



**FACULTY OF ENGINEERING AND THE ENVIRONMENT  
DEPARTMENT OF MINING ENGINEERING**

**ROCK ENGINEERING  
EMI 5101**

**Final Examination Paper  
SEPTEMBER 2024**

**Time Allowed:** 3 hours  
**Total Marks:** 100  
**Examiner's Name:** Mr. T. Dombo

**INSTRUCTIONS**

1. This paper contains **TWO** sections with **SIX** questions.
2. Answer **ALL QUESTIONS IN SECTION A** and **any other THREE** questions from **SECTION B**.
3. Each question carries **20 marks**.
4. Where a question contains subdivisions, the mark value of each subdivision is shown in brackets.
5. Illustrate your answer, where appropriate, with large clearly labelled diagrams.
6. Start each question on a new page.
7. This paper comprises 9 printed pages.

**Additional Requirements**

- Calculator
- Graph paper
- Formula Booklet

**MARK ALLOCATION**

<b>Question 1 to 6</b>	<b>20 Marks</b>
<b>Part Questions</b>	<b>As shown in each part question</b>
<b>Total Attainable</b>	<b>100</b>

## **Section A: ANSWER ALL QUESTIONS**

### **Question 1**

- a) Describe the importance of rock mass characterization in rock engineering projects. [10]
- b) How can the results of rock mass characterization be integrated into numerical modelling and stability analyses? [10]

### **Question 2**

- a) Describe the different failure modes that can occur in a rock slope. [6]
- b) A rock slope has the following characteristics:
- Slope height (H) = 50 m
  - Slope angle ( $\beta$ ) =  $55^\circ$
  - Failure plane angle ( $\alpha$ ) =  $40^\circ$
  - Persistence of the failure plane = 90%
  - Unit weight of the rock mass ( $\gamma$ ) = 26 kN/m<sup>3</sup>
  - Cohesion of the rock mass (c) = 0.4 MPa
  - Friction angle of the rock mass ( $\varphi$ ) =  $32^\circ$

Calculate the factor of safety against planar failure for the given rock slope using the limit equilibrium method. [10]

- c) Discuss the influence of discontinuities, such as joints and faults, on the stability of rock slopes. [4]

## **Section B: ANSWER ANY THREE QUESTIONS**

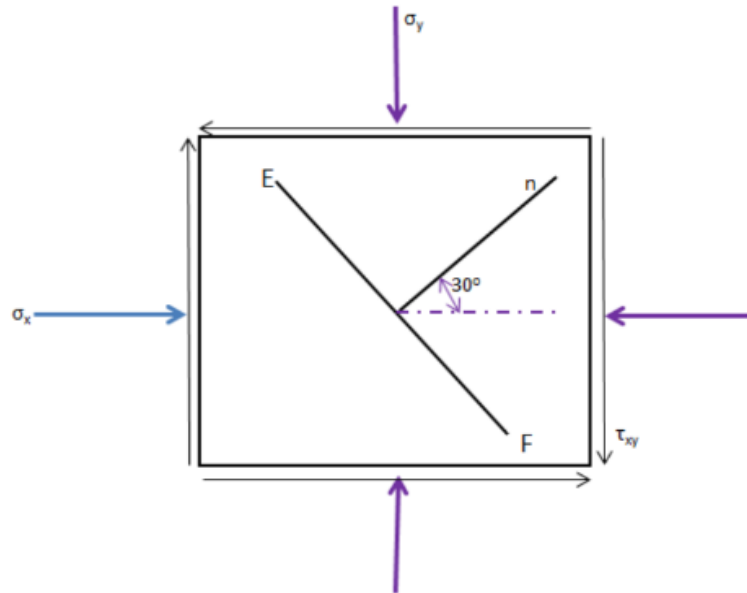
### **Question 3**

- a) Describe the different types of rock reinforcement techniques used in underground excavation. [8]
- b) Discuss the key considerations in the design of rock support systems for underground mines. [6]
- c) Discuss the challenges and strategies for rock tunnelling in difficult ground conditions. [6]

### Question 4

The element shown below is subjected to triaxial loading with stress components given

$$\sigma_x = 12\text{MPa} \quad \sigma_y = 20\text{MPa} \quad \tau_{xy} = 8\text{MPa}$$



- Construct the Mohr's Circle diagram representing this state of stress. [6]
- Determine from the diagram the magnitude of the principle stresses and the inclination of the principle axis relative to the x reference direction. [4]
- Determine from the diagram the normal and shear stress components  $\sigma_x$  and  $\tau_{mm}$  on the EF plane oriented as shown. [4]
- State any three (3) purposes of underground mine pillars. [3]
- State five (5) uses of backfill material in underground mining operations. [3]

### Question 5

- Using Barton's Q system tables (Appendix A), calculate the Q value given the following information:
  - RQD = 88%
  - Joint set number = 3 sets
  - Joint roughness number = rough stepped (undulating)
  - Joint alteration number = unaltered, some stains
  - Joint water factor = dry excavation or minor inflow
  - Uniaxial compressive strength  $\sigma_c = 185$  MPa

- Major principal stress  $\sigma_1 = 5.4$  MPa

[10]

- b) The Q value from the previous question depicts the rock mass condition at Kangaroo mine in Gurube. An underground crusher chamber of dimensions 10.5 m width  $\times$  8 m height is to be excavated in one of the deeper levels of the mine. Using Barton's Support Chart (Appendix B), estimate the permanent and temporary support requirements for both the roof and walls of this excavation.

[10]

**NB: Attach the chart to your answer booklet.**

### **Question 6**

- a) Discuss the potential geological hazards that can impact rock engineering projects. [8]
- b) Explain the risk assessment and mitigation strategies employed in the design and construction of rock engineering structures. [8]
- c) How would you incorporate monitoring and early warning systems to manage geological risks during the operational phase of a rock engineering project? [4]

[3]

**Good luck!!!!!!!!!!!!!!!!!!!!!!!!!!!!**

**APPENDIX A: BARTON'S Q SYSTEM TABLES**

**APPENDIX A-1**

DESCRIPTION	VALUE	NOTES	
<b>1. ROCK QUALITY DESIGNATION</b>	<b><i>RQD</i></b>		
A. Very poor	0 - 25	1. Where <i>RQD</i> is reported or measured as $\leq 10$ (including 0), a nominal value of 10 is used to evaluate <i>Q</i> .	
B. Poor	25 - 50		
C. Fair	50 - 75	2. <i>RQD</i> intervals of 5, i.e. 100, 95, 90 etc. are sufficiently accurate.	
D. Good	75 - 90		
E. Excellent	90 - 100		
<b>2. JOINT SET NUMBER</b>	<b><math>J_n</math></b>		
A. Massive, no or few joints	0.5 - 1.0		
B. One joint set	2		
C. One joint set plus random	3		
D. Two joint sets	4		
E. Two joint sets plus random	6		
F. Three joint sets	9	1. For intersections use $(3.0 \times J_n)$	
G. Three joint sets plus random	12		
H. Four or more joint sets, random, heavily jointed, 'sugar cube', etc.	15	2. For portals use $(2.0 \times J_n)$	
J. Crushed rock, earthlike	20		
<b>3. JOINT ROUGHNESS NUMBER</b>	<b><math>J_r</math></b>		
<b>a. Rock wall contact</b>			
<b>b. Rock wall contact before 10 cm shear</b>			
A. Discontinuous joints	4		
B. Rough and irregular, undulating	3		
C. Smooth undulating	2		
D. Slickensided undulating	1.5	1. Add 1.0 if the mean spacing of the relevant joint set is greater than 3 m.	
E. Rough or irregular, planar	1.5		
F. Smooth, planar	1.0		
G. Slickensided, planar	0.5	2. $J_r = 0.5$ can be used for planar, slickensided joints having lineations, provided that the lineations are oriented for minimum strength.	
<b>c. No rock wall contact when sheared</b>			
H. Zones containing clay minerals thick enough to prevent rock wall contact	1.0 (nominal)		
J. Sandy, gravely or crushed zone thick enough to prevent rock wall contact	1.0 (nominal)		
<b>4. JOINT ALTERATION NUMBER</b>	<b><math>J_a</math></b>	<b><math>\phi_r</math> degrees (approx.)</b>	
<b>a. Rock wall contact</b>			
A. Tightly healed, hard, non-softening, impermeable filling	0.75	1. Values of $\phi_r$ , the residual friction angle, are intended as an approximate guide to the mineralogical properties of the alteration products, if present.	
B. Unaltered joint walls, surface staining only	1.0		25 - 35
C. Slightly altered joint walls, non-softening mineral coatings, sandy particles, clay-free disintegrated rock, etc.	2.0		25 - 30
D. Silty-, or sandy-clay coatings, small clay-fraction (non-softening)	3.0		20 - 25
E. Softening or low-friction clay mineral coatings, i.e. kaolinite, mica. Also chlorite, talc, gypsum and graphite etc., and small quantities of swelling clays. (Discontinuous coatings, 1 - 2 mm or less)	4.0		8 - 16

## APPENDIX A-2

<b>4. JOINT ALTERATION NUMBER</b>	$J_a$	$\phi$ degrees (approx.)	
<b>b. Rock wall contact before 10 cm shear</b>			
F. Sandy particles, clay-free, disintegrating rock etc.	4.0	25 - 30	
G. Strongly over-consolidated, non-softening clay mineral fillings (continuous < 5 mm thick)	6.0	16 - 24	
H. Medium or low over-consolidation, softening clay mineral fillings (continuous < 5 mm thick)	8.0	12 - 16	
J. Swelling clay fillings, i.e. montmorillonite, (continuous < 5 mm thick). Values of $J_a$ depend on percent of swelling clay-size particles, and access to water.	8.0 - 12.0	6 - 12	
<b>c. No rock wall contact when sheared</b>			
K. Zones or bands of disintegrated or crushed rock and clay (see G, H and J for clay conditions)	6.0		
M. conditions)	8.0 - 12.0	6 - 24	
N. Zones or bands of silty- or sandy-clay, small clay fraction, non-softening	5.0		
O. Thick continuous zones or bands of clay	10.0 - 13.0		
P. & R. (see G.H and J for clay conditions)	6.0 - 24.0		
<b>5. JOINT WATER REDUCTION</b>	$J_w$	approx. water pressure (kgf/cm <sup>2</sup> )	
A. Dry excavation or minor inflow i.e. < 5 l/m locally	1.0	< 1.0	
B. Medium inflow or pressure, occasional outwash of joint fillings	0.66	1.0 - 2.5	
C. Large inflow or high pressure in competent rock with unfilled joints	0.5	2.5 - 10.0	1. Factors C to F are crude estimates; increase $J_w$ if drainage installed.
D. Large inflow or high pressure	0.33	2.5 - 10.0	
E. Exceptionally high inflow or pressure at blasting, decaying with time	0.2 - 0.1	> 10	2. Special problems caused by ice formation are not considered.
F. Exceptionally high inflow or pressure	0.1 - 0.05	> 10	
<b>6. STRESS REDUCTION FACTOR</b>		<b>SRF</b>	
<b>a. Weakness zones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated</b>			
A. Multiple occurrences of weakness zones containing clay or chemically disintegrated rock, very loose surrounding rock (any depth)	10.0		1. Reduce these values of SRF by 25 - 50% but only if the relevant shear zones influence do not intersect the excavation
B. Single weakness zones containing clay, or chemically disintegrated rock (excavation depth < 50 m)	5.0		
C. Single weakness zones containing clay, or chemically disintegrated rock (excavation depth > 50 m)	2.5		
D. Multiple shear zones in competent rock (clay free), loose surrounding rock (any depth)	7.5		
E. Single shear zone in competent rock (clay free). (depth of excavation < 50 m)	5.0		
F. Single shear zone in competent rock (clay free). (depth of excavation > 50 m)	2.5		
G. Loose open joints, heavily jointed or 'sugar cube', (any depth)	5.0		

## APPENDIX A-3

DESCRIPTION	VALUE		NOTES
<b>6. STRESS REDUCTION FACTOR</b>			<b>SRF</b>
<i>b. Competent rock, rock stress problems</i>			
	$\sigma_c/\sigma_1$	$\sigma_t/\sigma_1$	
H. Low stress, near surface	> 200	> 13	2.5
J. Medium stress	200 - 10	13 - 0.66	1.0
K. High stress, very tight structure (usually favourable to stability, may be unfavourable to wall stability)	10 - 5	0.66 - 0.33	0.5 - 2
L. Mild rockburst (massive rock)	5 - 2.5	0.33 - 0.16	5 - 10
M. Heavy rockburst (massive rock)	< 2.5	< 0.16	10 - 20
<i>c. Squeezing rock, plastic flow of incompetent rock under influence of high rock pressure</i>			
N. Mild squeezing rock pressure			5 - 10
O. Heavy squeezing rock pressure			10 - 20
<i>d. Swelling rock, chemical swelling activity depending on presence of water</i>			
P. Mild swelling rock pressure			5 - 10
R. Heavy swelling rock pressure			10 - 15

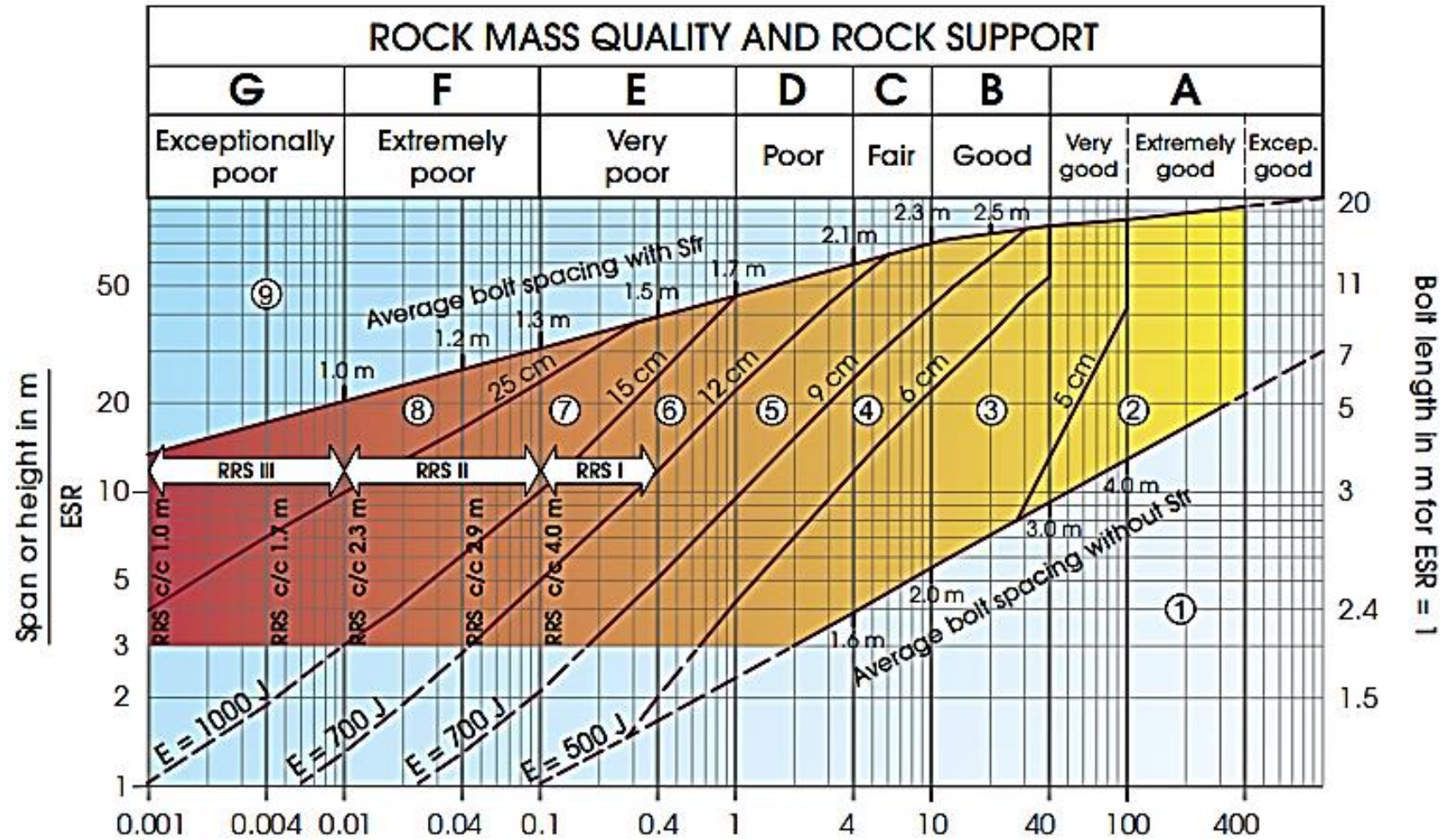
#### ADDITIONAL NOTES ON THE USE OF THESE TABLES

When making estimates of the rock mass Quality (Q), the following guidelines should be followed in addition to the notes listed in the tables:

1. When borehole core is unavailable, RQD can be estimated from the number of joints per unit volume, in which the number of joints per metre for each joint set are added. A simple relationship can be used to convert this number to RQD for the case of clay free rock masses:  $RQD = 115 - 3.3 J_v$  (approx.), where  $J_v$  = total number of joints per  $m^3$  ( $0 < RQD < 100$  for  $35 > J_v > 4.5$ ).
2. The parameter  $J_n$  representing the number of joint sets will often be affected by foliation, schistosity, slaty cleavage or bedding etc. If strongly developed, these parallel 'joints' should obviously be counted as a complete joint set. However, if there are few 'joints' visible, or if only occasional breaks in the core are due to these features, then it will be more appropriate to count them as 'random' joints when evaluating  $J_n$ .
3. The parameters  $J_r$  and  $J_a$  (representing shear strength) should be relevant to the weakest significant joint set or clay filled discontinuity in the given zone. However, if the joint set or discontinuity with the minimum value of  $J_r/J_a$  is favourably oriented for stability, then a second, less favourably oriented joint set or discontinuity may sometimes be more significant, and its higher value of  $J_r/J_a$  should be used when evaluating Q. The value of  $J_r/J_a$  should in fact relate to the surface most likely to allow failure to initiate.
4. When a rock mass contains clay, the factor SRF appropriate to loosening loads should be evaluated. In such cases the strength of the intact rock is of little interest. However, when jointing is minimal and clay is completely absent, the strength of the intact rock may become the weakest link, and the stability will then depend on the ratio rock-stress/rock-strength. A strongly anisotropic stress field is unfavourable for stability and is roughly accounted for as in note 2 in the table for stress reduction factor evaluation.
5. The compressive and tensile strengths ( $\sigma_c$  and  $\sigma_t$ ) of the intact rock should be evaluated in the saturated condition if this is appropriate to the present and future in situ conditions. A very conservative estimate of the strength should be made for those rocks that deteriorate when exposed to moist or saturated conditions.

## APPENDIX B: BARTON'S SUPPORT CHART

### APPENDIX B-1



## APPENDIX B-2

### Support categories

- ① Unsupported or spot bolting
- ② Spot bolting, **SB**
- ③ Systematic bolting, fibre reinforced sprayed concrete, 5-6 cm, **B+Sfr**
- ④ Fibre reinforced sprayed concrete and bolting, 6-9 cm, **Sfr (E500)+B**
- ⑤ Fibre reinforced sprayed concrete and bolting, 9-12 cm, **Sfr (E700)+B**
- ⑥ Fibre reinforced sprayed concrete and bolting, 12-15 cm + reinforced ribs of sprayed concrete and bolting, **Sfr (E700)+RRS I +B**
- ⑦ Fibre reinforced sprayed concrete >15 cm + reinforced ribs of sprayed concrete and bolting, **Sfr (E1000)+RRS II+B**
- ⑧ Cast concrete lining, **CCA** or **Sfr (E1000)+RRS III+B**
- ⑨ Special evaluation

Bolts spacing is mainly based on  $\varnothing 20$  mm

E = Energy absorption in fibre reinforced sprayed concrete

ESR = Excavation Support Ratio

Areas with dashed lines have no empirical data

**RRS** - spacing related to Q-value



**SI30/6  $\varnothing 16$  -  $\varnothing 20$  (span 10m)**

D40/6+2  $\varnothing 16$ -20 (span 20m)



SI35/6  $\varnothing 16$ -20 (span 5m)

**D45/6+2  $\varnothing 16$ -20 (span 10m)**

D55/6+4  $\varnothing 20$  (span 20m)



D40/6+4  $\varnothing 16$ -20 (span 5 m)

**D55/6+4  $\varnothing 20$  (span 10 m)**

Special evaluation (span 20 m)

SI30/6 = Single layer of 6 rebars,  
30 cm thickness of sprayed concrete

D = Double layer of rebars

$\varnothing 16$  = Rebar diameter is 16 mm

c/c = RSS spacing, centre - centre