EXAMINATION PAPER

SUBJECT:	EXAMINER:
ROCK MACHANICS CERTIFICATE PART 1: THEORY	JA MARITZ
SUBJECT CODE:	**MODERATOR:**
COMRMC1	M HANDLEY
EXAMINATION DATE:	**TOTAL MARKS:** [100]
OCTOBER 2011	**PASS MARK:** 60%
TIME: 3 Hours	

NUMBER OF PAGES: 8

SPECIAL REQUIREMENTS:

1. **Answer ALL 4 Questions.**
2. Start each question on a new page.
3. References other than those provided are not permitted.
4. Hand-held electronic calculators may be used.
5. Write your **examination number** on the outside cover of each book used and on any graph paper or other loose sheets handed in.

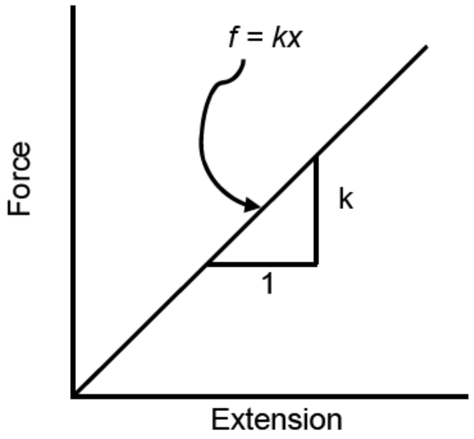
NB: your name must not appear on any answer book or loose sheets.

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

Question 1 – STRESS AND STRAIN (20 marks)

1.1 Name and discuss the empirical rule commonly referred to that explains the relationship and link between stress and strain. (5)

Hook's Law of linear elasticity✓



✓

As the force increases the extension would increase along a linear relation given a homogeneous½ and isotropic½ material. The gradient is referred to as the Young's modules✓ therefore the Hooke's law could be rewritten as...

$\sigma = E\varepsilon$ ✓

1.2 A solid 20 tonne granite block is placed on a 1.3 m high, rigid working surface supported by four legs. The legs have a material stiffness of 7.3 MN/m. Determine the height of the surface after the block has been placed on the surface, assuming any even distribution of the weight to all four legs. (5)

20t=20,000x9.81=196.2 kN

Hence one leg = 49.05 kN ✓

F=kx✓

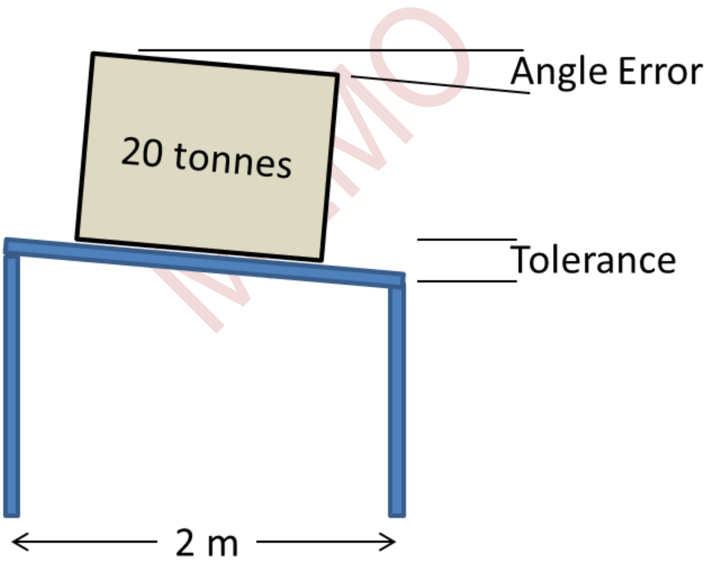
→ 49.05 kN = 7.3 MN · X
X = 6.72mm✓
Height = 1300-6.72 = 1293mm✓✓

1.3 During a bizarre incident, two of the surfaces' legs were damaged to such extend that it needed replacement. The apprentice however, not knowing the link between stress and strain, used a material with half the stiffness as the original legs. The next order of dimension stone was placed and the block was positioned on the surface. The saw that should cut the block square were set and the cutting started. After the cutting was completed, the supervisor inspected the block and rejected the product (block was not square). If the tolerance is 5 mm to either side of the desired dimension, would you have passed the product? Show all calculations. (10)

Assume equal load to all four legs ✓

Half stiffness = 7.3 ⁄ 2 = 3.65 MN/m ✓

Left legs	→ 49.05 kN = 7.3 MN · X
	X = 6.72mm
	Height = 1300-6.72 = 1293mm✓
Right Legs	→ 49.05 kN = 3.65 MN · X
	X = 13.44mm✓
	Height = 1300-13.44= 1287mm✓✓
Tolerance	6mm✓✓
Reject since the tolerance is greater than 5mm over the 2.0m✓✓	



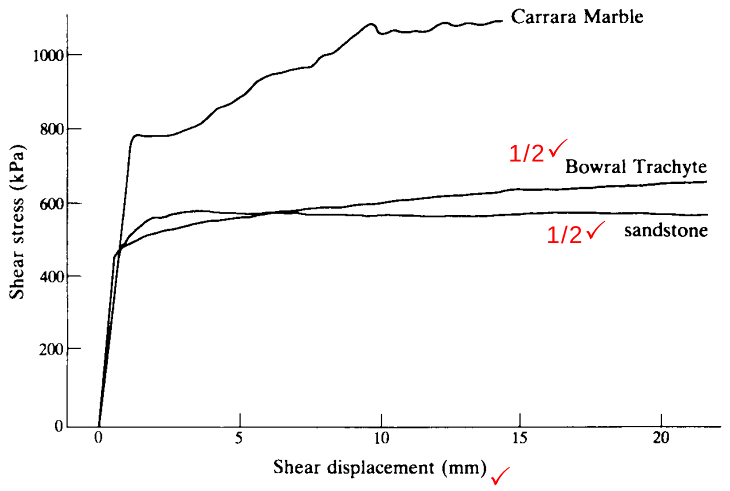
QUESTION 2 – JOINT STRENGTH (20 MARKS)

2.1 Describe and explain the effect of friction angle on a joint plane. (3)

FA would influence the strength of the plane. ✓ with an increase in the angle, the shear strength of the plane increase resulting in a more stable discontinuity. ✓

$$\tau = C_0 + \sigma \tan \phi$$ ✓

2.2 Sketch, describe and explain the typical shear resistance-displacement behaviour of a smooth joint plane indicating values for typical rock types. (7)



The peak strength at constant normal stress is reached after a small✓ shear✓ displacement. With further displacement, the shear resistance falls ✓until the residual strength is eventually reached. ✓

2.3 A particular fault on your mine did not show any seismic activity in the past. However, mining in the vicinity started which saw and increase in events recorded in the seismic network that could be associated to the fault. Using equations and sketches, discuss why the mining could impact on the change in field stresses. (10)

Discussions ✓ sketches on ESS lobes ✓ Equations✓ Relation to Seismic Magnitude✓

Stresses ahead of face discussion ✓ Sketches✓ Equations✓

QUESTION 3 – STRESS IN ROCK AND ROCKMASSES (20 MARKS)

3.1 Name and discuss five factors influencing the virgin state of stress in the earths' crust. (10)

Overburden✓ - Discussion✓

Tectonic stress✓ – Discussion✓

Geological Structures✓ – Discussion✓

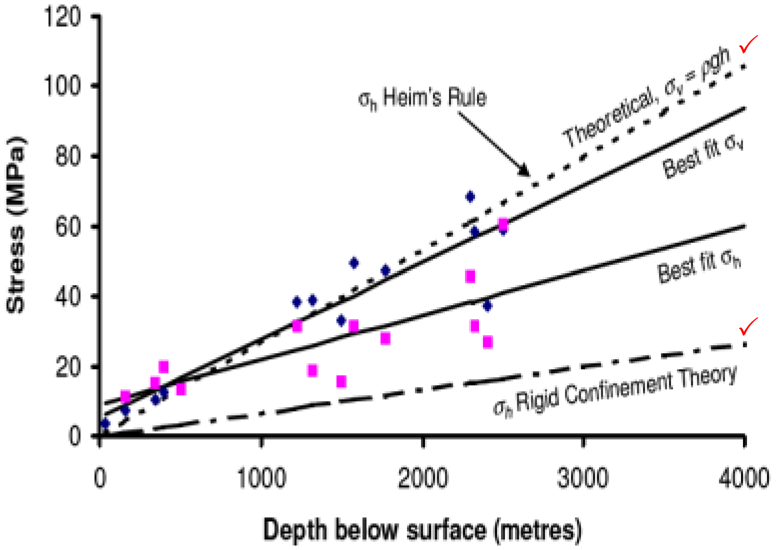
Residual Stresses✓ – Discussion✓

Pore water pressure✓– Discussion✓

3.2 Name, discuss and plot the empirical formulas to determine virgin stress. In each case, also comment on the short comings of the formulae (5)

Heim's rule $\sigma_v=\rho gh$ ½ Heim's Rule states that at depth, the rock stress tends towards the lithostatic½ state. $\sigma_1=\sigma_2=\sigma_3$½

Rigid confinement = $\sigma_h=\sigma_2=\sigma_3=(v/(1-v))\sigma_v$ ½ $\sigma_v=\sigma_1=\rho gh$ The Rigid Confinement Theory assumes that rock is elastic ½and when it is buried, by either sedimentation or tectonic processes, it is prevented from expanding sideways by the surrounding rock. The horizontal stresses are influence by the Poison's ratio½



3.3 As input parameters to your newly setup numerical modelling package, you need to establish the k-ratio and field stress gradient on your mine. Name and describe two methods or techniques to determine the in-situ field stress and how you will go about determining the k-ratio and respective stress increase gradients. (5)

The k ratio is determined by $k=\sigma_h/\sigma_v$✓

Flatjack ✓✓

Haudraulic fracturing✓✓ [4 (2 marks each for any two)]

Overcoring✓✓

Flatjack

The process that should be followed when a flat jack test is used

- *A field of displacement is determined by selecting points of reference, this points should be fixed to the surface from which the test will be conducted*
- *A slot is removed from the surface on which the stress would be measured. The slot should be perpendicular to the initially measured field of displacement*
- *Removal of a slot from the surface whereby stresses will be measured results in stress relief and thus deformation of the area around the slot. This will result in field of displacement being decreased. The decrease can be measured by determining the new "displacement zone, therefore d<di*
- *A thin jack is inserted into the slot and compressive stress is applied to the walls around the jack. The compressive stress cause the new displacement field (d) to move towards the initial*

displacement (di) until a point at which d≈di or d=di. when interpreting the results it is important to take note of the following factors:

- The stress that is needed to return the displacements to the state d=di is from the jack, but the jack provides more stress than necessary, therefore stress in the rock is less than the compressive stress from the hydraulic flat-jack. High stresses in the flat-jack is caused by tendency of the flat jack to resist expansion when pressurised
- The area of the slot is greater than that of the flat jack.

A sample is collected from bed joint and the destruction incurred by the strata is temporary and can be fixed once the test has been completed.

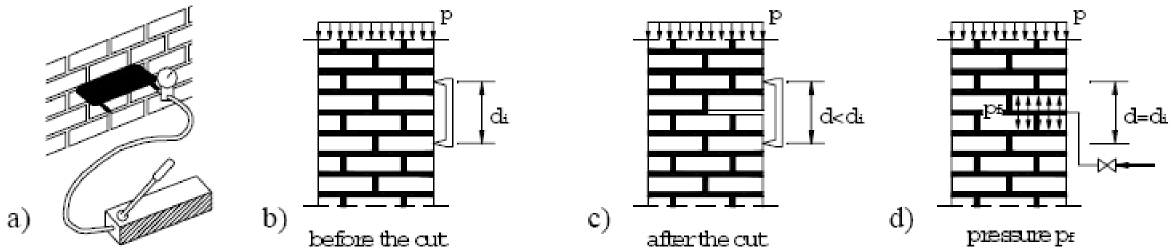
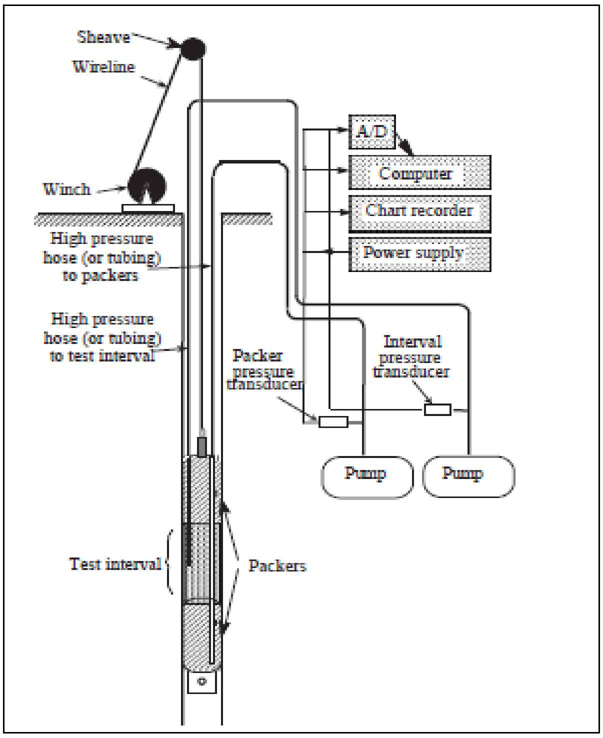


Figure demonstration of how a flat jack is used

Hydraulic fracturing [2]

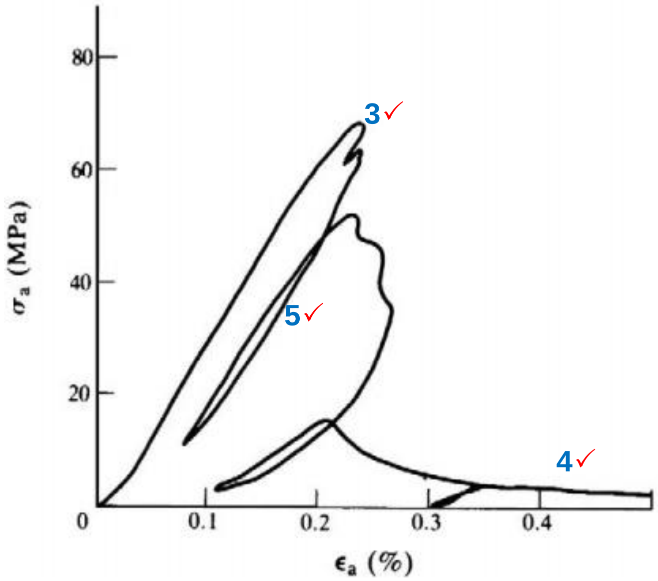
In order to measure the rock stress, a borehole has to be drilled and then sealed off with inflatable rubber packers. The borehole has to be drilled in an area which is free from any geological disturbances. Typical diameters of the borehole range between 76mm to 96mm. The area that needs to be sealed off is normally 1m of the borehole section. The rubber packers have to be pressurised in such a manner that allows them to stick to the sidewall of the borehole. The packers are normally pressurised to 2-4MPa, the reason for the low pressure is to avoid fracturing before conducting the method. Once that is achieved, a hydraulic fluid has to be pumped into the borehole at a constant flow rate; water is normally used as a hydraulic fluid but alcohol is also an option. Pumping a hydraulic fluid into the borehole increases the pressure, the pressure will increase to the peak pressure, and as a result, tensile stress is created at the sidewall of the borehole. The pressure that initiates a fracture (peak pressure) is known as the breakdown pressure. An increase in pressure will result into an increase in tensile stress which will result into initiation of a fracture. As soon as a fracture is initiated, the pumping has to be stopped; the pressure will gradually decrease until it is equal to the surrounding pressure. As the pressure decrease, the fracture closes, the pressure at which the fracture is closed is known as the shut-in pressure. In order to obtain accurate results, this procedure has to be repeated a number of times at a constant flow rate of the hydraulic fluid. (Haimson and Cornet, 2003; 1012)

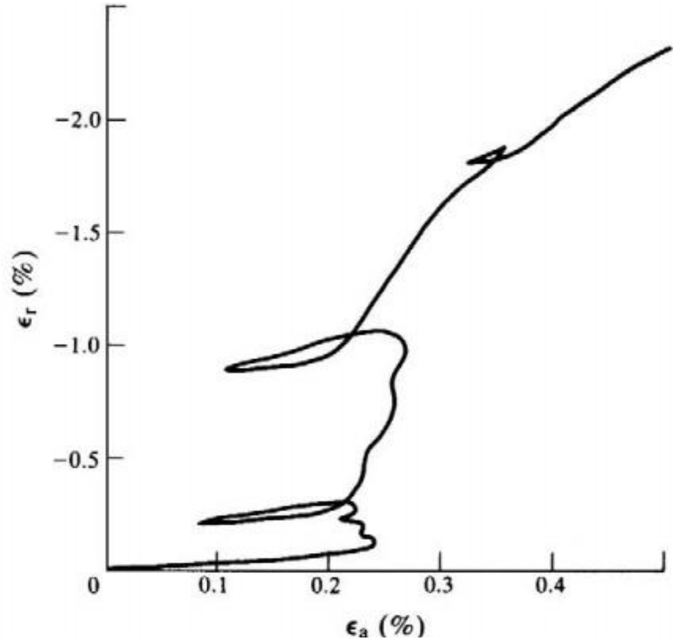


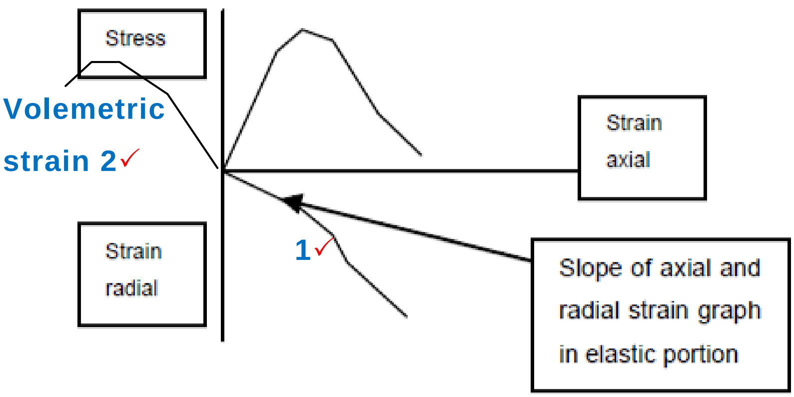
QUESTION 4 – ROCKMASS PROPERTIES & STRENGTH (20 MARKS)

4.1 Sketch and explain the complete axial stress-strain graph for rock in uniaxial compression, indicating the following: (15)

- **1** Radial strain
- **2** Volumetric strain
- **3** Brittle-ductile transition
- **4** Residual strength
- **5** Hysteresis in the post peak region.







1 Mark for position✓ on sketch, 2 marks for discussion✓✓ of each point

4.2 Name the five failure criterion used to determine rock strengths and comment on the applicability of each. (5)

Coulomb✓½	shear on existing or new plane governed by cohesion $\lvert F_s \rvert = C_0 + \mu F_n$ Empirical✓½
Mohr✓½	Shear failure on a plane in the solid $\tau = C_0 + \sigma \tan\phi$ Empirical✓½
Griffith ✓½	direct and indirect tensile - physical✓½
Hoek-Brown ✓½	no mechanism - empirical $\sigma_1 = \sigma_3 + \sqrt{m\sigma_c\sigma_3 + s\sigma_c^2}$ ✓½
Stacey✓½	strain ✓½

QUESTION 5 – ROCKMASS PROPERTIES & CLASSIFICATION (20 MARKS)

The Q Tunnelling Quality Index is evaluated by the formula:

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

5.1 Why is the Q-rating empirical? (3)

The rating was derived from civil work✓ during tunnelling operations. The rating was adapted✓ to be applicable for underground environment.

Include factors considered to have an influence on rock strength✓, yet exclude direction of the excavation

5.2 What are the three major aspects of tunnel stability that are assessed by the Q-Index? (3)

Rock strength and quality / Rock Block Size $\frac{RQD}{J_n}$ ✓

Joint condition / Joint shear strength $\frac{J_r}{J_a}$ ✓

Stress influence / confining stress $\frac{J_w}{SRF}$ ✓

5.3 Describe the meaning of each of the variables in the Q-Index formula and their influence on tunnel stability. (6)

RQD✓½	Rock Qaulity Designation – value for determining the qaulity of the rock mass *(RQD ↑ = Q ↑)* ✓½
Jn✓½	Joint set number – How many joint set are found in the mass *(Jn ↑ = Q ↓)* ✓½
Jr✓½	Joint roughness – Describing the condition of the joint surface *(Jr ↑ = Q ↑)* ✓½
Ja✓½	Joint alteration number – How is the joint filled

	(Ja ↑ = Q ↓) ✓½
Jw✓½	Joint water reduction – Pore pressure in the joint will influence the joint strength
	(Jw ↑ = Q ↑) ✓½
SRF✓½	Stress reduction factor – weak zones intersecting may loosen rock mass
	(SRF ↑ = Q ↓)✓½

5.4 A rockmass 600 m below surface has a joint density J_v=12 m^{-3}, an intact rock material uniaxial compresive strength of 180 MPa and an average density of 3000 kg/m^3. There are 3 joint sets, the first continuous, 30 cm spacing, moderately rough unweathered surfaces, no infill and dry. The first set is vertical, striking north-south. The second set has a spacing of 20 cm, discontinuous, with signs of water and is moderately rough with some iron straining. It dips at 80° in a direction of 045°. The third set is continuous, spaced 20-30 cm apart, relatively smooth, no infill and dry but with iron straining. This set dips at 85° and 305°. Determine the Q rating for the rockmass. (5)

Assume Rock to be POOR✓ with RQD 25-50 ✓since joint density = 12/m^3

Q (typical range) = 16.7✓ to 1.4✓

$$\frac{(25\ to\ 50)}{12}\ x\ \frac{(1\ to\ 3)}{(0.75\ to\ 1)}\ x\ \frac{(0.66\ to\ 1)}{1}$$

Q (ave) = 5.9✓

$$\frac{40}{12}\ x\ \frac{2}{0.9}\ x\ \frac{0.8}{1}$$ (allow 20% deviation)

5.5 Would there be a difference in the tunnel stability if the tunnel were orientated north-south, or east-west in this rockmass? Give reasons for you answer. (3)

Would not have in impact on Q rating✓, however joint orientation being parallel to the axis is in general not favoured. ✓

The Q system does not take the rock material strength into account explicitly, although it is implicitly included in arriving at the SRF assessment. The orientation of joints is also not taken into account since it is considered that the number of joint sets, and hence the potential freedom of movement ✓for rock blocks is more important.

Tables for classification of the rock mass based on the Q system

1. Rock Quality Designation		**RQD**
A	Very poor	0 – 25
B	Poor	25 – 50
C	Fair	50 – 75
D	Good	75 – 90
E	Excellent	90 – 100
Note i) Where RQD is reported or measured as ≤ 10 (including 0), a nominal value of 10 is used to evaluate Q. ii) RQD intervals of 5, i.e. 100, 95, 90 etc. are sufficiently accurate		

2. Joint Set Number		**Jn**
A	Massive, no or few joints	0.5 - 1.0
B	One joint set	2
C	One joint set plus random joints	3
D	Two joint sets	4
E	Two joint sets plus random joints	6
F	Three joint sets	9
G	Three joint sets plus random joints	12
H	Four or more joint sets, random, heavily jointed, ‘sugar cube’, etc.	15
J	Crushed rock, earth like.	20
Note i) For intersections, use 3 x Jn. ii) For portals, use 2 x Jn.		

3. Joint Roughness Number		**Jr**
a) Rock wall contact, and b) rock wall contact before 10 cm shear		
A	Discontinuous joints	4
B	Rough or irregular, undulating	3
C	Smooth, undulating	2
D	Slickensided, undulating	1.5
E	Rough or irregular, planar	1.5
F	Smooth, planar	1.0
G	Slickensided, planar	0.5
Note: i) Descriptions refer to small scale features and intermediate scale features in that order		
c) No rock wall contact when sheared		
H	Zone containing clay minerals thick enough to prevent rock wall contact	1.0
J	Sandy, gravely or crushed zone thick enough to prevent rock wall contact.	1.0
Note: i) Add 1.0 if the mean spacing of the relevant joint set is greater than 3 m.		

ii) Jr = 0.5 can be used for planar slickensided joints having lineations, provided the lineations are orientated for minimum strength.

4. Joint Alteration Number		**φr approx.**	**Ja**
a) Rock wall contact (no mineral filling, only coatings)			
A	Tightly healed, hard, non-softening, impermeable filling i.e. quartz or epidote.	---	0.75
B	Unaltered joint walls, surface staining only	25 - 35°	1.0
C	Slightly altered joint walls. Non-softening mineral coatings, sandy particles, clay free disintegrated rock, etc.	25 - 30°	2.0
D	Silty- or sandy-clay coatings, small clay fraction (non-softening)	20 - 25°	3.0
E	Softening or low friction clay mineral coatings i.e., kaolinite or mica. Also chlorite, talc, gypsum, graphite, etc. and small quantities of swelling clays	8 - 16°	4.0
b) Rock wall contact before 10 cm shear (thin mineral fillings)			
F	Sandy particles, clay free disintegrated rock, etc.	25 - 30°	4.0
G	Strongly over consolidated non-softening clay mineral fillings (continuous, but < 5 mm thickness)	16 - 24°	6.0
H	Medium or low over consolidation, softening, clay mineral fillings (continuous, but < 5 mm thickness)	12 - 16°	8.0
J	Swelling clay fillings, i.e. montmorillonite (continuous, but < 5 mm thickness). Value of Ja depends on percent of swelling clay-size particles, and access to water, etc.	6 - 12°	8 - 12
c) No rock wall contact when sheared (thick mineral fillings)			
K,L,M	Zones or bands of disintegrated or crushed rock and clay (see G, H, J for description of clay condition)	6 - 24°	6, 8, or 8 - 12
N	Zones or bands of silty- or sandy-clay, small clay fraction (non-softening)	---	5.0
O,P,R	Thick, continuous zones or bands of clay (see G, H, J for description of clay condition)	6 - 24°	10, 13, or 13 - 20

5. Joint Water Reduction Factor		**Water pres. (kg/cm^2)**	**Jw**
A	Dry excavations or minor inflow, i.e. < 5 l/min locally	<1	1.0
B	Medium inflow or pressure, occasional outwash of joint fillings	1 - 2.5	0.66
C	Large inflow or high pressure in competent rock with unfilled joints	2.5 - 10	0.5
D	Large inflow or high pressure, considerable outwash of joint fillings	2.5 - 10	0.33

E	Exceptionally high inflow or water pressure at blasting, decaying with time	> 10	0.2 - 0.1
F	Exceptionally high inflow or water pressure continuing without noticeable decay	> 10	0.1 - 0.05
Notes: i) Factors C to F are crude estimates; increase Jw if drainage measures are installed. ii) Special problems caused by ice formation are not considered.			

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
B	Single weakness zones containing clay or chemically disintegrated rock (depth of excavation ≤ 50 m)	5
C	Single weakness zones containing clay or chemically disintegrated rock (depth of excavation > 50 m)	2.5
D	Multiple shear zones in competent rock (clay free), loose surrounding rock (any depth)	7.5
E	Single shear zones in competent rock (clay free) (depth of excavation ≤ 50 m)	5.0
F	Single shear zones in competent rock (clay free) (depth of excavation > 50 m)	2.5
G	Loose, open joints, heavily jointed or ‘sugar cube’, etc. (any depth)	5.0
Note: i) Reduce these values of SRF by 25 - 50 % if the relevant shear zones only influence but do not intersect the excavation.		

b) Competent rock, rock stress problems		**σ_c/σ_1**	**σ_θ/σ_c**	**SRF**
H	Low stress, near surface, open joints	> 200	< 0.01	2.5
J	Medium stress, favourable stress condition	200 - 10	0.01 - 0.3	1
K	High stress, very tight structure. Usually favourable to stability, may be unfavourable for wall stability	10 - 5	0.3 - 0.4	0.5 - 2
L	Moderate slabbing after > 1 hour in massive rock	5 - 3	0.5 - 0.65	5 - 50
M	Slabbing and strain-burst after a few minutes in massive rock	3 - 2	0.65 - 1	50 - 200
N	Heavy strain-burst and immediate dynamic deformations in massive rock	< 2	> 1	200 - 400
Note: ii) For strongly anisotropic virgin stress field (if measured): when $5 \leq \sigma_1/\sigma_3 \leq 10$, reduce σ_c to 0.75 σ_c. When $\sigma_1/\sigma_3 > 10$, reduce σ_c to 0.5 σ_c. Here, σ_c = unconfined compression strength, σ_1 and σ_3 are the major and minor principal stresses, and σ_θ = maximum tangential stress (estimated from elastic theory).				

iii) 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 the influence of high rock pressure.		σ_θ/σ_c	SRF
O	Mild squeezing rock pressure	1.5	5 - 10
P	Heavy squeezing rock pressure	> 5	10 - 20
Note: iv) Cases of squeezing rock may occur for depth H > 350 $Q^{1/3}$ (Singh et al 1992). Rock mass compression strength can be estimated from q = 7 γ $Q^{1/3}$ (MPa) where γ = rock density in gm/cc (Singh 1993).			
d) Swelling rock: chemical swelling activity depending on pressure of water			
R	Mild swelling rock pressure		5 - 0
S	Heavy swelling rock pressure		10 - 15

Note: Jr and Ja classification is applied to the joint set or discontinuity that is least favourable for stability both from the point of view of orientation and shear resistance (where $\tau = \sigma_n \tan(Jr/Ja)$
$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$