CHAMBER OF MINES OF SOUTH AFRICA

# EXAMINATION PAPER

| SUBJECT: CHAMBER OF MINES OF SOUTH AFRICA – CERTIFICATE IN STRATA CONTROL – METALLIFEROUS | EXAMINER: Y. JOOSTE |
|---|---|
| **SUBJECT CODE:** **COMCSCM** | **MODERATOR:** D.A. ARNOLD. |
| **EXAMINATION DATE:** **10 MAY 2016** | **TOTAL MARKS:** [100] |
| **TIME**: 14:30 – 17:30 | **PASS MARK:** (60%) |

**NUMBER OF PAGES: 10**

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

SPECIAL REQUIREMENTS:

1. Answer **all 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. 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. **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 units) 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 are **NOT** allowed in the examination room.

## QUESTION 1 – DEFINITIONS

Define the following terms and where applicable give the symbol and units used:

1.1 Weight

1.2 Force

1.3 Triaxial compression

1.4 Shear stress

1.5 Safety factor

1.6 Rock mass

1.7 Intact rock

1.8 Abutment

1.9 Active support

1.10 Accelerometer

**[20]**

## QUESTION 2 – ROCK MASS CLASSIFICATION

2.1 Various Rock Mass Rating systems are available to classify the rock mass. State the names of the two rock mass rating methods below and list the parameters of each, and indicate the role and importance of each parameter.

- RMR
- Q (13)

2.2 Determine the rock mass quality of the zone described below by conducting a rock mass rating using the Q method. Motivate your reasons for each value chosen in the rock mass rating. A rock mass rating form is attached.

A borehole intersected an intensely jointed zone at approximately 900m below surface. The zone is some 60m in length and 190 joints have been recorded from the core. There appears to be two distinct joint sets, dipping at roughly 30 and 70 degrees respectively. Traces of serpentine filling, varying from zero to 3mm in thickness, are visible in the joint planes. The zone seems to be damp. There also appears to be a 1,2m thick lamprophyre dyke running through the middle of this zone, at an angle of 45 degrees. (9)

2.3 Why are Rock Mass Classification systems important for a Rock Engineer? (3)

**[25]**

**QUESTION 3– STRESSES**

3.1 You are working on a narrow tabular mine at an average depth of 1950m below surface. You noticed a horizontally drilled hole in the sidewall of an excavation. The hole is 4cm in diameter and shows signs of spalling on the sidewalls of the hole.

Make use of the analytical equations below to calculate the radial and tangential stresses on the sidewalls of the hole. The K-ratio on your mine is 0.5 and the overburden density is 2750kg/ $m^3$

$$\sigma_{rr} = \frac{p}{2}\left[(1+K)\left(1-\frac{a^2}{r^2}\right)-(1-K)\left(1-4\frac{a^2}{r^2}+\frac{3a^4}{r^4}\right)\cos 2\theta\right]$$

$$\sigma_{\theta\theta} = \frac{p}{2}\left[(1+K)\left(1+\frac{a^2}{r^2}\right)+(1-K)\left(1+\frac{3a^4}{r^4}\right)\cos 2\theta\right]$$

$$\sigma_{r\theta} = \frac{p}{2}\left[(1-K)\left(1+\frac{2a^2}{r^2}-\frac{3a^4}{r^4}\right)\sin 2\theta\right]$$

(9)

3.2 Describe the type of fracturing one can expect around ore-passes in highly stressed ground, including the resulting ore-pass shape and the extent of fracturing. (4)

3.3 How is virgin stress calculated? (2)

**[15]**

**QUESTION 4 – MINING**

4.1 Mining method selection is important to ensure that orebodies are extracted safely. What factors must be considered when selecting a mining method?

(5)

4.2 List the differences between sequential grid mining and longwall mining.

(5)

4.3 The depth of mining plays a central role when decisions need to be made with regards to mining method and support strategies. Redraw the table below on your answer sheet and complete it to indicate the differences in parameter values as the depth below surface increases.

| Parameter | Shallow | Intermediate | Deep |
|---|---|---|---|
| Typical depth (m) | | | |
| Typical ERR ($MJ/m^2$) | | | |
| Vertical virgin stress (MPa) | | | |
| Stress fracturing (intensity) | | | |
| Stope closure (mm/m advance) | | | |
| Influence of geology on h/w stability | | | |
| Rockburst hazard | | | |

(10)

**[20]**

**QUESTION 5–SUPPORT**

5.1 Explain the purposes of, and differences between, primary and secondary support in tunnels.

(4)

5.2 State the differences between the following tendon support types:

5.2.1 End-anchored bolts

5.2.2 Friction bolts (4)

5.3 Backfill is a common support method used when extracting orebodies. Explain briefly how and why backfill may be used to provide local and regional support. (8)

5.4 When calculating the energy absorption capacity of support elements in a support layout the following equation is used:

Energy absorption: $E = \frac{1}{2} mv^2 + mgh$

List the parameters in the above equation together with the unit of each parameter.

(4)

**[20]**

**TOTAL MARKS: [100]**

## APPENDIX A

## FORMULE SHEET

1. Total Energy = ½ m $v^2$ + mgh
2. $s_z = \frac{2(1-\nu)q}{G}\sqrt{l^2 - x^2}$
3. $l_c = \frac{s_m G}{2(1-\nu)q}$
4. $\sigma_s = 7.2\frac{R_0^{0.5933}}{V^{0.0667}}\left\{\frac{0.5933}{\varepsilon}\left[\left(\frac{R}{R_0}\right)^{\varepsilon} - 1\right] + 1\right\}MPa$
5. $e = 1 - \frac{w_1 w_2}{C_1 C_2}$
6. $ERR = \frac{\Delta U_m}{\Delta A} = \frac{\pi(1-\nu)lq^2}{2G}$
7. $v_p = \sqrt{\frac{\lambda + 2G}{\rho}}$ $\qquad v_s = \sqrt{\frac{G}{\rho}}$
8. $RCF = \frac{3\sigma_1 - \sigma_3}{F\sigma_c}$
9. $RQD = \frac{\sum lenght\ of\ core\ pieces > 10cm}{total\ lenght\ of\ core}\ x\ 100$
10. $\frac{h}{s} = \frac{1}{\sqrt{\frac{8h}{s} - 6}}$
11. Q = RQD/Jn x Jr/Ja x Jw/SRF
12. G = $\frac{E}{2(1+v)}$
13. $\tau = \sigma n\ tan(\text{Ø} + JRC\ 10\ \log \tan(^{JCS}/\sigma n\ ))$
14. APS = $q_v$/(1-e)
15. ε = Δℓ / L
16. E = σ/ε
17. $\nu = \varepsilon_r / \varepsilon_a$
18. $Ps = K\, w^{0.46} / h^{0.66}$

    $Ps = K\, w^{0.5} / h^{0.75}$

19.

20. Salamon

$$FS = 288 \frac{w^{2.46}}{Hh^{0.66}(w+b)^2}$$

21. D Merwe

$$S = 3.5\left(\frac{w}{h}\right)(MPa) \quad L = \frac{25\,H\,C^2}{w^2}$$

22 Squat

$$L = \frac{25\,H\,C^2}{w^2}$$

# APPENDIX B

Table 9a. Rock Quality Designation, RQD (Barton et al., 1974)

| **1. Rock Quality Designation** | RQD |
|---|---|
| A Very Poor | 0 – 25 |
| B Poor | 25 – 50 |
| C Fair | 50 – 75 |
| D Good | 75 – 90 |
| E Excellent | 90 – 100 |
| Note: (i) Where RQD is reported or measured as ≤ 10 (including 0), a nominal value of 10 is used to evaluate Q. (ii) RQD interval of 5, i.e., 100, 95, 90, etc., are sufficiently accurate. | |

| **2. Joint Set Number** | $J_n$ |
|---|---|
| A Massive, no or few joints | 0.5 – 1 |
| B One joint set | 2 |
| C One joint set plus random joints | 3 |
| D Two joint set | 4 |
| E Two joint set plus random joints | 6 |
| F Three joint set | 9 |
| G Three joint set plus random joints | 12 |
| H Four or more joint sets, heavily jointed | 15 |
| J Crushed rock, earthlike | 20 |
| Note: (i) For intersections, use ($3.0 \times J_n$). (ii) For portals, use ($2.0 \times J_n$). | |

| **3. Joint Roughness Number** | $J_r$ |
|---|---|
| ***(a) Rock-wall contact, and (b) Rock wall contact before 10 cm shear*** | |
| A Discontinuous joints | 4 |
| B Rough or irregular, undulating | 3 |
| C Smooth, undulating | 2 |
| D Slickensided, undulating | 1.5 |
| E Rough or irregular, planar | 1.5 |
| F Smooth, planar | 1.0 |
| G Slickensided, planar | 0.5 |
| Note: (i) Descriptions refer to small and intermediate scale features, in that order. | |
| ***(c) No rock-wall contact when sheared*** | |
| H Zone containing clay minerals thick enough to prevent rock-wall contact | 1.0 |
| J Sandy, gravelly or crushed zone thick enough to prevent rock-wall contact | 1.0 |
| Note: (ii) Add 1.0 if the mean spacing of the relevant joint set ≥ 3 m. (iii) $J_r$ = 0.5 can be used for planar slickensided joints having lineations, provided the lineations are oriented for minimum strength. | |

| 4. Joint Alteration Number | | $\varphi_r$ approx. | $J_a$ |
|---|---|---|---|
| **(a) Rock-wall contact (no mineral fillings, only coatings)** | | | |
| A | Tight healed, hard, non-softening, impermeable filling, i.e., quartz or epidote | – | 0.75 |
| B | Unaltered joint walls, surface staining only | 25 – 35° | 1.0 |
| C | Slightly altered joint walls. Non-softening mineral coating, sandy particles, clay-free disintegrated rock, etc. | 25 – 30° | 2.0 |
| D | Silty- or sandy-clay coatings, small clay fraction (non-softening) | 20 – 25° | 3.0 |
| E | Softening or low friction mineral coatings, i.e., kaolinite or mica. Also chlorite, talc, gypsum, graphite, etc., and small quantities of swelling clays | 8 – 16° | 4.0 |
| **(b) Rock wall contact before 10 cm shear (thin mineral fillings)** | | | |
| F | Sandy particles, clay-free disintegrated rock, etc. | 25 – 30° | 4.0 |
| G | Strongly over-consolidated non-softening clay mineral fillings (continuous, but < 5 mm thickness) | 16 – 24° | 6.0 |
| H | Medium or low over-consolidated softening clay mineral fillings (continuous, but < 5 mm thickness) | 12 – 16° | 8.0 |
| J | Swelling-clay fillings, i.e., montmorillonite (continuous, but < 5 mm thickness). Value of $J_a$ depends on percent of swelling clay size particles, and access towater, etc. | 6 – 12° | 8 – 12 |
| **(c) No rock-wall contact when sheared (thick mineral fillings)** | | | |
| K, L, M | Zones or bands of disintegrated or crushed rock and clay (see G, H, J for description of clay condition) | 6 – 24° | 6, 8, or 8 – 12 |
| N | Zones or bands of silty- or sandy-clay, small clay fraction (non-softening) | – | 5 |
| O, P, R | Thick, continuous zones or bands of clay (see G, H, J for clay condition description) | 6 – 24° | 10, 13, or 13 – 20 |

| 5. Joint Water Reduction Factor | | Water pressure | $J_w$ |
|---|---|---|---|
| A | Dry excavation or minor inflow, i.e., < 5 l/min locally | < 1 ($kg/cm^2$) | 1.0 |
| B | Medium inflow or pressure, occasional outwash of joint fillings | 1 – 2.5 | 0.66 |
| C | Large inflow or high pressure in competent rock with unfilled joints | 2.5 – 10 | 0.5 |
| D | Large inflow or high pressure, considerable outwash of joint fillings | 2.5 – 10 | 0.33 |
| E | Exceptionally high inflow or water pressure at blasting, decaying with time | > 10 | 0.2 – 0.1 |
| F | Exceptionally high inflow or water pressure continuing without noticeable decay | >10 ($kg/cm^2$) | 0.1 – 0.05 |
| Note: (i) Factors C to F are crude estimates. Increase $J_w$ if drainage measures are installed. (ii) Special problems caused by ice formation are not considered | | | |

| 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 |
| B | Single weakness zone containing clay or chemically disintegrated rock (depth of excavation ≤ 50 m) | 5 |
| C | Single weakness zone containing clay or chemically disintegrated rock (depth of excavation > 50 m) | 2.5 |
| D | Multiple shear zones in competent rock (clay-free) (excavation depth ≤ 50 m) | 7.5 |
| E | Single shear zone in competent rock (clay-free) (excavation depth ≤ 50 m) | 5 |
| F | Single shear zone in competent rock (clay-free) (excavation depth > 50 m) | 2.5 |
| G | Loose, open joint, heavily jointed (any depth) | 5 |
| Note: (i) Reduce SRF value by 25-50% if the relevant shear zones only influence but not intersect the excavation. | | |

| **(b) Competent rock, rock stress problems** | | $\sigma_c / \sigma_1$ | $\sigma_\theta / \sigma_c$ | SRF |
|---|---|---|---|---|
| H | Low stress, near surface, open joints | 200 | < 0.01 | 2.5 |
| J | Medium stress, favorable stress condition | 200 – 10 | 0.01 – 0.03 | 1 |
| K | High stress, very tight structure. Usually favorable to stability, may be unfavorable to wall stability | 10 – 5 | 0.3 – 0.4 | 0.5 – 2 |
| L | Moderate slabbing after > 1 hour in massive rock | 5 – 3 | 0.5 – 0.65 | 5 - 50 |
| M | Slabbing and rock burst after a few minutes in massive rock | 3 – 2 | 0.65 – 1 | 50 – 200 |
| N | Heavy rock burst (strain-burst) and immediate dynamic deformation in massive rock | < 2 | > 1 | 200 – 400 |

Note: (ii) For strongly anisotropic virgin stress field (if measured): when $5 \leq \sigma_1 / \sigma_3 \leq 10$, reduce $\sigma_c$ to 0.75 $\sigma_c$; when $\sigma_1 / \sigma_3 > 10$, reduce $\sigma_c$ to 0.5 $\sigma_c$; where $\sigma_c$ is unconfined compressive strength, $\sigma_1$ and $\sigma_3$ are major and minor principal stresses, and $\sigma_\theta$ is maximum tangential stress (estimated from elastic theory). (iii) Few case records are available where depth of crown below surface is less than span width. Suggest increase in SRF from 2.5 to 5 for such cases (see H).

| **(c) Squeezing rock: plastic flow in incompetent rock under the influence of high rock pressure** | | $\sigma_\theta / \sigma_c$ | SRF |
|---|---|---|---|
| O | Mild squeezing rock pressure | 1 – 5 | 5 – 10 |
| P | Heavy squeezing rock pressure | 5 | 10 – 20 |
| Note: (vi) Cases of squeezing rock may occur for depth H > 350 Q1/3. Rock mass compressive strength can be estimated from Q = 7 γ Q1/3 (MPa), where γ = rock density in g/cm$^3$. | | | |

| **(d) Swelling rock: chemical swelling activity depending on presence of water** | | SRF |
|---|---|---|
| R | Mile swelling rock pressure | 5 – 10 |
| S | Heavy swell rock pressure | 10 – 15 |

*Note: $J_r$ and $J_a$ classification is applied to the joint set or discontinuity that is least favorable for stability both from the point of view of orientation and shear resistance.*