Minerals Council South Africa

EXAMINATION PAPER

SUBJECT: CERTIFICATE IN ROCK MECHANICS **PAPER 1:** THEORY **SUBJECT CODE:** COMRMC **EXAMINATION DATE:** 12 MAY 2025 **TIME**: 14:00 – 17:00 (3 HOURS)	**EXAMINER:** DP ROBERTS **MODERATOR:** SZ PETHÖ **TOTAL MARKS:** [100] **PASS MARK:** (60%)

NUMBER OF PAGES: 8 (including this one)

EXAMINATION FORMAT: CLOSED BOOK. NO REFERENCES OTHER THAN WHAT ARE PROVIDED ARE ALLOWED.

SPECIAL REQUIREMENTS:

1. Answer all the questions in legible English.
2. Write your ID number (no names) on the outside cover page of each script used and on any graph paper or other loose sheets handed in.
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 wherever possible.
7. Final answers must be given with 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 used, as marks will be deducted if the incorrect unit is used, even if the calculated value is accurate.
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 on your person and must be handed to the invigilators or left in your vehicle.
11. You are encouraged to make use of the **CoMCert Tip-off Hotline** whenever you witness or suspect any wrongdoing related to the CoMCert Examinations on landline **0800 118 998** or alternatively you can use email **COMCert@tip-offs.com**. This tip-off hotline and tip-off email is managed anonymously and confidentially through an independent service provider.

QUESTION 1.

Q1.1

Given the following triaxial strength test results:

σ_3 (MPa)	σ_1 (MPa)
0	118
10	138.7
20	160.4
30	178.8

Plot the Mohr's circles and the resulting Mohr-Coulomb failure envelope. Determine the cohesion and friction angle.

(8)

Q1.2

Plot the failure envelope in the σ_1 - σ_3 space and determine the UCS and slope of the relationship (β_0). Extrapolate the failure envelope to σ_3 = 50 MPa.

(6)

Q1.3

It is suggested to use maximum shear stress as a failure criterion: τ_{max} = 59 MPa. Plot this failure criterion on the σ_1 - σ_3 graph. Indicate whether this criterion is conservative or optimistic, and comment on the appropriateness of this criterion.

(5)

Q1.4

An additional data point is generated using numerical modelling:

σ_3 = 50 MPa

σ_1 = 212.2 MPa.

It is suggested a Hoek-Brown criterion will better fit this new data. The following properties are suggested: m = 2.1 and s = 1

Plot this failure envelope (use at least four points and include the new data point). Indicate whether this criterion is conservative or optimistic, and comment on its appropriateness.

(6)

[25]

QUESTION 2.

Q2.1 Indicate whether the following stress tensors are viable or not. a) $\begin{bmatrix} -20 & 7 & 0 \\ -7 & -40 & 3 \\ 0 & 3 & -10 \end{bmatrix}$ b) $\begin{bmatrix} 20 & -7 & 0 \\ -7 & 40 & 3 \\ 0 & 3 & 10 \end{bmatrix}$ c) $\begin{bmatrix} 20 & -7 & 0 \\ -7 & 40 & 3 \\ 3 & 0 & 10 \end{bmatrix}$ d) $\begin{bmatrix} -10 & 0 & 0 \\ 0 & 30 & 0 \\ 0 & 0 & 40 \end{bmatrix}$	(4)
Q2.2 Given the stress tensor: $\begin{bmatrix} 25 & -12 \\ -12 & 45 \end{bmatrix}$ Determine the principal stresses and their orientations.	(5)
Q2.3 Describe the types of fractures encountered around a deep level tabular excavation.	(4)
Q2.4 Name and sketch the three types of beams encountered by Rock Engineers in the underground environment.	(6)
Q2.5 Sketch the response of a typical rock sample subjected to an unconfined compressive load. Label the important points. Sketch the response of a "type 2" brittle material.	(6)
	[25]

QUESTION 3.

Q3.1 Provide the units and range of values of the Joint Roughness Coefficient. Describe two ways of determining the value of this coefficient (no equations required).	(4)
Q3.2 Define JCS_0. What instrument can be used to estimate values of JCS_0 in the field?	(3)
Q3.3 A quartz infilled joint is subjected to a normal stress of 30 MPa. The unconfined compressive strengths of the host rock and infill are 120 MPa and 47 MPa, respectively. The roughness coefficient is 5.5 and the residual friction angle is 20°. Determine the shear strength of the joint.	(4)
Q3.4 A physical test is conducted on the joint described above. The resulting shear strength is 6.2 MPa higher than predicted. What joint property could account for this discrepancy? What is its value?	(2)
Q3.5 List the six parameters used to determine RMR in Bieniawski's Geomechanics Classification system.	(6)
Q3.6 List (in words) the six parameters used to determine the Q rating in Barton's classification system.	(6)
	[25]

QUESTION 4.

Q4 Two parallel circular tunnels with diameters of 4 m and 6 m are excavated in a rockmass 15 m apart (centre-to-centre). The horizontal in situ stress is 35 MPa, the k-ratio is 1.75, elastic modulus is 50 GPa, the Poisson ratio is 0.15 and the rock density is 2700 kg/m^3. Assume elastic conditions.	
Q4.1 At what depth are the tunnels located?	(2)
Q4.2 (a) Calculate the radial, tangential and shear stresses at the midpoint between the sides of the two tunnels. (b) Calculate the stresses at the position 2 m above this point.	(12)
Q4.3 Under what conditions are the plane stress and plane strain assumptions appropriate? Is the scenario above appropriate for representation in plane strain or plane stress?	(3)
Q4.4 Given the stress conditions: σ_x = 22.3 MPa σ_y = 27.3 MPa τ_{xy} = 0.21 MPa Determine the normal and shear strains in the plane. Assuming plane strain, determine the out-of-plane (z) stresses and strains.	(6)
Q4.5 Given the stress conditions: σ_x = 10 MPa σ_y = 10 MPa σ_z = 10 MPa What is this stress state known as? Where would this stress field typically be encountered?	(2)
	[25]

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. $\tau_{max} = \frac{1}{2}(\sigma_1 - \sigma_2)$
10. $\tau_{max} = \frac{1}{2}\sqrt{(\sigma_{xx} - \sigma_{yy})^2 + 4\tau_{xy}^2}$
11. $\tan 2\theta = \frac{2\tau_{xy}}{(\sigma_{xx} - \sigma_{yy})}$
12. $\sigma_1 = \frac{1}{2}\left(\sigma_{xx} + \sigma_{yy}\right) + \frac{1}{2}\sqrt{(\sigma_{xx} - \sigma_{yy})^2 + 4\tau_{xy}^2}$
13. $\sigma_2 = \frac{1}{2}\left(\sigma_{xx} + \sigma_{yy}\right) - \frac{1}{2}\sqrt{(\sigma_{xx} - \sigma_{yy})^2 + 4\tau_{xy}^2}$
14. $\varepsilon_n = \epsilon_{xx} cos^2\theta + \gamma_{xy} sin\theta cos\theta + \varepsilon_{yy} sin^2\theta$
15. $\gamma_{nm} = \left(\varepsilon_y - \varepsilon_x\right) \sin 2\theta + \gamma_{xy} \cos 2\theta$
16. $\tan 2\theta = \frac{\gamma_{xy}}{(\varepsilon_{xx} - \varepsilon_{yy})}$
17. $\varepsilon_1 = \frac{1}{2}\left(\varepsilon_{xx} + \varepsilon_{yy}\right) + \frac{1}{2}\sqrt{\left(\varepsilon_{xx} - \varepsilon_{yy}\right)^2 + \gamma_{xy}^2}$
18. $\varepsilon_2 = \frac{1}{2}\left(\varepsilon_{xx} + \varepsilon_{yy}\right) - \frac{1}{2}\sqrt{\left(\varepsilon_{xx} - \varepsilon_{yy}\right)^2 + \gamma_{xy}^2}$
19. $\tan 2\theta = {\gamma_{xy}}\big/{(\varepsilon_{xx} - \varepsilon_{yy})}$
20. $\gamma_{max} = (\varepsilon_1 - \varepsilon_2)$
21. $\gamma_{max} = \sqrt{(\varepsilon_{xx} - \varepsilon_{yy})^2 + \gamma_{xy}^2}$

22. $W = \frac{1}{2}(\sigma_1\varepsilon_1 + \sigma_2\varepsilon_2 + \sigma_3\varepsilon_3)$

23. $W = \frac{1}{2}(\sigma_x\varepsilon_x + \sigma_y\varepsilon_y + \sigma_z\varepsilon_z)$

24. $\sigma_1 = \frac{E}{1-\nu^2}(\varepsilon_1 + \nu\varepsilon_2)$

25. $\sigma_2 = \frac{E}{1-\nu^2}(\varepsilon_2 + \nu\varepsilon_1)$

26. $\varepsilon_x = \frac{1}{E}\{\sigma_x - \nu(\sigma_y + \sigma_z)\}$

27. $\varepsilon_y = \frac{1}{E}\{\sigma_y - \nu(\sigma_x + \sigma_z)\}$

28. $\varepsilon_z = \frac{1}{E}\{\sigma_z - \nu(\sigma_x + \sigma_y)\}$

29. $\gamma_{xy} = \frac{1}{G}\tau_{xy}$, $\gamma_{yz} = \frac{1}{G}\tau_{yz}$, $\gamma_{zx} = \frac{1}{G}\tau_{zx}$

30. $\sigma_x = \lambda\Delta + 2G\varepsilon_x$

31. $\sigma_y = \lambda\Delta + 2G\varepsilon_y$

32. $\sigma_z = \lambda\Delta + 2G\varepsilon_z$

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

34. $\Delta = \varepsilon_x + \varepsilon_y + \varepsilon_z$

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

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

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

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

39. $\sigma_r = \frac{1}{2}(q_h + q_v)(1-t^2) + pt^2 + \frac{1}{2}(q_h - q_v)(1-4t^2+3t^4)\cos 2\theta$, where $t = R/r$

40. $\sigma_\theta = \frac{1}{2}(q_h + q_v)(1+t^2) - pt^2 - \frac{1}{2}(q_h - q_v)(1+3t^4)\cos 2\theta$, where $t = R/r$

41. $\tau_{r\theta} = -\frac{1}{2}(q_h - q_v)(1+2t^2-3t^4)\sin 2\theta$, where $t = R/r$

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

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

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

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

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

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

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

49. $k = 0, 1, 2$

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

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

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

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

54. $RMR = 9lnQ + 44$

55. $\tau = \sigma_n \tan\left(\phi_r + \mathrm{JRClog_{10}(JCS/\sigma_n)}\right)$

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

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

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

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

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

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

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

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

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

65. $\sigma_{tm} = \frac{\sigma_{ci}}{2}\left(m_b - \sqrt{m_b{}^2 + 4s}\right)$

66. $\sigma_{cm} = \sigma_{ci}s^a$

67. $BTS = {}^{2(1-v)L}\!/_{\pi Dt}$