UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2010/2011

COURSE NAME	:	ENGINEERING GEOLOGY
COURSE CODE	:	BFC21303 / BFC3013
PROGRAMME	:	2 BFF / 3 BFF
EXAMINATION DATE	:	APRIL / MAY 2011
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWER QUESTION 1, 2 AND THREE (3) OTHER QUESTIONS.

THIS PAPER CONSISTS OF SEVENTEEN (17) PAGES

Q1 Given below were the data results of rock coring and testing to a proposed site of foundation which located on the horizontal surface of slate (metamorphic rock) :

RQD = 60
RMR = 65
σ_c = 130 MPa

The value of m and s were found to be 0.821 and 0.00293 respectively. You are required to determine the following :

(a) Compressive strength $\sigma_1' = \sigma_3' + (m\sigma_{u(r)}\sigma_3' + s\sigma_{u(r)}^2)^{1/2}$

(9 marks)

(b) Tensile strength $\sigma_t = 0.5\sigma_{u(r)}[m - (m^2 + 4s)^{1/2}]$

(4 marks)

(c) Bearing Capacity for the proposed shallow foundation

$$q_a = \frac{Cf_1 s^{1/2}\sigma_{u(r)}[1 + (ms^{-1/2} + 1)^{1/2}]}{SF}$$

(4 marks)

(d) Determine the size of square footing if SF = 3 is required and Cf_1 = 1.25 to retain the vertical load 400 kN

(3 marks)

Q2 As part of the application for an aggregate extraction license in Mantin, your company is required to check the stability of the proposed rock faces for the new quarry. The geological maps point to an outcrop of Carboniferous GRANITE, which has an average friction angle of 34° and all discontinuities observed are tight, clean and with no visible seepage. The discontinuity set/data and orientation of each rock face are as shown in the **Table Q2** :

Table Q2

Rock Face A	Dip 50°	Dip Direction 354°
Rock Face B	Dip 60°	Dip Direction 165°
Rock Face C	Dip 60° (NE)	Strike 174° - 354°
Joint Set 1 & 2	Plotted as pole as shown in **Figure Q2(a)**	
Joint Set 3	Dip 56°	Dip Direction 199°
Joint Set 4	Dip 44° (NE)	Strike 105° - 285°
Joint Set 5	Apparent Dip 42° Apparent Dip 34°	Apparent Dip Direction 240° Apparent Dip Direction 338°

(a) With clearly labelled diagrams, and making use of the stereonet (**Figure Q2(b)**) and tracing paper/s provided, analyse the data.

(11 marks)

(b) Using the analysis in part(a), write a short report on the stability of the proposed rock faces for the new quarry.

. (9 marks)

Q3 (a) The results of point load test has point load strength index, I_s = 40 (MPa). The diameter (D) of sample = 40 mm. Calculate the uniaxial compressive strength of this rock by using the formula :

$$I_{s(50)} = I_s \times F$$
$$F = (D/50)^{0.45}$$
$$\sigma_c = 22 I_{s(50)}$$

(5 marks)

(b) Define what's the poisson ratio ?

(5 marks)

(c) Define what is the stiffness E and the difference of E_t and E_s .
Explain the use of E in design calculation.

(5 marks)

(d) Explain the objective of these tests
- Uniaxial compressive test
- Slake durability test
- PUNDIT test

(5 marks)

Q4 (a) Describe briefly the three main geologic processes that change the structure of the earth's surface, and comment on the need for civil engineers to have a basic knowledge about these.

(4 marks)

(b) Define what is a tectonic plate?

(4 marks)

(c) And what are the names given for the **three (3)** main types of plate boundaries.

(4 marks)

(d) Discuss and giving appropriate field examples that support the theory of plate tectonics and its relevance to civil engineers.

(4 marks)

(e) Physical properties of minerals are characteristics that can be observed or determined by simple test. Differentiate between:

(i) color and streak
(ii) luster and transparency
(iii) cleavage and fracture

(4 marks)

Q5 Physical weathering is the mechanical breakdown of the rocks into smaller fragments without undergoing a change in chemical composition.

(a) What is the difference between frost action and unloading/ exfoliation process in physical weathering?

(4 marks)

(b) Write down and describe at least **two (2)** processes in chemical weathering

(4 marks)

(c) List down at least **two (2)** condition that will increase the rate of weathering

(4 marks)

(d) Explain that the type of sediments that from upper course of river are different with down stream

(4 marks)

(e) Mention the parameters that affect the Deposition of sediment resulted from weathering

(4 marks)

Q6 Geotechnical data and observations at the tunnel - rock mass interaction in a tunneling project are given in **Table Q6.**

Table Q6.

Details of the Tunnel driving	
Strike of the tunnel axis	30°- 210°
Dip of the tunnel drive	10°
Dip direction of the tunnel drive	120°
Span of tunnel	10m
Height of tunnel	10m
Details of Rock Mass	
Rock type	Granite
State of weathering	Moderate
RQD	54 %
No of dominant joint sets	2 plus random sets
Dip magnitude of dominant joint set	70°
Dip direction of dominant joint set	120°
Strike direction of the dominant joint set	30°- 210°
State of the rock joint surface	Slightly rough
Average length of joints	2m
Joint separation (aperture)	>1mm and < 5 mm
Joint infill	Up to 5mm with non softening mineral coating
Joint spacing	150 mm
Joint water condition	Occasionally wet
Strength of intact rock (based on point load test)	9 MPa

(a) Evaluate the Rock Tunneling Quality index, Q as given by the equation below

$$Q = \frac{RQD}{Jn} x \frac{Jr}{Ja} x \frac{Jw}{SRF}$$

Use the tables in **Table Q6(a)** and **Figure 6(a)**

(10 marks)

(b) Also evaluate the Rock Mass Rating and suggest the appropriate rock improvement / protection that will be required using **Table Q6(b)**

(10 marks)

You MUST attach all tracing paper/s to your answer book

Q1 Diberi data hasil keputusan penggerudian dan ujian keatas tapak untuk asas cetek yang terletak diatas permukaan mengufuk batuan slate (batuan metamorfik) :

RQD = 60
RMR = 65
σ_c = 130 MPa

Nilai *m* dan *s* adalah 0.821 dan 0.00293 . Anda diminta untuk menentukan perkara berikut :

(a) Kekuatan tekan (*Compressive strength*) $\sigma_1' = \sigma_3' + (m\sigma_{u(r)}\sigma_3' + s\sigma_{u(r)}^2)^{1/2}$

(9 markah)

(b) Kekuatan tegangan (*Tensile strength*) $\sigma_t = 0.5\sigma_{u(r)}[m - (m^2 + 4s)^{1/2}]$

(4 markah)

(c) Keupayaan galas asas tersebut menggunakan rumus :

$$q_a = \frac{Cf_1 s^{1/2}\sigma_{u(r)}[1 + (ms^{-1/2} + 1)^{1/2}]}{SF}$$

(4 markah)

(d) Kira saiz asas tersebut jika faktor diminta keselamatan (SF) = 3 dan Cf_1 = 1.25 untuk menahan beban pugak 400 kN

(3 markah)

Q2 Sebagai bahagian daripada lessen kebenaran pengeluaran agregat di Mantin, syarikat saudara diminta untuk mengkaji kestabilan permukaan cerun yang dicadangkan sebagai kauri baru. Peta geologi merujuk kepada granit dengan besi berkarbonat (*Carboniferous GRANITE*), yang mempunyai sudut geseran 34° dan semua ketakselanjaran adalah rapat, bersih dan tiada resipan. Arah dan data ketakselanjaran masing masing batuan adalah seperti dalam **jadual Q2** berikut :

Jadual Q2

Rock Face A	Dip 50°	Dip Direction 354°
Rock Face B	Dip 60°	Dip Direction 165°
Rock Face C	Dip 60° (NE)	Strike 174° - 354°
Joint Set 1 & 2	Plotted as pole as shown in **Figure Q2(a)**	
Joint Set 3	Dip 56°	Dip Direction 199°
Joint Set 4	Dip 44° (NE)	Strike 105° - 285°
Joint Set 5	Apparent Dip 42° Apparent Dip 34°	Apparent Dip Direction 240° Apparent Dip Direction 338°

(a) Analisa data , dengan diagram yang telah dilabel dengan jelas, dan guna stereonet **(Figure Q2(b))** dan *tracing paper/s* yang tersedia.

(11 markah)

(b) Menggunakan analisa daripada bahagian (a), tuliskan laporan ringkas tentang kestabilan batuan yang dicadang untuk kauri baru tersebut.

(9 markah)

Q3 (a) Hasil keputusan ujian beban titik (point load test) memberi nilai index kekuatan beban titik , I_s = 40 (MPa). Garis tengah (D) sample = 40 mm. Kira kekuatan tekan satu paksi (*uniaxial compressive strength*) batuan tersebut menggunakan rumus dibawah ini :

$$I_{s(50)} = I_s \times F$$
$$F = (D/50)^{0.45}$$
$$\sigma_c = 22 I_{s(50)}$$

(5 markah

(b) Definasikan apakah istilah nisbah poisson itu ?

(5 markah)

(c) Definasikan istilah keteguhan (*stiffness*) E dan perbezaan daripada E_t dan E_s . Terangkan penggunaan E dalam rekabentuk.

(5 markah)

(d) Terangkan objektif daripada ujian ujian berikut :
- Ujian tekan satu paksi (*Uniaxial compressive test*)
- Ujian ketahanan cuaca (*Slake durability test*)
- PUNDIT test

(5 markah)

Q4 (a) Jelaskan dengan ringkas **tiga (3)** proses geologi yang utama yang merubah struktur permukaan bumi, dan beri komen terhadap keperluan seorang jurutera perlu memahami terhadap pengetahuan asas tentang perkara ini.

(4 markah)

(b) Apakah yang dimaksud dengan plat tektonik (*tectonic plate*) ?

(4 markah)

(c) Nama apakah yang diberi terhadap **tiga (3)** jenis sempadan sempadan plat yang utama.

(4 markah)

(d) Bincangkan contoh tapak/lapangan yang sesuai yang menyokong teori plat tektonik dan keterkaitan dengan jurutera awam (*civil engineer*).

(4 markah)

(e) Sifat sifat fizikal mineral dapat diamati dan ditentukan dengan ujian sederhana. Bezakan antara istilah berikut :

(a) Warna dan serbuk warna (*color and streak*)
(b) Kilauan dan lut sinar *(luster and transparency)*
(c) Celah dan patahan *(cleavage and fracture)*

(4 markah)

Q5 Luluhawa fizikal adalah pemecahan secara mekanikal terhadap batuan menjadi patahan kecil tanpa mengalami perubahan susunan kimia.

(a) Apakah perbezaan antara proses tindakan membeku *(frost action)* dan nyahbeban *(unloading/ exfoliation)* dalam luluhawa fizikal?

(4 markah)

(b) Tulis dan terangkan **dua (2)** proses dalam luluhawa kimia.

(4 markah)

(c) Tulis **dua (2)** keadaan yang akan meningkatkan laju luluhawa.

(4 markah)

(d) Terangkan jenis mendapan yang datang dari hulu sungai yang berbeza dengan hilir sungai.

(4 marks)

(e) Terangkan parameter parameter yang mempengaruhi penempatan mendapan sebagai hasil daripada luluhawa.

(4 markah)

Q6 Data geoteknik dan pengamatan pada projek terowong diberi dalam **Table Q6.**

Table Q6.

Detail detail arah terowong	
Jurus daripada paksi terowong *(Strike of the tunnel axis)*	30°- 210°
Kemiringan ketakselanjaran dalam terowong *(Dip of the tunnel drive)*	10°
Arah kemiringan terowong *(Dip direction of the tunnel drive)*	120°
Lebar terowong *(Span of tunnel)*	10m
Tinggi terowong (Height of tunnel)	10m
Detail detail Massa batuan	
Jenis batuan *(Rock type)*	Granite
Keadaan Luluhawa *(State of weathering)*	Moderate
RQD	54 %
Jumlah kekar dominan *(No of dominant joint sets)*	2 plus random sets
Nilai kemiringan kekar *(Dip magnitude of dominant joint set)*	70°
Arah kemiringan daripada kekar *(Dip direction of dominant joint set)*	120°
Arah jurus daripada kekar *(Strike direction of the dominant joint set)*	30°- 210°
Keadaan permukaan kekar *(State of the rock joint surface)*	Slightly rough
Purata panjang kekar *(Average length of joints)*	2m
Lebar lobang kekar *(Joint separation (aperture))*	>1mm and < 5 mm
Kandungan material kekar *(Joint infill)*	Up to 5mm with non softening mineral coating
Jarak antara kekar *(Joint spacing)*	150 mm
Keadaan air dalam kekar *(Joint water condition)*	Occasionally wet
Kekuatan batuan segar *(Strength of intact rock (based on point load test))*	9 MPa

(a) Kira nilai index kualiti batuan dari terowong ini menggunakan rumus berikut :

$$Q = \frac{RQD}{Jn} x \frac{Jr}{Ja} x \frac{Jw}{SRF}$$

Gunakan jadual dalam **Table Q6(a) dan Figure Q6(a)**

(10 markah)

(b) Juga kira nilai Rating massa batuan *(Rock Mass Rating)* dan beri saranan proteksi/sokongan yang sesuai yang boleh diberi pada terowong tersebut menggunakan **Table Q6(b)**

(10 markah)

Anda mesti melampirkan tracing paper kedalam buku jawapan.

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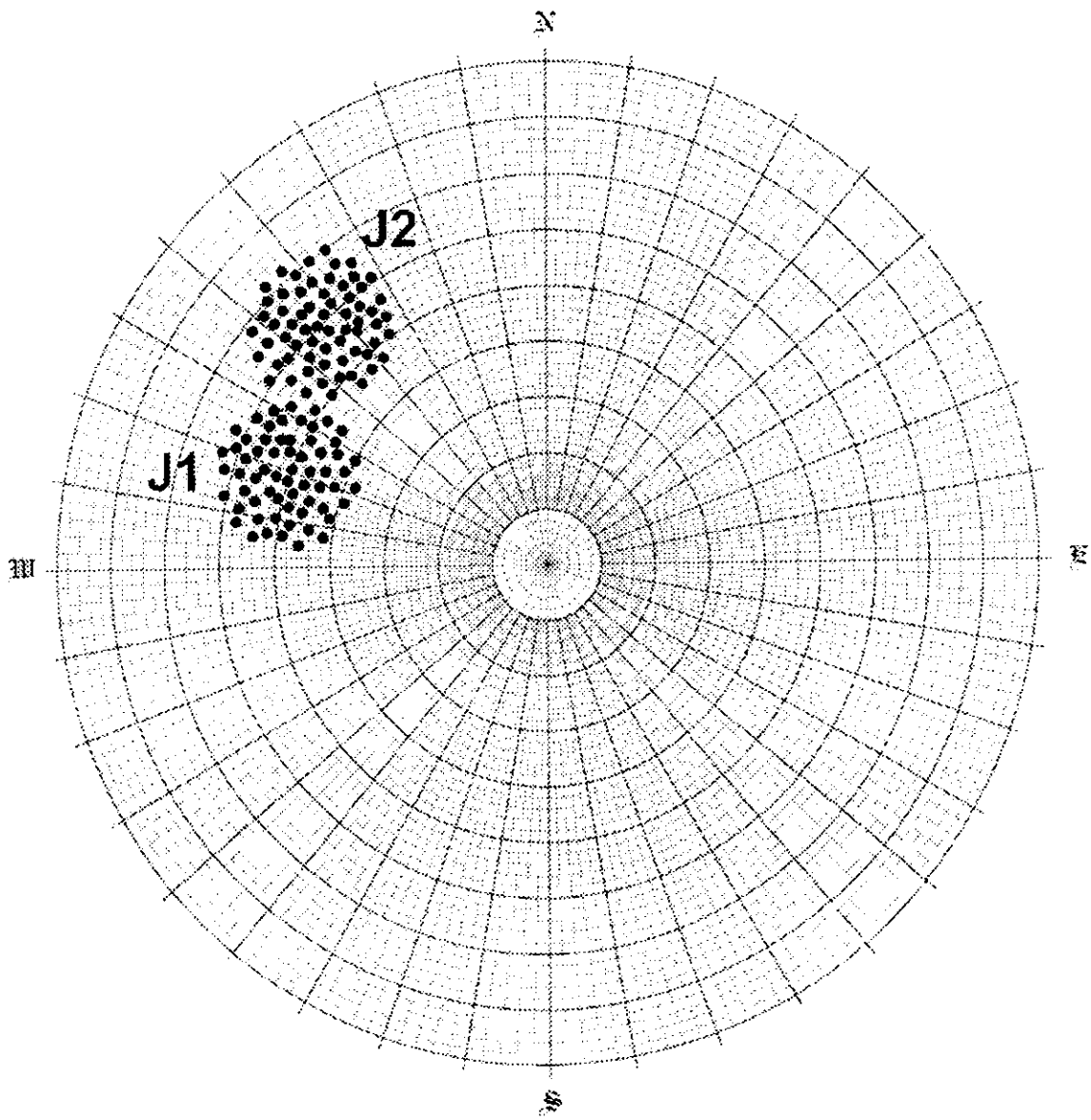

Figure Q2(a) : Polar equal-area streonet marked in 2° intervals

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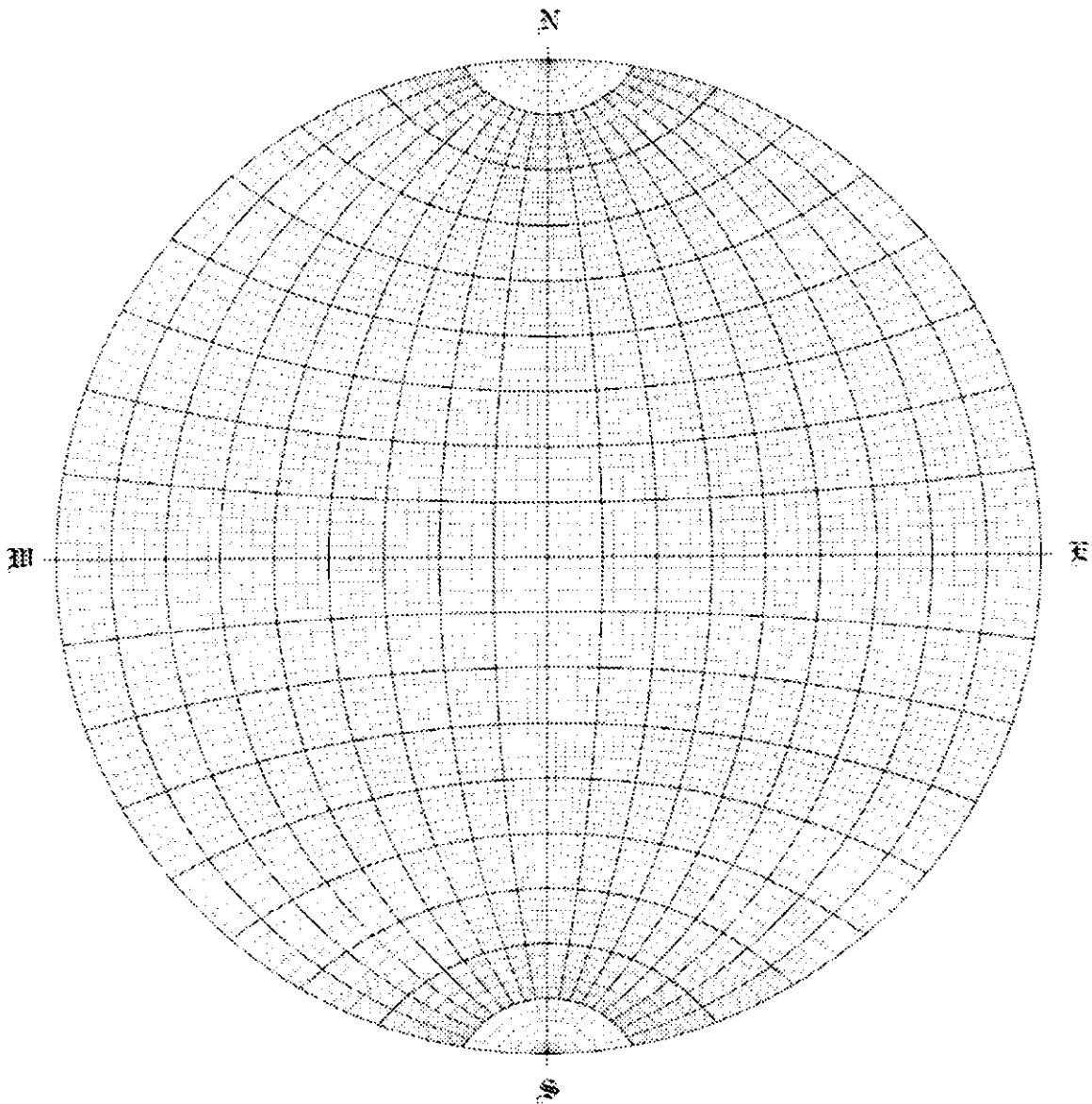

Figure Q2(b) : Equatorial equal-area stereo net marked in 2° intervals

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Table Q6(a)

DESCRIPTION	VALUE	NOTES
1. ROCK QUALITY DESIGNATION	***RQD***	
A. Very poor	0 - 25	1. Where *RQD* is reported or measured as ≤ 10 (including 0), a nominal value of 10 is used to evaluate *Q*.
B. Poor	25 - 50	
C. Fair	50 - 75	
D. Good	75 - 90	2. *RQD* intervals of 5, i.e. 100, 95, 90 etc. are sufficiently accurate.
E. Excellent	90 - 100	
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 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.
c. No rock wall contact when sheared		
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)	
4. JOINT ALTERATION NUMBER	J_a	ϕ_r (approx.)
a. Rock wall contact		
A. Tightly healed, hard, non-softening, impermeable filling	0.75	
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

1. Values of ϕ_r, the residual friction angle, are intended as an approximate guide to the mineralogical properties of the alteration products, if present.

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4. JOINT ALTERATION NUMBER	J_a	ϕ 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 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 zones 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	

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DESCRIPTION	VALUE			NOTES
6. STRESS REDUCTION FACTOR			***SRF***	
b. Competent rock, rock stress problems				
	σ_c/σ_1	σ_t/σ_1		2. For strongly anisotropic virgin stress field
H. Low stress, near surface	> 200	> 13	2.5	(if measured): when $5 \le \sigma_1/\sigma_3 \le 10$, 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 $\sigma_1/\sigma_3 > 10$,
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. Where 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.

Excavation category		*ESR*
A	Temporary mine openings.	3-5
B	Permanent mine openings, water tunnels for hydro power (excluding high pressure penstocks), pilot tunnels, drifts and headings for large excavations.	1.6
C	Storage rooms, water treatment plants, minor road and railway tunnels, surge chambers, access tunnels.	1.3
D	Power stations, major road and railway tunnels, civil defence chambers, portal intersections.	1.0
E	Underground nuclear power stations, railway stations, sports and public facilities, factories.	0.8

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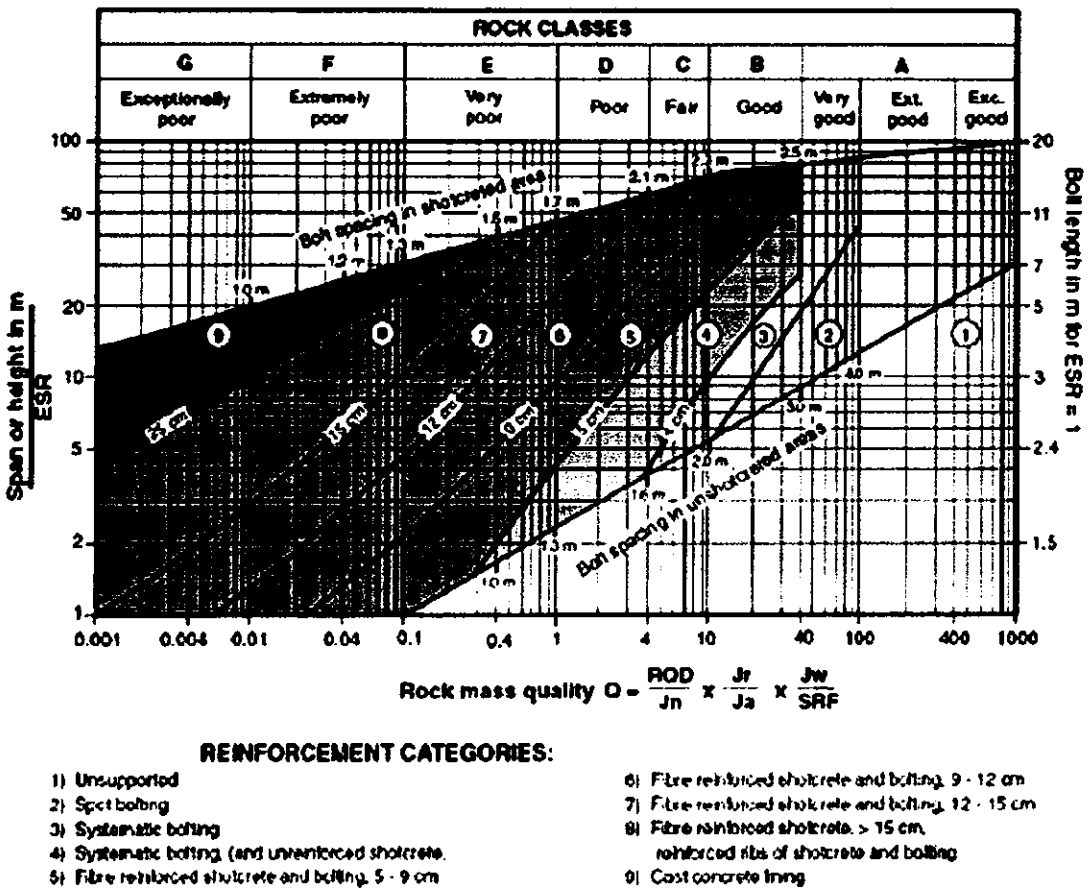

REINFORCEMENT CATEGORIES:

1) Unsupported
2) Spot bolting
3) Systematic bolting
4) Systematic bolting (and unreinforced shotcrete.
5) Fibre reinforced shotcrete and bolting, 5 - 9 cm
6) Fibre reinforced shotcrete and bolting, 9 - 12 cm
7) Fibre reinforced shotcrete and bolting, 12 - 15 cm
8) Fibre reinforced shotcrete, > 15 cm, reinforced ribs of shotcrete and bolting
9) Cast concrete lining

Figure Q6(a) : Estimated support categories based on the tunneling quality index, Q (After Grimstad and Barton, 1993, reproduced from Palmstrom and Broch, 2006)

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Table Q6(b) : Rock Mass Rating System (After Bieniawski, 1989)

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

Parameter			Ranges of values						
1	Strength of intact rock material	Point-load strength index	>10MPa	4-10MPa	2-4MPa	1-2MPa	For this low range-uniaxial compressive test is preferred		
		Uniaxial Compression strength	>250MPa	100-250MPa	50-100MPa	25-50MPa	5-25MPa	1-5MPa	<1MPa
	Rating		15	12	7	4	2	1	0
2	Drill core Quality RQD		90%-100%	75%-90%	50%-75%	25%-50%	<25%		
	Rating		20	17	13	8	3		
3	Spacing of discontinuities		>2mm	0.6-2mm	200-600mm	60-200mm	<60mm		
	Rating		20	15	10	8	5		
4	Condition of discontinuities (See E)		Very rough surfaces. Not continous. No separation. Unweathered wall rock.	Slightly rough surfaces. Separation <1mm. Slightly weathered walls.	Slightly rough surfaces. Separtion < 1 mm. Highly weathered walls.	Slickensided surfaces or Gouge<5 mm thick or Separtion 1-5 mm continous.	Soft gouge>5 mm thick or Separtion>5mm continous.		
	Rating		30	25	20	10	0		
5	Groundwater	Inflow per 10 m tunnel length (l/m)	None	<10m	10-25	25-125	>125		
		(Joint water press)/ (Major principal)	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 ORIENTATION (SEE F)

Strike and dip orientations		Very favourable	Favourable	Fair	Unfavorable	Very Unfavorable
Rating	Tunnels and mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	0

C. ROCK MASS CLASSES

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 ROCK CLASSES

Class number	I	II	III	IV	V
Average stand-up time	20 years for 15 m span.	1 year for 10 m span.	1 week for 5 m span	10 hours for 2.5 m span	30 minutes for 1 m span
Cohesion of rock mass (kPa)	>400	300-400	200-300	100-200	<100
Friction angle of rock mass (degree)	>45	35-45	25-35	15-25	<15

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY CONDITIONS * (1) IS RATING

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

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELING

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip- 45°-90°	Drive with dip- 20°-45°	Dip 45°-90°	Dip 20°-45°
Very favourable	Favourable	Very unfavourable	Fair
Drive against dip- 45°-90°	Drive against dip-20°-45°	Dip 0°-20° –Irrespective of strike	
Fair	Unfavourable	Fair	

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Cont'd

Rock Mass class	Excavation	Rock bolts (20 mm diameter, fully grouted)	Shotcrete	"Steel sets"
I-Very good rock RMR:81-100	Full face, 3 m advance	Generally no support required except spot bolting		
II-Good rock RMR:61-80	Full face, 1-1.5 m advance. Complete support 20 m from face.	Locally, bolts in crown 3 m long, spaced 2.5 m with occasional wire mesh	50 mm in crown where required.	None
III-Fair rock RMR:41-60	Top heading and bench 1.5-3 m advance in top heading. Commence support after each blast. Complete support 10 m from face	Systematic bolts 4 m long, spaced 1.5-2m in crown and walls with wire mesh in crown.	50-100 mm in crown and 30 mm in sides.	None
IV-Poor rock RMR:21-40	Top heading and bench 1.0-1.5 m advance in top heading. Install support concurrently with excavation, 10 m from face.	Systematic bolts 4 m long, spaced 1-1.5m in crown and walls with wire mesh.	100-150 mm in crown and 100 mm in sides.	Light to medium ribs spaced 1.5 m where required.
V-Very poor rock RMR<20	Multiple drifts 0.5-1.5 m advance in top heading. Install support concurrently with excavation. Shotcrete as soon as possible after blasting.	Systematic bolts 5-6 m long, spaced 1-1.5m in crown and walls with wire mesh. Bolt invert.	150-200 mm in crown, 150 mm in sides, and 50 mm on face.	Medium to heavy ribs spaced 0.75 m with steel lagging and fore poling if required. Close invert.