UNISA university of south africa

EXAMINATION PAPER

SUBJECT:	EXAMINER:
CERTIFICATE IN ROCK MECHANICS PAPER 1 : ROCK ENGINEERING THEORY	JWL HANEKOM
SUBJECT CODE:	**MODERATOR:**
COMRME	DF Malan
EXAMINATION DATE:	**TOTAL MARKS:** [100]
NOVEMBER 2009	**PASS MARK:** 60%
TIME: 9:00 – 12:00	

NUMBER OF PAGES: 12

SPECIAL REQUIREMENTS:

1. **Answer *ALL* questions**
2. References other than those provided are not permitted.
3. Hand-held electronic calculators may be used.
4. Put 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.

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

ROCK ENGINEERING THEORY

QUESTION 1

Give an explanation of the following, making use of internationally accepted definitions, sketches, equations / formulae and standard rock engineering notations:

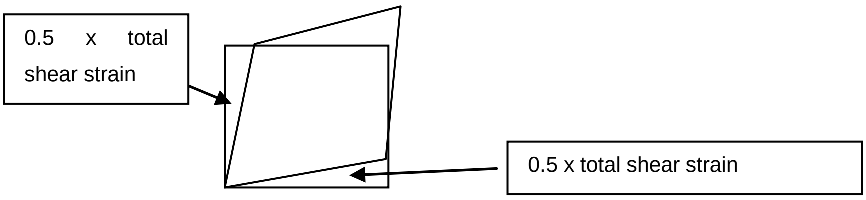
1.1 Elastic strain [2]

$$\varepsilon = \frac{Dimension\ original - Dimension\ new}{Dimension\ original}$$

Elastic strain is the ratio of the change in dimension to original dimension within the elastic range of rock behaviour and changes the dimensions or shape of a body. It has no unit but is normally expressed as 'mm/m'.

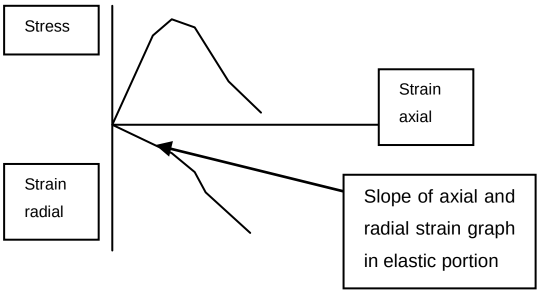
1.2 Elastic shear strain [3]

Shear strain changed the shape of a body and is measured as an angle in radians. Occurs when an element of a material is subjected to shear stress which causes a deviation in the right angle between two orthogonal unit vectors.



1.3 Poisson's Ratio [2]

Poisson's ratio is a material property that expresses the straining of a material under stress in two perpendicular directions, usually vertical and horizontal or the ratio of the lateral strain to the axial strain in a body under the influence of stress". It is calculated from $v = \left|\frac{\varepsilon\ axial}{\varepsilon\ radial}\right|$ as radial strain is often negative. It has no units.



1.4 Rock mechanics sign conventions for: [8]

- Co-ordinate system

Right hand co-ordinate system means positive z is up if fingers indicate positive x to positive y axis directions.

- Positive stress

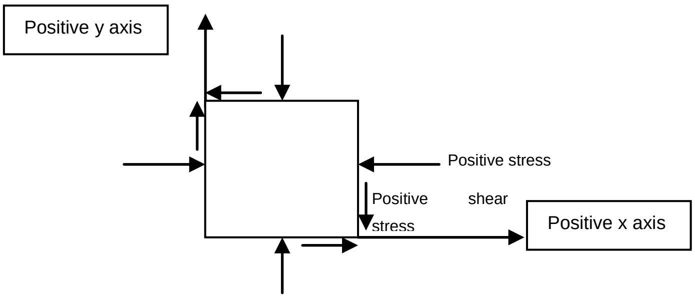
Compressive stress is positive and orientation is towards negative co-ordinate axis.

- Positive strain

Positive strain results in decreasing sample dimensions.

- Positive shear stress

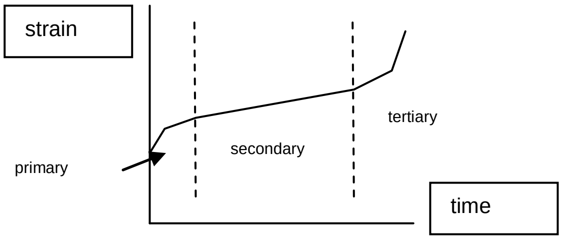
Positive shear stress rotates body towards origin on positive stress faces and away from origin on negative stress faces or On a positive surface (outward normal points in positive coordinate direction), the shear stresses acting against the positive coordinate direction are considered to be positive.



1.5 Creep by referring to:

- Definition and explanation

Time dependant deformation of rock material at a constant level of stress. Creep consists of three phases, primary, secondary and tertiary creep. Primary creep is a rapid increase in strain, which decreases and remains at a constant rate in the secondary phase and accelerated strain in the tertiary phase can lead to failure.



- Conditions that impact on creep and creep rate

  Stress levels

  Humidity

  Temperature

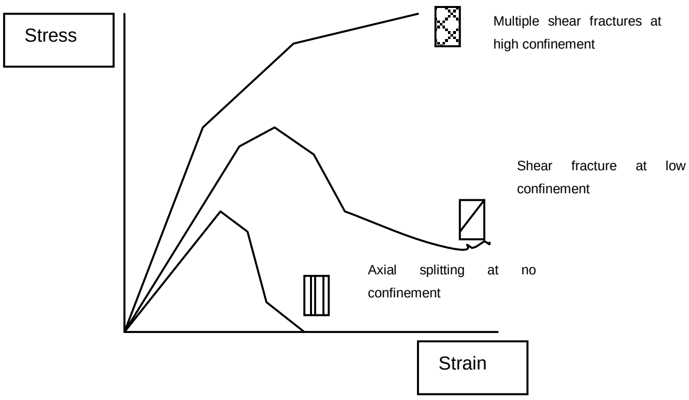
  Chemical bonds (Presence of chemicals that weaken the molecular bonds in the rock fabric) [5]

[20 MARKS]

QUESTION 2

Several rock samples from your mine are being tested in the laboratory until sample failure occurs.

2.1 Describe the modes of failure you would expect to see in samples tested under uni-axial and tri-axial conditions. Utilise a stress-strain curve to indicate the impact of increasing confinement on failure mode. [6]



At low confinement (UCS) the sample will tend to split along the edges of the sample, i.e. fractures parallel to the sample edges, especially if the platens are friction free and allows redial deformation of the whole sample.

As confinement increases, a shear fracture forms in the sample due to deviatoric stress conditions (difference between stresses applied). The sample fails along this plane.

At high confinement, deformation is difficult and failure occur as crushing of the sample as failure is induced along several flat dipping shear planes.

2.2 Give examples of underground conditions / situations where these sample failure modes can be observed and explain the underground mode of failure using your understanding of underground uni-axial and tri-axial loading conditions. [4]

Tunnel sidewalls are subjected to unconfined conditions and fracturing forms parallel to the tunnel sidewalls.

Shear fractures ahead of longwall mines are created when stress conditions provide some confinement, at points within the solid rock but not too close to mining excavations.

2.3 Several failure criteria are applied in rock engineering practice. Describe and explain the Mohr-Coulomb criterion by referring to (use graphs / sketches / equations to assist in the description):

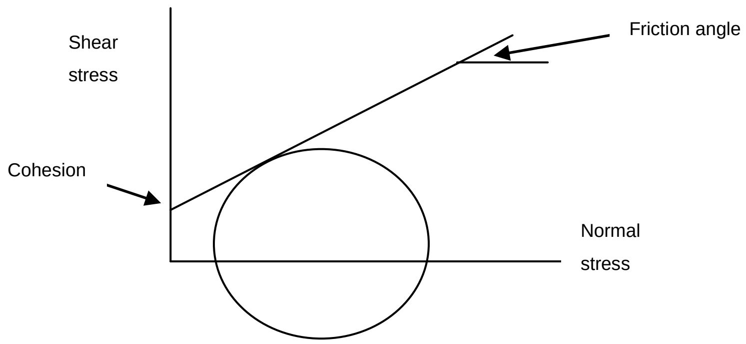
- Failure mechanism proposed in this criterion

Failure occurs in shear along a plane (pre-existing or newly formed) on which the shear stress exceeds the shear strength.

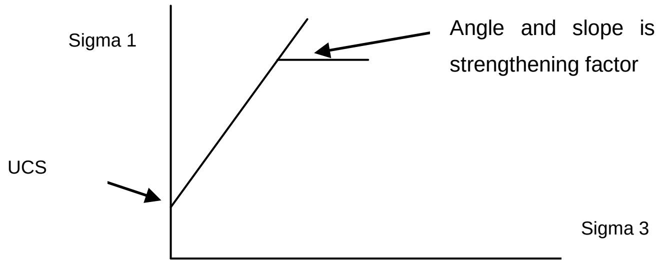
- The Mohr-Coulomb failure criterion in mathematical format

$\tau_{strength} = Cohesion + Tan\emptyset\,.\sigma_n$ where $\emptyset$ = internal friction angle and σ_n = stress normal to the failure plane.

- Presentation in shear stress / normal stress space showing all information that can be deduced from this presentation

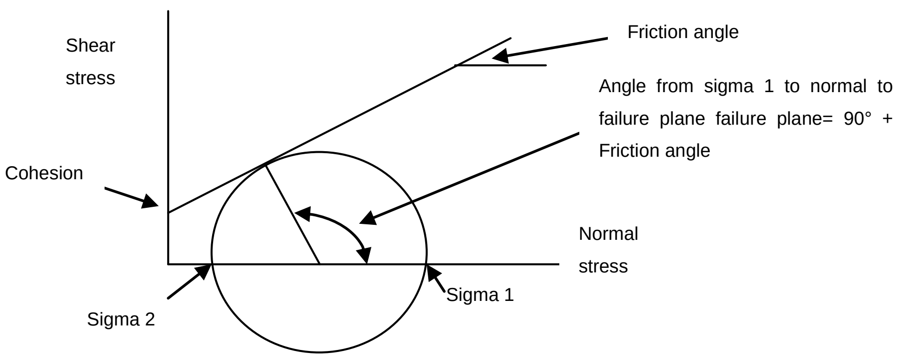


- Presentation in principal stress space showing all information that can be deduced from this presentation [10]



2.4 Prove, using the Mohr circle, that failure of an intact rock sample according to Mohr-Coulomb will create a shear plane that makes an angle of $(45° - \frac{\emptyset}{2})$, where $\emptyset$ is the material internal friction angle, with the major principal stress.

[5]



In Mohr circle all angles are 2 x diagram angle, thus

Angle between sigma 1 and normal to failure plane in diagram is (90°+ϕ) / 2 = 45°+ϕ/2. The failure plane will make a 90° angle with this normal, thus

Failure plane is (90° - (45°+ϕ/2)) = 45°-ϕ/2.

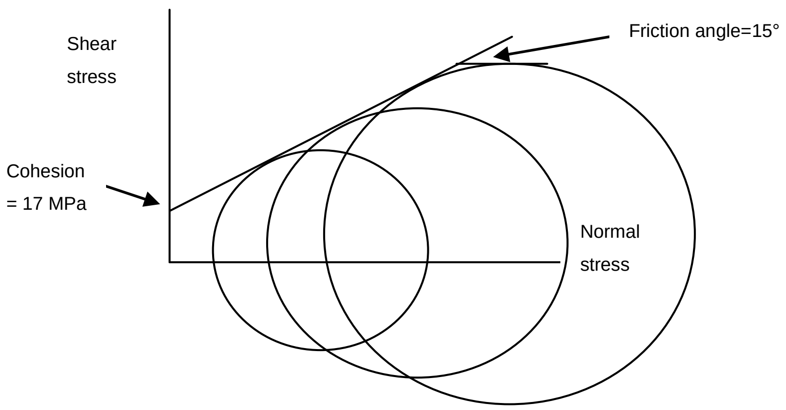
[25 MARKS]

QUESTION 3

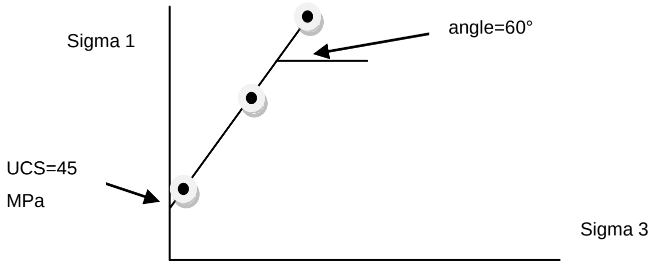
Apply the Mohr-Coulomb failure criterion by answering the following:

3.1 Samples of a specific rock type has been subjected to the application of stresses in tri-axial tests as shown below. Plot the stress conditions in shear stress / normal stress space to determine the internal friction angle and cohesion of the rock material. [4]

Major principal stress (MPa)	Confinement stress (MPa)
54	6
86	26
109	41



3.2 Plot the same stress conditions in principal stress space and confirm your results in 3.1 above by executing the necessary calculations to determine the internal friction angle and cohesion of the material. [6]



Using appropriate equations, friction angle and cohesion can be calculated.

$Tan\varphi = \frac{1+sin\emptyset}{1-sin\emptyset}$ - insert angle and solve for friction angle

Tan60 = (1+sinϕ)/(1-sinϕ)

1.73 = (1+sinϕ)/(1-sinϕ)

1.73-1.73Sinϕ = 1 + sinϕ

1.73-1 = 1.73sinϕ + sinϕ

0.73 = 2.73 Sinϕ

0.267 = sinϕ

ϕ = 15.5°

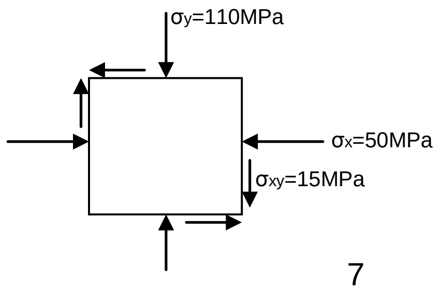
$\sigma c = \frac{2cCos\emptyset}{1-sin\emptyset}$ - insert UCS and friction angle calculated above and solve for Cohesion

45 = (2cCos15.5)/(1-sin15.5)

45 = 1.927c / 0.932

C = 17.1 MPa

3.3 The figure below represents the state of stress at a point in the rock mass. If the internal friction angle of the material is 21° and its cohesion 10MPa, perform the required calculations to determine whether this material will fail according to the Mohr-Coulomb failure criterion. [12]



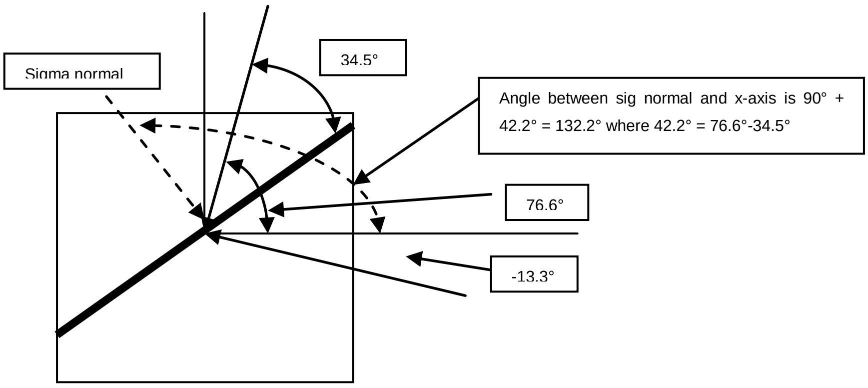
If it will fail according to MC, then a failure plane that makes an angle with 45°-friction angle / 2 with sigma 1. This plane is not given and must be found to solve the question. Thus, find direction of sigma 1, then measure the angle between sigma 1 and plane to get the failure plane and then solve for normal stress and shear stress on the plane to test against MC failure criterion.

Tan2θ=(2 x shear stress) / (sigx – sigy)

Tan2 θ = 30 / -60 = -0.5

2θ = -26.5° or 2 θ=153.4°

θ = -13.3° or θ = 76.6° (using signs in quadrants show that θ1=76.6° and θ2=13.3°)



Now, angle between sigma 1 and failure plane is (45°-ϕ/2) = 34.5°. Draw it in on the diagram and get the angle between sigma normal and x-axis = 132.2°.

Use appropriate equations, to calculate sigma normal and shear stress on plane using the 132.2°, sigma x, sigma y and shear stress given.

Sigma normal = sigx.$Cos^2\theta$ +2sigxy.Sin θ.Cos θ +sigy.Sin^2 θ = 67.99 MPa

Shear stress = ½(sigy – sigx)Sin2 θ+Sigxy.Cos2 θ = -31.3MPa

MC states that:

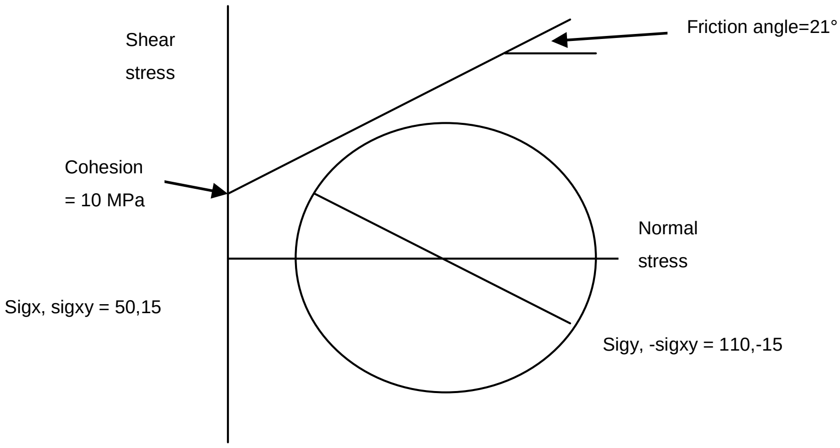
Shear strength = Cohesion + Tan ϕ.Sigma normal = 36.1 MPa

But

Shear stress = 31.3 MPa (sign only direction)

Thus no failure according to MC (strength > Stress)

3.4 Confirm your answer in 3.3 by representing the stress state on a Mohr circle together with the material properties in a shear stress / normal stress space presentation and indicating whether failure will occur or not. [6]



Plot sigx, sigy and sigxy as above, draw mohr circle and also line that represents failure envelope (friction angle, cohesion) and indicate that failure will not occur.

[28 MARKS]

QUESTION 4

A 50mm high, 32mm diameter rock sample taken from geological core is subjected to a 100kN force along the core axis. If the change in height due to the application of the force is 0.8mm and the increase in diameter 0.15mm, determine the following:

4.1 Material properties:

- Young's Modulus
- Poisson's ratio [6]

Area = 0.0008m2

Stress = 100kN/Area = 125 MPa

Strain axial = 0.8/50 = 0.016

Strain radial = -0.15 / 32 = -0.0047

Poisson's ratio = Abs value of (-0.0047/0.016)=0.294

Young's Modulus = stress axial / strain axial = 125MPa / 0.016 = 7.812 GPa

4.2 Elastic strain energy stored in the sample (note: assume horizontal stress is zero), using the results of 4.1. [3]

Strain energy density W = ½ (sig1.strain1) = ½(125MPa x 0.016) = 1 MJ/m3

Elastic strain energy stored in sample = volume x W = 0.0004m^3 x W = 40 J

4.3 How does this energy storage concept relate to the underground environment? [3]

Stresses underground deform rock material around the excavations and store energy within the rock mass. This energy can be transformed into heat, fracturing or seismic activity. The higher the stress levels are, the more strain energy is stored and the more fracturing, heat and seismic activity results, as experienced in the deep gold mines.

4.4 It is suggested that in a shallow mining environment, rock mass behaviour is very dependant on joint strength. Explain the impact of each of the following on joint strength:

- Friction angle

Increased friction angle would increase the shear strength as the resistance against shear increases. The friction angle is a function of the surface roughness and increased roughness would increase difficulty to shear. Extreme roughness would require shearing through intact rock and would also increase shear strength.

- Presence of water

Water reduced friction and adds pore pressure to a surface on which shear can take place. Reduction in friction reduces resistance against shear and pore pressure reduced normal stress on the plans and thus also improves the possibility of shear occurring.

- Infilling type

Soft infill types would significantly reduce friction on a plane as shearing surfaces of the wall rock does not come into contact. Very hard infill types also increase cohesion on the plane. Since shear strength is a function of both these parameters, it will be greatly affected by any changes in infill type.

- Normal stress to the joint

Normal stress to the joint clamps the shear plane and increases the shear strength. Extremely high normal stresses, can though, damage asperities and reduce shear strength as shown in the Barton joint strength criterion.

- Scale effect (joint length)

Increased joint lengths decreases parameters such as Jointwall Compressive strength and Joint roughness coefficient, as determined by Barton and Bandis who suggested that the JCS and JRC values should be downgraded as the length of the joint increases.

[10]

4.5 Explain how you would determine the strength of a significantly jointed rock mass to estimate failure under certain stress conditions (give criterion and explain how the necessary input parameters can be obtained). [5]

The most appropriate failure criterion for significantly jointed rock mass is the Hoek-Brown failure criterion. This criterion states that

$\sigma 1 = \sigma 3 + \sqrt{s.\sigma c^2 + m.\sigma c.\sigma 3}$ gives the strength of the significantly jointed rock mass.

The parameters in this criterion are:

Sig3 : measurement of stress

S: estimate from tables or determine from RMR

Sig c: Rock sample tests of the relevant rock material

M: estimate from tables or calculate from RMR and intact m.

[27 MARKS]