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Instruction Manual

Model 5000

Borehole Deformation Gage

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1. INTRODUCTION

The Model 5000 BDG is designed to measure in-situ stresses in a rock mass. A process of ‘overcoring’ is used in which the BDG is installed inside an EX diamond drill hole which is then ‘overcored’ using a 150mm (6 inch) diameter thin-walled diamond-drill core barrel. This overcoring process produces a core of rock material in which the in-situ stresses have been relieved allowing the rock core to expand. This expansion is measured by the BDG in three directions spaced 60 degrees apart, and the test results are then analyzed to yield the magnitude and direction of the major and minor principal strains in the plane perpendicular to the borehole at that location in the rock mass. Concurrent tests on the overcored rock cores are made to measure the Young’s Modulus of the rock cores and this allows the principle strains to be converted to principle stresses. Further measurements from overcoring tests in boreholes drilled in other directions in the rock mass are then combined to yield the magnitude and direction of the three principle stresses operating in the rock mass.

Tests in underground pillars need only one borehole. Tests from the ground surface in a single borehole commonly assume the vertical stress to be equal to the superincumbent load.

2. LIMITATIONS

The difficulty of the work involved in these tests and the length of time and the amount and cost of apparatus required to get good results are quite large.

In order for this method to be successful it is necessary that the rock should not split or fracture during the overcoring process. Thus a core of a minimum length of around 350mm (14 inches) should be obtainable. In cases where the core ‘discs’, owing to very high in-situ stresses, a special Reverse Case (Geokon Model 5000-2) can be attached to the BDG to position the BDG plungers closer to the mouth of the EX borehole. The Reverse Case is described more fully in Appendix 1

In underground situations three boreholes are required in three, preferably orthogonal, directions. Ideally, five good sets of data are required from each borehole.

Overcoring depths are usually within 10 meters. Borehole depths of up to 30 meters have been attempted but the amount of work and the difficulty increases rapidly beyond 10 meters.

To obtain in-situ stresses that are uninfluenced by the presence of the opening from which the tests are conducted, tests should not begin until the depth of the borehole is at least one opening diameter.

3. DRILLING REQUIREMENTS

3.1 **A diamond Drill machine** powerful enough to turn a 150mm diameter core barrel. The drill must be capable of running smoothly at a rate of about 120rpm while overcoring at a rate of 15 to 25mm per minute.

3.2 **Drill rods and drill bits**. The EX diamond drill hole into which the BDG is placed has a diameter of 38mm when used with a reamer in addition to the bit, (in order to keep a constant hole diameter). EW drill rods are used along with a double tube core barrel 1 or 2 meters in length. The 150mm overcoring bit may be turned on BQ wireline drill rods (55.6mm O.D., 46mm I.D.), or an equivalent with couplings large enough to freely pass the signal cable coming from the BDG. **Special centralizers** are required every 3 meters along the drill string to support both the EW rods and the BQ wireline rods inside the 150mm diameter borehole. It is advisable to have extra drill bits on hand, especially in hard rock, so that the job can be completed without interruption.

3.3 The diameter of the overcoring bit must be chosen carefully so that the core it leaves behind fits snuggly inside the biaxial modulus chamber. A core diameter of 150mm to 143 mm is ideal. Slightly smaller diameters can be accommodated by building up the core diameter using several layers of duct tape.

3.4 **Adapter subs** for connecting the various size drill rods will be required.

3.5 For purposes of starting the EX borehole exactly in the center of the 150mm diameter borehole a very **short EX core barrel** is required or a stabilizer/centralizer on a long core barrel.

3.6 **A modified water swivel** is required (Geokon Model 5030-4) with a cable gland on the rear end to allow the signal cable to pass through the back end of the drill string.

Figure 1 Modified Water Swivel

3.7 Equipment is required for retrieving cores from the borehole, such as a **core-breaking wedge, a core shovel and a core puller** (All included in Geokon Model 5030-2). See Figures 4,5 and 6.

4. BOREHOLE DEFORMATION GAGE, CABLE AND READOUT BOX.

Figure 2 Model 5000 Borehole Deformation Gage

4.1 The Model 5000 BDG has three pairs of strain–gaged, beryllium copper cantilevers oriented at 60 degree intervals. The inner ends of three pairs of tungsten carbide tipped plungers contact the tips of these cantilevers, and the outer ends of the plungers contact the walls of the borehole. As the borehole expands during overcoring the plungers move outwards thus changing the deflection of the cantilevers and the output of the strain gages.

The strain gages on each opposite pair of cantilevers are connected in a full Wheatstone Bridge and are connected via an eight-conductor cable to a strain indicator readout box. See Figure 3. The BDG Wiring Diagram is shown in Appendix 3.The entire gage is fully waterproof.

At the back end of the BDG is a placement and orientation pin designed to engage a slot in the installation rods and enable the gage to be set at a known orientation inside the borehole.

4.2 The cable (Geokon Model 5000-1) has eight color-coded conductors encased in a neoprene outer jacket. The outer end of the cable has bare wires only, because, during overcoring, it has to be passed through the gland in the water swivel before being connected to the terminal panel attached to the readout box. The terminal panel has eight color coded terminals to which the cable conductors are connected color for color and a three position switch to facilitate rapid switching from one pair of cantilevers to the next – necessary during the overcoring procedure.

4.3 The GK 502 Readout Box – and color coded terminal/switch box are shown in figure 3

Figure 3 Model GK502 Readout Box

The readout box is connected to the terminal panel by means of a short cable and 10-pin plug that mates with the 10 pin plug on the readout box. The readout box displays digits in mV/V which can be converted to microinches/digit using the calibration constants provided with the BDG calibration sheet an example of which is shown in Figure 11.

An alternative readout box is the Vishay Micro-Measurements Model P3 Strain Indicator.

5. PLACEMENT AND ORIENTATION RODS.

Placement and Orientation rods, (Geokon Model 5030), are made from aluminum tubing and are 2 meters (6ft) long with quick connects on either end except for the first rod, which carries a bayonet shaped rod designed to engage the placement and orientation pin on the back end of the BDG. When the pin is fully engaged in the slot, Axis 1 of the BDG is aligned with the quick-connect buttons on the orientation rods. The rods are stored within the carrying case supplied.

6. ANCILLIARY EQUIPMENT.

The **Calibration Rig,** described more fully in Appendix 2, is used for periodic re-calibration of the BDG and the **Biaxial Modulus Chamber**, described more fully in sections 7 and 11.2, is for measuring the Young's Modulus of the rock cores created during the overcoring process.

7. THE OVERCORING PROCEDURE.

7.1 Site Selection

For full 3 dimensional in-situ stress ellipsoid determination two hole can be drilled in the wall of the underground opening at an angle of 45 degree to each other in holes inclined 2 degrees upwards to allow the drilling water to drain from the hole. The third hole can be drilled upwards or downwards. In general downward holes are preferred even though the hole fills with water and debris. Upward holes present a difficulty of holding the drill rods in place while extending the depth and there is a danger when recovering cores that they will fall down the borehole. With downward directed holes care must be taken to ensure that the water pressure will not be large enough to depress the plungers on the BDG.

7.2 Overcoring

Unless the rock stress close to the underground opening is to be studied actual overcoring should not begin less than one opening diameter away from the opening. At this distance the effect of the opening on the in-situ stress is minimal.

a) Start the hole using the large over core bit and drill to the depth at which overcoring is to begin, removing cores, as necessary, from the core barrel. Use the core breaker wedge pushed into borehole on the end of E-rods until the point of the wedge sits in the slot left by the drill bit, now hammer on the end of the E-rods until the core breaks from the back of the hole.

Figure 4 Core Breaker Wedge

b) Remove the cores by sliding the end of the core shovel beneath the core and then once the core sits on the shovel pull the core from the hole.

Figure 5 Core Shovel

(in downward holes this is not so easy and either use a core catcher on the core barrel or use the core puller supplied to engage an EX hole drilled in the core before the core is formed.

Figure 6 Core Catcher

c) Using the **short EX core barrel** start the EX hole in the back of the overcore hole and then extend it for approximately 2 meters using a double-tube core barrel. It is important that the EX hole remain in the center of the overcore hole so don't overextend the EX hole beyond the bottom of the overcore hole. Examine the EX rock core for zones of fracture plains and avoid these zones when overcoring.

[A **borehole scribe** is available (Geokon Model 5030-3) which when connected to the placement rods can be used to scratch a line on the inside of the EX borehole. This line will be in line with axis 1 of the borehole gage. This procedure is not always used but it is useful in orienting the BDG when placing it inside the Biaxial Modulus chamber to duplicate its position during the overcoring. If the orienting can be done by eye with sufficient accuracy, using striation marks or bedding planes as a guide, then the borehole scribe is not necessary].

d) Insert the 150mm core barrel and BQ wireline drill rods into the borehole but do not connect to the drill. Thread the BDG readout cable through the drill chuck and quill and out through the water swivel.

e) Connect the BDG readout cable to the readout box and take initial readings with the BDG outside the borehole.

f) Using the placement rods insert the BDG into the EX borehole and orient the gage by keeping the buttons of the setting rods vertical – this will place Axis #1 of the BDG in a vertical orientation. Now take a reading on all three axes and compare with the initial readings previously taken. The reading difference should be about 75% to 90% of the range of the cantilevers, equivalent to a reading change of 10,000 to 12,000 digits on the GK502 readout box. (The higher the reading change the more firmly is the BDG gripped inside the EX borehole and the less likely it is to be dislodged by drilling vibrations and pulsations). If the reading difference is too small or too large then the plungers need to be adjusted by either adding or removing shims. This is done using one of the special pliers provided to pull the plungers from the BDG. A second set of pliers is used to grip the other end of the plunger and twist so as to unthread one half of the plunger from the other. This will then allow brass shims to be added or removed. The brass shims provided are 0.005, 0.015 or 0.025 inches thick. There is a stop inside the BDG that prevents the cantilevers from being over-deflected.

g) When the correct reading change has been obtained the cantilever tips should be placed at least 150mm and preferably 225mm past the end of the 150mm diameter overcore borehole. This will ensure that the presence of the overcore hole does not significantly affect the in-situ stress field at the point of the measurement.

h) Take up excess slack in the BDG cable and connect the drill stem to the drill. Turn on the drilling water and allow 10 minutes or so to elapse to allow the BDG to come to thermal equilibrium as evidenced by unchanging readout digits. Tie the cable to some support in line with the back of the drill stem so that it issues straight out of the water swivel. This will allow the water swivel to slide over the cable smoothly as the overcoring proceeds and will prevent the cable from becoming bunched up inside the drill stem.

i) Start the overcoring with chuck speeds of around 120 rpm and a penetration rate of around 20mm per minute. Record the BDG readings on all three axes at every 10 or 20mm of penetration.

j) Overcoring should proceed until the overcoring has passed over the cantilever plungers and beyond for a distance of at least 150mm and preferably 225mm. The total length of the overcore should thus be between 300mm to 450mm. In the ideal situation as the overcore proceeds the readings should increase slightly then drop quickly to reach a lower constant value. If the readings fluctuate wildly during the overcore this is evidence that the core is breaking up and overcoring should then cease immediately or the BDG may be damaged.

Some typical field data sheets are shown in figures 9 and 10.

k) On completion of the overcore, disconnect the drill from the drill rods, use the placement rods to engage the orientation pin on the back of the BDG and pull the BDG from the borehole. Do not pull on the cable. [An alternative, better, method is to leave the BDG in place and use the core breaker and core shovel to remove the overcore with the BDG still inside. Then the core can be placed directly into the Biaxial Chamber and test performed on the overcore to find the Young's Modulus].

l) If Modulus tests are not immediately performed, the core should be identified, oriented and stored in a safe place for modulus tests to be performed later. Tests should be performed as soon as possible – especially with rocks that deteriorate when exposed. If this is a possibility, wrap the core in aluminum foil or plastic wrap to prevent it from drying.

m) Replace the BDG and continue overcoring until at least three to five good sets of reading have been obtained from each borehole. Extend the EX borehole for an additional 2 meters, as necessary, each time the previous EX borehole has been completely overcored. Do not place the cantilever tips closer than 250mm from the bottom of the EX borehole.

8. MEASURING THE ROCK MODULUS.

Figure 7 Biaxial Modulus Chamber with Pressure Gage and Hand Pump

Place the rock core inside the Biaxial Modulus Chamber Apparatus, (Geokon Model 5075-1), so that the BDG plungers are in the middle of the chamber. Orient the BDG so that it occupies the same position within the core as during the overcoring. (But see Section 7.2k for the best method) Use the hand pump to apply a radial pressure to the rock core as measured by the pressure gage. Maximum pressure levels should be similar to the best estimates of the in-situ rock stress, (but not to exceed 3000psi, (20MPa)). Record BDG readings, on all three axes, at each load increment. Use at least 5 increments on both loading and unloading cycles. Use the unloading cycle to calculate the Young's Modulus. The test results can be tabulated in a manner depicted in Figure 8

Biaxial Chamber membranes are somewhat delicate so it s advisable to have two or three spare membranes on hand. Geokon Model No 5075-1-3.

BI-AXIAL TEST DATA SHEET

Gauge: ____________________ File: ____________________

Readout: ____________________ By: ____________________ Date: ____________

Chamber: ____________________ Boring: ____________________

Core diameter: ____________ Depth: ____________________

Core length: ____________

Applied Pressure	Axis no.1	ΔR_1	Axis no.2	ΔR_2	Axis no.3	ΔR_3	

Figure 8 Biaxial Test Data Sheet

9. DATA MANIPULTATION

During the overcoring the readings, **R**, from all three channels can be tabulated on an Overcore Field Data Sheet such as that shown in Figure 9. Values of **ΔR** are calculated on another sheet as shown in figure10**.**

A typical calibration sheet for the BDG is shown in Figure 11. On the calibration sheet are shown the three calibration factors, K,

The values of U_1 , U_2 and U_3 the changes of diameter in micro inches are obtained by multiplying the values of K by the values of **ΔR** for each axis. The values of U_1 , U_2 and U_3

can then be entered on the Calculation Sheet shown in Figure 12.

OVERCORE FIELD DATA SHEET

CLIENT'S NAME ____________________

JOB NUMBER ____________ DATE STARTED ________ DATE COMPLETED ________

SITE ____________________ HOLE ________

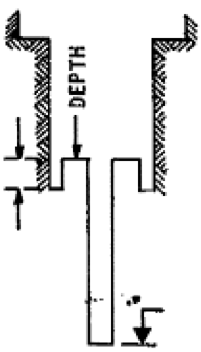
AZIMUTH DIRECTION OF HOLE ____________ COLLAR ELEVATION ____________

TEST No. ________ GAUGE IDEN. ____________ READOUT IDEN. ____________

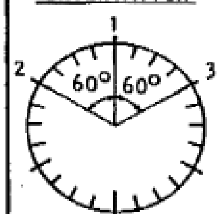
FIELD ENGINEER/GEOLOGIST ____________________

DISTANCE FROM START OF OVERCORE TO CANTILEVER TIPS ____________

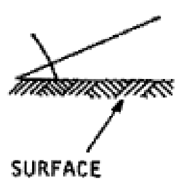
SKETCH OF BOREHOLE WITH DEPTHS (PRE-OVERCORE)



ORIENTATION



INCLINATION



DIST. OF OVER CORE	READING UNITS			TIME	REMARK
	1	2	3		

DRILLING CO. ____________________

RIG TYPE ________ RECORDER(S)NAME(S) ____________

PAGE___ OF___

Figure 9 Overcore Field Data Sheet

SITE ____________ FILE ____________

HOLE ____________ SHEET ______ OF ______

DEPTH ____________ U_1 ORIENTATION ____________

TEST NO ____________

DEPTH OF OVERCORE (X SHEET NO.)

	R_1	R_2	R_3	ΔR_1	ΔR_2	ΔR_3
·0"						
0.5"						
1.0"						
1.5"						
2.0"						
2.5"						
3.0"						
3.5"						
4.0"						
4.5"						
5.0"						
5.5"						
6.0"						
6.5"						
7.0"						
7.5"						
8.0"						
8.5"						
9.0"						
9.5"						
10.0"						

ΔR = '0' READING MINUS READING AT DEPTH

BY ________ DATE ________ CHECKED BY ________ DATE ________

OVERCORE DEFORMATION – CALCULATION

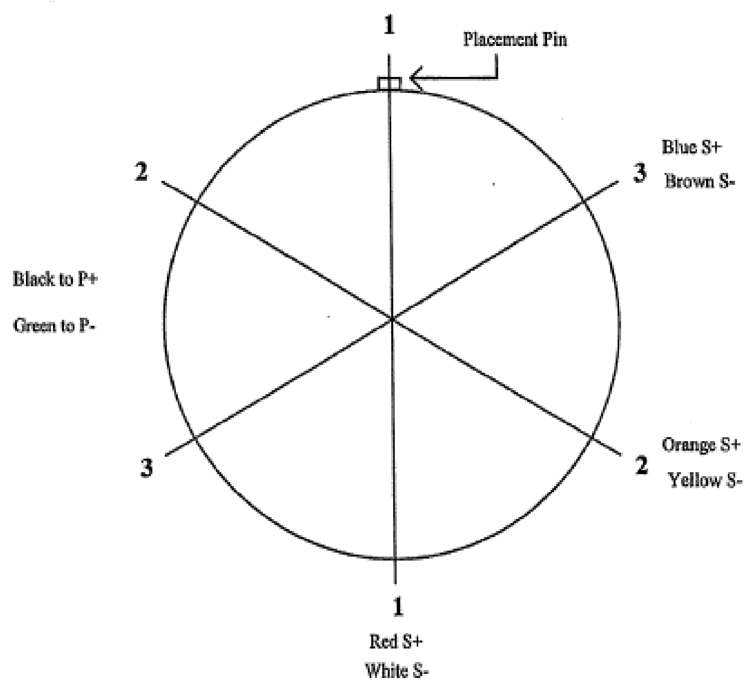
Figure 10 Overcore Deformation - Calculation

Borehole Gage Calibration

Customer: ________ Job Number: 20030854 Date: 06/28/2012

Serial Number: 1216841

Orientation: Looking into the hole



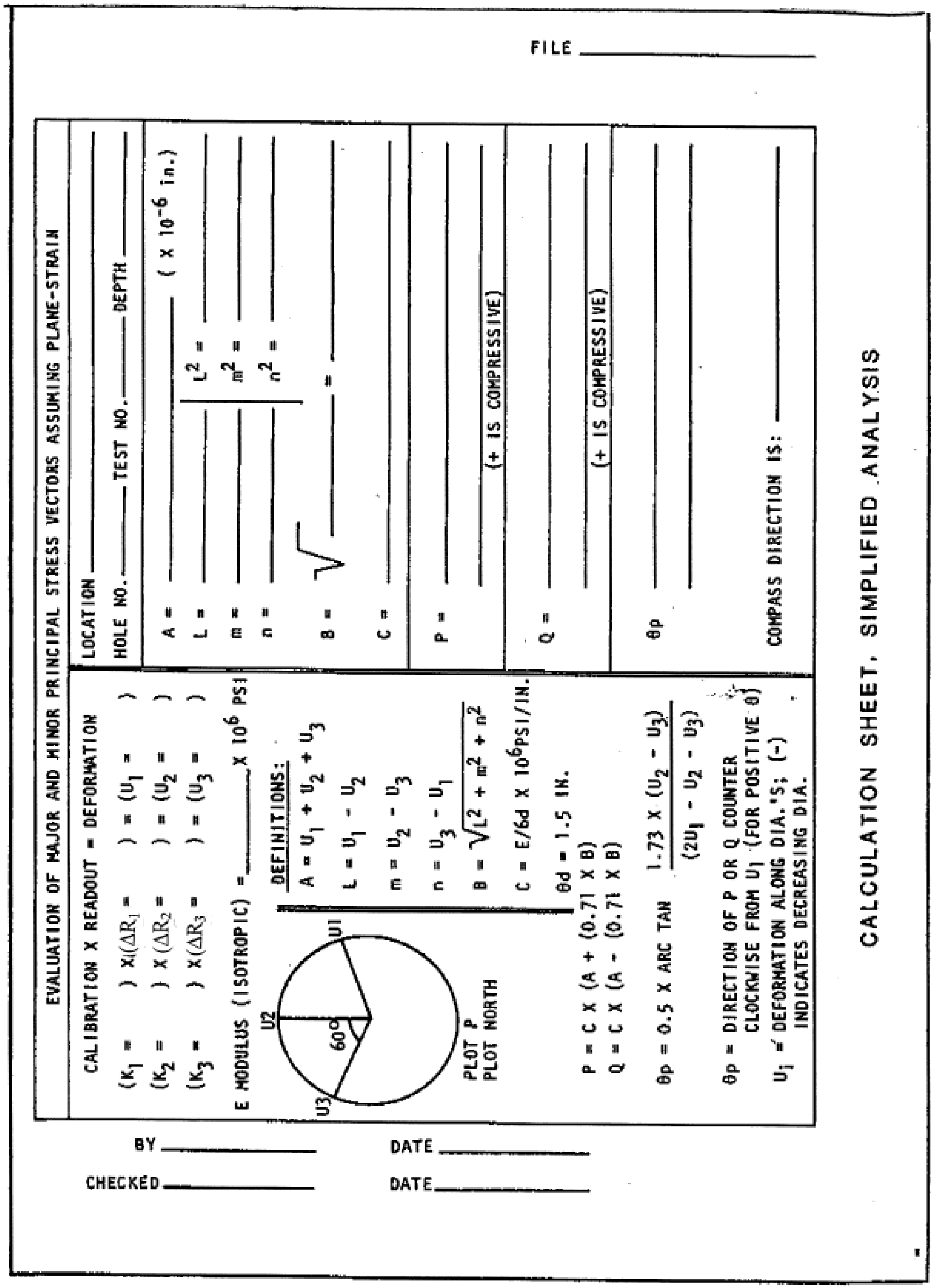
Colors refer to Belden #8418 cable (Geokon standard wiring)

Calibration Factors K

Axis	Change in diameter per unit readout change (micro-inch/digit)
1.	**2.32**
2	**2.39**
3	**2.35**

Note: The readout value decreases as the hole diameter increases

Figure 11 Typical Calibration Sheet



FILE ______

EVALUATION OF MAJOR AND MINOR PRINCIPAL STRESS VECTORS ASSUMING PLANE-STRAIN

CALIBRATION X READOUT = DEFORMATION

(K_1 =) X(ΔR_1 =) = (U_1 =)

(K_2 =) X (ΔR_2 =) = (U_2 =)

(K_3 =) X(ΔR_3 =) = (U_3 =)

E MODULUS (ISOTROPIC) = ______ X 10^6 PSI

DEFINITIONS:

$A = U_1 + U_2 + U_3$

$L = U_1 - U_2$

$m = U_2 - U_3$

$n = U_3 - U_1$

$B = \sqrt{L^2 + m^2 + n^2}$

C = E/6d X 10^6 PSI/IN.

θd = 1.5 IN.

P = C X (A + (0.71 X B)

Q = C X (A - (0.71 X B)

$\theta p = 0.5 \text{ X ARC TAN } \dfrac{1.73 \text{ X } (U_2 - U_3)}{(2U_1 - U_2 - U_3)}$

θp = DIRECTION OF P OR Q COUNTER CLOCKWISE FROM U_1 (FOR POSITIVE θ)

U_i = DEFORMATION ALONG DIA.'S; (-) INDICATES DECREASING DIA.

LOCATION ______

HOLE NO. ______ TEST NO. ______ DEPTH ______

A = ______ (X 10^{-6} in.)

L = ______ L^2 = ______

m = ______ m^2 = ______

n = ______ n^2 = ______

B = $\sqrt{}$ ______ = ______

C = ______

P = ______

______ (+ IS COMPRESSIVE)

Q = ______

______ (+ IS COMPRESSIVE)

θp ______

______

COMPASS DIRECTION IS: ______

CALCULATION SHEET, SIMPLIFIED ANALYSIS

BY ______ DATE ______

CHECKED ______ DATE ______

Figure 12 Calculation Sheet

10. CALCULATIONS

Calculations of In-situ stresses involve varying degrees of complexity depending on whether the stress field being examined is 2-dimensional, (mine pillars, or close to mine roofs) or 3-dimensional in character and on the degree of elastic anisotropy.

10.1 Stress Calculations

Theoretically, where the stress along the borehole axis is zero, (i.e., plane stress conditions), such as might occur close to the ground surface or the walls of an opening, the change in diameter of the borehole, ***U***, due to a change in the in-situ rock stress is given by the equation

$$U = \frac{d}{E}[(P + Q) + 2(P - Q)]\cos 2\theta$$

Where

P and ***Q*** are the major and minor principal stresses in the plane perpendicular to the borehole. (Tensile stress changes and increasing borehole diameters are positive.

d, is the diameter of the EX borehole.

$\boldsymbol{\vartheta}$ is the angle between the direction of P, the major principle stress, and the direction of $\boldsymbol{U_1}$

which is the same direction as Axis 1 of the BDG.

In the case of the BDG, which measure changes in borehole diameter in three axes, $\boldsymbol{U_1}$, $\boldsymbol{U_2}$ and $\boldsymbol{U_3}$ spaced 60 degrees apart, in a counterclockwise direction looking into the borehole, the major and minor principal stresses and their orientations are given by the equations:

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

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

$$\theta_p = \tfrac{1}{2}\tan^{-1}\frac{\sqrt{3}(U_2 - U_3)}{2U_1 - U_2 - U_3}$$

Where

ϑ_p = is the angle measured from the direction of ***U_1*** to the direction of ***P*** in a counterclockwise direction, and if:-

$U_2 > U_3$ and $(U_2 + U_3) < 2U_1$,

θ_p is in range 0°–45°

$U_2 > U_3$ and $(U_2 + U_3) > 2U_1$,

θ_p is in range 45°–90°

$U_2 < U_3$ and $(U_2 + U_3) > 2U_1$,

θ_p is in range 90°–135°

$U_2 < U_3$ and $(U_2 + U_3) < 2U_1$,

θ_p is in range 135°–180°.

These equations can be used in the field to provide a rough estimate of stress levels even in the three-dimensional case.

A more rigorous treatment of the three-dimensional case would have to assume conditions of plane strain and include the effects of elastic anisotropy. For isotropic conditions

$$U = \frac{d(1-v^2)}{E}[(P+Q)+2(P-Q)\cos 2\theta] - v\epsilon_z d$$

Where $\boldsymbol{\varepsilon_z}$ is the strain in the axial direction along the borehole. If an estimate of $\boldsymbol{\sigma_z}$ the axial stress, is available (e.g., the assumed superincumbent load in vertical boreholes from the ground surface) then if the Poisson's ratio, $\boldsymbol{v}$**,** is known, $\boldsymbol{\varepsilon_z}$ can be calculated from the equation below and substituted in the equation above.

$$\varepsilon_z = [\sigma_z - v(P + Q)]\,/E$$

For the theory behind a full 3-dimensional treatment see

Panek, Louis, A,. Calculation of the Average Ground Stress Components from Measurements of the Diametral Deformation of a Drill Hole. USBM RI 6732, 1966, 41pp.

10.2 Young's Modulus Calculations

Values of Young's Modulus, ***E***, are calculated from the Biaxial Modulus Chamber tests using the Thick-Walled Cylinder formula:

$$E = \frac{D^2}{D^2 - d^2} \cdot \frac{2dP}{U}$$

Where ***D*** is the diameter of the rock core, ***d,*** is the diameter of the EX borehole and ***, P*** the magnitude of the applied radial pressure.

U is the average value of the three measured changes in the three axes U_1, U_2 and U_3

Where the rock is anisotropic the values of U_1, U_2 and U_3 will be seen to differ. However, the effect of anisotropy on the calculated stresses is quite small and in most cases can be ignored. For instance a ratio of 2.5 :1 between maximum and minimum values of U_1, U_2 and U_3 give rise to an error of only 25% in the calculated stress magnitudes and 25 degrees in orientation if isotropic elastic conditions are assumed.

11. REPORTING THE RESULTS

The report should contain the following:

11.1 A diagram, photograph and detailed description of test equipment and methods used for measuring the deformations during overcoring and for measuring the elastic moduli.

11.2 Copies of the Field data Sheets showing the data from each successful overcoring run and the measured values of U_1, U_2 and U_3 from that run.

11.3 Plots of radial pressure versus borehole deformation from Biaxial Modulus Chamber tests, or, in cases where no rock cores are available due to fractured ground, stress/strain curves from small laboratory strain gaged rock cores if they are available.

11.4 A Table showing hole number, hole bearing, hole inclination, depth of overcore, measured values of U_1, U_2 and U_3 , orientation of U_1, Young's Modulus and Poisson's Ratio.

11.5 Where measurements are being made of in situ stress distributions around underground openings, plots showing secondary principal stress magnitudes and directions versus depth of overcore. An example is shown in figure 13

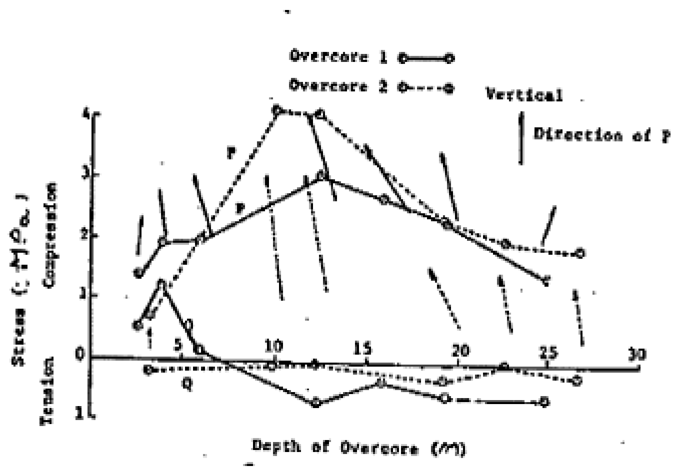


Figure 13 Depiction of Maximum and Minimum Principal Stress Magnitudes and Orientations

Appendix - 1 Use of the Reverse Case in Fractured or Highly Stressed Rock

In cases where the core 'discs' (i.e. breaks up into poker chip size pieces as the overcore procedes), owing to very high in-situ stresses; or in highly fractured rock where a core sufficiently large to place in the Biaxial Chamber cannot be obtained, a special Reverse Case (Geokon Model 5000-2) can be attached to the BDG to position the BDG plungers closer to the mouth of the EX borehole

Figure 14 Reverse Case

The regular tip on the borehole gage is removed and is replaced by the reverse case.

The springs on the front end of the reverse case now serve to steady and centralize the BDG while the overcoring takes place. The phenomenon of 'discing' is explained more fully in the following publications:

Obert, L., and Stephenson, D. L.< Stress Conditions Under Which Core Discing Occurs. Trans.AIME, V.232, 1965. pp227-235. and

Verne E, Hooker, David I, Bickel and James R, Aggson, In Situ Determination of Stresses in Mountainous Topography, U.S.B.M. RI 7654, 1972.

The stresses measured while using the reverse case are distorted and magnified by the close proximity of the large overcoring hole and require correcting in order to infer what the undisturbed in-situ stresses are. The solution to the problem of stress distribution around the end of a borehole has been covered by Hooker at al (Ref 1). Figure 15 shows the correction factor that must be applied to the measure deformations, as a function of the distance of the BDG plungers away from the bottom of the overcore hole for various values of Poisson's Ratio.

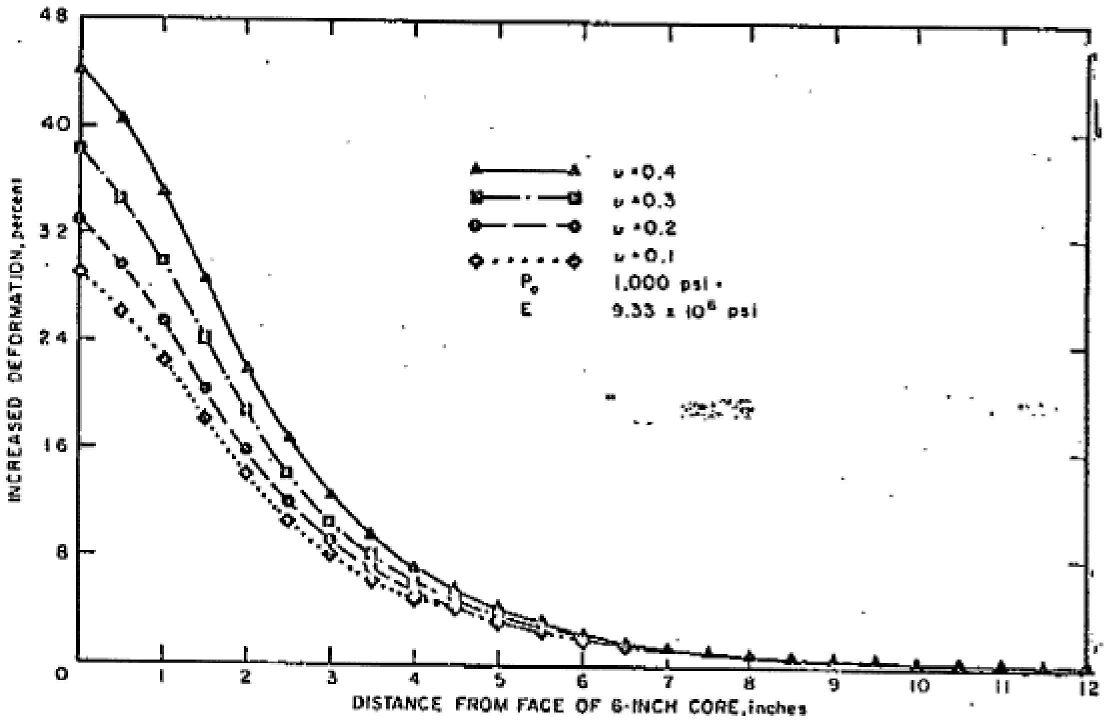


Figure 15 Showing the Corrections needed when using the Reverse Case

As an example, when the Poisson's Ratio is O.3 and the distance of the plungers from the face of the 6 inch core is 2 inches, the required correction to the measured values of U_1, U_2 and U_3 is to multiply them by the correction factor 1/1.9 = 0.53.

Appendix 2 – The Calibration Rig

The Calibration Rig, (Geokon Model 5080), is shown in Figure 16, is designed for periodic re-calibration of the BDG. The BDG is lowered into the rig and oriented so that a plunger appears inside a viewing hole drilled at a 60 degree angle to the direction of the two depth micrometers. This places a pair of plungers directly in line with the depth micrometers.

Figure 16 BDG Calibration Rig

Connect the BDG cable to a GK 502 readout box.(It will be necessary to use the flying leads that come with the readout box). Use the correct pair of color coded wires, (see Figure 18, Appendix 3 for the wiring diagram), corresponding to the axis being calibrated.

The two depth micrometers are adjusted until they just touch the BDG plungers. Read the readout box – this is the zero reading. Now adjust both depth micrometers by an equal amount until the readout box shows a reading of around 4000 to 5000 digits. Make sure that both depth micrometers are adjusted so that the vernier line on the shaft lies exactly on one of the depth micrometer drum divisions. Take the zero reading.

Now, rotate the depth micrometer drums for a change of 0.016 inches on both drums (for a total cantilever pair depression of 0.032 inches). Hold this reading for a couple of minutes, take a reading then release back 0.016 inches on each drum to take another zero reading.

Rotate the drums for 0.016 inches each and take another reading.

Rotate the drums back in 0.004 inch increments, taking readings at each increment.

Repeat this procedure three times.

Repeat the procedure for the other two cantilever pairs

Record the results on a sheet similar to that shown in Figure 17

Calculate the average total reading change ΔR from the three changes measure on each cantilever.

Calculate the gage factors for each cantilever pair = 0.032 *10^6/ ΔR

	Channel 1		Channel 2		Channel 3	
0	-246		-509		1141	
0	5631		4618		4863	
0.032	18994		18292		18276	
0.032	18946		18277		18270	
0.024	15340	3606	14620	3657	14675	3595
0.016	11953	3387	11243	3377	11226	3449
0.008	8685	3268	7968	3275	7846	3380
0	5420	3265	4600	3368	4495	3351
0.032	18865		18345		18248	
0.032	18851		18340		18245	
0.024	15253	3598	14545	3795	14662	3583
0.016	11994	3259	11170	3375	11225	3437
0.008	8664	3330	7890	3280	7834	3391
0	5408	3256	4619	3271	4553	3281
0.032	18867		18085		18203	
0.032	18857		18073		18200	
0.024	15261	3596	14511	3562	14678	3522
0.016	12012	3249	11275	3236	11313	3365
0.008	8684	3328	7858	3417	7846	3467
0	5400	3284	4587	3271	4487	3359
Total change first series	13526		13677		13775	
Total change second series	13443		13721		13692	
Total change third series	13457		13486		13713	
Average total change	13475		13628		13727	
Gage factor micro inches/Digit	2.37		2.35		2.33	

Figure 17 A typical BDG Calibration Data Sheet.

Appendix 3 – BDG Wiring Diagram

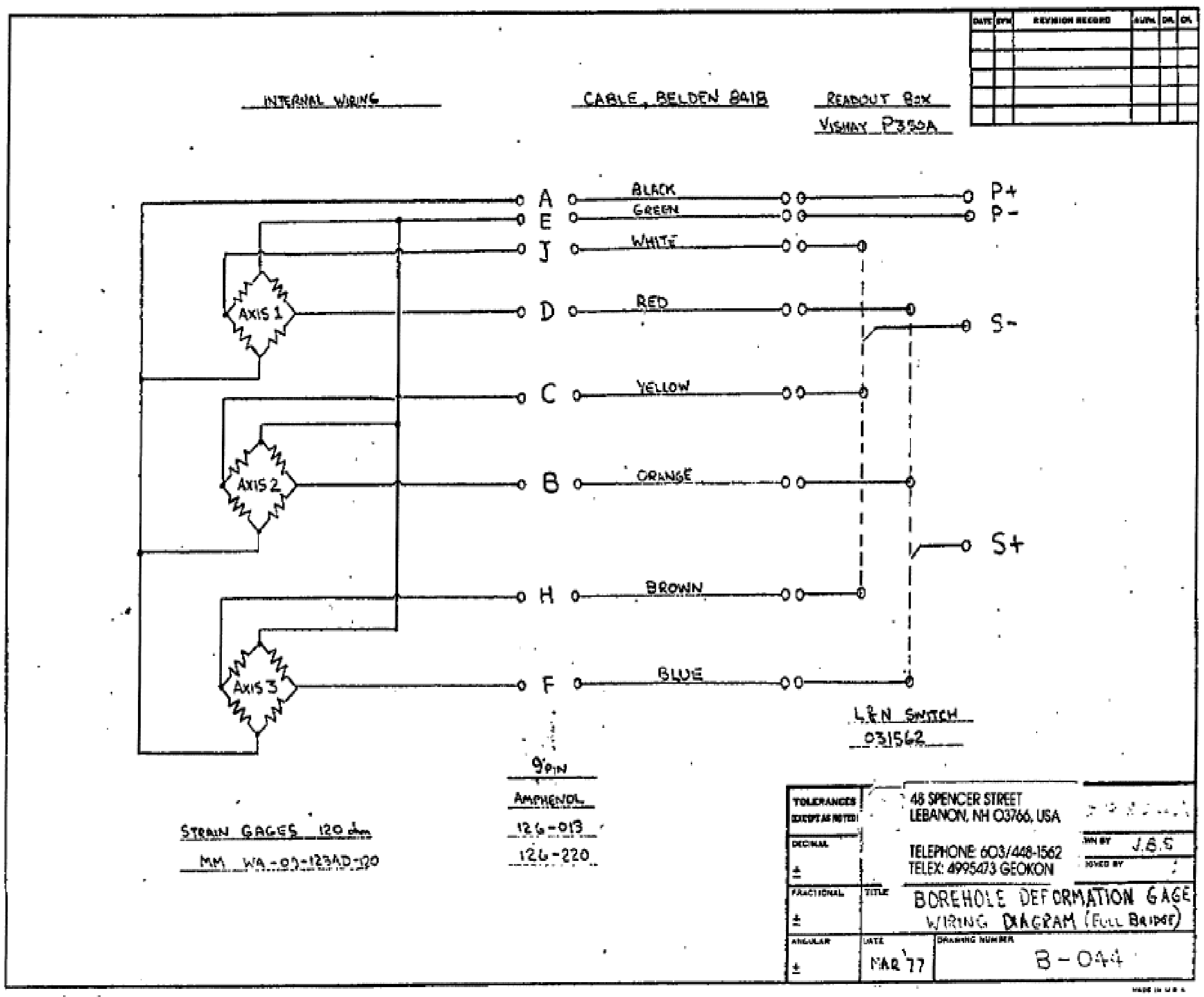


Figure 18 BDG Wiring Diagram

Appendix 4 Bibliography and Acknowledgements

As an aside:

This Manual is based on a paper entitled 'Suggested Method for Determining In Situ Stress Using the U,S.B.M Method' written by the current author, J.B. Sellers, and submitted to the International Society for Rock Mechanics for publication in the year 1974. Publication of the paper was delayed until 1987 when it appeared as 'Method 3' in a paper entitled 'Commission of Testing Methods' and subtitled 'Suggested Methods for Rock Stress Determination'. The ISRM paper appeared under the Joint Co-ordination of K. Kim and J. A. Franklin and was said to have been written by members of a group of 25 individual contributors from 11 different countries. 'Method 3' is the same, practically word for word, as the paper submitted by the current author some 13 years earlier, but, by some happenstance, the attributions failed to acknowledge where the actual text for "Method 3" originated since the name of J. B. Sellers did not appear among the 25 contributors.

A regrettable omission, one might say, and more so, since the 1974 paper included an error that was faithfully reproduced in the 1987 copy. Thus the formula presented in this manual as

$$\varepsilon_z = [\sigma_z - \nu(P + Q)] / E$$

appeared in both the 1974 submittal and 1987 ISRM publication as

$$\epsilon_z = -\sigma_z \frac{1}{E} \nu(P + Q)$$

which is plainly wrong just from a dimensional standpoint and, an error that escaped detection, not only by the perpetrator in 1974, but also by all 25 gentlemen responsible for reviewing the draft 1987 publication - so much for peer review and academic integrity.

Further references giving more details on the topic of the overcoring procedure are here reproduced from the 1987 ISRM publication.

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