Minerals Council South Africa

EXAMINATION PAPER

SUBJECT: CERTIFICATE IN ROCK MECHANICS **PAPER 2:** BASIC ROCK MECHANICS PRACTICE **SUBJECT CODE: COMRMC** **DATE: 08 OCTOBER 2024** **TIME**: **14H30 TO 17H30**	**EXAMINER:** N Netshivhazwaulu **MODERATOR:** S Durapraj **TOTAL MARKS:** [100] **PASS MARK:** (60%)

NUMBER OF PAGES: 15

THIS IS NOT AN OPENBOOK EXAMINATION – ONLY REFERENCES PROVIDED ARE ALLOWED

SPECIAL REQUIREMENTS:

1. Answer all the questions in legible English.
2. Write your ID number on the outside cover of each script 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.
3. Show all calculations and check the calculations on which the answers are based.
4. Hand-held electronic calculators may be used for calculations. Reference notes may not be programmed into calculators.
5. Write legibly in black ink on the right-hand page only. Left-hand pages will not be marked.
6. Illustrate your answers using sketches or diagrams wherever possible.
7. Final answers must be given to an accuracy typical of practical conditions, however, be careful not to use too few decimal places during your calculations, as rounding errors may result in incorrect answers.

   NB: Ensure that the correct unit of measure (SI unit) is recorded as marks will be deducted if the incorrect unit is used even if the calculated value is correct.
8. In answering the questions, full advantage should be taken of your practical experience as well as the data given.
9. You are not allowed to contact your examiner or moderator regarding this examination.
10. Cell phones and other smart devices are not allowed in the examination room.

QUESTION 1. MINING LAYOUT, SUPPORT AND MONITORING

1.1. **Define** the following concepts which may be helpful to as stope/mine layout design criteria. a) Energy Release Rate (ERR) b) Excess Shear Stress (ESS) c) Volumetric Excess Shear stress (VESS) d) Face Shape Index (FSI)	(4)
1.2. Longwall mining configurations were introduced in a deep-level gold mine in the Witwatersrand Basin, South Africa, where depths exceed 2,000 meters. a) Provide (draw) an annotated diagram of a typical longwall mining configuration (5) b) Describe the advantages that longwall mining configurations have over scattered mining operations if practiced at depths below 2000m (4) c) Provide (draw) an annotated diagram depicting the principles associated with a scattered mining configuration when encountering a significant geological structure in order to manage the impact of seismicity and falls of ground. d) What are the typical practical problems associated with underhand mining configuration (**explain** three). (3)	(16)
1.3. During the full production of an underground mine, the mine uses range of support, which includes resin bolts, cable anchors, shotcrete & welded mesh, etc.. According to your legal appointment (Reg. 14.1 (6)), you are required to have a Mining Product Support Quality Assurance/Quality Control (QA/QC) strategy (from manufacture to installation). **Design** a support **QA/QC management strategy** or process for the mine. Provide an description of what that process will entail and **briefly describe** each phase or stage.	(10)
1.4.. Seismicity is experienced when mining at various depths and there is a need to establish monitoring systems. **Explain** what the primary objectives of establishing a seismic monitoring system are?	(5)
	[35]

QUESTION 2. GEOTECHNICAL INVESTIGATION AND STRUCTURAL GEOLOGY

A team of strata control officers has conducted detailed geotechnical mapping within a tunnel where a large (15mW x 13mH x 22mL) underground workshop is to be excavated using a conventional technique. The workshop will be located within the shaft pillar at a depth of 875m below the surface. The mapping revealed that the workshop is situated within a massive rock mass (UCS 220MPa) with prominent jointing. Three joint sets, including a 1,0 m thick shear zone, were identified during the mapping exercise.

Joint Set	Dip	Dip Dir	Joint Spacing		Condition
J1	75	306	mean	0,552	1-slightly smooth surface, undulating serpentine infill< 1mm 2- Rough Planner, No infill 3-Calcite infill >3mm Rough surface & undulating . (all surfaces were fresh) Shear Zone (shear planes & closely spaced joints, oriented the same as J3)
			SD	0,787	
J3	47	69	mean	0,22	
			SD	0,243	
J2	52	151	Mean	0,048	
			SD	0,068	

2.1. Describe five **objectives** of conducting rock mass classification. (2.5)

2.2. Discuss five common rock mass classification disadvantages. (5)

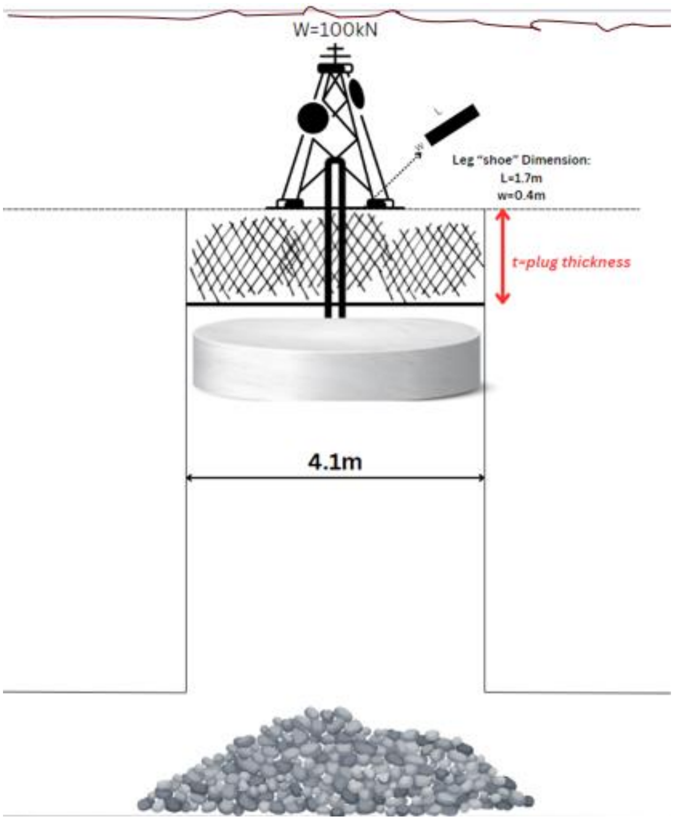
2.3. List five names of standard rock mass classification systems you know. Which rock mass classification system would you use for the provided scenario and why? (2.5)

2.4. Use the system chosen in **2.3** to **classify** the described rock mass. (5)

2.5. Which one of the three given joint sets has **the lowest** friction angle? Show all calculations. (5)

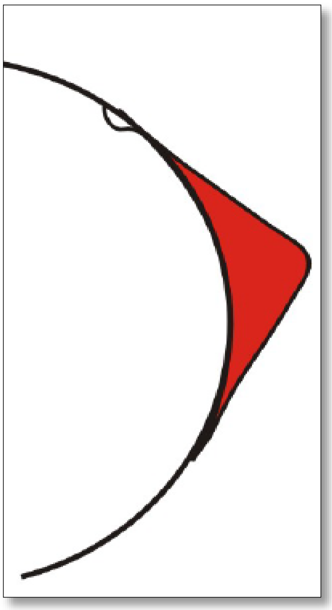
[20]

QUESTION 3. SHAFTS AND BEAM BEHAVIOUR `

3.1 Describe the concept of **beam behaviour** in rock mechanics. **List** and **briefly describe** the three typical beam types described in rock mechanics.	(8)
3.2. A vertical shaft is planned between two levels of an underground mechanised mine. The shaft is scheduled as one of the ventilation airways connecting the two levels and will be developed with a tunnel or raise boring machine. The Raise boring machine will be located on the top level, and during the reaming process, the machine will be positioned directly on top of the Raise/shaft. As drilling approaches completion, it is imperative to leave a plug to ensure the safe decommissioning of the raised boring equipment. The plug must possess specific characteristics: it must be thin enough to allow for effective drilling and blasting post-decommissioning of the Raise Boring Machine. However, it must also be thick enough to ensure stability and support the combined weight of the plug itself and machine weight. The machine's weight is documented as 100kN, evenly distributed across two shoes (footplate). The rock mass where the shaft is being developed is relatively good, without any structure cutting through. This rock type will only fail in tension. The rock's density is 2800kg/m3, and its tensile strength is 12Mpa.  	

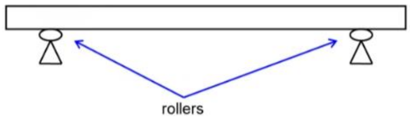
3.2.1. Describe the purpose of ventilation in a mine.	(3)
3.2.2. Which beam type/analyses is most appropriate for this application? Why?	(3)
3.2.3. Determine the thickness of the plug that will be required to yield **FOS of 2** given a maximum tensile stress on the plug of 5000kN/m^2 under the following conditions: a) There is no geological structure on the plug (3). b) There is a single geological structure on the plug, cutting vertically (3).	(6)
	[20]

QUESTION 4. NUMERICAL MODELLING AND REHABILITATION

4.1. Describe the relationship between numerical modelling and monitoring in rock mechanics.	(2)
4.2. Describe two shear-based failure criteria commonly applied in numerical modelling codes. **List** their limitations when applied to numerical modelling.	(6)
4.3. List 2 examples of FEM codes (2). **Describe** the basic theory of a Finite Element Method (FEM) or analysis (2), its application (2), and its limitations (2).	(8)
4.4. During an underground visit, you notice that a rock pass is damaged, as depicted below. Which failure criterion will you consider on the finite element model (FEM) to simulate the shape of damage depicted?  	(2)
4.5. What is the effect of Mesh/grid size during numerical modelling?	(2)
4.6. Over time and under high and/or variable stress conditions, shaft orepasses may degrade/spall and prevent the effective usage thereof. Although there are many methods to rehabilitate these orepasses**, describe 2 methods and briefly discuss the advantages and disadvantages of both.**	(5)
	[25]

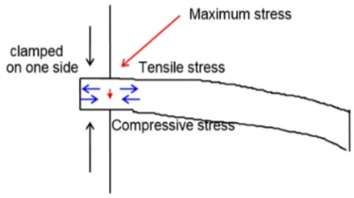
Total Marks = [100]

FORMULA SHEET



$\sigma_{max} = \dfrac{3.W.L^2}{4t^2}$ (centre) and $\tau_{max} = \dfrac{3.W.L}{2.t}$ (ends)

$\sigma_{max} = \dfrac{3.W.L^2}{t^2}$ and $\tau_{max} = \dfrac{3.W.L}{2.t}$



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

$$\sigma_1 = \sigma_c + \beta_o\sigma_3$$

$$\varepsilon_3 = \frac{\left[\sigma_3 - \nu\left(\sigma_1 + \sigma_2\right)\right]}{E}$$

$$\sigma_1 = \sigma_3 + \sigma_{ci}\left(m_b \frac{\sigma_3}{\sigma_{ci}} + s\right)^a$$

$$\sigma_1 = \sigma_3 + \sigma_{ci}\sqrt{m_i \frac{\sigma_3}{\sigma_{ci}} + 1}$$

$$\tau = C_o + \mu\sigma_n$$

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

$$\tau = \sigma' \tan\left(\phi + \text{JRC}\log_{10}\left(\frac{\text{JCS}}{\sigma'}\right)\right)$$

$$\phi_j \approx \tan^{-1}\left(\frac{J_r}{J_a}\right)$$

Appendix 1: Geotechnical Investigation

Table 1

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS									
	Parameter		Range of values						
1	Strength of intact rock material	Point-load strength index	>10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred		
		Uniaxial comp. strength	>250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa	1 - 5 MPa	< 1 MPa
	Rating		15	12	7	4	2	1	0
2	Drill core Quality *RQD*		90% - 100%	75% - 90%	50% - 75%	2% - 50%	< 25%		
	Rating		20	17	13	8	3		
3	Spacing of		> 2 m	0.6 - 2 . m	200 - 600 mm	60 - 200 mm	< 60 mm		
	Rating		20	15	10	8	5		
4	Condition of discontinuities (See E)		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensidd surfaces or Gouge 5 mm thick or Separaton 1 -5 mm Continuou	Soft gouge >5 mm thick or Separation > 5 mm Continuous		
	Rating		30	25	20	10	0		
5	Groundwater	Inflow per 10 m tunnel length (l/m)	None	< 10	10 - 25	25 - 125	> 125		
		(Joint water press)/ (Major principal σ)	0	< 0.1	0.1, - 0.2	0.2 - 0.5	> 0.5		
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
	Rating		15	10	7	4	0		

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)						
Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Ratings	Tunnels & mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS					
Rating	100 ← 81	80 ← 61	60 ← 41	40 ← 21	< 21
Class number	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. MEANING OF ROCK CLASSES					
Class number	I	II	III	IV	V
Average stand-up time	20 yrs for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 min for 1 m span
Cohesion of rock mass (kPa)	> 400	300 - 400	200 - 300	100 - 200	< 100
Friction angle of rock mass (deg)	> 45	35 - 45	25 - 35	15 - 25	< 15

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions					
Discontinuity length (persistence) Rating	< 1 m 6	1 - 3 m 4	3 - 10 m 2	10 - 20 m 1	> 20 m 0
Separation (aperture) Rating	None 6	< 0.1 mm 5	0.1 - 1.0 mm 4	1 - 5 mm 1	> 5 mm 0
Roughness Rating	Very rough 6	Rough 5	Slightly rough 3	Smooth 1	Slickensided 0
Infilling (gouge) Rating	None 6	Hard filling < 5 mm 4	Hard filling > 5 mm 2	Soft filling < 5 mm 2	Soft filling > 5 mm 0
Weathering Ratings	Unweathered 6	Slightly weathered 5	Moderately weathered 3	Highly weathered 1	Decomposed 0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING**			
Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45 - 90°	Drive with dip - Dip 20 - 45°	Dip 45 - 90°	Dip 20 - 45°
Very favourable	Favourable	Very unfavourable	Fair
Drive against dip - Dip 45-90°	Drive against dip - Dip 20-45°	Dip 0-20 - Irrespective of strike°	
Fair	Unfavourable	Fair	

Table 2

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)	

DESCRIPTION	VALUE	ϕr degrees (approx.)	NOTES
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	

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	

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 (if measured): when $5 \leq \sigma_1/\sigma_3 \leq 10$, reduce σ_c to $0.8\sigma_c$ and σ_t to $0.8\sigma_t$. When $\sigma_1/\sigma_3 > 10$, reduce σ_c and σ_t to $0.6\sigma_c$ and $0.6\sigma_t$, where σ_c = unconfined compressive strength, and σ_t = tensile strength (point load) and σ_1 and σ_3 are the major and minor principal stresses.
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	3. Few case records available where depth of crown below surface is less than span width. Suggest *SRF* increase from 2.5 to 5 for such cases (see H).
c. Squeezing rock, plastic flow of incompetent rock under influence of high rock pressure				
N. Mild squeezing rock pressure			5 - 10	
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.

Table 3

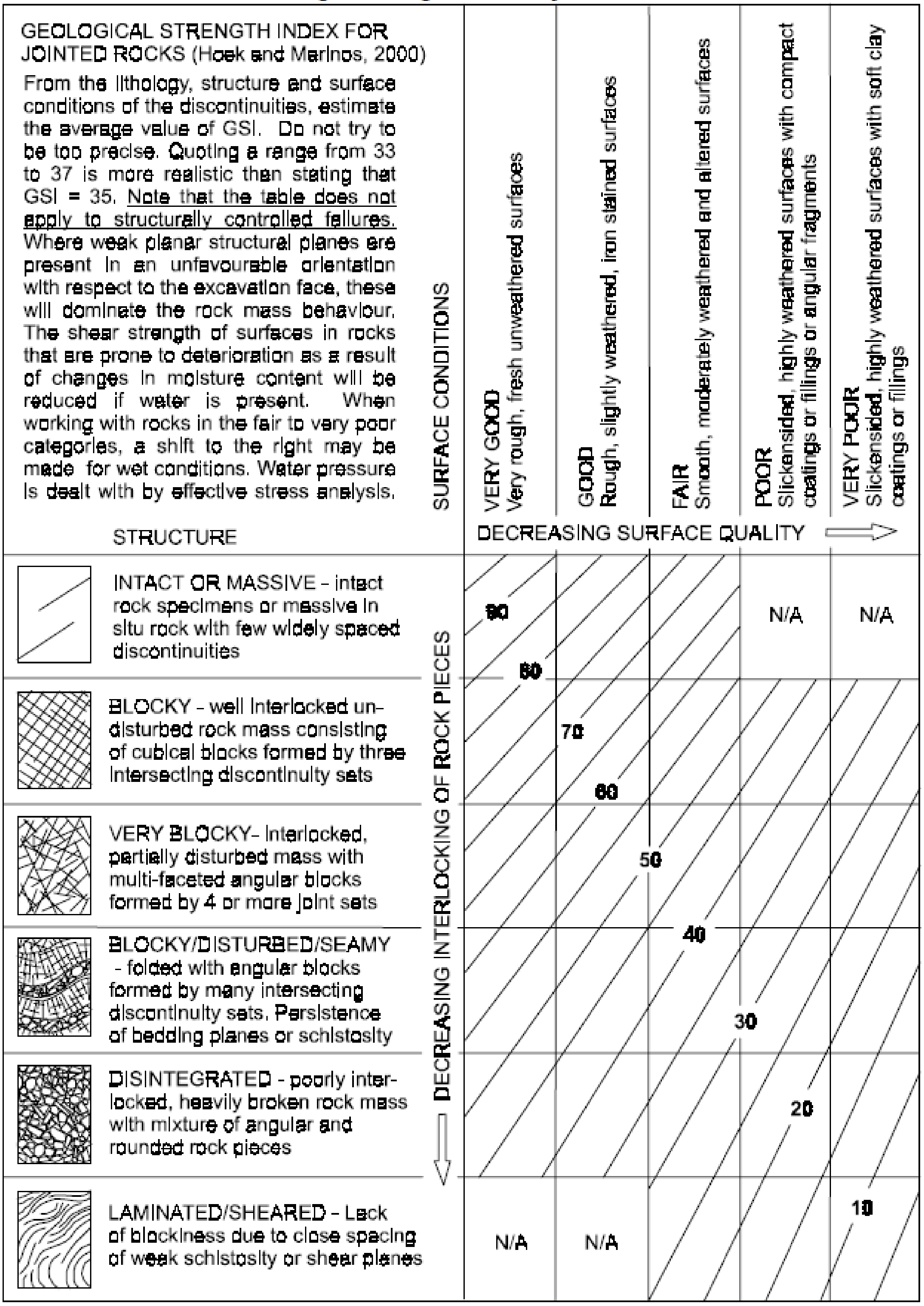

GEOLOGICAL STRENGTH INDEX FOR JOINTED ROCKS (Hoek and Marinos, 2000)
From the lithology, structure and surface conditions of the discontinuities, estimate the average value of GSI. Do not try to be too precise. Quoting a range from 33 to 37 is more realistic than stating that GSI = 35. Note that the table does not apply to structurally controlled failures. Where weak planar structural planes are present in an unfavourable orientation with respect to the excavation face, these will dominate the rock mass behaviour. The shear strength of surfaces in rocks that are prone to deterioration as a result of changes in moisture content will be reduced if water is present. When working with rocks in the fair to very poor categories, a shift to the right may be made for wet conditions. Water pressure is dealt with by effective stress analysis.
SURFACE CONDITIONS
VERY GOOD Very rough, fresh unweathered surfaces
GOOD Rough, slightly weathered, iron stained surfaces
FAIR Smooth, moderately weathered and altered surfaces
POOR Slickensided, highly weathered surfaces with compact coatings or fillings or angular fragments
VERY POOR Slickensided, highly weathered surfaces with soft clay coatings or fillings
STRUCTURE
DECREASING SURFACE QUALITY
INTACT OR MASSIVE - intact rock specimens or massive in situ rock with few widely spaced discontinuities
BLOCKY - well interlocked un-disturbed rock mass consisting of cubical blocks formed by three intersecting discontinuity sets
VERY BLOCKY- interlocked, partially disturbed mass with multi-faceted angular blocks formed by 4 or more joint sets
BLOCKY/DISTURBED/SEAMY - folded with angular blocks formed by many intersecting discontinuity sets. Persistence of bedding planes or schistosity
DISINTEGRATED - poorly inter-locked, heavily broken rock mass with mixture of angular and rounded rock pieces
LAMINATED/SHEARED - Lack of blockiness due to close spacing of weak schistosity or shear planes
DECREASING INTERLOCKING OF ROCK PIECES
N/A
N/A
90
80
70
60
50
40
30
20
10
N/A
N/A

Table 4

GEOLOGICAL PARAMETERS AND RATINGS

1. Meaning of the ratings

	1		2		3		4		5	
Class	A	B	A	B	A	B	A	B	A	B
Rating	100 – 81		80 – 61		60 – 41		40 – 21		20 – 0	
Description	Very Good		Good		Fair		Poor		Very Poor	
Colour	Blue		Green		Yellow		Brown		Red	

Distinguish between the A and B sub-classes by colouring the A sub-class full and cross-hatch the B.

2. Parameters and ratings

IRS–MPa rating %		RQD rating %		Joint spacing m	Fracture frequency, FF/m			
					Average per metre	Rating 1 set	2 set	3 set
> 185	20	97–100	15	0<—>25	0,1	40	40	40
165–185	18	84–96	14	See Fig. 2	0,15	40	40	40
145–164	16	71–83	12		0,20	40	40	38
125–144	14	56–70	10		0,25	40	38	36
105–124	12	44–55	8		0,30	38	36	34
85–104	10	31–43	6		0,50	36	34	31
65–84	8	17–30	4		0,80	34	31	28
45–64	6	4–16	2		1,00	31	28	26
35–44	5	0–3	0		1,50	29	26	24
25–34	4				2,00	26	24	21
12–24	3				3,00	24	21	18
5–11	2				5,00	21	18	15
1–4	1				7,00	18	15	12
					10,00	15	12	10
					15,00	12	10	7
					20,00	10	7	5
					30,00	7	5	2
					40,00	5	2	0
					ALLOW FOR CORE RECOVERY			

TABLE I (continued opposite)

TABLE II
FACTORS TO GIVE AVERAGE FRACTURE FREQUENCY

Sampling procedure	Factor
a. One set of three sets on a line, or one set only	1,0
b. Two sets of three sets on a line or two sets only	1,5
c. All of the sets on a line or borehole core	2,0
d. Two sets on one line and one on another	2,4
e. Three sets on three lines at right-angles	3,0

TABLE III
BOREHOLE LOG SHEET

Borehole No:		**Date:**
Zoning of borehole		
Interval length (A)		
Total sound core (B)		
RQD, % $\frac{B}{A} \times 100$		
	Low angle 0–29	Number Mean spacing (A) True distance = A × sin (0,26)
Joint spacing	Moderate angle 30–59	Number Mean spacing (B) True distance = B × sin (0,71)
	High angle 60–90	Number Mean spacing (C) True distance = C × sin (0,97)

Average frequency = $\frac{\text{Sum of individual FF/m (inverse of spacing)}}{2}$

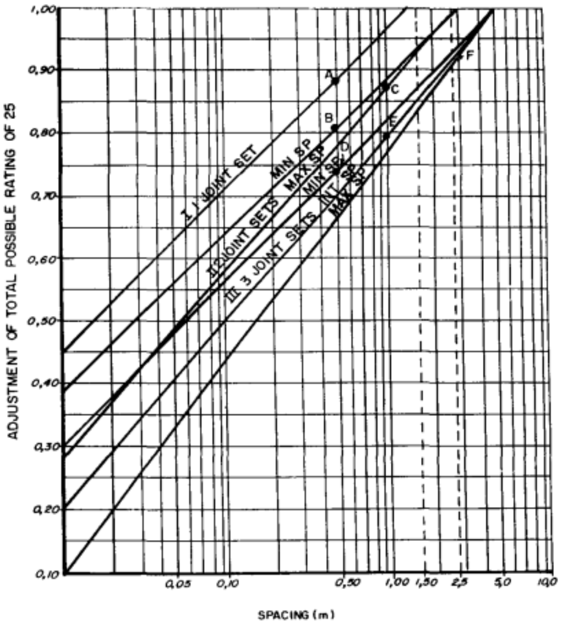


Fig. 2—Assessment of joint-space rating (after Taylor[4])

NB x = spacing × 100

A 1-Joint set $R = 25 \times ((26{,}4 \times \log_{10} x) + 45)/100$

B 2-Joint set $R = 25 \times ((25{,}9 \times \log_{10} x_{min}) + 38)/100 \times ((30{,}0 \times \log_{10} x_{max}) + 28)/100$

C 3-Joint set $R = 25 \times ((25{,}9 \times \log_{10} x_{min}) + 30)/100 \times ((29{,}6 \times \log_{10} x_{int}) + 20)/100 \times ((33{,}3 \times \log_{10} x_{max}) + 10)/100$

TABLE I (continued from opposite page) **3. Assessment of joint condition**

Parameter	Description	Accumulative % adjustment of possible rating of 40: Dry	Adjustment, %: Moist	Adjustment, %: Mod. pressure 25–125 1/m	Adjustment, %: High pressure >125 1/m
A	Multi wavy directional	100	100	95	90
	Uni	95	90	85	80
Large-scale joint expression	Curved	85	80	75	70
	Slight undulation	80	75	70	65
	Straight	75	70	65	60
B	Rough stepped/irregular	95	90	85	80
	Smooth stepped	90	85	80	75
Small-scale joint expression	Slickensided stepped	85	80	75	70
	Rough undulating	80	75	70	65
200 mm × 200 mm	Smooth undulating	75	70	65	60
	Slickensided undulating	70	65	60	55
	Rough planar	65	60	55	50
	Smooth planar	60	55	50	45
	Polished	55	50	45	40
C Joint wall alteration weaker than wall rock and only if it is weaker than the filling		75	70	65	60
D	Non-softening and sheared material — Coarse	90	85	80	75
	Medium	85	80	75	70
	Fine	80	75	70	65
Joint filling	Soft sheared material, e.g. talc — Coarse	70	65	60	55
	Medium	60	55	50	45
	Fine	50	45	40	35
	Gouge thickness < amplitude of irregularities	45	40	35	30
	Gouge thickness > amplitude of irregularities	30	20	15	10

TABLE VI
ADJUSTMENTS FOR WEATHERING

Degree of weathering	Potential weathering and adjustments, %				
	½ y	1 y	2 y	3 y	4 + y
Fresh	100	100	100	100	100
Slight	88	90	92	94	96
Moderate	82	84	86	88	90
High	70	72	74	76	78
Complete	54	56	58	60	62
Residual soil	30	32	34	36	38

Blasting Effects

Blasting creates new fractures and loosens the rock mass, causing movement on joints, so that the following adjustments should be applied:

Technique	*Adjustment, %*
Boring	100
Smooth-wall blasting	97
Good conventional blasting	94
Poor blasting	80.

Summary of Adjustments

Adjustments must recognize the life of the excavation and the time-dependent behaviour of the rock mass:

Parameter	*Possible adjustment, %*
Weathering	30–100
Orientation	63–100
Induced stresses	60–120
Blasting	80–100.

Maximum Stress

The maximum principal stress can cause spalling of the wall parallel to its orientation, the crushing of pillars, and the deformation and plastic flow of soft zones. The deformation of soft intercalates leads to the failure of hard zones at relatively low stress levels. A compressive stress at a large angle to joints increases the stability of the rock mass and inhibits caving. In this case, the adjustment can be up to 120 per cent, i.e. improving the strength of the rock mass.

Minimum Stress

The minimum principal stress plays a significant role in the stabilities of the sides and back of large excavations, the sides of stopes, and the major and minor apexes that protect extraction horizons. The removal of a high horizontal stress on a large stope sidewall will result in relaxation of the ground towards the opening.

Stress Differences

A large difference between maximum and minimum stresses has a significant effect on jointed rock masses, resulting in shearing along the joints. The effect increases as the joint density increases (since more joints will be unfavourably orientated) and also as the joint-condition ratings decrease. The adjustment can be as low as 60 per cent.

TABLE VII
PERCENTAGE ADJUSTMENTS FOR JOINT ORIENTATION

No. of joints defining the block	No. of faces inclined away from the vertical				
	70%	75%	80%	85%	90%
3	3		2		•
4	4	3		2	
5	5	4	3	2	1
6	6	5	4	3	2,1