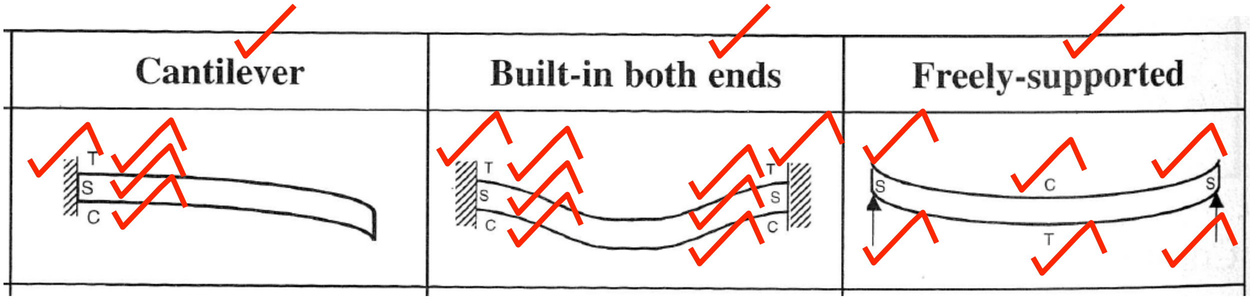
CHAMBER OF MINES OF SOUTH AFRICA

MEMORANDUM

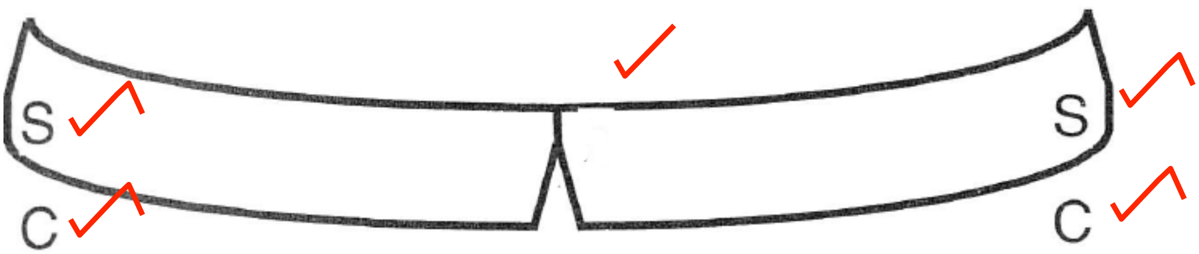
SUBJECT: CERTIFICATE IN ROCK MECHANICS PAPER 1 : THEORY **SUBJECT CODE:** COMRMC **EXAMINATION DATE:** OCTOBER 2017 **TIME**:	**EXAMINER:** WM BESTER **MODERATOR:** H YILMAZ **TOTAL MARKS:** [100] **PASS MARK:** (60%)

QUESTION 1 - (BEAM THEORY)

1.1 Sketch three different types of elastic beams, indicating on each the maximum compressive, tensile and shear stresses. (12)



1.2 Sketch a simple Voussoir beam, indicating the maximum compressive and shear stresses. (3)



1.3 List three potential modes of failure of a Voussoir beam. (3)

shear or *crushing* failure at the abutments, or elastic '*snap-through*' failure

1.4 What are the fundamental assumptions governing Voussoir beams? (2)

The assumptions here are that no external horizontal stress is present, but the abutments provide *rigid* lateral confinement. As the beam deflects, joints at the abutments and at mid-span open, but the remainder of the structure still behaves elastically and is still potentially stable due to kinematic 'jamming' of the blocks involved.

[20]

QUESTION 2 - (ROCK MASS CLASSIFICATION)

2.1 List and describe the five parameters of the original Geomechanics Classification system (RMR). (5)

1. Strength of intact rock material – point-load index or uniaxial compressive strength.

2. Rock Quality Designation (RQD) – drill core quality (measured or calculated from Jv)

3. Spacing of discontinuities – perpendicular distance between two joints within a joint set (the lowest rating should be considered if there is more than one joint set and the spacing of joints varies)

4. Condition of discontinuities – surface roughness, separation, infill, etc.

5. Groundwater conditions – inflow rate or ratio of joint water pressure to confining stress.

2.2 What adjustments are made to the Geomechanics Classification to obtain an overall rock mass description? (2)

Type of excavation (tunnels, foundations or slopes) and orientation of joints relative to the excavations (Very unfavourable, Unfavourable, Fair, Favourable, Very Favourable).

2.3 List and briefly discuss the modifications required to the Geomechanics Classification to calculate MRMR, according to Laubscher and Taylor? (9)

Laubscher and Taylor (1976) suggested modifications to the Geomechanics Classification system, and its associated support recommendations. These 'MRMR' modifications were intended to cater for the differences in support requirements between the original civil environment and a mining environment. The modifications represent an alteration (percentage) of the individual ratings within the RMR as a function of weathering, stress environment, excavation orientation relative to the rock mass structure, and the excavation method.

The influence of weathering is applied to the intact rock strength (decrease down to 96 %), RQD (decrease down to 95 %) and condition of joints (decrease down to 82 %), dependent on the degree of weathering. The influence of the stress environment is a function of the initial field stress level and any potential stress changes, and is considered to influence the relative joint condition. Where the stress environment is, or becomes, compressive relative to the rock mass structure and excavation periphery, this will be favourable to joint conditions (increase up to 120 %). Where shear deformation may be anticipated on the joints in the periphery of the excavation, or a low stress results in the opening of joints, this will be unfavourable to rock mass stability (decrease down to 90 % or 76 % respectively). Where subsequent stress changes occur, this may also cause adverse shear movement or joint opening within the excavation peripheral rock mass (decrease down to 60 %).

Laubscher and Taylor (1976) also considered the influence of the excavation orientation relative to the rock mass structure to be insufficient as accounted for by Bieniawski and thus suggested further adjustments. These adjustments are made to the joint spacing rating and are based on the number of non-vertical rockwalls of the excavation and the number of joints

A further adjustment to the joint spacing rating was also considered necessary for the presence and orientation of shear zones (decrease dependent on angle of incidence; 0 – 15° : 76%, 15 – 45° : 84 % and 45 – 75° : 92 %). Finally an adjustment may be made to the RQD and condition of joints rating for the influence of the method of excavation. The degree of reduction of the parameters is based on the consideration of the adverse effects of blasting (boring: 100 %, smooth wall blasting: 97 %, good conventional blasting: 94 %, poor conventional blasting: 80 %) on the stability of the immediate peripheral rock mass of excavations.

2.4 Estimate the in situ Hoek-Brown 'm' and 's' parameters suitable for underground mining of a rock mass that has a Barton's Q value of 25 and internal friction angle of 53°. (4)

$\beta_o = (1 + \sin\varphi_i) / (1 - \sin\varphi_i) = 8.9$

$m_i = 2\,(\beta_o - 1) = 15.9$

$RMR = 9 \ln(Q) + 44 = 73$

$s = e^{\frac{(RMR-100)}{9}}$ **= 0.05**

$m = m_i\, e^{\frac{(RMR-100)}{28}}$ **= 6**

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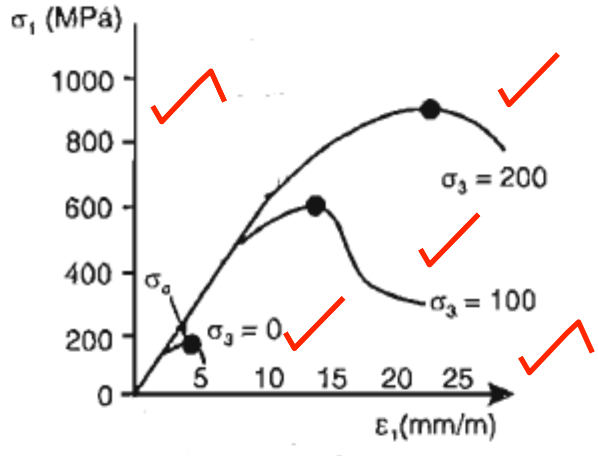
QUESTION 3 - (ROCK PROPERTIES)

3.1 Sketch stress-strain graphs of typical triaxial compression tests, illustrating the effect of increased confinement on rock strength and failure behaviour. (5)



At increased confinement the peak strength increases, as does the amount of strain before failure. Failure becomes less brittle and more ductile with increased confinement.

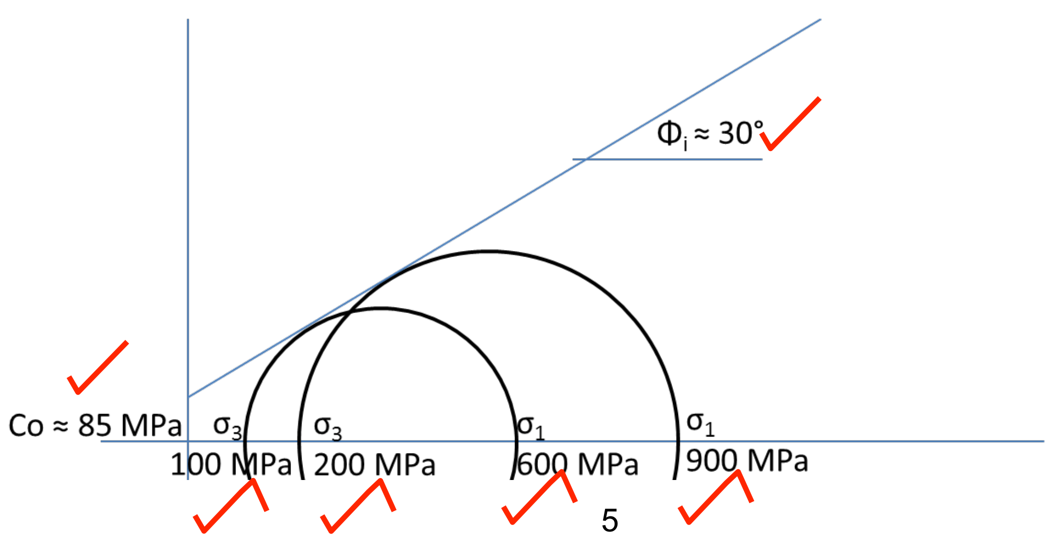
3.2 Two rock samples were subjected to triaxial compression testing. The samples failed at the following stresses:

Test 1: σ_1 = 600 MPa σ_3 = 100 MPa

Test 2: σ_1 = 900 MPa σ_3 = 200 MPa

i) Draw the Mohr circles that represent these two tests. (2)

ii) Determine the cohesion and internal friction angle using your drawing. Assume Mohr-Coulomb failure. (2)



3.3 Which strength criterion is commonly used when assessing the strength of in-situ rock that is transected by many closely-spaced joint sets at multiple angles? Discuss the limitations of this criterion. (5)

Hoek-Brown:

- **purely empirical**
- **fits lab low-stress regimes well**
- **overestimate strengths at high confinement**
- **needs back analysis on 'm' and 's' values**

3.4 Study the table of typical elastic constants and strength properties of different rock types below. Discuss the difference in rock behaviour expected of these rock types in laboratory testing in terms of axial and radial deformation, triaxial strength and shear strength. (6)

Rock Type	E (GPa)	v	σ_c (MPa)	C_o (MPa)	φ_i°
Quartzite	70	0.23	220	45	35
Pyroxenite	100	0.3	120	20	50
Sandstone	30	0.1	70	20	30
Granite	60	0.2	220	30	55

Elastic behaviour:

Under the axial loading, pyroxenite will axially deform the least and sandstone the most, while granite and quartzite behave very similarly. Pyroxenite radial strain to axial strain is however proportionally the most and sandstone the least, hence all rock types are expected to have fairly similar radial deformation under axial loading.

Strength:

Granite and quartzite are the strongest in unconfined compression, and sandstone the weakest. Quartzite has the highest cohesion, but granite and pyroxenite strength increases more rapidly with confinement (β_o). Quartzite shear strength is hence highest under low normal stress, but under high normal stress granite shear strength is highest, with quartzite strength more on par with pyroxenite. Granite will have the highest triaxial strength, increasing most rapidly with confinement, while sandstone will be the weakest.

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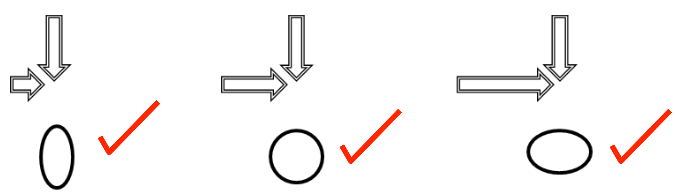
QUESTION 4 - (STRESS IN ROCK)

4.1 The virgin or primitive state of stress is a function of several influencing factors. List and describe at least four of these factors. (4)

1. **Weight of the overlying strata in terms of depth, average overburden density and gravitational acceleration.**
2. **Superimposed tectonic stress, which is derived from regional forces that shape the crust and determine its structure.**
3. **Local stress variations imposed by individual geological structures such as faults, dykes, sills and joints.**
4. **Residual stresses, which endure in the rock long after the forces that caused them have dissipated.**

4.2 The database of in situ stress measurements carried out in Southern Africa lists horizontal stress components in deep level mines ranging between 0.3 and 1.5 times the vertical stress component. Sketch the expected shape of break-out (sockets) around shotholes for k = 0.5, k = 1 and k = 1.5. (3)



k = 0.5   k = 1   k = 1.5

4.3 Use the Kirsch equations to calculate the tangential stress in terms of the vertical virgin stress (q) at mid-height on the periphery of a circular tunnel for each of the scenarios listed in Question 4.2 above. Which k-ratio should result in the least stress damage to the sidewalls of the tunnel? (8)

R/r = 1 $\Theta = 0°$

k = 0.5 => $\sigma_{\Theta\Theta} = 2.5\ q$

k = 1 => $\sigma_{\Theta\Theta} = 2\ q$

k = 1.5 => $\sigma_{\Theta\Theta} = 1.5\ q$ => (least stress damage)

4.4 Calculate the k-ratio that will result in tangential stress of zero at the crown of the tunnel. (5)

R/r = 1   Θ = 90°

$\sigma_{\theta\theta}$ = ½ q (1 + k) (1 + 1) + ½ q (1 - k) (1 + 3) cos 180° = 0 MPa

q (1 + k) – 2 q (1 - k) = 0

3 k = 1

k = 1/3 **[20]**

QUESTION 5 - (STRESS AND STRAIN)

5.1 The 2D virgin stress tensor measured at a depth of 1788 m below surface is given by:

$$\begin{pmatrix} \sigma_{xx} & \tau_{xy} \\ \tau_{yx} & \sigma_{yy} \end{pmatrix} = \begin{pmatrix} 40 & -8.66 \\ -8.66 & 50 \end{pmatrix}$$

Calculate:

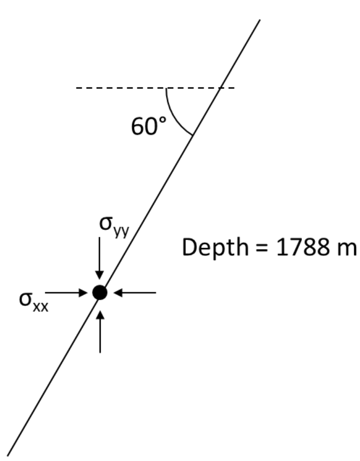
i) the average overburden density (1)

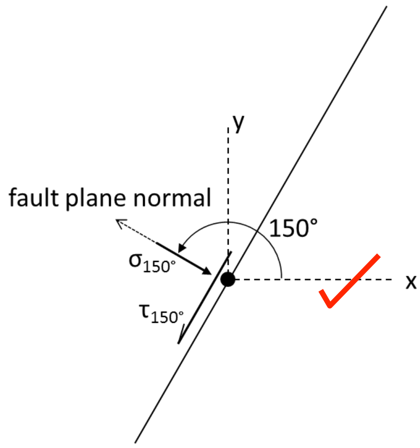
ii) the k-ratio (2)

$\sigma_{yy} = q_v = \rho g h$ => ρ = 2.85 t/m^3

$k = q_h{:}q_v = \sigma_{xx}{:}\sigma_{yy}$ => k = 0.8

5.2 Calculate and plot the normal and shear stresses acting on a 60° dipping fault as depicted below, when subjected to the virgin stresses listed in Question 5.1.(5)





$\sigma_{150°} = 40 \cos^2(150°) - 17.32 \sin(150°)\cos(150°) + 50 \sin^2(150°)$

$= 30 + 7.5 + 12.5$

$= 50$ MPa

$\tau_{150°} = ½ (50-40) \sin(300°) - 8.66 \cos(300°)$

$= - 4.33 - 4.33$

$= - 8.66$ MPa

5.3 Calculate the magnitude and direction of the major principal stress of the stress state given in Question 5.1 above. (6)

$$\sigma_1 = \frac{1}{2}(\sigma_{xx} + \sigma_{yy}) + \frac{1}{2}\sqrt{\left[(\sigma_{xx} - \sigma_{yy})^2 + 4\tau_{xy}^2\right]}$$

$= ½ (40 + 50) + ½ \sqrt{[(40 - 50)^2 + 4 (-8.66)^2]}$

$= 45 + 10$

$= 55$ MPa

$$\theta = \frac{1}{2}\arctan\left[2\tau_{xy}/(\sigma_{xx} - \sigma_{yy})\right]$$

$= ½ \arctan[2 (-8.66)/(40 - 50)]$

$= 30°$

Because $\sigma_{xx} < \sigma_{yy}$ and $\tau_{xy} < 0$ => $\Theta_1 = \Theta - 90°$

Θ_1 = - 60° (down from the horizontal x-axis)

5.4 A wooden table has four identical legs, each 900 mm long with 90 mm diameter. The axial elastic modulus of wood is 4 GPa. Assuming that the legs do not break, calculate the shortening of each leg when a mass of 10 tonnes is placed on the table. Assume that the mass is distributed evenly on the four legs. (6)

Area per leg = πr^2 = 0.0064 m^2

Total mass = 10 tonne => mass per leg = 2.5 tonne

$F = mg =$ **24.5 kN per leg**

$\sigma = \frac{F}{A}$ **= 3.9 MPa**

$E = \frac{\sigma}{\varepsilon}$ **=> ε = 9.6 x 10^{-4}**

$\varepsilon = \frac{\Delta l}{l}$ **=>** $\mathbf{\Delta} l = 0.87 \text{ mm}$

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TOTAL MARKS: [100]