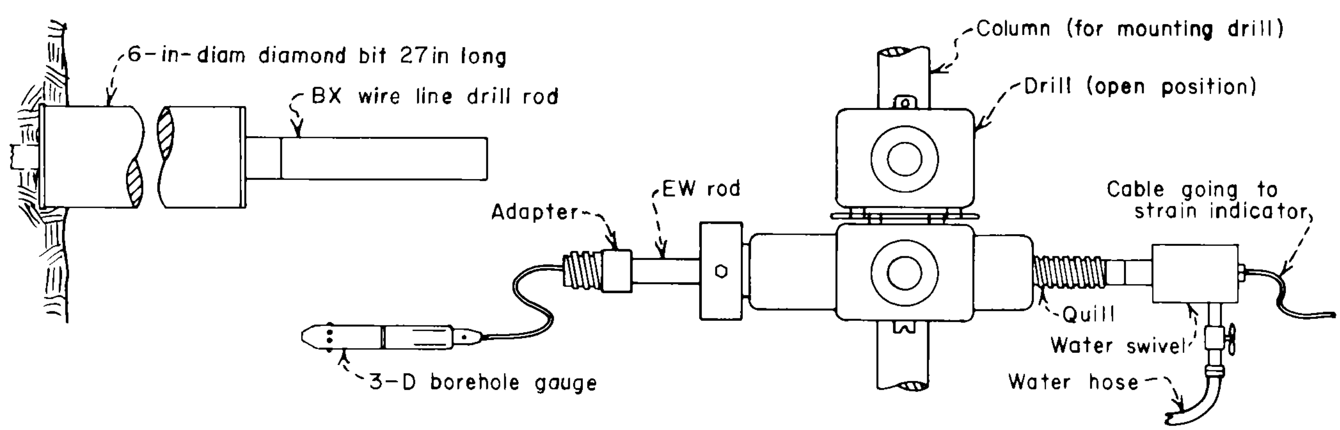
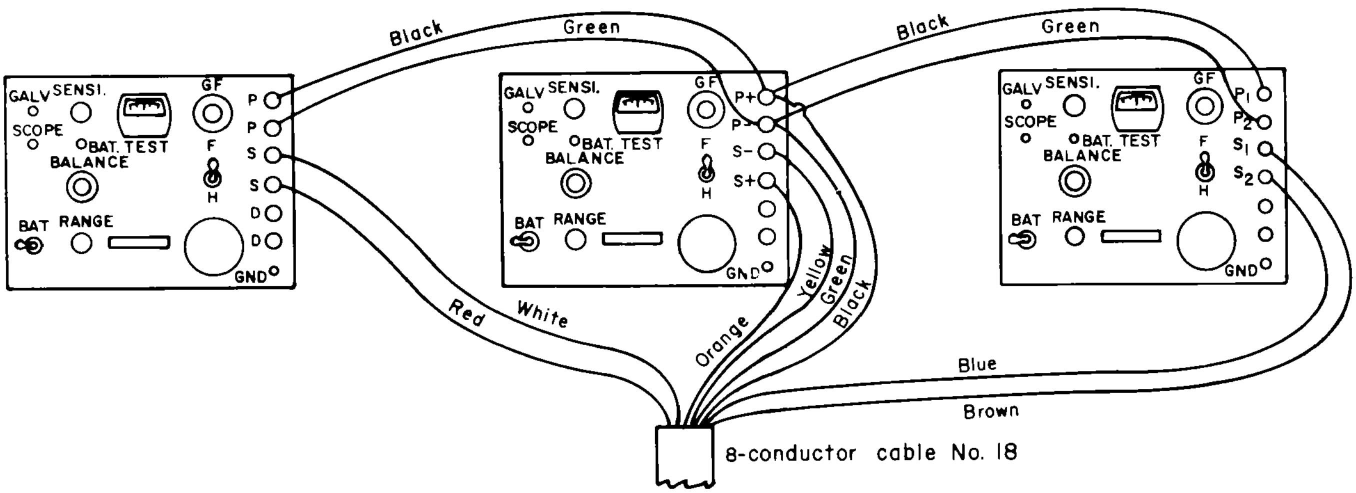


FIGURE 18. - Setup for three-component (3-D) borehole gauge emplacement.

Sensitivity knob: turn full clockwise.
Balance knob: put in midrange (5 turns of the 10-turn potentiometer).
Bridge switch: to full.



NOTE.-- Hook black and green wires to indicator 2 and use 2 other wires (No. 18 or No. 20) to common P+ and P- (or P_1 and P_2) of all 3 indicators.

FIGURE 19. - Wire hookup to strain indicators.

switching unit must be used. If no switching unit is available, proceed as follows: (1) Hook up the indicator as shown in figure 19, first indicator, (2) take a reading U_1, (3) replace the white and red wires with the yellow and orange wires, (4) take another reading U_2, (5) replace the yellow and orange wires with the brown and blue wires, and (6) read U_3.

It is strongly recommended that three strain indicators be used when overcoring. This allows the indicator reader to monitor all three components of the gauge simultaneously, and if a fracture or mineralized vein separates, it can be detected and noted on the field data sheet (fig. 20) so that the deformation reading can be corrected. Also, a breaking core will be immediately detected and the drill operator notified so that the drill can be stopped before the gauge is damaged. When a switching unit is used and the core happens to break while the unit is being switched from one channel to another, the gauge will spin with the 6-in-diam barrel. This will twist the cable and tear the wires from the connecting plug, resulting in a major gauge repair. Also, if a fracture or mineralized vein opens but does not completely separate during channel switching, it will not be detected. Thus, without anyone's knowing, the deformation reading(s) would be erroneous.

7. Place the 6-in-diam core barrel into the kerf cut by the starter barrel.

8. Holding the gauge with the notch indicating U_1 (component 1) up, engage the orientation pins of the gauge with the placement and retrieval tool using a clockwise rotation. The notch is filed in front of the piston hole in the gauge case.

Hole No. ____________ Date ____________ Orientation: U_1 ____________

Gauge No. ____________ Calibration factor U_1 ____________

Gauge factor ____________ U_2 ____________

True bearing of hole ____________ U_3 ____________

DEPTH			DEFORMATION			TIME			TEMP.		REMARKS
			INDICATOR READING								
Gauge	Hole (+)		U_1	U_2	U_3	Gauge Set	Overcore Start	Deformation Read	Rock	Water	
		Zero									
9"	Face	Bias									
	½"										
	1"										
	1½"										
	2"										
	2½"										
	7"										
	7½"										
	8"										
	8½"										
Pistons	9"										
	9½"										
	10"										
	10½"										
	11"										
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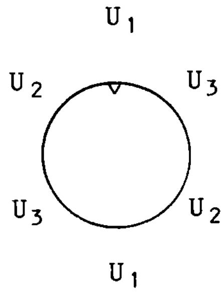
	15½"										
	16"										
	16½"										
	17										
	17½"										
	18										

NOTE.--Next relief would start at 18 in and go to 36 in; gauge would be orientated at a depth of 27 in.

FIGURE 20. - Field data sheet.

POSITION OF COMPONENTS



Notch in gauge (at U_1)

Viewed from cable end of gauge.

The clockwise rotation sets and orients the gauge. Since U_1 (the notch in the gauge) is perpendicular to the orientation handle, a small level can be used on the handle for orientation in horizontal holes. (Note.--If the gauge is oriented too far clockwise, a counterclockwise motion of more than 120° will allow the gauge to be moved counterclockwise, then reoriented correctly with the clockwise rotation.)

9. With the placement rod, put the gauge through the 6-in-diam core barrel and into the EX hole 9 in past the 6-in-diam kerf, and orient the gauge (fig. 21). (Note.--The 9-in gauge placement can be reduced to 6 in, thereby reducing the total length of the overcore from 18 to 12 in, and good results will still be obtainable. A further reduction in core length can be obtained using the reversed gauge case (5) in rock that consistently breaks prematurely.)

10. Check the bias of the gauge on the strain indicators. (See the next section, "Procedure for Operating the Three-Component Borehole Gauge," for amount of bias needed and for changing bias.)

11. Turn the placement tool counterclockwise (approximately 60°) to free it from the gauge.

12. Remove the tool from the hole.

13. Close the drill.

14. Pull all excess cable through the drill.

15. Couple the EW drill rod in the chuck to the BX wire line drill rod extending out of the drill hole.

16. Hold or tie the cable behind the water swivel.

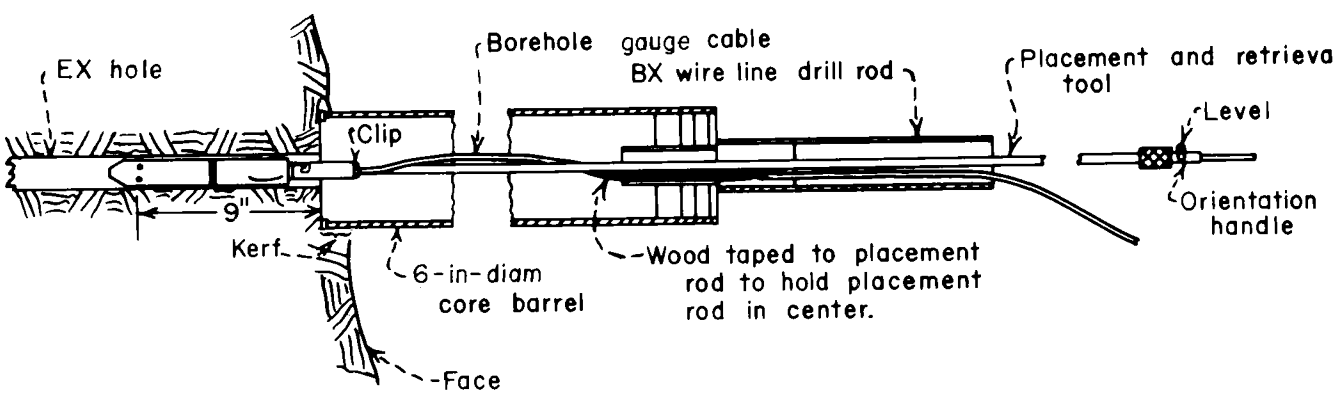


FIGURE 21. - Positioning three-component (3-D) borehole gauge with placement rod through the 6-in-diam core barrel and drill rod.

17. Turn on water. Allow approximately 10 min from the time the gauge is set for the gauge, drill water, and rock to come to temperature equilibrium.

18. Start the overcore with a chuck speed of approximately 120 rpm and a penetration rate of 1/2 in per 40 s; 120 rpm gives very satisfactory bit life and will lessen the chance of damaging the gauge if the core should break during overcoring. (Note.--If the core breaks during overcoring, this breakage will be shown by the indicators fluctuating or the cable twisting through the drill rod. If this happens, the drill should be shut down immediately and the gauge and broken core retrieved.)

Each 1/2-in penetration should be signaled to the indicator reader, and the indicator readings (deformation measurements) should be recorded on the field data sheet (fig. 20). The rate of penetration of 1/2 in every 40 s allows just enough time for recording three diametral readings. Overcoring should proceed for a total of 18 in, which is 9 in beyond the plane of measurement. This will result in 36 sets of readings. (See note in step 9.)

19. Upon completion of overcoring or if the core breaks prematurely, uncouple the BX wire line drill rod at the adapter sub.

20. Pull a little slack in the cable so the drill can be opened.

21. Hook the retrieval tool onto the gauge cable with the wire clip and insert it through the BX wire line drill rod while holding the handle of the tool counterclockwise approximately 60° from horizontal. Then push the retrieval tool into the borehole until the tool slips onto the gauge. Rotate the handle clockwise until the tool stops against the orientation pins on the gauge. Remove the gauge from the borehole.

22. Remove the core barrel and drill rod from the hole.

23. Use the core breaker to break core.

24. Retrieve the core with the core shovel in a horizontal hole or with the core puller in a vertical hole. Exercise great care not to rotate the core puller as it is lowered into the 6-in-diam hole, to ensure orientation of the core. Mark the orientation, depth, and plane of measurement on the core.

25. Place the 6-in-diam core barrel and drill rod back into the hole.

26. Repeat steps 8 through 25 for each additional set of readings in the remaining EX pilot hole. Do not position the gauge pistons closer than 12 in to the bottom of the pilot hole.

Overcores should be tested in a biaxial chamber as soon as conveniently possible after recovery to determine the modulus of elasticity.

The 7-ft EX hole allows for approximately five complete overcores. After they are completed, the remaining EX hole is drilled out, a new pilot hole is drilled, and additional overcores are performed. Stabilizers are inserted in the drill stem at 10-ft intervals or when drill rod vibration occurs.

In all drilling, the EX pilot hole should be cored with a double-tube barrel so that the core can be obtained for observations. This core indicates the fractures and/or if core disking is occurring so that the gauge can be placed in the competent zones. Disking areas or highly fractured areas should be drilled out.

If the only interest is to determine the stress field outside the influence of the mine opening, time can be saved by first drilling a 6-in-diam hole without instrumentation to a depth of one diameter of the mine opening. Then, centered in the bottom of the 6-in-diam hole, approximately 7 ft of EX hole is drilled for gauge emplacement and subsequent overcore determinations (fig. 10). At a distance of one diameter from the mine opening, at least three good sets of readings are required from each hole in order to obtain a good statistical determination of the average ground stress components.

Surface topography influences the gravitational stress in underground openings. The loading values attributable to topography should be calculated (7) and compared with the calculated stresses determined from the overcoring.

PROCEDURE FOR OPERATING THE THREE-COMPONENT BOREHOLE GAUGE

The procedures described in this section have been developed through use of the borehole gauge over a long period of time. It is important that the details be followed closely in order to minimize any chance of damage to the gauge and to provide the most reliable data acquisition.

1. Hook the gauge to the indicators, as shown in figure 19, or to a switching unit and one indicator.

2. Remove all the pistons from the gauge with special pliers (fig. 13). The special pliers are made by brazing a 1/2-in-diam by 3/8-in-long brass rod to the jaws of a standard pair of pliers. The cylindrical axis of the rod is parallel to the handles of the pliers.[6] An 11/32-in-diam hole is drilled axially through the center of the brass. The pliers are opened by sawing through the brass along the diameter perpendicular to the handles of the pliers leaving a half-round piece of brass attached to each jaw. The outside edges are then filed to fit inside the 1/2-in-wide milled flats of the gauge case.

3. Record the zero reading for each of the three diametral components. Label them U_1, U_2, and U_3 zero reading.

4. Grease the O-ring on each piston and insert the pistons into their proper place in the gauge.

5. Place the gauge into the EX hole or into a test specimen if the work is being done in the laboratory. Caution.--Do not force the gauge into the EX hole. If it fits very tightly, remove washers from the pistons as follows:

   a. Remove one piston of a diametral pair with the special pliers.

   b. Hold the piston with both pliers and screw it apart, being careful not to grasp the O-ring with the pliers.

   c. Remove a washer and screw the piston firmly back together.

   d. Grease the O-ring and insert the piston into the gauge.

   e. Repeat steps a through d for the remaining two diametral pairs. Reset the gauge in the EX hole. If the gauge is still too tight, remove a washer from the remaining three pistons as stated in steps a through d. If upon the initial insertion the gauge is very loose inside the EX hole, remove the pistons one at a time and add a washer using steps a through d.

6. When the gauge is properly sized, it should offer minimal to moderate resistance as it is placed into the EX hole. After the gauge is inserted to the proper depth, position it in the desired orientation.

7. Read all three components (U_1, U_2, and U_3).

When relieving stress, as in field overcoring, the bias set on each component should be between 13,000 and 20,000 indicator units (microinches per inch), with a G.F. of 0.40. When stress is applied to a specimen, as in the

[6]See the appendix, figure A-1.

laboratory or in the biaxial chamber, the bias set on each of the components should be between 8,000 and 15,000 indicator units for the same G.F.

The following tabulation shows typical zero readings and calibration factors for a G.F. of 0.40:

Zero readings (pistons out), µin/in:
- $U_1 \simeq -4,000$
- $U_2 \simeq +3,100$
- $U_3 \simeq +4,100$

Calibration factors, µin per µin/in:
- $U_1 = 1.00$
- $U_2 = 1.00$
- $U_3 = 1.04$

Care must be exercised not to overload the transducers, since not all borehole gauges have the element safety plug installed in the gauge case. Maximum load on any component must not exceed 50,000 indicator units with a G.F. of 0.40. The purpose of the element safety plug is to restrict the end displacement of the transducer to less than 0.025 in.

Lowering the G.F. increases sensitivity. A G.F. of 0.40 provides a reading of one indicator unit for 1 µin of deformation.

When a G.F. other than 0.40 is used, the working range and calibration factor must be determined in advance of operating.

PROCEDURE FOR BIAXIAL TESTING OF THE OVERCORE TO DETERMINE ITS ANISOTROPIC PARAMETERS

The cores recovered from the overcoring stress relief should be biaxially tested (4) as soon as possible to determine the modulus of elasticity (E). Generally, the cores recovered from an overcoring hole are tested while the setup is made on the second hole and preliminary drilling performed. The core to be tested must be intact for at least 6 in. Cores cut with a used bit will fit the testing apparatus properly. Those cut with a new bit may require one wrap of 0.015-in-thick plastic to fit properly. The core, either wrapped or unwrapped, is inserted into the biaxial chamber with the plane of measurement centered in the chamber and with the orientation mark (position U_1) at the 12-o'clock position. If it is not possible to center the plane of measurement, it should be positioned in the center third of the chamber keeping U_1 in the 12-o'clock position. The clearance is checked between the circumference of the core and the biaxial chamber at the 12-o'clock position. If there is more than approximately 1/16 in (0.06 in) clearance, then the core must be centered in the chamber with wooden wedges to prevent the liner from "popping out" and releasing oil when pressure is applied. This would also require repairing the liner and chamber. The core is centered by using four pieces of wood approximately 1/32 in thick, 1/8 in wide, and 3 to 4 in long with the last inch beveled to an edge. Place two wedges at each end between the core and the chamber at the 4:30 and 7:30 positions, inserting the wood about 3/4 in. Then apply about 100 psi to the core while the valve is slowly opened to remove any entrapped air in the system. Repressure the core (about 50 psi) to hold it rigid, then emplace the borehole gauge.

The borehole gauge is positioned and oriented at the same position in the core as it was during the overcoring stress relief, if possible. The core is preloaded three times to a selected stress level and then a set of data is recorded. (Note.--Care must be taken not to select a stress level that exceeds the tensile strength of the rock in the axial direction: otherwise, the core will fail in tension and the test for the modulus of elasticity will be lost. Values for the stress level should range from 1,500 psi for granites down to 250 psi for tuff or fractured rock.) A run consists of (1) recording a no-load reading for each component (U_1, U_2, and U_3), (2) pressuring the core to the selected stress level and reading each component, and (3) releasing the pressure and recording the component readings after unloading.

The gauge is rotated counterclockwise within the core 15°, preloaded twice, and another run made. These three sets of readings are labeled U_1+15, U_2+15, and U_3+15. This procedure is followed three more times. The last run is a repetition of the first run, except U_3 is now positioned at U_1, U_1 at U_2, and U_2 at U_3. The three sets of readings from the third run are labeled U_1+30, U_2+30, and U_3+30. The fourth run is labeled U_1+45, U_2+45, and U_3+45. The fifth or redundant readings are U_1+60, U_2+60, and U_3+60.

Root reciprocals $[U]^{-1/2}$ of these 12 readings are plotted, and a least squares fit (8) is performed to determine the maximum and minimum axes of the deformations. From these data, the maximum and minimum E values or anisotropic parameters of the core are obtained.

BOREHOLE GAUGE CALIBRATION

The following describes the procedure for calibrating the three-component borehole gauge. The gauge should be calibrated before it is used. It is a good practice to recalibrate the gauge after use, also, to assure that no damage has occurred to it.

1. Grease all pistons.

2. Put them into the gauge.

3. Place the gauge into the calibration jig.

4. Position the gauge so that the pistons for component 1 (U_1) are visible through the micrometer holes.

5. Tighten the three wingnuts.

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

7. Set the strain indicator on "Full Bridge," center the balance knob if there is one, and set the G.F. at 0.40 or the factor desired. (Note.--The G.F. setting for calibration must be the same as that used in the field for overcoring and biaxial testing.)

8. Hook the wires for component 1 (U_1) (black, green, white, and red) to the indicator as shown in figure 19 and balance it.

9. Turn one micrometer in, until the needle of the indicator just starts to move. The micrometer is now in contact with the pistons.

10. Do the same with the opposite micrometer.

11. Rebalance the indicator if necessary.

12. Record this no-load reading (zero displacement).

13. Turn each micrometer in 0.0160 in (a total of 0.0320 in displacement for component 1). (Note.--The micrometer reads to ten-thousandths of an inch.)

14. Balance the indicator.

15. Record the reading.

16. Wait 2 min and check the combined creep for the two transducers. Creep for 2 min should not exceed 20 µin/in.

17. Record the new reading.

18. Back off each micrometer 0.0040 in (a total of 0.0080 in for the component).

19. Balance and record.

20. Continue this procedure until the micrometers are back to the zero position. This reading is also the zero displacement reading for the second run.

21. Repeat steps 13 through 20 for the second cycle.

22. Loosen the wingnuts and rotate the gauge clockwise to line up component 2 (U_2) with the micrometers.

23. Retighten the wingnuts.

24. Hook up the wires for component 2 (U_2) (black, green, yellow, and orange) to the strain indicator.

25. Repeat steps 9 through 21 for component 2.

26. Calibrate component 3 (U_3) in a similar manner.

CALIBRATION DATA ANALYSIS

The following is an example using two runs for one component, calibrated at a G.F. of 0.40:

Displacement, in	Indicator reading, µin/in	Difference, µin/in
	RUN 1[1]	
0	-693	NAp
.0320	+30,140	([2])
.0320	30,055	30,535
.0240	21,920	22,400
.0160	14,040	14,520
.0080	6,380	6,860
0	-480	NAp
	RUN 2[1]	
0	-480	NAp
.0320	+30,034	([2])
.0320	29,980	30,430
.0240	21,914	22,364
.0160	13,975	14,425
.0080	6,335	6,785
0	-450	NAp

NAp Not applicable.

[1]Calibration factor: $\frac{\text{Known displacement (µin)}}{\text{Indicator units}}$ = µin/indicator unit.

[2]Wait 2 min.

Subtract the zero displacement reading (last reading of each run) from all the other indicator readings to determine the differences. These values are in microinches per inch. Because of friction between the piston O-ring and the wall of the hole in the gauge case, the least difference value (in run 1, 6,860 µin/in at 0.0080-in displacement) is subtracted from the largest difference value (30,535 µin/in at 0.0320 in). This difference (23,675), in microinches per inch, is divided into the deformation difference for the given range; in this case 0.0240 in or 24,000 µin. The result is the calibration factor. Repeat these calculations for the second run and average them to obtain the calibration factor for component 1.

Thus, for run 1,

$$\frac{24{,}000}{23{,}675} = 1.014,$$

and for run 2,

$$\frac{24{,}000}{23{,}645} = 1.015.$$

Use a calibration factor of 1.01 for the component.

Repeat the above procedure to determine the calibration factors for components 2 and 3.

The above method is a faster means of calculation and yields results accurate to within 1 pct of the least squares method. However, if desired, a least squares determination can be made using a plot of micrometer displacement versus indicator units.

IDENTIFICATION OF SOURCE OF BOREHOLE GAUGE MALFUNCTION

LACK OF BALANCE ON ONE OR MORE INDICATORS

If balance on one or more of the indicators is not achieved, recheck the wiring hookup to see that it is in accordance with the wiring diagrams in figure 19 and that all connections are tight. If balancing is still not achieved, the problem may be in the plug-in cable connection to the borehole gauge. This is checked by removing all of the screws from the placement end of the gauge, removing the end, turning off the knurled clamping nut, and pushing in the cable to ensure good connection. With the indicators set to their respective zero readings, each component will provide indicator balance when a good connection is made. Screw the knurled clamping nut very tightly into place and replace the end. (Note.--Nonbalance may occur when too much pull has been exerted on the cable accidentally or intentionally during gauge retrieval after overcoring. Sometimes in a vertical hole, cuttings or broken rock drop into the EX hole, impeding the gauge retrieval tool from hooking onto the orientation pins of the gauge. Do not attempt to retrieve the gauge by pulling the cable. Instead, remove the drilling rod and the 6-in-diam core barrel and break off the core with the gauge still in place. Remove the gauge cable from the drill, the 6-in-diam core barrel, and the drill rod. String the cable through one of the holes in the end of the core puller and then retrieve both core and gauge with the core puller.)

INSENSITIVITY OF ONE OR MORE ELEMENTS ON INDICATOR

If elements become insensitive to deflection of the pistons or nonresponsive to the turning of the indicator dial, the probability exists that moisture has entered the connecting plug or cable. In this case, do the following:

1. Remove the pistons and the borehole gauge case to check for water. If water is present, check the piston O-rings for a possible cut that may have occurred from gripping the O-ring with pliers. Grease the O-rings and replace the case.

2. Remove the placement end as described previously. Check the grommet seal. If water is found inside the gauge or in the cable connecting plug, dry out completely, regrease the cable where it passes through the grommet, and tighten the knurled nut firmly. Replace the placement end.

LACK OF COMPONENT BALANCE

If one component does not balance anywhere on the indicator dials or balances intermittently, this situation indicates a disconnected wire or possibly a cold solder joint. Remove the borehole gauge case and check all wires going to this component including the plug-in cable connector. Solder where needed and replace the gauge case.

SENSITIVITY OF INDICATORS WHEN TOUCHED

If indicators are sensitive when being touched, this sensitivity generally occurs after the instruments are used for a period of time in very humid conditions. Use plastic or other insulating material underneath the indicators during the working day. Each night the indicators should be brought out of the mine and allowed to dry.

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APPENDIX.--EQUIPMENT DIAGRAMS

Working drawings of this equipment are available from Denver Research Center, Bureau of Mines, Building 20, Denver Federal Center, Denver, CO 80225.

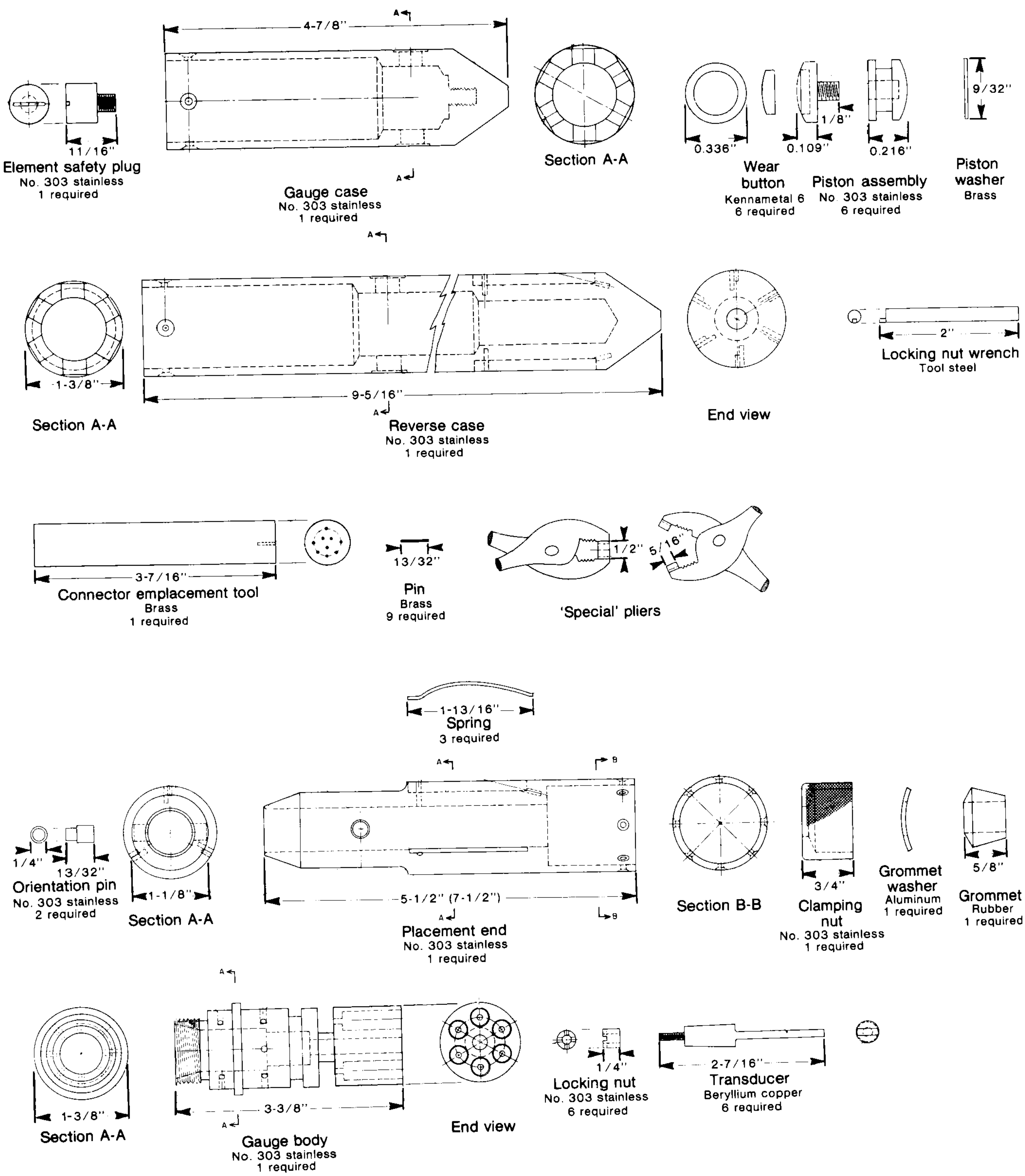

FIGURE A-1. - Three-component (3-D) borehole gauge.

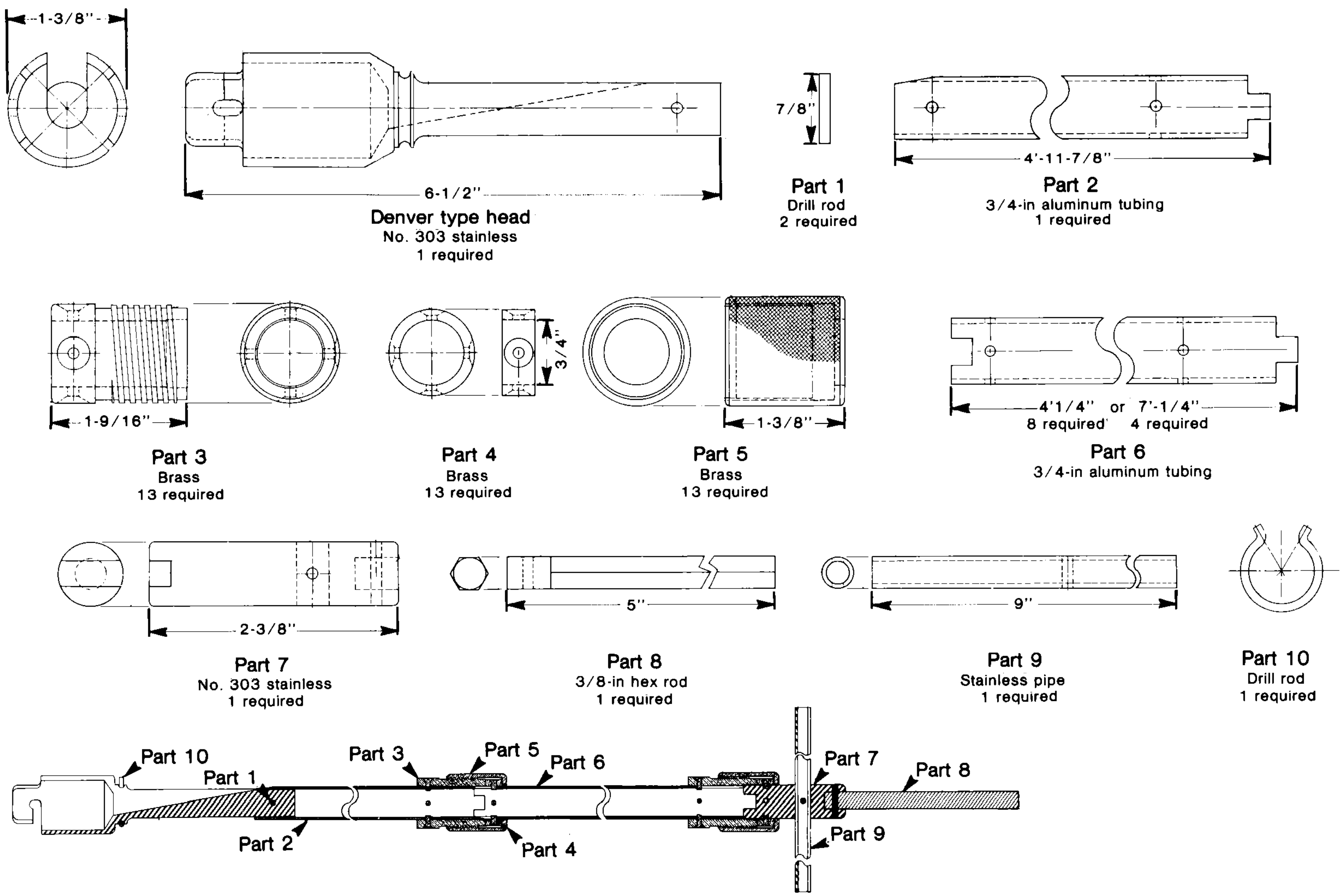

FIGURE A-2. - Borehole gauge placing and retrieving tool.

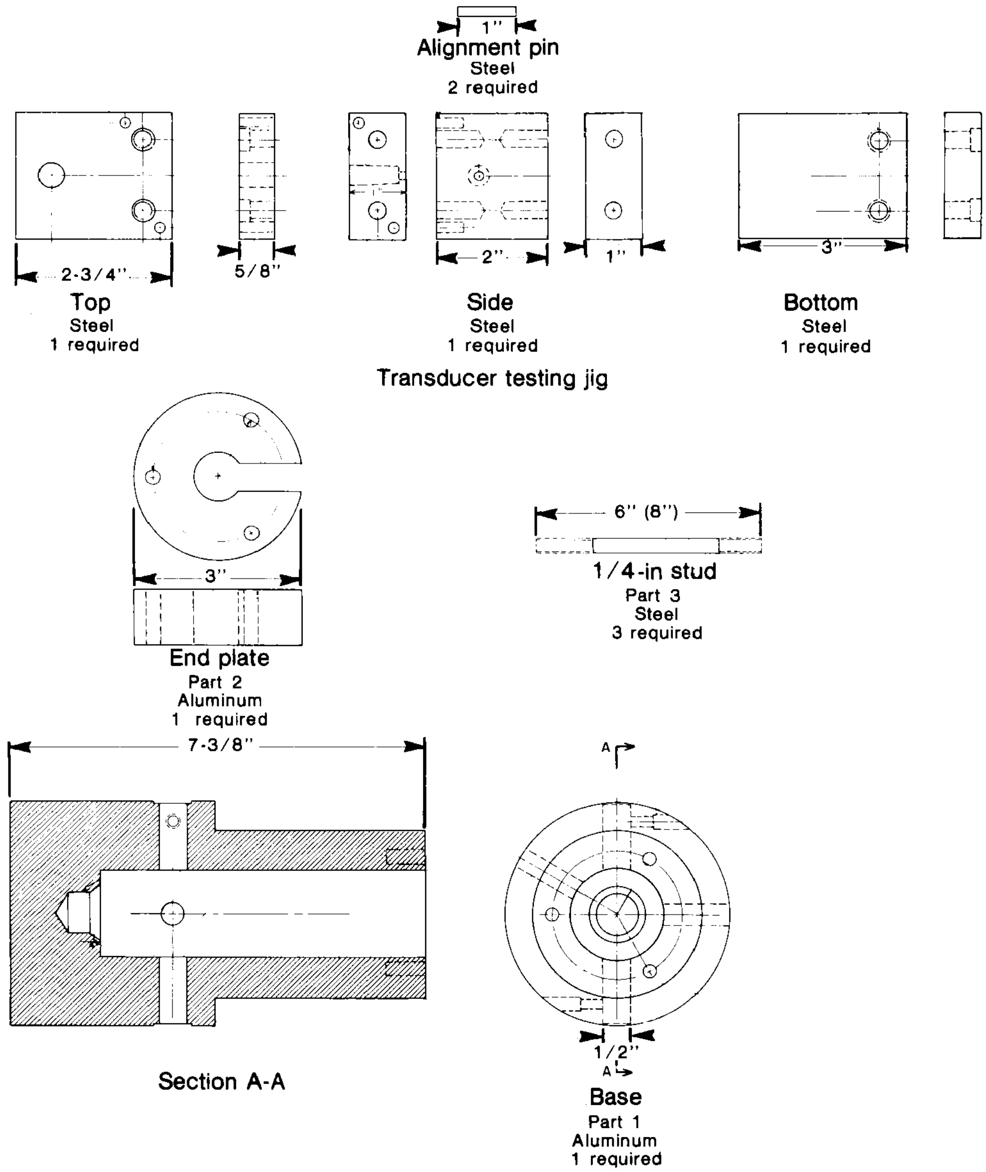

FIGURE A-3. - Calibration jig and transducer testing jig.

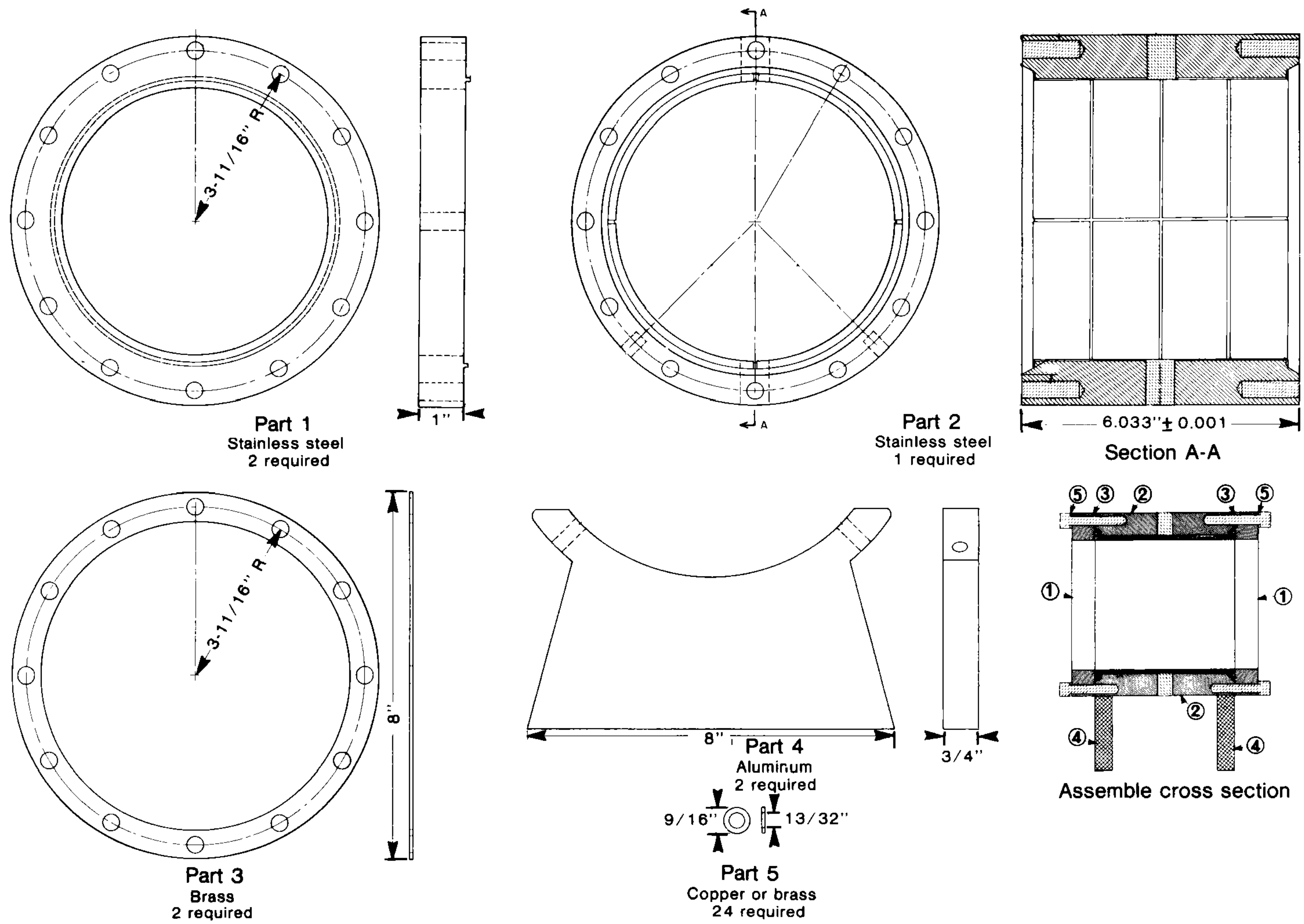

FIGURE A-4. - Biaxial pressure chamber.

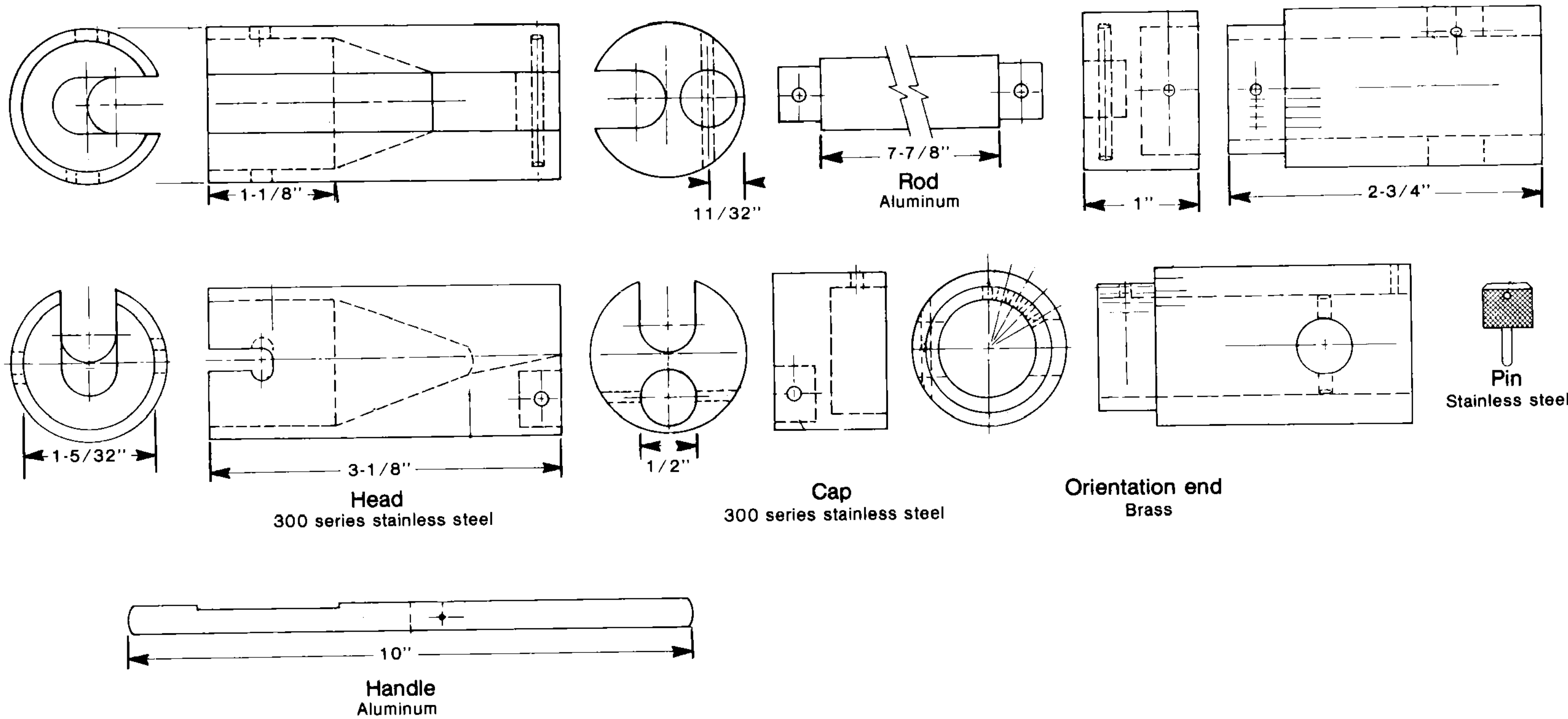

FIGURE A-5. - Borehole gauge placement tool for biaxial chamber.

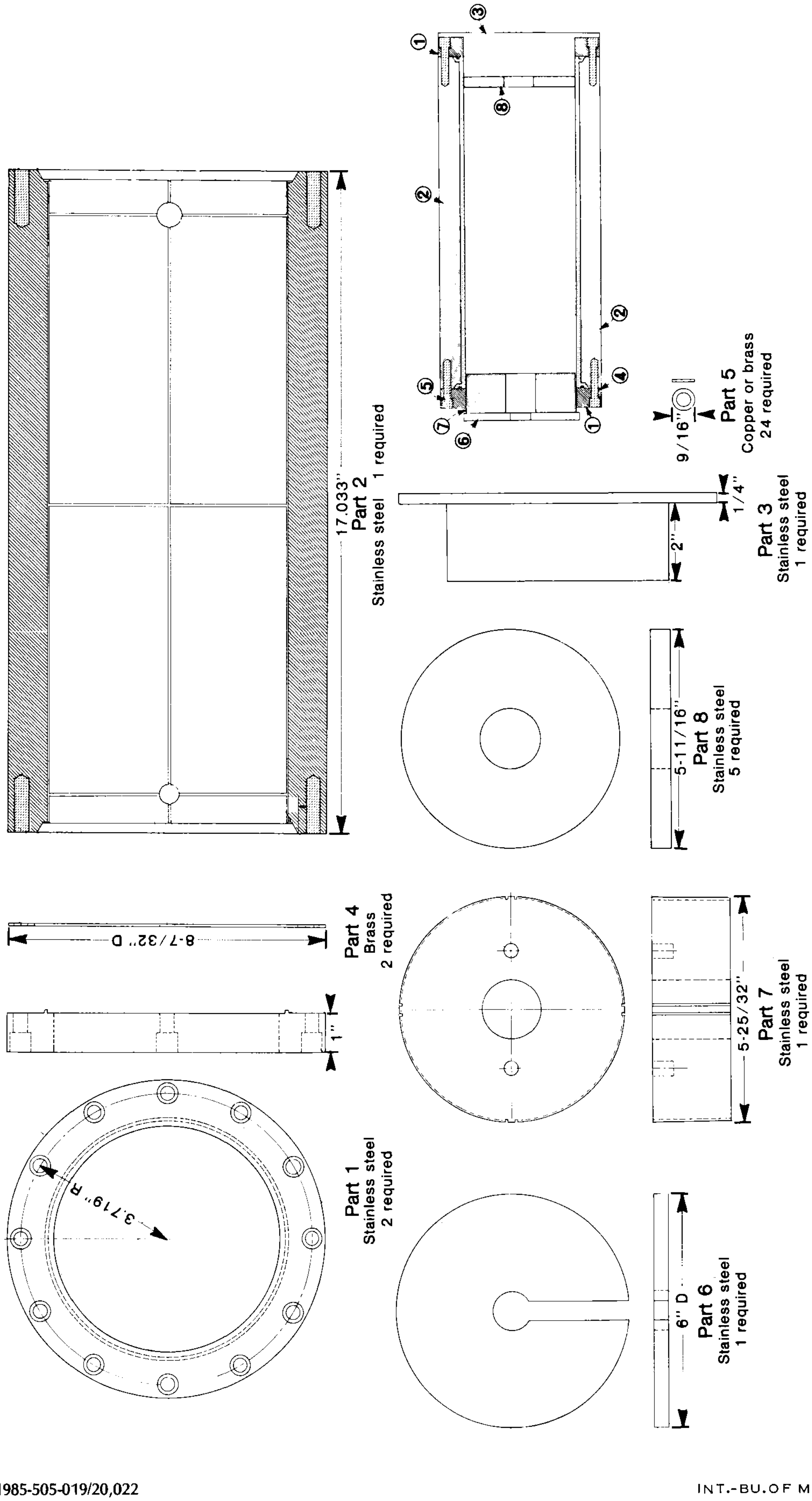

FIGURE A-6. - Triaxial pressure chamber.