CHAMBER OF MINES OF SOUTH AFRICA

EXAMINATION PAPER

<table>
<tr><td>SUBJECT:
CHAMBER OF MINES OF SOUTH AFRICA - CERTIFICATE IN ROCK MECHANICS
PAPER 1 : THEORY

SUBJECT CODE: COMRMC1

EXAMINATION DATE: 08 MAY 2018

TIME: 14:30 – 17:30</td><td>EXAMINER: WM BESTER

MODERATOR: H YILMAZ

TOTAL MARKS: [100]

PASS MARK: (60%)</td></tr>
</table>

NUMBER OF PAGES: 11

THIS IS NOT AN OPENBOOK EXAMINATION – ONLY REFERENCES PROVIDED ARE ALLOWED

SPECIAL REQUIREMENTS:

1. Answer **all four questions**. Answer the questions **legibly** in English.
2. Write your **ID 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.

3. Show all calculations **and check calculations on which the answers are based.**
4. **Only non-programmable basic scientific calculators** may be used for calculations.
5. Write **legibly** in ink on the **right hand page** only – **left hand pages will not be marked**.
6. Illustrate your answers by means of sketches or diagrams wherever possible.
7. **Final answers** must be given to an accuracy which is typical of practical conditions, However be careful not to use too few decimal places during your calculations, as rounding errors may result in incorrect answers

NB: Ensure that the correct unit of measure (SI unit) are recorded as marks will be deducted from answers if the incorrect unit is used even if the calculated value is correct.

8. In answering the questions, full advantage should be taken of your practical experience as well as data given.
9. Please note that you are not allowed to contact your examiner or moderator regarding this examination.
10. Cell phones are **NOT** allowed in the examination room.

QUESTION 1

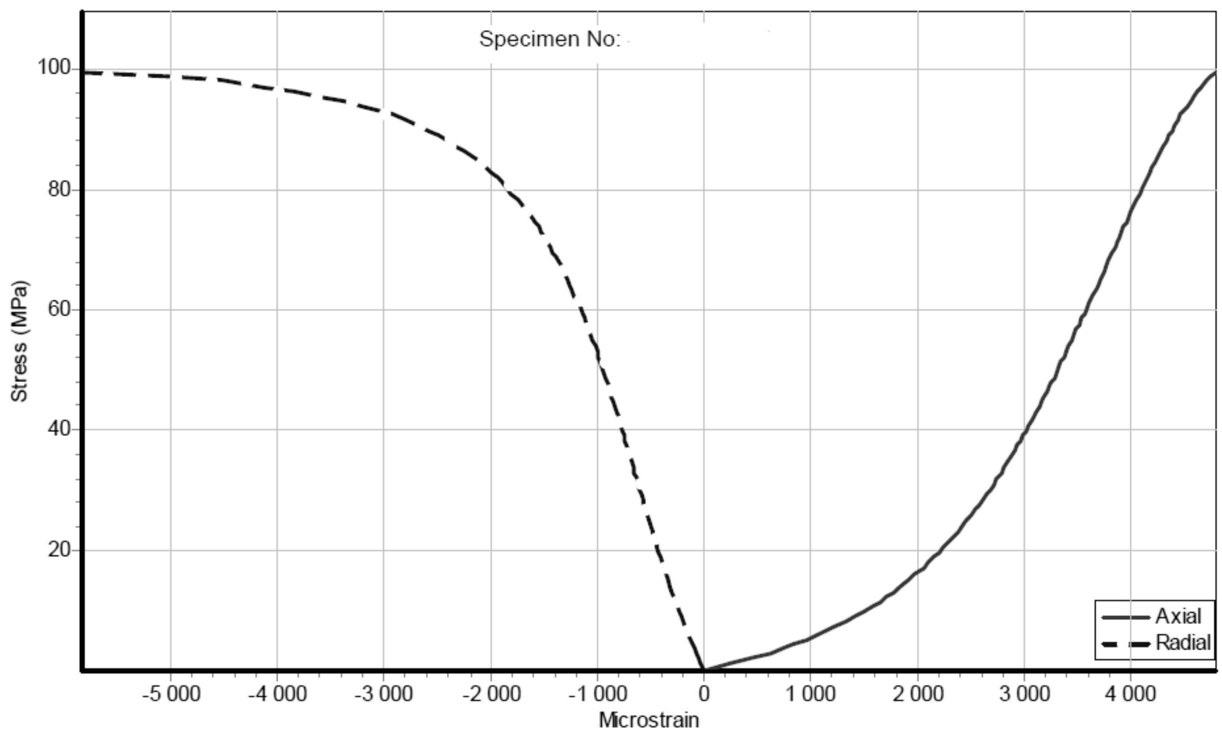
1.1 Given the 3D **stress tensor** in x y z Cartesian coordinates below:

$$\begin{pmatrix} \sigma_{xx} & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_{yy} & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_{zz} \end{pmatrix}$$

(a) **Plot** each of these nine stress components on a cubic element. (9)

(b) List the required relationships between pairs of **shear** stress components for equilibrium to be maintained. (3)

1.2 Given the stress-strain curve of uniaxial compressive testing below:

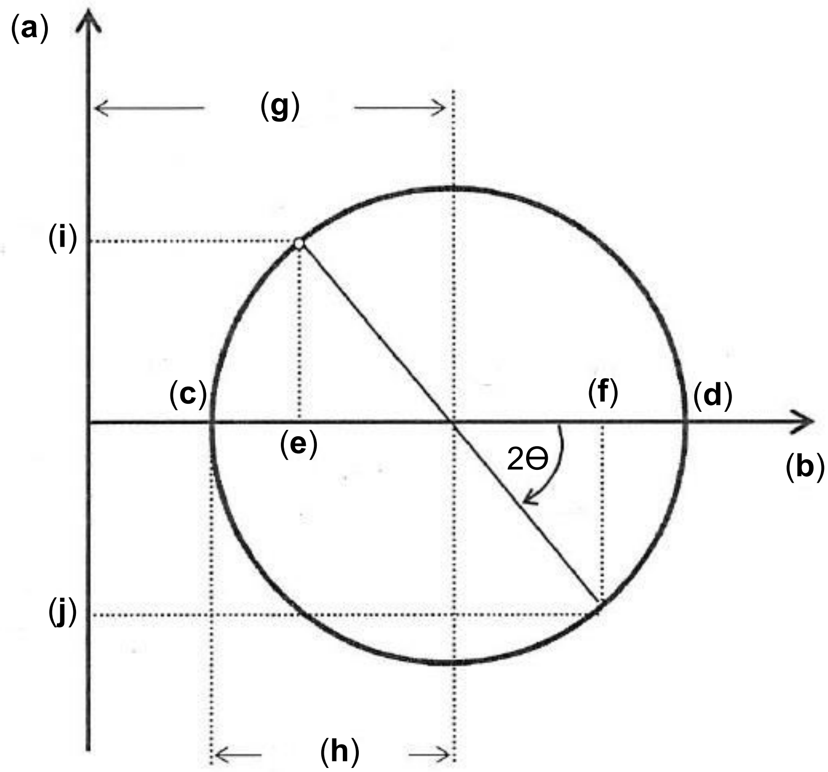


(a) Calculate the **tangent** elastic modulus at 50% strength. (3)

(b) Describe the **constitutive** behaviour exhibited between 0 MPa and 40 MPa. (2)

(c) Describe and explain the behaviour exhibited between 70 MPa and 100 MPa.(3)

1.3 Given the Mohr's **strain** circle below. List the annotations (a) to (j). (5)



[25]

QUESTION 2

A rock mass is transected by 3 intersecting joint sets. **J_1** has 30 cm joint mean spacing, is continuous, with moderately rough unweathered surfaces, no infill and is dry. **J_2** has a spacing of 20 cm, is planar and discontinuous, with signs of water and is moderately rough with some iron staining. **J_3** is undulating and continuous, spaced 20-30 cm apart, relatively smooth, no infill and dry, but with iron staining. Intact rock uniaxial compressive strength is 80 MPa, and overburden density is 2720 kg/m^3.

2.1 Calculate the vertical virgin stress at a depth of 1500 m below surface. Comment on the ratio of rock strength to stress and likely consequences thereof. (3)

2.2 Calculate the number of joints per unit volume of the rock mass. (2)

2.3 Estimate the **RQD** of the rock mass. (2)

2.4 List the six variables in Barton's **Q** System. Determine their values and calculate the Q-rating of the rock mass using the attached tables. (7)

2.5 The Geomechanics Classification of the rock mass is 69, indicating Good Rock. Compare this to your Q-rating above and provide possible reasons for any difference between the ratings. (3)

2.6 What adjustments are required to the basic **RMR** value to obtain an overall rock mass description? (2)

2.7 Use Kirsch equations to calculate the k-ratio that will result in zero stress in all directions on the periphery, at mid-height of the sidewall, of a circular tunnel mined through this rock mass. (6)

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QUESTION 3

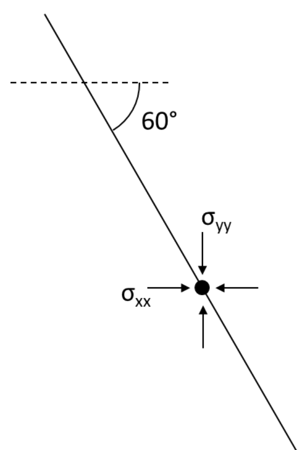
3.1 Define the following: (5)

a) Normal stress
b) Shear stress
c) Isotropic rock mass
d) Lithostatic stress conditions
e) Principal stress

3.2 The 2D virgin stress tensor as measured at a point of interest is given by:

$$\begin{pmatrix} \sigma_{xx} & \tau_{xy} \\ \tau_{yx} & \sigma_{yy} \end{pmatrix} = \begin{pmatrix} 40 & 8.66 \\ 8.66 & 50 \end{pmatrix} \text{ MPa}$$

Calculate and plot the normal and shear stresses acting on a 60° dipping fault as depicted below, when subjected to these virgin stresses. (5)



3.3 The normal and shear stress components at a point of interest on a fault plane are σ_n = 55 MPa and τ = 9.7 MPa. Calculate the minimum internal friction angle required for the fault to maintain stability, assuming no cohesion on the fault plane and **Mohr-Coulomb** failure. (3)

3.4 Barton and Choubey developed the following equation to calculate shear strength on a plane:

$$\tau = \sigma_n \times \tan\left\{\varphi_b + JRC \times log_{10}\left({}^{JCS}\!/_{\sigma_n}\right)\right\}$$

(a) Describe a laboratory procedure to directly determine the **base** friction angle.(2)

(b) For a joint roughness coefficient of 10 and joint wall compressive strength of 110 MPa, calculate the minimum base friction angle required to maintain stability at the point of interest for the fault described in Question 3.3 above. (3)

(c) What significance is there with an increase in normal stress? (2)

3.5 Given an internal friction angle of 36° and base friction angle of 33°, calculate the normal stress at which the Barton-Choubey discontinuity shear strength is equal to the 'intact' rock Mohr-Coulomb shear strength on the fault plane described in Question 3.3 above. (5)

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QUESTION 4

4.1 A force of 1000 kN acts on the end-surface of a piece of core with original diameter 34 mm and length 71 mm. The core sample decreases in length to 65 mm and increases in diameter to 35 mm.

(a) Calculate the stress acting on the sample. (2)

(b) Calculate the axial and radial strain of the sample. (2)

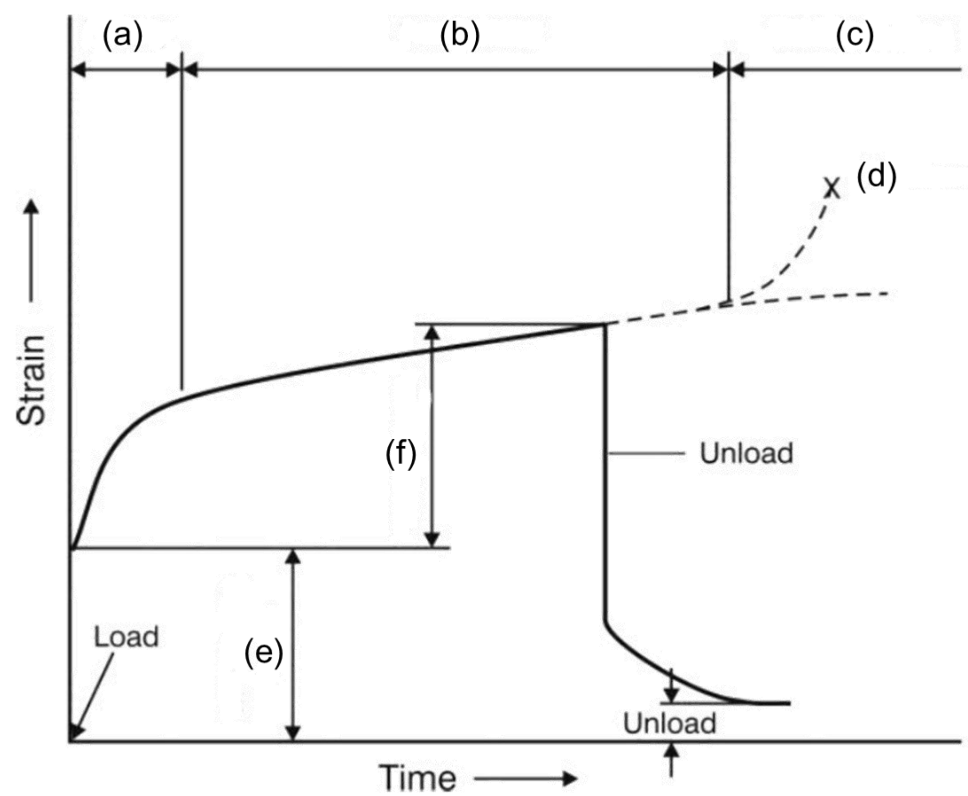
(c) Calculate the Young's modulus of the material. (1)

(d) Calculate the Poisson's ratio of the material. (2)

(e) Calculate the **shear** modulus of the material. (1)

(f) Calculate the **bulk** modulus of the material. (1)

4.2 The figure below illustrates a typical **laboratory creep** curve for rock suddenly subjected to a fixed elevated axial stress. List the annotations (a) to (f). (6)



4.3 Given the 3D **strain tensor** below (where $\Gamma = \gamma/2$), a Poisson's ratio of 0.25 and elastic modulus of 60 GPa.

$$\begin{pmatrix} \varepsilon_{xx} & \Gamma_{xy} & \Gamma_{xz} \\ \Gamma_{yx} & \varepsilon_{yy} & \Gamma_{yz} \\ \Gamma_{zx} & \Gamma_{zy} & \varepsilon_{zz} \end{pmatrix} = \begin{pmatrix} 0.0024 & 0.0012 & 0.0019 \\ 0.0012 & 0.0018 & 0.0003 \\ 0.0019 & 0.0003 & 0.0012 \end{pmatrix}$$

(a) Calculate the **normal** stress components, using generalized Hooke's Law equations. (6)

(b) Explain why the maximum value of the Poisson's ratio for isotropic, linear elastic material such as rock at small strains is **ν < 0.5**. (4)

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TOTAL MARKS: [100]

FORMULAE SHEET

1. $m_i = 2(\beta_o - 1)$
2. $F = mg$
3. $q_v = \rho gh$
4. $\beta_o = \frac{(1+\sin\varphi_i)}{(1-\sin\varphi_i)}$
5. $RQD = 115 - 3.3\ Jv$
6. $RMR = 9 \ln Q + 44$
7. $\mu = tan\varphi_i$
8. $\mathbf{s} = \mathbf{e}^{\frac{(\mathbf{RMR}-\mathbf{100})}{\mathbf{9}}}$
9. $\mathbf{m} = \mathbf{m_i}\, \mathbf{e}^{\frac{(\mathbf{RMR}-\mathbf{100})}{\mathbf{28}}}$
10. $k = \frac{v}{1-v}$
11. $K = \frac{E}{3(1-2v)}$
12. $G = \frac{E}{2(1+v)}$
13. $W = \frac{1}{2}\sigma\varepsilon$
14. $\varepsilon = \Delta\ell / L$
15. $E = \sigma/\varepsilon$
16. $\varepsilon_r = -v\varepsilon_a$
17. $\sigma_{xx} = \left[\frac{E}{(1+v)(1-2v)}\right]\left[(1-v)\varepsilon_{xx} + v\left(\varepsilon_{yy} + \varepsilon_{zz}\right)\right]$
18. $\sigma_{yy} = \left[\frac{E}{(1+v)(1-2v)}\right]\left[(1-v)\varepsilon_{yy} + v(\varepsilon_{xx} + \varepsilon_{zz})\right]$
19. $\sigma_{zz} = \left[\frac{E}{(1+v)(1-2v)}\right]\left[(1-v)\varepsilon_{zz} + v\left(\varepsilon_{xx} + \varepsilon_{yy}\right)\right]$
20. $\tau_{xy} = G\gamma_{xy}$ $\tau_{xz} = G\gamma_{xz}$ $\tau_{yz} = G\gamma_{yz}$
21. $\sigma_n = \sigma_1 cos^2\theta + \sigma_2 sin^2\theta$
22. $\tau_{nm} = -\frac{1}{2}(\sigma_1 - \sigma_2)sin2\theta$
23. $\tau_n = c + \mu\sigma_n$
24. $\sigma_1 = \frac{1}{2}\left(\sigma_x + \sigma_y\right) + \frac{1}{2}\sqrt{}\left[\left(\sigma_x - \sigma_y\right)^2 + 4\tau_{xy}^2\right]$
25. $\sigma_2 = \frac{1}{2}\left(\sigma_x + \sigma_y\right) - \frac{1}{2}\sqrt{}\left[\left(\sigma_x - \sigma_y\right)^2 + 4\tau_{xy}^2\right]$
26. $\theta = \frac{1}{2} arc\tan\left[2\tau_{xy}/\left(\sigma_x - \sigma_y\right)\right]$

27. $\tau_{max} = \frac{1}{2}(\sigma_1 - \sigma_2)$

28. $\sigma_{x\prime} = \sigma_x cos^2\theta + 2\tau_{xy} \sin\theta \cos\theta + \sigma_y sin^2\theta$

29. $\sigma_{y\prime} = \sigma_x sin^2\theta - 2\tau_{xy} \sin\theta \cos\theta + \sigma_y cos^2\theta$

30. $\tau_{x\prime y\prime} = \frac{1}{2}(\sigma_y - \sigma_x) \sin 2\theta + \tau_{xy} \cos 2\theta$

31. $J_v = \frac{1}{J_1} + \frac{1}{J_2} + \frac{1}{J_3}$

32. $\sigma_{rr} = \frac{1}{2} q(1+k)\left(1 - \frac{R^2}{r^2}\right) - \frac{1}{2} q(1-k)\left(1 - \frac{4R^2}{r^2} + \frac{3R^4}{r^4}\right)\cos 2\theta$

33. $\sigma_{\theta\theta} = \frac{1}{2} q(1+k)\left(1 + \frac{R^2}{r^2}\right) + \frac{1}{2} q(1-k)\left(1 + \frac{3R^4}{r^4}\right)\cos 2\theta$

34. $\tau_{r\theta} = \frac{1}{2} q(1-k)\left(1 + \frac{2R^2}{r^2} - \frac{3R^4}{r^4}\right)\sin 2\theta$

35. $Q = \frac{RQD}{Jn} \times \frac{Jr}{Ja} \times \frac{Jw}{SRF}$

Table 1 Joint set number

Number of Joint Sets	**Joint Set No.**
Intact, no or few joints	0.5 — 1.0
One joint set	2
One joint set plus random joints	3
Two joint sets	4
Two joint sets plus random joints	6
Three joint sets	9
Three joint sets plus random joints	12
Four or more joint sets, random, heavily jointed, sugar cube, etc.	15
Crushed rock, earthlike	20

Table 2 Joint Roughness Number

Description of Joint Surface Roughness	**Discontinuous**	**Undulating**	**Planar**
Rough	4.0	3.0	1.5
Smooth	3.0	2.0	1.0
Slickensided	2.0	1.5	0.5
Planes containing gouge thick enough to prevent rockwall contact	1.5	1.0	1.0

Table 3 Joint Alteration Number

Description of Gouge	Joint Alteration Number J_a for Joint Separation (mm)		
	<1.0	1.0-5.0	>5.0
Tightly healed, hard, non-softening impermeable rock mineral filling	0.75	-	-
Unaltered joint walls, surface staining only	1.0	-	-
Slightly altered, non-softening, non-cohesive rock mineral or crushed rock filling	2.0	4.0	6.0
Non-softening strongly over-consolidated clay mineral filling, with or without crushed rock	3.0	6.0	10.0
Softening or low friction clay mineral coatings and small quantities of swelling clays	4.0	8.0	13.0
Shattered or micro-shattered (swelling) clay gouge, with or without crushed rock	5.0	10.0	18.0

Table 4 Joint Water Reduction Factor

Condition of Groundwater	Head of water (m)	Joint Water Reduction Factor J_w
Dry excavation or minor inflow 5 litre/minute locally	<10	1.0
Medium inflow, occasional outwash of joint/fissure fillings	10 – 25	0.66
Large inflow in competent ground with unfilled joints/fissures	25-100	0.5
Large inflow with considerable outwash of joint/fissure fillings	25-100	0.33
Exceptionally high inflow upon excavation, decaying with time	>100	0.2-0.1
Exceptionally high inflow continuing without noticeable decay	>100	0.1-0.05

Table 5 Stress Reduction Factor for competent rock and rock stress problems

Description	UCS/σ_1	σ_t/σ_1	*SRF* Value
Low stress, near-surface	>200	>13	2.5
Medium stress	200-10	13-0.66	1.0
High stress, very tight structure (usually favourable to stability, may be unfavourable for wall stability)	10-5	0.66-0.33	0.5-2
Mild rock burst (massive rock)	5-2.5	0.33-0.16	5-10
Heavy rock burst (massive rock)	<2.5	<0.16	10-20