CHAMBER OF MINES OF SOUTH AFRICA

WRITTEN EXAMINATION FOR THE CERTIFICATE IN ROCK MECHANICS

METALLIFEROUS & COAL OPTIONS

PART 1 - THEORY 10 November 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.

EXAMINATION INSTRUCTIONS

1. References are not permitted.

2. Hand-held electronic calculators may be used.
   (NO PRE-PROGRAMMING)

3. Write your examination number on 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.

4. Write on one side of the paper only.

5. State clearly any assumptions you make and show all calculations on which your answers are based.

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

7. 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.

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QUESTION 1

Rock strength

i) Brittle failure of rock commences by the propagation of micro cracks in rock. If the rock is under uniaxial compression, explain how the cracks are able to propagate.

5 marks

ii) Calculate the strength of failed rock for confining pressures of 5, 10, 20, 40 MPa if it has the following properties for the Hoek-Brown equation: m = 1,5, s = 0.0, uniaxial compressive strength of the intact material is 180 MPa. Plot your results on the graph paper, because you will need them for the next question. Also, explain what is the mechanism that allows the failed rock to develop strength under confinement.

5 marks

iii) Assume the failed rock in the above question contains a natural discontinuity whose normal makes an angle of 62,5° to the direction of the major principal stress. (Note this is the most unfavourable orientation for Coulomb shear). The sample may therefore fail either by sliding along the discontinuity or by failing according to the Hoek-Brown equation. Make use of the Coulomb equation to determine at what confining pressure the rock will cease to slide along the discontinuity and rather fail according to the Hoek-Brown equation. The discontinuity friction angle is 35° and the cohesion is 5 MPa.

7 marks

iv) Violent failure of rock around mining excavations is related to the decrease in the strength after initial failure, why?

3 marks

TOTAL 20 marks

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QUESTION 2

Joints and rock mass strength

i) If we assume that the two surfaces of a joint are not welded together (ie - there is no resistance if you pull the surfaces apart), explain how it is possible for the joint to have cohesion.

5 marks

ii) 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

iii) If a rock mass contains joints in one predominant direction, its strength will not be isotropic. Make use of an annotated free hand sketch to indicate the typical variation in strength that will exist in the rock mass as the orientation with the joints varies from zero to 180°. Now indicate how the addition of a second joint set, which strikes parallel to the first, but the dip differs by 45° from the first set, will affect the strength of the rock mass.

5 marks

iv) Calculate the apparent cohesion of a joint surface at a normal stress of 2 MPa, using Barton's equation for joint shear strength. The following parameters are given: Base friction angle = 30°, joint roughness coefficient = 7, joint wall strength = 40 MPa.

5 marks

TOTAL 20 marks

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QUESTION 3

Basic principles of stress and strain

i) The following strain components were measured at a point in rock

$$\epsilon_x = 0{,}003, \qquad \epsilon_y = 0{,}00012, \qquad \gamma_{xy} = 0{,}0005$$

Determine the principal stresses in the x-y plane given that the modulus of elasticity is 72 GPa and the Poisson's ratio is 0,2.

5 marks

ii) The following stress state exists at a point in rock:

σ_x = 20 MPa
σ_y = 40 MPa
τ_{xy} = 10 MPa

a) Make use of the Mohr circle diagram to depict the stress state, indicate the maximum and minimum principal stresses.

b) Indicate on the diagram how you would determine the normal and shear stresses on a plane whose normal makes an angle of 15°, measured anti-clockwise with the x-axis.

c) Make a free-hand sketch to illustrate the orientation of the principal stresses relative to the x-y axes.

10 marks

iii) During the elastic part of the stress strain behaviour of rock, does the volume of the rock increase or decrease? Make use of an example calculation to show the effect of the Poisson's ratio on the change in volume.

5 marks

TOTAL 20 marks

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QUESTION 4

Stress and rock behaviour around excavations

i) Initial failure of rock due to high stresses may be predicted by using elastic numerical models. If the failed material is removed in the model, further failure will occur; this process could continue indefinitely in numerical models. In practice, failure does not continue indefinitely, but stops at a certain depth into the walls of an excavation. Make use of an example of a tunnel to illustrate why, in reality, the failure comes to a halt in the sidewalls.

5 marks

ii) A circular excavation with a diameter of 4 m is going to be developed by a tunnel borer in rock with the following stress field:

σ_x = 43 MPa
σ_y = 68 MPa
τ_{xy} = 22 MPa

Determine whether failure will take place in the skin of the excavation if the uniaxial compressive strength is 120 MPa. Indicate in an annotated free-hand sketch the location where failure is likely to initiate on the periphery of the tunnel.

10 marks

iii) If you were asked to evaluate the relative merits of a concrete lining or rock bolt support for the above excavation, using numerical models:

a) what type of modelling method would you use and why?
b) what input parameters would you require?
c) what will you look for in the model to decide which support type is likely to be the most successful in controlling the failed rock?

5 marks

TOTAL 20 marks

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QUESTION 5

Monitoring

i) You have to monitor the effects of mining on a pillar in a platinum mine. Mining is to take place in such a manner that the pillar is expected to yield over the next two months. You are interested in determining the strength of the pillar and its load deformation curve, beyond its peak strength if possible. There is a possibility that the pillar will yield by punching into the footwall. Mining has just exposed the pillar and it is unfractured at present. The pillar measures 5 m x 3 m in plan and is 1,4 m high. You will be able to access the pillar from a safe accessway during the experiment.

a) What parameters will you monitor? Motivate your answer.

b) Describe the types of instruments required and sketch their layout relative to the pillar.

c) Explain what problems you anticipate in obtaining the post peak characteristics of the pillar.

d) Explain how you will establish whether yield is taking place by failure of the pillar or by punching into the footwall.

15 marks

ii) The use of ground penetrating radar is being advocated as a tool for "seeing" into the rock around workings. What can you "see" with this method?

Name two potential applications and state briefly the current limitations of the method.

5 marks

TOTAL 20 marks

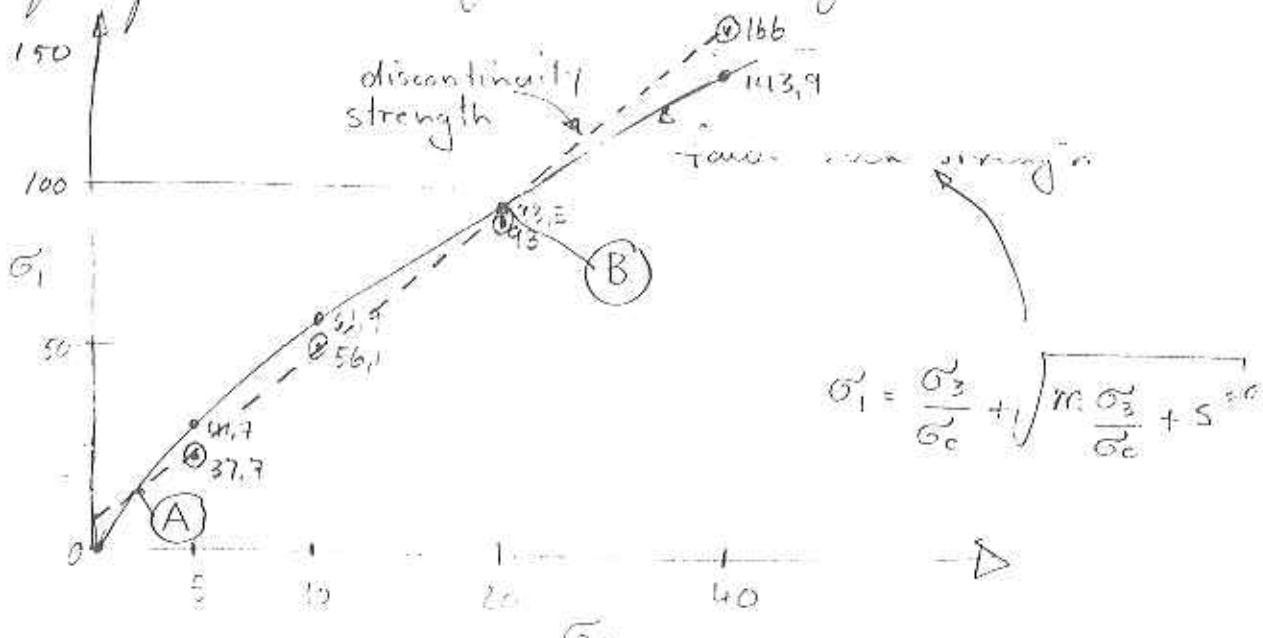
Paper 1 KM 1/12/94

Model Answers

Q1

i) Brittle fracture occurs when micro cracks extend in a direction // to major principal stress. This is possible because tensile stresses are induced at crack tips perpendicular to σ_1 - rock fails in tension at crack tip. Propagation continues until micro cracks coalesce into major fracture plane.

ii) Failed rock strength is caused by friction between fragments. Has no uniaxial strength but if confined will generate strength.



iii) Coulomb : $\sigma_1 = \dfrac{2c\cos\phi + \sigma_3(1+\sin\phi)}{1-\sin\phi}$

$c = 5$ MPa

$\phi = 35°$

Calculate strength (σ_1) for $\sigma_3 = 0, 5, 10$ etc

σ_3	σ_1
0	19,2
5	37,7
10	56,1
20	93
40	166

Plot on graph.

Between (A) and (B) will fail according to Hoek & Brown.

Q3

i) the Hooke laws:

$$\sigma_x = \frac{E}{1-\nu^2}(\varepsilon_x + \nu \varepsilon_y)$$

$$= \left(\frac{72000}{1-0,2^2}\right)(0.003 - 0,2 \cdot 0,00012)$$

$$= 226,8 \text{ MPa}$$

$$G = \frac{E}{2(1+\nu)} = 30 \text{ GPa}.$$

Similarly:

$$\sigma_y = 54 \text{ MPa}$$

$$\tau_{xy} = G\gamma_{xy} = 30000 \cdot 0,0005 = 15 \text{ MPa}.$$

Now calc σ_1:

$$\sigma_1 = \tfrac{1}{2}(\sigma_x + \sigma_y) + \tfrac{1}{2}\sqrt{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2}$$

$$= \underline{228,1 \text{ MPa}} \rightarrow$$

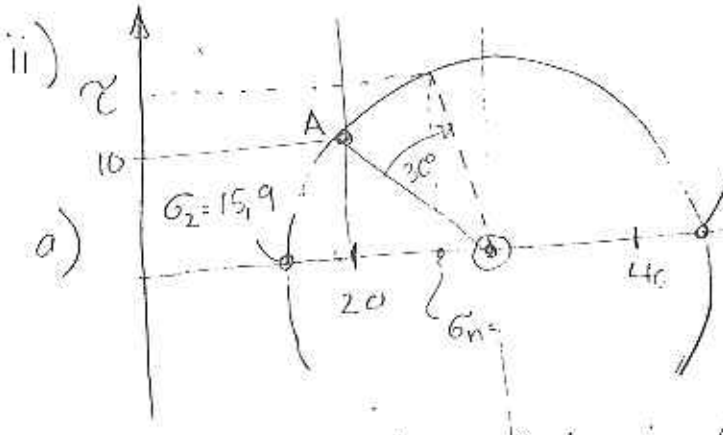
$$\sigma_2 = (\sigma_x + \sigma_y) - \sigma_1$$

$$= 280,8 - 228,1 = \underline{52,7 \text{ MPa}} \rightarrow$$

$$\Theta_1 = \tfrac{1}{2} \arctan \frac{2\tau_{xy}}{\sigma_x - \sigma_y} = \frac{2 \cdot 15}{(226 - 54)}$$

$$= \tfrac{1}{2}(9,2^\circ) = 4,92^\circ$$

ii)



OA is x-axis

from x-axis to σ_1 is 135°

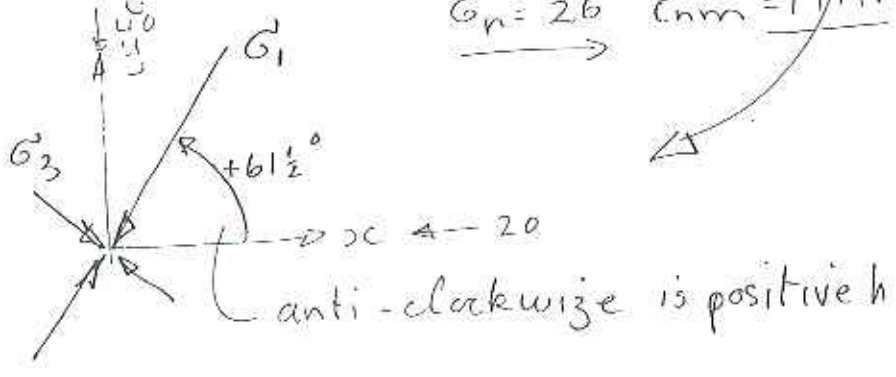
$\Rightarrow \Theta_1 = \frac{135}{2} = +67\frac{1}{2}^\circ$

a)

b) Draw 30° line clockwize from A, read σ, τ as:

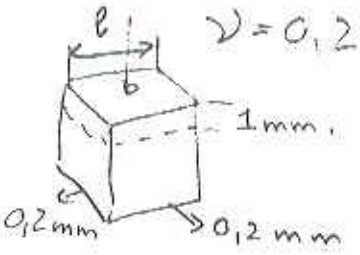
$\sigma_n = 26$ $\tau_{nm} = 14$ MPa

c) Sketch



Q3 cont'd

iii) Volume decrease - consider:



if cube shortens by 1mm will expand by 0,2mm

New dimensions: reduced by 1 mm in vertical direction, increased by 0,2 mm in width:

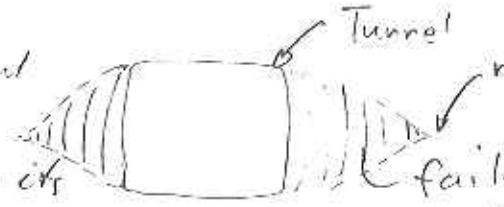
$\Rightarrow$ Volume = $(l + 0,2) \times (l + 0,2) \times (l - 1)$

if $l = 10$ mm

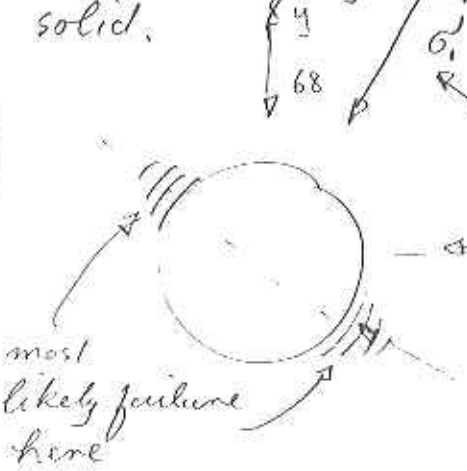
Volume = 936 mm^3 $\Rightarrow$ reduced from 1000 mm^3

Q4

i) Failed rock provides confinement to rock not yet failed. As depth of failure increases it's height decreases, until a notch is formed where failed rock becomes highly confined - also σ_3 increases rapidly into solid.



ii)



Calculate principal stresses and their orientation

σ_1 = 80,8 MPa

σ_3 = 30,2 MPa

θ_1 = 59,8°

Stress on edges of tunnel $3\sigma_1 - \sigma_3$ = 212,2 MPa

This is almost twice u.c.s. of rock - will definitely fail.

iii) a) Non-linear model to model post peak behaviour of rock, dilation, interaction with liner / bolts

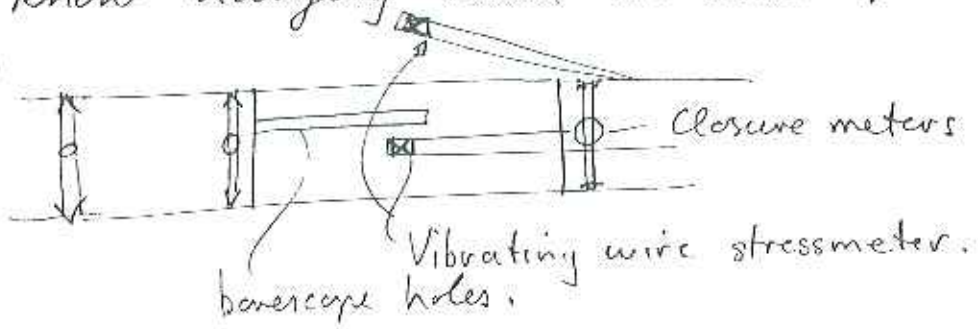
b) Post peak friction, cohesion, dilation of rock, bolt & concrete properties, stress history etc.

c) Deformation of sidewalls, stresses in support, depth of failure.

Q5(i)

a) Need stress/closure graph. Also need to identify whether footwall heave took place. Also need to know hanging wall behaviour. (4)

b)



- Attempt to measure absolute stress using doorstopper at start.
- Use vibrating wire stressmeters to get stress changes as mining proceeds.
- Inspect with borescope - dep't of fractures etc.
- Closure meters next to pillar and further away to pick up footwall heave.
- Photographic records.
-

c) Edges of pillar fail and out of instrumented holes, (can't measure closure at centre of pillar Punching will affect results - won't get pillar behaviour. How to get "average" pillar stress?

d) Look at closure around pillar - should be uniform. Footwall lifting is sign of punching Could try and see shear planes in footwall by drilling down, borescope. If pillar stops scaling

ii) GPR - see changes in electromag properties caused by changes in moisture, mineralisation, fracturing. Could use to see water fissures, depth of fracturing. Limited range and interference with steel etc...