Standard Test Method for Determination of In Situ Stress in Rock Mass by Overcoring Method—USBM Borehole Deformation Gauge[1]

This standard is issued under the fixed designation D4623; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method covers the determination of the ambient local stresses in a rock mass and the equipment required to perform in situ stress tests using a three-component borehole deformation gauge (BDG). The test procedure and method of data reduction are described, including the theoretical basis and assumptions involved in the calculations. A section is included on troubleshooting equipment malfunctions.

NOTE 1—The gauge used in this test method is commonly referred to as a USBM gauge (U.S. Bureau of Mines three-component borehole deformation gauge).[2]

1.2 The values stated in inch-pound units are to be regarded as standard. No other units of measurement are included in this standard.

1.3 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D4394 Test Method for Determining In Situ Modulus of Deformation of Rock Mass Using Rigid Plate Loading Method

D4395 Test Method for Determining In Situ Modulus of Deformation of Rock Mass Using Flexible Plate Loading Method

D6026 Practice for Using Significant Digits in Geotechnical Data

D7012 Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

3. Terminology

3.1 *Definitions:* See Terminology D653 for general definitions.

3.2 *Definitions:*

3.2.1 *deformation*—displacement change in dimension of the borehole due to changes in stress.

3.2.2 *in situ stress*—the stress levels and orientations existing in the rock mass before excavation.

4. Summary of Test Method

4.1 The overcore test measures the diametral deformation of a small-diameter borehole as it is removed from the surrounding stress field by coaxially coring a larger diameter hole. Deformation is measured across three diameters of the small hole, spaced 60° apart, using a deformation gauge developed by the U.S. Bureau of Mines. With knowledge of the rock deformation moduli, the measured borehole deformation can be related to the change in stress in a plane perpendicular to the borehole. This change in stress is assumed to be numerically equal, although opposite in sense to the stresses existing in the parent rock mass. Deformation measurements from three nonparallel boreholes, together with rock deformation moduli, allow calculation of an estimate of the complete three-dimensional state of stress in the rock mass.

5. Significance and Use

5.1 Either virgin stresses or the stresses as influenced by an excavation may be determined. This test method is written assuming testing will be done from an underground opening;

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

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[2] Considerable information presented in this test method was taken from *Bureau of Mines Information Circular No. 8618*, and Hooker, V.E., and Bickel, D.L., "Overcoring Equipment and Techniques Used in Rock Stress Determination," Denver Mining Research Center, Denver, CO, 1974.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard.**

however, the same principles may be applied to testing in a rock outcrop at the surface.

5.2 This test method is generally performed at depths within 50 ft (15 m) of the working face because of drilling difficulties at greater depths. Some deeper testing has been done, but should be considered developmental. It is also useful for obtaining stress characteristics of existing concrete and rock structures for safety and modification investigations.

5.3 This test method is difficult in rock with fracture spacings of less than 5 in. (130 mm). A large number of tests may be required in order to obtain data.

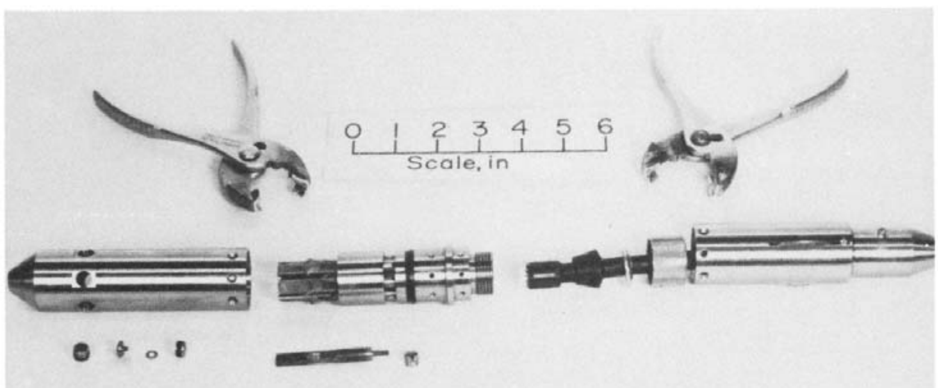

FIG. 1 Special Pliers, the Bureau of Mines' Three-Component Borehole Gauge, a Piston, Disassembled Piston and Washer, and a Transducer with Nut

5.4 The rock tested is assumed to be homogeneous and linearly elastic. The moduli of deformation and Poisson's ratio of the rock are required for data reduction. The preferred method for determining modulus of deformation values involves biaxially testing the recovered overcores, as described in Section 8. If this is not possible, values may be determined from uniaxial testing of smaller cores in accordance with Test Method D7012. However, this generally decreases the accuracy of the stress determination in all but the most homogeneous rock. Results may be used from other in situ tests, such as Test Method D4394 and Test Method D4395.

5.5 The physical conditions present in three separate drill holes are assumed to prevail at one point in space to allow the three-dimensional stress field to be estimated. This assumption is difficult to verify, as rock material properties and the local stress field can vary significantly over short distances. Confidence in this assumption increases with careful selection of the test site.

5.6 Local geologic features with mechanical properties different from those of the surrounding rock can influence significantly the local stress field. In general, these features, if known to be present, should be avoided when selecting a test site location. It is often important, however, to measure the stress level on each side of a large fault. All boreholes at a single test station should be in the same formation.

5.7 Since most overcoring is performed to measure undisturbed stress levels, the boreholes should be drilled from a portion of the test opening at least three excavation diameters from any free surface. The smallest opening that will accommodate the drilling equipment is recommended; openings from 8 to 12 ft (2.4 to 3.6 m) in diameter have been found satisfactory.

5.8 A minimum of three nonparallel boreholes is required to determine the complete stress tensor. The optimum angle each hole makes with the other two (trihedral arrangement) is 90°. However, angles of 45° provide satisfactory results for determining all three principal stresses. Boreholes inclined upward are generally easier to work in than holes inclined downward, particularly in fractured rock.

NOTE 2—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/ and the like. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Instrumentation*:

6.1.1 *Borehole Deformation Gauge*—The USBM borehole deformation gauge is shown in Fig. 1 (in fractured rock, the reverse-case modification of the gauge is recommended). The gauge is designed to measure diametral deformations during overcoring along three diameters, 60° apart in a plane perpendicular to the walls of an EX (1½-in. (38-mm) diameter) borehole.[4] Required accessories are special pliers, 0.005 and 0.015 in. (0.127 and 0.381 mm) thick, brass piston washers, and silicone grease.

6.1.2 *Strain Readout Indicators*—Three strain indicators normally are used to read the deformations. (Alternatively, one indicator with a switch and balance unit may be used or one indicator may be used in conjunction with a manual wire changing to obtain readings from the three axes.) These units

[4] More details of the gauge are described in: Hooker, V.E., Aggson, J.R., and Bickel, D.L., *Improvements in the Three-Component Borehole Deformation Gauge and Overcoring Techniques*, Report of Investigation 7894, U.S. Bureau of Mines, Washington, DC, 1984.

need a full range digital readout limit of 40 000 indicator units. Indicators need to be capable of measuring to an accuracy of $\pm 5 \times 10^{-6}$ in. (13×10^{-5} mm) with a resolution of 1×10^{-6} in. (25×10^{-6} mm). 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 gauge factor used. Normally, a gauge factor of 0.40 gives a good balance between range and sensitivity. Fig. 2 shows a typical strain indicator, calibration jig, and a switching unit. Newer data acquisition systems and microcomputer may be substituted for the indicators.

6.1.3 *Cable*—A shielded eight-wire conductor cable transmits the strain measurements from the gauge to the strain indicators. The length of cable required is the depth to the test position from the surface plus about 30 ft (10 m) to reach the strain indicators. A spare cable or an entire spare gauge and cable should be considered if many tests are planned.

6.1.4 *Orientation and Placement Tools*— The orientation and placement tools consist of:

6.1.4.1 Placement tool or "J slot tool" as shown in Fig. 3.

6.1.4.2 Placement rod extensions as shown in Fig. 3.

6.1.4.3 Orientation tool or "T handle," also shown in Fig. 3.

6.1.4.4 A scribing tool, for making an orientation mark on the core for later biaxial testing, is optional. It consists of a bullet-shaped stainless steel head attached to a 3-ft (1-m) rod extension. Projecting perpendicularly 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 inward.

6.1.4.5 Pajari alignment device for inserting 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.

6.1.5 *Calibration Jig*—A calibration jig (Fig. 2) is used to calibrate the BDG before and after testing.

6.1.6 *Biaxial Chamber*—A biaxial chamber with hand hydraulic pump and pressure gauge is used to determine the deformation modulus of the retrieved rock core. A schematic of the apparatus is shown in Fig. 4.

6.2 *Drilling Equipment*—A detailed description of the drilling apparatus is included in Annex A1.

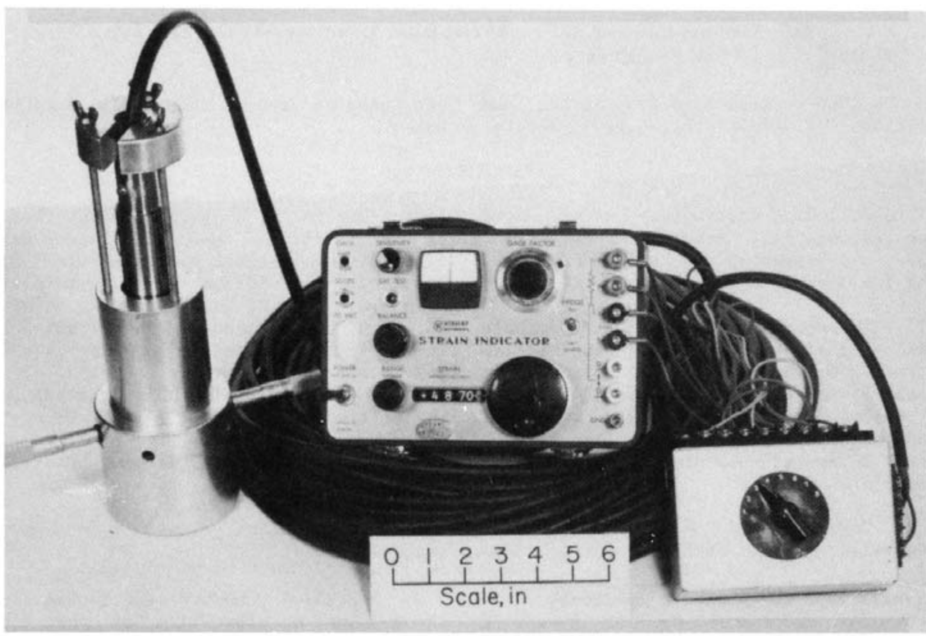

FIG. 2 The Calibration Device (Left Side) and a Switching Unit (Right Side)

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

7. Calibration and Standardization

7.1 *Gauge Calibation*—Calibrate the BDG prior to beginning and end of the test program, or more frequently if conditions require. Also recalibrate the BDG if it has undergone severe vibration (especially to the signal cable), or if there are any other reasons that exist to suspect that the gauge performance has changed. The recommended calibration procedure is as follows:

7.1.1 Grease all gauge pistons with a light coat of silicone grease and install them in the gauge.

7.1.2 Place the gauge in the calibration jig as shown in Fig. 2, with the pistons of the *U* axis visible through the micrometer holes of the jig. Tighten the wing nuts.

7.1.3 Install the two micrometer heads, and lightly tighten the set screws.

7.1.4 Set the strain indicators on "Full Bridge," and then center the balance knob and set the gauge factor to correspond to the respective anticipated in-situ range and sensitivity

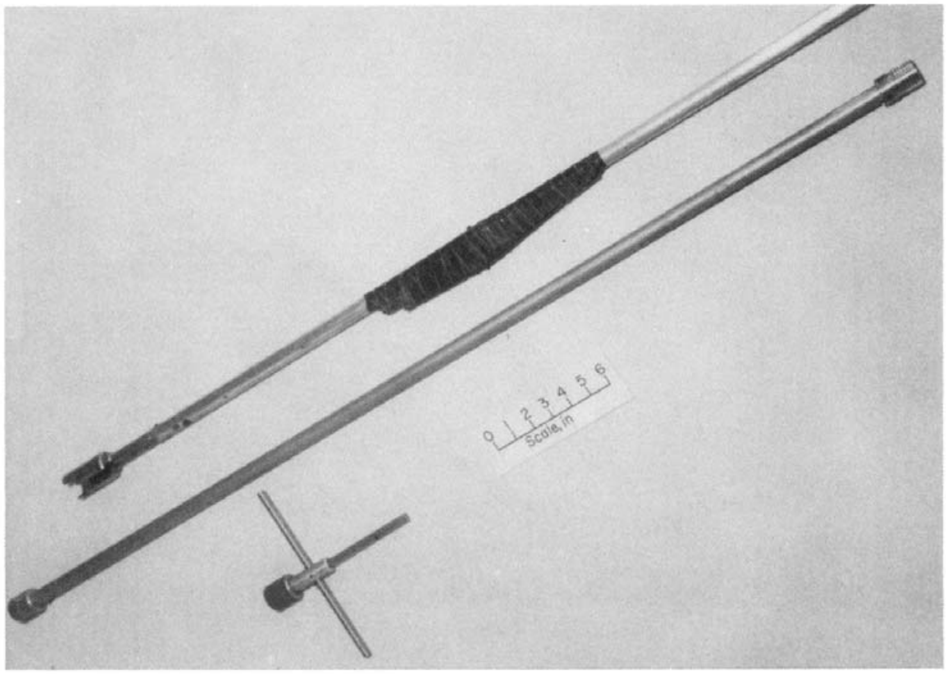

FIG. 3 Placement and Retrieval Tool

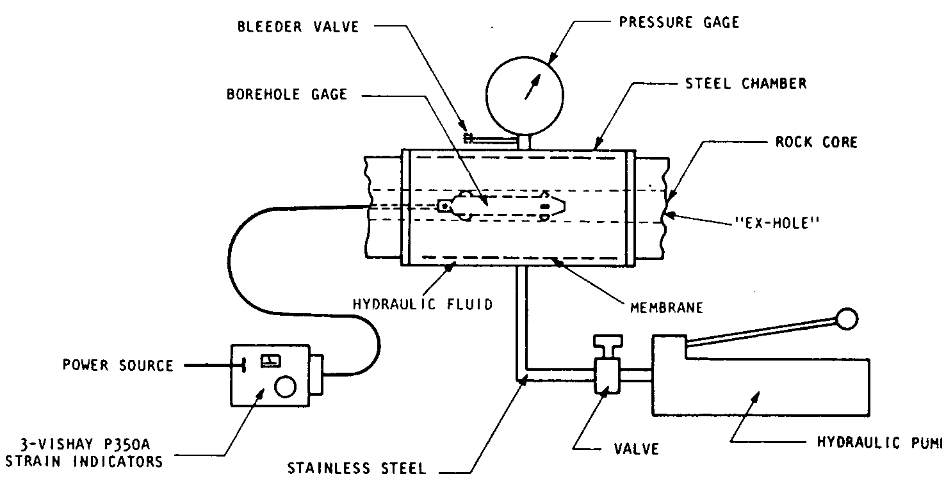

FIG. 4 Schematic: Biaxial Test Apparatus

requirements. A lower gauge factor results in higher sensitivity. The gauge factor used should be the same for calibration, in-situ testing, and modulus tests.

7.1.5 Wire the gauge to the indicators as shown in Fig. 5 or to a switching and balance unit and one indicator.

7.1.6 Balance the indicator using the "Balance" knob (if using three indicators).

7.1.7 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.

7.1.8 Rebalance the indicator.

7.1.9 Record this no load indicator reading for the *U* axis.

7.1.10 Turn in each micrometer 0.0160 in. (0.406 mm), or a total of 0.0320 in. (0.813 mm) displacement.

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

7.1.12 Wait 2 min to check the combined creep of the two transducers. Creep should not exceed 20 µin./in. (20 µmm/mm) in 2 min.

7.1.13 Record the new reading.

7.1.14 Back out each micrometer 0.0040 in. (0.102 mm) a total of 0.0080 in. (0.203 mm).

7.1.15 Balance and record.

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

7.1.17 Repeat the operations described in 7.1.10-7.1.16.

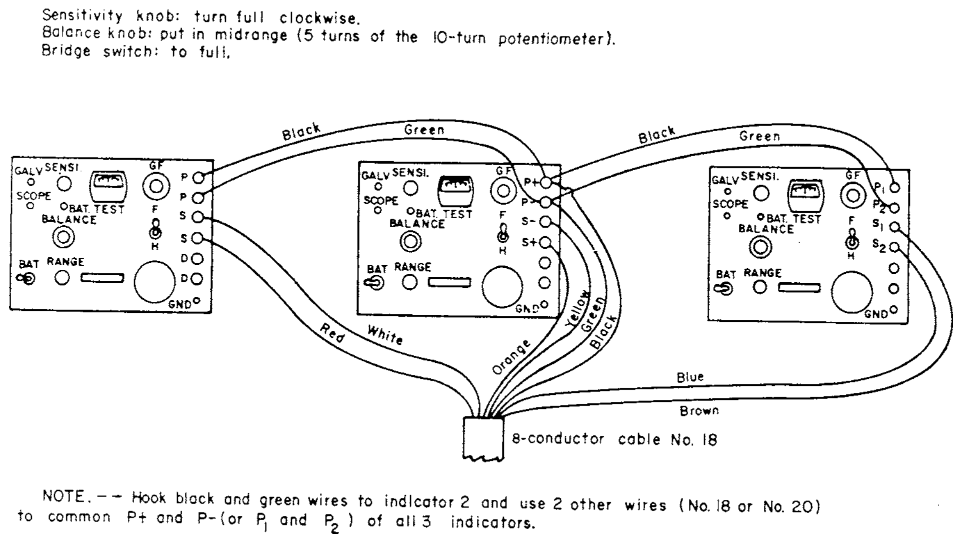

FIG. 5 Wire Hookup to Model P-350 Strain Indicators

7.1.18 Loosen the wing nuts, and rotate the gauge to align the piston of the U_2 axis with the micrometer holes.

7.1.19 Retighten the wing nuts.

7.1.20 Repeat the operations described in 7.1.6-7.1.17.

7.1.21 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 axis.

7.1.22 Determine the calibration factor for each axis as follows:

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

7.1.22.2 Subtract the difference in indicator units at 0.0080-in. (0.203-mm) deflection from the difference in indicator units at 0.0320-in. (0.813-mm) deflection.

7.1.22.3 Divide the difference in deflection 0.0240 in. (0.610 mm) by the corresponding difference in indicator units just calculated to obtain the calibration factor for that axis.

7.1.22.4 Repeat for the second cycle and take the mean as the calibration factor.

7.1.22.5 See Appendix X1 for an example of the calibration for one axis, calibrated at a gauge factor of 0.40.

8. Procedure

8.1 The procedure for obtaining data to determine in-situ stresses can be divided into two testing phases: (*a*) strain relief measurements in-situ, and (*b*) determination of Young's modulus of the rock by recompression in a biaxial chamber.

8.1.1 *General*—Holes of two sizes are drilled for the overcore test: an EX-size (1.5-in. (38-mm) diameter) hole for the deformation gauge and a large-diameter overcore hole, generally 5.625-in. (143-mm) diameter core size and 6.00 in. (152 mm) in diameter hole size. The two boreholes shall be concentric to within 1.25 in. (32 mm) of the circumference of the core diameter. All 6-in. (152-mm) drilling is done with thin-walled diamond bits. Any pressure gauge or other meters shall be functional and accurate to specifications.

8.2 *Strain Relief Measurements*:

8.2.1 *Test Planning*:

8.2.1.1 *Test Intervals*—At least six tests per borehole are recommended beyond the zone of influence of the excavation. In fractured rock, it may be necessary to test as often as possible to obtain a sufficient amount of usable data. In any case, begin the testing beyond the zone of damage caused by the excavation of the test adit, as determined from prior exploratory drilling or the initial coring of the overcore hole.

8.2.1.2 *Coaxial Requirements*—The EX and large diameter boreholes shall be concentric to within 1.25 in. (32 mm) of the circumference of the core diameter. When this tolerance is exceeded, overcore out the rock containing the existing EX hole and restart drilling.

8.2.1.3 *Test Location*—If possible, locate the plane of deformation measurements at least one diameter of the large borehole ahead of the larger hole at the start of overcoring. If this is not feasible, for instance because of fractures, locate the plane of measurements as far ahead of the large borehole as possible. Do not locate the borehole deformation gauge so that the measuring buttons and support springs are located in different blocks of rock, which will undergo differential movement when overcored. The exact test location may be determined from examination of the EX core. In highly fractured rock, examination of the EX borehole with a borescope or borehole camera is recommended before testing.

8.2.2 *Drill Setup*—To obtain high-quality data from the overcore test, it is important to minimize drilling vibrations during the test. To accomplish this, support the drill to prevent any vibratory motion or misalignment while drilling. Rock bolts, roof jacks, timber posts and wedges, and other support systems have been used successfully. Start approximately horizontal holes 5° upward from horizontal to facilitate removal of water and cuttings.

8.2.3 To start a test borehole, use a 6-in. (152-mm) starter barrel. Once the barrel has been advanced sufficiently, remove it, attach the regular 6-in. (152-mm) bit and barrel and extend the 6-in. (152-mm) hole to within 12 in. (305 mm) of the desired test depth.

8.2.4 Retrieve the core and insert the necessary length of casing, including stabilizers.

8.2.5 Insert the EX bit and reamer coupled to the EX core barrel and rods. Drill 2 to 7 ft (0.6 to 2.1 m) of EX hole.

8.2.6 Retrieve the EX core and inspect. Insert the scribing tool (if this method of orienting the core is used) coupled to the rod extensions to the beginning of the EX hole. Attach the orientation handle and orient the scribe mark as desired. Shove the scribe straight down the hole. (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. If fractures are detected, extend the hole and try again. When the EX hole has been scribed, remove the scribing tool.

8.2.7 Tape together the ends of the cable from the BDG so no moisture can enter and thread the conductor cable through the chuck and water swivel. Reconnect the wires to the strain indicator(s) exactly as during calibration.

8.2.8 Take zero deformation readings for each axis and record on the Field Data Sheet (Fig. 6) in the row labeled "zero" and in the three columns labeled U_1, U_2, and U_3. If only one strain indicator is being used, a switching unit is necessary. 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. Check tightness of cable connection.

8.2.9 Engage the orientation pins of the BDG with the placement tool using a clockwise motion. Secure the conductor cable with the wire retainer clip in the placement tool. Make sure the orientation pins of the BDG are aligned with the U_1 axis. Push the gauge through the stabilizer tube and about 9 in. (229 mm) into the EX hole. With the gauge 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. To add or remove a washer, pull the piston out with the special pliers, unscrew the two piston halves, remove or add a washer and screw back together. Be careful not to damage the O ring and reinstall the piston in the gauge. Do this initially to only one piston in each diametral pair. If the gauge is still too tight or loose, repeat for the remaining pistons.

8.2.10 The orientation of the borehole deformation gauge in a particular position is not required; a variety of orientations are recommended to minimze systematic errors and uncertainties due to rock anisotropy. Each orientation, however, shall be accurately measured to within ±5°. This may be accomplished by a measurement device on the end of the setting tools, by examining the gauge in the borehole with a low-power telescope, or by other suitable means.

8.2.11 With the gauge installed at the test depth and correctly oriented, check the bias of the gauge on the strain indicators. The bias set on each component should be between 13 000 and 20 000 indicator units with a gauge factor of 0.40 for overcoring strain relief tests. For recompression tests in the biaxial chamber, the bias should be between 8 000 and 12 000 indicator units with a gauge factor of 0.40. With a gauge factor of 1.50, the bias should be between 4500 and 7000 indicator units for overcoring tests and between 1800 and 3600 indicator units for recompression tests. Take care to avoid overloading the transducers. Maximum load on any component should not exceed 20 000 indicator units with a gauge factor of 0.40 and 4560 units with a gauge factor of 1.50.

8.2.12 Turn the placement tool counterclockwise approximately 60° to disengage it from the BDG and remove the tool. (When retrieving the BDG, this procedure is reversed.)

8.2.13 Pull the slack conductor cable through the chuck and water swivel. Avoid excess tension in the cable or the gauge may be pulled out of the EX hole. Close the drill and couple the casing to the chuck adaptor. Tie off the cable with a rope to some secured object. Only slight tension in the rope is necessary in order to keep the cable from twisting during drilling.

8.2.14 Turn on the water. Allow approximately 10 min for gauge, water, and rock to reach temperature equilibrium. The circuits in the borehole deformation gauge have been designed to minimize thermal drift. Measure the temperature of the drilling water at the beginning and end of each test and at any other time when thermal drift is suspected. To better monitor thermal effects, install a temperature sensing device like a thermistor in the gauge itself. When the drift criterion has been satisfied, obtain new zero readings for each axis.

8.2.15 With the 6-in. (152-mm) bit resting on the bottom of the hole, tape a yardstick to the drill so as to monitor drilling advancement as overcoring proceeds; check the advance rate by timing with a stopwatch. Alternatively, the exposed casing on the drill hydraulic guides may be marked at ½-in. (13-mm) increments to regulate the advance rate.

8.2.16 Start overcoring at an approximate penetration rate of ½ in. (13 mm)/40 s and a chuck speed of 50 rpm. Use a stopwatch to calibrate the drill to this rate. Each ½-in. (13-mm) penetration should be signaled to the recorder who records the indicator readings for each axis on the field data sheet. Continuously overcore approximately 12 to 18 in. (305 to 457 mm) 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 gauge 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 occur. This may take only a few minutes or it may take 2 or 3 h, depending on the rock.

8.2.17 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.

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

NOTE 3—Steps 8.2.17 and 8.2.18 are not necessary if there is an excess length of cable. If so, sufficient length may be drawn through the water swivel and chuck to allow enough slack to maneuver the BDG.

8.2.19 Secure the cable to the placement tool with the retainer clip and insert the tool over the BDG. When the

Hole No. ________ Date ______ Orientation: U1 ________

Gage No. ________ Calibration Factor U1 ________

Gage factor ________ U2 ________

True Bearing of Hole ________ U3 ________

DEPTH			DEFORMATION INDICATOR READING			TIME			TEMP.		REMARKS
Gage	Hole (+)		U1	U2	U3	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"										
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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. 6 Field Data Sheet

placement tool engages the pins on the BDG, turn the tool 60° clockwise to secure the BDG. Pull the BDG and cable out of the hole.

8.2.20 Remove the core barrel and BX rod or EX casing.

8.2.21 Retrieve the core (if it was not brought up inside the barrel) using the core breaker and core puller (or shovel in horizontal holes). Mark the original orientation on the core after the core is brought to the collar of the hole.

8.2.22 Mark the core suitable for biaxial testing with the following information: (*a*) depth of each end of the core, (*b*) location of measurement plane, (*c*) orientation of the gauge in the core, and (*d*) orientation of the core itself.

8.2.23 Plot the change in indicator units versus inches overcored for each test as shown in Fig. 7. Steady relief during overcoring and smooth curves from the data indicate that a test is successful.

8.2.24 Repeat this procedure for each additional test.

8.3 *Procedure for Determining Young's Modulus of Elasticity of the Rock Core:*[5]

8.3.1 Test the retrieved rock core in a biaxial chamber (Fig. 4) as soon as conveniently possible after recovery to determine the modulus of elasticity.

8.3.2 Place the calibrated BDG in the EX hole in the core at the same point and orientation where the in-situ test was performed.

8.3.3 Slide the rubber membrane over the rock core and place in the biaxial chamber. Some biaxial chambers have the rubber membrane attached within.

8.3.4 Record initial or zero readings for all axes.

[5] A practice for biaxial testing of the overcore to determine anisotropic parameters is described by Bickel, D.L., "Overcoring Equipment and Techniques Used in Rock Stress Determination," *Bureau of Mines Information Circular 9013*, Denver Mining Research Center, Denver, CO, 1985.

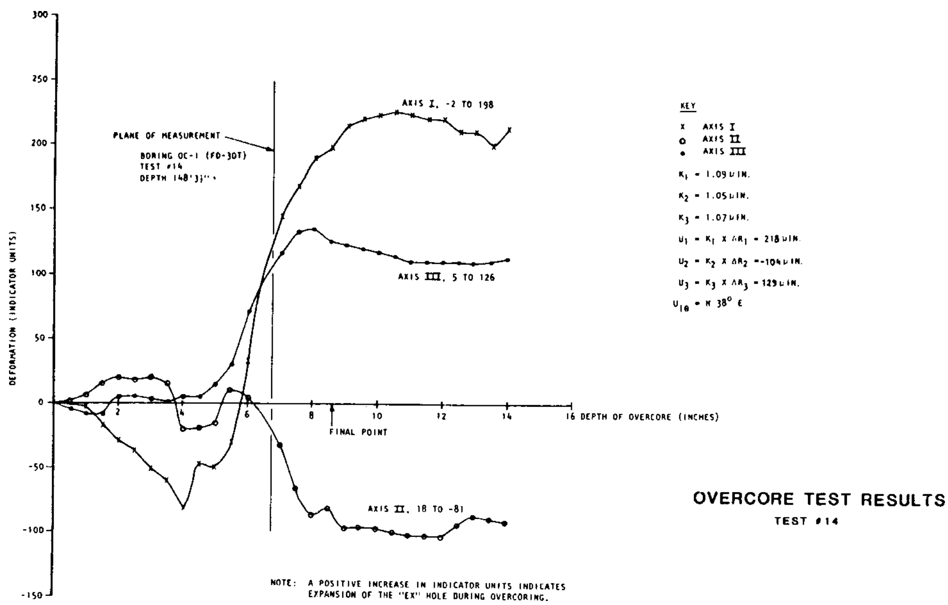


FIG. 7 Overcore Test Results

8.3.5 Increase hydraulic pressure in increments up to the measured in-situ strain level and unload in identical increments. Be sure to stay within the capacity of the chamber.

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

8.3.7 Repeat 8.3.4 through 8.3.6 for a second cycle.

8.3.8 Plot the applied pressure (lbf/in.^{2}(kN/cm^2)) versus diametral deformations (µin. (µmm)) for each axis as shown in Fig. 8. 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 Eq 4 from Section 9.

8.3.9 This test procedure requires an intact piece of core at least 6⅛ in. (156 mm) long.

8.3.10 Alternatively, the modulus may be obtained by laboratory testing the NX core from another drill hole at the same depth in uniaxial compression using standard procedures described in Test Method D7012.

8.4 *Troubleshooting Equipment Malfunctions*:

8.4.1 Perform the following procedure if balance on one or more indicators cannot be achieved:

8.4.1.1 Check wiring hookup against wiring diagram (Fig. 5). Make sure all connections are tight.

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

8.4.1.3 Nonbalance may occur when too much tension has been applied to the conductor cable during gauge retrieval. Sometimes in a vertical hole, cuttings or rock fragments drop into the 1½-in. (38-mm) hole on top of the gauge, making it impossible to hook the placement and retrieval tool onto the gauge pins. A tendency always exists to try to retrieve the gauge by pulling on the cable. Do this only as a last resort. Instead, snap the core off and bring it up with the gauge inside if overcoring has been successfully completed.

8.4.2 Perform the following procedure if core breaks during overcoring:

8.4.2.1 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.

8.4.2.2 Disconnect the casing from the chuck and insert the retrieval tool, but leave the 6-in. (152-mm) bit on the bottom. If the retrieval tool will slide over BDG pins, retrieve the BDG. If the retrieval tool will not slide over the pins, a piece of rock probably has fallen in on top of it.

8.4.2.3 Overcore past the end of the gauge, snap the core off below the gauge and bring core and gauge up inside the core barrel. Keep light tension on the conductor cable as gauge isbrought up. If the core does not come up with the barrel, use the core puller.

8.4.3 Perform the following procedure in the event one or more elements become insensitive on indicators:

8.4.3.1 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 gauge connections or at the cable connector plug.

8.4.3.2 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 a thin coat of silicone grease to O rings before reinserting pistons.

8.4.3.3 Check the cable connector plug by removing the placement end of gauge 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 gauge.

8.4.4 Perform the following procedure in the event that one component does not balance anywhere on the indicator dial or balances intermittently:

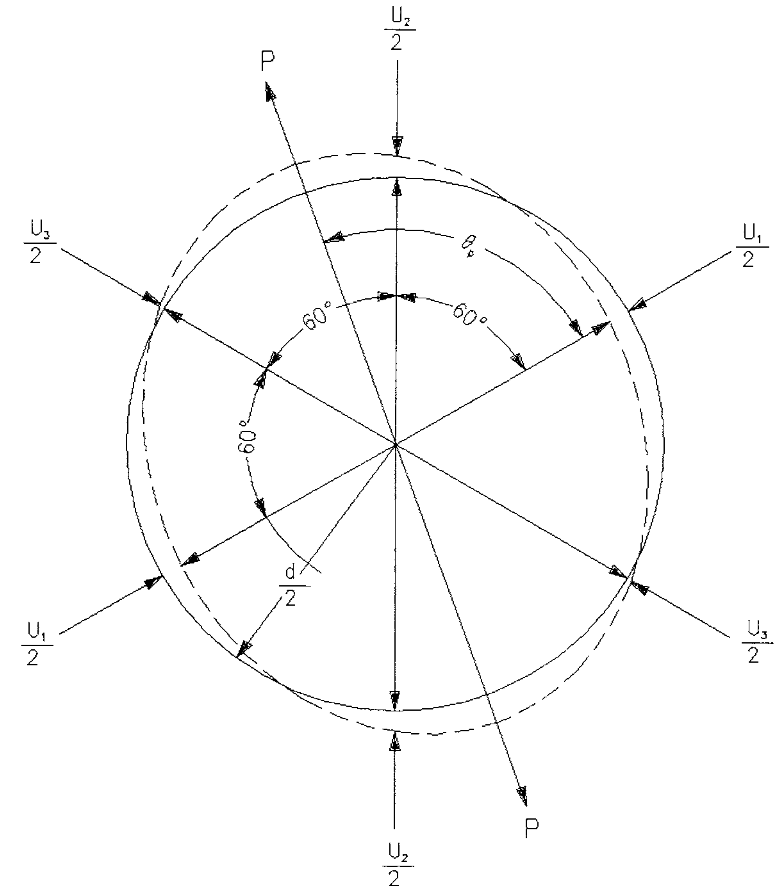


FIG. 8 Orientations of Deformations and Secondary Principal Stresses

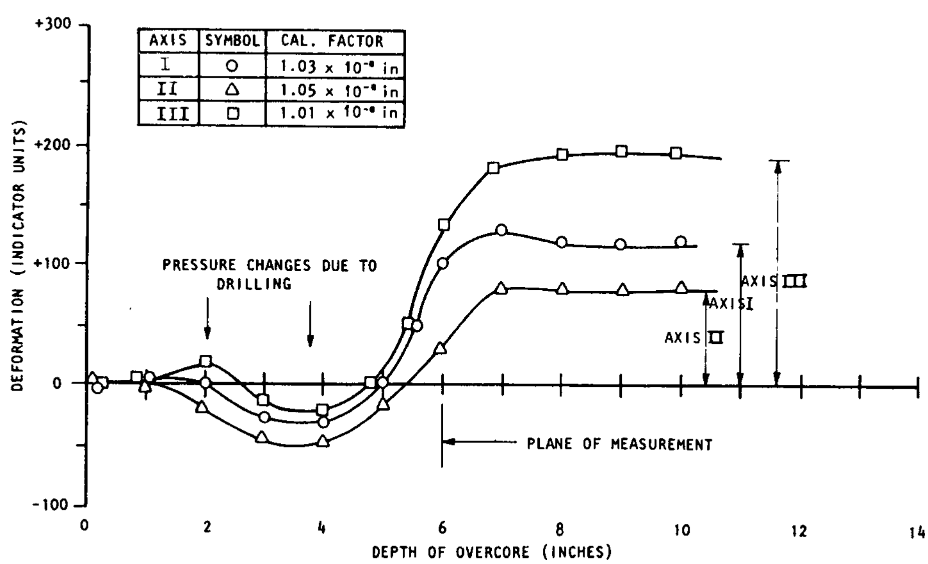


FIG. 9 Idealized Overcore Results

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

8.4.5 Perform the following procedure in the event that the indicator needles are sensitive to touch:

8.4.5.1 If the 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 the indicators in a dry place when not in use to allow them to dry out.

9. Calculation

9.1 *Secondary Principal Stresses*:

9.1.1 The deformations measured by the BDG are used to compute planar principal stresses in a plane perpendicular to the axis of the borehole at each test station within the hole. Since the overcoring technique with the USBM gauge does not measure rock deformation along the axis of the borehole, an exact calculation of the secondary principal stresses is not possible unless some additional data are obtained regarding either axial deformation or axial stress. If the simplifying assumption that zero stress exists along the axis of the borehole is made, then the secondary stresses can be calculated using a plane stress solution.[6] This solution, although not exact, results in an error of less than about 10 %.

9.1.2 The magnitude and direction of planar principal stresses as shown in Fig. 8 are determined by the following expressions:

$$P = \frac{E}{6d}(U_1 + U_2 + U_3) + \frac{1}{\sqrt{2}}[(U_1 - U_2)^2 + (U_2 - U_3)^2 + (U_3 - U_1)^2]^{1/2} \quad (1)$$

$$Q = \frac{E}{6d}(U_1 + U_2 + U_3) - \frac{1}{\sqrt{2}}[(U_1 - U_2)^2 + (U_2 - U_3)^2 + (U_3 - U_1)^2]^{1/2} \quad (2)$$

$$\theta p = 1/2 \arctan \frac{\sqrt{3}(U_2 - U_3)}{2U_1 - U_2 - U_3} \quad (3)$$

where:

P = major secondary principal stress,
Q = minor secondary principal stress perpendicular to P,
E = modulus of deformation of the rock,
d = borehole diameter,
U_1 = diametral deformation across diameter 1, 2, or 3 at 60° intervals of the EX hole, and
θp = orientation of major secondary principal stress measured counterclockwise from U_1 to P.

9.1.2.1 θp can have two values 90° apart. The following rules are used for determining the correct angle:

$U_2 > U_3$ and $U_2 + U_3 < 2U_1$ then θp is between 0° and 45°.
$U_2 > U_3$ and $U_2 + U_3 > 2U_1$ then θp is between 45° and 90°.
$U_2 < U_3$ and $U_2 + U_3 > 2U_1$ then θp is between 90° and 135°.
$U_2 < U_3$ and $U_2 + U_3 < 2U_1$ then θp is between 135° and 180°.

9.1.3 The modulus of elasticity is calculated using the biaxial test results in the following equation:

$$E = \left(\frac{2b^2a}{b^2 - a^2}\right)\left(\frac{P}{U}\right) \quad (4)$$

where:

b = outside diameter of specimen,
a = inside diameter of specimen,
P = biaxial pressure applied, and
U = average deformation of borehole as a result of P.

9.2 *Three-Dimensional Principal Stresses*:

9.2.1 At any point in the rock mass, the three-dimensional state of stress is fully defined by a total of six independent stress components (stress tensor). These are the three orthogonal components of normal stress, σ_x, σ_y, and σ_z and the three components of shear stress, τ_{xy},τ_{yz}, and τ_{zx}. If a local (1, 2, 3) coordinate system is defined at an overcore test location such that σ_2 acts along the axis of the borehole, then components τ_{12} and τ_{23} act parallel to the axis of the borehole and, thus have negligible effect on the diametral deformation of the borehole. The change in the diameter of borehole is, therefore, a function of the three stress components σ_1, σ_3 and τ_{13} acting perpendicular to the borehole axis, and the component σ_2 acting parallel to the borehole axis.

9.2.2 Using the plane strain condition of the theory of elasticity (that is, $\varepsilon_2 = 0$), solve for the borehole deformation caused by σ_1, σ_3, and τ_{13}. The effect of σ_2 on the diametral deformation is then superimposed on this solution. The total change in borehole diameter, U, may be expressed as follows:

$$U = \sigma_1 f_1 + \sigma_2 f_2 + \sigma_3 f \sigma_3 + \tau_{13} f_4 \quad (5)$$

where:

$$f_1 = d(1 + 2\cos 2\theta)(1 - v^2)/E + dv^2/E \quad (6)$$

$$f_2 = -dv/E \quad (7)$$

$$f_3 = d(1 - 2\cos 2\theta)(1 - v^2)/E + dv^2/E \quad (8)$$

$$f_4 = d(4\sin 2\theta)(1 - v^2)/E \quad (9)$$

where:

d = diameter of borehole,
θ = angle of the diametral measurement axis from the horizontal of the local coordinate system,
ν = Poisson's ratio of the rock, and
E = modulus of deformation of the rock.

9.2.3 Each overcore test measures the borehole deformation, across three different diameters 60° apart. However, no information is obtained about either σ_2 or ε_2 acting perpendicular to the axis of measurement. Thus, Eq 5 cannot be solved for the stress components unless additional information is obtained or assumed. Tests in differently oriented boreholes provide this information. When determinations of U are made in more than one drill hole, all of the measurements must be related to a common coordinate system. Each stress component of the local coordinate system may be expressed as a function of the stress tensor of the common (x, y, z) system according to the standard rules of transforming stresses from one rectangular coordinate system to another. Doing this allows Eq 5 to be rewritten as follows:

$$U = J_1\sigma_x + J_2\sigma_y + J_3\sigma_z + J_4\tau_{xy} + J_5\tau_{yz} + J_6\tau_{zx} \quad (10)$$

where:

J_1 = a function of the f_1 defined in Eqs Eq 6-9 and the direction cosines between the two coordinate systems.

[6] Equations for determining the magnitude and direction of planar principal stresses are derived from Merrill, R.H., and Peterson, J.R., "Deformation of a Borehole in Rock," *U.S. Bureau of Mines Report RI 5881*, 1961. These equations are based on the deformation of a hole in an infinite, isotropic, elastic plate under uniaxial or biaxial loads.

9.2.3.1 With six independent measurements of *U*, the components of the stress tensor can be determined.

NOTE 4—Austin has shown that measurements in at least three nonparallel boreholes are required to define fully this tensor.[7] In practice, the precision of the stress component determination is increased by applying statistical methods to the data. The method generally used is a least squares solution that combines all the deformation measurements from any number of boreholes regardless of their orientation. Once the stress tensor is determined, the principal stresses in the rock mass are calculated using standard methods. The statistical approach to the data reduction allows confidence levels to be assigned to the results.

10. Report

10.1 This section establishes the minimum requirements for a complete and usable report. Further details may be added as appropriate, and the order of items may be changed if necessary. Applications of the test results are beyond the scope of this procedure, but may be an integral part of some testing programs. In that case, an applications section compatible with the format described below should be included.

10.2 *Introductory Section of the Report*—The introductory section is intended to present the scope and purpose of the testing program, and the characteristics of the material tested.

10.2.1 *Scope of Testing Program*:

10.2.1.1 Present a graphic presentation of the location and orientation of the overcore holes.

10.2.1.2 Discuss the reasons for selecting the test locations.

10.2.1.3 Discuss in general terms the areas of interest which are not covered by the testing program and the limitations of the data within the areas of application.

10.2.2 Present a brief description of the test site geology and describe macroscopically the rock type. Discuss structural features affecting the overcore testing and interpretation of the results, as appropriate.

10.3 *Test Method*:

10.3.1 Include a detailed listing of the equipment actually used for the test, including the name, model number, and basic specifications of each major piece.

10.3.2 List in detailed steps the procedure actually used for the test.

10.3.3 If the actual equipment or procedure varies from the requirements contained in this procedure, note each variation and the reasons for it. Discuss the effect of the variation upon the test results.

10.4 *Theoretical Background*:

10.4.1 Clearly present and fully define all equations used to reduce the data. Note any assumptions inherent in the equations or limitations in their applications, and discuss the effect on the results.

10.4.2 *Site-Specific Influences*—Discuss the degree to which the actual test site conditions conform to the assumptions contained in the data reduction equations and fully explain any factors or methods applied to the data to correct for a nonideal situation.

[7] Austin, W.G., "Development of a Stress Relief Method with a Three-Directional Borehole Deformation Gauge," *Bureau of Reclamation Report REC-OCE-70-10*.

10.5 *Results*:

10.5.1 As a minimum, present for each test a summary table including the test number, borehole depth, probe orientation, and deformation of each channel.

10.5.2 Present for each test the secondary principal stresses, including depth from the adit face, orientations, and magnitudes. A graphic presentation, as well as a tabular summary, is recommended.

10.5.3 Present the orientations and magnitudes of the three-dimensional principal stresses. A graphic presentation, as well as a tabular summary, is recommended.

10.5.4 The following other types of data analyses and presentations may be included as appropriate: (*1*) the stress gradient away from the adit may be evaluated either by secondary principal stresses or, if sufficient tests have been run, by the complete stress tensor or principal stresses, and (*2*) the stresses in different rock formations or in different relationships to geologic structures may be evaluated.

10.6 *Error Estimate*:

10.6.1 Analyze the results using standard statistical methods. Calculate all uncertainties using a 95 % confidence interval.

10.6.2 *Measurement Error*—Evaluate the error associated with a single test; this includes the combined effects of all transducers, power supplies, readout devices, and the like.

10.6.3 *Stress Error*—The uncertainty associated with each component of the principal stresses is usually evaluated from the multiple regression analysis of the deformation data. This uncertainty results from random errors from the measurements and errors from the assumptions used in the data reduction. This uncertainty may also include the effects of systematic differences in material properties or local stress fields between individual boreholes. Discuss these factors separately as quantitatively as possible.

10.7 *Appended Data*:

10.7.1 Include in an appendix a deformation versus drill bit penetration plot for each test.

10.7.2 Include in an appendix a plot of deformation versus time for each test.

11. Precision and Bias

11.1 Due to the nature of rock materials tested by this test method, it is, at this time, either not feasible or too costly to produce multiple specimens which have uniform physical properties. Therefore, since specimens which would yield the same test results cannot be tested. Subcommittee D18.12 cannot determine the variation between tests since any variation observed is just as likely to be caused by specimen variation as by operator or laboratory testing variation.

11.1.1 Subcommittee D18.12 welcomes proposals to resolve this problem that would allow for development of a valid precision statement.

11.2 There is no accepted reference value for this test method; therefore, bias cannot be determined.

12. Keywords

12.1 borehole; core; deformation; drilling; gauge; in situ; measurements; moduli; overcoring; rock; stress

ANNEX

(Mandatory Information)

A1. DRILLING APPARATUS

A1.1 *Drill*—A drill with a chuck speed ranging down to 50 rpm and a penetration rate of ½ in. (13 mm)/30 to 50 s when using a 6-in. (152-mm) diameter overcoring bit. Achievement of this lower-end speed will usually require a reduction gear.

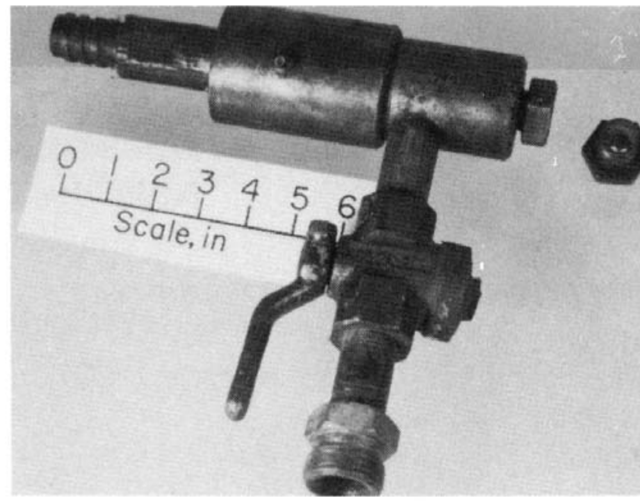
A1.2 *EWX Single-Tube Core Barrels*, 2 ft (0.7 m) and 5 ft (1.5) in length are required (Fig. A1.1). An alternate is an EWX double-tube swivel-type core barrel.

A1.3 *EX Diamond Bit* (Fig. A1.1).

A1.4 *Reamer*—A reamer is used with the EX bit for the 1½-in. (38-mm) diameter pilot gauge hole (Fig. A1.1).

A1.5 *EW Drill Rods*—EW drill rods are used with the EX bit. The required length is dependent on the test depth.

A1.6 *Drill Rod or Casing*—BX wireline drill rod, EX casing, or AWT rod is used with the 6-in. (152-mm) core barrel and bit. The required length will depend on test depth. An adapter is required to couple the rod or casing to the 6-in. (152-mm) core barrel.



NOTE 1—Plug at right used during overcoring.

FIG. A1.2 Water Swivel with Solid Plug

FIG. A1.1 EX Size Bit with Core Spring, Reamer, and 2-ft (0.7 m) EWX Core Barrel

A1.7 *Water Swivel*—A water swivel (Fig. A1.2) is required with a ½-in. (13-mm) hole for the conductor cable to pass through and a plug to fit the hole when the gauge is not being used. This is not necessary if reverse circulation is used.

A1.8 *Starter Barrel*—A 6-in. (152-mm) diameter starter barrel, 1 ft (304 mm) long with a detachable 1½-in. (38-mm) diameter pilot shaft in the center (Fig. A1.3) is required. The pilot shaft should extend about 5 in. (127 mm) beyond the diamonds of the starter barrel. This barrel is used to center the 6-in. (152-mm) diameter hole over an initial 1½-in. (38-mm) diameter hole at the face.

A1.9 *EW Core Barrel*—An EW core barrel to replace the pilot shaft should be cut to extend 1 in. (25 mm) beyond the starter barrel. When the bit and reamer are attached, the unit is used to drill a 1½-in. (38-mm) diameter starter hole 4 in. (102 mm) deep at the end of a 6-in. (152-mm) hole. This piece of equipment is not needed in vertical down holes if a steel ring,

FIG. A1.3 Six-inch (152-mm) Diameter Starter Barrel with Pilot and Expander Head Adapted for EW Drill Rod

2 in. (51 mm) in outside diameter, 1.448 in. (36.779 mm) in

inside diameter, and ¾ in. (19 mm) wide is placed on the EWX barrel in front of the centering stabilizer for retrieving the centering stabilizer.

A1.13 *Core Shovel*—A 6-in. (152-mm) core shovel (Fig. A1.4) to fit an EW rod is needed for retrieving core from horizontal holes.

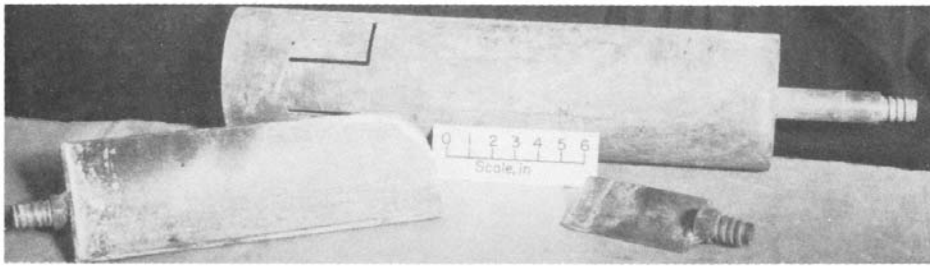


FIG. A1.4 Core Breaker (Lower Right), Core Shovel (Lower Left), and Core Puller (Center)

A1.10 *Diamond Drill*—A standard 6-in. (152-mm) diamond drill bit or a 6-in. (152-mm) thin wall masonry bit, long enough to obtain 18 in. (0.5 m) of overcoring with a 5⅝-in. (143-mm) diameter is used for overcoring.

A1.11 *Stabilizers*—Stabilizers are required to minimize wobbling and to maintain approximate alignment of the BX wireline drill rod or EX casing and 6-in. (152-mm) bit. A recommended method is to attach 1-ft (0.3-m) long sections of old 6-in. (152-mm) barrel to the casing by welding a cross-shaped metal piece to the casing at the barrel. Water is still able to flow through the stabilizer. A rod or casing with stabilizer should be included in the drill string approximately every 10 ft (3 m).

NOTE A1.1—For centering and drilling the EX borehole, the EX bit with EW rod can be inserted through a string of BX wireline drill rod or EX casing with attached stabilizer as necessary.

A1.12 *Core Breaker*—A core breaker, at least 2½-in. (64-mm) wide and hardened to fit the EW rod (Fig. A1.4) is required.

A1.14 *Core Puller*—A 6-in. (152-mm) core puller (Fig. A1.4), approximately 18 in. (0.5 m) long to fit an EW drill rod is sometimes needed for retrieving the core from vertical holes. The core puller may be made from a used 6-in. core barrel. A ⅝-in. (16-mm) thick steel plate is welded to the end of the barrel with an EW rod welded in the center. Three 1½-in. (38-mm) diameter holes on 120° centers are drilled into the plate to allow water to pass through. Four "U" cuts, 90° 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. Such devices, as an anchor device that fits into the EW borehole, will also suffice. Normally, the core can be retrieved inside the 6-in. (152-mm) diameter barrel. An EX anchor attached to one end of a rocker arm, which screws into an EW drill rod, also works by inserting the anchor into the EX hole of the core.

NOTE A1.2—The shovel and core puller can be made from used 6-in. (152-mm) core barrels.

A1.15 *Water Pump and Hose*—A high-capacity water pump and hose are required unless a water pipeline is available.

APPENDIX

(Nonmandatory Information)

X1. SAMPLE CALIBRATION

See Table X1.1.

TABLE X1.1 Calibration of Axis U_1[A]

	Displacement, in.	Indicator Reading	Difference, µin./in.
Run 1	0	−693	...
	0.0320	+ 30 140	Wait 2 min
	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 min
	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	...

[A] Equation as follows:

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

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

$$\text{For Run 2, } K_1 = \frac{32\,000 - 8\,000}{30\,430 - 6\,785} = \frac{24\,000}{23\,645}\ 1.0.15$$

Use $K_1 = 1.01$ µin. per indicator unit.

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D4623 – 05) that may impact the use of this standard. (Approved July 1, 2008.)

(*1*) Revised Section 1.2.