CHAMBER OF MINES OF SOUTH AFRICA

EXAMINATION PAPER

SUBJECT: ROCK MACHANICS CERTIFICATE PART 1: THEORY **SUBJECT CODE:** COMRMC1 **EXAMINATION DATE:** May 2015 **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:

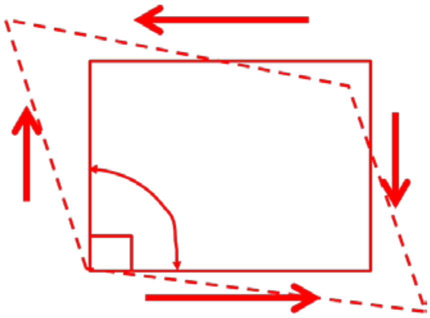
1. Answer **all questions**. Answer the questions **legibly** in English.
2. Write your **ID Number** on the outside cover of each book used and on any graph paper or other loose sheets handed in.

   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.

QUESTION 1 – STRESS AND STRAIN (20)

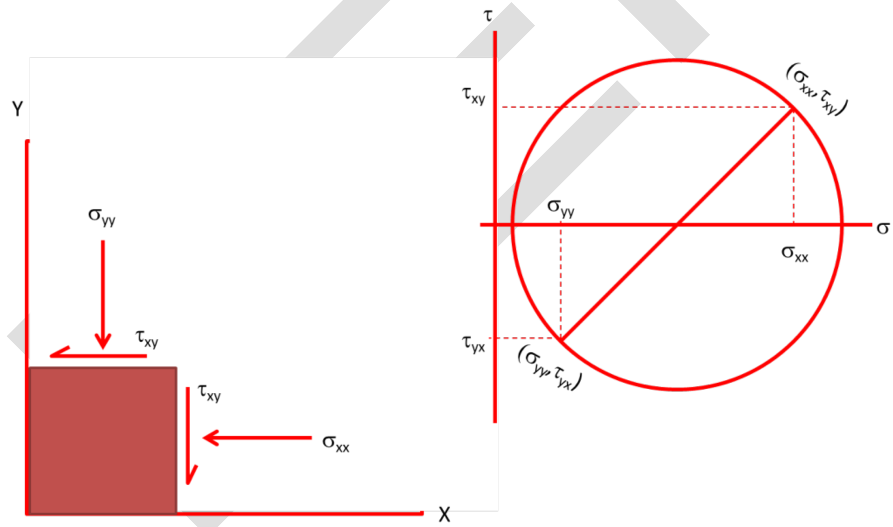
1.1. By means of a sketch, indicate the effect positive shear strain has on a square sample. [2]



1.2. State the factors that would make the stress to be a valid tensor in 2D? [3]

Magnitude of the stresses
Direction of the stresses
Area

1.3. Draw the state of stress (2D) on a free body diagram and Mohr–Circle for the following stress matrix: : $\begin{bmatrix} \sigma_{xx} & \tau_{xy} \\ \tau_{yx} & \sigma_{yy} \end{bmatrix}$; $\sigma_{xx} > \sigma_{yy}$ [4]



[2+2]

1.4. Calculate the principle stress state of $\begin{bmatrix} \sigma_{xx} & \tau_{xy} \\ \tau_{yx} & \sigma_{yy} \end{bmatrix} = \begin{bmatrix} 15 & 7 \\ 7 & 35 \end{bmatrix}$ MPa [4]

$$\tan 2\theta = \frac{2\tau_{xy}}{\sigma_{xx} - \sigma_{yy}} \quad \sigma_1 + \sigma_2 = \sigma_{xx} + \sigma_{yy}$$

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

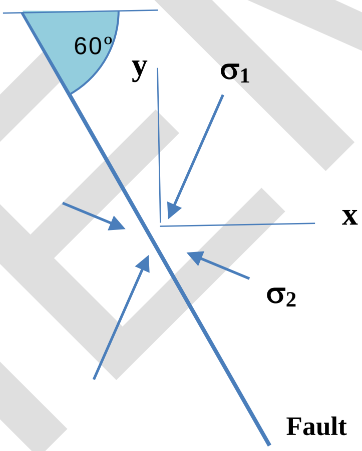
$$\sigma_2 = \frac{1}{2}(\sigma_{xx} + \sigma_{yy}) - \frac{1}{2}\sqrt{(\sigma_{xx} - \sigma_{yy})^2 + 4\tau_{xy}^2}$$

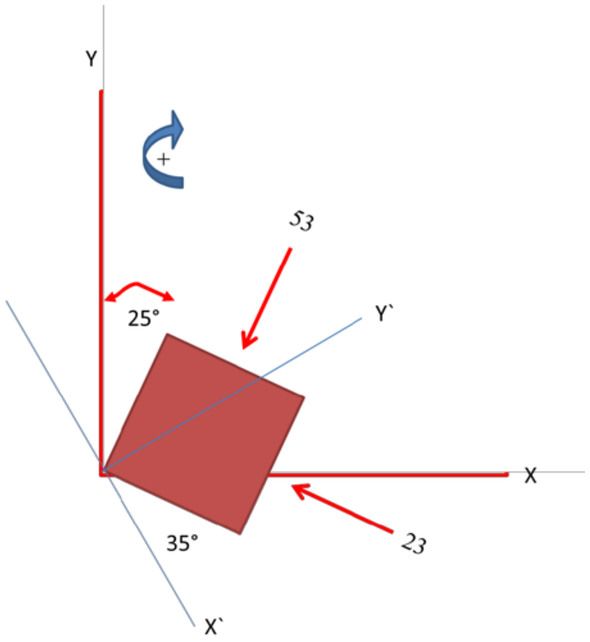
~~σ_1 =49.41 MPa~~
~~σ_2 = 0.59 MPa~~
~~θ = -17.5° hence σ_1 measured 17.5° anti-clockwise from Y-axis or 107.5° from X-axis~~

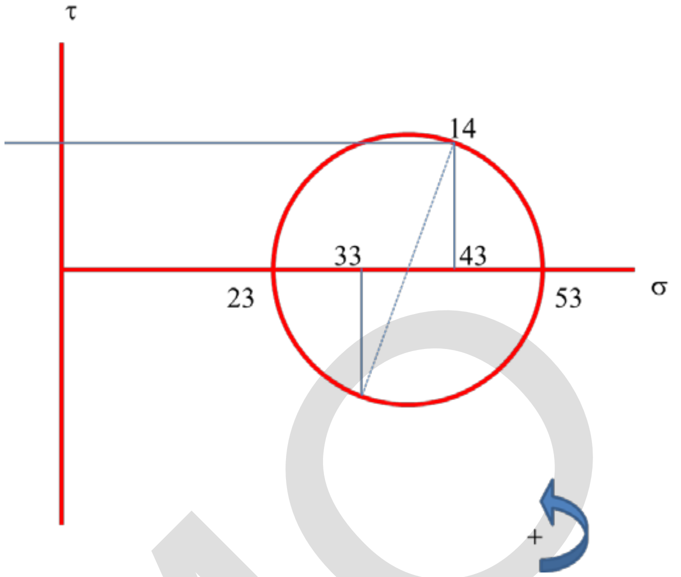
σ_1 =	**37.21**	**MPa**	**θ_1 =**	**72.50**	**° from X anticlockwise**
σ_2 =	**12.79**	**MPa**	**θ_2 =**	**162.50**	**° from X anticlockwise**

1.5. The principle stresses are 53 MPa and 23 MPa. The direction of the major stress was determined as being 25° clockwise from Y. Graphically, by means of a Mohr's circle, determine the stress state on a fault plane dipping at 60°.

[6]







Rotation to plane is 35° CW on FB hence 70° ACW on MC
$\sigma_{x`}$=33 MPa (stress parallel)
$\sigma_{y`}$=43 MPa (stress normal)
$\tau_{xy`}$=14 MPa

1.6. For calculating the maximum deflection in a cantilever beam $\delta = \frac{3\gamma L^4}{2Et^2}$ is used. For calculating the maximum deflection in a build-in beam $\delta = \frac{\gamma L^4}{32Et^2}$ is used. What length of build-in beam would result in the same maximum deflection as a 4 m cantilever beam with the same material properties? [2]

$\delta = \frac{\gamma L^4}{32Et^2} = \frac{3\gamma 4^4}{2Et^2}$ *solve for L hence L=5.26m*

QUESTION 2 – CONSTITUTIVE BEHAVIOUR (20)

2.1. Complete the statement(s) below by answering with only the missing word(s) in your answer book: [5]

*Note - Each word account for ½ mark

2.1.1. _Elastic deformation___ occurs when a body is deformed in response to a stress, but returns to its original shape when the stress is removed.(1)

2.1.2. In the elastic analysis it is assumed that elastic strain is a function of _stress__ only. (strain also depends on Elastic Modulus and Poisson's Ratio) (½)

2.1.3. Plastic deformation is __irreversible__ strain without visible fractures (½) (permanent and irrecoverable → also correct)

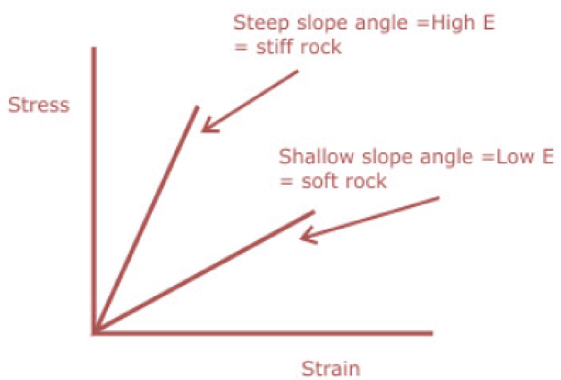
2.1.4. __Strain energy__ is the work done in deforming a body. (1)

2.1.5. The term __dilatation OR dilation OR Volumetric Strain __ is defined as the quotient of the change in volume to the original volume of the body submitted to stress. (½)

2.1.6. Strain softening occurs when the deformation of the sample beyond its peak strength by continued loading, results in an __increase__ in the strain and __decrease__ in stress sustained by the sample. (1)

2.1.7. In __tertiary__ creep stage the strain rate increases rapidly. (½)

2.2. On the same graph, graphically explain the difference between a stiff and soft rock sample. [3]



2.3. In a plane strain environment, it is assumed that the strain in the plane perpendicular direction equals 0, yet the stress in that direction CANNOT be zero. With a ε_x = 0.0015 and ε_y = 0.002, present the stress matrix, assuming no shear influence. E = 55 GPa, υ = 0.2 [10]

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

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

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

Solving σ_x with ε_x => σ_x = $(82.5(10)^6 + 0.24\sigma_y)/0.96$ {i}
Solving σ_y with ε_y => σ_y = $(110(10)^6 + 0.24\sigma_x)/0.96$ {ii}
*Substitute {i} in {ii} to solve σ_y => **σ_y = 145.1 MPa***
*Substitute σ_y in {1} to solve σ_x => **σ_x = 122 MPa***
*Solve σ_z => **σ_z = 53.5 MPa***

$$\begin{bmatrix} xx & 0 & 0 \\ 0 & yy & 0 \\ 0 & 0 & zz \end{bmatrix} = \begin{bmatrix} 122.0 & 0 & 0 \\ 0 & 145.1 & 0 \\ 0 & 0 & 53.4 \end{bmatrix} MPa$$

The following equations could also be used

$$\sigma_x = \frac{2G}{1-2\nu}[(1-\nu)\varepsilon_x + \nu\varepsilon_y]$$

$$\sigma_y = \frac{2G}{1-2\nu}[(1-\nu)\varepsilon_y + \nu\varepsilon_x]$$

$$\sigma_z = \frac{2\nu G}{1-2\nu}(\varepsilon_x + \varepsilon_y)$$

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

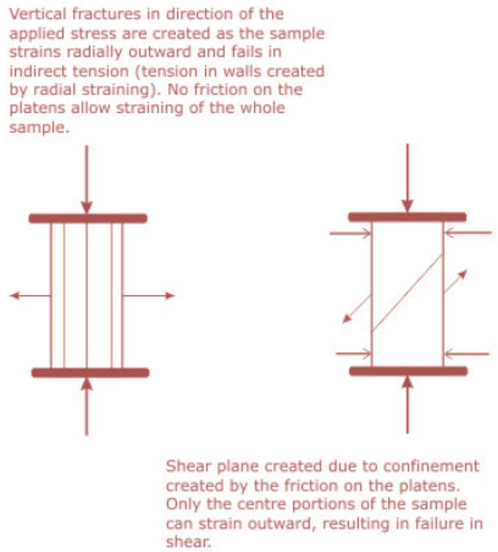
2.4. If the strain energy density of a sample resulted in $0.1481 MJ/m^3$, explain what the effect of sample initial volume would be when calculating strain energy. [2]

Increase in volume would increase the stored strain energy.

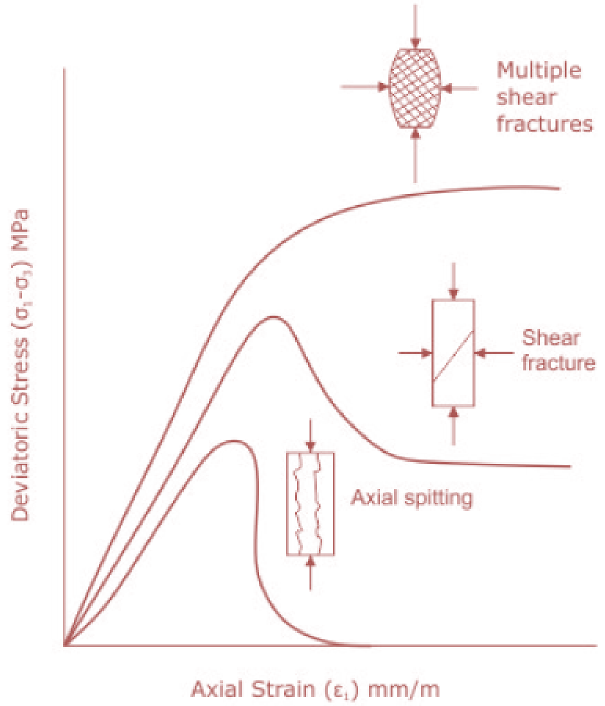
QUESTION 3 – ROCK & JOINT STRENGTHS (25)

3.1. Name and sketch the two modes of failure of rock in uni-axial compression and confined compression. [2]

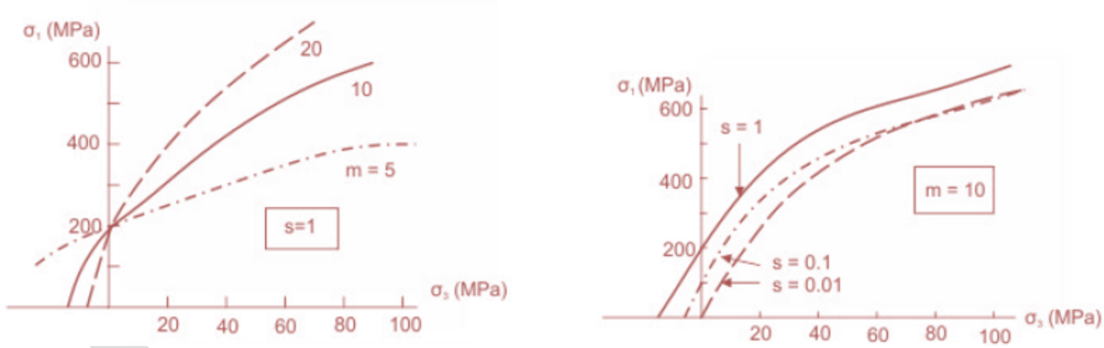
Indirect tension / Shear



3.2. Sketch the post failure behaviour of a rock sample with an increase in confining pressure [5]



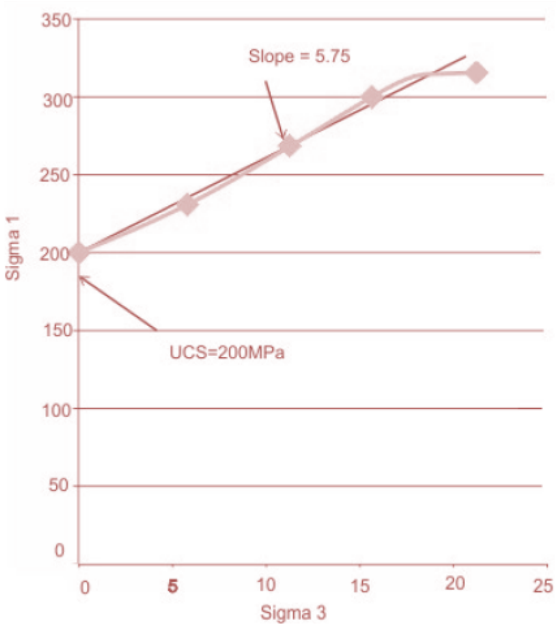
3.3. In the Hoek-Brown failure criteria, two rock constants are used to determine the strength of a rock specimen. By means of a Hoek-Brown yield curve, show how a change in each parameter would affect the curve. [4]



3.4. Given the following set of test results (sample UCS = 200 MPa), determine the Mohr-Coulomb parameters of the rock. [8]

Confinement Stress (MPa)	**Peak Stress (MPa)**
5	228
10	264
15	300

20	315



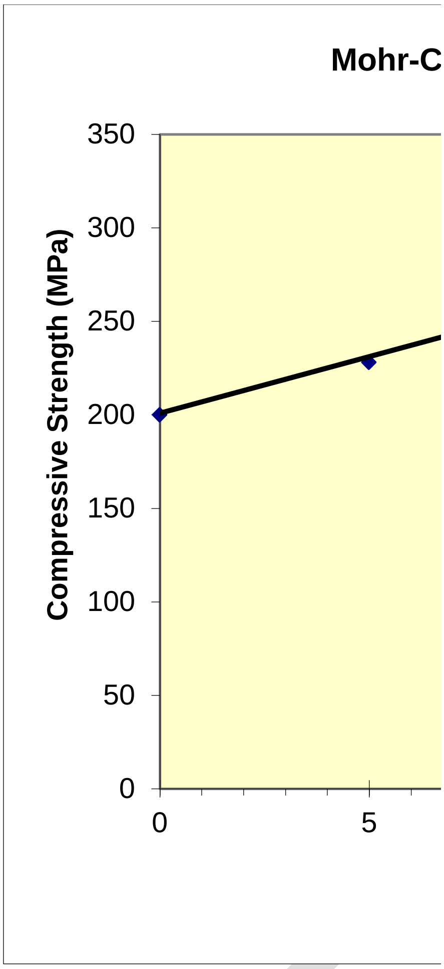
Plot in principle stress space ***(2)***

$sin\phi_i = \frac{(\beta_0 - 1)}{(\beta_0 + 1)}$ and $C_0 = \frac{\sigma_c}{\sqrt{\beta_0}}$ *Determine slope* (β_0)*=5.75* ***(2)***

ϕ *= 44.7°* ***(2)***

C_o *= 41.7 MPa* ***(2)***

There could be variation in the answers that should be considered. See below



β	C_o	ϕ
6.04	40.9	45.7

3.5. Name 3 factors influencing joint shear strengths and indicate how these factors influence the shear strengths. [6]

Any 3

Factors	***Strength influence***
Joint Roughness +	*+*
Normal stress +	*+*
Water +	*-*
Roughness angle +	*+*

QUESTION 4 – STRESS IN ROCK AND ROCKMASSES (25)

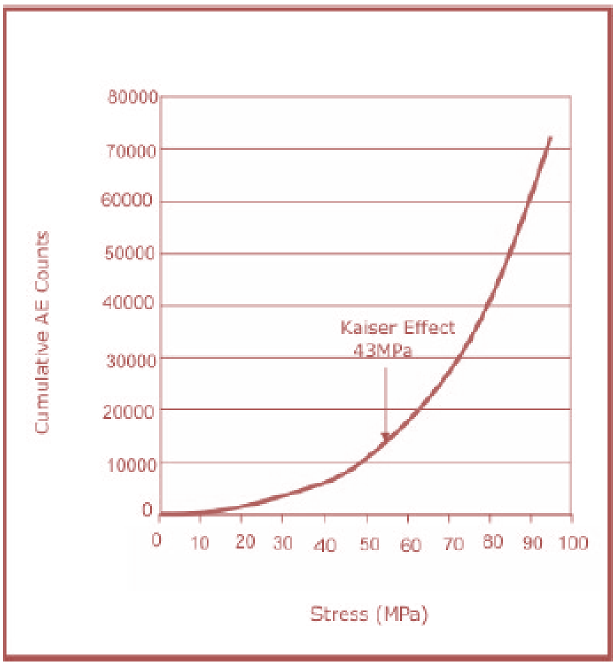
4.1. At a depth of 800 m, determine the k-ratio using Heim's rule and Rigid confinement theory for an environment with a rock density of 2650 kg/m^3, and $\upsilon = 0.28$. [5]

HR: $\sigma_v = 20.79$ MPa $= \sigma_h$ => K = 1

RCT: $\sigma_v = 20.79$ MPa => $\sigma_h = 8.09$ MPa => K = 0.39

4.2. Draw a typical cumulative acoustic emissions counts vs. stress graph and explain the Kaiser effect [5]

Using the data obtained during the laboratory experiment, an acoustic emission versus stress graph can be plotted from which the Kaiser Effect change point, shown in Figure 27, where there is a change in the slope of the graph. The change point is associated with the maximum stress the rock was subjected to underground. A sufficient number of secondary core tests should be conducted to be able to determine the three dimensional states of stress.



4.3. By using the Kirsch equations, determine the Induced stresses (vertical and horizontal) at a distance 3 times the diameter into the sidewall of a raised bore tunnel and expresses these Induced stresses as a percentage of the field stress at 1200 mbs and a k-ratio of 0.6. [15]

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

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

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

Candidate to have assumed density (1 mark), radius (1 mark) – these parameters does not effect the answer %

σ_{tan}=Induced + Virgin => (σ_{tan}-virgin vertical)/σ_{tan} = 1.6%

σ_{rad}=Induced + Virgin => (σ_{rad}-virgin horizontal)/σ_{rad} = 0%

There should be futher breakdown of 15 marks for marking fairness.

QUESTION 5 – ROCKMASS PROPERTIES & CLASSIFICATION (10)

5.1. Describe and illustrate how joint frequency is determined and the unit for this frequency. [3]

*Joint frequency is determined by measuring **all joints** that **intersect a scan line** used during the mapping of joints or along the core during the logging of core – presented as **Number of joints per run / per meter***

5.2. What formula is used in determining the rock quality designation? [1]

$$RQD = \frac{\sum Core\ sample\ lengths > 100mm}{(Total\ Core\ length)}$$

5.3. Assume a MRMR value of 68. Adjustment values are as provided below. Determine the Adjusted MRMR. [2]

Adjustment for	**Adjustment Value (%)**
Weathering	88
Joint orientation	75
Mining induced stresses	100
Blasting effects -smooth wall blasting-	97
Adj MRMR	*= 68 x 0.88 x 0.75 x 1 x 0.97* *= 43.5*

5.4. Name the two scenarios identified where the Hoek-Brown criterion would be applicable [2]

Intact rock

Highly fractured rock

5.5. State any differences between RMR_{89} and RMR_{76}. [1]

Nothing, 89 is a mere update of the 76 classification which seen a change in the values per section.

TOTAL MARKS: [100]

Useful Equations

$$\sigma_{nn} = \sigma_{xx}\cos^2\theta + 2\tau_{xy}\sin\theta\cos\theta + \sigma_{yy}\sin^2\theta \quad \sigma'_{xx} = \sigma_{xx}\cos^2\theta + 2\tau_{xy}\sin\theta\cos\theta + \sigma_{yy}\sin^2\theta$$

$$\sigma_{mm} = \sigma_{xx}\sin^2\theta - 2\tau_{xy}\sin\theta\cos\theta + \sigma_{yy}\cos^2\theta \quad \sigma'_{yy} = \sigma_{xx}\sin^2\theta - 2\tau_{xy}\sin\theta\cos\theta + \sigma_{yy}\cos^2\theta$$

$$\tau_{nm} = \frac{1}{2}(\sigma_{yy} - \sigma_{xx})\sin 2\theta + \tau_{xy}\cos 2\theta \qquad \tau'_{xy} = \frac{1}{2}(\sigma_{yy} - \sigma_{xx})\sin 2\theta + \tau_{xy}\cos 2\theta$$

$$\tan 2\theta = \frac{2\tau_{xy}}{\sigma_{xx} - \sigma_{yy}} \quad \sigma_1 + \sigma_2 = \sigma_{xx} + \sigma_{yy}$$

$$\sigma_1 = \frac{1}{2}(\sigma_{xx} + \sigma_{yy}) + \frac{1}{2}\sqrt{(\sigma_{xx} - \sigma_{yy})^2 + 4\tau_{xy}^2} \quad \sigma'_{xx} + \sigma'_{yy} = \sigma_{xx} + \sigma_{yy}$$

$$\sigma_2 = \frac{1}{2}(\sigma_{xx} + \sigma_{yy}) - \frac{1}{2}\sqrt{(\sigma_{xx} - \sigma_{yy})^2 + 4\tau_{xy}^2} \quad \tau_{\max} = \frac{1}{2}\sqrt{(\sigma_{xx} - \sigma_{yy})^2 + 4\tau_{xy}^2}$$

$$\sigma_{nn} = \sigma_1\cos^2\theta + \sigma_2\sin^2\theta \quad \tau_{\max} = \frac{1}{2}(\sigma_1 - \sigma_2)$$

$$\sigma_{mm} = \sigma_1\sin^2\theta + \sigma_2\cos^2\theta$$

$$\sigma_{nn} = \frac{1}{2}(\sigma_1 + \sigma_2) + \frac{1}{2}(\sigma_1 - \sigma_2)\cos 2\theta \qquad \tau_{nm} = -\frac{1}{2}(\sigma_1 - \sigma_2)\sin 2\theta$$

$$\sigma_{mm} = \frac{1}{2}(\sigma_1 + \sigma_2) - \frac{1}{2}(\sigma_1 - \sigma_2)\cos 2\theta$$

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

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

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

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

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

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

$sin\phi_i = \frac{(\beta_0 - 1)}{(\beta_0 + 1)}$ and $C_o = \frac{\sigma_c}{\sqrt{\beta_0}}$

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

$$\sigma_h = \left(\frac{\upsilon}{1-\upsilon}\right)\sigma_v$$