Rock Mechanics Paper 1 Model Answers May 2006

Question 1

1a) We must assume plane stress at the flattened end of the borehole

Then $\varepsilon_{zz} = \dfrac{-\lambda\Delta}{2G}$

$E = 50000 \Rightarrow G = 20000\,\text{MPa}$ and $\lambda = 20000\,\text{MPa}$

$$\varepsilon_{zz} = \frac{-20000\,(\varepsilon_{xx} + c_{yy} + \varepsilon_{zz})}{2 \times 20000}$$

$$\Rightarrow \frac{3}{2}\varepsilon_{zz} = -\frac{1}{2}(\varepsilon_{xx} + \varepsilon_{yy}) \Rightarrow \varepsilon_{zz} = -\frac{1}{3}(0.000228 + 0.000188)$$

$$\underline{\varepsilon_{zz} = -0.000139}$$

$$\sigma_{xx} = \lambda\Delta + 2G\varepsilon_{xx} = 20000\,(0.000228 + 0.000188 - 0.000139)$$
$$+ 2 \times 20000\,(0.000228)$$

$$\underline{\sigma_{xx} = 14.67\,\text{MPa}}$$

$$\sigma_{yy} = \lambda\Delta + 2G\varepsilon_{yy} = 20000\,(0.000277) + 40000\,(0.000188)$$

$$\underline{\sigma_{yy} = 13.06\,\text{MPa}}$$

$$\sigma_{xy} = 2G\varepsilon_{xy} = 40000 \times -0.000113 = \underline{-4.52\,\text{MPa}}$$

②

$$\sigma_1 = \frac{1}{2}(\sigma_{xx} + \sigma_{yy}) + \frac{1}{2}\sqrt{(\sigma_{xx} - \sigma_{yy})^2 + 4\sigma_{xy}^2}$$

$$\sigma_1 = 13.86 + 4.59 = 18.45 \text{ MPa}$$

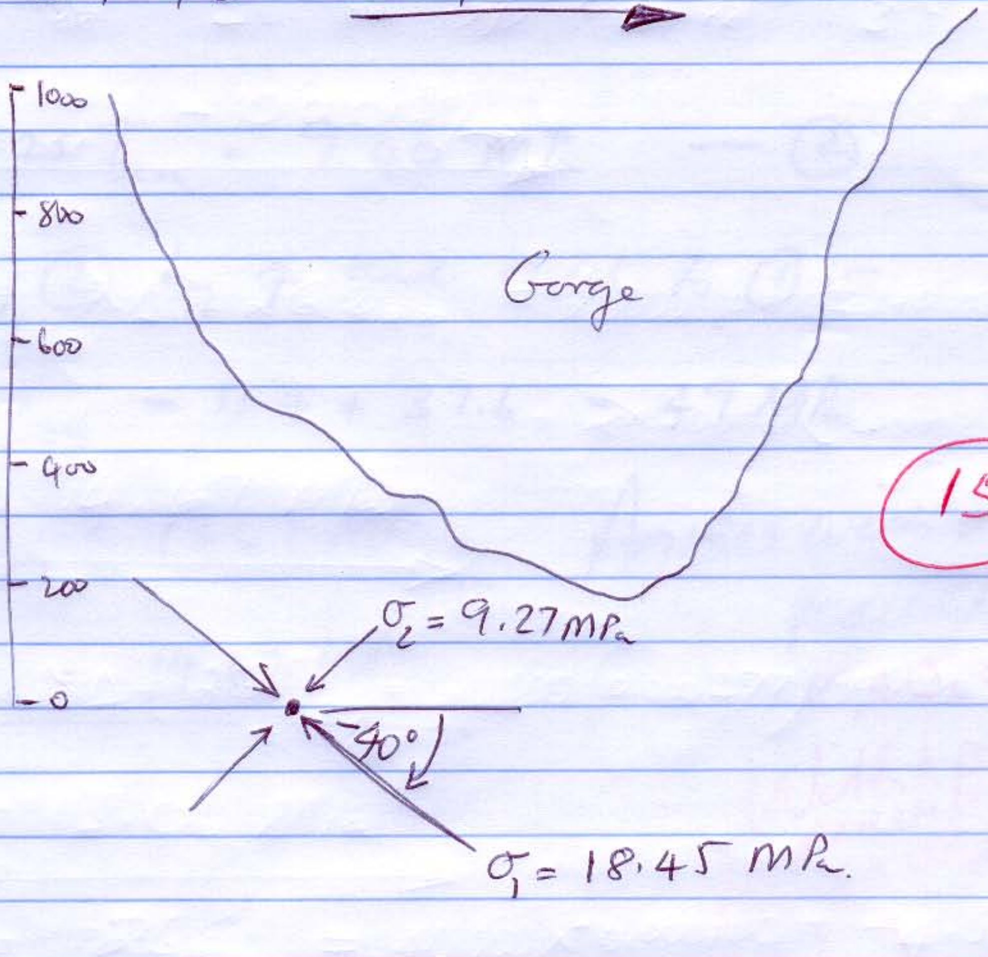
$$\sigma_2 = \frac{1}{2}(\sigma_{xx} + \sigma_{yy}) - \frac{1}{2}\sqrt{(\sigma_{xx} - \sigma_{yy})^2 + 4\sigma_{xy}^2}$$

$$= 13.86 - 4.59 = 9.27 \text{ MPa}$$

$$\theta = \frac{1}{2}\tan^{-1}\left(\frac{2\sigma_{xy}}{\sigma_{xx} - \sigma_{yy}}\right)$$

$$= \frac{1}{2}\tan^{-1}\left(\frac{-9.04}{1.61}\right)$$

$$= -39.96^\circ \cong -40^\circ$$



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The other way of getting the stresses is to:-

$$\varepsilon_{xx} = \frac{1}{E}\left(\tau_{xx} - \nu(\tau_{yy})\right) \quad [\tau_{zz} = 0]$$

In this case we do have to assume plane stress, by taking $\tau_{zz} = 0$

$$0.000228 = \frac{1}{50000}\left(\tau_{xx} - 0.25\,\tau_{yy}\right)$$

$$\tau_{xx} - 0.25\,\tau_{yy} = 11.40 \text{ MPa} \quad — ①$$

$$\varepsilon_{yy} = \frac{1}{E}\left(\tau_{yy} - 0.25\,\tau_{xx}\right)$$

$\tau_{xx} \equiv \sigma_{xx}$
$\tau_{yy} \equiv \sigma_{yy}$

$$.000188 = \frac{1}{50000}\left(\tau_{yy} - 0.25\,\tau_{xx}\right)$$

$$\tau_{yy} - 0.25\,\tau_{xx} = 9.40 \text{ MPa} \quad — ②.$$

Multiply ② by 4 and add to ①:-

$$3.75\,\tau_{yy} - 11.4 + 37.6 = 49 \text{ MPa}$$

$$\underline{\tau_{yy} = 13.07 \text{ MPa}}$$

$$\underline{\tau_{xx} = 14.67 \text{ MPa}}$$

Agrees with other results.

σ_1 & σ_2 calculations and plots on previous page
With this is also work

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Question 1.2

Vertical Stress at borehole due to overburden weight

$$\sigma_v = \rho g h \cong 2900 \times 9.81 \times 490m$$

$$\sigma_v = 13.94 \, MPa$$

This compares with $\sigma_{yy} = 13.06 \, MPa$.

This is not considered to be significantly different from ~~σ_{yy}~~ the borehole measurement because the rock stress measurements are found to vary 20% around expected values, so

$$13.94 \pm 2.79 \, MPa \Rightarrow 11.15 \leq \sigma_v \leq 16.73 \, MPa,$$

and the borehole result falls within this range.

Secondly the principal stresses are found to lie more or less ‖el to the gorge profile, which also suggests that the measurements are reasonable. Thirdly the largest principal stress lies parallel to gorge profile while smallest is ⊥ to it, also a reasonable result. The measurement obtained is therefore considered reasonable.

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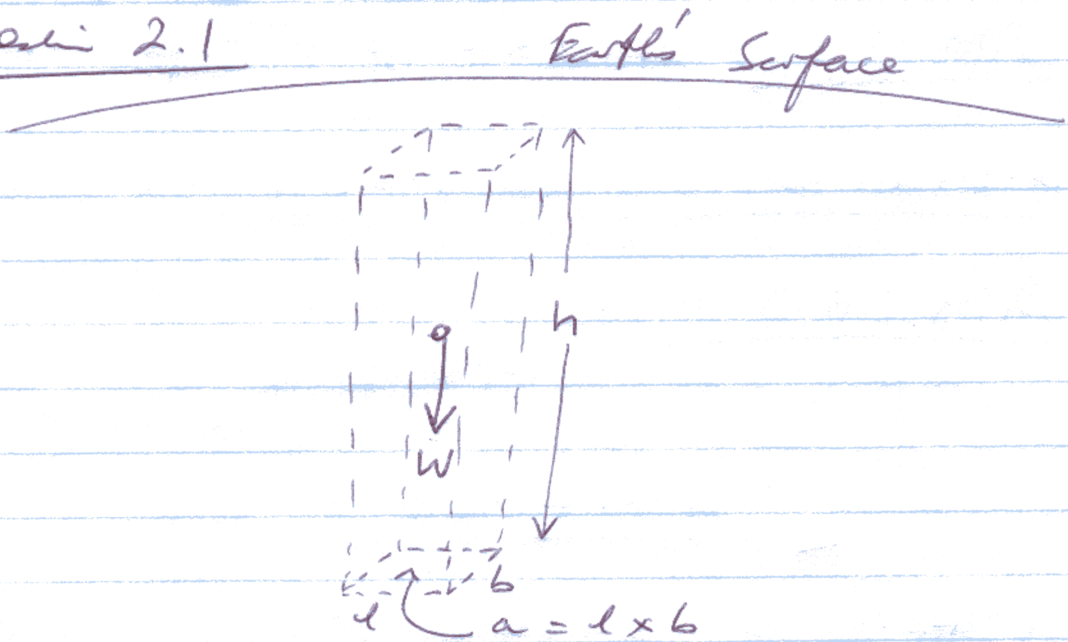
Question 2

Question 2.1



Weight of imaginary prism of rock $= l \times b \times h \times \rho \times g$

$$W = \rho g l b h.$$

Stress is $\frac{\text{force}}{\text{area}} \Rightarrow \sigma_v = \frac{\rho g l b h}{l b}$ 5

$$\sigma_v = \rho g h$$ qed.

Question 2.2

Stress at A: $\sigma_v = 15 \times 22000 + 15 \times 30000 + 6 \times 15000 + 10 \times 27000$

$= 330\ kPa + 450\ kPa + 90\ kPa + 270\ kPa$

At A: $\sigma_v = 1.14\ MPa$

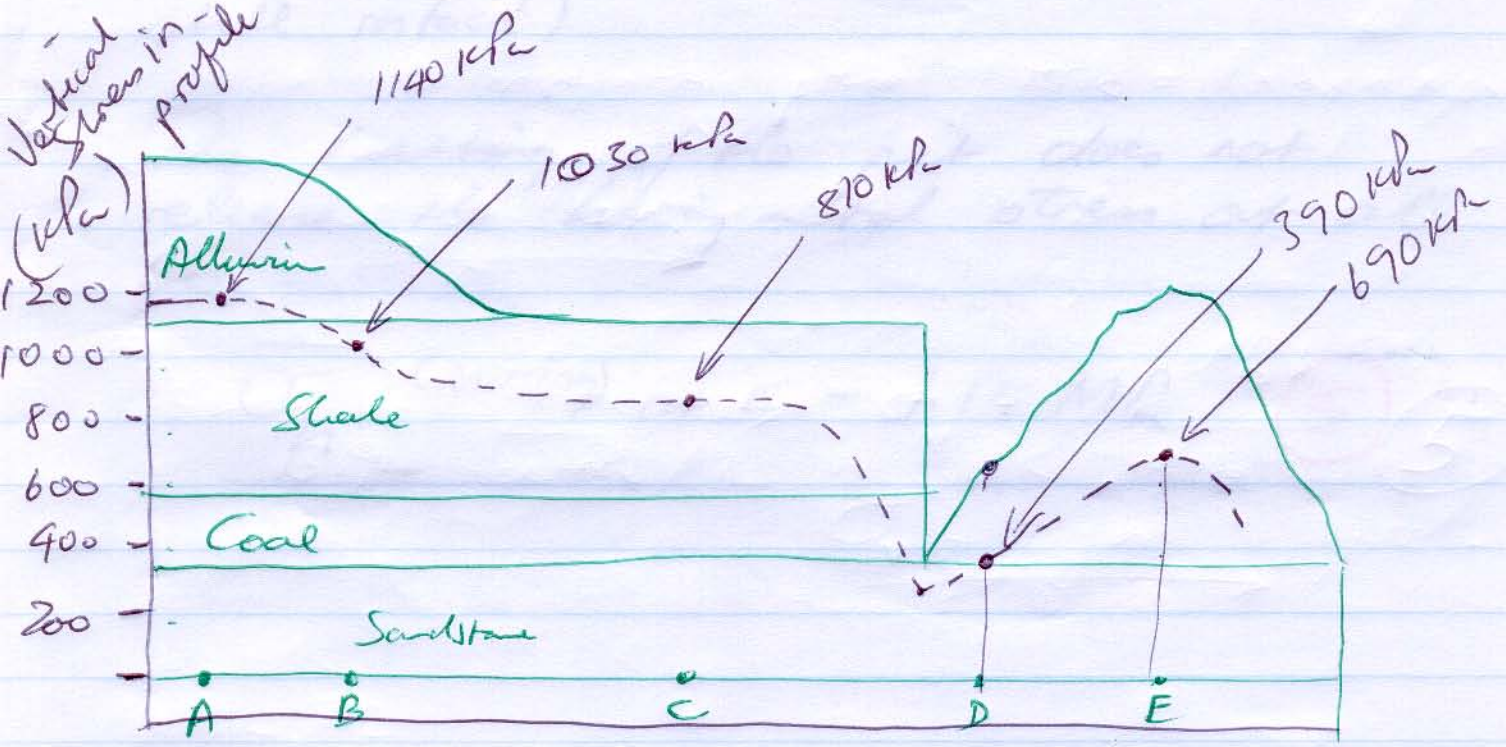
(6)

B : 1030 kPa = 1.03 MPa

C : 450 + 90 + 270 kPa = 0.81 MPa

D : 270 + 120 = 0.39 MPa

E : 270 + 420 = 0.69 MPa



Vertical Stress shown by dotted black line

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Quest 2.3

Vertical Virgin stress at E is given by

σ_v (virgin) $= 15 \times 22000 + 15 \times 30000 + 6 \times 15000 + 10 \times 27000$

$= 330$ kPa $+ 450$ kPa $+ 90$ kPa $+ 270$ kPa

σ_v (virgin) $= 1.14$ MPa

$\therefore \sigma_h$ (Virgin) $= 1.14$ MPa at E, because it will be the same as the stress is now at A (with all the overburden above still intact).

The cutting of the pit does not release the horizontal stress at all so --

σ_h (mining) at $E = 1.14$ MPa

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Question 3

Question 3.1

Because the stope is very shallow-dipping and panels on both sides of the gully will be mined simultaneously, we can assume that the analytical model for stope ~~closu~~ convergence in an elastic medium will provide a reasonable estimate of convergence.

Hence

$$S_z = \frac{2(1-\nu)\sigma_v}{G}\sqrt{l^2 - x^2}$$ is a reasonable model.

The props are assumed to be 1.2m long when installed, hence if they can take 30% of their length in convergence, they can be compressed a total of 0.36m or 360 mm, before they will fail.

Hence $S_z = 0.36\,m$

$$\sigma_v = 3000 \times 1800 \times 9.81 = \underline{52.97\,MPa}$$

Assume: $\nu = 0.25$

$$G = \frac{E}{2(1+\nu)} = \frac{60\,000}{2(1+0.25)} = \underline{40\,000\,MPa}$$

$$0.36 = \frac{2(1-0.25)\overset{52.97}{}}{240\,00}\sqrt{l^2 - 2^2}$$

$\sqrt{l^2 - x^2} = 108.7\ m \Rightarrow l^2 = 11825 - 4 = 11821$

next page

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$l = 108.7$ m. $\simeq 109$ m.

The panel had already advanced 5 m from gully centre when props were installed, and we assume negligible ~~closure~~ convergence when props were installed. The panels are expected to be able to advance 109 - 5 m before the props are compressed 30% of their length (i.e. they are reaching the point of failure). Therefore stope ½ span is 104 m and we can expect to mine 10 months @ 10m/month face advance before props will fail.

This distance is probably larger than half the raise-line distance i.e. if raise lines are 200 m apart, the stope faces will only advance 100 m before they hole into the stope faces from the next raise line.

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Question 3.2

Between crush pillars, we can expect a mined span of 27 m on dip between the dip crush pillars. Convergence for a 14½ m stope half-span is:-

$$S_z = \frac{2(1-\nu)}{G}\sigma_v\sqrt{l^2 - x^2}$$

Here $x = 0$

$$S_z = \frac{2(1-0.25)\ 52.97}{24000} \cdot .27$$

$$S_z = 89 \text{ mm}$$

This is far less than the 360mm yield that the props can undergo, hence if there are crush pillars, unless they crush more than about 20% of the original height it is not expected that the props will ever fail on the gully shoulder.

Note that we assume that this is true for all mining half-spans greater than 30m, ie. when mining is more than 3 months in progress.

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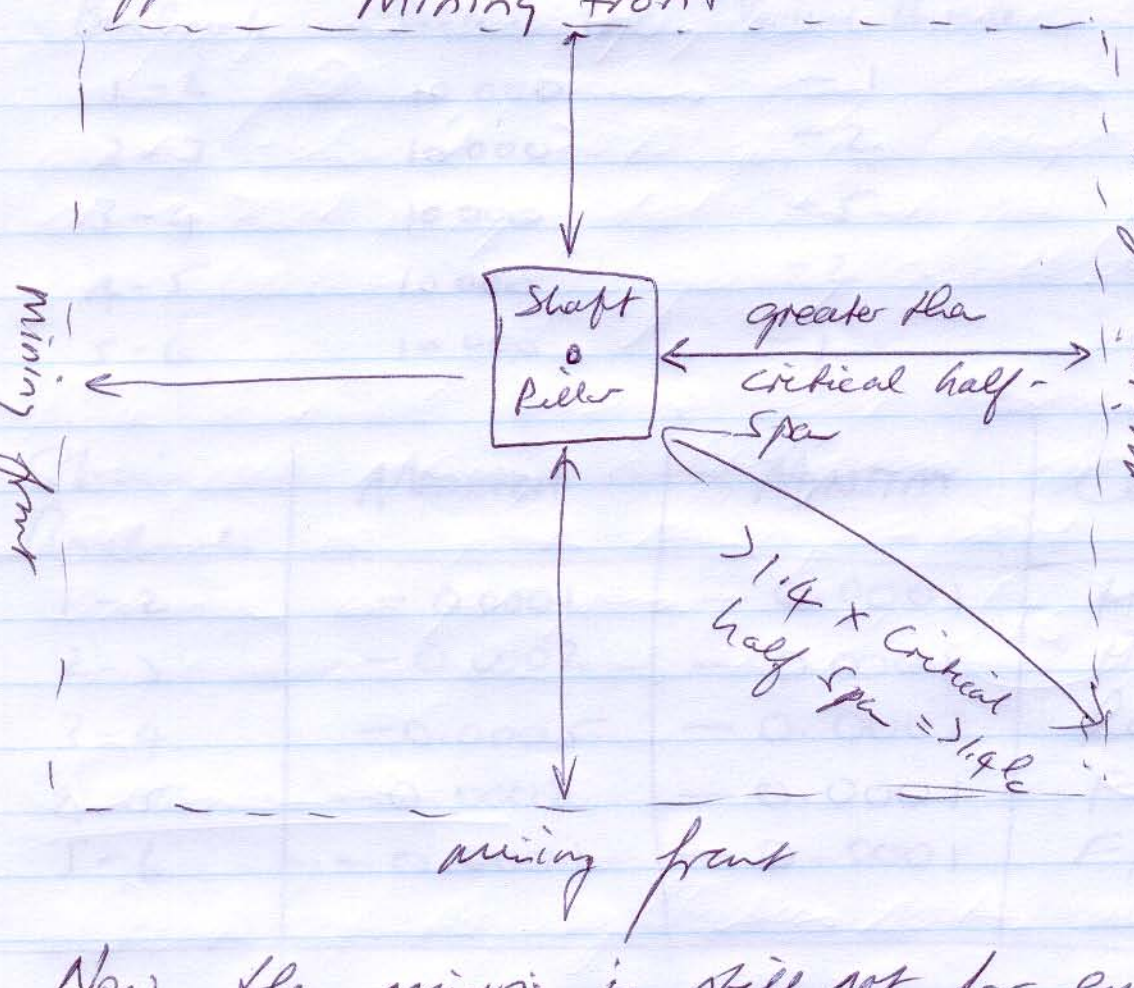
Question 4

Out of the syllabus notes and textbooks.

Question 5

Question 5.1

Since stoping had extended beyond the critical half span on all sides surrounding the pillar, the following simple drawing suffices:



Now, the mining is still not far enough to have total closure halfway between the pillar and the mining front, so stress increases with increasing distance of the mining front from the shaft pillar will still be significant.

5.2 Vertical Strain in Shaft Barrel

Ignore the displacements in the y-direction. These represent closure or opening of the shaft barrel itself. It is a good approximation to ~~measure~~ use only the vertical displacements in the shaft to measure vertical strains.

DISPLACEMENTS

Benchmark	Distance to	Measured Reduction in Vertical Distance	MINSIM Reduction
1 - 2	10 000	−1	−1.
2 - 3	10 000	−2	−1
3 - 4	10 000	−5	−2
4 - 5	10 000	−2	−1
5 - 6	10 000	−1	−1

Strain Benchmarks	Measured	MINSIM	Comments
1 - 2	−0.0001	−0.0001	H/W
2 - 3	−0.0002	−0.0001	H/W
3 - 4	−0.0005	−0.0002	Reef
4 - 5	−0.0002	−0.0001	F/W
5 - 6	−0.0001	−0.0001	F/W

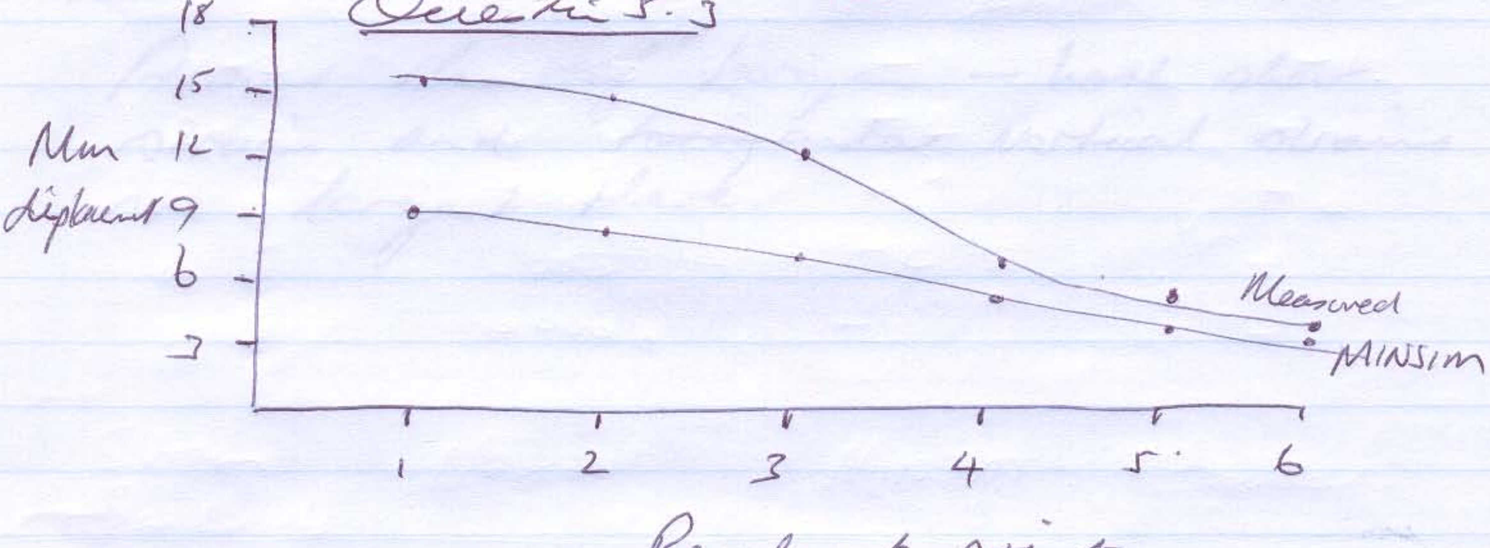
MINSIM deviates most from the measured strains near the reef horizon, and the difference further away became smaller.

The reason for this is firstly that in MINSIM, the Young's Modulus for intact rock was probably used, whereas in the field, the Young's modulus will be less because of the presence of discontinuities – joints, bedding and faults, fractures etc.

~~Question~~ 5.2

Minsim estimates only half the induced strain near the reef, so it is a good idea to monitor the situation, as has been done. (10).

Question 5.3



1) As we go deeper into the footwall the displacements become less
2) The downward displacements (U_z positive down) accumulate upwards into the hanging wall
3) Change in displacement gradient (MINSIM and measured) are greatest in the vicinity of the reef. (5)

Question 5.4

We cannot det. horizontal strain from displacements in the shaft. We would need extensometers mounted in horizontal holes to measure horizontal strain.

Question 5.5

Shear strain ~~cannot~~ can be ~~measured~~ calculated from the benchmark displacements.

Question 5.6

Around the reef horizon. - both shear strains and ~~horizontal~~ vertical strains are largest here.