Q+A

CHAMBER OF MINES OF SOUTH AFRICA

WRITTEN EXAMINATION FOR THE CERTIFICATE IN ROCK MECHANICS

METALLIFEROUS & COAL OPTIONS

PART 1 - THEORY	12 May 1997
EXAMINER:	Mr GS Esterhuizen
MODERATOR:	Mr KR Noble

Maximum time allowed 3 hours (09:00 - 12:00)

ANSWER ALL QUESTIONS

A pass mark is 60 per cent.

References are not permitted.

Hand-held electronic calculators may be used. (No pre-programming.)

Put your examination number of the outside cover of each book used, and on any graph paper or other loose sheets handed in.

NB: Your name must not appear on any answer book or loose sheets.

Write on one side of the paper only.

Show all calculations on which your answers are based.

In answering these questions, full advantage should be taken wherever necessary of your practical experience as well as of the data given.

Unless stated otherwise, assume the density of quartzite is 2 700 kg/m^3, the Poisson ratio is 0,2 and the modulus of elasticity is 72 GPa.

PART 1 - THEORY

QUESTION 1

Intact rock strength

(a) A number of compression tests were carried out on 50 mm diameter samples of quartzite.
The results were as follows (results in MPa):

Test:	1	2	3	4	5	6	7	8	9
σ_3	0	0	0	5	5	5	10	10	20
σ_1	180	183	175	201	198	207	231	244	269

Make use of the graph paper to plot the test results and to determine the uniaxial compressive strength of the rock, the friction angle and the cohesion. The equations on the attached page may be of assistance.
10 marks

(b) You have determined that the above rock tends to split by extension fracturing when the extension strain (negative strain) is greater than -0,03 x 10^{-3}. Determine the minimum strain for test No. 6 in the above table, and comment on whether the specimen may have failed owing to the extension strain. The intact rock has an elastic modulus of 52 GPa and a Poisson's ratio of 0,22.
5 marks

(c) Which of the following failure criteria should provide the best representation of the rock strength in the above case: Coulomb criterion or Hoek-Brown criterion? Motivate your answer.
5 marks

TOTAL 20 marks

PART 1 - THEORY

QUESTION 2

Jointed rock and rock mass behaviour

(a) When creating excavations in jointed rock it is always recommended that the support be installed as close as possible to the advancing face. Refer to the behaviour of joints under shear to justify this practice.

5 marks

(b) The dilation caused by joints when they shear can have a stabilising effect. Explain with the aid of a sketch how this dilation may assist in improving the stability of an excavation in jointed rock.

5 marks

(c) Make use of the attached classification table to classify a rock mass for which the following data are known:
The rock mass contains one well developed joint set which dips at 70° to the South. A few randomly oriented joints have been observed. A tunnel will be developed from East to West through this rock mass.
Intact rock uniaxial compressive strength: 162 MPa.
Rock Quality designation: 88%
Joint spacing: 1,5 to 2 m
Joint condition: Slightly rough with infilling of 1 to 2 mm
Groundwater: Dry
Make use of the classification parameters to calculate the uniaxial compressive strength of the rock mass using the Hoek-Brown criterion. The m-value for intact rock was found to be 12,5 based on triaxial strength tests. Comment on the validity of the strength which you have just calculated. The equations on the attached page may be useful.

10 marks

TOTAL 20 marks

PART 1 - THEORY

QUESTION 3

Stresses in the earth and monitoring

(a) Determine the horizontal component of the tectonic stress if the following stresses were measured at a depth of 500 m in norite:
Horizontal stress 22 MPa in all directions
Vertical stress 15,7 MPa
The norite rocks have an elastic modulus of 88 GPa, a Poisson's ratio of 0,25 and a density of 3 200 kg/m^3. Assume g = 9,81 m/s^2.
5 marks

(b) The measurement of stress in rock is a task which must be carried out with great care. Name and discuss three factors which may cause inaccurate stress measurement results when using a triaxial strain gauge.
6 marks

(c) You have been given the task of monitoring a vertical shaft whilst mining is taking place in the vicinity of the shaft. It is not expected that the shaft will be damaged, but as a cautionary measure, the management would like to know whether there are any risks to safety and equipment during the mining operation which will take approximately 18 months to complete. What would you monitor, what type of instruments would you use and what monitoring programme would you recommend?
9 marks

TOTAL 20 marks

PAPER 1 - THEORY

QUESTION 4

Analytical and numerical models

(a) A vertical shaft with a diameter of 6 m has been excavated by a boring machine. It is intended to drill vertical ore passes close to this shaft. You have told the mine design staff that the ore passes should be at least 20 m away from the shaft. However, they are reluctant to abide by your recommendation and want to place the ore passes 10 m away from the shaft (skin to skin) as shown in figure 4.1. Make use of the equations for the stresses around circular excavations to demonstrate that your recommendation is valid.

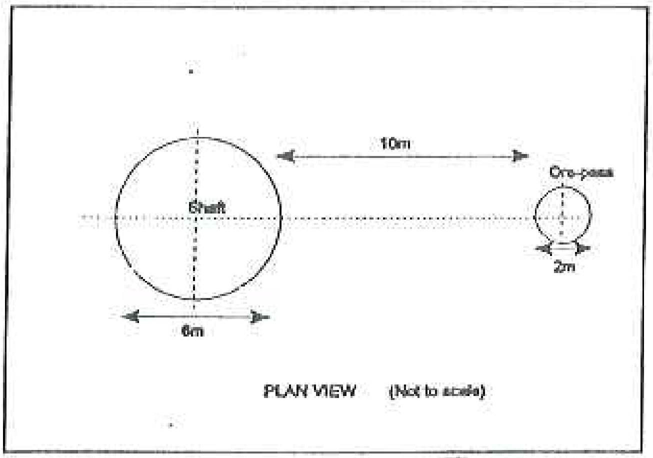

Figure 4.1 Plan view of proposed shaft and ore-pass

The following data are available. Horizontal k-ratio = 1 (Hydrostatic), horizontal stress = 50 MPa, estimated large scale strength of rock = 140 MPa. The formula for maximum tangential stress at boundary of circular excavation is on the attached page.

The proposed layout is as shown in figure 4.1
The equations for stresses at a point in the rock mass near a circular excavation for a hydrostatic stress field are on the attached page.

q is the field stress, r is the radius of the excavation and R is the radial distance to the point of interest.

10 marks

(b) Assume that the stresses at the proposed ore pass position are high enough to cause rock failure. Sketch the approximate location and type of failure of the surrounding rock that can be expected, and also explain why this failure would have more serious consequences in the ore pass than in a tunnel for example.

5 marks

(c) You intend to model the above shaft and ore pass using a two-dimensional elastic numerical model. State briefly the shortcomings of such a model and also state how the extent of potential failure around the excavations can be determined using the elastic model.

5 marks

TOTAL 20 marks

PAPER 1 - THEORY

QUESTION 5

The following stresses were computed at a point 1 m into the sidewall of a tunnel, using a two dimensional stress analysis program:
$\sigma_x = 4$ MPa, $\sigma_y = 192$ MPa, $\tau_{xy} = 44$ MPa.
The x-axis is horizontal. The program assumes plane strain conditions. The rock properties are as follows:
E = 65 GPa, $\nu = 0{,}18$

(a) Determine the out of plane stress and determine whether this stress is the minimum principal stress.

7 marks

(b) Calculate the strength of the rock at the above point and determine whether it will fail if the following data are available for the Coulomb failure criterion:
cohesion = 12 MPa, friction angle = 32°. Indicate the orientation of the Coulomb failure plane relative to the excavation sidewall.

3 marks

TOTAL 10 marks

CSIR GEOMECHANICS CLASSIFICATION OF JOINTED ROCK MASSES

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

	PARAMETER		RANGES OF VALUES						
1	Strength of intact rock material	Point load strength index	> 8 MPa	4 - 8 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred		
		Uniaxial compressive strength	> 200 MPa	100 - 200 MPa	50 - 100 MPa	25 - 50 MPa	10-25 MPa	3-10 MPa	1-3 MPa
	Rating		15	12	7	4	2	1	0
2	Drill core quality RQD		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%		
	Rating		20	17	13	8	3		
3	Spacing of joints		> 3m	1 - 3m	0.3 - 1m	50 - 300 mm	< 50 mm		
	Rating		30	25	20	10	5		
4	Condition of joints		Very rough surfaces Not continuous No separation Hard joint wall rock	Slightly rough surfaces Separation < 1 mm Hard joint wall rock	Slightly rough surfaces Separation < 1 mm Soft joint wall rock	Slickensided surfaces or Gouge < 5 mm thick or Joints open 1 - 5mm Continuous joints	Soft gouge > 5mm thick or Joints open > 5mm Continuous joints		
	Rating		25	20	12	6	0		
5	Ground water	Inflow per 10m tunnel length	None		< 25 litres/min	25 - 125 litres/min	> 125 litres/min		
		OR Ratio $\frac{\text{joint water pressure}}{\text{major principal stress}}$	0		OR 0.0 - 0.2	OR 0.2 - 0.5	OR > 0.5		
		OR General conditions	Completely dry		OR Moist only (interstitial water)	OR Water under moderate pressure	OR Severe water problems		
	Rating		10		7	4	0		

B. RATING ADJUSTMENT FOR JOINT ORIENTATIONS

Strike and dip orientations of joints		Very favourable	Favourable	Fair	Unfavourable	Very unfavourable
Ratings	Tunnels	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	-60

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 — 81	80 — 61	60 — 41	40 — 21	< 20
Class No	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. MEANING OF ROCK MASS CLASSES

Class No	I	II	III	IV	V
Average stand-up time	10 years for 5m span	6 months for 4 m span	1 week for 3 m span	5 hours for 1.5 m span	10 min. for 0.5m span
Cohesion of the rock mass	> 300 kPa	200 - 300 kPa	150 - 200 kPa	100 - 150 kPa	< 100 kPa
Friction angle of the rock mass	> 45°	40° - 45°	35° - 40°	30° - 35°	< 30°

TABLE 6 - THE EFFECT OF JOINT STRIKE AND DIP ORIENTATIONS IN TUNNELLING

Strike perpendicular to tunnel axis				Strike parallel to tunnel axis		Dip 0° - 20° irrespective of strike
Drive with dip		Drive against dip				
Dip 45° - 90°	Dip 20° - 45°	Dip 45° - 90°	Dip 20° - 45°	Dip 45° - 90°	Dip 20° - 45°	
Very favourable	Favourable	Fair	Unfavourable	Very unfavourable	Fair	Unfavourable

$$\tan\psi = \frac{1 + \sin\phi}{1 - \sin\phi}$$

$$\sigma_c = \frac{2c\cos\phi}{1 - \sin\phi}$$

$$\frac{m}{m_i} = e^{\left(\frac{RMR - 100}{24}\right)}$$

$$s = e^{\left(\frac{RMR - 100}{9}\right)}$$

$$\sigma_1 = \sigma_3 + (m\sigma_c\sigma_3 + s\sigma_c^2)^{\frac{1}{2}}$$

$$\sigma_{max} = 3\sigma_1 - \sigma_3$$

$$\sigma_r = q\left(1 - \frac{r^2}{R^2}\right)$$

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

$$\tau_{r\theta} = 0$$

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Q1 a) Plot of results should show $\phi \approx 35-40^\circ$
and $C \approx 35$ MPa
the equation $\sigma_c = \dfrac{2c\cos\phi}{1-\sin\phi} = \dfrac{2.35\cos 40^\circ}{1-\sin 40^\circ} = 150$ MPa.

b) ε_3 for test no 6:
In triax test $\sigma_2 = \sigma_3$ N.B. 3D situation!

$$\varepsilon_3 = \frac{1}{E}\left(\sigma_3 - \nu(\sigma_1 + \sigma_2)\right)$$

$$= \frac{1}{52000}\left(5 - 0{,}22\,(207 + 5)\right)$$

$$= -0{,}8 \times 10^{-3}$$

Yes: likely to have failed in extension

c) Hoek Brown - because Coulomb assumes rock fail in shear - this is not the case if specimens fail by splitting. H & B criterion does not assume a failure mechanism, but merely attempts to fit the actual results.

Q2 a) Joint strength τ
reaches peak
after small displacement

If blocks allowed to move
shear strength destroyed and becomes less stable.
Early support will assist in keeping shear strength in pre-peak range & preserve peak strength

b) In ug excavation when joint starts to move dilation occurs due to roughness,
if  dilation forces increase normal stress on shearing planes ⇒ increases shear resista

2
c) Rock classification using RMR

UCS: 162	12
RQD: 88 %	17
Joint Sp: 1.5 - 2	25
Join Cond: SR fill 1-2mm	12
GW: Dry	10
	76

Individual ratings may differ based on personal interpreta

$m_i = 12,5$ given

adjustment confer -
UCS if $\sigma_3 = 0$

$\Rightarrow \sigma_c = UCS \times \sqrt{S}$

$= 42,7 MPa.$

$S = e^{\left(\frac{RMR - 100}{9}\right)}$

$= 0,06948$

$m = m_i e^{\left(\frac{RMR - 100}{24}\right)}$

$= 4,599$

Strength is only valid for large rock sample where side dimension is say 10x joint spacing (ie 10-20 m block)

Q3 a) $q = \rho g h = 3200 \times 9,81 \times 500 = 15,7 MPa$

Poisson effect $\sigma_h = \frac{\nu}{1-\nu} \sigma v = \frac{0,25}{0,75} \sigma_v = 5,2M$

$\Rightarrow$ Tectonic effect $22 - 5,2 = \underline{16,8 MPa}$ Horiz

b) 1) Grain size of rock (eg quartz pebbles in conglomerate) local effects may override strain measurements

2) Poor contact between strain gauge & rock surface - difficulty in using glue down a small hole

3) Incorrect orientation of strain gauges - difficulty in working in small hole

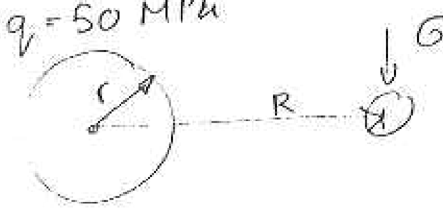
4) Local fractures in rock - small scale discontinuities will affect small scale measurements.

3(c) Main cause of damage is differential strain which may damage steelwork / lining. Need to measure vertical & horizontal displacement

- Install pegs for survey to measure vertical
- Need accurate steel tape extensometer
- Institute logging system during shaft exams to note changes in steelwork / buckling / cracks in concrete lining
- Programme - weekly inspections during shaft exam + measurement of pegs - plot and present graphically. (9
- Borescope to see behind lining
- Seismic monitoring to see if potential damage near shaft - active structures etc

Q4 a) Calc effect of shaft on stress field at one pass

$\sigma_\theta = q\left(1 + \frac{r^2}{R^2}\right)$ R = 3 + 10 + 1 = 14m, r = 3



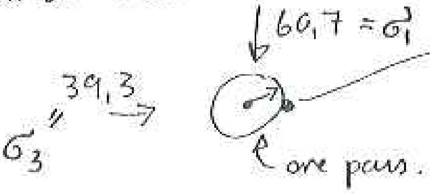
$= 50\left(1 + \frac{3}{14}\right)$

$= 60{,}7$ MPa

$\sigma_r = 50\left(1 - \frac{3}{14}\right)$

$= 39{,}3$ MPa

Max Stresses around ore pass:



σ_{max} at side of o/p. $= 3\sigma_1 - \sigma_3$

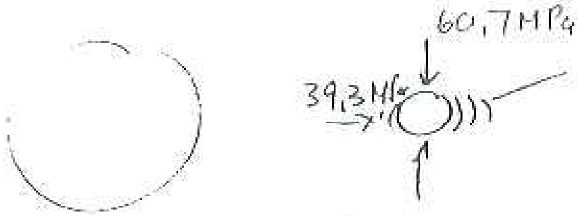
$= 3 . 60{,}7 - 39{,}3$

$= 142{,}6$ MPa

If no shaft effect max stress at ore pass will be: $\sigma_{max} = 3 . 50 - 50 = 100$ MPa (10

⇒ [illegible] 42,6 increase in stre

4 b)



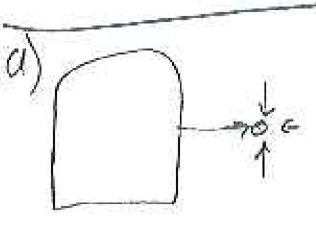
fracturing will be in form of dog earing here

More screens in ore pass because ore tipped will remove fractured rock & cause further fracturing to continue - could carry on till ore pass holes into shaft ! (5)

4 c) Elastic model does not model failure, assumes rock is continuous, etc. Will not take into account already failed material. Failure extent can be estimated using say H & Brown criterion and apply it at "benchmark" points in surrounding rock. (5)

Question 5

a)



$\sigma_x = 4$
$\sigma_y = 192$
$\tau_{xy} = 44$

First calc out of plane stress:

$$\varepsilon_z = 0 = \frac{1}{E}\left(\sigma_z - \nu(\sigma_x + \sigma_y)\right) \text{Hc}$$

$$\Rightarrow \sigma_z = \nu(\sigma_x + \sigma_y) = \underline{35,3 \text{ MPa}}$$

This is a principal stress.

Determine principal stresses in 2D plane.

$\sigma_1 = \frac{1}{2} \ldots$ not really required

$$\sigma_2 = \frac{1}{2}(\sigma_x + \sigma_y) - \frac{1}{2}\sqrt{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2}$$

$$= \frac{1}{2}(196) - \frac{1}{2}\left(\sqrt{188^2 + 4(44)^2}\right.$$

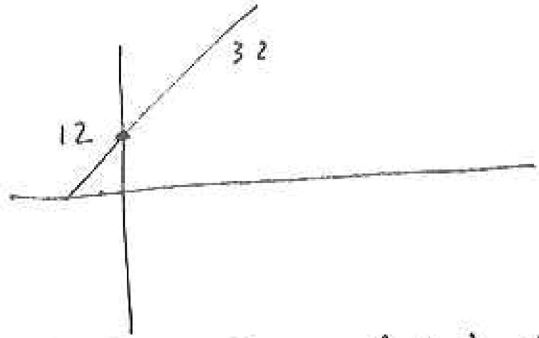
$$= 98 - 103,8$$

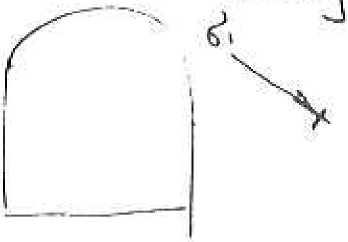
$$= -5,78 \text{ MPa}$$

$\Rightarrow \sigma_z$ is not minimum principal stress!

5b) Calc strength:

Rock will fail in tension or may shear:





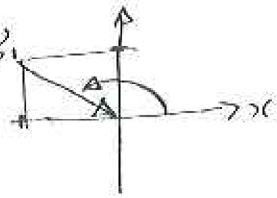
Angle of θ_1 relative to x-axis:

$$\theta_1 = \frac{1}{2}\arctan\frac{2\tau_{xy}}{(\sigma_x - \sigma_y)}$$

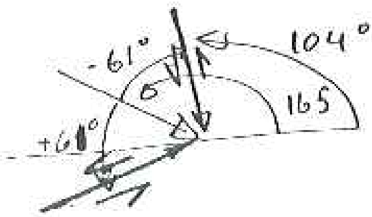
$$= \frac{1}{2}\arctan\left(\frac{88}{-188}\right)$$

$= 25°$ (2nd quard

ie $= 165°$



Shear plane is $45° + \phi/2$ from this orientation: ie $45 + 16 = 61°$



Two shear planes at 104° and 226° from horizontal