Minerals Council South Africa

EXAMINATION PAPER

SUBJECT: CHAMBER OF MINES CERTIFICATE IN ROCK MECHANICS PAPER 1 : THEORY **SUBJECT CODE:** COMRMC1 **EXAMINATION DATE:** 07 MAY 2019 **TIME**: 14:30 – 17:30	**EXAMINER:** W M BESTER **MODERATOR:** H YILMAZ **TOTAL MARKS:** [100] **PASS MARK:** (60%)

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.

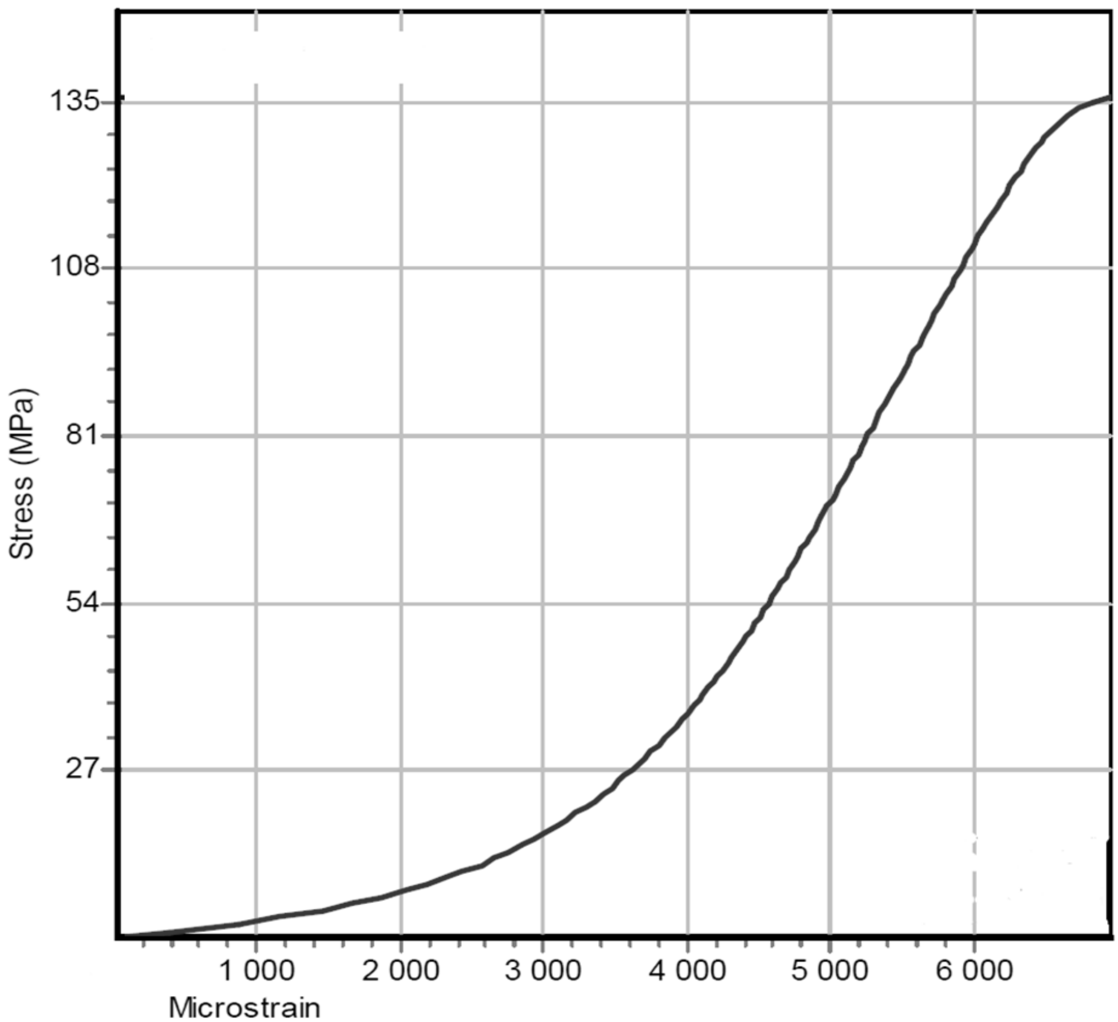
3. Show all calculations **and check calculations on which the answers are based.**
4. **Only non-programmable basic scientific calculators** may be used for calculations.
5. Write **legibly** in ink on the **right hand page** only – **left hand pages will not be marked**.
6. Illustrate your answers 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 A piece of norite core with original diameter 48.3 mm and length 74.9 mm is subjected to uniaxial compressive strength testing. The axial stress-strain curve until failure is provided below:



(a) **Calculate** the load at failure. (2)

(b) The mass of the piece of core is 406.9 grams. **Calculate** the density of the specimen. (1)

(c) **Illustrate** the tangent Young's modulus on a simple sketch and **determine** the tangent Young's modulus at 20% strength. (3)

(d) **Determine** the tangent Young's modulus at 60% strength. (2)

(e) **Illustrate** the secant Young's modulus on a simple sketch and **determine** the secant Young's modulus at 40% strength. (3)

(f) **Describe** the constitutive behaviour exhibited between 0 MPa and 54 MPa. (2)

(g) **Describe** the constitutive behaviour exhibited between 54 MPa and 108 MPa.(2)

1.2 Typical elastic constants and strength properties of different rock types are provided below:

Rock Type	**E (GPa)**	**ν**	**σ_c (MPa)**	**C_o (MPa)**	**φ_i°**
Quartzite	70	0.23	220	45	35
Pyroxenite	100	0.3	120	20	50
Sandstone	30	0.1	70	20	30
Granite	60	0.2	220	30	55

(a) **Calculate** the strengthening parameter (β_o) for each of these rock types. (2)

(b) **Calculate** the confinement (σ_3) required for pyroxenite and quartzite triaxial strength to be equal, assuming 'Mohr-Coulomb' failure. (4)

(c) **Calculate** the normal stress (σ_n) required for granite and quartzite shear strength to be equal, assuming 'Mohr-Coulomb' failure. (4)

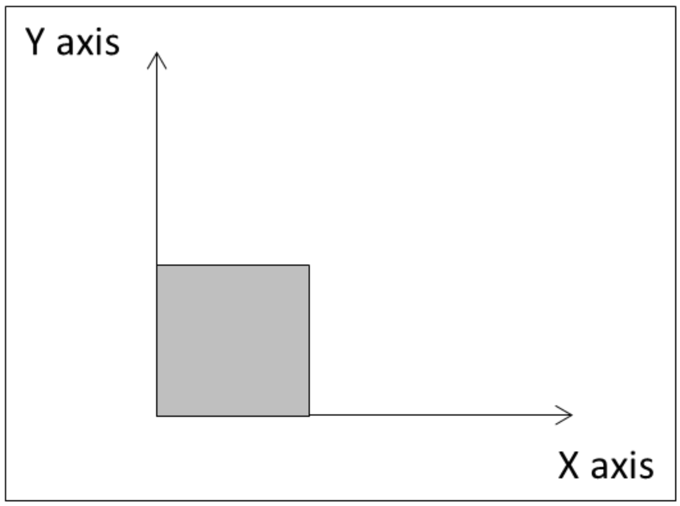
[25]

QUESTION 2

The following 2D state of stress is given:

$$\begin{pmatrix} \sigma_{xx} & \tau_{xy} \\ \tau_{yx} & \sigma_{yy} \end{pmatrix} = \begin{pmatrix} -5 & -26 \\ -26 & 25 \end{pmatrix} \text{ MPa}$$

2.1 **Draw and label** the state of stress on the following body diagram. (3)



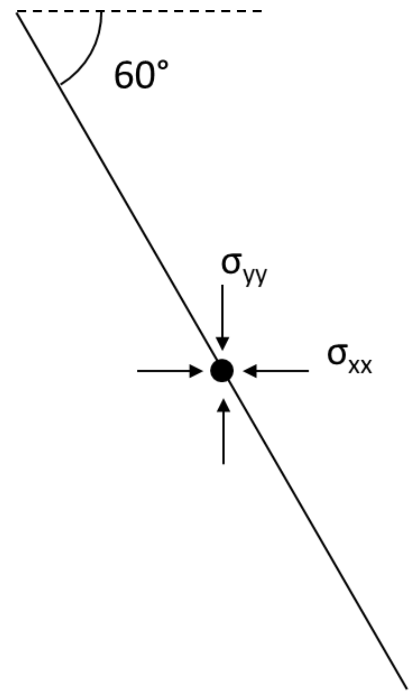
2.2 **Calculate** the normal and shear strain components in 2D.
(Given: E = 33 GPa and ν = 0.33) (3)

2.4 **Illustrate** the change in body shape resulting from these strains. (5)

2.5 **Calculate** the principal strains. (2)

2.6 Using the **Mohr stress circle** (no calculations) find the magnitudes of the principal stresses and maximum shear stress. (7)

2.7 **Calculate** the normal and shear stresses acting on a 60° dipping fault as depicted below, and **comment** on the physical implications thereof. (5)



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QUESTION 3

A rock mass contains 3 intersecting joint sets. $\mathbf{J_1}$ has 10 cm mean joint spacing, is continuous, with smooth planar surfaces, no infill and is dry. $\mathbf{J_2}$ has a mean spacing of 20 cm, is undulating and discontinuous, and is moderately rough with some iron staining. $\mathbf{J_3}$ is undulating and continuous, spaced 200-300 cm apart, relatively smooth with some outwash of 3 mm thick clay infill. Intact rock uniaxial compressive strength is 130 MPa, and overburden density is 2850 kg/m^3.

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

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

3.3 **Calculate** the vertical virgin stress at a depth of 930 m below surface, and the ratio of intact rock strength to stress. (2)

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

3.5 Which strength criterion is commonly used when assessing the strength of in-situ rock that is transected by many closely-spaced joint sets at multiple angles? **Discuss** the limitations of this criterion. (5)

3.6 **Estimate** the in situ Hoek-Brown 'm' and 's' parameters suitable for underground mining of a rock mass that has a Barton's Q value of 0.4 and internal friction angle of 30°. (5)

3.7 **Calculate** the Hoek-Brown strength of the rock mass, assuming 'm' and 's' parameters of 0.4 and 0.001 and a confining stress of 13 MPa. (2)

[25]

QUESTION 4

4.1 The database of in situ stress measurements carried out in Southern Africa lists horizontal stress components in deep level mines ranging between 0.3 and 1.5 times the vertical stress component. **Calculate** the horizontal virgin stress at a depth of 930 m below surface for k = 0.5, k = 1 and k = 1.5, assuming overburden density is 2850 kg/m^3. (3)

4.2 **Calculate** the radial, tangential and shear stresses at the periphery of a 3 m diameter tunnel, assuming lithostatic loading in Question 4.1. (3)

4.3 **Calculate** the tangential stress at mid height along the sidewalls of a 3 m diameter tunnel for k = 0.5 and k = 1.5. (4)

4.4 **Calculate** the tangential stress at top centre of a 3 m diameter tunnel for k = 0.5 and k = 1.5. (4)

4.5 D**iscuss** the practical implications of your results calculated in Questions 4.3 and 4.4 above. (4)

4.6 **Estimate** the depth of failure into the sidewall of a 3 m diameter tunnel to 20 cm accuracy, assuming k = 0.5 and Hoek-Brown failure of a rock mass with ‘m’ and ‘s’ parameters of 0.4 and 0.001. (7)

[25]

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. $\tau = C_o + \mu\sigma_n$
8. $\sigma_1 = \sigma_c + \beta_o\sigma_3$
9. $\mu = tan\varphi_i$
10. $\mathbf{s} = \mathbf{e}^{\frac{(\mathbf{RMR}-\mathbf{100})}{\mathbf{9}}}$
11. $\mathbf{m} = \mathbf{m_i}\,\mathbf{e}^{\frac{(\mathbf{RMR}-\mathbf{100})}{\mathbf{28}}}$
12. $\sigma_1 = \sigma_3 + \sqrt{(s\sigma_c^2 + m\sigma_c\sigma_3)}$
13. $k = \frac{v}{1-v}$
14. $K = \frac{E}{3(1-2v)}$
15. $G = \frac{E}{2(1+v)}$
16. $W = \frac{1}{2}\sigma\varepsilon$
17. $\varepsilon = \Delta\ell / \ell_o$
18. $E = \sigma/\varepsilon$
19. $\varepsilon_r = -v\varepsilon_a$
20. $\sigma_{xx} = \left[\frac{E}{(1+v)(1-2v)}\right]\left[(1-v)\varepsilon_{xx} + v\left(\varepsilon_{yy} + \varepsilon_{zz}\right)\right]$
21. $\sigma_{yy} = \left[\frac{E}{(1+v)(1-2v)}\right]\left[(1-v)\varepsilon_{yy} + v(\varepsilon_{xx} + \varepsilon_{zz})\right]$
22. $\sigma_{zz} = \left[\frac{E}{(1+v)(1-2v)}\right]\left[(1-v)\varepsilon_{zz} + v\left(\varepsilon_{xx} + \varepsilon_{yy}\right)\right]$
23. $\tau_{xy} = G\gamma_{xy}$ $\tau_{xz} = G\gamma_{xz}$ $\tau_{yz} = G\gamma_{yz}$
24. $\sigma_n = \sigma_1 cos^2\theta + \sigma_2 sin^2\theta$
25. $\tau_{nm} = -\frac{1}{2}(\sigma_1 - \sigma_2)sin2\theta$
26. $\sigma_1 = \frac{1}{2}\left(\sigma_x + \sigma_y\right) + \frac{1}{2}\sqrt{\left[\left(\sigma_x - \sigma_y\right)^2 + 4\tau_{xy}^2\right]}$

27. $\sigma_2 = \frac{1}{2}(\sigma_x + \sigma_y) - \frac{1}{2}\sqrt{\left[(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2\right]}$

28. $\theta = \frac{1}{2} arc \tan\left[2\tau_{xy}/(\sigma_x - \sigma_y)\right]$

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

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

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

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

33. $\varepsilon_x = \frac{1}{E}(\sigma_x - v\sigma_y)$

34. $\varepsilon_y = \frac{1}{E}(\sigma_y - v\sigma_x)$

35. $\varepsilon_1 = \frac{1}{2}(\varepsilon_x + \varepsilon_y) + \frac{1}{2}\sqrt{\left[(\varepsilon_x - \varepsilon_y)^2 + \gamma_{xy}^2\right]}$

36. $\varepsilon_2 = \frac{1}{2}(\varepsilon_x + \varepsilon_y) - \frac{1}{2}\sqrt{\left[(\varepsilon_x - \varepsilon_y)^2 + \gamma_{xy}^2\right]}$

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

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

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

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

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

Barton's Q Index - parameter tables:

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

Table 6 Stress Reduction Factor for weakness zones

Description	*SRF* Value
Multiple occurrences of weakness zones containing clay or chemically disintegrated rock, very loose surrounding rock (any depth)	10
Single weakness zones containing clay or chemically disintegrated rock (depth of excavation < 50m)	5
Multiple shear zones in competent rock (clay-free), loose surrounding rock (any depth)	2.5
Single shear zones in competent rock (clay-free), loose surrounding rock (any depth)	7.5
Single shear zones in competent rock (clay-free) (depth of excavation < 50m)	5.0
Single shear zones in competent rock (clay-free) (depth of excavation > 50m)	2.5
Loose open joints, heavily jointed or “sugar-cube” etc (any depth)	5.0