CHAMBER OF MINES OF SOUTH AFRICA

EXAMINATION FOR THE CERTIFICATE IN ROCK MECHANICS

PAPER 2

METALLIFEROUS OPTION

SUBJECT:	EXAMINER:
CERT. IN ROCK MECHANICS PAPER 2 (METALLIFEROUS OPTION)	L J GARDNER
SUBJECT CODE:	**MODERATOR:**
COMRME	M K C ROBERTS
EXAMINATION DATE:	**TOTAL MARKS:** [100]
MAY 2006	**PASS MARK:** 60%

NUMBER OF PAGES: 7

SPECIAL REQUIREMENTS:

1. **Answer *ALL THE* questions**
2. References other than those provided are not permitted. (Refer No. 10)
3. Hand-held electronic calculators may be used.
4. Put 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.

5. Write in ink on the **RIGHT HAND SIDE** of the paper only.
6. Show all calculations on which your answers are based.
7. Illustrate your answers by sketches of diagrams wherever possible.
8. In answering these questions, full advantage should be taken wherever necessary of your practical experience as well as of the data given.
9. Answers must be given to an accuracy which is typical of practical conditions.
10. A list of formulae and any other essential charts and tables will be issued at time of the examination.

QUESTION 1 – GEOTECHNICAL INVESTIGATIONS

1.1 The primary purpose of rock mass rating systems is to classify the condition of the rock mass. The different rock mass rating systems generally employ several common measures, or elements. List four of these elements, and describe their role or effect on the overall rock mass condition. (10)

a) RQD – a basic measure of the rock mass integrity, can be expressed as a percentage out of 100. Definition can be included if desired. It is generally separated into 5 classes, from very poor to excellent. If RQD increases, rock mass condition (RMC) increases, if RQD decreases, RMC decreases.

b) *Joint integrity – is generally expressed as a combination of joint roughness and joint infilling. Rougher joints generally improve RMC, smooth planar joints deteriorate RMC. Tightly healed joints improve RMC, while joints infilled with thick, weak filling will obviously reduce RMC.*

c) *Presence of water – no water ensures that RMC remains in a static state, while the presence of increasing amounts of water results in associated reduction in RMC.*

d) Presence of additional discontinuities – no additional discontinuities ensures that RMC remains in a static state, while it deteriorates proportional to the number / quantity of additional discontinuities.

1.2 As part of a geotechnical investigation, you have submitted rock samples to a laboratory for rock property testing. The results of the tests are shown on the attached tables. You are required to analyse the results and determine the following (make use graph paper if required):

a) Tensile strength (1)
b) Uniaxial compressive strength (1)
c) Young's modulus (1)
d) Poisson's ratio (1)
e) Cohesion value (3)

f) Friction angle (3)

a) A simple numerical average of the five samples is 7.6 MPa

b) After eliminating result no 3 as it failed prematurely, the average of the remaining three samples is 185 MPa

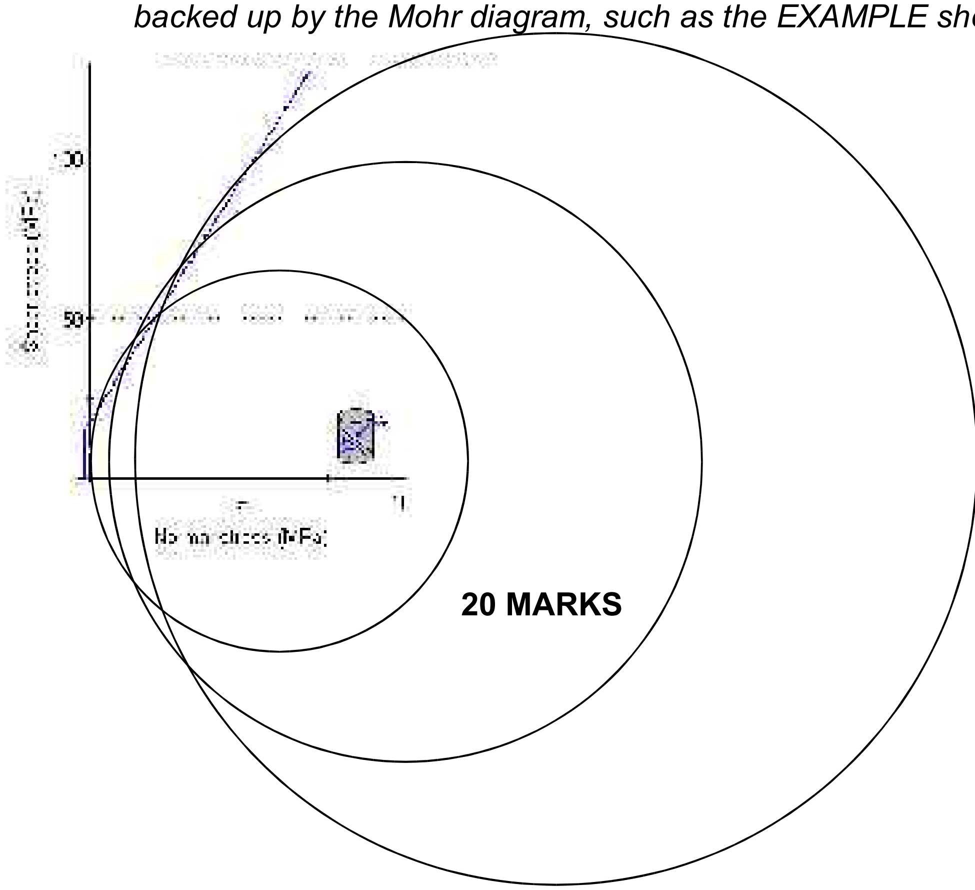
c) After eliminating result no 3 as it failed prematurely, the average of the remaining three samples is 60.83 GPa for the tangent modulus and 39.7 GPa for the secant modulus

d) After eliminating result no 3 as it failed prematurely, the average of the remaining three samples is 60.83 GPa for the tangent modulus and 39.7 GPa for the secant modulus

e) From the graph paper, the cohesion value is approximately 18 MPa

f) From the graph paper, the cohesion value is approximately 58 degrees

(for both e and f, a wide range of values was accepted if they could be backed up by the Mohr diagram, such as the EXAMPLE shown below)



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QUESTION 2 – PILLAR DESIGN

You have been contracted by the manager of a small, shallow mine to design a suitable stable pillar system for their proposed mechanised mining of a tabular orebody. The following information has been provided:

- The orebody dips at approximately 5 degrees
- The anticipated mining height is 2.0 – 2.5 metres
- Mining will take place from 150 – 400 metres below surface
- A standard room-and-pillar mining method is proposed, with 7 m rooms
- The average UCS of tested rock samples for the ore body is 240 MPa
- The average adjusted rock mass rating is 35 for the area in question, using the Laubscher MRMR system

2.1 Based on empirical evidence (not a formula), what value would you use for the rock mass strength and why? (3)

Literature suggests that the UCS be derated by between 50 and 67 % to achieve a rock mass strength that considers the implication of discontinuities. In view of the low RMR (35 out of a possible 100), it would probably be appropriate to derate by up to 67%, giving a DRMS of 80 MPa.

2.2 Based on the approach adopted by Hedley and Grant and using a 1.6 minimum safety factor, propose pillar sizes for the range of mining depths at 50 metre intervals, together with the appropriate extraction percentage. (10)

Depth below surf	Pillar Width	Pillar Length	Holing distance	Panel length	Mining height	Extr Ratio	DRMS	Pillar stress flat	Pillar strength Hedley	Safety factor Hedley
150	3.5	3.5	7.0	7.0	2.5	88.89	80.0	39.7	75.3	1.9
200	4.0	4.0	7.0	7.0	2.5	86.78	80.0	44.5	80.5	1.8
250	4.5	4.5	7.0	7.0	2.5	84.69	80.0	48.1	85.4	1.8
300	5.0	5.0	7.0	7.0	2.5	82.64	80.0	50.9	90.0	1.8
350	5.5	5.5	7.0	7.0	2.5	80.64	80.0	53.2	94.4	1.8
400	5.5	5.5	7.0	7.0	2.5	80.64	80.0	60.8	94.4	1.6

2.3 In view of the observed rock mass ratings, what minimum width pillar would you recommend and why? (3)

Despite the strong rock, the observed rock mass ratings are low, indicating numerous discontinuities. Based on this, a width: height ratio of at least 2:1 would probably be a good starting point, maybe even going as far as 3:1. This would result in pillar widths of between 5 and 7 metres

2.4 How would you propose monitoring the behaviour of the pillars and the successful implementation of the design? (4)

- *Visual inspection – particularly of smaller pillars, which can be identified easily by painting or otherwise marking them*
- *Photographic records*
- *Extensometers*
- *Borehole camera examination*
- *Stress measurements (for the really ambitious!)*

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QUESTION 3 – MINING LAYOUTS

As part of the design team planning a new intermediate depth (1500 metre) shaft for a new platinum mine, you are required to conduct an early shaft pillar extraction in order to minimise the complications associated with a conventional shaft pillar.

3.1 Using diagrams and short notes, explain how you would propose to go about this task. Your notes should include:

a) Location of the reef cut in relation to other levels and infrastructure

Reef should ideally be located ½ way between 2 levels, or at least a reasonable distance (20 m?) above / below the nearest level

Excavations such pump and hoist chambers or fridge plants should be located well away from the reef horizon, on either upper or lower levels

Provision must be made for either overstoping or placing within a pillar such excavations as station tips, station crosscuts, main ore passes and drain holes

Main intake and return airways should be located well away from the inner pillar extraction area

b) Dimensions, extraction sequence and support strategy for the inner cut

The inner cut will have to be cut from the shaft itself during the sinking phase, which impacts on sinking time.

A minimum of 5 m should be cut around the shaft, to give a cut of between 20m x 20m and 30m x 30m.

The cut should be extracted either in a circular or square shape, using some logical sequence that can be blasted and cleaned (establish small gullies and faces, etc).

Typical support should consist of tendons combined with yielding elongates, followed by either yielding cementitious packs or some form of fill. This must NOT be placed directly on the shaft edge, but be located a small distance off it.

c) General sequence for mining the outer section of the pillar area

The sequence for the outer pillar should aim to mine radially away from the shaft in a consistent fashion. This can be achieved in a number of ways, the simplest being to establish raises either side of the inner pillar from which to stope.

Of importance is that faces should "bombshell" away from the shaft at the same time in an orderly fashion, with minimal leads & lags, or deviation from the planned pattern.

d) Location and design criteria for satellite pillars (20)

The aim of the satellite pillars is to reduce the amount of closure across the shaft pillar area, and absorb the stress generated by the extraction without transmitting it back onto the shaft barrel.

The satellite pillars should thus obviously not be located over major infrastructure, and should ideally be symmetrically laid out around the shaft

Design criteria could include the following:

- *Minimum width: height ration of 10:1 (must be stable pillars)*
- *Maximum stress level not to exceed 2.5 x UCS of host rock*

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QUESTION 4 – SEISMICITY

4.1 Explain the correct names, characteristics and typical propagation velocities of P- and S-waves (6)

P – Primary / pressurewave, compressional wave, approx 6000 m/s

S – Secondary / shear wave, transverse wave, approx 3500 m/s

4.2 Explain the difference between a typical "crush" and a "slip" type event (you may use of appropriate sketches / seismograms if required) (4)

Crush event typically involves the explosion of a pillar or face, resulting in an event with higher P-wave energy

Slip event usually involves movement along a natural or artificial plane, such as a fault or rupture plane, resulting in an event with higher S-wave energy

4.3 If the typical P-wave velocity for a certain area is 2000 metres / second and the S-wave velocity is 1500 metres / second (note that these are NOT typical values), how far away from the seismometer did the event occur if the difference in arrival times is 1.2 seconds? (3)

$$D = \frac{VpVs \times t}{(Vp-Vs)}$$

$$= (((2000 \times 1500) \times 1.2) / (2000 - 1500))$$

$$= 7200 \text{ m}$$

4.4 Sketch, name and describe the functions of the different components of a typical mine seismic network (7)

Needed to include seismometer (geophone or accelerometer), amplifier, analogue to digital converter, transmission system, data concentrator, control unit, GPS with common timing, seismic data storage and analysis unit.

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QUESTION 5 – TENDON SUPPORT

Making use of a table, list four different tendon support systems, their RELATIVE advantages and disadvantages, typical applications and relative cost / unit (20)

Description	*Advantages*	*Disadvantages*	*Cost per inst.*
Rebars installed with grout	*Simple* *Well known* *Cheapest installation cost* *Grout protects the bar from corrosion*	*Pasive support* *Grout needs time to set* *Unable to check grout quality & quantity* *Need longer unit to achieve critical bond length* *Prone to human error*	*R 29.58*
Rebars installed with resin	*Active support (can be pre-loaded)* *No need for temporary support* *Binds well fractured rock* *Resin protects the bar from corrosion*	*Special training of crews needed* *Works well only with automated installation* *Point-anchored version susceptible to blast or impact damage* *Expensive*	*R 73.55*
End anchor roofbolt	*Simple and quick installation* *Active support (5 tons pre-load)* *Load indicator* *No need for temporary support*	*Ineffective in fractured areas* *Would require grout to be effective* *Susceptible to blast or impact damage* *Useless if nut is loose*	*R 32.00*
End anchor roof bolt with grout	*Active support (5 tons pre-load)* *Grout protects the bar from corrosion* *Also effective in fractured areas*	*More expensive and time consuming* *Unable to check grout quality & quantity*	*R 45.72*
Hydrabolt/ X-Panda bolt	*Simple and quick installation* *Provides lateral confinement* *Maintains the load even if some pressure is lost*	*Long-term load loss due to corrosion* *Has potential to open joints in blocky ground by inducing tension in rockmass* *New, untested system in long run* *Expensive* *Installation angle could be a problem (bending failure vs tensile)*	*R 52.87*

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SPECIMEN DIMENSIONS						SPECIMEN TEST RESULTS			
Rock Specimen Diameter	Rock Specimen Height	Loading End Piece Diameter	Ratio of Height to Diameter	Mass	Density	Confining Pressure δ_3	Failure Load P	Strength (TCS) δ_1	Note
mm	mm	mm		g	g/cm³	MPa	kN	MPa	
43.6	87.0	66.0	2.0	356.0	2.74	10.0	484.9	312.2	
43.3	89.5	66.0	2.1	363.2	2.76	20.0	615.4	392.2	
43.3	84.9	66.0	2.0	348.0	2.78	30.0	693.8	431.6	
43.3	90.2	66.0	2.1	364.0	2.75	40.0	776.6	475.6	

Note: All tests were conducted according to the ISRM Specification.
TCS - stands for Triaxial Compressive Strength.
1 - Specimen was failed on existing crack /joint, the strength of intact rock (free of crack /joint) may be higher that that reported.

SPECIMEN DIMENSIONS				SPECIMEN TEST RESULTS			
Diameter	Height	Mass	Density	Failure Load	Tensile Strength	Tensile Strength Aver. ± Std.	Note
mm	mm	g	g/cm³	kN	MPa	MPa	
43.2	20.9	81.1	2.65	10.8	7.6		
43.7	23.5	93.2	2.65	12.8	7.9		
43.0	20.2	74.4	2.54	8.5	6.2		
42.9	22.3	83.0	2.58	11.9	7.9		
36.6	18.7	52.3	2.67	9.0	8.4		

SPECIMEN DIMENSIONS					SPECIMEN TEST RESULTS							
Diameter	Height	Ratio of Height to Diameter	Mass	Density	Failure Load	Strength (UCS)	Tangent Elastic Modulus @ 50% UCS	Secant Elastic Modulus @ 50% UCS	Poisson's Ratio Tangent @ 50% UCS	Poisson's Ratio Secant @ 50% UCS	Linear Axial Strain at Failure	Note
mm	mm		g	g/cm³	kN	MPa	GPa	GPa			micro-strain	
36.36	87.4	2.4	248.7	2.74	227.8	219.4	69.2	57.4	0.45	0.26	3651	
36.20	76.2	2.1	214.3	2.73	170.3	165.5	54.5	28.5	0.48	0.17	4428	
43.38	108.0	2.5	441.6	2.77	115.8	78.3	63.8	58.7	0.25	0.18	1249	1
43.21	108.7	2.5	436.9	2.74	251.2	171.3	58.8	33.2	0.53	0.22	4237	