UNISA university of south africa

EXAMINATION PAPER

SUBJECT: ROCK MACHANICS CERTIFICATE PART 1: THEORY **SUBJECT CODE:** COMRMC1 **EXAMINATION DATE:** MAY 2011 **TIME:** 3 Hours	**EXAMINER:** JA MARITZ **MODERATOR:** M HANDLEY **TOTAL MARKS:** [100] **PASS MARK:** 60%

NUMBER OF PAGES: 7

SPECIAL REQUIREMENTS:

1. **Answer ALL 4 Questions.**
2. Start each question on a new page.
3. References other than those provided are not permitted.
4. Hand-held electronic calculators may be used.
5. Write your **examination 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.

6. **<u>Write in ink on the RIGHT HAND SIDE of the paper only (only the right hand pages will be marked).</u>**
7. Show all calculations on which your answers are based.
8. Illustrate your answers by sketches or diagrams wherever possible.
9. In answering these questions, full advantage should be taken wherever necessary of your practical experience as well as of the data given.
10. Answers must be given to an accuracy that is typical of practical conditions.

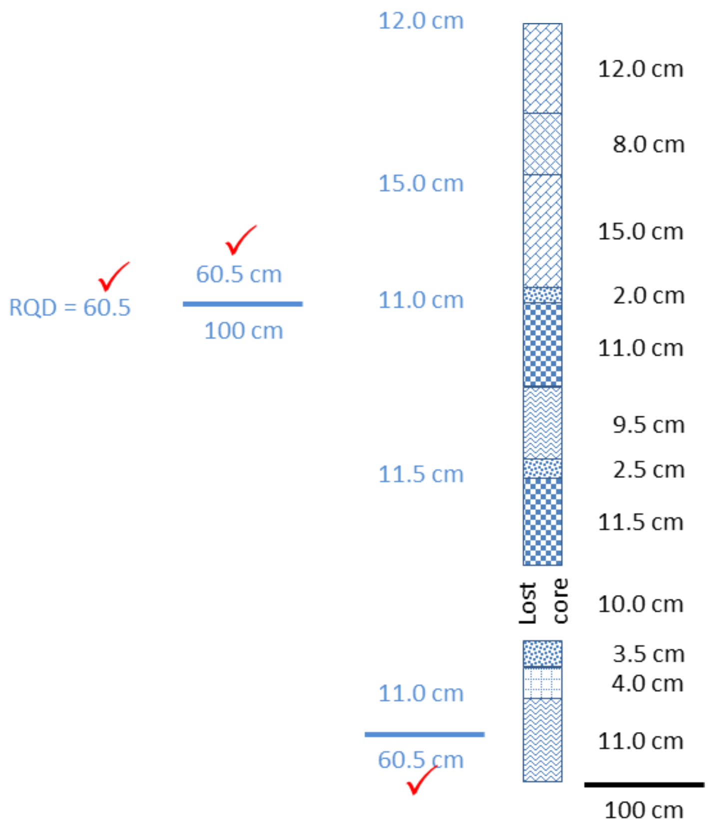
Question 1 – Rock mass classifications and strength **(25 marks)**

1.1 Rock Quality Designation is generally used in classification. Define RQD and supply the used equation. (2 marks)

RQD is defined as the ratio of length of core recovered counting the lengths > 100 mm to the total length of core.

$$RQD = \frac{\sum Length\ of\ core > 100\ mm}{\sum total\ length\ core\ recovered}$$

1.2 A 1.0m (or part of) core sample has been recovered during a project exploration phase. Determine the RQD from the recovered core as presented below. (3 marks)



1.3 Name and indicate how the different factors from the Barton's Rock Tunnelling Quality Index (Q) could influence the rock quality (4 marks)

$Q = (RQD / J_n) \times (J_r / J_a) \times (J_w / SRF)$

RQD:	Rock Quality Designation	Increase
Jn:	Joint set number	Decrease
Jr:	Joint roughness	Increase
Ja:	Joint alteration	Decrease
Jw:	Joint water reduction factor	Increase
SRF:	Stress reduction factor	Decrease

1.4 Barton and Choubey developed an equation to calculate shear strength on a plane.

i) Provide this equation and define each of the four parameters required as input: (3 marks)

$\tau = \sigma_n \cdot \tan(\Phi_b + JRC \cdot \log_{10}(JCS / \sigma_n))$ ✓

σ_n : Normal stress √
Φ_b: Basic friction angle √
JRC: Jointwall Roughness Coefficient √
JCS: Jointwall Compresive strength √

ii) Given the following: $\Phi_b = 28^O$, JRC = 17 and JCS = 110 MPa, calculate the shear strength of the plane when σ_n = 0.5 MPa and σ_n = 3.0 MPa respectively. (2 marks)

σ_n	τ	
0.5	**1.23**	✓
3.0	**4.22**	✓

iii) What significance is there with an increasing σ_n? (1 mark)

τ Increase✓

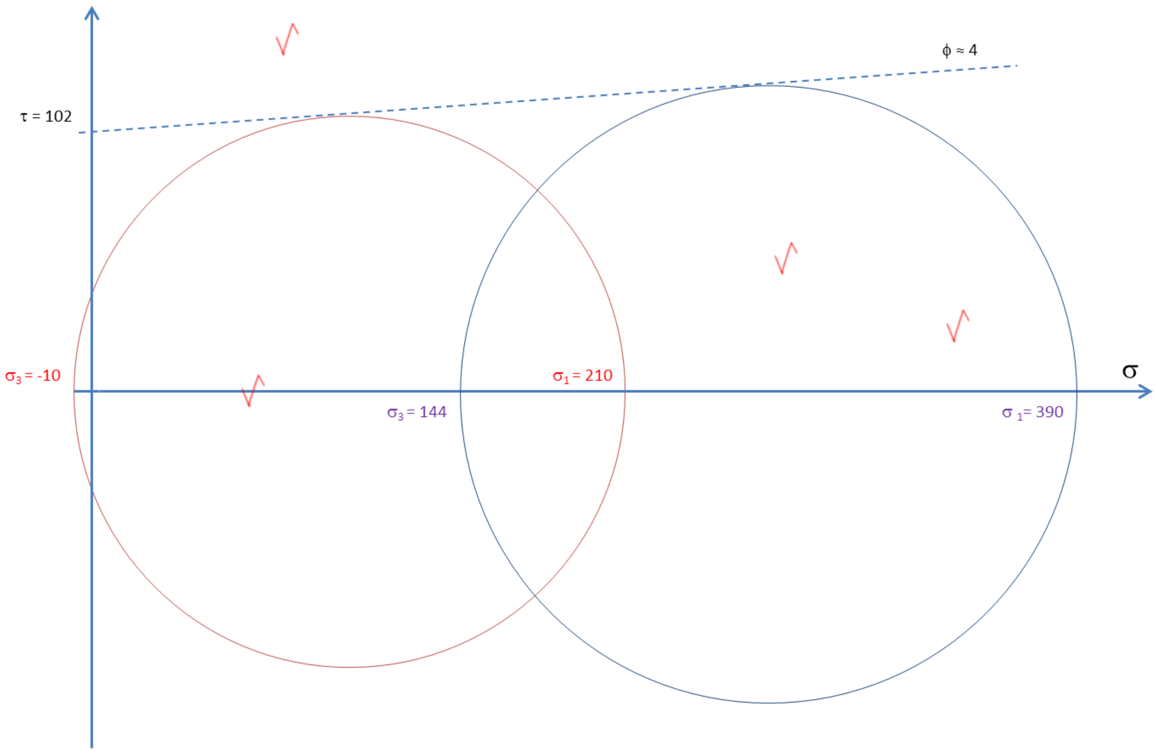
1.5 Two rock samples were tested in a triaxial shear strength test machine and failed at the following principle stress values;

Test 1: σ_1 = 210kPa σ_3 = -10kPa

Test 2: σ_1 = 390kPa σ_3 = 144kPa

i) Explain by means of a sketch how the triaxial shear strength test machine works. (5 marks)

ii) Draw the Mohr circles that represent the two tests. (2 marks)



iii) Determine the Joint cohesion (1 mark)

c = 102 kPa✓

iv) Determine the Joint friction angle (1 mark)

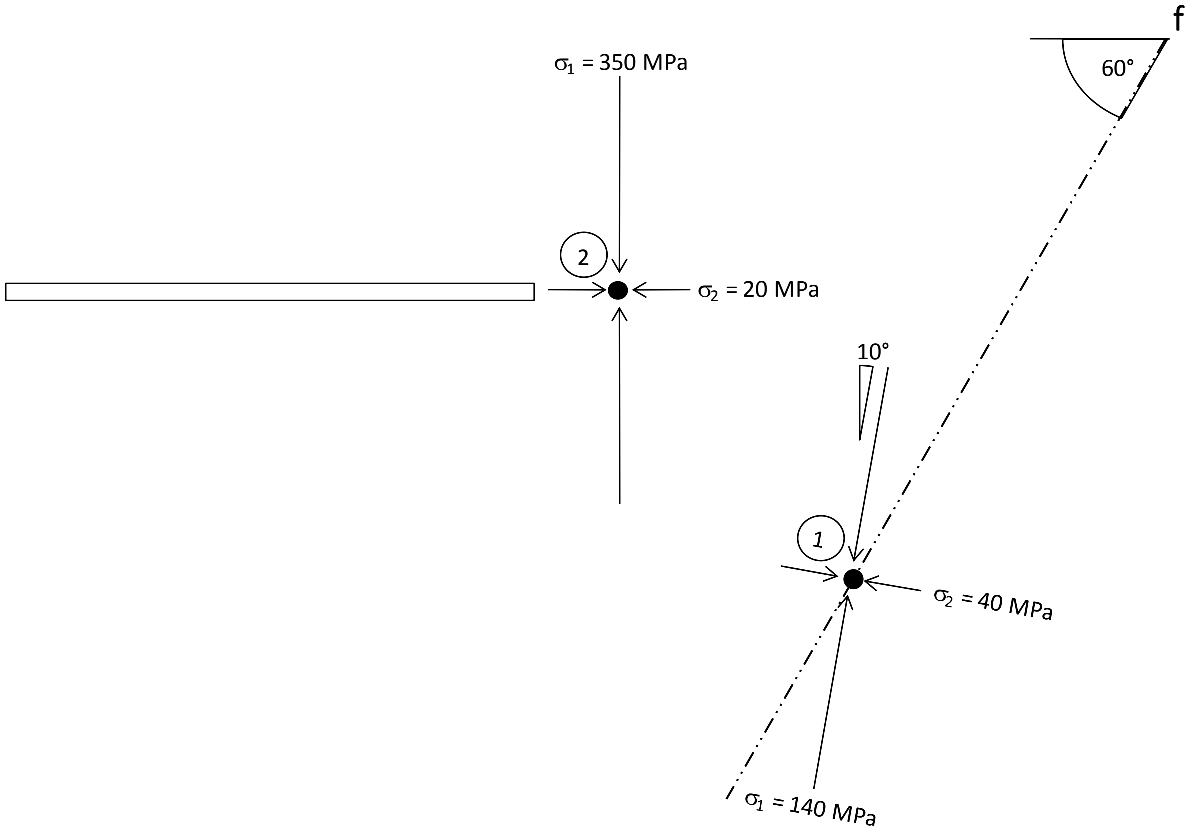
$\phi \approx 4°$✓

v) Determine the shear strength of the joint if a normal stress of 300kPa is applied across the joint. (1 mark)

$\tau \approx 122.9$ kPa✓ ($\tau = \sigma_n \tan\phi + c$)

QUESTION 2 – ROCK STRESS **(25 MARKS)**

The two dimensional stress state at two points in a homogeneous rockmass are shown below where lithostatic stress conditions does not necessary exist.



2.1 Define the following rock engineering parameters and provide symbols and SI units where applicable (make use of a sketch where possible). (5 marks)

2.1.1 Normal stress

σ_n Pascal Pa√

The **perpendicular** √ force acting on a surface $\sigma_n = \frac{F}{A}$

2.1.2 Shear stress

τ_m Pascal Pa√

The **parallel** √ force acting on a surface $\tau_m = \frac{F}{A}$

2.1.3 Homogeneous rockmass

A homogeneous rockmass assumes the **same characteristics** ✓ throughout the rockmass.

2.1.4 Lithostatic stress conditions

The stress in all three directions are **equal** ✓ $\sigma_1 = \sigma_2 = \sigma_3$ or $\sigma_x = \sigma_y = \sigma_z$

2.1.5 Poisson's ratio

$\upsilon = -\frac{\epsilon_{lat}}{\epsilon_{ax}}$ No unit√

Poisson's ratio is the ratio of the lateral strain to the axial strain √when a sample is under compression.

2.2 If the fault has a friction angle of 30° and cohesion of 2.0 MPa, comment on its stability at Point 1. Show all calculations. (10 marks)

Rotation angle = -70° ✓✓

Use eq $\sigma_n = \sigma_1 cos^2\theta + \sigma_2 sin^2\theta$ or $\sigma_n = \frac{1}{2}(\sigma_1 + \sigma_2) + \frac{1}{2}(\sigma_1 - \sigma_2)cos2\theta$ to determine the normal stress on the fault plane:

σ_n = 51.7 MPa ✓✓ **σ_{mm} = 128.3 MPa**

Use $\tau_{nm} = -\frac{1}{2}(\sigma_1 - \sigma_2)sin2\theta$ to determine the driving shear stress on the fault plane:

τ_m = 32.14 MPa ✓✓

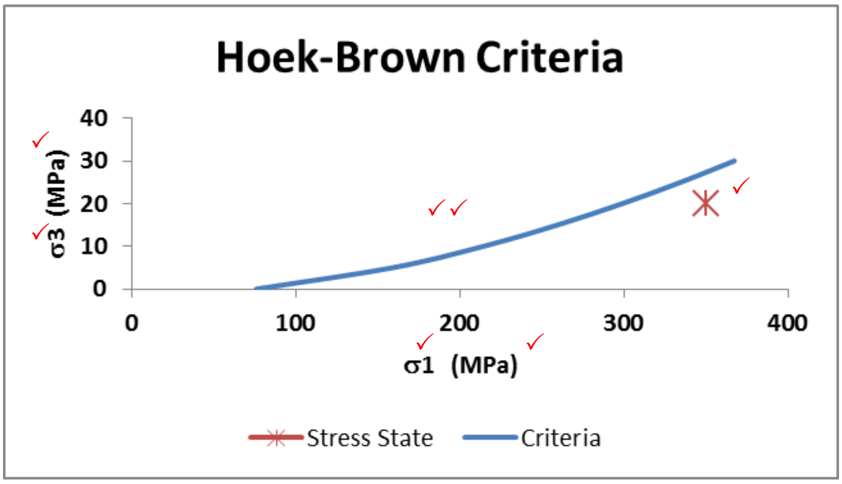
Use $\tau_n = c + \mu\sigma_n$ to determine maximum resisting shear stress on fault plane:

τ_{max} = 31.8 MPa ✓✓

Failure possible ✓**expected on the fault plane due to FOS at Point 1 appr. 1**✓

2.3 The rock mass has Hoek-Brown values of m = 15 and s = 0.1, while σ_c = 240 MPa. Plot the yield curve for this rockmass as well as the stress state at Point 2 and comment whether the rockmass should be in a state of failure or not. (10 marks)

Use Hoek-Brown formula $\sigma_1 = \sigma_3 + \sigma_c\sqrt{m\frac{\sigma_3}{\sigma_c} + s}$ ✓ to plot graph and plot stress condition.



No failure ✓**is expected as the stress state plot below the graph.**✓

QUESTION 3 – STRESS IN ROCK AND ROCKMASSES **(25 MARKS)**

Two circular excavations are to be bored in an elastic, homogeneous and isotropic rockmass.

3.1 As the acting rock engineer on the mine, name the equation or theory you would apply to determine the distance between the excavations to avoid stress interaction between the two excavations. (1 mark)

Kirch Eq or (3 times combined Diameter)✓

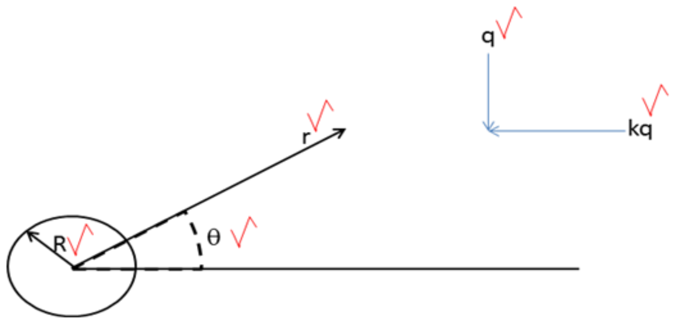
3.2 The radial and tangential stress regime around a tunnel is defined by the Kirsch equation. The respective equations are:

$$\sigma_\theta = \frac{1}{2}q(1+k)\left(1+\frac{R^2}{r^2}\right)+\frac{1}{2}q(1-k)\left(1+\frac{3R^4}{r^4}\right)Cos2\theta$$

and

$$\sigma_r = \frac{1}{2}q(1+k)\left(1-\frac{R^2}{r^2}\right)-\frac{1}{2}q(1-k)\left(1-\frac{4R^2}{r^2}+\frac{3R^4}{r^4}\right)Cos2\theta$$

The input parameters for the calculation include k, q, R, r and θ. Explain these input parameters by means of a sketch. (5 marks)



R = Radius of Excavation√

r = Distance to point where stresses will be calculated√

θ = angle between the horisontal axis an r√

q = vertical virgin stress√

kq = horizontal vergin stress (k ratio x vertical stress) √

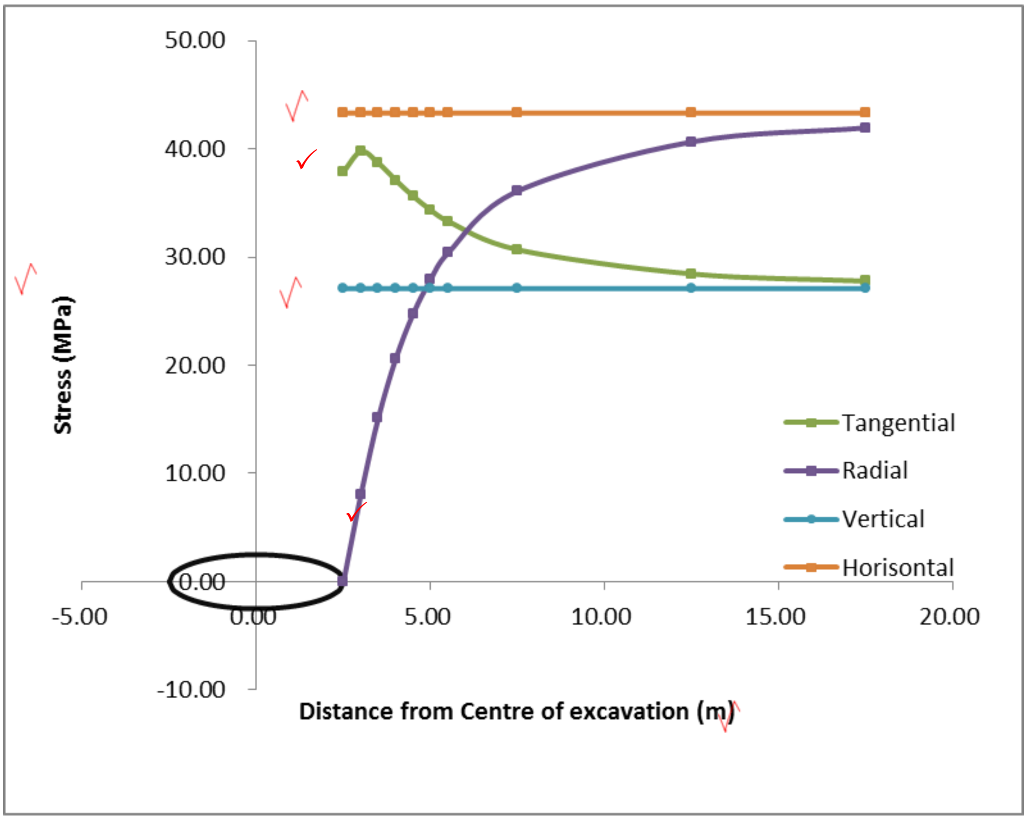
3.3 The tunnel to be bored is 5 m in diameter. Determine the tangential and radial stresses in the sidewall at 1000 m below surface. The rock has a uniaxial strength of 180 MPa and a relative density of 2,76. Assume gravitational acceleration as 9,81 m/s^2. The calculated k ratio in this area of the mine is 1,6. Reproduce and complete the table below. (4 marks)

Distance into Sidewall	σ_θ	σ_r
0.0	37.91	0.00
0.5	39.77	8.07
1.0	38.69	15.13
1.5	37.11	20.60
2.0	35.62	24.75
5.0	30.69	36.10
10.0	28.44	40.65
15.0	27.78	41.95

3.3.1 Plot the stress in relation to the distance into the sidewall for both the radial and tangential stresses. In addition to these two stresses, also indicate the value of the vertical and horizontal stresses when applying Heim's Rule.

(6 marks)

Heim's Rule => $\sigma_v = \rho g h$ = 27.08 MPa and σ_h = 43.32 MPa



3.3.2 On viewing the results from your graph, express your opinion with regards to the validity of the rule of thumb that suggests the spacing of two excavations should not be less than three time the combined width of the excavations. (2 marks)

Valid rule✓.

At three times the excavation diameter the radial and tangential stress return to the original levels.✓

3.3.3 Explain how you would determine the principle stresses at this point and then calculate the principle stresses. (5 marks)

Far enough✓ into the sidewall the Kirsch equation will return virgin stress conditions. Given the conditions and calculating the stress 25m into the sidewall will result in these stresses. In the sidewall the tangential stress will relate to the vertical stress ✓and the radial stress will relate to the horizontal stress✓. Hence

σ_r = 42.76 MPa ✓

σ_θ = 27.36 MPa ✓

3.3.4 Calculate the tangential and radial stresses on the side of the excavation in hangingwall. (2 marks)

θ = 90°

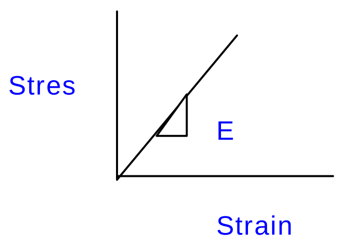
σ_r = 0.0 MPa ✓

σ_θ = 80.13 MPa ✓

QUESTION 4 – ROCK ENGINEERING THEORY (25 MARKS)

4.1 Explain each of the following terms by utilising sketches and formulae (where appropriate) and give examples of how and where they can impact on rock engineering design.

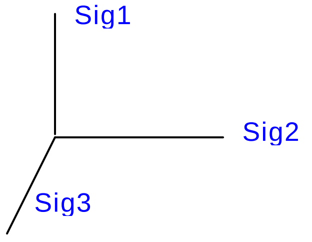
4.1.1 Elastic modulus (3 marks)



- Young's Modulus – slope of stress-strain graph
- Stiffness of material
- Numerical models – used to estimate deformation

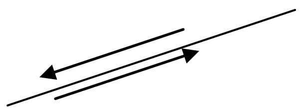
- Lower E allows more rock mass deformation, higher E less deformation

4.1.2 Principal stress (3 marks)



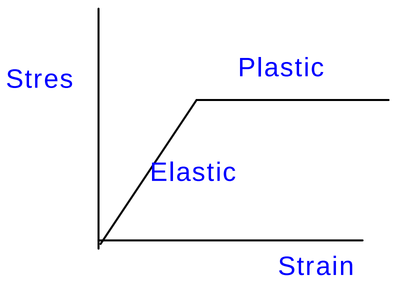
- Stress field at zero shear stress
- Consists of 3 parts in an 3D field, namely sigma 1, sigma 2 and sigma3 90 deg apart in direction
- High stress levels induce rock failure and interaction between underground excavations
- Direction of principal stresses impact on excavation design
- Ratios between the three stress directions impact on excavation design
- Impact on seismic activity

4.1.3 Shear stress (3 marks)



- Stress parallel to a plane or
- Function of large normal stresses where shear stress = 0.5 (sigma 1 – sigma 2)
- Induces shear deformation on a plane
- Support design in jointed rock requires analysis of shear strength of joint and shear and normal stress to the joint
- Seismic activity is also a function of shear stress ahead of the face or on faults.

4.1.4 Elasto-plastic behaviour (2 marks)



- Stress – strain behaviour that describes behaviour of rock as first elastic and then plastic;
- Used as constitutive law governing rock behaviour

4.2 Explain the following concepts, listing the limitations and areas of appropriate application in each case (provide sketches, examples and where appropriate, formulae or equations).

4.2.1 RCF (4 marks)

- $RCF = \frac{3(\sigma_1 - \sigma_3)}{F\,\sigma_c}$

- Stress / strength relationship describing failure around tunnels
- Caters for a 2D analysis of a tunnel (plane stress)
- Stresses used must be principal perpendicular to tunnel perimeter and not principal in any other direction
- Developed for circular tunnels
- Caters for impact of geology on failure through factor F
- Not applicable to environments where failure is governed by geology and not stress

4.2.2 ERR (4 marks)

- Energy release rate – usually calculated with 0.5*(stress x closure) by numerical models used to indicate areas of high ERR
- These areas of high ERR are viewed as high risk to seismic activity
- Utilised in deep level longwall mines to estimate energy levels available for release in seismic activity
- Energy is available due to rock deformation by stress (E= F x s = work done)
- Concept not so applicable to deeper scattered mining environments due to seismic activity governed by geological structures and impact of geological losses on reducing stress levels and thus indicating lower ERR while risk is still high

4.2.3 ESS (3 marks)

- Excess shear stress
- ESS = Shear stress – shear strength where shear strength is given by Cohesion + σ_n x Tan (friction angle)
- Used to indicate the risk to failure on a surface or plane
- Calculate potential for seismic activity on fault / dyke planes
- Difficult to use in actual terms as cohesion and friction angles of planes must be estimated
- Used to calculate potential seismic event magnitude

4.2.4 RMR (3 marks)

- Rock mass rating of Bienawski
- Used to calculate quality of rock material based on rock strength, RQD, joint spacing, joint condition and groundwater
- Can cater for joint orientation in tunneling
- Used from borehole core logging

- Used to calculate Hoek and Brown parameters for failure analysis
- Does not directly cater for stress levels as intended initially for civil use
- Can be used to estimate stable spans, support types

Formula sheet

$$\sigma_n = \sigma_x Cos^2\theta + 2\tau_{xy} Sin\theta . Cos\theta + \sigma_y Sin^2\theta$$

$$\tau_{nm} = \frac{1}{2}(\sigma_y - \sigma_x) Sin2\theta + \tau_{xy} Cos2\theta$$

$$Tan2\theta = \frac{2\tau_{xy}}{(\sigma_x - \sigma_y)}$$

$$\sigma_{12} = \frac{1}{2}(\sigma_x + \sigma_y) \pm \frac{1}{2}\sqrt{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2)}$$

$$\varepsilon_n = \varepsilon_x Cos^2\theta + \gamma_{xy} Sin\theta . Cos\theta + \varepsilon_y Sin^2\theta$$

$$\sigma_n = \frac{1}{2}(\sigma_1 + \sigma_2) + \frac{1}{2}(\sigma_1 - \sigma_2).Cos2\theta$$

$$\tau_{nm} = -\frac{1}{2}(\sigma_1 - \sigma_2).Sin2\theta$$

$$\sigma_1 = \frac{E}{(1-v^2)}(\varepsilon_1 + v\varepsilon_2) \qquad \sigma_2 = \frac{E}{(1-v^2)}(\varepsilon_2 + v\varepsilon_1)$$

$$\sigma_x = \frac{E}{(1-v^2)}(\varepsilon_x + v\varepsilon_y) \qquad \sigma_y = \frac{E}{(1-v^2)}(\varepsilon_y + v\varepsilon_x)$$

$$\varepsilon_1 = \frac{1}{E}(\sigma_1 - v\sigma_2) \qquad \varepsilon_2 = \frac{1}{E}(\sigma_2 - v\sigma_1)$$

$$\varepsilon_x = \frac{1}{E}(\sigma_x - v\sigma_y) \qquad \varepsilon_y = \frac{1}{E}(\sigma_y - v\sigma_x)$$

$$\tau_{max} = \frac{1}{2}(\sigma_1 - \sigma_2)$$

$$s = e^{\frac{(RMR-100)}{6}}$$

$$\varepsilon_{12} = \frac{1}{2}(\epsilon_0 + \epsilon_{90}) \pm \frac{1}{2}\sqrt{(\varepsilon_0 - \epsilon_{90})^2 + (2\epsilon_{45} - \epsilon_0 - \epsilon_{90})^2}$$

$$Tan2\theta = \frac{2\epsilon_{45} - \epsilon_0 - \varepsilon_{90}}{(\epsilon_0 - \epsilon_{90})}$$

$$w = \frac{1}{2}(\sigma_1.\varepsilon_1 + \sigma_2.\varepsilon_2 + \sigma_3.\varepsilon_3)$$

$$Q = w.Volume$$

$$G = \frac{E}{2(1+v)} \qquad K = \frac{E}{3(1-2v)}$$

$$k = \frac{\sigma_h}{\sigma_v}$$

$$JCS_n = JSC_o \left(\frac{L_n}{L_o}\right)^{-0.03JRCo}$$

$$\sigma_r = \frac{1}{2}q(1+k)\left(1-\frac{R^2}{r^2}\right) - \frac{1}{2}q(1-k)\left(1-\frac{4R^2}{r^2}+\frac{3R^4}{r^4}\right)Cos2\theta$$

$$\sigma_\theta = \frac{1}{2}q(1+k)\left(1+\frac{R^2}{r^2}\right) + \frac{1}{2}q(1-k)\left(1+\frac{3R^4}{r^4}\right)Cos2\theta$$

$$\tau = C_0 + \mu\sigma_n$$

	Cantilever	Built-in both ends	Freely supported
Maximum deflection δ	$^3/_2\ \gamma L^4 / Et^2$	$^1/_{32}\ \gamma L^4 / Et^2$	$^5/_{32}\ \gamma L^4 / Et^2$

$$\sigma_1 = \sigma_3 + \sqrt{s\sigma_c^2 + m\sigma_c\sigma_3}$$

$$\sigma_c = 2C_0\sqrt{\beta_0}$$

$$JRC_o = \frac{(\alpha - \emptyset_r)}{Log_{10}\left(\frac{JCS_o}{\sigma_n}\right)} \qquad Sin\emptyset = \frac{\beta_0 - 1}{\beta_0 + 1}$$

$$m = 10 * e^{\frac{(RMR-100)}{14}}$$

$$C_0 = \frac{UCS}{2.\sqrt{\beta_0}} \qquad \sigma_h = \frac{v}{1-v}.\sigma_v$$

$$Tan\varphi = \beta_0 = \frac{1+Sin\emptyset}{1-Sin\emptyset} \qquad \sigma_n = \frac{m.g.Cos\alpha}{A}$$

$$JRC_n = JRC_o \left(\frac{L_n}{L_o}\right)^{-0.02JRCo}$$

$$sin\varphi_p = \frac{(2v_p - 1)}{(2v_p + 1)}$$

$$Q = \left(\frac{RQD}{J_n}\right) x \left(\frac{J_r}{J_a}\right) x \left(\frac{J_w}{SRF}\right) \qquad \tau = \sigma_n \cdot tan\left(\phi_b + JRC \cdot log_{10}\left(\frac{JCS}{\sigma_n}\right)\right)$$