CHAMBER OF MINES OF SOUTH AFRICA

EXAMINATION PAPER

SUBJECT: ROCK MACHANICS CERTIFICATE PART 1: THEORY **SUBJECT CODE:** COMRMC1 **EXAMINATION DATE:** Oct 2014 **TIME:** 3 Hours	**EXAMINER:** JA MARITZ **MODERATOR:** H YILMAZ **TOTAL MARKS:** 100 **PASS MARK:** 60

NUMBER OF PAGES:13 (*including Cover*)

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 unit) 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.

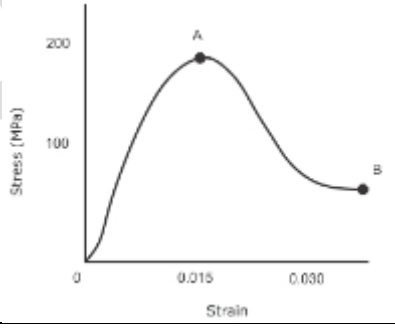
MEMO

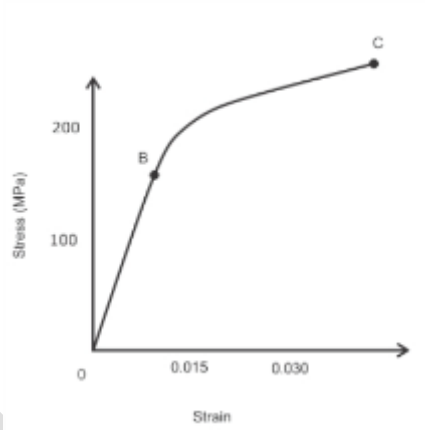
QUESTION 1 – MULTIPLECHOICE (26)

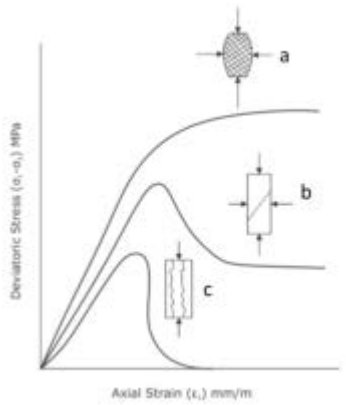
You will find the answer sheet at the end of your question set. Remove the sheet from the set, write your ID on the sheet and submit with your script.

Mark allocation *Correct answer* = *1.0*

Wrong answer = *0.0*

1.1	Positive shear stress…	A	Is compressive.
		B	Results in decreasing sample dimensions.
		C	Results in increasing of all the right angles during the change in free body shape.
		D	Rotates a body towards the origin of positive stress faces and away from the origin of negative stress faces.
1.2	Determine the magnitude of the principle stresses of the given stress matrix with X-axis horizontal and Y-axis vertical. $\begin{bmatrix} 48 & 14 \\ 14 & 17 \end{bmatrix}$ MPa	A	σ_1=48MPa, σ_2=11.613MPa
		B	σ_1=53.39MPa, σ_2=11.61MPa
		C	σ_1=11.61MPa, σ_2=53.39MPa
		D	None of the above.
1.3	Name the following beam: 	A	Cantilever beam
		B	Free supported beam
		C	Simply supported beam
		D	None of the above.
1.4	What behaviour is represented by the segment AB in the test graph below? 	A	Linear elastic behaviour
		B	Strain softening behaviour
		C	Strain hardening behaviour
		D	Elasto-plastic behaviour

1.5	Positive shear stress is defined as…	A	Causes a counter-clockwise rotation in body diagram.
		B	Causes a clockwise rotation in body diagram.
		C	Is the minimum of the two values where the circle intersects the normal stress axis.
		D	Is the maximum of the two values where the circle intersects the normal stress axis.
1.6	Rocks that experience large amounts of plastic deformation before rupturing can be classified as?	A	Brittle behaviour
		B	Ductile behaviour
		C	Visco-elastic
		D	Elastic limit
1.7	What behaviour is represented by the segment BC in the test graph below? 	A	Linear elastic behaviour
		B	Strain softening behaviour
		C	Strain hardening behaviour
		D	Elastic-plastic behaviour
1.8	Define Poissons Ratio	A	Ratio between the strains in the two mutually perpendicular directions.
		B	Ratio of axial strain to transverse strain.
		C	All of the above.
		D	None of the above.
1.9	Define Creep	A	Always increases with temperature.
		B	Deformation does not occur upon the application of stress.
		C	The tendency of a solid material to slowly move or deform permanently under the influence of stresses.
		D	All of the above.

1.10	Annotate the stress strain curves of a specimen at increasing confinement. 	A	a=shear fracture, b=axial splitting, c=multiple shear fractures
		B	a=shear splitting, b=axial fractures, c=multiple splitting
		C	a=multiple shear fractures, b=shear fractures, c=axial splitting
		D	None of the above.
1.11	What effect does water have on joint strength?	A	Reduction in normal stress to the joint reduces the friction component of the joint strength.
		B	$\tau=C_o+Tan\beta.\sigma_x$
		C	The lubrication increases the friction angle of the joint surface and reduces the joint strength.
		D	All of the above.
1.12	A higher joint roughness coefficient will increase joint strength as a rougher surface increases the friction angle and therefore shear strength.	A	JCS
		B	Stress normal to joint.
		C	JRC
		D	Residual friction angle.
1.13	Complete the following statement: *Fractures…*	A	Show no signs of shear displacements.
		B	Are not parallel to lithological variations.
		C	Are stress always induced.
		D	Are natural discontinuities.
1.14	Complete the following statement: *Joints...*	A	Occur if the rock is subjected to tensile stress conditions.
		B	Develop in a plane as a result of excessive shear stress exerted in the plane.
		C	Are stress induced.
		D	Are natural discontinuities.
1.15	Determine σ_h using Heim's rule if: ρ = 2750kg/m^3, g = 9.81m/s^2, h = 1800m, v = 0.21	A	12.91 MPa
		B	12.91 kPa
		C	48.56 MPa
		D	48.56 kPa

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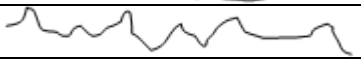
1.16	The photo below shows a core sample with disk thickness (t/D) of 0.3. The stress condition (σ_1/σ_t) is likely to be: 	A	High
		B	Medium
		C	Low
		D	Equal to 1
1.17	When considering the stress distribution around a circular opening with the major applied stress vertical, the tangential stress $\sigma_{\theta\theta}$ is a minimum when θ is equal to:	A	0°
		B	45°
		C	90°
		D	10°
1.18	Which of the following is an advantage of the "hydraulic testing of pre-existing fractures" method?	A	The method can be applied to rocks with a larger range of volume than that of the HF method
		B	Testing is quick
		C	The method can be applied where over-coring has failed
		D	The measurements can only be taken in 3D
1.19	Which of the following conditions are not suited to using the Hoek-Brown failure criterion?	A	A heavily jointed rock mass
		B	Intact rock specimens
		C	Many joint sets present
		D	One joint set present
1.20	Which of the following GSI ranges could refer to laminated rock which has soft, dry fillings and is slickensided and highly weathered?	A	30-40
		B	1-12
		C	85-95
		D	59-69
1.21	What is the MRMR adjustment value of rock conditions in a bored tunnel if: MRMR = 60, Weathering adjustment = 86%, 4 Joints and 4 block faces inclined away from the vertical are present. Mining has not caused notable induced stress **Adjustment (%)** Number of block faces inclined away from the vertical **Number of joints defining the block** | 70 | 75 | 80 | 85 | 90 3 | 3 | - | 2 | - | - 4 | 4 | 3 | - | 2 | - 5 | 5 | 4 | 3 | 2 | 1 6 | 6 | 5 | 4 | 3 | 2 or 1	A	36.12
		B	51.6
		C	32.51
		D	30.702
1.22	An excavation support ratio (ESR) for a permanent mine opening used in estimation of the Barton's Q rating is generally taken as?	A	0.8
		B	1.3
		C	1.6
		D	3 to 5

1.23	Which of these joint conditions would have the most degrading effect on MRMR?	A	Curved, very rough, no infilling
		B	Straight, polished, soft, fine sheared
		C	Wavy, striated, non-softening, coarse sheared
		D	Wavy, smooth, soft, coarse sheared
1.24	Put these rock types/conditions in descending order of grade used to estimate intact rock strength: 1. Coal; 2. Granite; 3. Chalk; 4. Stiff fault gouge	A	4; 3; 1; 2
		B	2; 1; 3; 4
		C	2; 3; 1; 4
		D	4; 1; 3; 2
1.25	When the effect of joint frequency on the strength of a rock mass is determined, which of the following should be taken into account?	A	Drilling induced fractures
		B	Stress fractures
		C	Both A and B
		D	Neither A nor B
1.26	Which of the following joints are the most likely to cause a fall of ground?	A	
		B	
		C	
		D	

QUESTION 2 – STRESS AND STRAIN (20)

2.1. When doing transformation calculations, what would be the sum of the rotated normal stresses compared to a matrix $\begin{bmatrix} 15 & 8 \\ 8 & 7 \end{bmatrix}$ MPa when the angle of rotation is clockwise 18°? [2]

22 = SigX + SigY = Sig1 + Sig2 = Sig X` + SigY`

2.2. Draw a cantilever beam. Indicate at what point the maximum deflection will be calculated? [2]

2.3. Two gauge marks are made 4 cm apart along the axis of a cylindrical rock specimen that is 6 cm in length, with a cross-sectional area of 7 cm^2. The specimen is then subjected to a uni-axial compressive force of 100 kN. Given that E = 60 GPa and v = 0.2, calculate the following:

2.3.1. the stress exerted on the specimen [2]

σ = F / a

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= 100 000 N / (7 / 10 000) m^2
= 142.86 MPa (2 marks)

2.3.2. the strain in the specimen [2]

$E = \sigma / \varepsilon$
$\varepsilon = \sigma / E$
= 142.86 MPa / 60 000 MPa
= 0.002 38
= 2.38 millistrains (2 marks)

2.3.3. the contraction between the gauge marks [2]

$\varepsilon = \Delta\ell / \ell$
$\Delta\ell = \varepsilon \cdot \ell$
= 0.00238 x 4 cm
= 0.009 cm
= 0.09 mm (2 marks)

2.3.4. the total contraction of the specimen [2]

$\varepsilon = \Delta\ell / \ell$
$\Delta\ell = \varepsilon \cdot \ell$
= 0.00238 x 6 cm
= 0.014 cm
= 0.14 mm (1 mark)

or

$\Delta\ell$ = 6 cm / 4 cm X 0.09 mm
= 0.135 mm

2.3.5. the change in cross-sectional area of the specimen [4]

$v = \varepsilon_{radial} / \varepsilon_{axial}$
$\varepsilon_{radial} = v \cdot \varepsilon_{axial}$
= 0.2 x 0.00238
= 0.000476

$A = D^2 \cdot \pi / 4$
$D = (4 \cdot A / \pi)^{0.5}$
= (4 x 7 / π)$^{0.5}$
= 2.985 cm

or

$A_{final} = A_{initial} \times (1 + \varepsilon_{radial})^2$
= 7 cm^2 x (1 + 0.000476)^2
= 7.007 cm^2

$\varepsilon = \Delta\ell / \ell$
$\Delta\ell = \varepsilon \cdot \ell$
= 0.000476 x 2.985 cm
= 0.0014 cm

$D_{final} = D_{initial} + \Delta\ell$
= 2.985 + 0.0014
= 2.987 cm

$A_{final} = D^2 \cdot \pi / 4$
= (2.987 cm)^2 x π / 4
= 7.007 cm^2

Δ Area = $Area_{initial} - Area_{final}$
= 7.007 cm^2 – 7 cm^2
= 0.007cm^2 (3 marks)

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2.4. When analysing conditions on the sidewall of an excavation, what assumption would you make to eliminate the stress third dimension from your analysis [2]

Plane stress

2.5. Define the positive sign convention for normal stress and strain [2]

Normal stress: Compressive
Normal strain: Decrease / shorten

QUESTION 2 – CONSTITUTIVE BEHAVIOUR (15)

2.1. Define STRAIN ENERGY and name the SI unit. [3]

Work done in **deforming** a body
Joule

2.2. What is the SI unit for STRAIN ENERGY DENSITY [1]

J/m^3

2.3. Define DILATION ANGLE and comment on where it is determined on the stress strain graph. [3]

The **ratio** of incremental plastic **volumetric strain** and plastic **shear strain**.

2.4. Using $= \frac{(2v_p - 1)}{(2v_p + 1)}$, calculate the dilation angle for a material with a plastic radial:axial strain ratio of 0.9. [2]

16.6°

2.5. Indicate on a graph, the stress-strain relationship during rock sample testing for the onset of inelastic behaviour, dilation and strain softening [6]

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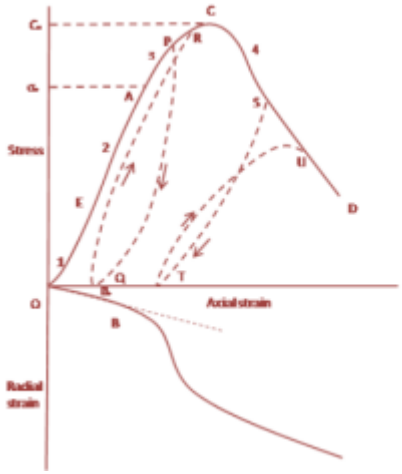
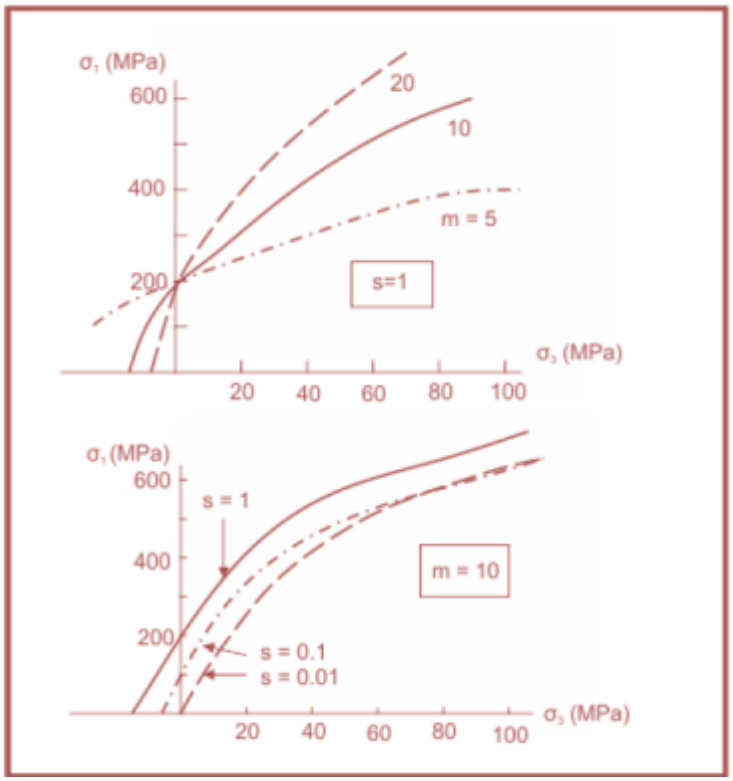


A: Inelastic behaviour
B: Dilation
C-D: Strain softening

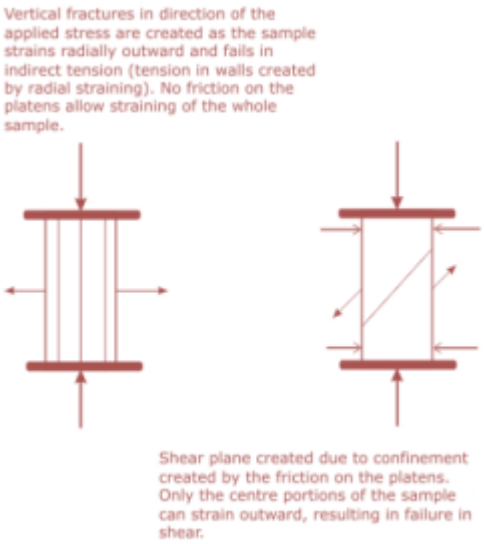
QUESTION 3 – ROCK & JOINT STRENGTHS (14)

3.1. Assuming the application of the Hoek-Brown failure criterion and by means of a graph, explain how a change in the m and s values influences the strength of the rockmass. [6]

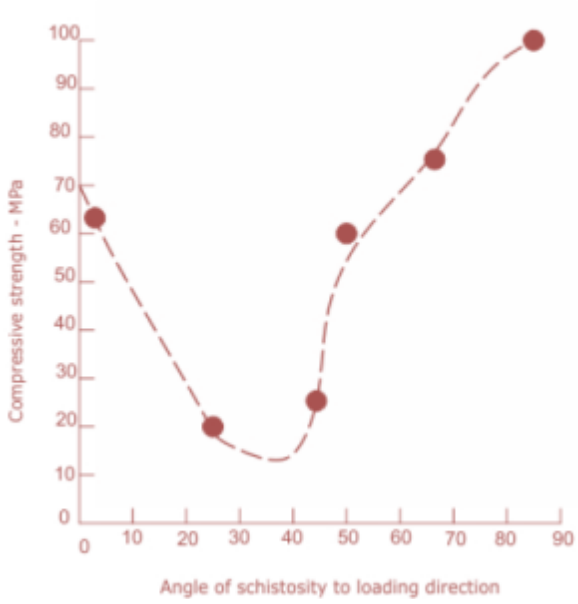


3.2. Name, sketch and discuss the two possible modes of failure of rock in uni-axial and tri-axial compression [6]

Indirect tension + Sketch + Discuss
Shear + Sketch + Discuss



3.3. By means of a sketch and graph, briefly explain how the angle between the loading direction and the lamination influence rock strength [2]

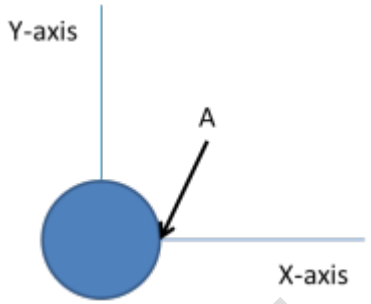


QUESTION 4 – STRESS IN ROCK AND ROCKMASSES (20)

4.1. You are appointed as the Project Rock Engineer tasked with the responsibility of determining the length of support required for stabilizing the sidewall (point A in the sketch) of a vertical shaft prior to shaft pillar extraction. The shaft has a diameter of 9.0 m and intersects the reef horizon at 1850 mbs. The k-ratio in the Y direction is 0.8 with the k-ratio

in the X direction also calculated as 0.8. The rock mass has a relative density of 2.75 and a UCS value of 55 MPa, RMR of 65. The m and s values are 6.0 and 0.02 respectively. [20]

Tip: Assume length of tendon to be 1.0m longer than the depth of fracturing.



h	1850	m		
Density	2750	kg/m^3		
q	49.9084	MPa	Sy=39.9	
k	1.0		Sx=39.9	
R	4.5	m		
r		m		
θ	0	°		

Distance in Sidewall	R	r	Tangential	Radial	Distance in Sidewall	HK	Failure Y/N
0	4.5	4.5	99.82	0.00	0	7.8	Y
0.15	4.5	4.65	96.65	3.17	0.15	36.4	Y
0.8	4.5	5.3	85.89	13.93	0.3	82.2	Y
0.9	4.5	5.4	84.57	15.25	0.45	86.6	N

Bolt length > 1.9

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QUESTION 5 – ROCKMASS PROPERTIES & CLASSIFICATION (10)

5.1. Define Rock Mass Strength and how this is related to a rock mass' classification. [2]

Empirical approach to determine the strength of a rock mass **based on the MRMR**

5.2. Name three classifications that are generally used in the rock engineering discipline and name the one parameter common to all. [4]

Barton's Q, Bieniawski RMR, Laubscher's MRMR – RQD

5.3. Name the criterion and discuss the limitations of the criterion used when assessing the strength of in-situ rock that is transected by many closely-spaced joint sets of multiple angles. [4]

Hoek and Brown Criteria
Purely empirical
Fits lab low-stress regimes well, overestimate strengths at high confinement
Needs back analysis on "m" and "s" values.

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TOTAL MARKS: [100]

ID Number _____

Question 1

EXAMPLE	A		B	X	C		D	
1.1	A		B		C		D	
1.2	A		B		C		D	
1.3	A		B		C		D	
1.4	A		B		C		D	
1.5	A		B		C		D	
1.6	A		B		C		D	
1.7	A		B		C		D	
1.8	A		B		C		D	
1.9	A		B		C		D	
1.10	A		B		C		D	
1.11	A		B		C		D	
1.12	A		B		C		D	
1.13	A		B		C		D	
1.14	A		B		C		D	
1.15	A		B		C		D	
1.16	A		B		C		D	
1.17	A		B		C		D	
1.18	A		B		C		D	
1.19	A		B		C		D	
1.20	A		B		C		D	
1.21	A		B		C		D	
1.22	A		B		C		D	
1.23	A		B		C		D	
1.24	A		B		C		D	
1.25	A		B		C		D	
1.26	A		B		C		D	