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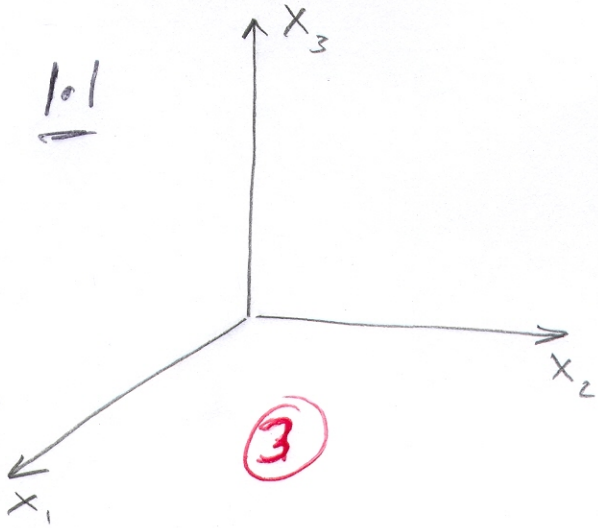
Rock Mechanics Paper 1 Model Answers
October 2005

Question 1.

1.1



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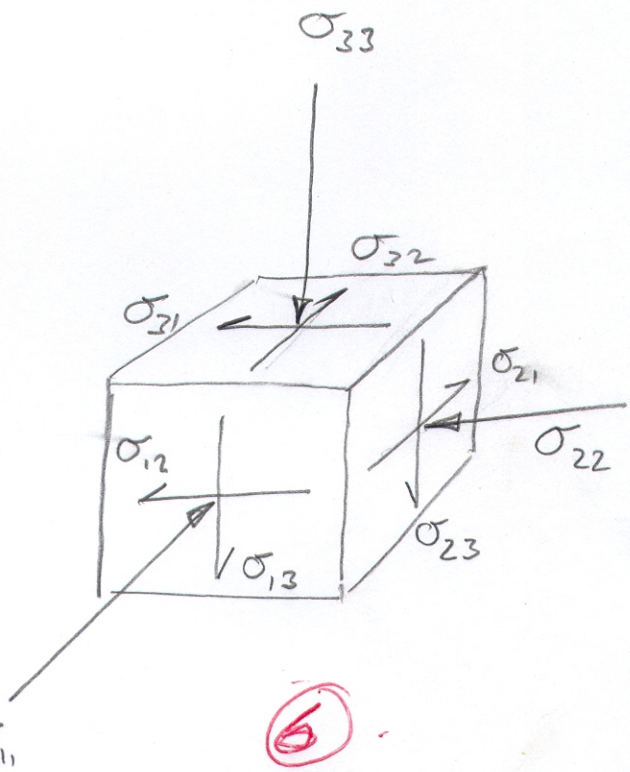
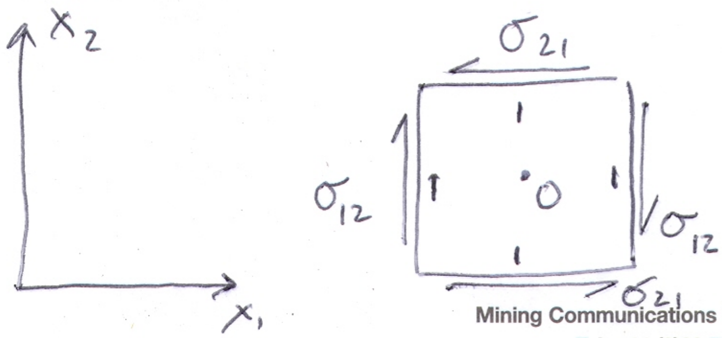


$\boxed{19}$

6.

1.2 In two dimensions the shear stress acting on the sides of a square element are as follows



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Assuming the square element has centre O, ~~the~~ ~~Moments at~~ and sides of length 1 and unit thickness:-

Moments about O :-

Clockwise moments:

$0.5 \times \sigma_{12} \times 1 + 0.5 \times \sigma_{12} \times 1 = \sigma_{12}$ N-M. $= M_c$

Anticlockwise moments

$0.5 \times \sigma_{21} \times 1 + 0.5 \times \sigma_{21} \times 1 = \sigma_{21}$ N-M. $= M_a$

If the element is not to rotate, then

$$M_c = M_a$$

$$\Rightarrow \boxed{\sigma_{12} = \sigma_{21}}$$

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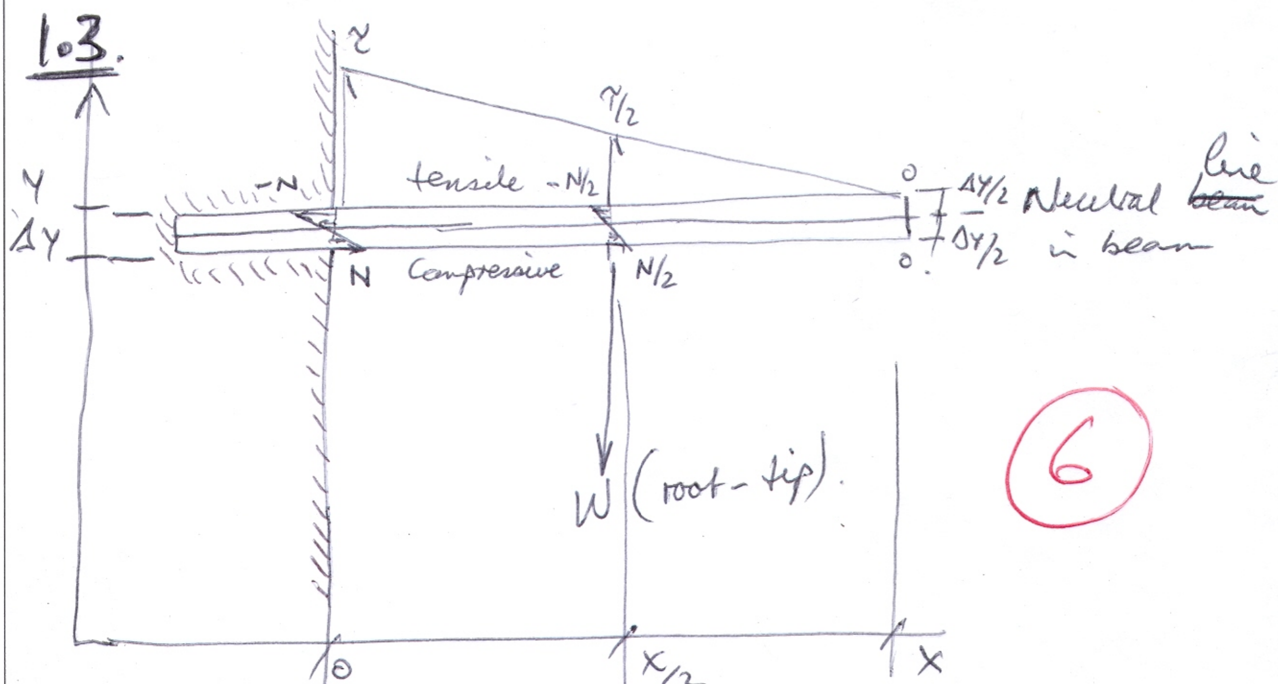
1.3.



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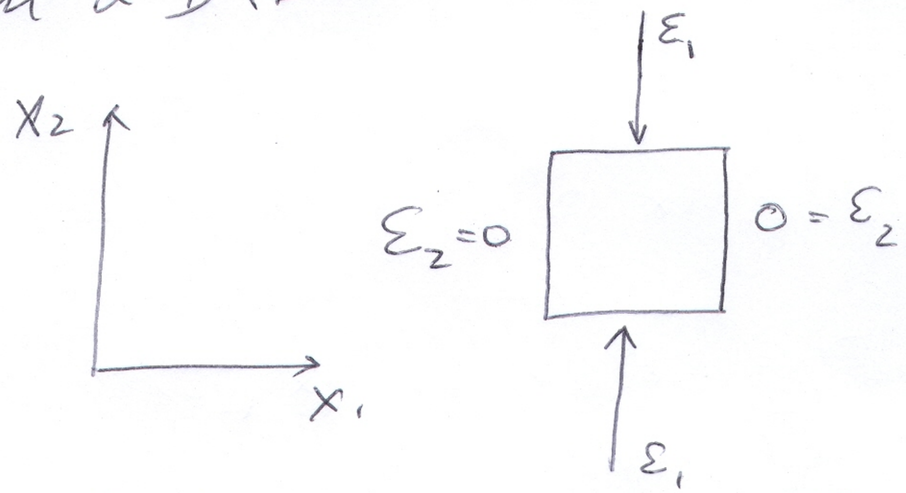
1.4

Plane strain is that condition in which all the strains on one surface are zero.

In 2-D :-



Condition is shown where $\varepsilon_2 = 0$, ε_1 = Comp. (RMSC.)

The equations of elasticity are as follows:-

$$\varepsilon_1 = \frac{1}{E}(\sigma_1 - \nu\sigma_2)$$

$$\varepsilon_2 = \frac{1}{E}(\sigma_2 - \nu\sigma_1) \Rightarrow \varepsilon_2 = 0 = \sigma_2 - \nu\sigma_1$$

$$\Rightarrow \sigma_2 = \nu\sigma_1$$

$$\therefore \boxed{\varepsilon_1 = \frac{1-\nu^2}{E}\sigma_1.} \boxed{\varepsilon_2 = 0.}$$

$$\therefore \boxed{\sigma_1 = \frac{\varepsilon_1 E}{1-\nu^2}; \quad \sigma_2 = \nu\sigma_1.}$$

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Questi

2.1

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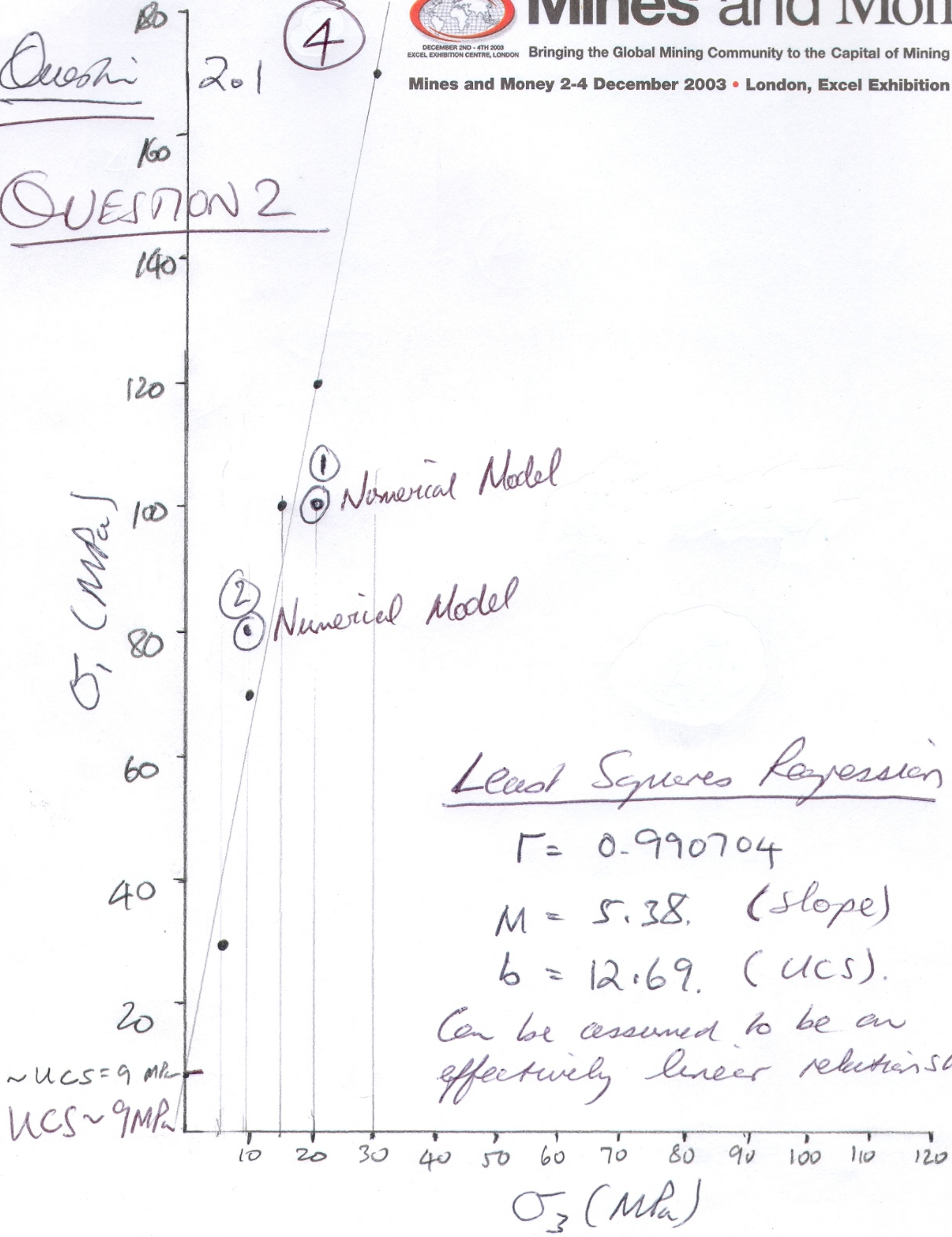
QUESTION 2



<u>Least Squares Regression</u>

r = 0.990704

M = 5.38 (slope)

b = 12.69 (UCS).

Can be assumed to be an effectively linear relationship.

2.1 UCS = 9 MPa

(12.7 MPa from LR)

(Least Squares fit)

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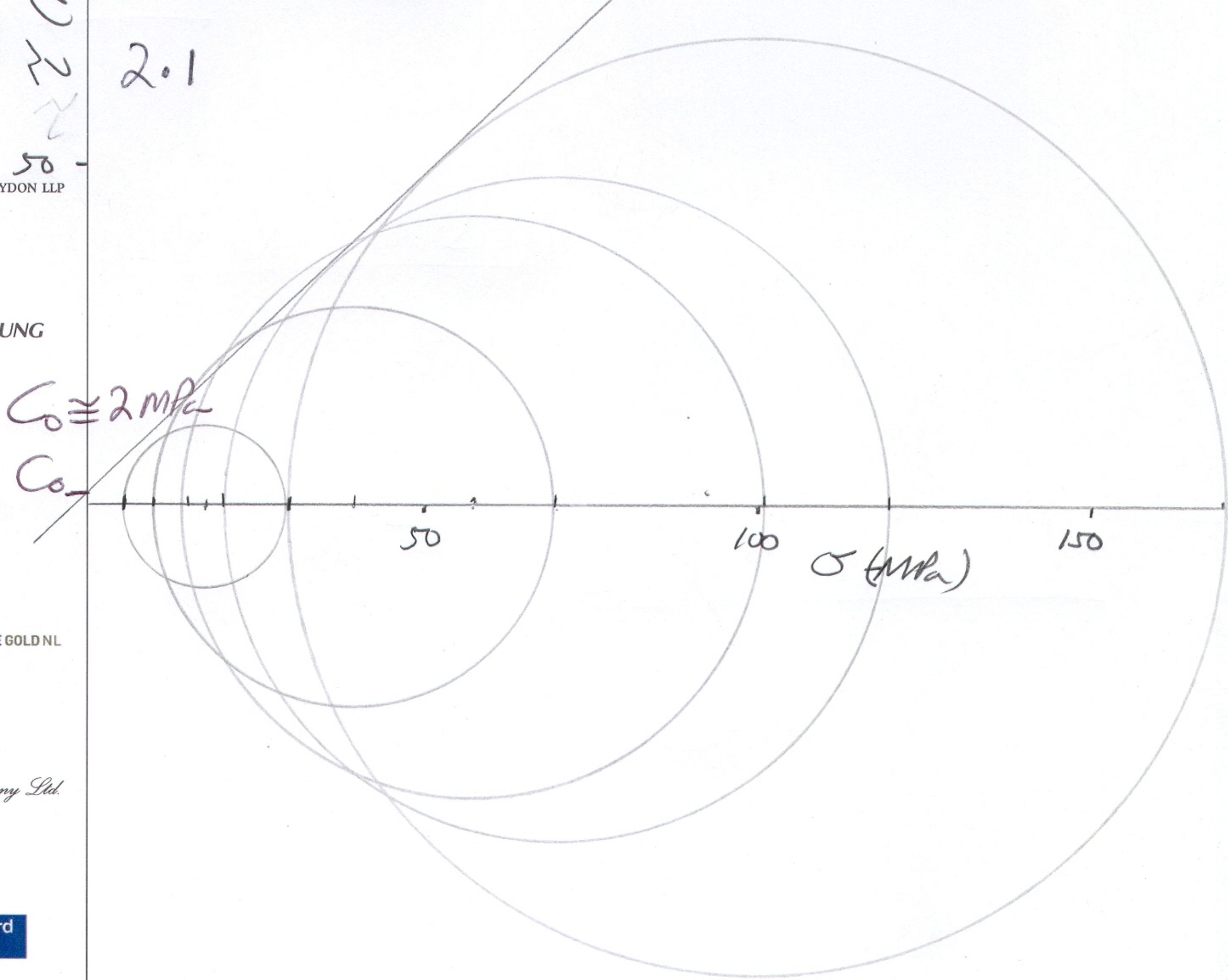
Questi 2

2.1



2.2. $C_0 \cong 2$ MPa 6

2.3 43° (est) 6

2.4. σ_1 and σ_3 have a near linear relationship 3.

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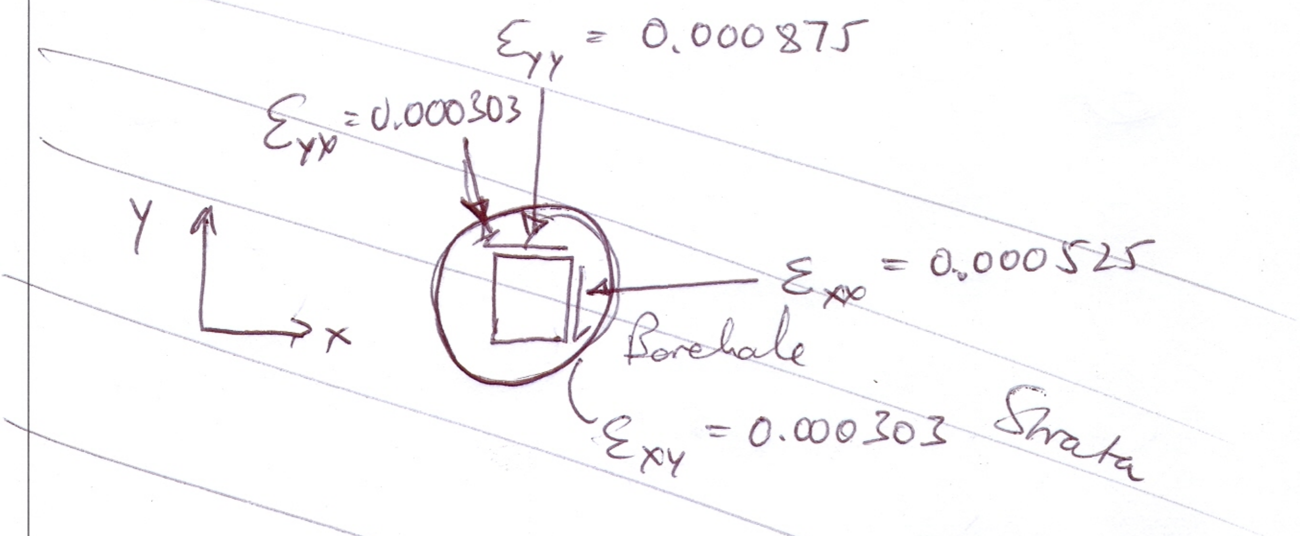
2.5 at (100, 20) no failure
at (80, 10) failure. 4

2.6 The data does <u>not</u> imply any failure model. Since the UCS and C_0 are relatively low 10MPa confinement ~ UCS and 10MPa confinement > C_0, hence I would expect a strain softening / shear failure mode for the material. 4

Question 3



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3.1 $$\varepsilon_{xx} = \frac{1}{E}\left(\sigma_{xx} - \nu\,\sigma_{yy}\right)$$

$$0.000525 = \frac{1}{60000}\left(\sigma_{xx} - 0.2\,\sigma_{yy}\right).$$

$$\sigma_{xx} - 0.2\sigma_{yy} = 31.5. \quad — (1).$$

$$\varepsilon_{yy} = \frac{1}{60000}\left(\sigma_{yy} - 0.2\sigma_{xx}\right).$$

$$\Rightarrow -0.2\sigma_{xx} + \sigma_{yy} = 52.5. \quad — (2).$$

Multiplying (2) by 5 and adding to (1):

$$-0.2\sigma_{yy} + 5\sigma_{yy} = 31.5 + 262.5$$

$$\sigma_{yy} = \frac{294}{4.8} = 61.25 \text{ MPa}.$$

Hence $$\sigma_{xx} = 31.5 + 0.2 \times 61.25$$

$$\sigma_{xx} = 43.75 \text{ MPa}$$

$$\cancel{\sigma_{xy} = \frac{1}{2G}\varepsilon_{xy} = \frac{1+\nu}{E}\varepsilon_{xy}}$$

$$\cancel{= \frac{1.2}{60\,000}}$$

PTO

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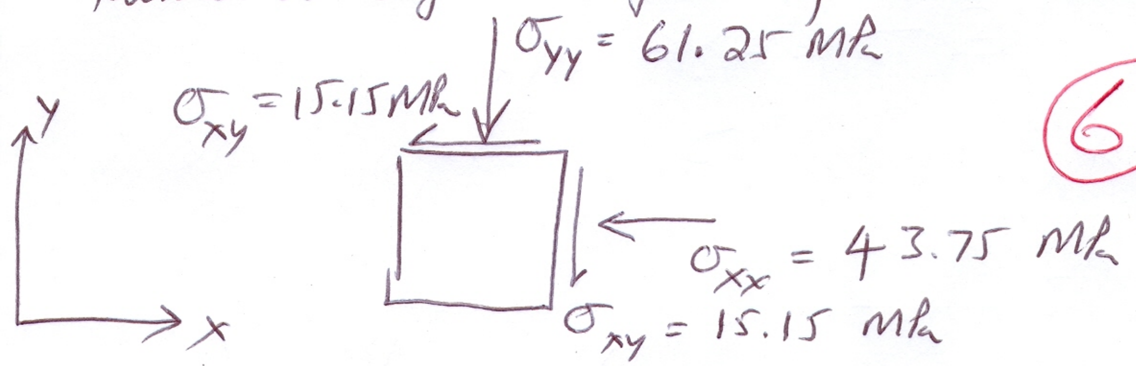
8.

$$\sigma_{xy} = 2G\,\varepsilon_{xy} = \frac{E}{1+\nu}\,\varepsilon_{xy}$$

$$= \frac{60\,000}{1.2}\,0.000303.$$

$$= 15.15\ \text{MPa}$$

∴ Tunnel is subjected to following stress state



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3.2. $\sigma_v = \rho g h = 3058 \times 9.81 \times 2200$

$= 66$ MPa.

4

The measurement at 61.25 MPa is quite plausible/reasonable. Stress is not distributed uniformly through rock masses because of discontinuities, small movements, residual stresses locked in, and tectonics. Even water pressure can affect the stress state, leading to variations. The average stress must be equal to the overburden weight, but point stresses can deviate from this.

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3.3 $$\sigma_{1,3} = \frac{1}{2}(\sigma_{yy} + \sigma_{xx}) \pm \sqrt{\frac{1}{4}(\sigma_{yy} - \sigma_{xx})^2 + \tau_{xy}^2}$$

$$= \frac{1}{2}(61.25 + 43.75) \pm \sqrt{\frac{1}{4}(61.25 - 43.75)^2 + 15.15^2}$$

(My mistake in deriving eqn!)

$$\Rightarrow \sigma_1 = \cancel{72.06 \text{ MPa}} \quad 69.999 = 70 \text{ MPa}$$

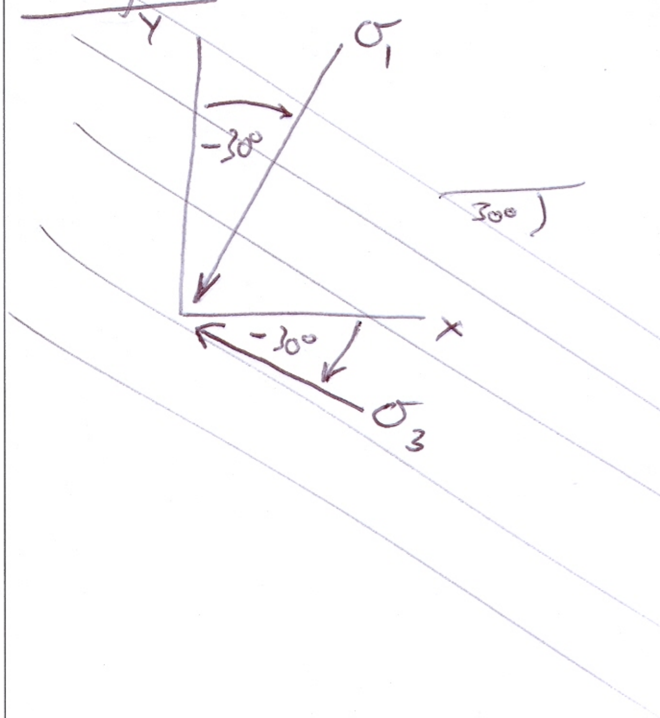
$$\Rightarrow \sigma_3 = \cancel{32.94 \text{ MPa}} \quad 35.004 = 35 \text{ MPa}$$

Check: $\sigma_1 + \sigma_3 = 105 \text{ MPa} = \sigma_{xx} + \sigma_{yy}$.

$$\Theta = \frac{1}{2}\arctan\left(\frac{2\tau_{xy}}{\sigma_{xx} - \sigma_{yy}}\right)$$

$$= \frac{1}{2} \frac{30.30}{43.75 - 61.25} = -30^\circ$$

Diagram



Strata dip at 30° to right as seen from borehole. Hence σ_1 is $\perp$ to strata and σ_3 is $\parallel$el to strata.

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3.4. No.

5 Reasons

1) Stress will change in vicinity of geological structures

2) Mining induced stresses (this haulage will clearly serve mining, so it must be influenced by differing levels of mining induced stresses along its length).

This is not relevant - question asked about virgin stresses.

3) Non-homogeneity of rockmass hence non-homogeneity of stresses at tunnel level (good rock = higher stress, poor rock = lower stress)

4) Tectonic effects (although these tend to be more regional).

5) Rockmass structure will affect stress levels.

6) Residual stresses locked into the rockmass.

7) Topography (although the effect of this in typical SA conditions is likely to be relatively small: hills etc likely to be small in relation to depth)

8) Groundwater.

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Question 4

4.1. Vertical Virgin Stress in coal before gold mining = 0.025h = 0.025 x 180 MPa

= 4.5 MPa = σ_h (2)

Vertical Virgin Stress in Coal after gold Mining = 1.33 x 0.025h

= 1.33 x 4.5

σ_v = 6 MPa (2)

σ_h = 4.5 MPa

Stress Condition in coal pillar after coal mining = 2 x 1.33 x 4.5 MPa

σ_v = 12 MPa (2)

σ_h = 4.5 MPa

$\boxed{6}$

4.2 The radial and tangential stresses in the shaft barrel will be essentially unchanged by the mining (the numerical modelling shows this.)

The horizontal stress is also the same in all directions and remains essentially so once all the 'mining' has been completed.

$$\sigma_h \text{ (base of Mudstone } \cancel{\text{Sandstone}}) = 0.025h \text{ MPa}$$
$$= 0.025 \times 177 \text{ MPa}$$
$$= 4.43 \text{ MPa}$$

$$\sigma_h \text{ (base of Coal)} = 4.50 \text{ MPa.}$$

$$\sigma_h \text{ (base of Sandstone)} = 0.025h \text{ MPa}$$
$$= 5.00 \text{ MPa}$$

Because the horizontal stresses are equal in all directions, Θ has no meaning in the Kirsch equation because $\sigma_{h1} - \sigma_{h2} = 0$; $K = 1$.

Simplifying for $K = 1$:

$$\Rightarrow \sigma_{rr} = q\left(1 - \frac{R^2}{r^2}\right) = 0 \quad (r = R)$$

$$\sigma_{\theta\theta} = q\left(1 + \frac{R^2}{r^2}\right) = 2q \quad (r = R).$$

$$\sigma_{r\theta} = 0 \text{ for all } \theta.$$

Strata	σ_{rr}	$\sigma_{\theta\theta}$	$\sigma_{r\theta}$
Mudstone	0	8.86	0
Coal	0	9.00	0
Sandstone	0	10.00	0

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4.3

(a) Mudstone – in sidewall

(H+B) $\sigma_1 = \sigma_3 + \sqrt{m\sigma_c\sigma_3 + s\sigma_c^2}$

$\sigma_c = 40\text{ MPa}$

$\sigma_1 = 0 + \sqrt{0.01 \times 1600}$

$= 4\text{ MPa}$

This is much less than the 8.86 MPa that the mudstone is subjected to, so expect failure all around the shaft in rings:

Vertical fractures in concentric rings.

Shaft inspection show that the shaft remains in good condition even at these stresses, and since they won't change with coal mining, the rockmass condition will not change, excepting that the vertical stress will increase to 11.8 MPa vertical from 5.9 MPa vertical before mining. This stress change may induce failure in the mudstone.

Comment: It appears that current shaft conditions suggest that the mudstone strength is underestimated.

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(b) i Sidewall

$$\sigma_1 = 0 + \sqrt{0.1 \times 400}$$
$$= 6.32 \text{ MPa.}$$

According to this strength estimate, the coal should be in good condition in the shaft sidewall after gold mining. However, it may fail too as σ_v increase to 12 MPa from the current 6 MPa, with concentric rings of fracturing developing around the shaft. So failure will be driven by σ_v, not $\sigma_{\theta\theta}$, which becomes intermediate principal stress.

(c) Sandstone (use base, vertical stress is highest here).

$$\sigma_1 = 0 + \sqrt{0.1 \times 60^2}$$
$$= 18.97 \text{ MPa}$$

At the base of the sandstone, it will be subject to 10 MPa tangential stresses, and 12.67 MPa vertical stresses after coal mining, so no failure is expected in the sandstone.

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4.4 As discussed above

Shaft

Vertical Fractures in concentric rings around shaft.

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