Minerals Council South Africa

EXAMINATION PAPER

SUBJECT: CERTIFICATE IN ROCK MECHANICS **RMC PAPER 1 :** THEORY **SUBJECT CODE:** **COMRMC** **EXAMINATION DATE:** 10 MAY 2022 **TIME**: 14H30 TO 17H30	**EXAMINER:** H YILMAZ **MODERATOR:** G KOTZE **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 and other smart devices e.g. Smartwatch are **NOT** allowed in the examination room.

QUESTION 1.

1.1 A cubic rock piece with 6m side length rests on nine cubic pieces of the same rock type with 0.1m side length. Smaller pieces are equally spaced as seen in Figure b. If the density of rock is 3000 kg/m^3, calculate the stress on a single 0.1m cubic piece. Neglect the weight of small pieces. (6)

1.2 If the smaller cubic pieces are failing, recommend at least four solutions to maintain their stability. (4)

(Not to scale)

Figure a

Figure b

1.3 A mine has a 6m diameter vertical ventilation shaft. Calculate the radial, circumferential and shear stresses 0.2m **into** the rock at the north point (A) for a depth of 2500m below surface. Draw a simple sketch of the shaft showing the stresses, directions, the point A with proper labels. The principal in situ horizontal stress in the north-south direction is equal to half the overburden stress, and the principal in situ horizontal stress in the east-west direction is twice the overburden stress. The unit weight of the rock γ is 0,025 MN/m^3. The modulus of elasticity of the rock E is 50 GPa, and Poisson's ratio for the rock ν is 0,25. Assume that the rock behaves elastically. (15)

[25]

QUESTION 2.

2.1 A marble specimen having 60 mm diameter and 150 mm length original dimensions is subjected to loading as shown in Figure a. A simplified stress strain graph is provided. The axial and radial strain values when the normal stress is 20 MPa are measured and provided on the graph. A second marble specimen shaped as rectangular prism is tested under loading conditions as shown in Figure b.

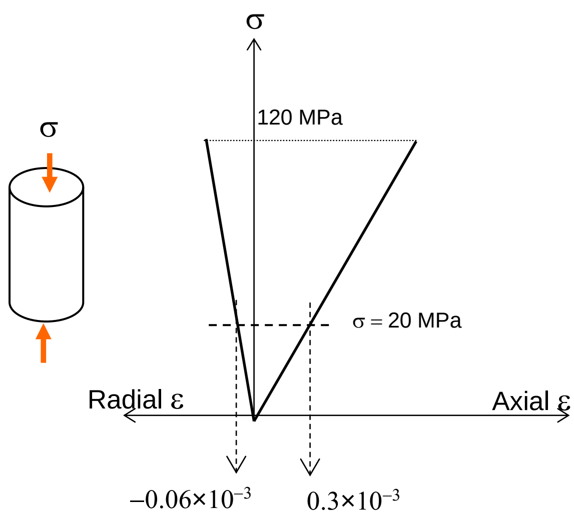


Figure a

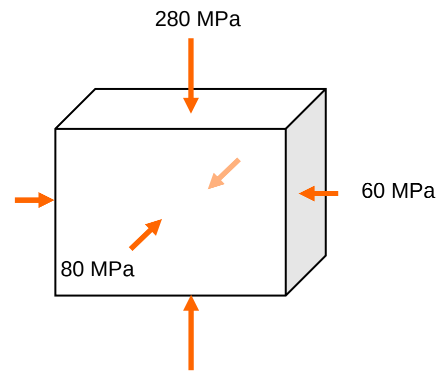


Figure b

i) If the rock fails at 120 MPa, calculate the strain energy density in Figure a. (6)

ii) Determine the normal strains under loading conditions in Figure b. (11)

iii) Calculate the strain energy density in Figure b. (2)

iv) Name the loading conditions in Figure a and Figure b. (2)

v) Define isotropic behaviour and principal stress. (4)

[25]

QUESTION 3.

3.1 A series of triaxial tests were carried out on specimens of a given rock, and it was found that failure occurred for the following combinations of principal stresses:

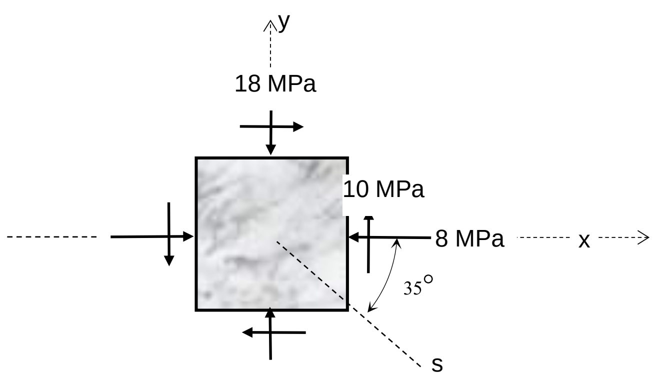
σ_1 (MPa)	52	88	124	160
σ_3 (MPa)	10	20	30	40

i) draw Mohr's envelope for the rock, (4)

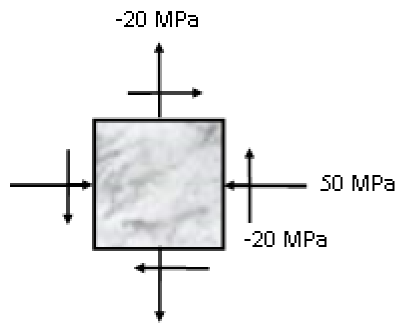
ii) estimate the cohesion and angle of internal friction for the rock, (2)

iii) estimate compressive stress which would produce failure in uniaxial compression. (2)

3.2 For the stress state depicted below, calculate the stress components acting on a plane where the normal of the plane is along direction “s”. Plot these stresses indicating their directions. (7)



3.3 Calculate the magnitudes and directions of the principal stresses for the following stress state. (6)



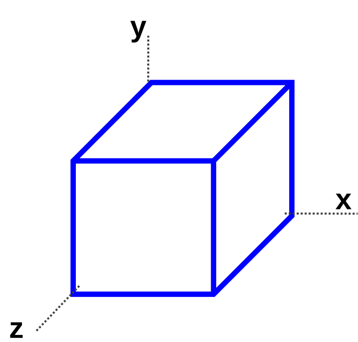
3.4 Describe the methods for estimating the "Joint Roughness Coefficient" in Barton's shear strength criterion. (4)

[25]

QUESTION 4.

Provide short answers. Use the boxes or as sketches where necessary. No credit will be given for any working shown. You may hand in Question 4 with your script.

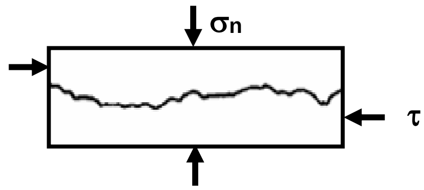
(a) Sketch the state of stress $\begin{bmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_y & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_z \end{bmatrix} = \begin{bmatrix} 3 & 0 & -3 \\ 0 & 1 & 0 \\ -3 & 0 & -2 \end{bmatrix}$ MPa, on the cubic element; (2)

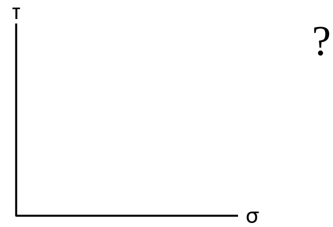


(b) List three factors that increase compressive strength of intact rock material in laboratory testing: (3)

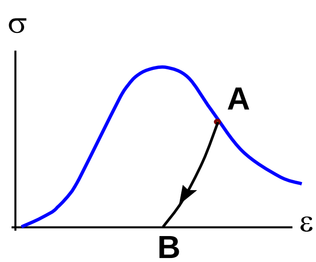
(c) List two factors that influence the stress distribution around a circular tunnel. (2)

(d) Plot the possible Shear strength versus Normal stress graph as a result of shear testing of a discontinuity with the roughness profile shown in the following sketch? (Assume no cohesion) (2)



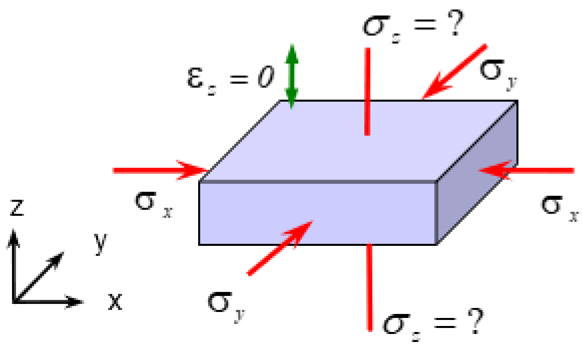


(e) A rock sample is unloaded at A with the unloading path shown during a UCS test. Plot the path if reloading takes place at point B? (2)



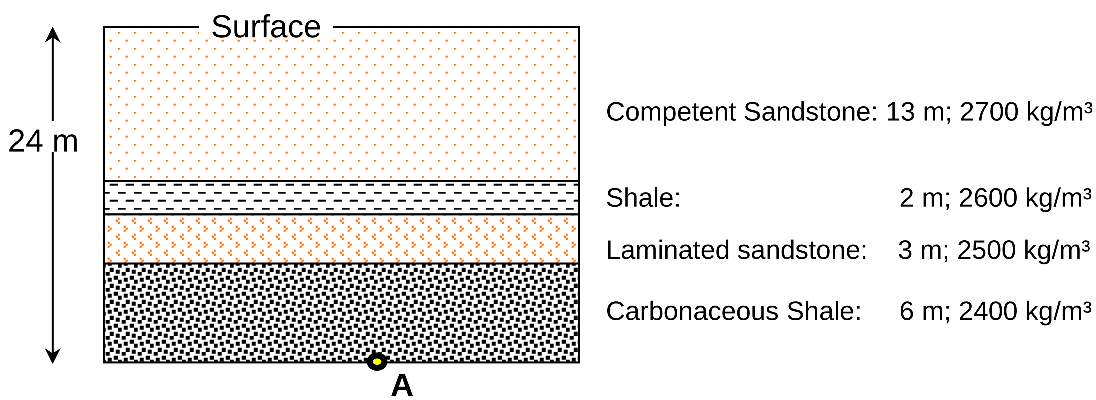
(f) If the normal strain is zero in the z direction, calculate the stress in the z direction provided that; (3)

σ_x = 16 MPa; σ_y = 12 MPa; E = 70 GPa; G = 28 GPa; ν = 0.25



Answer

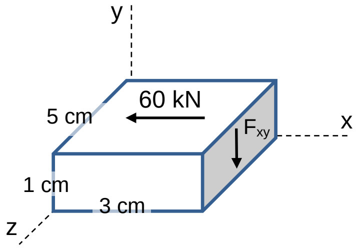
(g) Calculate the virgin vertical stress at point A if the overlying rocks consist of the following thicknesses and densities; (take g = 10 m/s^2). (3)



Answer

(h) List three factors that increase the shear strength of discontinuities. (3)

(i) The magnitude of F_{xy} for equilibrium condition is; (2)



Answer

(j) Fill in the blank spaces; (3)

- Coefficient "$I_1 = \sigma_{x'} + \sigma_{y'} = \sigma_x + \sigma_y = \sigma_1 + \sigma_2$" is called ________________________, is constant and don't depend on the orientation of the coordinate system.
- The value of the Poisson's ratio cannot be greater than _____________________.
- According to ______________________ law, the strain of an elastic material is proportional to the stress applied to it.

[25]

FORMULAE SHEET

1. $F = mg$ $\sigma = F/A$
2. $q_v = \rho g h$
3. $\beta_o = \frac{(1+\sin\varphi_i)}{(1-\sin\varphi_i)}$
4. RQD = 115 – 3.3 Jv
5. $\tau = C_o + \mu\sigma_n$
6. $\sigma_1 = \sigma_c + \beta_o\sigma_3$
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. $\sigma_1 = \sigma_3 + \sqrt{(s\sigma_c^2 + m\sigma_c\sigma_3)}$
11. $k = \frac{v}{1-v}$
12. $K = \frac{E}{3(1-2v)}$
13. $w = \frac{1}{2}(\sigma_x\varepsilon_x + \sigma_y\varepsilon_y + \sigma_z\varepsilon_z + \tau_{xy}\gamma_{xy} + \tau_{yz}\gamma_{yz} + \tau_{zx}\gamma_{zx})$
14. $Q = \frac{1}{2}\sigma\varepsilon \times Volume$
15. $\varepsilon = \Delta\ell / \ell_o$ $E = \sigma/\varepsilon$ $\varepsilon_r = -v\varepsilon_a$
16. $\sigma_{xx} = \left[\frac{E}{(1+v)(1-2v)}\right]\left[(1-v)\varepsilon_{xx} + v\left(\varepsilon_{yy} + \varepsilon_{zz}\right)\right]$
17. $\sigma_{yy} = \left[\frac{E}{(1+v)(1-2v)}\right]\left[(1-v)\varepsilon_{yy} + v(\varepsilon_{xx} + \varepsilon_{zz})\right]$
18. $\sigma_{zz} = \left[\frac{E}{(1+v)(1-2v)}\right]\left[(1-v)\varepsilon_{zz} + v\left(\varepsilon_{xx} + \varepsilon_{yy}\right)\right]$
19. $\sigma_x = \frac{E}{1-\nu^2}(\varepsilon_x + \nu\varepsilon_y)$ $\sigma_y = \frac{E}{1-\nu^2}(\varepsilon_y + \nu\varepsilon_x)$
20. $\sigma_1 = \frac{E}{1-\nu^2}(\varepsilon_1 + \nu\varepsilon_2)$ $\sigma_2 = \frac{E}{1-\nu^2}(\varepsilon_2 + \nu\varepsilon_1)$

21. $\sigma_n = \sigma_1 cos^2\theta + \sigma_2 sin^2\theta$ $\qquad \tau_{nm} = -\frac{1}{2}(\sigma_1 - \sigma_2)sin2\theta$

22. $\sigma_1 = \frac{1}{2}(\sigma_x + \sigma_y) + \frac{1}{2}\sqrt{\left[(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2\right]}$

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

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

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

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

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

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

29. $\varepsilon_{x'} = \varepsilon_x \cos^2\theta + \gamma_{xy} \sin\theta\cos\theta + \varepsilon_y \sin^2\theta$

30. $\varepsilon_{y'} = \varepsilon_x \sin^2\theta - \gamma_{xy} \sin\theta\cos\theta + \varepsilon_y \cos^2\theta$

31. $\gamma_{x'y'} = (\varepsilon_y - \varepsilon_x) \sin2\theta + \gamma_{xy} \cos2\theta$

32. $\varepsilon_{x'} = \varepsilon_x \cos^2\theta + \gamma_{xy} \sin\theta\cos\theta + \varepsilon_y \sin^2\theta$

$$\varepsilon_1 + \varepsilon_2 = \frac{2}{3}(\varepsilon_{0^\circ} + \varepsilon_{60^\circ} + \varepsilon_{120^\circ}),$$

33. $$(\varepsilon_1 - \varepsilon_2)^2 = \frac{4}{3}(\varepsilon_{60^\circ} - \varepsilon_{120^\circ})^2 + \frac{4}{9}(2\,\varepsilon_{0^\circ} - \varepsilon_{60^\circ} - \varepsilon_{120^\circ})^2$$

$$\tan 2\theta = \frac{\sqrt{3}(\varepsilon_{60^\circ} - \varepsilon_{120^\circ})}{2\,\varepsilon_{0^\circ} - \varepsilon_{60^\circ} - \varepsilon_{120^\circ}}$$

34. $\varepsilon_x = \frac{1}{E}[\sigma_x - \nu(\sigma_y + \sigma_z)]$ $\qquad \gamma_{xy} = \frac{1}{G}\tau_{xy}$ $\qquad G = \frac{E}{2(1+\nu)}$

$\varepsilon_y = \frac{1}{E}[\sigma_y - \nu(\sigma_x + \sigma_z)]$ $\qquad \gamma_{yz} = \frac{1}{G}\tau_{yz}$

$\varepsilon_z = \frac{1}{E}[\sigma_z - \nu(\sigma_x + \sigma_y)]$ $\qquad \gamma_{zx} = \frac{1}{G}\tau_{zx}$

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

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

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

$\sigma_z^t = \sigma_z^v + \nu\,(\sigma_r^i + \sigma_\theta^i)$