Minerals Council South Africa

EXAMINATION PAPER

SUBJECT: CERTIFICATE IN ROCK MECHANICS **PAPER 1:** THEORY **SUBJECT CODE:** COMRMC **EXAMINATION DATE:** 3RD OF OCTOBER 2023 **TIME**: 14H30 TO 17H30 (3 HOURS)	**EXAMINER:** SZ PETHÖ **MODERATOR:** O RAKUMAKOE **TOTAL MARKS:** [100] **PASS MARK:** (60%)

NUMBER OF PAGES: 7

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

SPECIAL REQUIREMENTS:

1. **Answer All the 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, on any graph paper or loose sheets.

3. Show all your calculations **and check the calculations on which the answers are based.**
4. Hand-held electronic calculators may be used for calculations. **Reference notes may not be programmed into calculators.**
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. **Make use of the provided graph paper** where required, including all annotations and units.
8. **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) is recorded as marks will be deducted from answers if the incorrect unit is used, even if the calculated value is correct.

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

QUESTION 1.

1.1 Describe and explain the concept of plane strain using a simple sketch, and how it can be applied in a typical underground situation.	(4)
1.2 Using a typical stress-strain graph for a rock material describe, explain, and clearly indicate and annotate the onset of inelastic behaviour, dilation and strain softening.	(5)
1.3 In a series of triaxial compression tests on a sandstone sample, the following represent the stresses obtained at peak load conditions:	

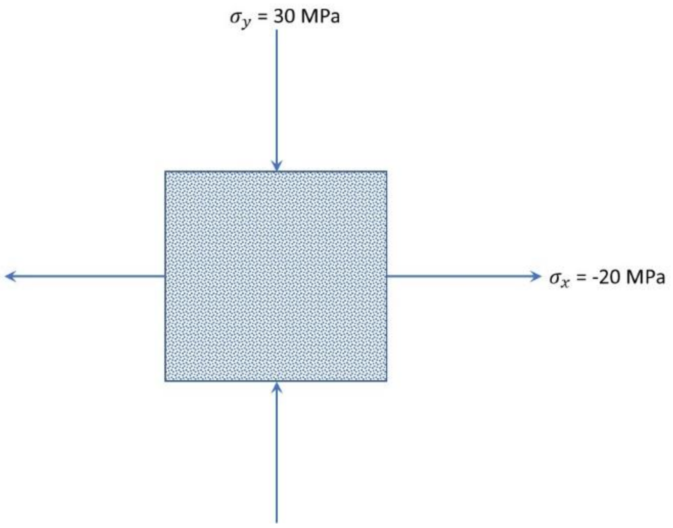
Test	σ_3 (MPa)	σ_1 (MPa)
1	1.0	9.6
2	5.2	28.4
3	9.1	48.7
4	15.0	74.0

Determine the values of c and ϕ that best fit the data, by graphical and analytical means in the σ_1 and σ_3 principal stress space. (10)

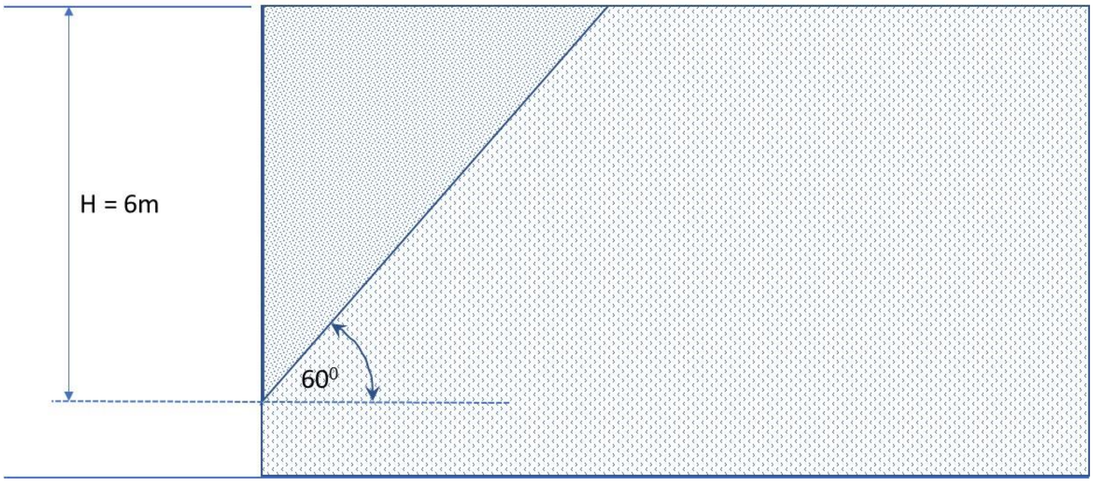
$\tan\psi = \frac{1+\sin\phi}{1-\sin\phi}$ and $\sigma_c = 2c\sin\phi/1-\sin\phi$

1.4 The initial state of stress at a point in the ground, in the sandstone discussed above in Question 1.3, is as follows: $\sigma_3 = 9.0$ MPa, and $\sigma_1 = 34.5$ MPa. The pore water pressure (ρ_w) will be raised by the construction of a reservoir. What value of (ρ_w) will cause fracturing of the sandstone in situ (assume that the fracture occurs at peak stress)?	(3)
1.5 Explain what 3D stress invariants are, and how are they used?	(3)
TOTAL	**[25]**

QUESTION 2.

2.1 Explain the basis for establishing the Hoek-Brown criterion.	(3)
2.2 Describe each parameter and the impact each parameter in Barton's equation has on the joint shear strength.	(6)
2.3 For a rough discontinuity surface in rock, the following data were obtained from in-situ observations and laboratory tests: Basic friction angle: 30 degrees, JRC: 10, and JCS: 7 MPa. In the normal stress range from 0 kPa to 350 kPa, plot Barton's relationship between the normal stress and shear strength.	(6)
2.4 Using the data derived in Question 2.3, determine Coulomb's equation for the straight-line representation of the normal stress – shear strength relationship in the normal stress range from 100 kPa to 300 kPa and plot the straight line on the diagram produced in Question 2.3.	(4)
2.5 If an element of an elastic material is to be subjected to the stresses as indicated below, determine the magnitude of σ_z required to maintain the element in a plane strain condition.  Also, calculate the strain energy density present in the material on completion of the loading. Assume, E = 50 GPa and υ = 0.2	(6)
TOTAL	**[25]**

QUESTION 3.

<table>
<tr><td>3.1 A vertical cut has been excavated, with a joint plane mapped as indicated in the sketch below:


The following information is available for the joint plane:
$\tau = 30 + 0.58\sigma_n$ (kPa),
$\rho = 2700$ kg / m^3, and
g = 9.81 m / s^2.
Calculate the Factor of Safety by using either the forces or the stresses, and stipulating all assumptions used for the calculations.</td><td>(12)</td></tr>
<tr><td>3.2 Describe and explain what effect the orientation of the planes of weakness has on the strength results for anisotropic rocks, with examples.</td><td>(4)</td></tr>
<tr><td>3.3 Describe and explain how the m parameter for intact rock (m_i) required for the Hoek and Brown criterion may be obtained.</td><td>(3)</td></tr>
<tr><td>3.4 Discuss the different types of stress fracturing that occur in response to mining, and indicate these by means of a simple sketch?</td><td>(6)</td></tr>
<tr><td>TOTAL</td><td>[25]</td></tr>
</table>

QUESTION 4.

4.1 Explain with a simple sketch how core discing can be used as an indirect method to determine in-situ rock stress levels based on rock behaviour.	(4)
4.2 Discuss how the flat jack method is employed in practice, and the advantages offered with using this technique.	(6)
4.3 Discuss Laubscher's classification system and how it is used.	(3)
4.4 The following strains have been measured at a point on the free surface of a solid body: Direction | Angle [θ] | Strain [ε] a | 0^0 | 0.002 b | 120^0 | 0.002 c | 240^0 | -0.001 Determine the principal strains in the plane of the surface and the principal directions of strain relative to direction a.	(7)
4.5 Draw the Mohr's circle for the state of strain specified in Question 4.4 and determine the maximum shear strain value.	(5)
TOTAL	**[25]**

Direction	Angle [θ]	Strain [ε]
a	0^0	0.002
b	120^0	0.002
c	240^0	-0.001

Total Mark = [100]

Formula Sheet

1. $\tau = c + \sigma_n \tan\phi$
2. $\sigma_1 = \sigma_c + \tan\psi\, \sigma_3$
3. $\tan\psi = (1 + \sin\phi)/(1 - \sin\phi)$
4. $\sigma_c = 2c\cos\phi/(1 - \sin\phi)$
5. $\phi = \sin^{-1}(\tan\psi - 1| \tan\psi + 1)$
6. $c = \sigma_c/2\sqrt{\tan\psi}$
7. $\sigma_n = \sigma_{xx}cos^2\theta + 2\tau_{xy}\sin\theta\cos\theta + \sigma_{yy}sin^2\theta$
8. $\tau_{nm} = \frac{1}{2}\left(\sigma_{yy} - \sigma_{xx}\right) sin2\theta + \tau_{xy}\cos 2\theta$
9. $\tan 2\theta = \frac{2\tau_{xy}}{(\sigma_{xx} - \sigma_{yy})}$
10. $\sigma_1 = \frac{1}{2}\left(\sigma_{xx} + \sigma_{yy}\right) + \frac{1}{2}\sqrt{(\sigma_{xx} - \sigma_{yy})^2 + 4\tau_{xy}^2}$
11. $\sigma_2 = \frac{1}{2}\left(\sigma_{xx} + \sigma_{yy}\right) - \frac{1}{2}\sqrt{(\sigma_{xx} - \sigma_{yy})^2 + 4\tau_{xy}^2}$
12. $\varepsilon_n = \epsilon_{xx}cos^2\theta + \gamma_{xy}sin\theta cos\theta + \varepsilon_{yy}sin^2\theta$
13. $\gamma_{nm} = \left(\varepsilon_y - \varepsilon_x\right)\sin 2\theta + \gamma_{xy}\cos 2\theta$
14. $\tan 2\theta = \frac{\gamma_{xy}}{(\varepsilon_{xx} - \varepsilon_{yy})}$
15. $\varepsilon_1 = \frac{1}{2}\left(\varepsilon_{xx} + \varepsilon_{yy}\right) + \frac{1}{2}\sqrt{\left(\varepsilon_{xx} - \varepsilon_{yy}\right)^2 + \gamma_{xy}^2}$
16. $\varepsilon_2 = \frac{1}{2}\left(\varepsilon_{xx} + \varepsilon_{yy}\right) - \frac{1}{2}\sqrt{\left(\varepsilon_{xx} - \varepsilon_{yy}\right)^2 + \gamma_{xy}^2}$
17. $\tan 2\theta = {\gamma_{xy}}\big/{(\varepsilon_{xx} - \varepsilon_{yy})}$
18. $W = \frac{1}{2}(\sigma_1\varepsilon_1 + \sigma_2\varepsilon_2 + \sigma_3\varepsilon_3)$
19. $\sigma_1 = \frac{E}{1-\nu^2}(\varepsilon_1 + \nu\varepsilon_2)$
20. $\sigma_2 = \frac{E}{1-\nu^2}(\varepsilon_2 + \nu\varepsilon_1)$
21. $\varepsilon_x = \frac{1}{E}\{\sigma_x - \nu(\sigma_y + \sigma_z)\}$
22. $\varepsilon_y = \frac{1}{E}\{\sigma_y - \nu(\sigma_x + \sigma_z)\}$
23. $\varepsilon_z = \frac{1}{E}\{\sigma_z - \nu(\sigma_x + \sigma_y)\}$
24. $\gamma_{xy} = \frac{1}{G}\tau_{xy}, \quad \gamma_{yz} = \frac{1}{G}\tau_{yz}, \quad \gamma_{zx} = \frac{1}{G}\tau_{zx}$

25. $\lambda = \frac{E\nu}{(1+\nu)(1-2\nu)}$

26. $G = \frac{E}{2(1+\nu)}$

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

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

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

30. $\sigma_3 - \mathrm{I}_1\sigma^2 - \mathrm{I}_2\sigma - \mathrm{I}_3 = 0,$

31. $\mathrm{I}_1 = \sigma_{xx} + \sigma_{yy} + \sigma_{zz}$

32. $\mathrm{I}_2 = -(\sigma_{xx}\sigma_{yy} + \sigma_{yy}\sigma_{zz} + \sigma_{zz}\sigma_{xx}) + \tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2$

33. $\mathrm{I}_3 = \sigma_{xx}\sigma_{yy}\sigma_{zz} + 2\tau_{xy}\tau_{yz}\tau_{zx} - \sigma_{xx}\tau_{yz}^2 - \sigma_{yy}\tau_{zx}^2 - \sigma_{zz}\tau_{yx}^2$

34. $Q = (3I_2 + I_1^2)^{0.5}$

35. $\cos\phi = (9\mathrm{I}_1\mathrm{I}_2 + 27\mathrm{I}_3 + 2\mathrm{I}_1^3)/2Q^3$

36. $\sigma_p = \frac{1}{3}\left[2Q\cos\left(\frac{\phi}{3} + k.120°\right) + \mathrm{I}_1\right]$

37. $k = 0, 1, 2$

38. $\mathrm{I}_1 = \sigma_1 + \sigma_2 + \sigma_3 = \sigma_{xx} + \sigma_{yy} + \sigma_{zz}$

39. $\mathrm{I}_2 = (\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_3\sigma_1) = -\left(\sigma_{yy}\sigma_{zz} + \sigma_{zz}\sigma_{xx} + \sigma_{xx}\sigma_{yy}\right) + {\tau_{yz}}^2 + {\tau_{zx}}^2 + {\tau_{xy}}^2$

40. $\mathrm{I}_3 = \sigma_1\sigma_2\sigma_3 = \sigma_{xx}\sigma_{yy}\sigma_{zz} + 2\tau_{yz}\tau_{zx}\tau_{xy} - \sigma_{xx}{\tau_{yz}}^2 - \sigma_{yy}{\tau_{zx}}^2 - \sigma_{zz}{\tau_{xy}}^2$

41. $Q = \frac{RQD}{J_n}\ x\ \frac{J_r}{J_a}\ x\ \frac{J_w}{SRF}$

42. $\tau = \sigma_n \tan\left(\phi_r + \mathrm{JRC}\log_{10}(\mathrm{JCS}/\sigma_\mathrm{n})\right)$

43. $\tau = \sigma_n \tan(\phi_b + \mathrm{i})$

44. $\sigma_1 = \sigma_3 + \sigma_{ci}\left(m_b\, {}^{\sigma_3}/_{\sigma_{ci}} + s\right)^a$

45. $\sigma_1 = \sigma_3 + \sigma_{ci}\left(m_i\, {}^{\sigma_3}/_{\sigma_{ci}} + 1\right)^{0.5}$

46. $GSI = RMR_{89} - 5$

47. $m_b = m_i exp\left(\frac{GSI-100}{28}\right)$

48. $For\ GSI > 25, s = exp\left(\frac{GSI-100}{9}\right), and\ a = 0.5$

49. $For\ GSI < 25, s = 0, and\ a = 0.65 - {}^{GSI}/_{200}$

50. $When\ \sigma_{ci} > 100\ MPa,\ E_m = 10^{\left(\frac{GSI-10}{40}\right)}$ (GPa)

51. $When\ \sigma_{ci} < 100\ MPa,\ E_m = \sqrt{{}^{\sigma_{ci}}/_{100}}\, 10^{\left(\frac{GSI-10}{40}\right)}$ (GPa)