Designation: ~~D4623 – 08~~ D4623 – 16

Standard Test Method for
Determination of In Situ Stress in Rock Mass by Overcoring ~~Method—USBM~~ Method—Three Component 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 (principal and secondary) in a rock mass and the equipment required to perform in situ stress tests using a three-component borehole deformation gauge (BDG) that was developed by the U.S. Bureau of Mines (USBM); see Note 1.

1.2 The test procedure and method of data reduction are described, including the theoretical basis and assumptions involved in the calculations.

1.3 ~~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]~~

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

1.4 The values stated in inch-pound units are to be regarded as ~~standard. No other units of measurement are included in this standard.~~ standard, except as noted below. The values given in parentheses are mathematical conversions to SI units, which are provided for information only and are not considered standard. Reporting of test results in units other than SI shall not be regarded as nonconformance with this test method.

1.5 *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

D4971 Test Method for Determining In Situ Modulus of Deformation of Rock Using Diametrically Loaded 76-mm (3-in.) Borehole Jack

D6026 Practice for Using Significant Digits in Geotechnical Data

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

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[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.

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3. Terminology

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

3.1.1 For terminology used in this test method, refer to Terminology D653.

3.2 ~~Definitions:~~*Definitions of Terms Specific to This Standard:*

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

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

3.2.3 *principal plane, n—*any plane in which the shear stresses are zero.

3.2.4 *principal stresses, n—*the normal stresses acting on the three principal planes and which are perpendicular to each other.

3.2.4.1 *Discussion—*

The major, intermediate or minor normal or principal stresses refers to the maximum, intermediate and minor normal stresses occurring in the rock element.

3.2.5 *reverse case, n—*in rock which tends to fracture easily, "disc" or "poker chip" during overcoring, the borehole gauge can be modified by replacing the standard housing with a "reverse case" housing which allows the cantilever plungers to be positioned very close to the start of the EX hole.

3.2.6 *secondary principal stresses, n—*the maximum, intermediate and minimum stresses for stress ellipsoids other than the stress ellipsoid that contains the three maximum principal stresses.

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. Deformation measurements in only one drill hole direction will only give the secondary principal stresses unless something is known about one of the principal stress directions and the drill hole axis is aligned with that principal stress direction.

5. Significance and Use

5.1 Either ~~virgin~~ the in situ 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 with this gauge 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.~~ This test method has a long and proven record and considered very accurate relative to many other techniques, both new and old, out there. Other overcoring methods that use instruments that are different, but follow much of the same basic concepts are now available and can go deeper; however, the pros and cons of each method need to be carefully compared to this test method.

5.3 It is also useful for obtaining stress characteristics of existing concrete and rock structures, such as mass concrete dams, for safety (such as alkali aggregate issues), vetting of computer models, and modification investigations.

5.4 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.

5.5 The rock tested is assumed to be homogeneous and linearly elastic. The moduli of deformation and Poisson's ratio of the rock overcore 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~~ and isotropic rock. Modulus of deformation results may be used from other in situ tests, such as Test ~~Method~~Methods D4394 and Test Method D4395~~.~~, D4971 or other test methods that can determine the modulus of deformation in specific directions.

5.6 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.
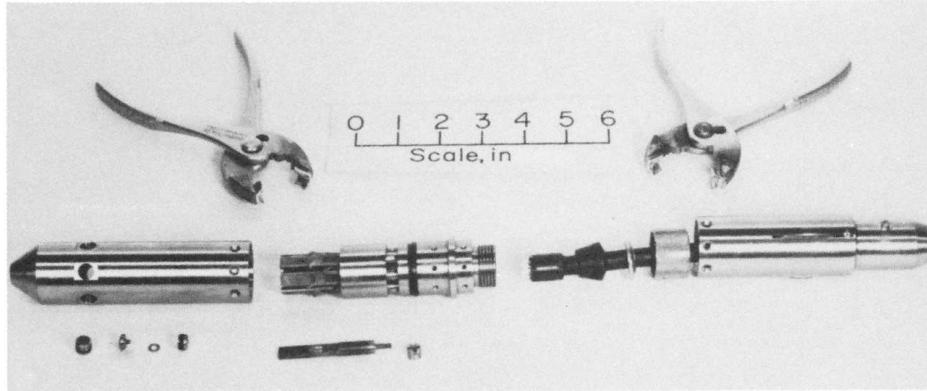
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FIG. 1 **Special Pliers, the Bureau of Mines' Three-Component Borehole Gauge, a Piston, Disassembled Piston and Washer,** ~~Three-Component Borehole Deformation Gauge Showing Outer Housing Pulled Apart with Cable Assembly on Top Right; Three-Component Pistom Assembly in Center and Outer Protective Cover on Left.~~ **Special Pliers for Working on Gauge at the Top, a Piston, Disassembled Piston and Washer (lower left),** **and a Transducer with Nut (lower right)**

5.7 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.~~ formation or rock mass.

5.8 Since most overcoring is performed to measure ~~undisturbed~~ in situ stress levels, the boreholes should be drilled from a portion of the test opening and the testing performed 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.

5.9 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 readout indicators ~~normally~~ are normally used to read the deformations. (Alternatively, one indicator with a switch and balance unit may be used (see Fig. 2) 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~~ 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.

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[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.
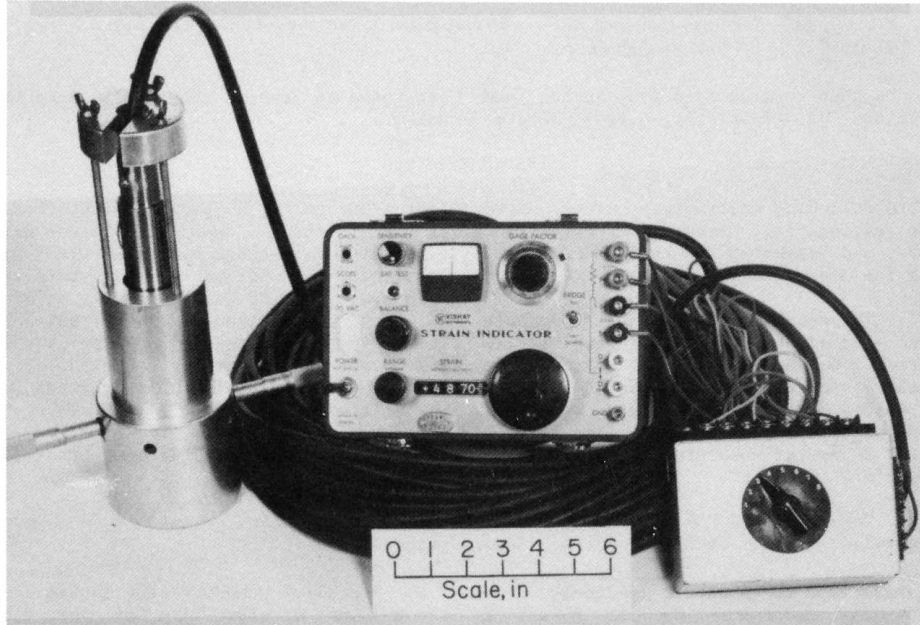
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FIG. 2 The Calibration ~~Device (Left Side)~~ Jig (Left Side), with the BDG Inserted, Strain Readout Unit in Middle and a Switching <u>and Balancing</u> Unit (Right Side)

~~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.~~

6.1.4 *Calibration Jig*—A ~~calibration~~ jig (Fig. 2) ~~is~~ used to calibrate the BDG before and after ~~testing.~~ testing with the use of two micrometer heads.

6.1.5 *Biaxial* ~~Chamber—~~*Modulus Chamber Apparatus—*A ~~biaxial chamber with~~ steel chamber incorporating an internal neoprene membrane which is sized to hold the rock overcore internally and which in conjunction with a hand hydraulic pump and pressure gauge ~~is used to determine~~ and permits a known and sufficient biaxial pressure to be applied hydraulically to the overcore sample while the BDG is inserted and deformation readings are taken. Ideally the maximum pressure should be similar to the best estimates of the in situ rock stress, but usually should not exceed 3000 psi (20MPa). The biaxial chamber is used to obtain data that is then used for determining the deformation modulus of the retrieved rock core. A schematic of the <u>entire</u> apparatus is shown in Fig. 4~~3~~.

6.2 *Orientation, Placement, and Retrieval Tools—*

6.2.1 Placement and retrieval tool or "J slot tool" as shown in Fig. 4.

6.2.2 Placement or retrieval rod extensions as shown in Fig. 4.

6.2.3 Orientation tool or "T" handle, also shown in Fig. 4.

6.2.4 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.

6.2.5 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.

6.3 *Drilling Equipment—*A detailed description of the drilling apparatus <u>required</u> is included in Annex A1.

6.4 *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~~Allen wrenches, a hammer, electrical tape, a yardstick, carpenter's rule, chalk, <u>indelible markers,</u> stopwatch, and a thermometer.
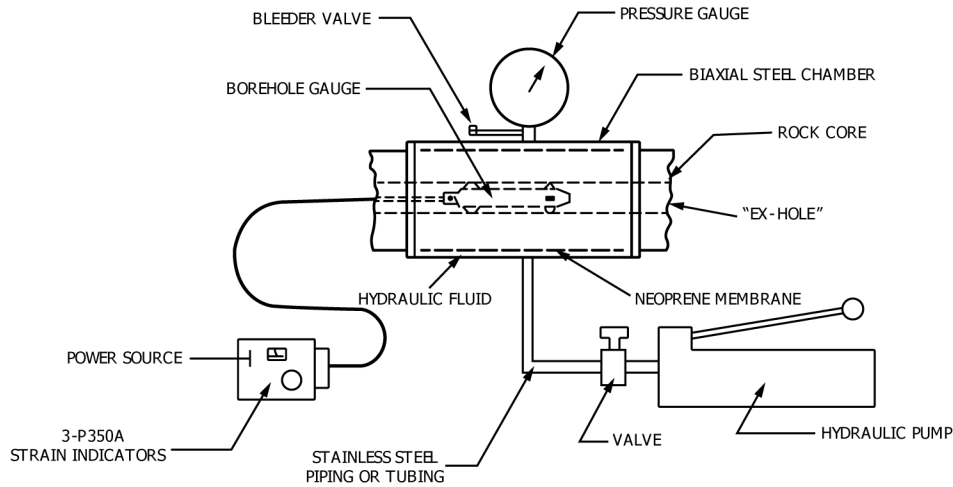
FIG. 4̶3̶ S̶c̶h̶e̶m̶a̶t̶i̶c̶:̶ B̶i̶a̶x̶i̶a̶l̶ T̶e̶s̶t̶ A̶p̶p̶a̶r̶a̶t̶u̶s̶Schematic of Biaxial Modulus Chamber Test Apparatus for Overcore Rock Section
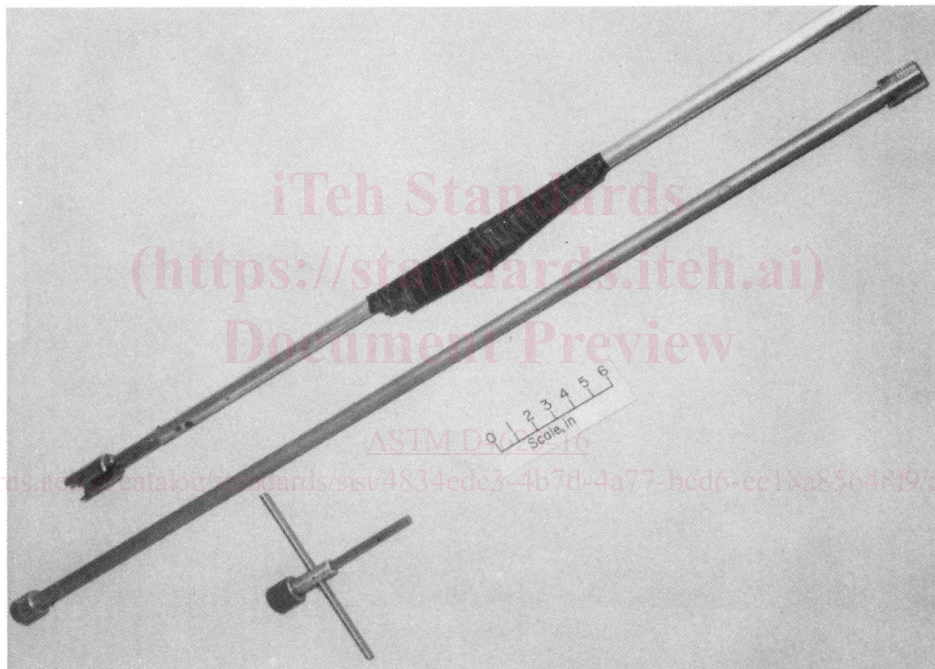

FIG. 3̶4̶ Placement and Retrieval T̶o̶o̶l̶Tools. From top to bottom, "J" slot tool, Extension rod, and "T" handle.

7. Calibration and Standardization

7.1 *Gauge C̶a̶l̶i̶b̶a̶t̶i̶o̶n̶—Calibration—*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 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).

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Sensitivity knob: turn full clockwise.
Balance knob: put in midrange (5 turns of the 10-turn potentiometer).
Bridge switch: to full.
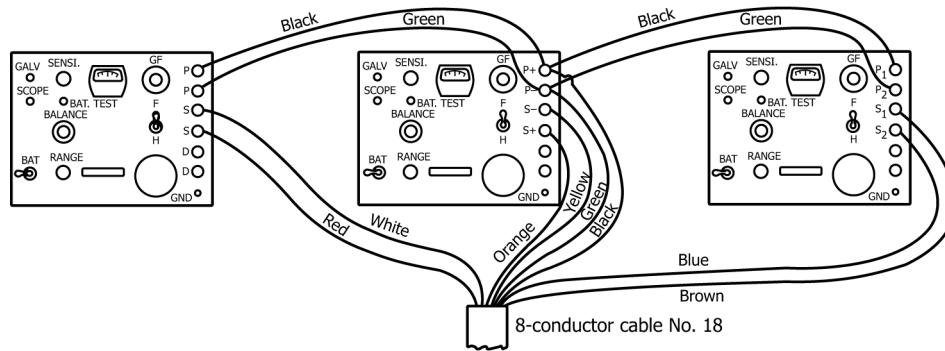
NOTE. – – Hook black and green wires to indicator 2 and use 2 other wires (No. 18 or No. 20) to common P+ and P– (or P_1 and P_2) of all 3 indicators.

FIG. 5 Wire Hookup to ~~Model P-350~~ the Strain Readout 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.

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 :~~ Measurements:*