CHAMBER OF MINES OF SOUTH AFRICA

EXAMINATION FOR THE CERTIFICATE IN ROCK MECHANICS

PAPER 3.1

METALLIFEROUS OPTION

SUBJECT: CERT. IN ROCK MECHANICS PAPER 3.1 (METALLIFEROUS OPTION)	**EXAMINER:** Mr. T RANGASAMY
SUBJECT CODE: COMRME	**MODERATOR:** Dr. T O' HAGAN
EXAMINATION DATE: OCTOBER 2007	**TOTAL MARKS:** [100] **PASS MARK:** 60%

NUMBER OF PAGES: 6

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 a level of 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.

CERT. IN ROCK MECHANICS: PAPER 3.1

METALLIFEROUS OPTION

QUESTION 1

Rock mass ratings were obtained for the UG2 orebody from drill core for a greenfields project in a platiniferous mine located in the South African Bushveld Complex. The final operating depth of the mine is estimated at 600 metres below surface. Stress measurements indicate a k-ratio of 1.5 throughout the orebody. The seam height and orebody dip are 1.2m and 10 degrees, respectively. The overburden density is 3 tons/m^3.

Classification	Mean	Standard deviation
RMR	66.22	11.07
Q	2.80	1.74
MRMR	53.05	3.91

1.1 Describe the rating parameters used for each of the classification schemes listed in the above table **(10)**

Ryder J.A & Jager A.J, A textbook on rock mechanics for tabular hard rock mines, Pages 367 – 375 describes the parameters for the RMR, MRMR and Q systems

1.2 Uniaxial compressive strength tests have indicated mean orebody strengths of 87 MPa. Determine the mean, minimum and maximum design rock mass strength (DRMS) using the following formula and accompanying UCS rating table: **(3)**

$$DRMS = UCS \times (MRMR - R_{UCS})/100$$

UCS (MPa)	164-145	144-125	124-105	104-85	84-65	44-25	24-5	4-0
Rating	14	12	10	8	6	4	2	0

Using table of rock mass ratings, the mean, maximum and minimum MRMR are:

Mean = 53.05

Maximum = 56.96

Minimum = 49.14

CERT. IN ROCK MECHANICS: PAPER 3.1

METALLIFEROUS OPTION

The R_{UCS} = 8 using the rating for strengths between 85-100 i.e. given mean strength = 87 MPa

Hence $DRMS_{mean}$ = 87 x (53.05 – 8)/100 = 39.19 MPa

Hence $DRMS_{max}$ = 87 x (56.96 – 8)/100 = 42.60 MPa

Hence $DRMS_{min}$ = 87 x (49.14 – 8)/100 = 35.79 MPa

3.0. Using the approach adopted by Hedley and Grant and assuming Tributary Area Loading,

1.3.1 Calculate the strength of a 5m wide square pillar **(2)**

$$\sigma_s = DRMS_{mean} \frac{w^{0.5}}{h^{0.75}} (MPa)$$

$$\sigma_s = 39.19 \frac{5^{0.5}}{1.2^{0.75}} = 76.43 MPa$$

1.3.2 Calculate the FOS of the above pillar for the maximum depth of the operation assuming bord and pillar workings with bord widths of 6m. **(3)**

$$FOS = \frac{\sigma_s}{APS}$$

$$APS = \frac{q_v}{(1-e)}, \; q_v = \rho g h, \; e = \frac{A_t - A_p}{A_t}$$

$$q_v = 3000 x 9.817 x 600 = 17.67 MPa$$

$$e = \frac{121-25}{121} = 0.793$$

$$APS = \frac{17.67}{(1-0.793)} = 85.36 MPa$$

$$FOS = \frac{76.43}{85.36} = 0.90$$

1.4 If the relationship between RMR and Q is governed by the following empirical relationship: RMR = 9 ln Q + 44, provide comment on the appropriateness of this relationship for measured RMR and MRMR results **(2)**

Using equation and mean Q, RMR = 53.27. Measured mean RMR = 66.22

Using equation and mean Q, RMR = 53.27. Measured MRMR = 53.05

Results indicate poor correlation with RMR and very good correlation with MRMR. Candidates need to perform calculations to check correlations.

(20 marks)

CERT. IN ROCK MECHANICS: PAPER 3.1

METALLIFEROUS OPTION

QUESTION 2

An isolated block of ground containing 5000 m^2 of Carbon Leader Reef is planned for extraction between two sub-parallel dip trending faults at approximately 2500 mbs. Seismic polygons using a 10 year catalogue of events indicates a maximum possible event size of M_L = 3.2. Prior to implementing an extraction programme, the mines Code of Practice requires a rock related risk assessment to be performed, formally drafted and incorporated into mine design. Provide a single tabulation describing the:

2.1 Rock related hazards

2.2 Rock engineering/seismic methods used to quantify risks

2.2 Measures to mitigate/manage/eliminate risks

(20 marks)

Category	**Rock related hazards**	**Risk quantification techniques**	**Risk controls**
Candidates need to form the link between identifying hazards, linking these hazards to assessment techniques that aid in risk quantification and formulating controls. Major hazards pertaining to remnants and the Carbon Leader will be assessed. Knowledge of intense stress fracturing, the influence of the Greenbar, high closure rates, higher than normal fault frequencies, high rockburst potential, access philosophy etc will be assessed.			
Rockfalls	Cantilever of bedding planes	Voiussoir and simple beam analysis	Limiting unstable spans & beam suspension reinforcement
	Wedge failure of joint-joint blocks	Fall of ground statistics & wedge failure limit equillibrium analysis, Support resistance calcs	Appropriate support lengths or support resistance in combination with areal coverage
	Wedge failure of stress fracture-joint blocks	Fall of ground statistics & wedge failure limit equillibrium analysis, Support resistance calcs	Appropriate support lengths or support resistance in combination with areal coverage
	Sheet failure of stress fractured blocks	Keyblock analysis using simple codes such as JBlock	Appropriate support lengths or support resistance in combination with areal coverage
	Snap through upto Greenbar argillite	Voiussoir and simple beam analysis	Limiting unstable spans & beam suspension reinforcement
	Cantilever upto Greenbar argillite	Voiussoir and simple beam analysis, Support resistance calcs	Limiting unstable spans & beam suspension reinforcement
	Brow failure	Bedding thickness analysis	Support resistance

	Toppling of overhanging face	Blasting practice	Audit blasting practice
	Wedge failure on sympathetic fault-joint-stress fracture interfaces	Fall of ground statistics & wedge failure limit equillibrium analysis, Support resistance calcs	Appropriate support lengths or support resistance in combination with areal coverage
	Quasi-static design performance of support exceeded through high closure rates	Closure profiling using instrumentation and numerical modelling	QA/QC of support performance, support instrumentation
	Siting of access development	Numerical modelling	Observational, areal coverage etc
	On-reef accessways		
Rockbursts	Face bursting	ERR analysis	Routine numerical modelling, seismic assessments **(see tables that follow)**
	Slip on major faults	ESS analysis	Routine numerical modelling, seismic assessments **(see tables that follow)**
	Slip on sympathetic faults	ESS analysis	Routine numerical modelling, seismic assessments **(see tables that follow)**
	Dynamic design performance of support exceeded through high closure rates	Closure profiling using instrumentation and numerical modelling	QA/QC of support performance, support instrumentation

Other hazards
Fractured rock at the stope face and the periphery of the remnant
Systematic temporary, permanent and/or regional support in the stope face not installed to standard
Non identification of geological features
Lack of additional support along geological features, brows or overhanging faces
Poor hangingwall as a result of bad drilling and blasting practice
Lagging strike gullies
Gullies developed parallel to geological structures
Poor quality of support
Gully dimensions not correct
Stoping width not controlled
Holing into adjacent workings
Opening up of collapsed panels
Entering old workings
Rock bursting resulting from highly stressed faults and dykes
Incorrect face configuration
Unstable hangingwall
Removal of reef in footwall and/or hangingwall
Failure of support systems
Gully sidewall failure
Mining in new geotechnical areas
Overbreak into weak hangingwall
Reef rolls
Migration of back area failure to the face
Strain bursting
Exposing Green Bar
Variable payable stope widths
FOG in panel and back area
Quartz veining/jointing
Terrace slopes
Jointing in hangingwall
Depth of mining
Poor layout
Lack of information
Large spans
Mining rate
Lack of backfill
Anomalous closure rates
Unknown rock properties
Far removed from major infrastructure
Inadequate on-reef and off-reef access and escape routes
Reasons for leaving remnants
Geometry of remnants
Influence of extraction on stability of geological structures and other pillars

Observational controls

METALLIFEROUS OPTION

Phase	Responsible personnel	Parameter Assessed	Frequency
Preliminary remnant extraction planning	Production personnel	Review plans Review routes Review emergency procedures Review required safety precautions Review procedures required to establish safe conditions	During planning meetings During the underground investigation At remnant planning review meetings
	Environmental, Safety & Health	Monitor Air temperature Monitor air borne gases Monitor intake and exhaust air volumes Mark existing ventilation routes Devise action plan to address above if required	During underground visit done during preliminary planning Thereafter as required by mine procedures and mining regulations
	Rock Engineer	Monitor/assess existing conditions of access Assess best possible layouts Monitor seismic history Review existing accident databases Comparative numerical modelling of layouts Assess best possible support and stoping strategy	During planning meetings During the underground investigation
	Surveyor	Mark routes Record conditions Measure face and end positions to last installed pegs Review measured positions with those recorded on plans Record mineable size and shape of remnant	During the underground investigation
	Geology	Observe and record position of reef Observe and record position of structures Evaluate grade and assess financial feasibility given rehabilitation and layout requirements	During the underground investigation At remnant planning review meetings
	Risk Assessor	Mediate risk assessment process using collated information derived from above process	At remnant planning review meetings

Monitoring using numerical modelling

Region	Types of models	Parameters assessed	Frequency	Potential outputs
Far West Rand	MINSIM-W MAP3D	ERR, ESS, face stresses, average remnant stresses, RCF	During remnant planning phase Once a month after measuring After a damaging seismic event After an investigation into an accident When requested by an auditor	• Comparative best possible layout • Potential stopping distances • Bracket or regional pillar design • Siting of off-reef infrastructure • Correlation of recorded seismicity with face and structure positions • Optimum mining spans • Optimum rates of advance • Potential seismic magnitudes

Klerksdorp/Free State	MINSIM-W	ESS, average remnant stresses, RCF	During the remnant planning phase After an investigation into an accident	• Evaluate best possible layout • Evaluate potential seismic magnitudes • Siting of off-reef infrastructure

Seismic controls

Seismic parameter	Use	Response
Seismic event clustering and activity rate	• Depicts potential sites that are at higher risk than others • Related to parameters that control the layout – face length, advance and lead/lags • Small event filters used – clusters normally shown for events above M_L 1. • Event clustering normally correlated with time and production rates • Used to delineate geological structures • Used to assess potential magnitudes of seismic events	• Inform production line supervision of anomalous trends • Team based formulation of reasons for clustering • Modify or change layout or production rate based on reasons formulated • Plan bracket/regional/satellite pillars at clustered areas • Terminate extraction program partially or totally
Seismic parameter time histories	• Normal practice to use energy index (EI) and apparent volume (AV) • Gradient changes linked to seismic alert rating systems • Used to indicate time frame within which rock mass instability can occur • Formalized and ad hoc use of EI and AV	• Change production rate • Continuously monitor EI and AV during extraction process • Restrict the number of panels blasted • Restrict the number of personnel working in a remnant • Stop all work in remnant blocks either temporarily or permanently
Gutenberg-Richter event distributions	• Plots of cumulative number of events for specific magnitude ranges for remnant areas and areas adjacent to remnant blocks	• Estimate of largest possible event sizes • Estimate of the number of events within magnitude ranges • Used to formulate optimum production rates
On shift/Off Shift ratios	• Graphical depictions of number of events triggered by blast versus number of events occurring during populated shifts	• Check for changes in ratios • Formulate desired ratios • Alter mining sequence and/or mining rate to change distribution • Terminate or temporarily abandon extraction
Mean reoccurrence time	• Use time between historical events to predict time between events while mining the remnant	• Potential time based risk analysis can be done • Match extraction rate with onset of large events

CERT. IN ROCK MECHANICS: PAPER 3.1

METALLIFEROUS OPTION

QUESTION 3

Excavation support design follows a logical design process, which includes but is not exhaustive to gaining knowledge and understanding of:

- The geotechnical parameters that influence stability,
- The factors that govern stability (panel and regional scale)
- The rock engineering/seismic techniques that will be applied to assess stability
- The quality assurance and quality control measures that need to be implemented to ensure that actual performance mimics designed performance

List and describe the role of each of the above for the following geotechnical environments:

3.1 A chrome mine mining the LG6/6a in the Bushveld Complex **(10)**

3.2 A platinum mine undermining the Merensky Reef in pothole reef facies **(10)**

3.3 A gold mine mining the Basal Reef at 2400 mbs **(10)**

3.4 Sections of a shaft barrel intersecting the VCR at 2000 mbs **(10)**

(40 marks)

Parameters	Chrome mine	Platinum mine	Gold mine	Shaft

Geotechnical	Typically two subvertical joint sets 1-5m thick layers Dome structures Shear bands Minor faults Potholes IRUP areas Low frequency dykes with chill margins Variable chromitite strengths (50-70 MPa)	Triplets Two dominant joint sets + 1 random low angled 1-5m thick layers Ol-rich pyroxenite immediately above triplets Harzburgite between PseudoReefs Dome structures Shear bands Minor faults Potholes IRUP areas Low frequency dykes with chill margins Variable chromitite strengths (70-110 MPa)	Strongly bedded 0.5-0.75m thick Khaki shale above reef (0.5-1.5m thick) Stress fractured (FF = 10-15) Intensely faulted Dolerite dykes Strong conglomerates (180-200 MPa)	Weak lavas Strong lavas (Alberton porphyry) Slope and terrace structures Sheared contact above VCR Wedges on faults and dykes

CERT. IN ROCK MECHANICS: PAPER 3.1

METALLIFEROUS OPTION

Factors governing stability	Length, thickness and strength of beams Wedge formation Height and extent of domes Potential delamination of beams Upturned/Down turned layers at rims of potholes Impact of changing rock mass strength on pillar design Changing rock mass ratings and DRMS at shear/fault/pothole and dyke intersections Heights of tensile zone	Heights of rockmass in tension Beam stability upto ol-rich pyroxenites and PseudoReefs Voiussoir stability in discontinuous rock mass Span versus interburden thickness Other factors similar to chrome mines	Thickness of Khaki shales Thickness of bedding Wedges formed between stress fractures/jts and bedding Strong ground motion High closure rates	Size, shape, weight and shear strength of wedge surfaces Visco-plastic flow of soft layers Water ingress Jointed rockmass
Techniques for assessment	Page 113-191, Jager A.J & Ryder J.A, 1999	Page 113-191 Jager A.J & Ryder J.A, 1999	Pages 113-191 & Pages 281-286 Jager A.J & Ryder J.A, 1999	Page 225-248 Jager A.J & Ryder J.A, 1999
QA/QC	Page 311-327, Jager A.J & Ryder J.A, 1999	Page 311-327, Jager A.J & Ryder J.A, 1999	Page 311-327, Jager A.J & Ryder J.A, 1999	Page 311-327, Jager A.J & Ryder J.A, 1999

CERT. IN ROCK MECHANICS: PAPER 3.1

METALLIFEROUS OPTION

QUESTION 4

Numerical modelling if used appropriately is an important tool for Rock Engineering design. Describe the numerical modelling programmes or combinations you would use, the input parameters and results you will analyse to determine each of the following:

4.1. The width and spacing of regional dip stabilising pillars in a deep gold mine **(5)**

4.2. The dimensions of rigid pillars in a platinum mine that uses conventional hand-held drilling and blasting techniques with scraper cleaning **(3)**

4.3. The location of a decline cluster below the UG2 seam in rock mass with a mean RMR = 42 **(6)**

4.4. The thickness of a crown pillar between the base of the openpit and the start of underground UG2 extraction **(6)**

(20 marks)

Assessment	Regional pillars	Rigid pillars	Decline cluster	Crown pillar
Numerical modelling programmes	MINSIM, MAP3D, BESOL-MS	MINSIM, BESOL-MS, MAP3D	UDEC, FLAC	UDEC, FLAC
Input parameters	Stress tensor, elastic modulus, poisson's ratio, element size, hyperbolic or quadratic backfill curve, RCF and stress on tunnels below pillars	Stress tensor, elastic modulus, poisson's ratio, element size	Rock material properties, joint properties, stress gradient, boundary or loading conditions, strain softening parameters, constitutive laws for joints and rock blocks	Rock material properties, joint properties, stress gradient, boundary or loading conditions, strain softening parameters, constitutive laws for joints and rock blocks, pore water pressure

Results analysed	APS for foundation failure, ERR on pillars	APS on pillars, height of tensile zone	Crown and sidewall stresses, plastic failure around tunnel, zones of delamination using displacements and joint opening	Shear stress on hinge points, midpoint deflection using displacements assessed against buckling limits