# RMP1 Model Answers October 2007.

## Question 1

a) Notes ②

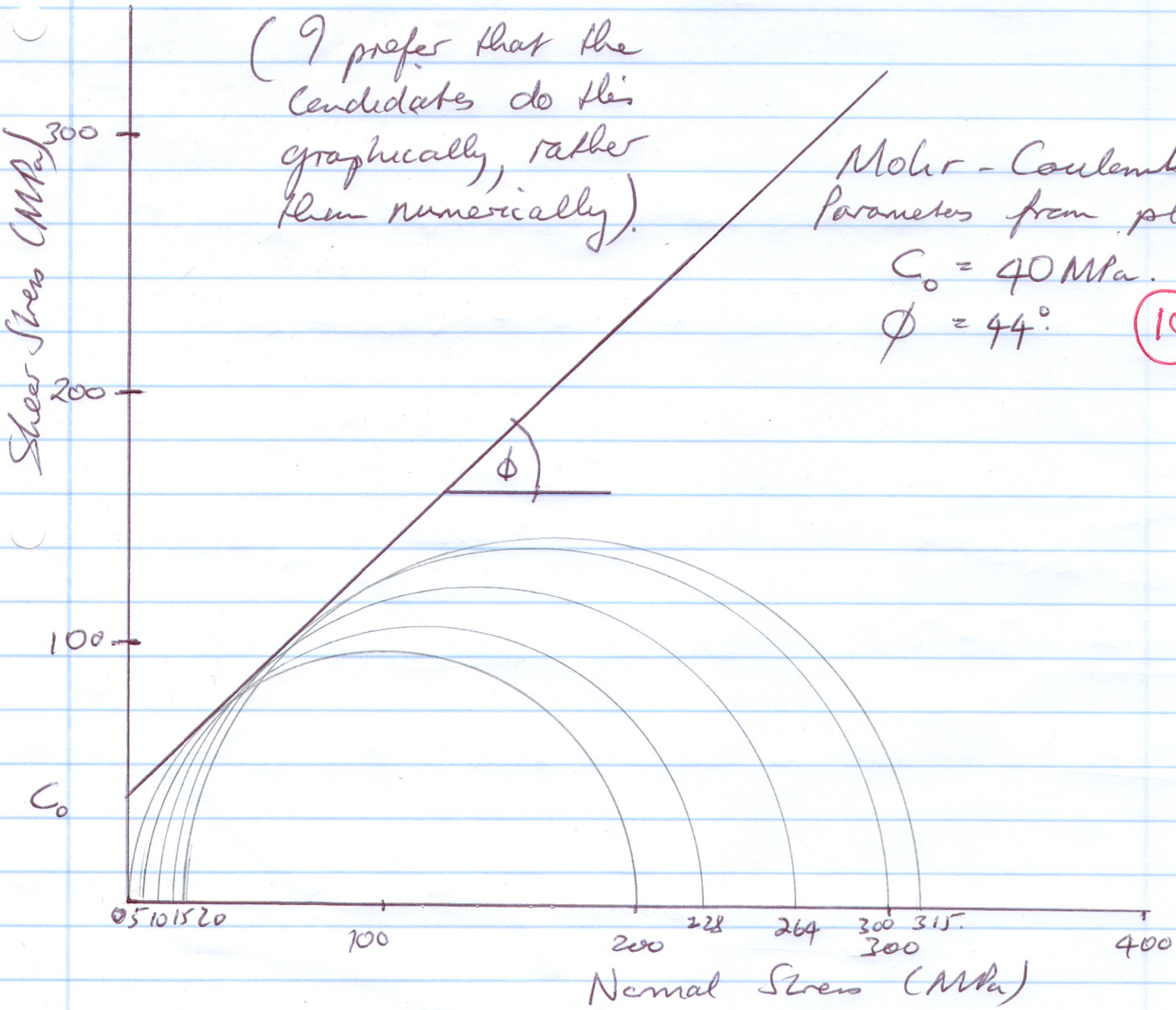
b) Notes ②

c) Notes ②

d) Notes ④

e) Notes ②

f).



(I prefer that the candidates do this graphically, rather than numerically).

Mohr-Coulomb Parameters from plot;

$C_o = 40$ MPa.

$\phi = 44°$. ⑩

g) $\sigma_1 = \sigma_3 + \sqrt{m\sigma_c\sigma_3 + s\sigma_c^2} = 20 + \sqrt{15 \times 200 \times 20 + 1 \times 200^2}$

$= 20 + \sqrt{60\,000 + 40000} = 20 + 316 = \underline{336 \text{ MPa}} \rightarrow$

PTO

g) Continued.

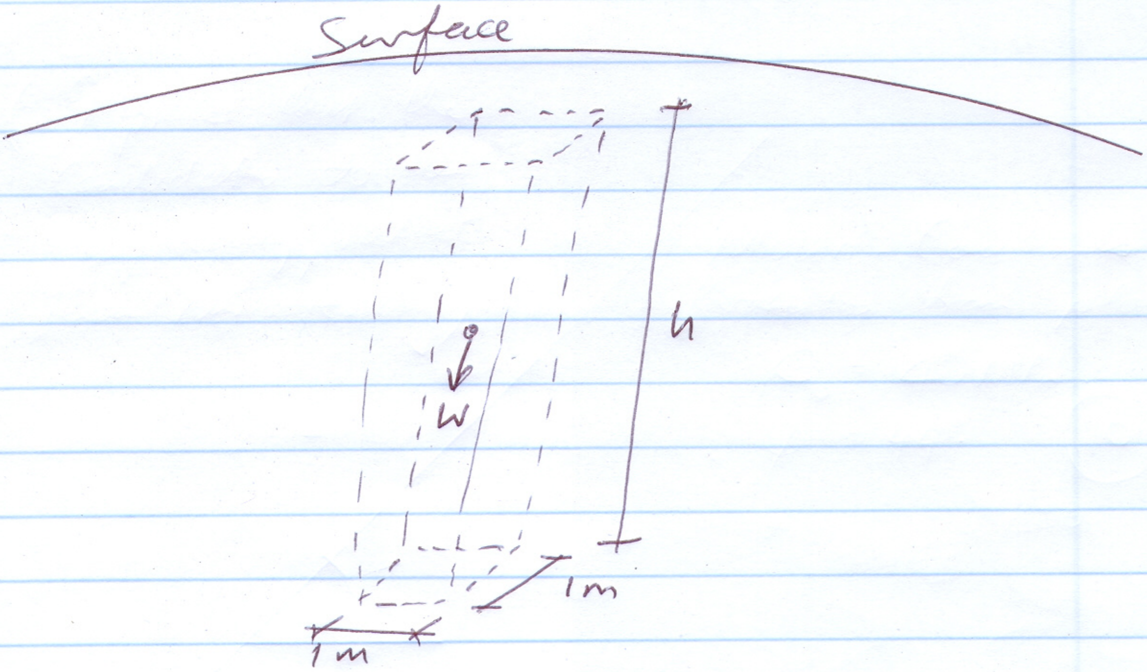
| | $\sigma_3$ | $\sigma_1$ |
|---|---|---|
| M-C Measurement | 20 | 315 |
| H-B Prediction | 20 | 336 |

③

The results are 6% different – so agreement is considered good because sample variance could account for the difference easily.

## Question 2

2.1



Imagine a vertical column of rock in the Earth's crust 1 x 1m in cross section, and h m high (deep). Assume the density is constant at $\rho$ and that the acceleration due to gravity is g:-

$$W = \rho V g = \rho \times 1 \times 1 \times h \times g.\ N.$$

⑤

At the imaginary base of the column, a stress acting upward must be the same for equilibrium

$$\sigma_v = \frac{W}{a} = \frac{\rho \times 1 \times 1 \times h \times g}{1 \times 1} = \rho g h = \text{overburden weight.}$$

## 2.2

$$\varepsilon_1 = \frac{1}{E}\left(\sigma_1 - \nu(\sigma_2 + \sigma_3)\right)$$

$$\varepsilon_2 = \frac{1}{E}\left(\sigma_2 - \nu(\sigma_1 + \sigma_3)\right)$$

$$\varepsilon_3 = \frac{1}{E}\left(\sigma_3 - \nu(\sigma + \sigma)\right)$$

In the uniaxial strain case, $\varepsilon_2 = \varepsilon_3 = 0$. This also implies that $\sigma_2 = \sigma_3$ if the material is isotropic. (We can safely assume so here).

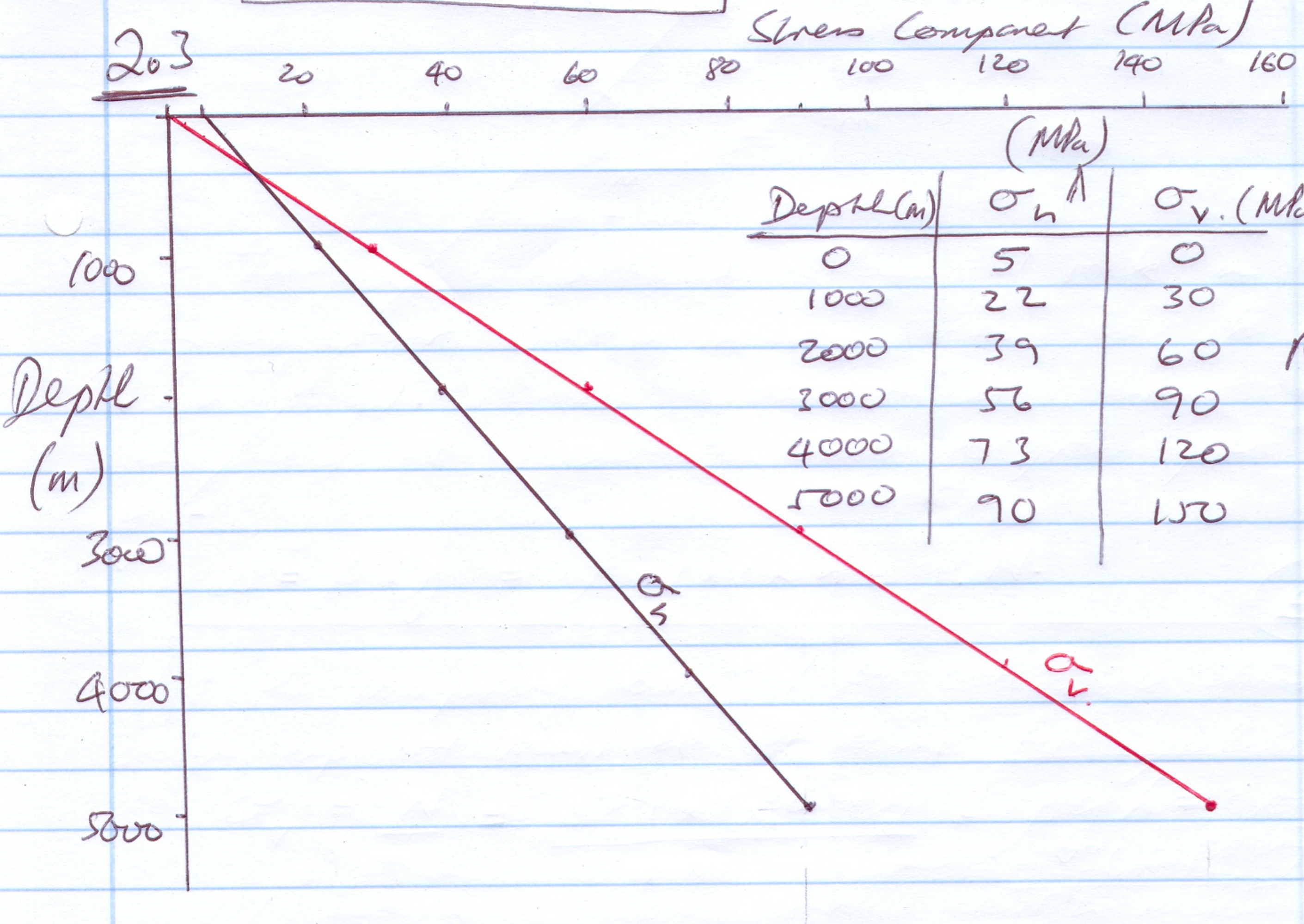
$$\Rightarrow \varepsilon_2 = \varepsilon_3 = 0 = \sigma_2 - \nu(\sigma_1 + \sigma_2) \text{ from above}$$

and rearranging

$$\boxed{\sigma_2 = \frac{\nu}{1-\nu}\,\sigma_1.}$$

⑥.

## 2.3



| Depth(m) | $\sigma_h$ (MPa) | $\sigma_v$. (MPa) |
|---|---|---|
| 0 | 5 | 0 |
| 1000 | 22 | 30 |
| 2000 | 39 | 60 |
| 3000 | 56 | 90 |
| 4000 | 73 | 120 |
| 5000 | 90 | 150 |

MPa

Feature

$\sigma_h \neq 0$ at surface, $\sigma_v = 0$ at surface

$\sigma_h$ and $\sigma_v$ vary linearly with depth

$\sigma_h = \sigma_v$ at $90 + 0.017(h-5000) = 120 + 0.030(h-5000)$

$$0.013h = \quad 5\ m$$

at: $\Rightarrow$ $h = 385$ m.

⑨.

## 2.4.

Shortcomings

1). When the depth is at ~ 100 km, $\sigma_h \cong \sigma_v$ – this model does not predict that

2) That both $\sigma_h$ and $\sigma_v$ vary ~~linearly~~ with depth is only an approximation. There is NO reason why $\sigma_h$ should vary linearly with depth, and $\sigma_v$ will only vary linearly with depth if the rock density is uniform (which it generally will not be).

3) The prediction that $\sigma_h = \sigma_v$ at 385 m may not necessarily be correct.

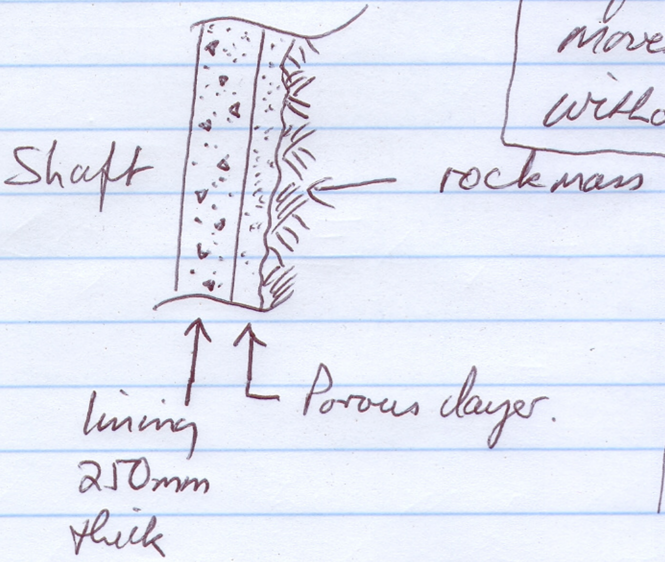
4) The only geological process taken into account in this model is erosion. The horizontal stress is influenced by other geological factors e.g. plate tectonics, intrusions etc.

5) The horizontal stress relaxation coefficient is a guess (or an estimate if several in situ stress measurement results are available).

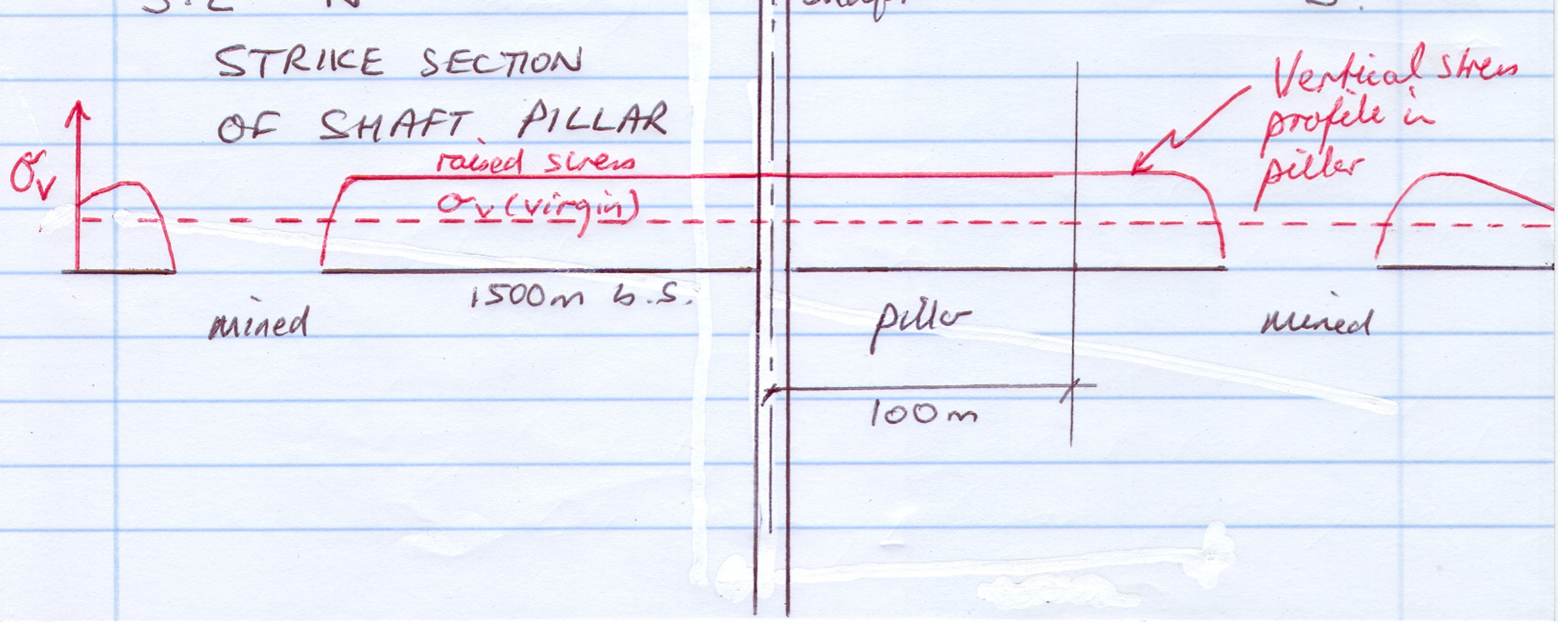
⑤

## Question 3

3.1 The lining will have neglegible effect on movements in the rockmass. In order to keep the lining as stress free as possible, there is a 50mm thick layer of porous concrete between the lining and the rockmass. This is expected to deform to take up elastic movements in the rockmass without deforming (and stressing) the lining. If mining induced displacements in the rockmass are greater than 50mm, the lining itself will become deformed and may even fail. Even in these circumstances, the influence of the lining on rockmass movements will be small.



3.2



From diagram above I assume:-

1) Stress is raised in the shaft piller uniformly, with a fall-off at the ends due to mining induced fracturing (hence strain changes are uniform too).
2) The shaft has no influence on the vertical stress

⑤

3) The horizontal stress changes are compressive and the same in all directions (the peg Movements show this)
4) The measured peg movements are elastic
5) The piller (with dip of 5°) can be assumed to be flat and the equations given for horizontal displacements in a uniformly stressed plate will hold.

Because of the assumption of elasticity, the incremental expression of the displacement equation will be correct as well:

$$\Delta u_r = \frac{-a^2}{2Gr}\left[\frac{\Delta\sigma_1 + \Delta\sigma_2}{2} - \frac{\Delta\sigma_1 - \Delta\sigma_2}{2}\left\{2(1-2\nu) + \frac{a^2}{r^2}\right\}\cos 2\theta\right]$$

Now $\Delta\sigma_h = \Delta\sigma_1 = \Delta\sigma_2$ (horizontal stress changes same in all directions)

hence

$$\Delta u_r = \frac{-a^2\Delta\sigma_h}{2Gr}$$

$a$ = shaft radius = 5m

$r$ = 5m (measure displacements at shaft lining-rockmass contact).

$$\therefore \Delta\sigma_h = \frac{2Gr\Delta u_r}{-a^2}$$

Note:-
($\Delta u_\theta = 0$ because $\Delta\sigma_h$ is the same in all directions).

Since the displacements are <u>inwards</u> they are negative.

$$G = \frac{E}{2(1+\nu)} = \frac{50\,000}{2(1+0.25)} = \underrightarrow{20000 \text{ MPa}}$$

$$\Delta\sigma_h = \frac{2 \times 20\,000 \times 5 \times -0.0015}{-25}$$

④

$$\underrightarrow{\Delta\sigma_h = +12 \text{ MPa}.}$$ (increase in compression).

At 100m from shaft there is no concentration of stress by the shaft so this can be seen as a stress applied at infinity.

From the equations of elasticity:

$$\Delta\varepsilon_{zz} = \frac{1}{E}\left(\Delta\sigma_{zz} - \nu\left(\Delta\sigma_{xx} + \Delta\sigma_{yy}\right)\right)$$

and $\Delta\sigma_{yy} = \Delta\sigma_{zz} = \Delta\sigma_h \Rightarrow \nu(\Delta\sigma_{xx} + \Delta\sigma_{yy}) = 2\nu\Delta\sigma_h$.

$$\Delta\varepsilon_{zz} = 13/20000 = \underrightarrow{0.00065}$$ (compressive).

$$\Delta\sigma_{zz} = E\Delta\varepsilon_{zz} + 2\nu\Delta\sigma_h$$

$$= 50\,000 \times 0.00065 + 2 \times 0.25 \times 12 \text{ MPa}$$

$$\underrightarrow{\Delta\sigma_{zz} = 38.5 \text{ MPa}} = \Delta\sigma_v.$$ (in pillar).

3.3) $\sigma_h$ is same in all directions, hence $K = 1$. Also $r = R$ (at the shaft lining rockmass interface).

$\therefore$ $\sigma_{rr} = 0$ from Kirsch Equations

But $\Delta\sigma_{rr} = \sigma_{rr}\,(\text{final}) - \sigma_{rr}\,(\overset{\text{virgin}}{\text{initial}})$.

$$\Delta\sigma_{rr} = 0 - (90 + 0.017(1500 - 5000))\,\text{MPa}$$

$$\underrightarrow{= -30.5\ \text{MPa}.}$$ ②

Even when pillar has formed, $\sigma_{rr}$ will still be zero, so the stress change $\Delta\sigma_{rr}$ was induced when the shaft was reamed out to 10m diameter. (We are not considering the effect of raiseboring first here).

For the tangential stress

$$\Delta\sigma_{\theta\theta} = \sigma_{\theta\theta}\,(\text{after pillar formation}) - \sigma_h\,(\text{virgin}).$$

$$\Delta\sigma_{\theta\theta} = 2q\,(\text{horizontal}) - \sigma_h\,(\text{virgin})$$

$q$ (horizontal) = total horizontal stress in pillar,

$$\underrightarrow{= \sigma_h(\text{virgin}) + \Delta\sigma_h}$$

$$\Delta\sigma_{\theta\theta} = 2\sigma_h(\text{virgin}) + 2\Delta\sigma_h - \sigma_h(\text{virgin})$$

$$= 2\times 30.5 + 24 - 30.5\ \text{MPa}$$

$$\underrightarrow{= +54.5\ \text{MPa}\ (\text{compressive}).}$$

3.4) The ~~total~~ vertical stress from 3.2

is : $\sigma_V$ (total) = $\sigma_V$ (virgin) + $\Delta\sigma_V$

= 150 + 0.03(1500−5000) +

$\sigma_V$(total) = 45 + 38.5 (from 2.3 & 3.2)

= 83.5 MPa

From TAT the shaft piller should be bearing the weight of half the mine span around the piller perimeter. Since the mine span is given as 100m, ½ mined span is 50m hence :-

$$\sigma_V \text{ (total)} = \frac{400^2}{300^2} \times 45 \text{ MPa}$$

$$\sigma_V\text{(total)} = 80 \text{ MPa}$$

This is about 4% lower than the total piller stress derived from shaft measurements, so is considered to be a good result ie. results compare well.

## Question 4

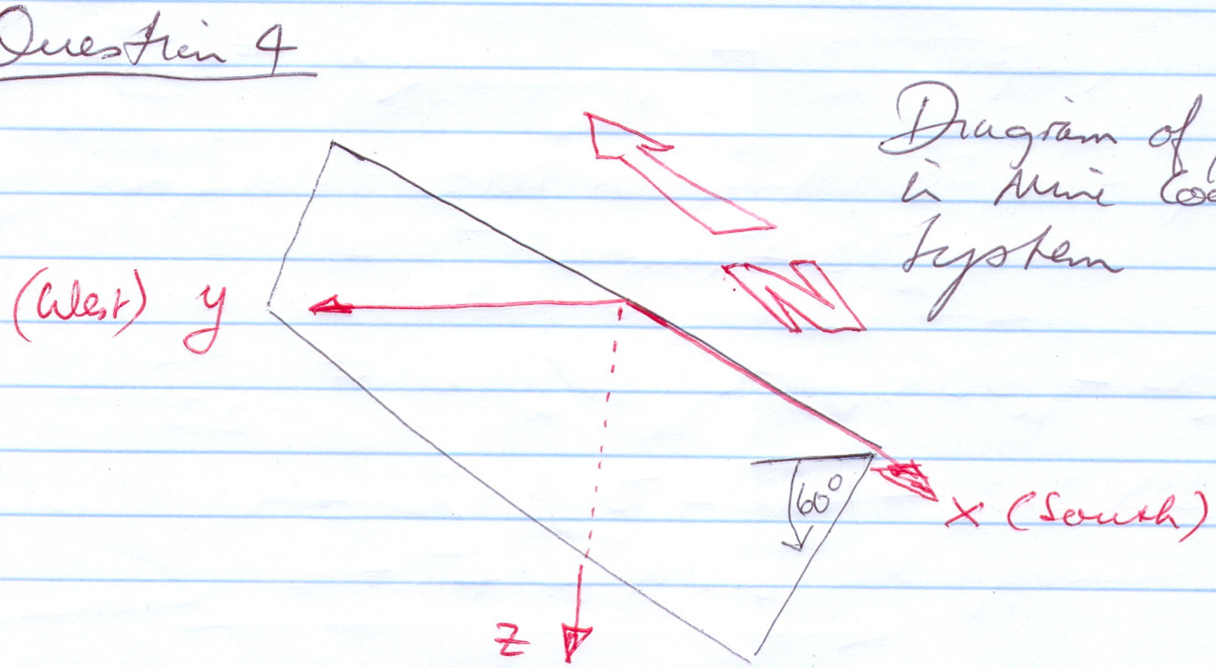
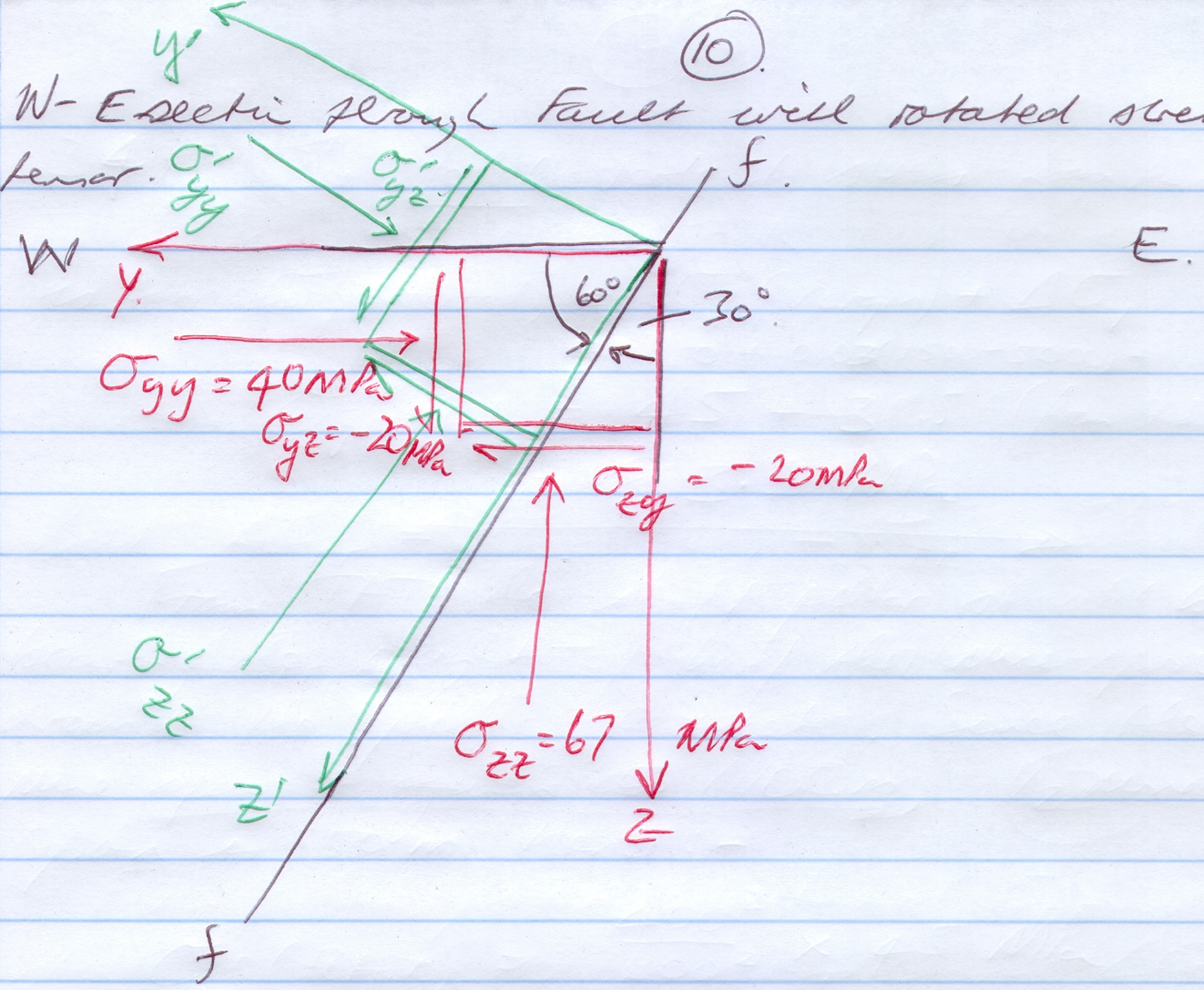


Diagram of fault in Mine Coordinate System

W-E section through fault with rotated stress tensor.



4.1). $\sigma_v = \rho g h \Rightarrow h = \dfrac{\sigma_v}{\rho g} = \dfrac{67e6}{2700 \times 9.81}$

②

$h = 2530$ m below surface

4.2) The water pressure sufficient to just force the fault open is $\sigma'_{yy}$, the normal stress clamping the fault. Using the stress rotation equations

$$\sigma'_{yy} = \sigma_{yy}\cos^2\theta + 2\tau_{yz}\sin\theta\cos\theta + \sigma_{zz}\sin^2\theta$$

$$= 40 * \cos^2(-30°) + 2\times -20 \sin -30 \cos -30 + 67 * \sin^2(-3)$$

$$= 30 + 17.32 + 16.75 = 67.82 \text{ MPa.}$$

⑤

4.3)

For slip to occur the Mohr-Coulomb slip criteria must be satisfied:

$$|\tau_{yz}| \geq (\sigma_n - p_w)\tan\phi + C_0$$

where $\phi$ is fault friction angle

$$p_w \geq \frac{\sigma_n \tan\phi + C_0 - |\tau_{yz}|}{\tan\phi}$$

$$p_w \geq \frac{67.82 * \tan 15^\circ + 4 - |\tau_{yz}|}{\tan 15^\circ}$$

$$|\tau'_{yz}| = \left|\tfrac{1}{2}(\sigma_{zz} - \sigma_{yy})\sin 2\theta + \tau_{yz}\cos 2\theta\right|$$

$$= \left|\tfrac{1}{2}(67 - 45)\sin(-60^\circ) + -20 * \cos(-60)\right|$$

$$= |-9.53 - 10|$$

$$= +19.53\text{MPa}$$

$$p_w \geq \frac{17.17 + 4 - 19.53}{\tan 15}$$

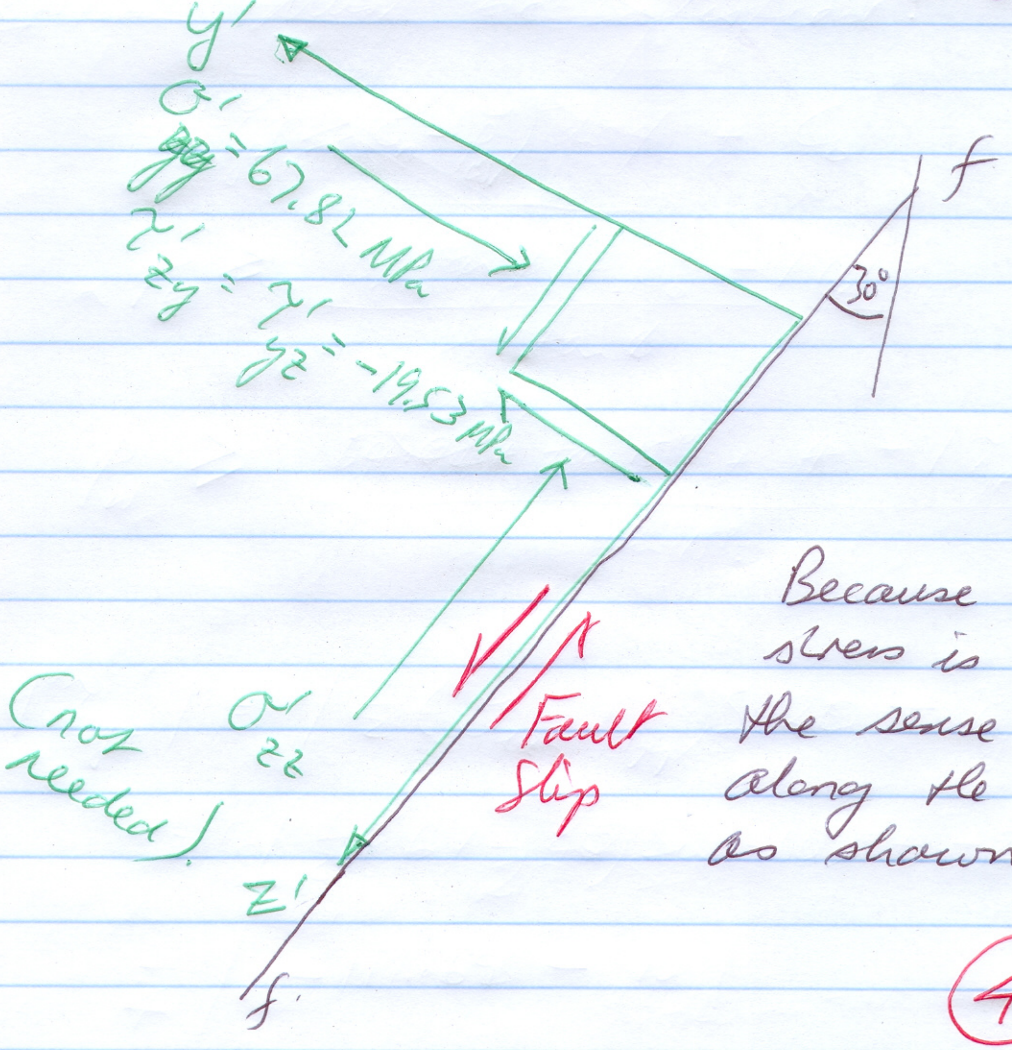
$$\geq 6.12\text{ MPa}$$

⑩

PTO.

4·5)

From diagram at begining of Questi 4:



Because the shear stress is negative, the sense of slip along the fault is as shown in the red.

4

4·4) (Sorry – forgot to do this first)

No. This is a two-dimensional problem and the other stresses are out-of-plane. Hence there is no room for any of the other shear stresses in the equations. Note that only the y and z axes are relevant.

(This is for information of the candidate).

If we considered the problem in 3 dimensions, then we would have to consider the shear stresses in the y-x direction – that is shear along strike – the

⑬

y-z direction is the dip shear component, in the problem as it is given.

④.

Exam Nº 16