FACULTY OF ENGINEERING AND THE ENVIRONMENT

DEPARTMENT OF MINING ENGINEERING

ROCK ENGINEERING

EMI 5101

Final Examination Paper

January 2021

This examination paper consists of 8 pages

Time Allowed: **3 hours**

Total Marks: **100**

Examiner's Name: **Mr. R Nyirenda**

INSTRUCTIONS

1. This paper contains **ONE** section with **FIVE** questions.
2. Answer **QUESTION ONE** and **any other THREE questions**.
3. Each question **carries 25 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 **8** printed pages.

Additional Requirements

Calculator

MARK ALLOCATION

Question 1 to 5	**25Marks**
Part Questions	**As shown in each part question**
Total Attainable	**100**

Question One

a) 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 σ_c = 185 MPa
   - Major principal stress σ_1 = 5.4 MPa

[10 marks]

b) The Q value from the previous question depicts the rock mass condition at Kangaroo mine in Guruve. An underground crusher chamber of dimensions 10.5 m width × 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.

[15 marks]

NB: Attach the chart to your answer booklet.

Question Two

a) Concerning discontinuities in any rock mass, briefly describe the influence of the following on shear strength of the discontinuities:
   i. Surface roughness. **[4 marks]**
   ii. Discontinuity scale. **[4 marks]**
   iii. Discontinuity infill. **[4 marks]**

b) Using stress-strain curves, explain the differences between ductile and brittle deformation. **[10 marks]**

c) Explain how the stress-strain curve can be used to design yielding pillars for deep underground mines. **[3 marks]**

Question Three

a) The density of a certain rock mass is 2.7 t/m³ with a *k* value of 0.75. If the depth of mining in the rock mass is at 650 m, calculate the following:
   i. Vertical in-situ stress **[3 marks]**
   ii. Horizontal in-situ stress **[2 marks]**

b) i. Briefly describe 5 factors that influence in-situ stresses in a rock mass. **[10 marks]**

ii. Specify, in detail, the typical steps that are followed in a stress measurement programme for mining depths > 1 000m. **[10 marks]**

Question Four

Nyati mine is a room and pillar metalliferous operation where the rock mass has a density of 3.0 t/ t/m³ and with an intact uniaxial compressive strength of 185 MPa. The depth of mining is at 350 m from the surface and the expected extraction ratio is 75%.

a) Using the tributary area method, calculate the pillar stress assuming that the mining layout is horizontal. **[6 marks]**

b) For an expected factor of safety value of 1.6 and stoping height of 4 m, determine the appropriate pillar width dimension. **[14 marks]**

NB: $Pillar\ Strength = DRMS\,.\frac{W^{0.5}}{H^{0.75}}$ (Equation 1)

c) Comment on the main limitation of using the tributary area method and Equation 1 to determine pillar width. Highlight a possible measure to mitigate this limitation.

[5 marks]

Question Five

a) Describe any 6 factors that contribute to instability of rock engineering structures. **[12 marks]**

b) Differentiate between the 2 principal classes of rock support (i.e., active and passive support). Indicate 3 examples of support elements for each of 2 classes of rock support.

[8 marks]

c) Recommend the appropriate rock support design approach for the following situations:
   i. During the exploration and feasibility study stages
   ii. During the later stages of the life of a mine.

[5 marks]

END OF EXAMINATION PAPER

APPENDIX A: BARTON'S Q SYSTEM TABLES

APPENDIX A-1

DESCRIPTION	VALUE		NOTES
1. ROCK QUALITY DESIGNATION	***RQD***		
A. Very poor	0 - 25		1. Where *RQD* is reported or measured as ≤ 10 (including 0),
B. Poor	25 - 50		a nominal value of 10 is used to evaluate Q.
C. Fair	50 - 75		
D. Good	75 - 90		2. *RQD* intervals of 5, i.e. 100, 95, 90 etc. are sufficiently
E. Excellent	90 - 100		accurate.
2. JOINT SET NUMBER	J_n		
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		
3. JOINT ROUGHNESS NUMBER	J_r		
a. Rock wall contact			
b. Rock wall contact before 10 cm shear			
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
E. Rough or irregular, planar	1.5		greater than 3 m.
F. Smooth, planar	1.0		
G. Slickensided, planar	0.5		2. J_r = 0.5 can be used for planar, slickensided joints having
c. No rock wall contact when sheared			lineations, provided that the lineations are oriented for
H. Zones containing clay minerals thick enough to prevent rock wall contact	1.0 (nominal)		minimum strength.
J. Sandy, gravely or crushed zone thick enough to prevent rock wall contact	1.0 (nominal)		
4. JOINT ALTERATION NUMBER	J_a	ϕr degrees (approx.)	
a. Rock wall contact			
A. Tightly healed, hard, non-softening, impermeable filling	0.75		1. Values of ϕr, the residual friction angle,
B. Unaltered joint walls, surface staining only	1.0	25 - 35	are intended as an approximate guide to the mineralogical properties of the
C. Slightly altered joint walls, non-softening mineral coatings, sandy particles, clay-free disintegrated rock, etc.	2.0	25 - 30	alteration products, if present.
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

4, JOINT ALTERATION NUMBER	J_a	ϕr degrees (approx.)	
b. Rock wall contact before 10 cm shear			
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	
c. No rock wall contact when sheared			
K. Zones or bands of disintegrated or crushed	6.0		
L. rock and clay (see G, H and J for clay	8.0		
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		
5. JOINT WATER REDUCTION	J_w	approx. water pressure (kgf/cm^2)	
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	
6. STRESS REDUCTION FACTOR		*SRF*	
a. Weakness zones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated			
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 dis-tegrated rock (excavation depth < 50 m)		5.0	
C. Single weakness zones containing clay, or chemically dis-tegrated 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
6. STRESS REDUCTION FACTOR			***SRF***	
b. Competent rock, rock stress problems				
	σ_c/σ_1	$\sigma_t\sigma_1$		2. For strongly anisotropic virgin stress field
H. Low stress, near surface	> 200	> 13	2.5	(if measured): when $5 \leq \sigma_1/\sigma_3 \leq 10$, reduce σ_c
J. Medium stress	200 - 10	13 - 0.66	1.0	to $0.8\sigma_c$ and σ_t to $0.8\sigma_t$. When σ_1/σ_3 > 10,
K. High stress, very tight structure	10 - 5	0.66 - 0.33	0.5 - 2	reduce σ_c and σ_t to $0.6\sigma_c$ and $0.6\sigma_t$, where
(usually favourable to stability, may				σ_c = unconfined compressive strength, and
be unfavourable to wall stability)				σ_t = tensile strength (point load) and σ_1 and
L. Mild rockburst (massive rock)	5 - 2.5	0.33 - 0.16	5 - 10	σ_3 are the major and minor principal stresses.
M. Heavy rockburst (massive rock)	< 2.5	< 0.16	10 - 20	3. Few case records available where depth of
c. Squeezing rock, plastic flow of incompetent rock				crown below surface is less than span width.
under influence of high rock pressure				Suggest *SRF* increase from 2.5 to 5 for such
N. Mild squeezing rock pressure			5 - 10	cases (see H).
O. Heavy squeezing rock pressure			10 - 20	
d. Swelling rock, chemical swelling activity depending on presence of water				
P. Mild swelling rock pressure			5 - 10	
R. Heavy swelling rock pressure			10 - 15	

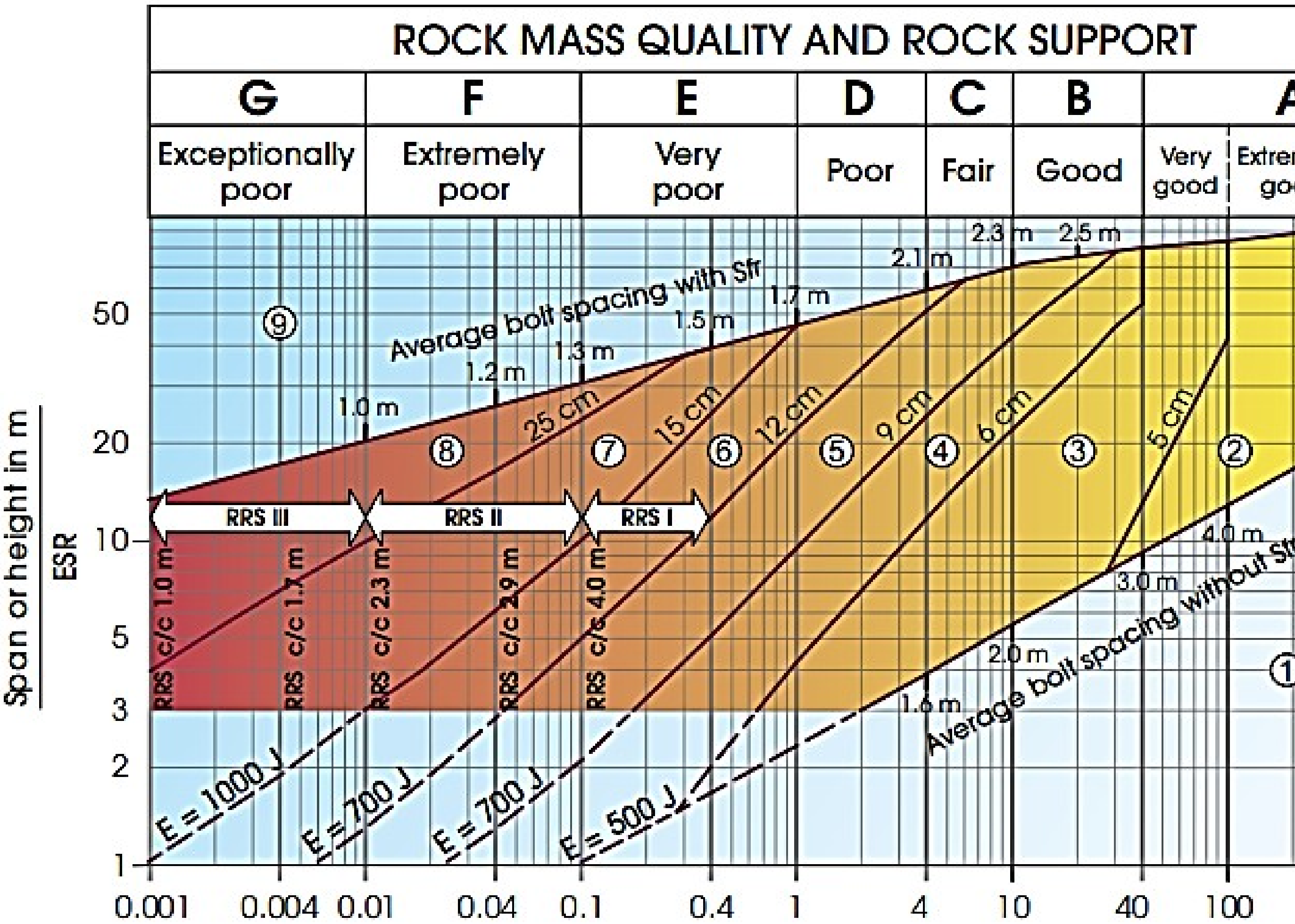
ADDITIONAL NOTES ON THE USE OF THESE TABLES

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 (σ_c and σ_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



ROCK MASS QUALITY AND ROCK SUPPORT
G
F
E
D
C
B
Exceptionally poor
Extremely poor
Very poor
Poor
Fair
Good
Very good
Average bolt spacing with Sfr
Average bolt spacing without Sfr
RRS III
RRS II
RRS I
25 cm
15 cm
12 cm
9 cm
6 cm
5 cm
E = 1000 J
E = 700 J
E = 700 J
E = 500 J
RRS c/c 1.0 m
RRS c/c 1.7 m
RRS c/c 2.3 m
RRS c/c 2.9 m
RRS c/c 4.0 m
Span or height in m / ESR
0.001
0.004
0.01
0.04
0.1
0.4
1
4
10
40
100

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 Ø20 mm

E = Energy absorbtion in fibre reinforced sprayed concrete

ESR = Excavation Support Ratio

Areas with dashed lines have no empirical data

RRS - spacing related to Q-value

I
Si30/6 Ø16 - Ø20 (span 10m)
D40/6+2 Ø16-20 (span 20m)

II
Si35/6 Ø16-20 (span 5m)
D45/6+2 Ø16-20 (span 10m)
D55/6+4 Ø20 (span 20m)

III
D40/6+4 Ø16-20 (span 5 m)
D55/6+4 Ø20 (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

Ø16 = Rebar diameter is 16 mm

c/c = RSS spacing, centre - centre