UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESI 2009/2010

SUBJECT NAME	:	GEOLOGI KEJURUTERAAN
SUBJECT CODE	:	BFC 3013
COURSE	:	3 BFF
EXAMINATION DATE	:	NOVEMBER 2009
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWER ALL QUESTIONS FROM PART A AND ONE (1) QUESTION FROM PART B

THIS PAPER CONSIST OF TWENTY EIGHT (28) PAGES

PART A (75 marks)

Q1 (a) The knowledge of Geology and Engineering Geology are important in the Civil Engineering field.

(i) Give the definition of rocks and minerals.

(2 marks)

(ii) List **FOUR (4)** engineering works that need the understanding of the geological aspect.

(2 marks)

(iii) Describe all major concepts of earth physical features.

(4 marks)

(b) Weathering is one of the most important geological processes that leads to the disintegration or decomposition of geologic deposits.

(i) List **FOUR (4)** physical forces that contribute to the physical weathering.

(2 marks)

(ii) Sketch and describe spheriodal weathering.

(3 marks)

(iii) Explain **TWO (2)** engineering works that requires the understanding of the weathering of rock.

(4 marks)

(c) Rock testing is an important part of Rock Mechanics as it provides means for assessing and evaluating the rock material properties.

(i) List **TWO (2)** testing methods or procedures for rock testing.

(1 mark)

(ii) Explain **FOUR (4)** types of strength of rock material and mass that need to be evaluated for the design of civil engineering structures.

(4 marks)

(iii) State **THREE (3)** disadvantages of the strergth test.

(3 marks)

Q2 (a) Calculate the Rock Quality Designation (RQD) value from **Figure Q2** if height of the tunnel is 15m.

(4 marks)

(b) A 20m span of civil defence chamber for an underground mine is to be excavated at a depth of 2100m below ground surface. The rock mass contains three joint sets plus random controlling stability. These joints are smooth, planar and the rock wall contact is tightly healed, hard, non-softening and impermeable filling. Laboratory test on core samples of intact rock give an average uniaxial compressive strength of 100MPa. The principal stress are approximately vertical and horizontal and the magnitude of the horizontal principal stress is approximately 1.5 times that of the vertical principal stress. The rock is a competent rock and having a stress problem. The rock mass is locally damp with minor inflow. By using the RQD value obtained from **Q2(a)**, calculate Q based on data given in **Figure Q2(b)**.

(8 marks)

(c) A tunnel is constructed and driven through slightly weathered gabbro with a dominant joint set dipping at 40° against the direction of the tunnel drive. The discontinuities strike perpendicular to the tunnel axis. Based on the point load test, the rock strength is 7 MPa. The joints are rough and average length of the joint is 4 m with a separation between 0.1 to 0.5 mm, with 3 mm hard infilling materials and spacing between the joints is 3 m. Groundwater of the tunneling condition is anticipated to be damp. By using the RQD value obtained from **Q2(a)**, calculate the Rock Mass Rating (RMR) value based on the data given in **Figure Q2(c)**.

(13 marks)

Q3 (a) A proposed highway alignment is shown in **Figure Q3**. A discontinuity survey was conducted along the proposed cut slopes A and B, and the results are given in **Table 3**.

Table 3

Joint set 1, °	Joint set 2, °	Joint set 3, °
78/60	312/50	175/54
77/51	312/60	176/66
67/62	322/60	208/66
65/53	322/50	209/54

(i) Plot all the poles above for the slope discontinuity orientation data on a stereonet by using the equal area equatorial net as given in **Figure Q3(a)(i)** and the tracing paper given.

(3 marks)

(ii) Estimate and plot the mean poles for each data plotted from **Q3 (a)** and draw the great circle for all respective mean poles. Determine the values of dip direction and dip angle for all mean great circles plotted and tabulate the values in **Figure Q3(a)(ii)**.

(3 marks)

(b) Answer the following question with reference to **Figure Q3**.

(i) Determine the values of strikes and dip directions for the proposed cut slope A and B and tabulate the values in **Figure Q3(b)**.

(4 marks)

(ii) Calculate the values of dip angle for the proposed cut slopes A and B, and tabulate the values in **Figure Q3(b)**.

(4 marks)

(iii) By using the answer from **Q3(b)(i)** and **Q3(b)(ii)**, draw the great circle for the cut slope on all direction (A and B).

(2 marks)

(iv) A study of joint sets reveals that all joints have a friction angle of 25°. Draw the friction angle for slope A and B on the same tracing paper.

(1 marks)

(c) Based on the answers from **Q3(a)** and **Q3(b)**, analyze the entire mode of failure at the proposed rock slope (A and B) and state the criteria as an evidence. Tabulate the results in the **Figure Q3(c)**.

(8 marks)

PART B (25 marks)

Q4 (a) During a site study, it was found that a tension crack was 2.0 meter deep and filled saturated with water of its depth. The friction angle value is the same as given in **Q3(b)(iv)**. Other information from the site study and laboratory works are given as follows:

Rock unit weight = 25 kN/m^3
Water unit weight = 9.81 kN/m^3
Height of plane = 70 m
Cohesion of all discontinuities = 50 kPa
Bars for Y_{25} = 10 ton = 100 kN

Using the cut slope data from **Q3(b)**, calculate and conclude the safety factor for plane failure for slope A based on the formula given in **Figure Q4(a)**.

(7 marks)

(b) From **Q4(a)**, estimate the required reinforcement with tensioned anchor bolts (T) of slope A based on the formula given in **Figure Q4**. Given the installation of anchor bolts at angle (Ω) is 20° and the safety factor needed by the client is 1.5.

(5 marks)

(c) Propose the appropriate excavation and support system based on the Q value obtained from **Q2(b)** and based on **Figure Q4(c)**.

(3 marks)

(d) The deep foundation of a high rise building should penetrate deeper to reach limestone rock layer formation due to insufficient capacity of the soft soil layer as shown in the **Figure Q4(d)**. Diameter of the pile is 40 cm.

(i) With the aid of sketch, explain the different between end bearing and drilled socket pile on rock. Then, explain the design steps of both end bearing and drilled socket pile

(4 marks)

(ii) Determine the vertical capacity if the pile is drilled 2 m to the rock layer based on **Figure Q4(d)(ii)**.

(6 marks)

Q5 (a) The electrical tower should be constructed on the rock formation of rhyolite. The information from the site study and laboratory works are given as follows:

Data of rock : RMR value = 60
Uniaxial compressive strength = 100 MPa

Data of loading from tower : Vertical load = 1500 ton
Moment load = 40 ton-meter
Horizontal load = 100 ton

(i) Explain the difference between uniaxial compressive strength of intact rock, uniaxial compressive strength of rock mass and bearing capacity

(3 marks)

(ii) Calculate the compressive strength of the rock and suggest the type of test to obtain the compressive strength based on **Figure Q5(a)** and **Figure Q5(a)(i)**.

(3 marks)

(iii) Calculate the tensile strength of the rock and what type of test to obtain this tensile strength based on **Figure Q5(a)** and **Figure Q5(a)(i)**.

(4 marks)

(iv) Design a suitable square footing foundation to support this electrical tower with an approved Safety Factor of bearing capacity = 2 and SF for horizontal load = 2.5. The strength parameter of cohesion and friction angle are 2 MPa and 35 ° respectively, Cfl for the square footing = 1.25 based on **Figure Q5(a)(i)** and use the formula below.

$$q_a = \frac{Cf_1 s^{1/2} \sigma_{u(r)} [1 + (ms^{-1/2} + 1)^{1/2}]}{SF} \quad \text{and} \quad SF = \frac{C_{ad} A + V \tan \delta}{H}$$

(8 marks)

(b) Determine the values of cohesion and friction angle for the gabbro according to the RMR value obtained from **Q2(c)** based on the values given in **Figure Q2(c)**.

(2 marks)

(c) Assess the stand up time of the tunnel without support using the RMR value obtained from **Q2(c)** and the values given in **Figure Q2(c)**.

(1 marks)

(d) Propose the appropriate excavation and support system based on the RMR value obtained from **Q2(c)** and based on **Figure Q5(d)**.

(4 marks)

BAHAGIAN A (75 markah)

S1 (a) Ilmu pengetahuan berkenaan Geologi dan Geologi Kejuruteraan adalah penting dalam bidang Kejuruteraan Awam.

(i) Berikan definisi mineral dan batu.

(2 markah)

(ii) Senaraikan **EMPAT (4)** kerja – kerja kejuruteraan yang memerlukan pengetahuan dalam bidang Geologi Kejuruteraan.

(2 markah)

(iii) Terangkan kesemua konsep penting berkenaan ciri – ciri fizikal bumi.

(4 markah)

(b) Luluhawa merupakan antara satu proses geologi yang penting dalam penyepaian dan penguraian bahan enapan geologi.

(i) Senaraikan **EMPAT (4)** daya - daya fizikal penyumbang kepada luluhawa jenis fizikal.

(2 markah)

(ii) Terangkan beserta lakaran berkenaan luluhawa *spheriodal*.

(3 markah)

(iii) Nyatakan **DUA (2)** kerja – kerja kejuruteraan yang memerlukan pengetahuan ilmu berkenaan luluhawa batuan.

(4 markah)

(c) Ujikaji batuan merupakan bidang penting dalam Mekanik Batuan kerana bidang ini mampu menunjukkan kaedah untuk penilaian sifat sesuatu bahan batuan.

(i) Senaraikan **DUA (2)** kaedah ujikaji atau prosedur yang terdapat dalam ujikaji batuan.

(1 markah)

(ii) Nyatakan **EMPAT (4)** jenis kekuatan bahan dan jasad batuan yang diperlukan untuk penilaian rekabentuk struktur kejuruteraan awam.

(4 markah)

(iii) Berikan **TIGA (3)** keburukan ujikaji kekuatan.

(3 markah)

S2 (a) Kirakan nilai Penanda Mutu Batuan (PMB) seperti yang ditunjukkan dalam **Figure Q2** jika ketinggian terowong ialah 15m.

(4 markah)

(b) Satu ruang pertahanan awam sepanjang 20m rentangan untuk lombong bawah tanah akan dikorek pada kedalaman 2100m dari aras permukaan bumi. Kestabilan jasad batuan bergantung kepada tiga set kekar tambah rawak. Kekar tersebut adalah licin dan bersatah. Sentuhan dinding batuan adalah rapat, keras, dan berpengisian tidak telap. Ujikaji makmal pada sampel korekan batuan sempurna memberikan nilai purata kekuatan mampatan satu paksi sebanyak 100MPa. Arah tegasan prinsip adalah dianggarkan mendatar dan pugak dan magnitud tegasan prinsip mendatar adalah dianggarkan sebanyak 1.5 lebih daripada tegasan prinsip pugak. Jasad batuan berkeadaan lembap setempat dengan pengaliran air sedikit. Dengan menggunakan nilai PMB daripada **S2(a),** kirakan nilai Q dengan berpandukan **Figure Q2(b).**

(8 markah)

(c) Sebuah terowong dibina melalui batuan gabbro sedikit terluluhawa di mana kekar dominannya bersudut kemiringan 40° dan miring bertentangan dengan arah laluan masuk pembinaan terowong. Jurus ketakselanjaran adalah berserenjang dengan paksi terowong. Berdasarkan ujian beban titik, kekuatan batuan adalah 7 MPa. Kekar menunjukkan sifat permukaan kasar, panjang kekar berpurata 4m, bukaan kekar berukuran antara 0.1mm hingga 0.5mm dengan bahan isian keras sebanyak 3mm dan purata jarak antara kekar adalah 3m. Keadaan aras air bumi terowong adalah berkeadaan lembap. Dengan menggunakan nilai PMB daripada **S2(a)**, kirakan nilai *Rock Mass Rating* (RMR) dengan berpandukan kepada **Figure Q2(c)**.

(13 markah)

S3 (a) Cadangan pembinaan jajaran lebuhraya adalah seperti yang diberikan dalam **Figure Q3**. Kerja-kerja tinjauan ketakselanjaran telah dilakukan di sepanjang cadangan cerun potong (A dan B) dan keputusannya adalah seperti yang diberikan dalam **Table 3**.

Table 3

Set Kekar 1, °	Set Kekar 2, °	Set Kekar 3, °
78/60	312/50	175/54
77/51	312/60	176/66
67/62	322/60	208/66
65/53	322/50	209/54

(i) Plotkan kesemua orientasi bagi setiap ketakselanjaran di atas secara plotan kutub dengan menggunakan jaringan stereo sama luas dalam **Figure Q3(a)(i)** dan kertas surih yang disediakan.

(3 markah)

(ii) Anggarkan dan plotkan kedudukan purata kutub untuk setiap set data yang telah diplot dari **S3(a)** dan lukiskan bulatan besar bagi setiap purata kutub untuk setiap set. Berikan nilai untuk arah dan sudut kemiringan bagi setiap set bulatan besar yang telah dilukiskan itu dalam **Figure Q3(a)(ii)**.

(3 markah)

(b) Dengan merujuk kepada **Figure Q3**, jawab soalan berikut:

(i) Berikan data bagi jurus dan arah miring bagi cerun potong A dan B dalam **Figure Q3(b)**.

(4 markah)

(ii) Kirakan nilai sudut kemiringan bagi cerun potong A dan B dan jadualkan nilai tersebut dalam **Figure Q3(b)**.

(4 markah)

(iii) Berdasarkan jawapan yang diperolehi daripada **S3(b)(i) dan S3(b)(ii)**, lukiskan bulatan besar bagi kesemua arah cerun tersebut (A dan B).

(2 markah)

(iv) Kajian set kekar mendapati kesemua nilai sudut geseran kekar batuan pada cerun tersebut adalah 25°. Lukiskan nilai sudut geseran tersebut pada kesemua cerun A dan B di atas kertas surih yang sama.

(1 markah)

(c) Berdasarkan jawapan dari **S3(a)** dan **S3(b)**, periksa dan tentukan kesemua mod kegagalan cerun batuan yang dicadangkan tersebut bersama-sama kriterianya sebagai bukti. Jadualkan keputusan tersebut pada **Figure Q3(c)**.

(8 markah)

BAHAGIAN B (25 markah)

S4 (a) Semasa kajian tapak, didapati kedalaman retakan ketegangan adalah sepanjang 2.0 meter dan berkeadaan tepu. Nilai sudut geseran adalah sama seperti yang diberikan pada **S3(b)(iv)**. Maklumat-maklumat lain yang diperolehi daripada kajian tapak dan makmal adalah seperti berikut:

Berat unit batuan = 25 kN/m^3
Berat unit air = 9.81 kN/m^3
Ketinggian satah = 70 meter
Daya jelekitan kesemua satah ketakselanjaran = 50 kPa
Tetulang jenis Y_{25} = 10 ton = 100 kN

Dengan menggunakan data cerun yang diperolehi daripada **S3(b)**, kirakan faktor keselamatan kegagalan satah bagi cerun A serta simpulkan kestabilannya berdasarkan keputusan yang diperolehi berpandukan **Figure Q4(a)**.

(7 markah)

(b) Daripada **S4(a)**, anggarkan tetulang bolt penambat tertegang (T) yang diperlukan oleh cerun B jika tetulang bolt penambat tertegang tersebut dimasukkan pada sudut (Ω) 20° pada nilai faktor keselamatan 1.5 seperti yang dikehendaki oleh klien dengan berpandukan **Figure Q4(a)**.

(5 markah)

(c) Cadangkan jenis sistem sokongan dan pengorekan yang harus digunakan dengan nilai Q yang diperolehi daripada jawapan **S2(b)** berpandukan kepada **Figure Q4 (c)**.

(3 markah)

(d) Asas dalam satu bangunan tinggi perlu dimasukkan dengan lebih dalam sehingga pada formasi batu kapur disebabkan oleh kekurangan kapasiti lapisan tanah lembut seperti yang ditunjukan dalam **Figure Q4(d)**. Diberi diameter cerucuk ialah 40 cm.

(i) Dengan bantuan lakaran, terangkan perbezaan antara *end bearing* dan *drilled socket pile* pada batuan Kemudian terangkan langkah - langkah rekabentuk untuk kedua - dua jenis asas *end bearing* dan *drilled socket pile*.

(4 markah)

(ii) Kirakan kapasiti pugak jika cerucuk tersebut digerudi sehingga 2 m ke dalam lapisan batuan berpandukan **Figure Q4(d)(ii).**

(6 markah)

S5 (a) Satu menara pencawang elektrik hendak dibina di atas permukaan formasi batuan riolit. Data daripada penyiasatan tapak dan makmal adalah seperti yang diberikan di bawah:

Data batuan:

Nilai RMR = 60
Kekuatan mampatan satu paksi = 100 Mpa

Data beban daripada menara pencawang elektrik:

Beban pugak = 1500 tan
Beban momen = 40 tan – meter
Beban ufuk = 100 tan

(i) Terangkan perbezaan antara kekuatan tekan satu paksi batuan utuh, massa batuan dan keupayaan galas batuan.

(3 markah)

(ii) Kirakan nilai kekuatan mampatan batuan berpandukan **Figure Q5(a)** dan **Figure Q5(i).**

(3 markah)

(iii) Kirakan nilai kekuatan regangan batuan dan apakah jenis ujikaji bagi mendapatkan kekuatan regangan **Figure Q5(a)** dan **Figure Q5(i).**

(4 markah)

(iv) Rekabentuk suatu asas cetek sama segi yang sesuai bagi menampung menara pencawang elektrik tersebut dengan nilai faktor keselamatan yang telah ditetapkan sebanyak 2.0 dan 2.5 untuk faktor keselamatan terhabdap beban ufuk. Nilai jelekitan dan sudut geser dalam adalah 2 Mpa dan 35° Cf_1 sebanyak 1.25 bagi asas cetek sama segi berpandukan **Figure Q5(i)** dan formula di bawah.

$$q_a = \frac{Cf_1 s^{1/2} \sigma_{u(r)} [1 + (ms^{-1/2} + 1)^{1/2}]}{SF} \text{ dan } SF = \frac{C_{ad} A + V \tan\delta}{H}$$

(8 markah)

(b) Berikan penilaian untuk nilai kejelekitan dan sudut geseran batu gabbro berpandukan dengan nilai RMR yang diperolehi dari **S2(c)** berpandukan kepada **Figure Q2(c)**.

(2 markah)

(c) Berikan penilaian mengenai ketahananan terowong tersebut tanpa sokongan dengan nilai RMR yang diperolehi dari soalan **S2(c)** berpandukan kepada **Figure Q2(c)**.

(1 markah)

(d) Cadangkan jenis sistem sokongan dan pengorekan yang harus digunakan dengan nilai RMR yang diperolehi daripada jawapan **S2(c)** berpandukan kepada **Figure Q5(d)**.

(4 markah)

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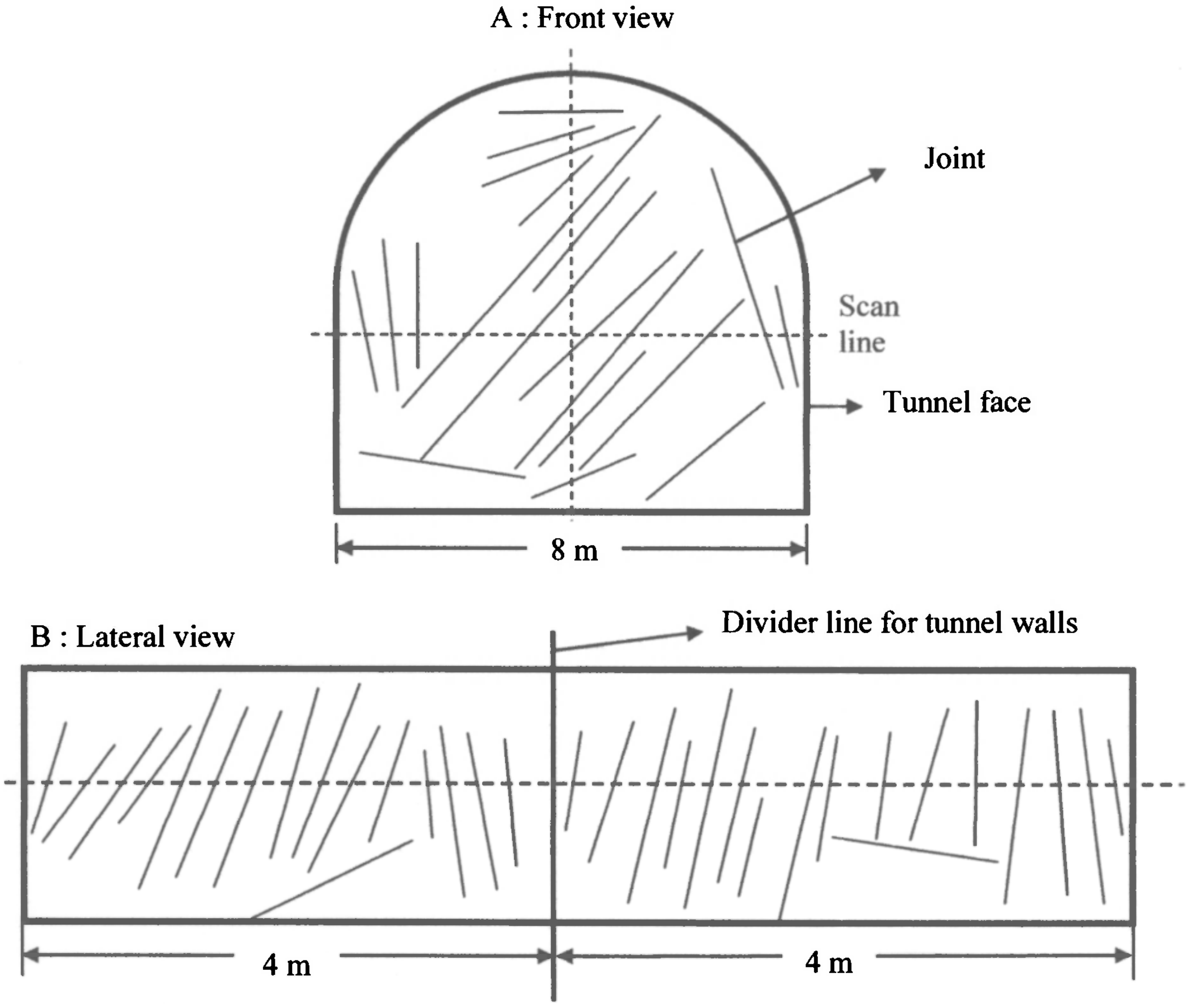

FIGURE Q2 : Discontinuities on surface of the tunnel wall viewed from the front and lateral.

(Drawing: Not to scale)

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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	ϕ_r degrees (approx.)	
a. Rock wall contact			
A. Tightly healed, hard, non-softening, impermeable filling	0.75		1. Values of ϕ_r, 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	

FIGURE Q2(b)

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4. JOINT ALTERATION NUMBER	J_a	ϕ_r 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	

FIGURE Q2(b) continued

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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. 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.

FIGURE O2(b) continued

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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

<u>FIGURE Q2(b)</u> continued

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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	

FIGURE Q2(c) : Rock Mass Rating System (After Bieniawski, 1989)

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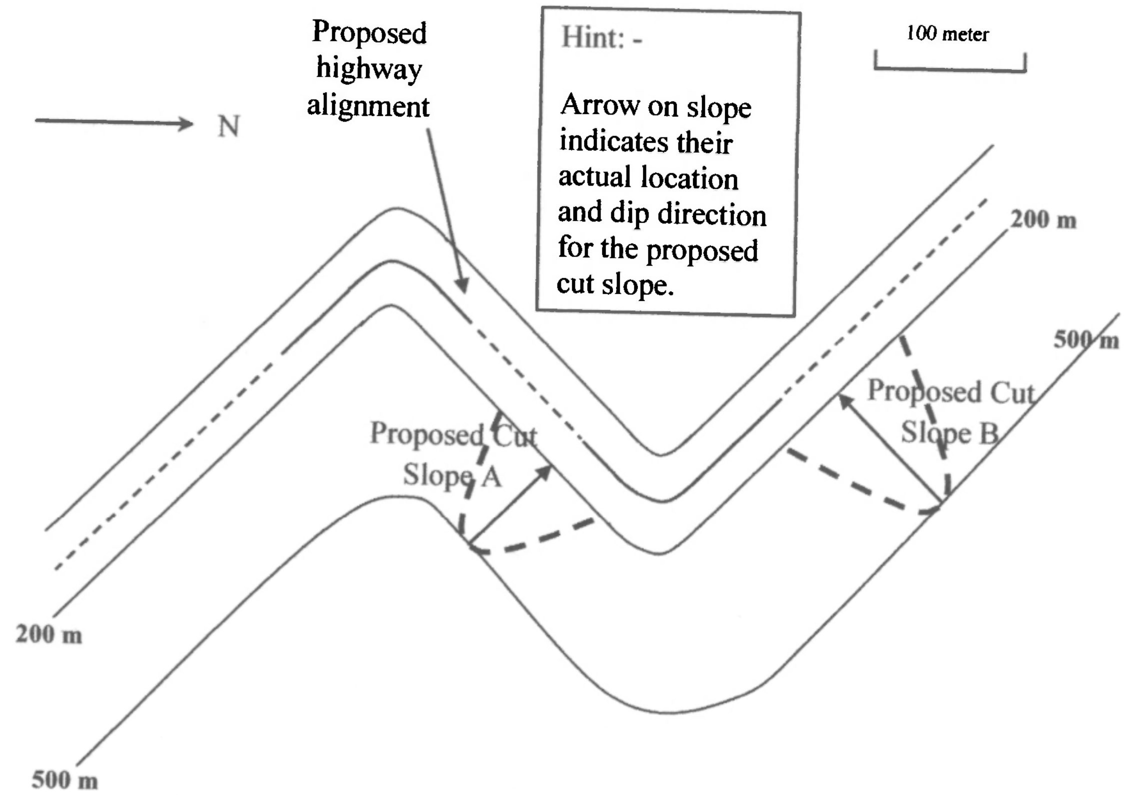

FIGURE Q3 : Proposed road alignment and the box cut of rock slope A side and B side from plan view

(Drawing: Scaled)

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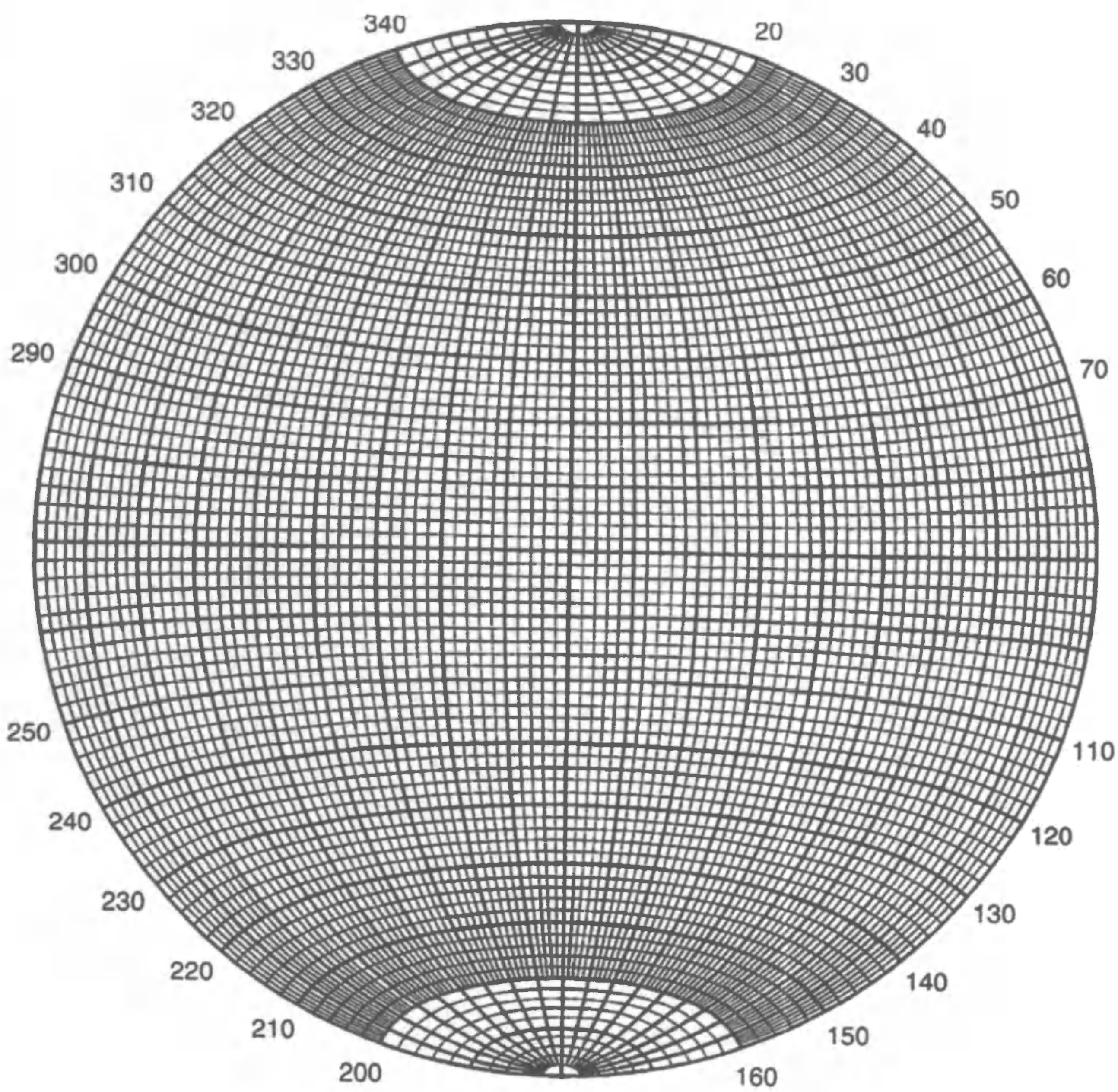

FIGURE Q3(a)(i) : **Equal-area equatorial net for plotting poles and great circles (DO NOT CHANGE THE SIZE)**

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Joint set	Dip direction, ° N	Dip angle, °
J1		
J2		
J3		

FIGURE Q3(a)(ii)

Slope	Strike, ° N	Dip direction, ° N	Dip angle, °
A			
B			

FIGURE Q3(b)

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Slope	Mode of failure	Joint set and data	Criteria	Stability
A	Plane			
A	Wedge			
A	Toppling			
B	Plane			
B	Wedge			
B	Toppling			

FIGURE Q3(c)

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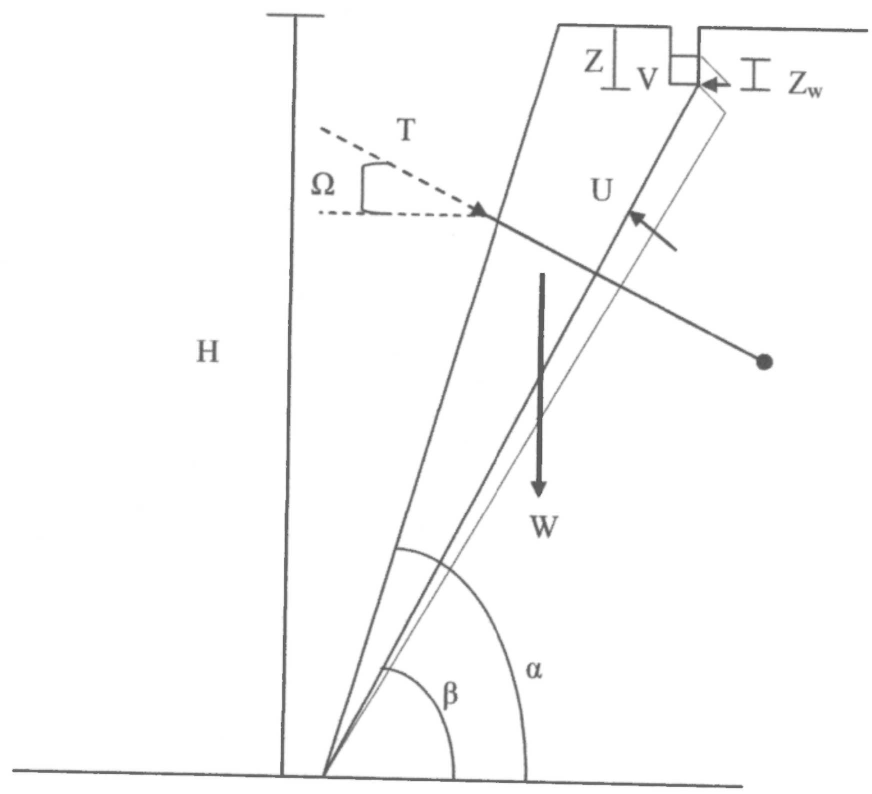

Given:

$$FOS = \frac{cA + (W\cos\beta - U - V\sin\beta + T\sin(\Omega+\beta))\tan\phi}{W\sin\beta + V\cos\beta - T\cos(\Omega+\beta)}$$

$A = (H-Z).\mathrm{cosec}\,\beta$

$W = \frac{1}{2}\gamma_r.H^2[(1-(Z/H)^2)\cot\beta - \cot\alpha]$

$U = \frac{1}{2}\gamma_w.Z_w.(H-Z).\mathrm{cosec}\,\beta$

$V = \frac{1}{2}\gamma_w.Z_w$

cosec = 1/sin sec=1/cos cot=1/tan

FIGURE O4(a)

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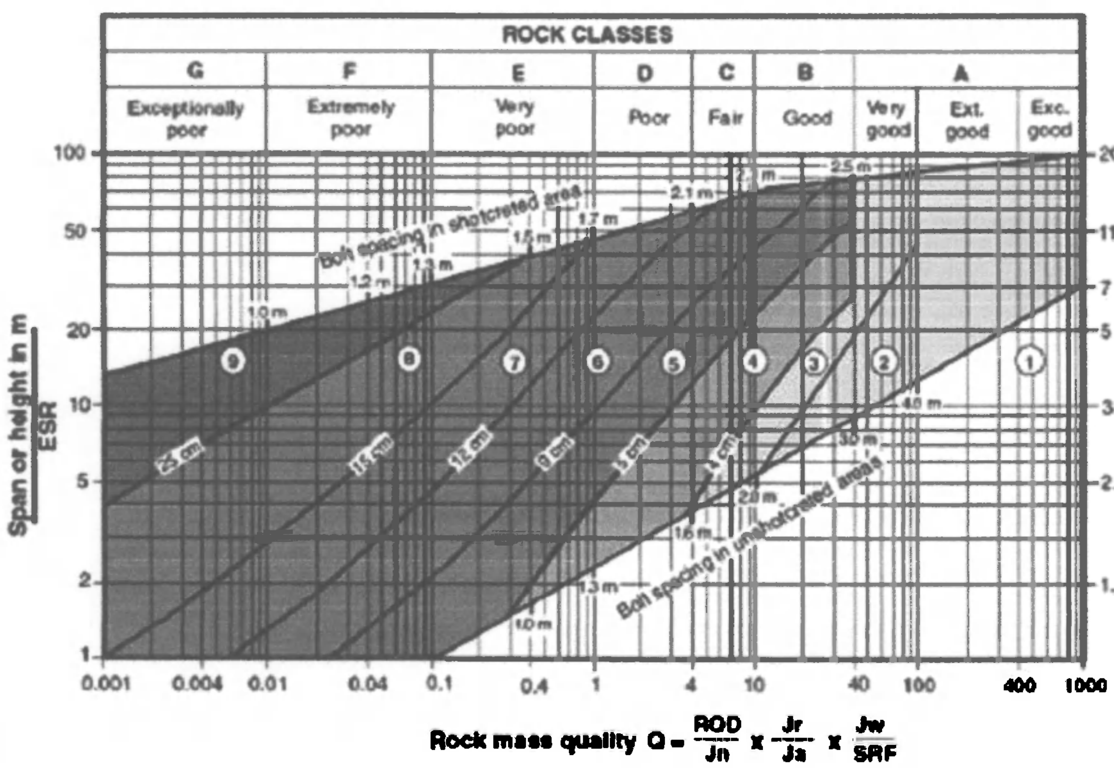

REINFORCEMENT CATEGORIES:

1) Unsupported
2) Spot bolting
3) Systematic bolting
4) Systematic bolting, (and unreinforced shotcrete, 4 – 5 cm)
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 Q4(c) : 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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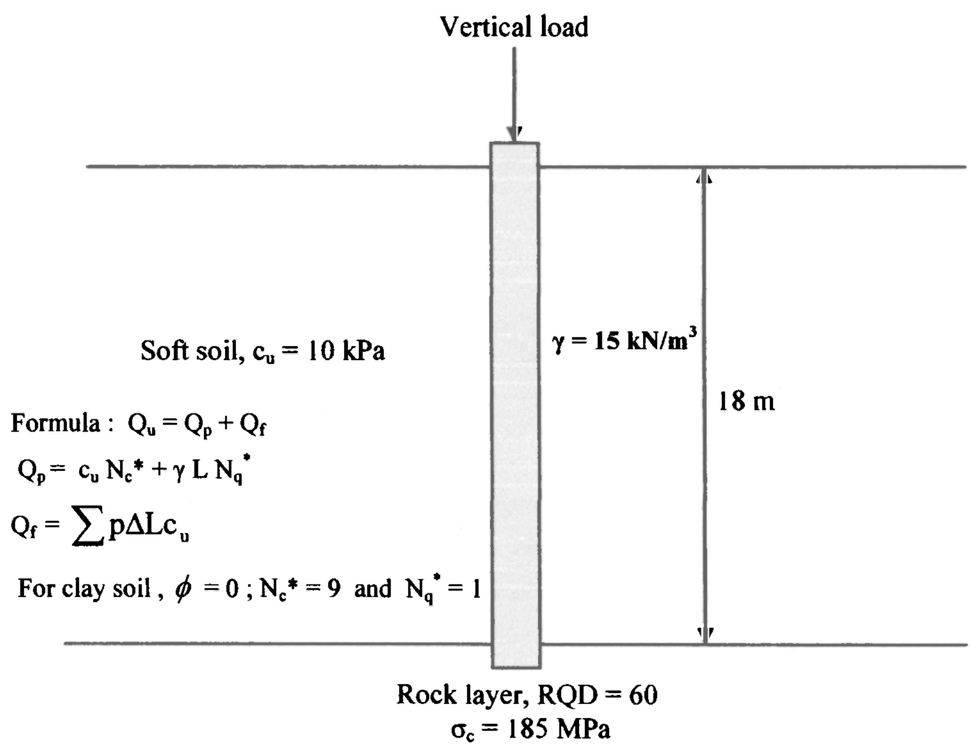

FIGURE Q4(d)

TABLE 5.17 Allowable Rock-Socket, Skin-Friction C_{bs}, and End-bearing Values for Bored Piles in Rocks (Tomlinson, 1977)

	Allowable Skin-Friction on Rock Socket		Allowable End-bearing Pressure	
Type of Rock	(kN/m²)	(tons/ft²)	(kN/m²)	(tons/ft²)
Manhattan schist	1330	13.9	—	—
Black Utica shale (Montreal)	1120	11.7	2,620	24.4
Black Billings shale (Ottawa)	1120	11.7	—	—
Dundas shale (Toronto)	1120	11.7	7,850	73.2
Limestone (Chicago)	1716	17.9	10,468	96
Fragmented shale	107	1.1	—	—
Widely fissured hard sandstone	429	4.5	—	—

where

p = pile perimeter ($= \pi B$ for circular pile)
L_s = socketed pile length in the rock
C_{bs} — allowable bond strength between concrete and rock

FIGURE Q4(d)(ii) : Allowable skin pressure (q_a) and end bearing pressure pressure

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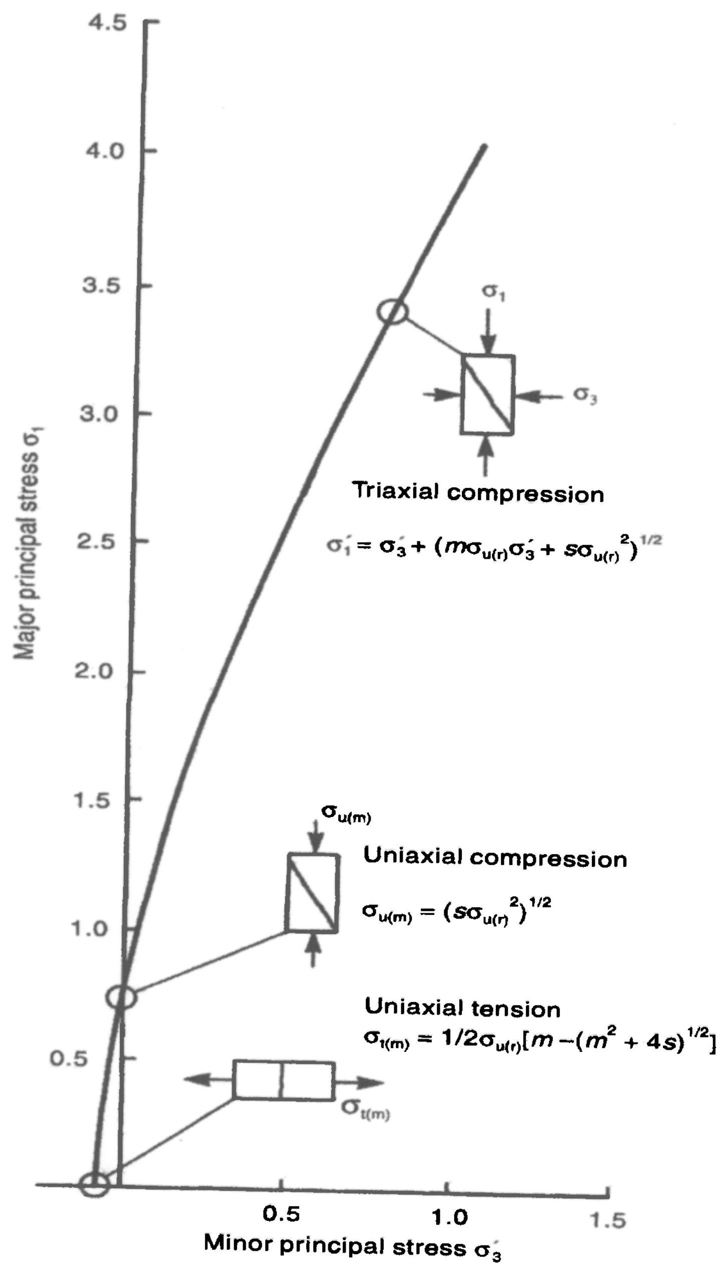

FIGURE Q5(a) : Strength of fractured rock (Hoek, 1983)

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Empirical failure criterion:
$\sigma_1' = \sigma_3' + \sqrt{m\sigma_{c(r)}\sigma_3' + s\sigma_{c(r)}^2}$
σ_1' = major principal effective stress
σ_3' = minor principal effective stress
$\sigma_{c(r)}$ = uniaxial compressive strength of intact rock, and
m and s are empirical constants.

		CARBONATE ROCKS WITH WELL DEVELOPED CRYSTAL CLEAVAGE *dolomite, limestone and marble*	LITHIFIED ARGILLACEOUS ROCKS *mudstone, siltstone, shale and slate (normal to cleavage)*	ARENACEOUS ROCKS WITH STRONG CRYSTALS AND POORLY DEVELOPED CRYSTAL CLEAVAGE *sandstone and quartzite*	FINE GRAINED POLYMINERALLIC IGNEOUS CRYSTALLINE ROCKS *andesite, dolerite, diabase and rhyolite*	COARSE GRAINED POLYMINERALLIC IGNEOUS & METAMORPHIC CRYSTALLINE ROCKS *amphibolite, gabbro gneiss, granite, norite, quartz-diorite*
INTACT ROCK SAMPLES *Laboratory size specimens free from discontinuities* *CSIR rating: *RMR* = 100 †NGI rating: *Q* = 500	m s	7.00 1.00	10.00 1.00	15.00 1.00	17.00 1.00	25.00 1.00
VERY GOOD QUALITY ROCK MASS *Tightly interlocking undisturbed rock with unweathered joints at 1–3 m* CSIR rating: *RMR* = 85 NGI rating: *Q* = 100	m s	2.40 0.082	3.43 0.082	5.14 0.082	5.82 0.082	8.56 0.082
GOOD QUALITY ROCK MASS *Fresh to slightly weathered rock, slightly disturbed with joints at 1–3 m* CSIR rating: *RMR* = 65 NGI rating: *Q* = 10	m s	0.575 0.00293	0.821 0.00293	1.231 0.00293	1.395 0.00293	2.052 0.00293
FAIR QUALITY ROCK MASS *Several sets of moderately weathered joints spaced at 0.3–1 m* CSIR rating: *RMS* = 44 NGI rating: *Q* = 1	m s	0.128 0.00009	0.183 0.00009	0.275 0.00009	0.311 0.00009	0.458 0.00009
POOR QUALITY ROCK MASS *Numerous weathered joints at 30–500 mm, some gouge. Clean compacted waste rock* CSIR rating: *RMR* = 23 NGI rating: *Q* = 0.1	m s	0.029 0.000003	0.041 0.000003	0.061 0.000003	0.069 0.000003	0.102 0.000003
VERY POOR QUALITY ROCK MASS *Numerous heavily weathered joints spaced <50 mm with gouge. Waste rock with fines* CSIR rating: *RMR* = 3 NGI rating: *Q* = 0.01	m s	0.007 0.0000001	0.010 0.0000001	0.015 0.0000001	0.017 0.0000001	0.025 0.0000001

*CSIR Council of Scientific and Industrial Research (Bieniawski, 1974).
†NGI Norwegian Geotechnical Institute (Barton *et al.*, 1974).

FIGURE Q5(a)(i) : Approximate relationship between rock mass quality and material constants (Hoek and Brown, 1988)

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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.

FIGURE Q5(d) : Guidelines for excavation and support of 10 m span rock tunnels in accordance with the RMR system (After Bieniawski, 1989)

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