CHAMBER OF MINES OF SOUTH AFRICA

WRITTEN EXAMINATION FOR THE CERTIFICATE IN ROCK MECHANICS

METALLIFEROUS & COAL OPTIONS

PART 1 - THEORY 13 May 1996

EXAMINER: Mr G S Esterhuizen

MODERATOR: Mr K R Noble

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

An Afrikaans version of this paper is attached.

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 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.

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

Define each of the following and explain briefly under what conditions each may be encountered in rock engineering applications:

(a) elastic strain energy — 2 marks
(b) kinetic energy — 2 marks
(c) dilation — 2 marks
(d) plane strain — 2 marks
(e) volumetric strain. — 2 marks

TOTAL 10 marks

QUESTION 2

(a) Calculate the principal stresses at a point in rock where the following stress components were measured. The x-axis is horizontal to the right and the y-axis points upwards. Compressive stresses are positive.

$$\sigma_x = 112 \text{ MPa}$$
$$\sigma_y = 30 \text{ MPa}$$
$$\tau_{xy} = -22 \text{ MPa}.$$

Draw a sketch to indicate the orientation of the principal stresses relative to the x-y axes. — 5 marks

(b) The strength of the rock at the above point is given by : cohesion = 15 MPa and friction angle = 32 °.

(i) Using the Coulomb equation, determine whether the rock will fail.

(ii) Indicate in a sketch the orientation of the potential failure planes and indicate the sense of sliding on each plane. — 10 marks

(c) Calculate the volumetric strain, assuming plane strain conditions, at the above point, given

E = 55 GPa and $\nu = 0.2$. — 5 marks

TOTAL 20 marks

PART 1 - THEORY

QUESTION 3

(a) A number of uni-axial and tri-axial rock tests were carried out on intact rock samples and the following results were obtained:

Sample	Confining stress (MPa)	σ_1 at failure (MPa)
1	0	120
2	5	150
3	10	180
4	15	210

Make use of the Mohr circle diagram to obtain the cohesion and friction angle of the rock. 6 marks

(b) Explain how you would obtain the m-parameter required for the Hoek and Brown failure criterion for the above rock. Also explain why the Hoek and Brown criterion is considered to be a better representation of rock strength than the Coulomb criterion. 9 marks

TOTAL 15 marks

QUESTION 4

The point load test may be used to estimate the compressive strength of rock. Explain the mechanism of failure in this test, how the uni-axial compressive strength is obtained and comment on the reliability of the results. TOTAL 5 marks

QUESTION 5

(a) Refer to the behaviour of rock joints in shear to explain why the rock block in the sketch could be stable, even in the absence of external clamping forces. 5 marks

(b) Make use of Barton's equation to determine the shear resistance of a joint at normal stresses of 5 MPa and 6 MPa and determine the effective friction angle. Explain why the calculated friction angle differs from the base friction angle. The following data is available:

JRC = 12, JCS = 15 MPa and base friction angle – 28°.

$$\tau = \sigma_n \tan\left(\phi + JRC \log \frac{JCS}{\sigma_n}\right)$$

10 marks

TOTAL 15 marks

PART 1 - THEORY

QUESTION 6

(a) A tunnel is being developed through a rock mass, and the tunnel axis is at 30° to the strike of the most dominant joint set. Make use of the attached classification table to classify the rock mass, which has the following characteristics:

UCS = 160 MPa; RQD = 65%; joints are spaced 1 m to 3 m apart; joint conditions are smooth; planar joints with 1 mm to 3 mm of soft infilling; and the rock mass is damp.

5 marks

(b) Make use of the equations below to calculate the uni-axial compressive strength of the rock mass in question (a), using the Hoek & Brown criterion if the m-parameter for the intact rock is 16,0.

$$\frac{m}{m_i} = e^{\left(\frac{RMR-100}{28}\right)}$$

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

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

5 marks

(c) Explain whether the above calculated rock mass strength will be applicable in the analysis of each of the following.

(i) stability of an orepass,
(ii) stability of a 3 m by 3 m tunnel; and
(iii) stability of a stope hanging wall.

Motivate your answers. 5 marks

TOTAL 15 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		
		Ratio joint water pressure / major principal stress	0		0.0 - 0.2	0.2 - 0.5	> 0.5		
		General conditions	Completely dry		Moist only (interstitial water)	Water under moderate pressure	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

PART 1 - THEORY

QUESTION 7

(a) You have to analyse the effect of 2 m rock tendons relative to 3 m tendons in a highly stressed tunnel under changing field stress conditions.

(i) What type of numerical model would you use to conduct this analysis?

(ii) What output would you look at to compare the effect of the two lengths of tendons?

(iii) Explain briefly the shortcomings of the model and state what input data is required. 10 marks

(b) You are given the task of monitoring the height of caving above tabular stope excavations in a shallow hard rock mining environment (depth of about 500 m).

(i) Name two types of monitoring instruments you would use.

(ii) How would they be installed?

(iii) What are you required to measure?

Motivate your choice of instrument. 10 marks

TOTAL 20 marks

KAMER VAN MYNWESE VAN SUID-AFRIKA

SKRIFTELIKE EKSAMEN VIR DIE SERTIFIKAAT IN ROTSMEGANIKA

METAAL- EN STEENKOOLKEUSE

DEEL 1 - TEORIE : 13 Mei 1996

EKSAMINATOR : Mnr. G S Esterhuizen

MODERATOR : Mnr. K R Noble

Maksimum tyd toegestaan: 3 uur (09:00 - 12:00)

'n Engelse weergawe van hierdie vraestel is aangeheg.

BEANTWOORD AL DIE VRAE

U moet 60 persent behaal om te slaag.

Naslaanwerke mag nie gebruik word nie.

Elektroniese handrekenmasjiene kan gebruik word. (Geen voorafprogrammering nie.)

Skryf u eksamennommer buiteop elke antwoordboek wat u gebruik, en op alle grafiekpapier of ander los velle wat u inlewer.

L.W.: U naam moet nie op die antwoordboek of los velle verskyn nie.

Skryf slegs op een kant van elke vel papier.

Toon alle berekenings aan waarop u antwoorde gegrond is.

Wanneer u hierdie vrae beantwoord, moet u u ondervinding van die praktiese sy van die onderwerp sowel as die gegewens ten volle benut waar dit ook al nodig is.

Tensy dit anders aangegee word, neem aan dat die digtheid van kwartsiet 2 700 kg/m^3 is, dat die Poisson-verhouding 0,2 is, en dat die elastisiteitsmodulus 72 GPa is.

DEEL 1 - TEORIE

VRAAG 1

Omskryf elk van die volgende, en verduidelik kortliks in watter omstandighede elkeen in rotsingenieurswesetoepassings aangetref sal word:

(a)	elastisiteitsvervormingsenergie	2 punte
(b)	kinetiese energie	2 punte
(c)	dilatasie	2 punte
(d)	vlakvervorming	2 punte
(e)	volumetriese vervorming	2 punte

TOTAAL 10 punte

VRAAG 2

(a) Bereken die hoofspannings by 'n punt in rots waar die volgende spanningskomponente gemeet is. Die x-as is horisontaal na regs, en die y-as loop opwaarts. Druksterktes is positief.

σ_x = **112 MPa**
σ_y = **30 MPa**
τ_{xy} = **- 22 MPa**

Teken 'n skets wat die oriëntering van die hoofspannings met betrekking tot die x- en y-as aandui.

(b) Die rotssterkte by bogenoemde punt word verstrek deur die volgende:
kohesie = 15 MPa, en wrywingshoek = 32°. 5 punte

(i) Gebruik die Coulomb-vergelyking, en stel vas of die rots sal instort.

(ii) Teken 'n skets en dui daarop die oriëntering van die potensiële swigtingsvlakke en die skuifrigting op elke vlak aan. 10 punte

(c) Veronderstel vlakvervormingstoestande, en bereken die volumetriese vervorming by bogenoemde punt as

E = 55 GPa en ν = 0,2. 5 punte

TOTAAL 20 punte

DEEL 1 - TEORIE

VRAAG 3

(a) 'n Aantal eenas- en driesasrotstoetse is op monsters soliede rots uitgevoer en die volgende resultate is verkry:

Monster	Inperkspanning (MPa)	σ_1 by swigting (MPa)
1	0	120
2	5	150
3	10	180
4	15	210

Gebruik die Mohr-sirkeldiagram en verkry die kohesie en wrywingshoek van die rots. 6 punte

(b) Verduidelik hoe u die m-parameter wat vir die Hoek-en-Brown-swigtingskriterium nodig is, vir bogenoemde rots sal bepaal. Verduidelik ook waarom die Hoek-en-Brown-kriterium as 'n beter verteenwoordiging van rotssterkte beskou word as die Coulomb-kriterium. 9 punte

TOTAAL 15 punte

VRAAG 4

Die puntlastoets kan gebruik word om die druksterkte van rots te skat. Verduidelik die swigtingsmeganisme van hierdie toets en hoe die eenasdruksterkte verkry word, en bespreek die betroubaarheid van die resultate.

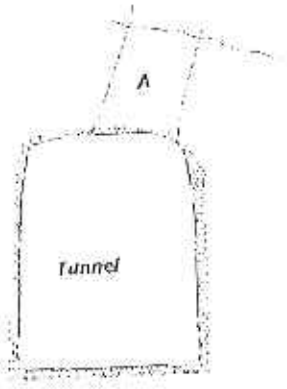
TOTAAL 5 punte

DEEL 1 - TEORIE

VRAAG 5

(a) Verwys na die gedrag van rotsnate in skuifskeuring om te verduidelik waarom die rotsblok in die skets stabiel kan wees, selfs in die afwesigheid van eksterne klemkragte. 5 punte

(b) Gebruik die Barton-vergelyking om die skuifweerstand van 'n naat by normaalspannings van 5 MPa en 6 MPa vas te stel, en bepaal die effektiewe wrywingshoek. Verduidelik waarom die berekende wrywingshoek van die basiswrywingshoek verskil. Die volgende gegewens is beskikbaar:



JRC = 12, JCS = 15 MPa en basis-wrywingshoek = 28°

$$\tau = \sigma_n \tan\left(\phi + JRC \log \frac{JCS}{\sigma_n}\right)$$

10 punte

TOTAAL 15 punte

DEEL 1 - TEORIE

VRAAG 6

(a) 'n Tonnel word deur 'n rotsmassa ontsluit, en die tonnelas is onder 'n hoek van 30° met die strekking van die dominantste naatgroep. Gebruik die aangehegte klassifikasietabel en klassifiseer die rotsmassa, wat die volgende eienskappe het:

Eenasdruksterkte = 160 MPa; rotsgehalte-aanwysing = 65%; nate is 1 m tot 3 m van mekaar; naattoestande is glad; egalige nate met 1 mm tot 3 mm van sagte vulsel; en die rotsmassa is vogtig. 5 punte

(b) Gebruik die vergelykings hieronder om die eenasdruksterkte van die rotsmassa in vraag (a) te bereken, en maak gebruik van die Hoek-en-Brown-kriterium as die m-parameter vir die soliede rots 16,0 is.

$$\frac{m}{m_i} = e^{\left(\frac{RMR-100}{28}\right)}$$

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

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

5 punte

(c) Verduidelik of die rotsmassasterkte wat hierbo bereken is, by die ontleding van elk van die volgende van toepassing sal wees:

(i) stabiliteit van 'n ertsstortbaan,
(ii) stabiliteit van 'n tonnel van 3 m by 3 m, en
(iii) stabiliteit van die dak van 'n afbouplek.

Verstrek redes vir u antwoorde. 5 punte

TOTAAL 15 punte

DEEL 1 - TEORIE

PART 1 - THEORY
QUESTION 6 VRAAG 6

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	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 - 5 mm Continuous joints	Soft gouge > 5 mm thick or Joints open > 5 mm Continuous joints		
	Rating		25	20	12	6	0		
5	Ground water	Inflow per 10 m tunnel length	None		< 25 litres/min	25 - 125 litres/min	> 125 litres/min		
		Ratio $\frac{\text{joint water pressure}}{\text{major principal stress}}$	OR 0		OR 0.0 - 0.2	OR 0.2 - 0.5	OR > 0.5		
		General conditions	OR Completely dry		OR Moist only (interstitial water)	OR Water under moderate pressure	OR Severe water problems		
	Rating		10		7	4	0		

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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

DEEL 1 - TEORIE

VRAAG 7

(a) U moet die uitwerking van 2 m-rotsstaalstange in vergelyking met dié van 3 m-rotsstaalstange in 'n tonnel onder groot spanning in veranderende veldspanningstoestande ontleed.

(i) Watter soort numeriese model sal u gebruik om hierdie ontleding te doen?

(ii) Na watter afvoerdata sal u kyk om die uitwerking van die twee lengtes staalstang te vergelyk?

(iii) Verduidelik die tekortkominge van die model kortliks, en meld watter toevoerdata nodig is. 10 punte

(b) Dit is u taak om die instorthoogte bokant afbou-uitgrawings in 'n tafelvormige ertsliggaam in 'n vlak harderotsmynbou-omgewing (sowat 500 m diep) te moniteer.

(i) Noem twee soorte moniteerinstrumente wat u sal gebruik.

(ii) Hoe word hulle geïnstalleer?

(iii) Wat moet u meet?

Verstrek redes waarom u die instrumente gekies het. 10 punte

TOTAAL 20 punte