Minerals Council South Africa

EXAMINATION PAPER

SUBJECT: MINERALS COUNCIL OF SOUTH AFRICA – CERTIFICATE IN STRATA CONTROL – METALLIFEROUS	**EXAMINER:** MH NGWENYA
SUBJECT CODE: COMCSCM	**MODERATOR:** Y RAJPAL
DATE – 07 MAY 2024	**TOTAL MARKS:** [100]
TIME: **14H30 TO 17H30**	**PASS MARK:** (60%)

NUMBER OF PAGES: 10

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 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 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 to an accuracy that 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.

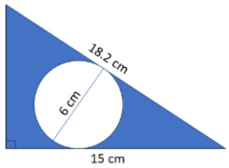
8. In answering the questions, full advantage should be taken of your practical experience as well as the data given.
9. Please note that you are not allowed to contact your examiner or moderator regarding this examination.
10. Cell phones AND OTHER SMART DEVICES are **NOT** allowed in the examination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

QUESTION 1

General Questions, Terms and Definitions

Show calculations.

1.1 Given the geometrical shape below, if the diameter of the circle is 6 cm and the two sides of the right-angle triangle are given as 18.2 cm and 15 cm, calculate the area shaded in blue. (3)



1.2 If the geometrical shape extends to 2.5 x diameter out of plane, calculate the volume of the cylindrical specimen. (1)

1.3 If a force of 200 kN is exerted normal to the surface area of the geometrical shape, calculate the stresses acting on the circular area and blue shaded area. (2)

1.4 If the exerted force results in axial contraction of 3 mm and lateral expansion of 0.15 mm on the cylindrical specimen, calculate the axial and lateral strain. (2)

1.5 Calculate the Poisson's ratio of the cylindrical sample. (1)

1.6 If the cylindrical specimen weighs 300 g, calculate its density. (1)

Choose the correct answer from the four options provided. Only write the letter a, b, c or d next to each question number.

1.7 A measure of the inherent surface unevenness and waviness of the discontinuity relative to its mean plane. (1)

a) Strike b) Dip c) Joint alteration d) Roughness

1.8 Divides sedimentary rocks into beds or strata. (1)

a) Stratigraphy b) Faults c) Bedding planes d) Sills

1.9 A test that can be used to determine joint strength (1)

a) UCS test b) Point Load test c) Shear box test d) Brazilian test

1.10 A stress measurement instrument is a (1)

a) Closure meter b) Doorstopper c) Accelerometer d) GPR

1.11 RCF is used to describe ground conditions of: (1)

a) Gullies b) Massive stopes c) Tabular stopes d) Tunnels

Definitions

Define the following terms and provide measurement units where applicable:

1.12	Brittle fracture	(2)
1.13	Ground Control District	(2)
1.14	Subsidence	(2)
1.15	Ductile deformation	(2)
1.16	Ride	(2)

Total [25]

QUESTION 2 – Rock joints and rock mass strength

2 The Q-value is expressed with six parameters as follows:

$$Q = \frac{RQD}{J_n} \cdot \frac{J_r}{J_a} \cdot \frac{J_w}{SRF}$$

2.1 Name the six parameters in the Q-value expression (3)

2.2 Explain how the following factors affect the strength of rock joints:

a) Infilling type.
b) Infilling thickness.
c) Joint roughness.
d) Joint friction angle.
e) Joint water. (10)

2.3 A 3.5 m diameter tunnel is to be driven east through a mottled anorthosite rock type at a maximum depth of 450 m. The mottled anorthosite is faced with sparsely spaced sub-vertical narrow pegmatite veins. Furthermore, joints that dips between 15^{o} and 20^{o} east-ward and those that dips between 50^{o} and 60^{o} west-ward will be exposed as the tunnel face advances. The overall rock is described as blocky. The recovered core indicates that the joints in the mottled anorthosite are dry, planar and rough with low-friction 2mm serpentine infilling. The RQD estimated from the recovered core gave a rating of 65. The average uniaxial compressive strength of the mottled anorthosite is 210 MPa. The vertical stress is about 14 MPa and the horizontal stress is about 17.5 MPa. Use the Q system to assess the quality of the rock mass. Motivate for values chosen for the Q-value parameters. (6)

2.4 From the calculated Q-value in question 2.3, how would you classify the quality of the rock mass? (1)

2.5 Barton and Choubey developed the following equation:

$$\tau = \sigma_n \tan\left(\theta_b + JRC \log_{10}\left(\frac{JCS}{\sigma_n}\right)\right)$$

2.5.1 What is the equation used to determine? (1)

2.5.2 What does each parameter represent? (2)

2.5.3 How will you obtain the field estimate of JRC? (1)

2.5.4 How will you obtain the field estimate of JCS? (1)

Total [25]

QUESTION 3 – Excavation Stability

3 The following equation is given:

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

3.1 Which quantity is expressed by this equation and for which type of excavation is it valid? (2)

3.2 Does the equation provide a solution for a 2D or a 3D state of stress or strain? (1)

3.3 Provide the terminology which describes the special state of stress or strain contemplated by the equation. (1)

3.4 Simplify the equation above for the case when horizontal virgin stress is equal to vertical virgin stress. (3)

3.5 From the simplified equation obtained in 3.4, give the approximation of $\sigma_{\theta\theta}$ when the radial distance is 4R. (2)

3.6 Determine the angular position for which the tangential stress is 2.25q on the skin of the circular tunnel when the vertical stress is twice the horizontal stress. (2)

3.7 A 3m wide circular tunnel is developed flat in a rock mass where the vertical stress field is 31MPa. The Young's modulus and Poisson's ratio is 80 GPa and 0.25 respectively. Estimate the radial and tangential deformation:

- 3.7.1 In the horizontal radial distance of 4R when the horizontal virgin stress is equal to vertical virgin stress. (4)
- 3.7.2 At the skin of the circular tunnel for which the tangential stress is 2.25q when the vertical stress is twice the horizontal stress. (4)

3.8 If the circular tunnel was rather 5m wide in question 3.7:

- 3.8.1 Would you expect a radial deformation that is higher or lower than the one calculated in question 3.7.1? (1)
- 3.8.2 Would you expect a tangential deformation that is higher or lower than the one calculated in question 3.7.1? (1)

3.9 If the Young's modulus was significantly lower than 80 GPa in question 3.7:

- 3.9.1 Would you expect a radial deformation that is higher or lower than the one calculated in question 3.7.1? (1)
- 3.9.2 Would you expect a tangential deformation that is higher or lower than the one calculated in question 3.7.1? (1)

3.10 Name and draw the tunnel profile that would exist as a result of stress fracturing where the k-ratio is 0.5. (2)

Total [25]

QUESTION 4 – Stope Support Elements

4 A Mine exploiting UG2 in tabular excavation stoping uses timber elongates and yield pillars as primary support in the UG2 stope panels. The timber elongates are installed 1.5 m on dip and 2.0 m on strike centre to centre. The information available to you includes the following:

- Depth of mining below surface = 1500 m
- Stoping width = 1.2 m
- Rock density = 3200 kg/m^3
- K-ratio = 0.95
- Excavation half span = 80 m
- The Poisson's ratio = 0.25
- The Young's modulus = 98 GPa
- The reef orebody dips at 18^o
- The fall out height in UG2 stopes = 0.7 m

4.1 Assuming a gravitational constant of 10 m/s^2, calculate the required support resistance (demand) in the stope. (1)

4.2 If the timber elongate is installed to support a brow in a stope 4m behind the face, calculate elastic closure that the timber elongate would undergo if the face is advanced for 15 m. (10)

4.3 Calculate the elastic closure rate in mm/m after the face is advanced for 15 m. (1)

4.4 Since the face advanced 15 m, you noticed a bed separation of 3 cm on the brow supported by the timber elongate. Calculate the new stoping width where the timber elongate is installed. (1)

4.5 Draw the load-deformation curves of the grout pack, pre-stressed timber pack, elongate prop and hydraulic prop, all together on a single graph paper. (3)

4.6 Which of the drawn support types will have high initial stiffness. (1)

4.7 Which of the drawn support types will be prestressed. (1)

4.8. Which of the drawn support types will provide large peak strength at low rates of closure? (1)

4.9. Which of the drawn support types will provide large peak strength at high rates of closure? (1)

4.10 With the aid of an annotated diagram, describe the effect of loading rate on the performance of timber support units when comparing the load / deformation characteristics determined in laboratory tests to the performance under i) quasi-static (rock fall) and ii) dynamic (rock burst) conditions. (5)

Total [25]

Barton's Classification System

DESCRIPTION	VALUE	NOTES
1. ROCK QUALITY DESIGNATION	***RQD***	
A. Very poor	0 - 25	1. Where *RQD* is reported or measured as ≤ 10 (including 0),
B. Poor	25 - 50	a nominal value of 10 is used to evaluate *Q*.
C. Fair	50 - 75	
D. Good	75 - 90	2. *RQD* intervals of 5, i.e. 100, 95, 90 etc. are sufficiently
E. Excellent	90 - 100	accurate.
2. JOINT SET NUMBER	J_n	
A. Massive, no or few joints	0.5 - 1.0	
B. One joint set	2	
C. One joint set plus random	3	
D. Two joint sets	4	
E. Two joint sets plus random	6	
F. Three joint sets	9	1. For intersections use ($3.0 \times J_n$)
G. Three joint sets plus random	12	
H. Four or more joint sets, random,	15	2. For portals use ($2.0 \times J_n$)
heavily jointed, 'sugar cube', etc.		
J. Crushed rock, earthlike	20	
3. JOINT ROUGHNESS NUMBER	J_r	
a. Rock wall contact		
b. Rock wall contact before 10 cm shear		
A. Discontinuous joints	4	
B. Rough and irregular, undulating	3	
C. Smooth undulating	2	
D. Slickensided undulating	1.5	1. Add 1.0 if the mean spacing of the relevant joint set is
E. Rough or irregular, planar	1.5	greater than 3 m.
F. Smooth, planar	1.0	
G. Slickensided, planar	0.5	2. J_r = 0.5 can be used for planar, slickensided joints having
c. No rock wall contact when sheared		lineations, provided that the lineations are oriented for
H. Zones containing clay minerals thick	1.0	minimum strength.
enough to prevent rock wall contact	(nominal)	
J. Sandy, gravely or crushed zone thick	1.0	
enough to prevent rock wall contact	(nominal)	
4. JOINT ALTERATION NUMBER	J_a	ϕr degrees (approx.)
a. Rock wall contact		
A. Tightly healed, hard, non-softening,	0.75	1. Values of ϕr, the residual friction angle,
impermeable filling		are intended as an approximate guide
B. Unaltered joint walls, surface staining only	1.0	25 - 35 to the mineralogical properties of the
C. Slightly altered joint walls, non-softening	2.0	25 - 30 alteration products, if present.
mineral coatings, sandy particles, clay-free		
disintegrated rock, etc.		
D. Silty-, or sandy-clay coatings, small clay-	3.0	20 - 25
fraction (non-softening)		
E. Softening or low-friction clay mineral coatings,	4.0	8 - 16
i.e. kaolinite, mica. Also chlorite, talc, gypsum		
and graphite etc., and small quantities of swelling		
clays. (Discontinuous coatings, 1 - 2 mm or less)		

4, JOINT ALTERATION NUMBER	J_a	ϕr degrees (approx.)	
b. Rock wall contact before 10 cm shear			
F. Sandy particles, clay-free, disintegrating rock etc.	4.0	25 - 30	
G. Strongly over-consolidated, non-softening clay mineral fillings (continuous < 5 mm thick)	6.0	16 - 24	
H. Medium or low over-consolidation, softening clay mineral fillings (continuous < 5 mm thick)	8.0	12 - 16	
J. Swelling clay fillings, i.e. montmorillonite, (continuous < 5 mm thick). Values of J_a depend on percent of swelling clay-size particles, and access to water.	8.0 - 12.0	6 - 12	
c. No rock wall contact when sheared			
K. Zones or bands of disintegrated or crushed	6.0		
L. rock and clay (see G, H and J for clay	8.0		
M. conditions)	8.0 - 12.0	6 - 24	
N. Zones or bands of silty- or sandy-clay, small clay fraction, non-softening	5.0		
O. Thick continuous zones or bands of clay	10.0 - 13.0		
P. & R. (see G.H and J for clay conditions)	6.0 - 24.0		
5. JOINT WATER REDUCTION	J_w	approx. water pressure (kgf/cm^2)	
A. Dry excavation or minor inflow i.e. < 5 l/m locally	1.0	< 1.0	
B. Medium inflow or pressure, occasional outwash of joint fillings	0.66	1.0 - 2.5	
C. Large inflow or high pressure in competent rock with unfilled joints	0.5	2.5 - 10.0	1. Factors C to F are crude estimates; increase J_w if drainage installed.
D. Large inflow or high pressure	0.33	2.5 - 10.0	
E. Exceptionally high inflow or pressure at blasting, decaying with time	0.2 - 0.1	> 10	2. Special problems caused by ice formation are not considered.
F. Exceptionally high inflow or pressure	0.1 - 0.05	> 10	
6. STRESS REDUCTION FACTOR		*SRF*	
a. Weakness zones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated			
A. Multiple occurrences of weakness zones containing clay or chemically disintegrated rock, very loose surrounding rock any depth)		10.0	1. Reduce these values of *SRF* by 25 - 50% but only if the relevant shear zones influence do not intersect the excavation
B. Single weakness zones containing clay, or chemically dis-tegrated rock (excavation depth < 50 m)		5.0	
C. Single weakness zones containing clay, or chemically dis-tegrated rock (excavation depth > 50 m)		2.5	
D. Multiple shear zones in competent rock (clay free), loose surrounding rock (any depth)		7.5	
E. Single shear zone in competent rock (clay free). (depth of excavation < 50 m)		5.0	
F. Single shear zone in competent rock (clay free). (depth of excavation > 50 m)		2.5	
G. Loose open joints, heavily jointed or 'sugar cube', (any depth)		5.0	

DESCRIPTION	VALUE			NOTES
6. STRESS REDUCTION FACTOR			*SRF*	
b. Competent rock, rock stress problems				
	σ_c/σ_1	$\sigma_t\sigma_1$		2. For strongly anisotropic virgin stress field (if measured): when $5 \leq \sigma_1/\sigma_3 \leq 10$, reduce σ_c to $0.8\sigma_c$ and σ_t to $0.8\sigma_t$. When $\sigma_1/\sigma_3 > 10$, reduce σ_c and σ_t to $0.6\sigma_c$ and $0.6\sigma_t$, where σ_c = unconfined compressive strength, and σ_t = tensile strength (point load) and σ_1 and σ_3 are the major and minor principal stresses.
H. Low stress, near surface	> 200	> 13	2.5	
J. Medium stress	200 - 10	13 - 0.66	1.0	
K. High stress, very tight structure (usually favourable to stability, may be unfavourable to wall stability)	10 - 5	0.66 - 0.33	0.5 - 2	
L. Mild rockburst (massive rock)	5 - 2.5	0.33 - 0.16	5 - 10	
M. Heavy rockburst (massive rock)	< 2.5	< 0.16	10 - 20	3. Few case records available where depth of crown below surface is less than span width. Suggest *SRF* increase from 2.5 to 5 for such cases (see H).
c. Squeezing rock, plastic flow of incompetent rock under influence of high rock pressure				
N. Mild squeezing rock pressure			5 - 10	
O. Heavy squeezing rock pressure			10 - 20	
d. Swelling rock, chemical swelling activity depending on presence of water				
P. Mild swelling rock pressure			5 - 10	
R. Heavy swelling rock pressure			10 - 15	

ADDITIONAL NOTES ON THE USE OF THESE TABLES

When making estimates of the rock mass Quality (*Q*), the following guidelines should be followed in addition to the notes listed in the tables:

1. When borehole core is unavailable, *RQD* can be estimated from the number of joints per unit volume, in which the number of joints per metre for each joint set are added. A simple relationship can be used to convert this number to *RQD* for the case of clay free rock masses: $RQD = 115 - 3.3\ J_v$ (approx.), where J_v = total number of joints per m^3 ($0 < RQD < 100$ for $35 > J_v > 4.5$).
2. The parameter J_n representing the number of joint sets will often be affected by foliation, schistosity, slaty cleavage or bedding etc. If strongly developed, these parallel 'joints' should obviously be counted as a complete joint set. However, if there are few 'joints' visible, or if only occasional breaks in the core are due to these features, then it will be more appropriate to count them as 'random' joints when evaluating J_n.
3. The parameters J_r and J_a (representing shear strength) should be relevant to the weakest significant joint set or clay filled discontinuity in the given zone. However, if the joint set or discontinuity with the minimum value of J_r/J_a is favourably oriented for stability, then a second, less favourably oriented joint set or discontinuity may sometimes be more significant, and its higher value of J_r/J_a should be used when evaluating Q. The value of J_r/J_a should in fact relate to the surface most likely to allow failure to initiate.
4. When a rock mass contains clay, the factor *SRF* appropriate to loosening loads should be evaluated. In such cases the strength of the intact rock is of little interest. However, when jointing is minimal and clay is completely absent, the strength of the intact rock may become the weakest link, and the stability will then depend on the ratio rock-stress/rock-strength. A strongly anisotropic stress field is unfavourable for stability and is roughly accounted for as in note 2 in the table for stress reduction factor evaluation.
5. The compressive and tensile strengths (σ_c and σ_t) of the intact rock should be evaluated in the saturated condition if this is appropriate to the present and future in situ conditions. A very conservative estimate of the strength should be made for those rocks that deteriorate when exposed to moist or saturated conditions.

FORMULAE SHEET

$$\varepsilon_{xx} = \frac{1}{E}\{\sigma_{xx} - \nu(\sigma_{yy} + \sigma_{zz})\} \quad \gamma_{xy} = \frac{1}{G}\tau_{xy} \quad \varepsilon_{xy} = \frac{1}{2G}\tau_{xy} \quad G = \frac{E}{2(1+\nu)}$$

$$\varepsilon_{yy} = \frac{1}{E}\{\sigma_{yy} - \nu(\sigma_{xx} + \sigma_{zz})\} \quad \gamma_{yz} = \frac{1}{G}\tau_{yz} \quad \varepsilon_{yz} = \frac{1}{2G}\tau_{yz} \quad K = \frac{E}{3(1-2\nu)}$$

$$\varepsilon_{zz} = \frac{1}{E}\{\sigma_{zz} - \nu(\sigma_{xx} + \sigma_{yy})\} \quad \gamma_{zx} = \frac{1}{G}\tau_{zx} \quad \varepsilon_{zx} = \frac{1}{2G}\tau_{zx}$$

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

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

$$\sigma_{zz} = \lambda\Delta + 2G\varepsilon_{zz} \quad \tau_{zx} = G\gamma_{zx} \quad \tau_{zx} = 2G\varepsilon_{zx} \qquad E = \sigma/\varepsilon$$

$$\sigma_{zz} = 0 \quad \varepsilon_{zz} = -\frac{\nu}{E}(\sigma_{xx} + \sigma_{yy}) \qquad \upsilon = \varepsilon_r/\varepsilon_a$$

$$\varepsilon_{xx} = \frac{1}{E}(\sigma_{xx} - \nu\sigma_{yy}) \quad \gamma_{xy} = \frac{1}{G}\tau_{xy} \quad \sigma_{xx} = \frac{E}{1-\nu^2}(\varepsilon_{xx} + \nu\varepsilon_{yy}) \quad \tau_{xy} = G\gamma_{xy}$$

$$\varepsilon_{yy} = \frac{1}{E}(\sigma_{yy} - \nu\sigma_{xx}) \quad \sigma_{yy} = \frac{E}{1-\nu^2}(\varepsilon_{yy} + \nu\varepsilon_{xx})$$

$$\varepsilon_{zz} = 0 \quad \sigma_{zz} = \nu(\sigma_{xx} + \sigma_{yy})$$

$$\varepsilon_{xx} = \frac{1}{E}\{(1-\nu^2)\sigma_{xx} - \nu(1+\nu)\sigma_{yy}\}$$

$$\varepsilon_{yy} = \frac{1}{E}\{(1-\nu^2)\sigma_{yy} - \nu(1+\nu)\sigma_{xx}\}$$

$$q = \rho g H \quad \sigma_v = q \quad \sigma_h = kq$$

$$s_z = \frac{2(1-\nu)q}{G}\sqrt{l^2 - x^2}$$

$$u_r = -\frac{qR^2}{4Gr}\left[(1+k) - (1-k)\left(4(1-\upsilon) - \frac{R^2}{r^2}\right)\cos 2\theta\right]$$

$$u_\theta = -\frac{qR^2}{4Gr}\left[(1-k)\left(2(1-2\upsilon) + \frac{R^2}{r^2}\right)\sin 2\theta\right]$$