INFLUENCES OF CHANGES IN YOUNG'S MODULUS OF AN OVERCORED SAMPLE ON THE CALCULATED FAR-FIELD STRESS

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ABSTRACT
3-D numerical simulations have been performed using FLAC^{3D}, an explicit finite difference computer program, to determine the influence of altered Young's modulus in an overcored sample on far-field stress calculations. Young's modulus is known to change during overcoring in highly stressed rock as a result of stress-relief damage. Modification factors have been proposed to take into account the influence of the reduction in Young's modulus on far-field stress calculations. A method of determining a Young's modulus value suitable for use in far-field stress calculations is described and the influence of the reduction in Young's modulus of an overcored sample on determining the stress ratio (SR) in the RPR method is analyzed. Using the proposed modification, the deep *in situ* stresses at the Atomic Energy of Canada Limited's Underground Research Laboratory are re-calculated based on twenty-one deep doorstopper measurements.

RÉSUMÉ
Des simulations numériques tridimensionnelles ont été réalisés à l'aide de FLAC^{3D}, un logiciel explicite de calculs en différences finies. Ces simulations visaient à déterminer les effets que la modification du module de Young d'un échantillon surcarotté pourrait avoir sur les calculs des contraintes en champ. Le module de Young tend à changer s'il subit un surcarottage dans une roche soumise à de fortes contraintes, à la suite d'un dommage dû à la détente des contraintes. On propose de modifier les facteurs pour tenir compte des effets que la réduction du module de Young a sur les calculs des contraintes en champ. On décrit une méthode visant à déterminer une valeur du module de Young qui serait adaptée aux calculs des contraintes en champ, ainsi que les effets que la réduction du module de Young d'un échantillon sur-carotté aurait sur la détermination du rapport de contrainte dans la méthode RPR analysée. À l'aide de la modification proposée, les contraintes profondes *in situ* du Laboratoire de recherches souterrain d'Énergie atomique du Canada limitée sont recalculées en fonction de vingt et unes mesures «doorstopper».

1. INTRODUCTION

The design and construction of underground cavities are influenced by geological conditions and technical requirements. One important geological parameter is the *in situ* stress state. Many techniques have been used in the determination of *in situ* stress over the past 35 years. Techniques based on the recovery principle are the most commonly used. One technique is overcoring using CSIR doorstopper cells (Leeman 1969). Considerable effort has been expended in making *in situ* stress determinations and refining the interpretation of the measured results (Leeman 1971, Rahn 1984, Chandler and Martin 1994, Corthésy et al. 1994, Martino and Thompson 1997, Tonon et al. 2001, Guo and Thompson 2004a and 2004b).

Canada is considering the plutonic rock of the Canadian Shield as a potential host medium for a nuclear fuel waste repository located at a depth of between 500 and 1000 m below the earth's surface. Design of the repository requires that the *in situ* stress conditions affecting the underground excavation be well understood and defined to a high level of certainty. Part of AECL's efforts in understanding the *in situ* stress conditions at depth has involved the development and application of the Deep Doorstopper Gauge System (DDGS) (Martino and Thompson 1994).

The DDGS, SwedPower's Triaxial Strain Cell (Hallbjörn et al. 1990) and hydraulic fracturing (Haimson 1978) were used to determine the *in situ* stress in deep boreholes at the Äspö Hard Rock Laboratory and to evaluate the effectiveness of each measurement method. Their findings showed that the stress inferred from DDGS were high compared to the results from the other two methods. The apparent anisotropy caused by micro-cracking in the DDGS overcored sample was thought to have influenced the results (Christiansson and Janson 2002).

Sample disturbance caused by overcoring can permanently change Young's modulus and Poisson's ratio in the DDGS overcored sample in high stress conditions. The values determined in the biaxial pressure test may not be representative of the *in situ* Young's modulus (E0) and the *in situ* Poisson's ratio (v0) of the rock. This raises the issue of what parameters should be used in calculating *in situ* stresses. The average of the measured Young's modulus (E) from the biaxial pressure test and the *in situ* Young's modulus determined by an estimation from multiple methods (e.g. back-analysis of tunnel displacements) and the *in situ* Poisson's ratio was suggested to be used in *in situ* stress calculations by Thompson and Martino (2001). The calculation of the local stresses at the borehole bottom is flawed because of the change in Young's modulus and Poisson's ratio during overcoring.

2. NUMERICAL MODELLING FOR DEEP DOORSTOPPER STRESS DETERMINATIONS

For the purpose of this paper, the following terms are defined. The *in situ* stresses represent the ambient triaxial principal stresses (S_1, S_2, S_3) and their orientations in the undisturbed rock mass. The far-field stresses are the stress components in the coordinate system (S_x, S_y, S_z, S_{xy}, S_{yz}, S_{zx}). The borehole bottom stresses are defined as σ_x, σ_y, σ_z, τ_{xy}, τ_{yz}, and τ_{zx} ($\sigma_z = \tau_{xz} = \tau_{yz} = 0$). In analyzing the stress state from a single borehole, the *in situ* stresses cannot be determined but the far-field stresses (S_x, S_y, S_z, S_{xy}) can be determined. This paper focuses on the far-field stress state.

Numerical analyses have been performed using FLAC^{3D}, an explicit finite difference computer program (Itasca Consulting Group 1994) to investigate the influence of overcoring-induced reduction in Young's modulus on the far-field stress calculation.

The 3-D model geometry used is a quarter section duplicating the actual geometry and dimensions of a DDGS overcore test and is shown in Figure 1. The axial dimension is 1040 mm. The plan view section is 528 mm by 528 mm. The borehole radius is 48 mm. The core-sample radius is 30.55 mm. The overcoring length is 140 mm.

The rock is assumed to be homogeneous, isotropic and linearly elastic. Two parameters, Young's modulus and Poisson's ratio, are used in this model. The value selected for the *in situ* Young's modulus is 1.0x10^4 MPa and for the *in situ* Poisson's ratio is 0.2.

In the numerical model, the sample was overcored layer by layer, for a total of seventeen layers. Change in Young's modulus is applied layer-by-layer during the overcoring simulation.

Three mechanical boundary conditions are as follows:

- The nodes with the coordinate of x=0 are fixed in the X-direction.
- The nodes with the coordinate of y=0 are fixed in the Y-direction.
- The nodes with the coordinate of z=1040 are fixed in the Z-direction.

For a general far-field stress state, there are six independent stress components, S_x, S_y, S_z, S_{xy}, S_{yz}, and S_{zx}. If the axis of the borehole coincides with the Z-directional axis, the components of S_{zx} and S_{yz} have no influence on the stresses at a borehole bottom (Gray and Toews 1968). Therefore, only four stress components, S_x, S_y, S_z and S_{xy}, affect the stresses at a borehole bottom. These four stress components can be determined using a combination of the results from a model with the boundary stresses of $S_x = S_0$ = 1 MPa, $S_y = S_z = S_{xy}$ =0 MPa and a model with the boundary stresses of $S_z = S_0$ = 1 MPa, $S_y = S_x = S_{xy}$ =0 MPa.

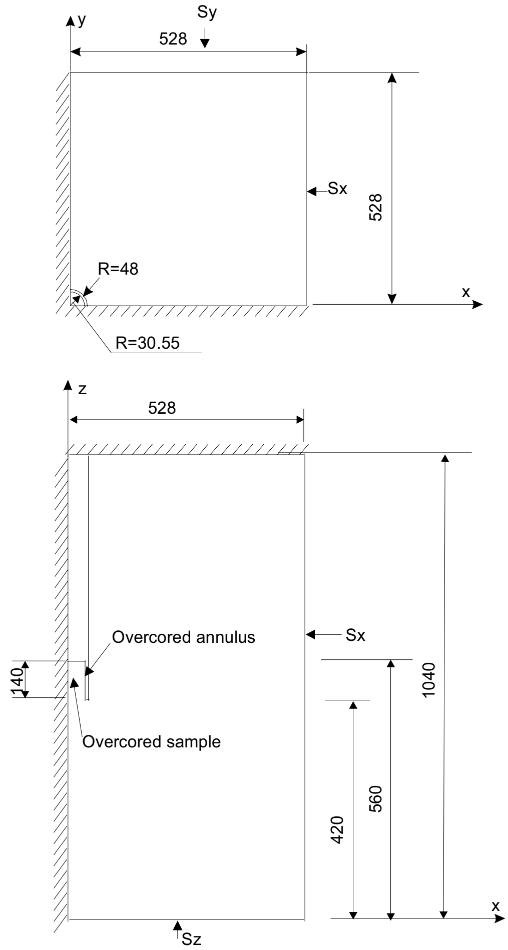

Figure 1: Model Dimensions for the *In Situ* Deep Doorstopper Gauge System Stress Measurement (unit: mm)

If the application of the boundary stresses of $S_x = S_0$ = 1 MPa and $S_y = S_z = S_{xy}$ = 0 MPa induces the stresses (σ_x^x, σ_y^x) and the application of the boundary stresses of $S_z = S_0$ = 1 MPa and $S_x = S_y = S_{xy}$ =0 MPa induces the stresses (σ_x^z, σ_y^z) ($\sigma_x^z = \sigma_y^z = \sigma^z$) at the bottom of the borehole, the stresses induced by the application of S_x, S_y, S_z, and S_{xy} can be calculated using the following equations:

$$\sigma_x = (S_x / S_0)\sigma_x^x + (S_y / S_0)\sigma_y^x + (S_z / S_0)\sigma^z \quad (1)$$

$$\sigma_y = (S_x / S_0)\sigma_y^x + (S_y / S_0)\sigma_x^x + (S_z / S_0)\sigma^z \quad (2)$$

$$\tau_{xy} = (S_{xy} / S_0)(\sigma_x^x - \sigma_y^x) \quad (3)$$

where σ_x, σ_y and τ_{xy} are the stresses at the borehole bottom. σ_x^x and σ_y^x are the X-directional stress and Y-directional stress at the borehole bottom induced by application of S_x = 1 MPa and $S_y = S_z = S_{xy}$ = 0 MPa, respectively. σ^z is the normal stress at the borehole bottom induced by the application of S_z=1 MPa and $S_x = S_y = S_{xy}$ =0 MPa.

3 RESULTS FROM FLAC^{3D} MODELLING

3.1 EFFECT OF CHANGE IN YOUNG'S MODULUS ON THE STRESSES IN THE ROCK AT THE BOREHOLE BOTTOM

The reduction in Young's modulus, resulting from overcoring stress relief, affects the strain invariants measured by the doorstopper strain gauge rosette. This reduction should not affect the calculated stresses, provided that the post-overcore value for Young's modulus (E_1) (Figure 2) is determined from a biaxial pressure test on an overcored rock sample, and assuming that the reduction in the material property occurs on the entire sample (all the layers in the model) at one time. However, in the model, the reduction in Young's modulus from its *in situ* value to its final value occurs gradually in a layer-by-layer process and its stress-strain relation is from A to C following, for example, Curve 1 not Line 2 in Figure 2. In such a case, the reduction in Young's modulus during overcoring does affect the calculated stress and cause some permanent deformation in the sample. As a result, the measured Young's modulus of the sample is not E_1 but E (Figure 2). Therefore, simply using the measured Young's modulus (E) as determined by the biaxial pressure test in the calculations is not appropriate.

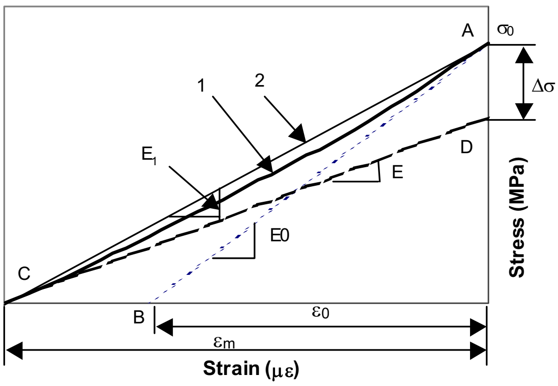

Figure 2: Schematic illustration of Change in Young's Modulus of the Overcored Sample during Overcoring

In order to get a better estimate of the *in situ* stresses from a DDGS overcore test, a factor should be incorporated into the Young's modulus determined from biaxial pressure tests on an overcored sample. The Young's modulus used in the calculations is a function of the ratio of the measured (E) to the *in situ* Young's modulus (E0) and the *in situ* Poisson's ratio (v0) as follows.

$$E_{1c} = E_{1c}(\frac{E}{E0}, \nu 0) = E \cdot a_{1e} \quad (4)$$

$$E_{2c} = E_{2c}(\frac{E}{E0}, \nu 0) = E \cdot a_{2e} \quad (5)$$

Where E_{1c} and E_{2c} are the moduli used in the calculation of the stresses at the borehole bottom induced by the stresses (S_x, S_y, and S_{xy}) and the stress (S_z), respectively; *E* is the measured Young's modulus of the sample; *E0* is the *in situ* Young's modulus of the rock measured by other means (e.g. tunnel displacements); $\nu 0$ is the *in situ* Poisson's ratio. a_{1e} and a_{2e} are the Young's modulus factors corresponding to the stresses parallel to the measurement plane and the axial stress, respectively.

The relations between the Young's modulus factors and the ratio of measured Young's modulus (E) to the *in situ* Young's modulus (E0) are shown in Figure 3 when S_x =1 MPa and $S_y = S_z = S_{xy}$ = 0 MPa are applied and Figure 4 when S_z = 1 MPa and $S_y = S_x = S_{xy}$ = 0 MPa are applied. When the Poisson's ratio is low, the Young's modulus used in the stress calculation should be larger than the value measured from the biaxial pressure test.

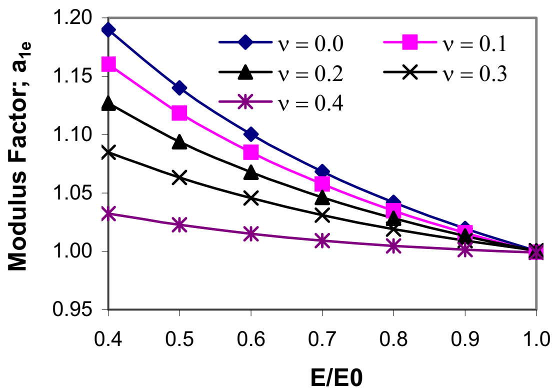

Figure 3: Young's Modulus Factor when Using the Measured Young's Modulus

The factor a_{ie} can be calculated by using Equation 6, as follows:

$$a_{ie} = d_{i1}(\frac{E}{E0})^2 + d_{i2}(\frac{E}{E0}) + d_{i3} \qquad i = 1, 2 \qquad (6)$$

where d_{i1}, d_{i2} and d_{i3} (i=1,2) are the least squares regression factors, which can be calculated by using Equation 7, as follows:

$$d_{ij} = e_{ij1}\nu + e_{ij2} \qquad i = 1, 2 \text{ and } j = 1, 2, 3 \qquad (7)$$

where e_{ij1} and e_{ij2} are factors which can be obtained by least squares regression (see Tables 1 and 2).

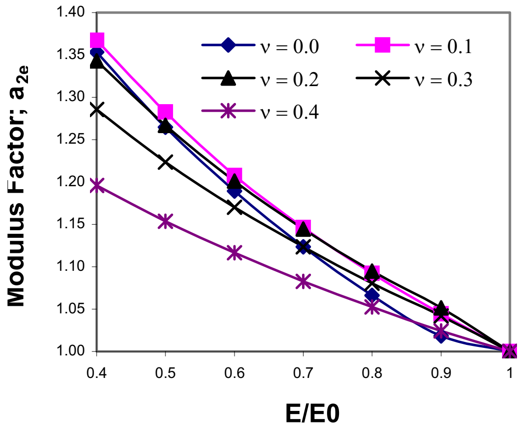

Figure 4: Young's Modulus Factor when Using the Measured Young's Modulus

Table 1: Factors of e_{ij1}

e_{ij1}	$i=1$	$i=2$
$j=1$	-0.5696	-0.9889
$j=2$	1.5	2.2701
$j=3$	-0.9847	-1.2808

Table 2: Factors of e_{ij2}

e_{ij2}	$i=1$	$i=2$
$j=1$	0.3026	0.5438
$j=2$	-0.7545	-1.4358
$j=3$	1.4602	1.8923

3.2 EFFECT OF CHANGE IN YOUNG'S MODULUS OF A SAMPLE ON THE STRESS RATIO

3.2.1 RPR Method

If the axial stress σ_z could be obtained, then determination of the stress components σ_x and σ_y would be possible in the calculation of far-field stress. Corthésy et al. (1994) proposed a method to determine the stress components based on their find of a relation between the Recovered to Peak Ratio, RPR, and the Stress Ratio, SR. RPR(ν) as given by,

$$RPR = \frac{D_r}{D_p} \qquad (8)$$

where D_r is the mean recovered strain invariant and D_p is the mean peak strain invariant.

The stress concentration factors for a given stress state are known to be a function of the Poisson's ratio only. RPR will obviously also be a function of Poisson's ratio. The stress ratio (SR) is given by,

$$SR = 2\frac{S_z}{S_x + S_y} \qquad (9)$$

where S_z is the far-field stress component parallel to the borehole axis and the sum S_x + S_y is the far-field stress invariant parallel to the measurement plane.

The relation between the SR and RPR gives the fourth equation required to completely determine the four unknowns in calculating the far-field stresses.

Corthésy et al. (1994) proposed using the following equation obtained by a least squares fit on the results of a finite element analysis to represent the relation between the RPR and the SR:

$$SR = d + e[\cot(f*(1+RPR))] + [\cot(f*(1+RPR))]^2 \qquad (10)$$

where d, e and f are the regression factors obtained by least squares.

Corthésy et al. (1994) concluded that the relation of the RPR and the SR is dependent on the Poisson's ratio and independent of the Young's modulus used in the calculation. This conclusion is applicable under the condition that overcoring has no effect on the Young's modulus of the sample. If the Young's modulus of a sample changes as a result of overcoring, the relation between the RPR and the SR is dependent on the change in Young's modulus of the sample. In practice, avoiding the effect of overcoring stress-relief on the sample is difficult. Therefore, the effect of the change in Young's modulus of a sample on the relation between the RPR and the SR must be investigated.

3.2.2 Effect Of Reduction in Young's Modulus of an Overcored Sample on the Stress Ratio in the RPR Method Calculation

Figure 5 shows the effect of overcoring-induced decrease in the Young's modulus of a sample on the relation between the RPR and the SR when the *in situ* Poisson's ratio is 0.2. In the RPR method, the SR is a function of the RPR and the Poisson's ratio. This modelling exercise shows that the SR is not only a function of the RPR and the *in situ* Poisson's ratio, but also a function of the ratio of the measured Young's modulus (E) to its *in situ* Young's modulus (E0), represented as follows:

$$SR = SR(RPR, \nu 0, E/E0) \quad (11)$$

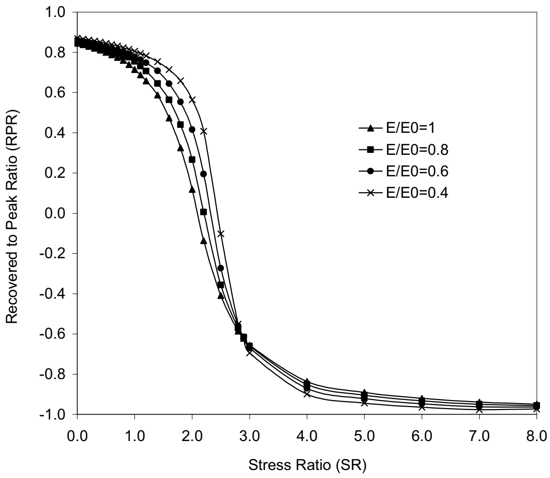

Figure 5: Effect of the Young's Modulus Decrease Caused by Sample Overcoring on the Relation of the RPR and the SR

When SR is less than a certain value, the RPR will increase if the sample's Young's modulus decreases as a result of overcoring. When the SR is greater than a certain value for a certain in situ Poisson ratio, the RPR will decrease if the sample's Young's modulus decreases as a result of overcoring. Therefore, when using the RPR method to calculate *in situ* stresses, if the effect of the change in Young's modulus is not considered, the far-field stresses will be underestimated when the SR is less than a certain value.

3.3 PARAMETERS CHOSEN IN CALCULATING THE *IN SITU* STRESSES

The parameters determined from the biaxial pressure test on an overcored sample are normally used to determine the stresses at the borehole bottom because the overcoring-induced displacements at the borehole bottom are only related to the parameters of the overcored sample and the stresses in it. As discussed above, the change in Young's modulus happens gradually, and its effect can be considered by introducing Young's modulus factors a_{ie}. In a general stress state, the effect of Young's modulus factors is incorporated in the calculation using the following steps.

In the total normal strains (ε_x, ε_y) in the borehole bottom rock, there are two parts. One part (ε_{x1}, ε_{y1}) is induced by the stresses (S_x, S_y) parallel to the measurement plane; another part (ε_{x2}, ε_{y2}) ($\varepsilon_{x2} = \varepsilon_{y2} = \varepsilon_2$) is induced by axial stress (S_z). They can be calculated using the following equations.

$$\sigma_x = \sigma_{x1} + \sigma_{x2} = \frac{E_{1c}(\varepsilon_{x1} + \nu\varepsilon_{y1})}{(1-\nu^2)} + \frac{E_{2c}(\varepsilon_{x2} + \nu\varepsilon_{y2})}{(1-\nu^2)}$$
$$= \frac{E_{1c}(\varepsilon_{x1} + \nu\varepsilon_{y1})}{(1-\nu^2)} + \frac{E_{2c}\varepsilon_2}{1-\nu} \quad (12)$$

$$\sigma_y = \sigma_{y1} + \sigma_{y2} = \frac{E_{1c}(\varepsilon_{y1} + \nu\varepsilon_{x1})}{(1-\nu^2)} + \frac{E_{2c}(\varepsilon_{y2} + \nu\varepsilon_{x2})}{(1-\nu^2)}$$
$$= \frac{E_{1c}(\varepsilon_{y1} + \nu\varepsilon_{x1})}{(1-\nu^2)} + \frac{E_{2c}\varepsilon_2}{1-\nu} \quad (13)$$

$$\sigma_{x1} + \sigma_{y1} = (a+b)(S_x + S_y) \quad (14)$$

$$\sigma_{x2} + \sigma_{y2} = 2 \cdot c \cdot S_z = c \cdot SR \cdot (S_x + S_y) \quad (15)$$

then $$\varepsilon_2 = \frac{c \cdot SR \cdot E_{1c}(\varepsilon_x + \varepsilon_y)}{2[E_{2c}(a+b) + c \cdot SR \cdot E_{1c}]} \quad (16)$$

If S_z is known, then

$$\varepsilon_2 = \frac{c \cdot S_z(1-\nu)}{E_{2c}} \quad (17)$$

$$\varepsilon_{x1} = \varepsilon_x - \varepsilon_2 \quad (18)$$

$$\varepsilon_{y1} = \varepsilon_y - \varepsilon_2 \quad (19)$$

$$\sigma_{x1} = \frac{E_{1c}(\varepsilon_{x1} + \nu\varepsilon_{y1})}{1-\nu^2} \quad (20)$$

$$\sigma_{y_1} = \frac{E_{1c}(\varepsilon_{y_1} + \nu\varepsilon_{x1})}{1-\nu^2} \quad (21)$$

$$\tau_{xy} = \frac{E_{1c}}{2(1+\nu)}\gamma_{xy} \quad (22)$$

$$\sigma_{x2} = \sigma_{y2} = \frac{E_{2c}\varepsilon_2}{1-\nu} \quad (23)$$

$$\sigma_x = \sigma_{x1} + \sigma_{x2} \quad (24)$$

$$\sigma_y = \sigma_{y1} + \sigma_{y2} \quad (25)$$

where ε_x, ε_y and γ_{xy} are the recovered strains in the borehole bottom rock during overcoring; ε_2 is the part of normal recovered strain corresponding to the far-field stress in the borehole axial direction. ε_{x1} and ε_{y1} are the part of normal recovered strain corresponding to the far-field stress parallel to the measurement plane. σ_x, σ_y, and τ_{xy} are the stresses at the borehole bottom. σ_{x1} and σ_{y1} are the part of the stresses at the borehole bottom corresponding to the far-field stresses parallel to the measurement plane. σ_{x2} and σ_{y2} are the stresses at the borehole bottom corresponding to the far-field axial stress. ν is the Poisson's ratio of the corresponding sample from the biaxial reloading test. E_{1c} and E_{2c} are the corrected moduli defined by Equations 4 and 5. a, b, and c are the concentration factors.

After the stresses at the borehole bottom are determined, the calculation of far-field stresses from the stresses at the borehole bottom should use the *in situ* Poisson's ratio, $\nu 0$, because the stresses at the borehole bottom have evolved based on $\nu 0$ before the overcoring happens. Therefore, the concentration factors and the stress ratio calculation using the RPR method should be calculated using $\nu 0$.

Since the measurements during overcoring are affected by stress-relief damage to the borehole bottom, the determination of the SR must consider the effect of the ratio of the measured Young's modulus to the *in situ* Young's modulus.

4 DDGS OVERCORE TESTING AT THE URL

A total of 21 deep overcoring tests (Thompson and Martino 2001) have been performed on the 420 Level of the URL. Sixteen are in borehole 405-047-OC1 with an azimuth of 296° N and a plunge of 76° and five in borehole 413-002-PH1 with an azimuth of 310° and a plunge of 76°. These 21 *in situ* tests are used to re-calculate the far-field stresses using the method proposed in this paper. The measurement parameters and measured results for the 21 tests are shown in Table 3. D_p and D_r are the average of the maximum strain invariants and the average of the residual strain invariants, respectively.

In the present formulation, the maximum possible value for RPR is 0.913 under the condition that Poisson's ratio is 0.49 and the *E*/*E0* is 0.4. Most of the test RPR values are larger than their corresponding upper limits. Therefore, only eight of the 21 tests, those showing their RPR values in Table 4, can be used to calculate the far-field stresses by the RPR method.

A reasonable estimate of the *in situ* Young's modulus and Poisson's ratio for the granite in the URL is 60 GPa and 0.2 (Thompson and Martino 2001). For the other tests where the RPR method cannot be applied, the lithostatic stress is used in the calculation.

$$S_z = \gamma g h \tag{26}$$

where γ is the density of granite (2.7 Mg/m^3);
g is the gravity acceleration (9.8 m/s^2); and
h is the depth below surface (m).

The calculated results for the 21 measurements using the method proposed in this paper are shown in Table 4.

Table 3: Key Data from DDGS Measurement in Borehole 405-047-OC1 and Borehole 413-002-PH1

Depth (m)	E (GPa)	ν	D_p (με)	D_r (με)	ε_h (με)	ε_v (με)	ε_{45} (με)	ε_{135} (με)
470.1	19.38	0.237	2622	2426	1169	1045	1225	1045
470.3	22.88	0.175	2721	2439	1296	1349	1296	1373
470.5	20.79	0.151	2554	2333	1098	1205	1179	1152
471.1	19.26	0.08	3375	2860	1509	1307	1568	1384
471.3	20.33	0.141	3149	2653	1146	1440	1362	1384
471.5	18.06	0.136	3363	2841	1461	1370	1704	1248
510.8	25.62	0.2*	2440	2243	1039	1215	1145	1088
511.1	25.34	0.2*	2287	2078	947	1143	1098	1021
579.5	27.4	0.2*	3136	2807	1352	1423	1234	1606
668.7	25.8	0.296	3470	3111	1409	1638	1436	1675
668.9	37	0.224	3521	3128	1436	1658	1675	1470
669.6	34	0.149	3811	3453	1795	1607	1556	1949
670.2	24.4	0.2*	2469	2273	1001	1278	1082	1186
670.8	24.4	0.2*	2617	2405	1148	1206	1055	1403
671.0	23.2	0.2*	2610	2298	1067	1206	1048	1275
745.0	23	0.2*	2685	2031	1048	929	758	1326
745.6	21.2	0.2*	2529	1988	997	881	962	1136
837.1	35.6	0.357	2681	2442	1248	1168	1195	1163
848.9	22	0.2*	3051	2228	1344	891	1103	1117
851.3	25.4	0.2*	2796	2203	801	1343	1237	1025
942.3	30.8	0.357	3409	2846	1400	1364	1217	1720

* Estimated values

Table 4: Re-calculated Results for the Measured Data at the URL

Depth (m)	SR	RPR	S_x (MPa)	S_y (MPa)	S_{xy} (MPa)	P^* (MPa)	Q^* (MPa)	P^{0*} (MPa)	Q^{0*} (MPa)
470.1	—	—	30.5	28.9	-1.1	31.0	28.3	43.7	37.7
470.3	—	—	36.0	36.7	0.6	37.1	35.7	45.5	44.1
470.5	—	—	28.7	30.4	-0.2	30.5	28.7	44.7	42.7
471.1	0.50	0.842	36.7	33.6	-1.3	37.2	33.1	50.6	46.6
471.3	0.58	0.842	36.8	41.1	0.2	41.1	36.8	42.9	40.4
471.5	0.70	0.847	41.8	41.0	-2.9	44.3	38.5	50.9	43.6
510.8	—	—	34.5	37.9	-0.5	38.0	34.4	46.3	43.8
511.1	—	—	32.2	35.9	-0.6	36.0	32.1	43.4	40.3
579.5	—	—	45.6	46.0	3.3	49.1	42.6	—	—
668.7	—	—	34.6	39.3	0.8	39.4	34.4	54.8	50.5
668.9	—	—	37.6	37.8	2.8	40.5	35.0	59.0	51.2
669.6	—	—	34.5	36.3	1.7	37.4	33.5	54.2	49.6
670.2	—	—	52.6	56.0	1.8	56.8	51.8	56.2	26.7
670.8	—	—	64.9	70.9	-2.3	71.7	64.2	66.8	62.8
671.0	—	—	65.0	58.9	4.3	67.2	56.7	70.5	62.4
745.0	1.3	0.756	79.9	76.6	4.3	82.8	73.7	—	—
745.6	1.2	0.786	63.9	61.4	1.2	64.4	60.9	—	—
837.1	—	—	63.5	61.9	-0.3	63.5	61.9	—	—
848.9	1.42	0.730	108.5	101.2	0.1	108.5	101.2	82.9	75.7
851.3	1.12	0.787	72.2	82.4	-1.7	82.7	71.9	54.7	48.2
942.3	0.51	0.835	76.2	74.1	4.3	79.6	70.7	54.0	37.7

* where P and Q are the re-calculated major and minor principal components in the x-y plane using the modified method proposed in this paper; P^0 and Q^0 are the originally calculated major and minor average principal components in the x-y plane.

Due to the overcored-induced change in the Poisson's ratio from the *in situ* Poisson's ratio, the calculated results in Table 4 still have some errors. For example, the measured Poisson's ratio for the test at a depth of 942.3 m is greater than the assumed *in situ* Poisson's ratio. As a result, the calculated stresses at this depth may be overestimated by 12% using the RPR method (Guo and Thompson 2004a and 2004b). Therefore, the major principal stress parallel to the measurement plane may be about 71 MPa. For the test at a depth of 848.9 m, the calculated stresses are the greatest. Because its Poisson's ratio was not measured, the effect of the change of Poisson's ratio cannot be estimated. The comparison of the calculated results to other measurements in the URL is shown in Figure 6.

5 SUMMARY

In situ stresses are an important parameter in the design of underground structures. A reasonable determination of the *in situ* stresses depends not only on the methods but also on the choice of parameters used in the stress calculations.

In calculating the *in situ* stress from deep overcoring tests using the DDGS method, Young's modulus measured by biaxial pressure tests on an overcored sample should normally be used. However, due to overcoring-induced disturbance in the sample, the Young's modulus correction factors should be incorporated into the measured Young's modulus.

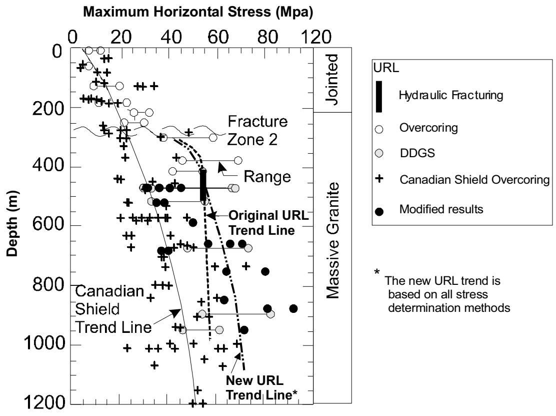

Figure 6: DDGS Measurement Results Compared to Other Canadian Shield and URL Measurements

The stress ratio (SR) in the RPR method depends not only on the Poisson's ratio but also on the ratio of the measured Young's modulus to its *in situ* Young's modulus.

Neglecting the overcoring-induced change of Young's modulus of an overcored sample may cause a significant error in estimating the far-field stress components of the *in situ* stresses.

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