NAMIBIA UNIVERSITY
OF SCIENCE AND TECHNOLOGY

FACULTY OF ENGINEERING AND THE BUILT ENVIRONMENT
DEPARTMENT OF CIVIL MINING AND PROCESS ENGINEERING

QUALIFICATION : BACHELORS OF ENGINEERING IN MINING ENGINEERING	
QUALIFICATION CODE: 08BMIN	LEVEL: 7
COURSE CODE: REE720S	COURSE NAME: ROCK ENGINEERING
SESSION: NOVEMBER 2022	PAPER: THEORY
DURATION: 3 HOURS	MARKS: 100

SECOND OPPORTUNITY QUESTION PAPER	
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MODERATOR:	Prof. Mapani Benjamin

INSTRUCTIONS
1. Answer all questions.
2. Read all the questions carefully before answering.
3. Marks for each question are indicated at the end of each question.
4. Please ensure that your writing is legible, neat and presentable.

PERMISSIBLE MATERIALS

1. Examination paper.
2. Tracing paper
3. Mathematical Instruments

THIS QUESTION PAPER CONSISTS OF 08 PAGES (Including this front page)

Instructions: Answer Question 1 and any 4 other questions. Excess questions will not be marked.

Question 1 is compulsory.

Time allowed: 3 hours

<div align="center">

Question I (20)

Short answer questions

</div>

a) What is pulp density of backfill? [1]

b) Why is the extraction ratio maintained at less than 0.75 in room and pillar mining? [1]

c) What are the conditions for wedge failure [2]

d) How are the crown holes (subsidence) formed? [1]

e) What is the optimum pulp density with respect to slurry back fill? [1]

f) What is the function of rib pillar? [1]

g) What factors influence the amount of subsidence tilt? [3]

h) Which rockmass parameters influence the stability of slopes? [2]

i) What are the different types of toppling failure? [3]

j) Which is the cheapest of backfills used in underground mines? [1]

k) What type of test is used to measure the bearing capacity of rockbolt? [1]

l) What is the point of inflexion with respect to subsidence? [1]

m) The sliding plane must 'daylight' in the slope face. What does this statement mean? [1]

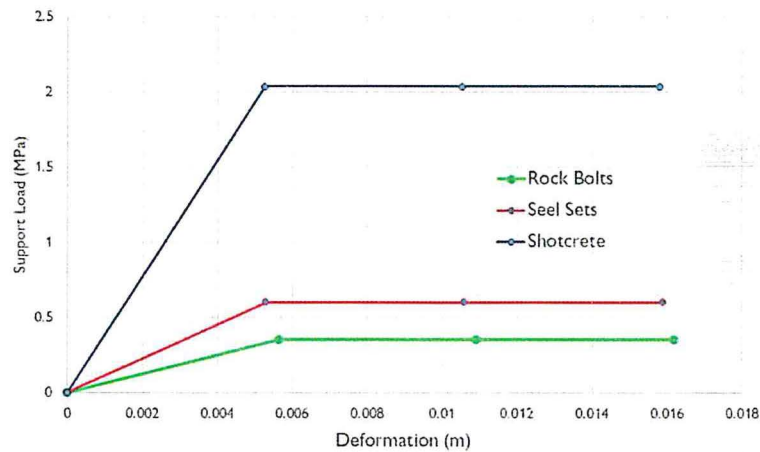n) Which one of these supports (rock bolts, steel sets and shotcrete) Figure 1 is stiffer?

Figure 1

Question II

a) A 2 m radius vertical shaft is to be excavated through a sandstone in which in situ stresses are 4 and 6 MPa. A vertical discontinuity at its closest point A, located a distance of 6 m from shaft wall. The discontinuity has Coulomb shear strength parameters C is 0.05 MPa, angle of internal friction (ϕ) is 20°. Determine the factor of safety of discontinuity at point B shown in Figure 2. (20)
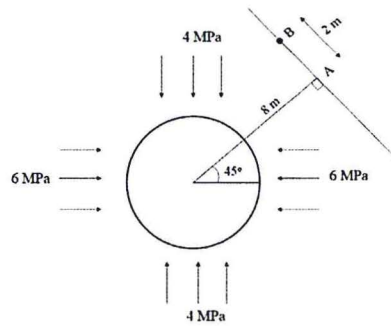

Figure 2

Question III

a) A metalliferous surface mine is operated with a bench as shown in Figure 3. The height of the bench is 10 m. The cohesion and angle of internal friction of failure plane are 15 kPa and 20° respectively. Density of water and the rockmass is 1000 kg/m³ and 3000 kg/m³ (29.43 kN/m²) respectively. Determine the effect water pressure in the crack on the factor of safety of the slope. (13)
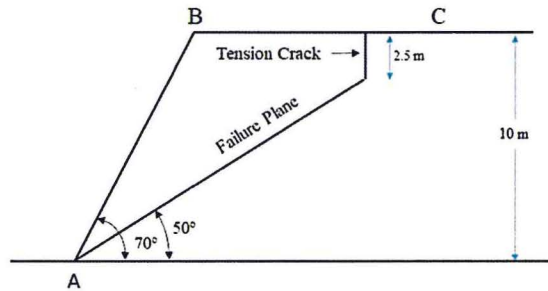

Figure 3

b) State the assumptions behind the derivation of Krisch equations used to determine stresses around underground openings. (7)

Question IV

a) Determine the subsidence tilt between the distance of 30-40 m from rib side under the following working conditions assuming that pre-subsidence profile is flat (10)
   - Depth of working 100 m
   - Length of panel 150 m
   - Mining height is 4 m

b) Briefly describe subsidence mechanism in high extraction mining (10)

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Question V

a)   A tunnel of 3 m radius excavated in a rock is subjected to a hydrostatic stress field of 10 MPa.   (20)
     Modulus of elasticity and Poisson's ratio of rockmass was estimated to be 600 MPa and 0.25
     respectively. Assuming cohesion and angle of internal friction of rockmass is 2.42 MPa and 30°
     i.   Estimate longitudinal deformation 2 m away from the tunnel face
     ii.   Determine the factor of safety of shotcrete applied on to the surface of the tunnel at 2 m away
           from tunnel face with following specifications

Concrete Young's Modulus (E_c) = 20.7 GPa
Poisson's Ratio(n) = 0.25
Lining thickness (t_c) = 0.3 m
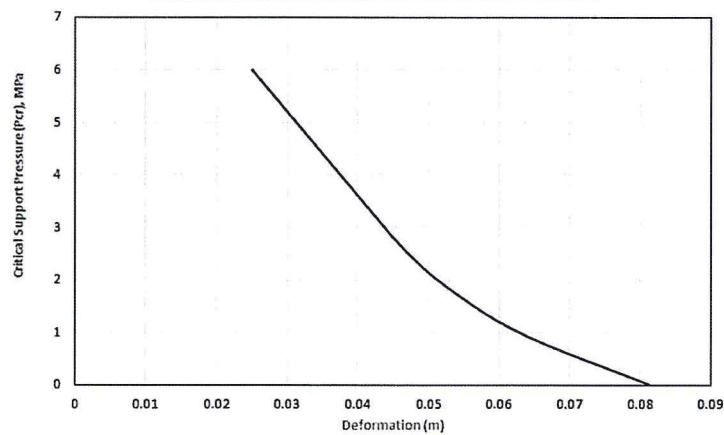Uniaxial compressive strength (s_{cc}) = 34.5 MPa

Figure 4: Tunnel support characteristics curve

Question VI

a)   What are the properties of backfill and how does pore pressure influences the stability of backfill?   (10)

b)   Compare mechanical anchored bolts with grouted rock bolts   (10)

Stresses around circular openings

$$\sigma_{rr} = \frac{p_0}{2}\left\{(1+k)\left(1-\frac{a^2}{r^2}\right) - (1-k)\left(1-4\frac{a^2}{r^2}+3\frac{a^4}{r^4}\right)\cos 2\theta\right\}$$

$$\sigma_{\theta\theta} = \frac{p_0}{2}\left\{(1+k)\left(1+\frac{a^2}{r^2}\right) + (1-k)\left(1+3\frac{a^4}{r^4}\right)\cos 2\theta\right\}$$

$$\tau_{r\theta} = \frac{p_0}{2}\left\{(1-k)\left(1+2\frac{a^2}{r^2}-3\frac{a^4}{r^4}\right)\sin 2\theta\right\}$$

Displacement around circular openings

$$u_r = \frac{p_0 a^2}{4Gr}\left\{(1+k)-(1-k)\left(4(1-v)-\frac{a^2}{r^2}\right)\cos 2\theta\right\}$$

$$u_\theta = \frac{p_0 a^2}{4Gr}\left\{(1-k)\left(2(1-2v)+\frac{a^2}{r^2}\right)\sin 2\theta\right\}$$

Stresses around circular openings with internal pressure

$$\sigma_{rr} = p_i + \frac{(p_o - p_i)}{2}\left\{(1+k')\left(1-\frac{a^2}{r^2}\right) - (1-k')\left(1-\frac{4a^2}{r^2}+3\frac{a^4}{r^4}\right)\cos 2\theta\right\}$$

$$\sigma_{\theta\theta} = p_i + \frac{(p_o - p_i)}{2}\left\{(1+k')\left(1+\frac{a^2}{r^2}\right) + (1-k')\left(1+3\frac{a^4}{r^4}\right)\cos 2\theta\right\}$$

$$\tau_{r\theta} = \frac{(p_o - p_i)}{2}\left\{(1-k')\left(1+\frac{2a^2}{r^2}-3\frac{a^4}{r^4}\right)\sin 2\theta\right\}$$

$$k' = \frac{kp_0 - p_i}{p_0 - p_i}$$

Stresses around circular openings **at infinite distance**

$$\sigma_{\theta\theta} = p_0[1 + k + 2(1-k)\cos 2\theta]$$

Stress transformation

$$\sigma_n = \frac{1}{2}(\sigma_{rr} + \sigma_{\theta\theta}) + \frac{1}{2}(\sigma_{rr} - \sigma_{\theta\theta})\cos 2\alpha + \tau_{r\theta}\sin 2\alpha$$

$$\tau_n = \tau_{r\theta}\cos 2\alpha - \frac{1}{2}(\sigma_{rr} - \sigma_{\theta\theta})\sin 2\alpha$$

Support System Characteristics

$$\sigma_c = \frac{2c\cos\phi}{1-\sin\phi} \qquad k = \frac{1+\sin\phi}{1-\sin\phi}$$

$$p_{cr} = \frac{2p_0 - \sigma_c}{1 + k}$$

Inward elastic displacement

$$u_{ie} = \frac{r_0(1 + v)}{E}(p_0 - p_i)$$

Radius of plastic zone around the tunnel

$$r_p = r_0 \left[\frac{2(p_0(k - 1) + \sigma_c)}{(1 + k)((k - 1)p_i + \sigma_c)} \right]^{\frac{1}{(k-1)}}$$

Total inward displacement

$$u_{ip} = \frac{r_0(1 + v)}{E} \left[2(1 - v)(p_0 - p_{cr})\left(\frac{r_p}{r_0}\right)^2 - (1 - 2v)(p_0 - p_i) \right]$$

Longitudinal displacement

Ratio of maximum plastic zone radius to tunnel radius

$$\frac{r_p}{r_0} = \left[\frac{2(p_0(k - 1) + \sigma_c)}{(1 + k)\sigma_c} \right]^{\frac{1}{(k-1)}}$$

Displacement at tunnel face

$$u_{if} = \left(\frac{u_{im}}{3}\right) e^{-0.15\left(\frac{r_p}{r_0}\right)}$$

Maximum displacement

$$u_{im} = \frac{r_0(1 + v)}{E} \left[2(1 - v)(p_0 - p_{cr})\left(\frac{r_p}{r_0}\right)^2 - (1 - 2v)p_0 \right]$$

The tunnel wall displacement ahead of the face (x < 0) is

$$u_i = u_{if} \, e^{x/r_0}$$

The tunnel wall displacement behind the face (x > 0) is

$$u_i = u_{im} - \left(u_{im} - u_{if}\right)e^{\frac{(-3x/r_0)}{(2r_p/r_0)}}$$

Rock Support Interaction

The displacement of the tunnel at support yield is given by

$$u_{iy} = u_{io} + \frac{p_{smax}}{K_s}$$

The factor of safety (FS) of the support

$$FS = \frac{p_{smax}}{p_{se}}$$

Steel Support

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$$p_{ssmax} = \frac{A_s \sigma_{ys}}{s_l r_0}; \quad K_{ss} = \frac{A_s E_s}{s_l r_0^2}$$

Shotcrete support

$$p_{scmax} = \frac{\sigma_{cc}}{2}\left[1 - \frac{(r_0 - t_c)^2}{r_0^2}\right]; \quad K_{sc} = \frac{E_c(r_0^2 - (r_0 - t_c)^2)}{2(1 - v^2)(r_0 - t_c)r_0^2}$$

Rock bolts

$$p_{sbmax} = \frac{T_{bf}}{s_l s_c}; \quad K_{sb} = \frac{E_s \pi d_b^2}{4l s_l s_c}$$

Pillar design

Average pillar stress

$$\sigma_p = \frac{\sigma_{zz}(w_0 + w_p)^2}{w_p^2}$$

Bearing capacity of **roof/floor with square pillar**

$$q_b = \frac{1}{2}\gamma w_p N_\gamma + c N_c$$

$$N_c = (N_q - 1)\cot\phi; \quad N_\gamma = 1.5(N_q - 1)\tan\phi; \quad N_q = e^{\pi \tan\phi}\tan^2\left[\left(\frac{\pi}{4}\right) + \left(\frac{\phi}{2}\right)\right]$$

Bearing capacity of roof/floor with rib pillar

$$q_b = \frac{1}{2}\gamma w_p N_\gamma S_\gamma + c\cot\phi\, N_q S_q - c\cot\phi$$

$$S_\gamma = 1 - 0.4\left(\frac{w_p}{l_p}\right); \quad S_q = 1 + \sin\phi\left(\frac{w_p}{l_p}\right)$$

Subsidence

Maximum subsidence

$$s_m = 0.39h\left(\frac{W}{H}\right)^{0.32}$$

Subsidence at a distance x from the rib side

$$S_x = 0.5S_m\left[\tanh\left(\frac{7x}{W} - 1.645\right) + 1\right]$$

Slope Stability

Planar slope failure

$$FoS = \frac{cA + w\cos\psi_p\tan\phi}{w\sin\psi_p}$$

Slope with Tension Crack in upper slope surface (**From equations**)

$$FoS = \frac{cA + (w.\cos\psi_p - U - V.\sin\psi_p)\tan\phi}{w.\sin\psi_p + V.\cos\psi_p}$$

$$A = \frac{(H - z)}{\sin\psi_p}; \quad U = \frac{\frac{1}{2}\gamma_w z_w (H - z)}{\sin\psi_p}; \quad V = \frac{1}{2}\gamma_w z_w^2$$

Weight of sliding block (Slope with Tension Crack in upper slope surface)

$$W = \frac{1}{2}\gamma H^2 \left\{ \left(1 - (z/H)^2\right)\cos\psi_p - \cos\psi_f \right\}$$

Weight of sliding block (Slope with Tension Crack in a slope face)

$$W = \frac{1}{2}\gamma H^2 \left\{ \left(1 - (z/H)^2\right)\cos\psi_p (\cot\psi_p . \tan\psi_f - 1) \right\}$$

Factor of safety of the slope in dimensionless form (from Figures)

$$F = \frac{(2c/\gamma H).P + \left(Q.\cot\psi_p - R(P + S)\right)\tan\phi}{Q + R.S\cot\psi_p}$$

$$P = \frac{(1 - z/H)}{\sin\psi_p}; \quad R = \frac{\gamma_w}{\gamma}.\frac{z_w}{z}.\frac{z}{H}; \quad S = \frac{z_w}{z}.\frac{z}{H}.\sin\psi_p$$

Slope with Tension Crack in the upper slope surface

$$Q = \left\{ \left(1 - (z/H)^2\right)\cos\psi_p - \cos\psi_f \right\}\sin\psi_p$$

Slope with Tension Crack in the slope face

$$Q = \left\{ \left(1 - (z/H)^2\right)\cos\psi_p (\cot\psi_p . \tan\psi_f - 1) \right\}$$