Designation: D 4623 – 05

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

This standard is issued under the fixed designation D 4623; 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 gage (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 gage used in this test method is commonly referred to as a USBM gage (U.S. Bureau of Mines three-component borehole deformation gage).[2]

1.2 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are provided for information only.

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]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock Used in Engineering Design and Construction

D 4394 Test Method for Determining the In Situ Modulus of Deformation of Rock Mass Using the Rigid Plate Loading Method

D 4395 Test Method for Determining the In Situ Modulus of Deformation of Rock Mass Using the Flexible Plate Loading Method

D 6026 Practice for Using Significant Digits in Geotechnical Data

D 7012 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 D 653 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 gage 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; 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

[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.

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.

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 D 7012. 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 D 4394 and Test Method D 4395.

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.

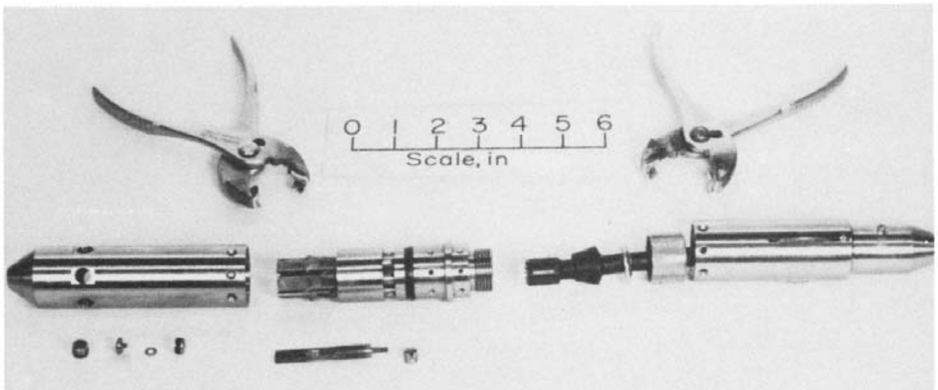

FIG. 1 Special Pliers, the Bureau of Mines' Three-Component Borehole Gage, a Piston, Disassembled Piston and Washer, and a Transducer with Nut

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 D 3740 are generally considered capable of competent and objective testing/sampling/inspection/ and the like. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Instrumentation*:

6.1.1 *Borehole Deformation Gage*—The USBM borehole deformation gage is shown in Fig. 1 (in fractured rock, the reverse-case modification of the gage is recommended). The gage 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 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.

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

The calibration factor for each axis will change proportionally with the gage factor used. Normally, a gage factor of 0.40 gives a good balance between range and sensitivity. 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.

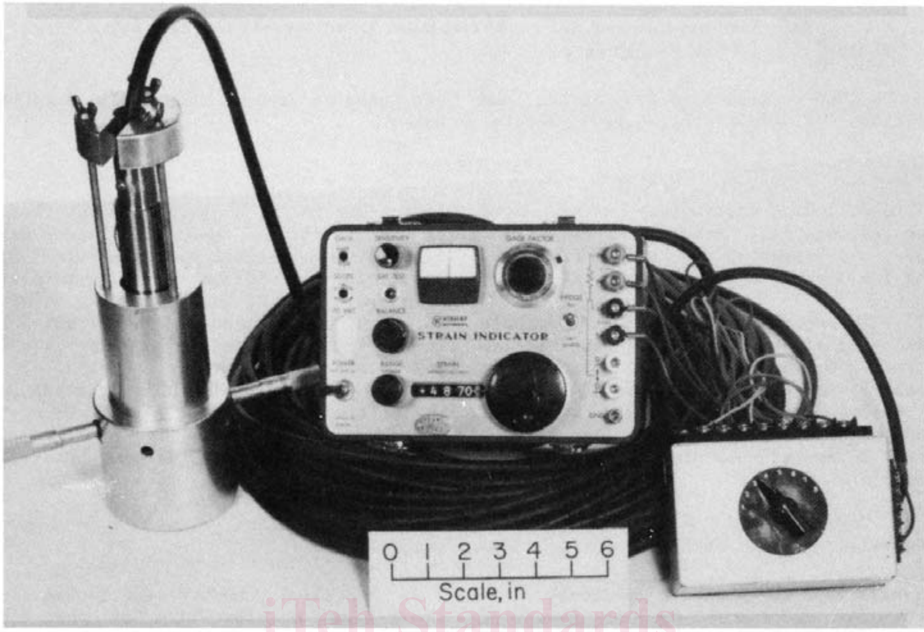

FIG. 2 The Calibration Device (Left Side) and a Switching Unit (Right Side)

6.1.3 *Cable*—A shielded eight-wire conductor cable transmits the strain measurements from the gage to the strain indicators. The length of cable required is the depth to the test position from the surface plus about 30 ft (10 m) to reach the strain indicators. A spare cable or an entire spare gage 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 gage 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.

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 *Gage 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 gage performance has changed. The recommended calibration procedure is as follows:

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

7.1.2 Place the gage 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 gage factor to correspond to the respective anticipated in-situ range and sensitivity

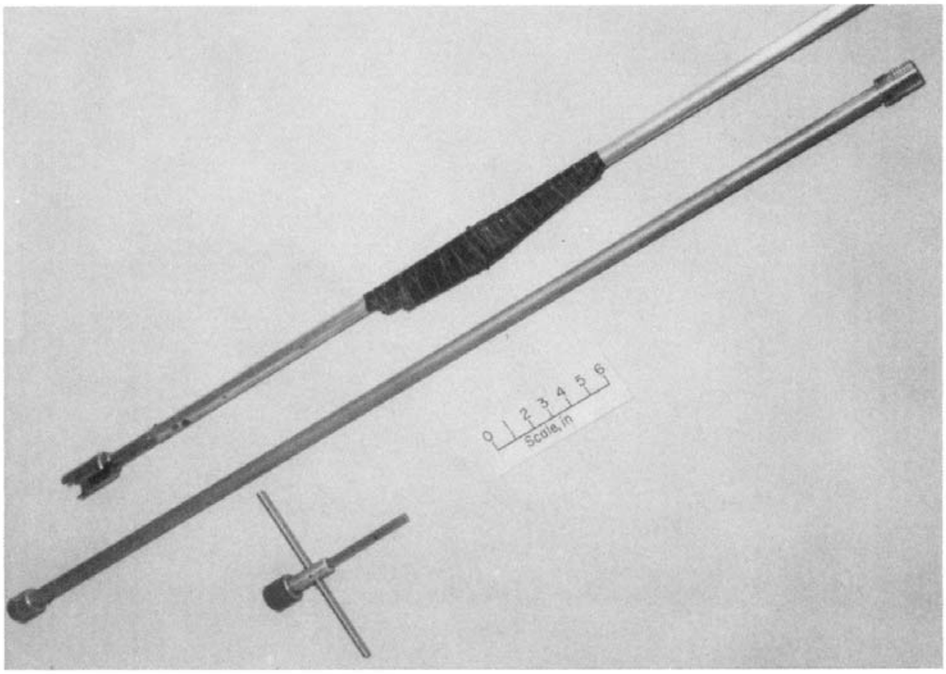

FIG. 3 Placement and Retrieval Tool

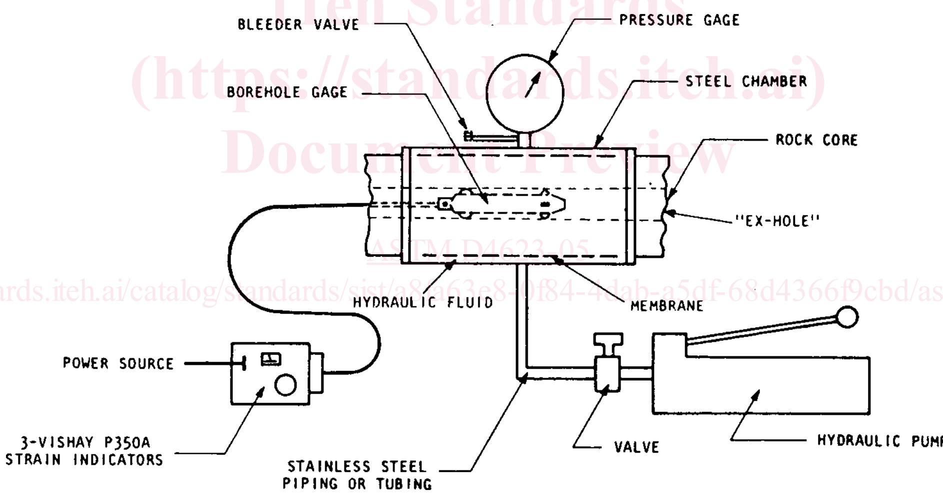

FIG. 4 Schematic: Biaxial Test Apparatus

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

7.1.5 Wire the gage 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.

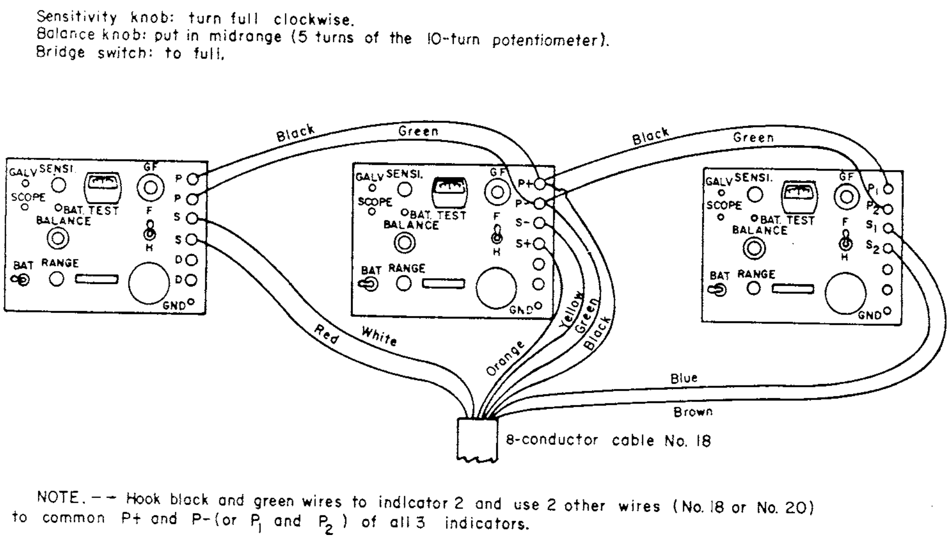

FIG. 5 Wire Hookup to Model P-350 Strain Indicators

7.1.18 Loosen the wing nuts, and rotate the gage 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 gage 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 gage 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 gage 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 gage 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 gage through the stabilizer tube and about 9 in. (229 mm) into the EX hole. With the gage at test depth, orient the U_1 axis along the scribe mark by turning clockwise. If the BDG feels too loose or too tight in the EX hole, it must be removed. If too tight, remove one washer from one piston of each axis and try again. If too loose, add one washer to one piston of each. 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 gage. Do this initially to only one piston in each diametral pair. If the gage is still too tight or loose, repeat for the remaining pistons.

8.2.10 The orientation of the borehole deformation gage 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 gage in the borehole with a low-power telescope, or by other suitable means.

8.2.11 With the gage installed at the test depth and correctly oriented, check the bias of the gage on the strain indicators. The bias set on each component should be between 13 000 and 20 000 indicator units with a gage 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 gage factor of 0.40. With a gage 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 gage factor of 0.40 and 4560 units with a gage 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 gage 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 gage, water, and rock to reach temperature equilibrium. The circuits in the borehole deformation gage 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 gage 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 gage and core. If overcoring is successfully completed, stop the drill and continue to take periodic readings, with the water still running, until no appreciable changes in readings 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