MINERALS COUNCIL SOUTH AFRICA

EXAMINATION PAPER

SUBJECT: CERTIFICATE IN ROCK MECHANICS PAPER 1 : THEORY **SUBJECT CODE:** COMRMC1 **EXAMINATION DATE:** 09 OCTOBER 2018 **TIME**: 3 HOURS	**EXAMINER:** WM BESTER **MODERATOR:** H YILMAZ **TOTAL MARKS:** [100] **PASS MARK:** (60%)

NUMBER OF PAGES: 8

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

Given the 3D **virgin stress tensor** as measured at a depth of 815 m below surface:

$$\begin{pmatrix} \sigma_{xx} & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_{yy} & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_{zz} \end{pmatrix} = \begin{pmatrix} 48 & -2 & 5.6 \\ -2 & 12 & 2.4 \\ 5.6 & 2.4 & 24 \end{pmatrix} MPa$$

1.1 The virgin or primitive state of stress is a function of several influencing factors. **List and describe** at least four of these factors. (4)

1.2 Assume $q_v = \sigma_{zz}$. **Calculate** the average overburden density. (1)

1.3 **Describe** the impact of in-situ stresses on stability of the rock mass at shallow, moderate and great depths. (6)

1.4 Intact rock uniaxial compressive strength is 95 MPa. What would be the **most critical** ratio of rock strength to virgin stress at a depth of 815 m? (1)

1.5 **Describe** the SRF variable in Barton's Q System. (3)

1.6 Assume competent rock. **Determine** the SRF value for the rock mass using your answer to Question 1.4 and the attached Q-parameter tables. (1)

1.7 Both σ_{xx} and σ_{yy} are horizontal. **Calculate** the k-ratios in horizontal directions. (2)

1.8 **Calculate** the tangential stress at the crown (top centre) of a 4 m diameter tunnel aligned with σ_{yy} at a depth of 815 m. (5)

1.9 **Sketch** the expected spalling and fracturing pattern around the tunnel described in Question 1.8. (2)

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QUESTION 2

2.1 By means of a **sketch**, indicate the applicability of the Hoek-Brown strength criterion to different rock mass conditions. (5)

2.2 Indicate the influence of the 'm' and 's' parameters on the Hoek-Brown strength criterion **graphically** in σ_1-σ_3 space. (4)

2.3 **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 10 and internal friction angle of 35°. (4)

2.4 **List and describe** the five parameters of Bieniawski's Geomechanics Classification system (RMR_{73}). (5)

2.5 **Calculate** Laubscher's MRMR for the rock mass described in Question 2.3 using modifications of 88% for weathering, 80% for joint orientation, 90% for mining induced stresses, and 80% for blasting effects. (2)

2.6 **Calculate** the minimum required hangingwall support density for a rock mass with a MRMR of 40 using the following empirical formula derived for Canadian hard rock mines:

$$D = -0.0214\ MRMR + 1.68 \qquad \text{(D = No. of support tendons per m}^2\text{)}$$

Recommend a practical tendon support pattern in a 4 m wide tunnel. (3)

2.7 **List** 4 factors that influence joint shear strength. (2)

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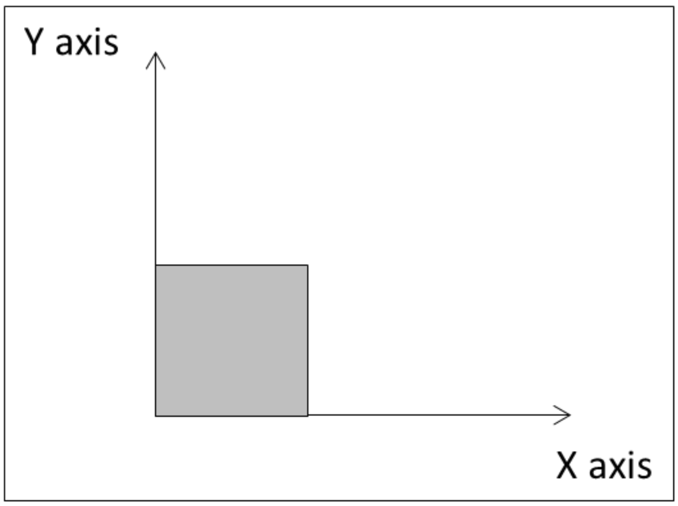
QUESTION 3

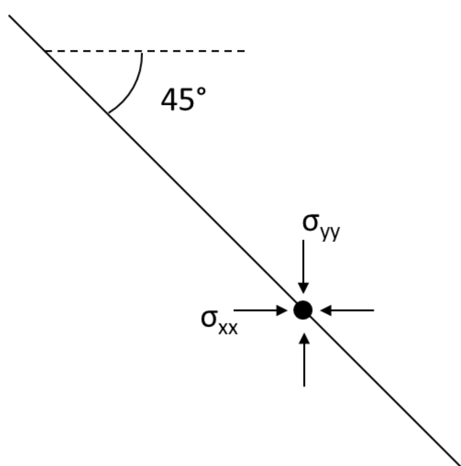
The following state of stress is given:

$$\begin{pmatrix} \sigma_x & \tau_{xy} \\ \tau_{yx} & \sigma_y \end{pmatrix} = \begin{pmatrix} 2.5 & 13 \\ 13 & -12.5 \end{pmatrix} \text{ MPa}$$

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



3.2 **Calculate and plot** the normal and shear stresses acting on a 45° dipping fault as depicted below, when subjected to these stresses. (5)



3.3 **Calculate** the normal and shear strain components.
(Assume E = 70 GPa and ν = 0.3) (3)

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

3.5 **Calculate** the principle strains. (2)

3.6 Using the **Mohr stress circle** (no calculations), find the magnitudes of the principal stresses and their directions from the X-axis. (7)

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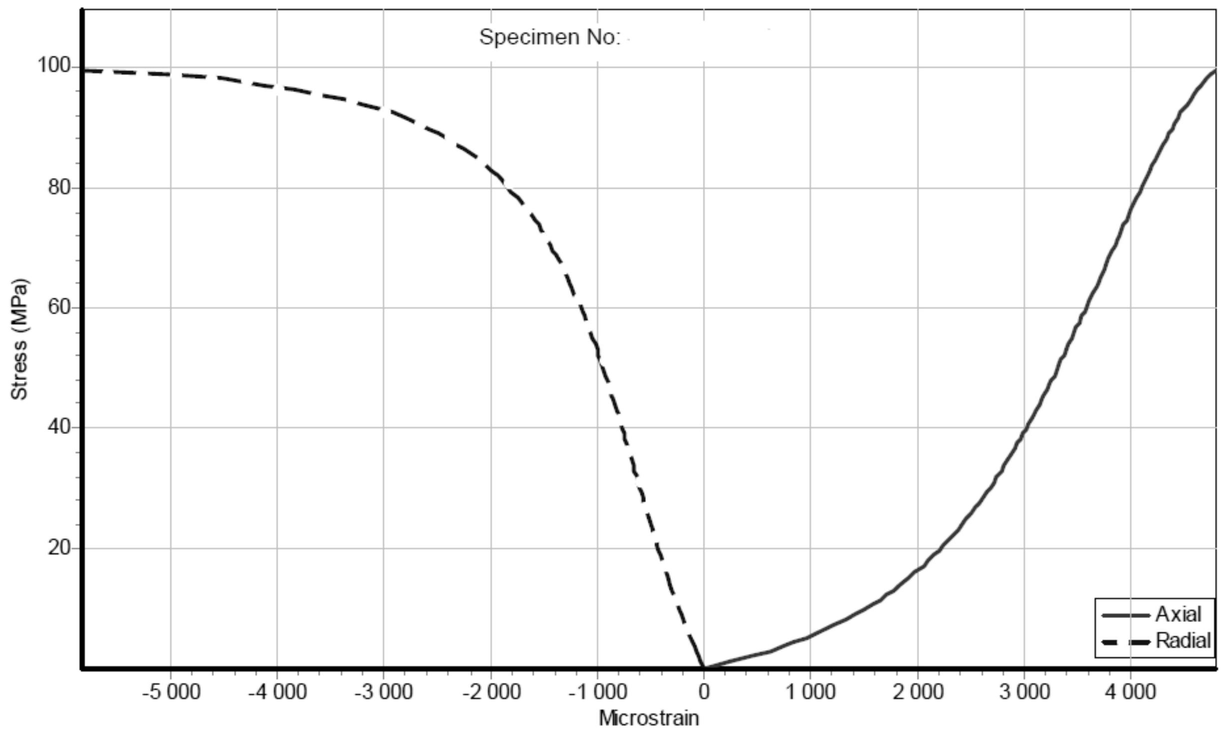
QUESTION 4

4.1 A piece of core with original diameter 40.2 mm and length 89.8 mm is subjected to uniaxial compressive strength testing. The stress-strain curve is provided below:



(a) The mass of the piece of core is 339.2 grams. **Calculate** the density of the specimen. (1)

(b) The failure load is 127 kN. **Calculate** the peak strength of the specimen. (1)

(c) Using the provided stress-strain curve, **determine** the change in diameter of the core specimen at 50% strength. (2)

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

(e) **Describe** the constitutive behaviour exhibited between 40 MPa and 70 MPa. (2)

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

(g) Using the provided stress-strain curve, **determine** the tangent Young's modulus at 50% strength. (3)

(h) **Define** the modulus of rigidity of a material, and **explain** the physical difference between this and the modulus of elasticity. (3)

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

Rock Type	**E (GPa)**	**v**	**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 shear moduli of the different rock types. (2)

(b) **Plot** the 'Mohr-Coulomb' relation for each of these rock types on the **same graph** in σ_1-σ_3 space for confinement ranging between 0 MPa and 30 MPa. (6)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

40. $Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$

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