Minerals Council South Africa

EXAMINATION PAPER

SUBJECT: CERTIFICATE IN ROCK MECHANICS	**EXAMINER:** THOVHEDZO GCUDA
PAPER 1: ROCK MECHANICS THEORY	**MODERATOR:** DAVE ROBERTS
SUBJECT CODE: COMRMC	**TOTAL MARKS:** [100]
DATE: 07 OCTOBER 2025	**PASS MARK:** (60%)
TIME: 14H00 TO 17H00	

NUMBER OF PAGES: 9 (including this one)

THIS IS NOT AN OPEN BOOK EXAMINATION – ONLY REFERENCES PROVIDED ARE ALLOWED

SPECIAL REQUIREMENTS:

1. Answer all the questions in legible English.
2. Write your ID number on the outside cover of each script 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 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 black ink on the right-hand page only. Left-hand pages will not be marked.
6. Illustrate your answers using sketches or diagrams and make use of the graph paper where applicable.
7. Final answers must be given to an accuracy 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 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 the data given.
9. You are not allowed to contact your examiner or moderator regarding this examination.
10. Cell phones and other smart devices are not allowed in the examination room.

QUESTION 1: Stress-Strain Relationships

A cylindrical rock sample with a diameter of 50 mm and a height of 100 mm is subjected to a uniaxial compressive load of 200 kN.

a. Calculate the axial stress experienced by the sample. 3

b. What will be the corresponding strain if the Young's modulus of the rock is 70 GPa? 2

c. The rock material exhibits linear elastic behaviour up to a stress of 140 MPa, beyond which it behaves plastically. Calculate the axial strain at the yield point. 1

d. If the Poisson's ratio is 0.25, calculate the radial and volumetric strains experienced by the rock. 5

e. A rock sample is subjected to a biaxial stress condition with σ_{xx} = 50 MPa, σ_{yy} = 30 MPa and τ_{xy} = 15 MPa. Calculate the principal stresses and the angle of the principal planes. 6

f. Calculate the stress tensor from the given strain tensor components using Hooke's Law for isotropic materials, given a Young's modulus of 60 GPa and a Poisson's ratio of 0.25. 8

$\epsilon_{xx} = 4.4\times10^{-3}$

$\epsilon_{yy}=3.8\times10^{-3}$

$\epsilon_{zz}=3.2\times10^{-3}$

$\gamma_{xy}=3.2\times10^{-3}$

$\gamma_{yz}=2.3\times10^{-3}$

$\gamma_{xz}=3.9\times10^{-3}$

[25]

QUESTION 2. Failure Criteria

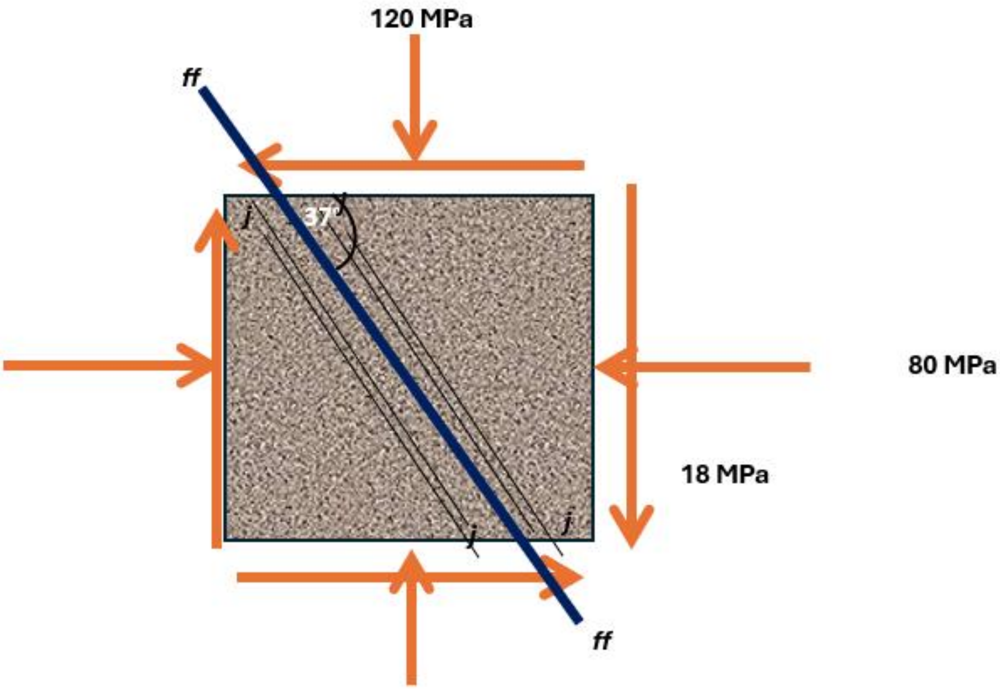
An underground tunnel is planned where the Rock Mass Rating (RMR) is 55, indicating moderate rockmass conditions, with parameters $m_i = 10$ and $s = 0.8$. The laboratory-determined UCS is 120 MPa.

a) Calculate the expected in situ UCS using the Hoek-Brown criterion. 6

b) A 5 m down-throw fault dipping at 37° (with a cohesion of 5 MPa and a friction angle of 30°) intersects this rock mass. Calculate the vertical stress at which the fault will begin to slip. 5

c) A sympathetic joint set (same dip and strike direction) associated with the fault has a joint roughness coefficient of 3, a joint wall strength of 20 MPa and a friction factor of 0.57735. For a vertical stress of 20 MPa, calculate the shear strength using the Barton's shear strength equation. 6

d) The Rockmass is subjected to the following stress condition. Will the above joint set remain stable? 8



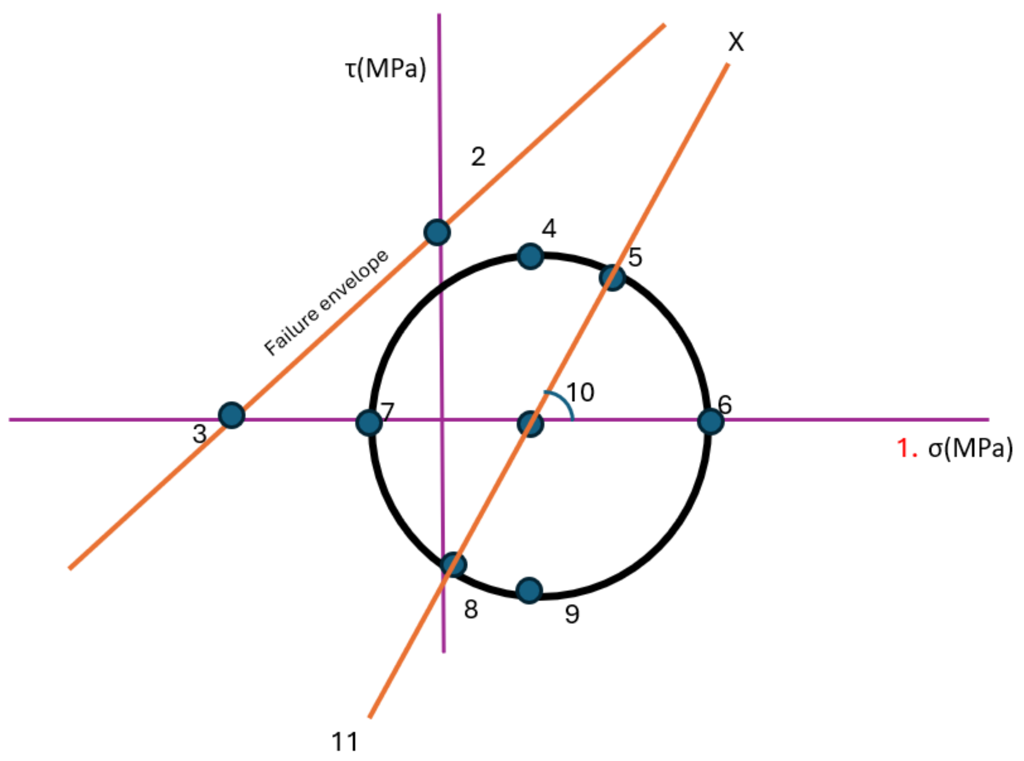
[25]

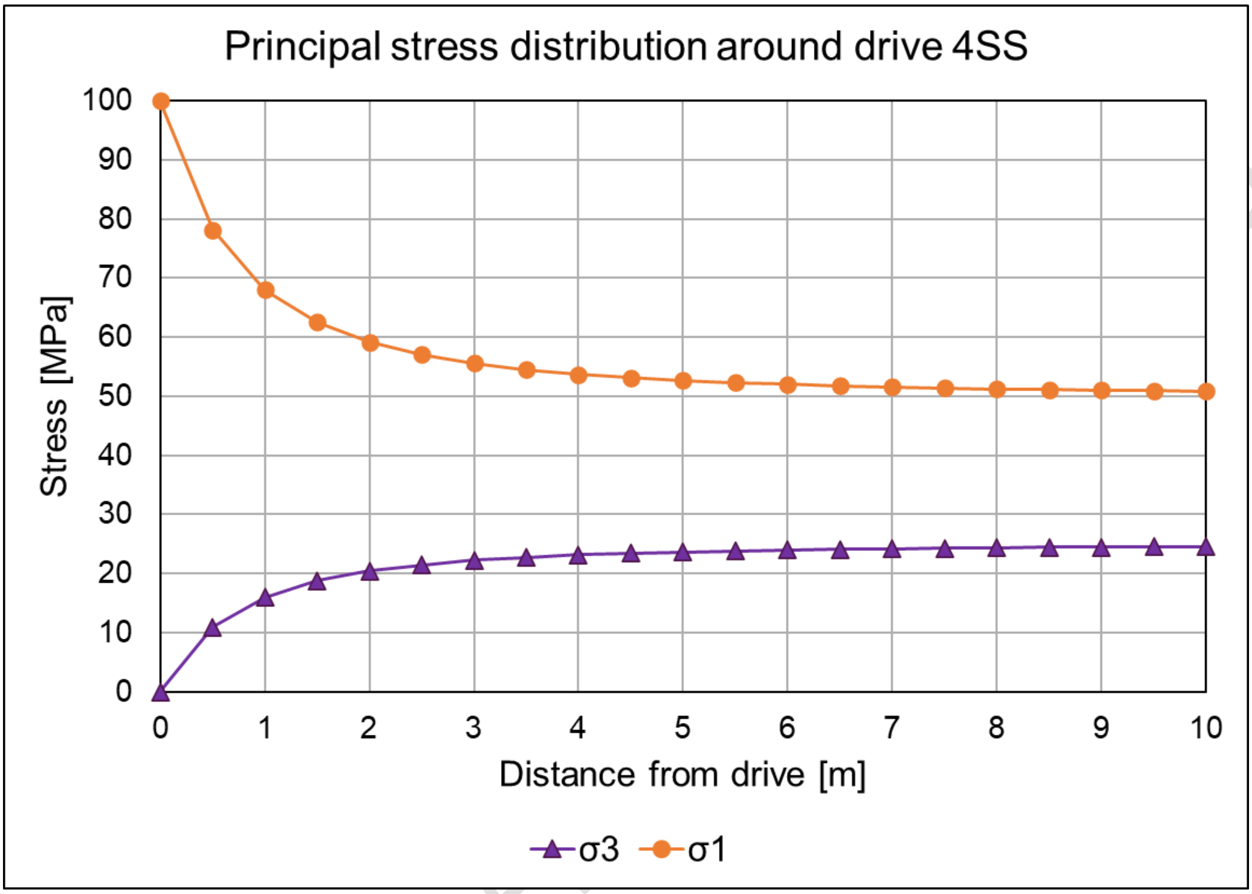
QUESTION 3. Mohr's Circles and Failure Criteria

The Mohr Circle is a fundamental tool in rock mechanics developed by Christian Otto Mohr in the 1800s.

a) Explain the significance of Mohr's Circles in rock engineering. 5

b) Label the Mohr circle diagram below (Do not redraw! E.g. 1.σ (MPa) representing different normal stress conditions in a rock sample). 10



c) Determine the support length required to support the failed zone using the following Mohr-Coulomb failure criteria (distance = 0m represents the skin of the drive): $\tau = 4.5 + \sigma_n \tan(30°)$	10
	
	[25]

QUESTION 4. Beams

a) In many underground mining situations, the hangingwall or roof acts as a beam. Describe three common types of beams encountered underground using sketches, showing compressive and tensile stress regions. Give an underground example for each beam type.	12
b) A 9 m wide tunnel is excavated in a chrome mine, with the triplets located 2.5 m above the immediate hangingwall. The rock density is 2900 kg/m^3, Poisson's ratio is 2.3 and Young's modulus is 75 GPa.	
i. Draw the mining condition described, showing the dimensions of the roof beam	2
ii. Determine the maximum tensile stress	2
iii. Determine the maximum compressive stress	2
iv. Determine the maximum deflection	2
v. Determine the horizontal stress for buckling	2
c) A vertical crack is observed at 3 m from the edge of the tunnel sidewall. Identify what type of beam is now represented and determine the maximum tensile stress in the remaining beam.	3
	[25]

Total Marks = [100]

Formulae 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. $\tau_{nm} = \frac{1}{2}(\sigma_{yy} - \sigma_{xx})\,sin2\theta + \tau_{xy}\cos 2\theta$
9. $\tan 2\theta = \frac{2\tau_{xy}}{(\sigma_{xx}-\sigma_{yy})}$
10. $\sigma_1 = \frac{1}{2}(\sigma_{xx} + \sigma_{yy}) + \frac{1}{2}\sqrt{(\sigma_{xx} - \sigma_{yy})^2 + 4\tau_{xy}^2}$
11. $\sigma_2 = \frac{1}{2}(\sigma_{xx} + \sigma_{yy}) - \frac{1}{2}\sqrt{(\sigma_{xx} - \sigma_{yy})^2 + 4\tau_{xy}^2}$
12. $\varepsilon_n = \epsilon_{xx}cos^2\theta + \gamma_{xy}sin\theta cos\theta + \varepsilon_{yy}sin^2\theta$
13. $\gamma_{nm} = (\varepsilon_y - \varepsilon_x)\sin 2\theta + \gamma_{xy}\cos 2\theta$
14. $\tan 2\theta = \frac{\gamma_{xy}}{(\varepsilon_{xx}-\varepsilon_{yy})}$
15. $\varepsilon_1 = \frac{1}{2}(\varepsilon_{xx} + \varepsilon_{yy}) + \frac{1}{2}\sqrt{(\varepsilon_{xx} - \varepsilon_{yy})^2 + \gamma_{xy}^2}$
16. $\varepsilon_2 = \frac{1}{2}(\varepsilon_{xx} + \varepsilon_{yy}) - \frac{1}{2}\sqrt{(\varepsilon_{xx} - \varepsilon_{yy})^2 + \gamma_{xy}^2}$
17. $\tan 2\theta = {}^{\gamma_{xy}}\!/_{(\varepsilon_{xx} - \varepsilon_{yy})}$
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. $\gamma_{xy} = \frac{1}{G}\tau_{xy}$, $\gamma_{yz} = \frac{1}{G}\tau_{yz}$, $\gamma_{zx} = \frac{1}{G}\tau_{zx}$

25. $\lambda = \frac{Ev}{(1+v)(1-2v)}$

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

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

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

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

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

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

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

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

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

52. $\sigma_{xx} = \lambda\Delta + 2G\varepsilon_{xx}$ $\tau_{xy} = G\gamma_{xy}$ $\tau_{xy} = 2G\varepsilon_{xy}$ $\Delta = \varepsilon_{xx} + \varepsilon_{yy} + \varepsilon_{zz}$

53. $\sigma_{yy} = \lambda\Delta + 2G\varepsilon_{yy}$ $\tau_{yz} = G\gamma_{yz}$ $\tau_{yz} = 2G\varepsilon_{yz}$ $\lambda = \dfrac{E\nu}{(1+\nu)(1-2\nu)}$

54. $\sigma_{zz} = \lambda\Delta + 2G\varepsilon_{zz}$ $\tau_{zx} = G\gamma_{zx}$ $\tau_{zx} = 2G\varepsilon_{zx}$

55. $\sigma_t = \dfrac{q.L^2}{2t_s^{\,2}}$ $q = \rho g(t_s + t_w)$ $\sigma = \dfrac{3qL^2}{t^2}$ $\eta = \dfrac{qL^4}{32Et^3}$

56. $\sigma_h = \dfrac{\pi^2 E}{3(1-\nu^2)}\left(\dfrac{t}{L}\right)^2$

57. $\sigma_t = -\dfrac{3cL^2}{t}$

58. $\sigma_t = \sigma_n - \dfrac{cL^2}{2t}$

59. $\sigma_c = \sigma_n + \dfrac{cL^2}{2t}$

60. $d = \dfrac{cL^4}{32Et^2}$