UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2010/2011

COURSE NAME	:	ENGINEERING GEOLOGY
COURSE CODE	:	BFC 21303 / BFC 3013
PROGRAMME	:	2 BFF / 3BFF
DATE	:	NOVEMBER / DECEMBER 2010
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWER **ALL** QUESTIONS FROM **PART A** AND **ONE** QUESTION FROM **PART B**

THIS PAPER CONSISTS OF THIRTY (30) PAGES

PART A (75 marks)

Q1 (a) Erosion is one of the important agent of removal and transportation of surficial materials which is the product of physical and chemical breakdown of rocks by process of weathering.

(i) List **FOUR (4)** types of sediment accumulate at continental environment.
(2 marks)

(ii) Describe **THREE (3)** factors that affect the rate at which running water will erode.
(3 marks)

(iii) List the sediment movement by:

(a) Water
(b) Wind
(3 marks)

(b) Over the past thousand million years of Earth history the crust of the Earth has been mobile and deform by squashed, stretched or fractured.

(i) Define the terms of joint, fault and fold.
(3 marks)

(ii) Describe all categories of fold.
(3 marks)

(iii) Define the terms of competent rock and incompetent rock in folded rock.
(2 marks)

(c) Conducting site investigations and rock testing is vital in the engineering geologist practice. The engineering geologist applies their geologic skills to the practical solution of engineering problems.

(i) Justify **TWO (2)** limitations of boring data in site investigation.
(2 marks)

(ii) Determine **THREE (3)** disadvantages of the seismic refraction application in geophysical site investigation.
(3 marks)

(iii) Explain the index test of rock testing.
(4 marks)

Q2 (a) Calculate the Rock Quality Designation (RQD) value from Figure **Q2(a)**.

(2 marks)

(b) An 12 m span of access tunnel for an underground mine will be excavated at a depth of 2100 m below ground surface. The rock mass contains crushed rock controlling stability. These joints are rough or irregular, planar and the rock wall contact is softening, or low friction clay mineral coatings. Laboratory test on core samples of intact rock give an average Uniaxial Compressive Strength of 60 MPa. 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 having a stress problem with a large inflow or high pressure in competent rock with unfilled joints. 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 highly weathered sandstone 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 2.5 MPa. The joints are slightly rough and average length of the joint is 4 m with a separation between 2 mm to 4 mm with 2 mm hard infilling materials and spacing between the joints is 0.3 m. Groundwater of the tunneling condition is anticipated to be dripping. 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)**.

(15 marks)

Q3 As a part of the application for an aggregate extraction license, it is required to check the stability of the proposed rock faces for the new quarry, outlined in Figure **Q3(a)**. The slopes of the quarry faces A, B and D are 65° / 040°, 75° / 138° and 60° / 345° respectively. The principal outcrop in the area is limestone with discontinuities that are tight, clean and dry with no visible seepage from them. Data collected from a rock discontinuity survey carried out on the proposed site is plotted as poles on a lower hemisphere, equal area polar stereo-net as shown in Figure **Q3(b)**. The angle of friction measured on the rock discontinuity surfaces is 32°.

(a) Obtain the representative dip and dip direction for each discontinuity set shown in Figure **Q3(b)** and tabulate your answers in Figure **Q3(c)**.

(5 marks)

(b) By clearly labelling your work and making use of the equatorial equal-area stereo - net given in Figure **Q3(d)**, draw the great circles for the representative discontinuity sets, tabulated in Figure **Q3(c)** on a tracing paper provided.

(5 marks)

(c) On the same tracing paper used for question **Q3(b)** or on a different tracing paper, draw and clearly label the great circles for the proposed slope faces, A, B and D of the proposed quarry.

(4 marks)

(d) On the same tracing paper used for the solution of question **Q3(c)**, indicate appropriately the friction angle of the discontinuities.

(2 marks)

(e) Analyse all possible modes of failure for the slope faces A, B and D of the proposed quarry. Tabulate in Figure **Q3(e)**, the results of your analysis stating clearly the evidence to support your statements.

(9 marks)

PLEASE NOTE: You **MUST** attach Figures **Q3(b), Q3(c), Q3(e)** and all tracing paper/s that you may use to your answer book.

PART B (25 marks)

Q4 (a) Observations from a site investigation for the stability assessment of a rock slope as shown in Table **1** and Table **2**.

Table **1**: Details of the rock mass

Type of anticipated failure	**Planar failure**
Dominant discontinuity plane of weakness (most probable failure plane)	32° in a direction 120°
Depth of tension cracks	4 m
Friction angle of dominant discontinuity planes	25°
Cohesion of the clay infill in the discontinuities	70 kPa
Unit weight of rock	26 kN/m^3

Table **2**: Details of the proposed rock slope design

Height of slope	50 m
Details of the inclination of the slope face	55° in a direction bearing 128°
Depth of water in the tension crack after a heavy rainfall	3 m
Unit weight of water	9.81 kN/m^3

(i) Investigate the safety of the proposed slope when the tension cracks are dry and by calculating the factor of safety based on the equation given in Figure **Q4(a)**.

(6 marks)

(ii) **Assess the stability of the slope, after a heavy rainfall by recalculating the safety factor value for when the tension cracks are water filled to a depth of 3 m. Use the equation given in Figure Q4(a).**

(4 marks)

(iii) What stabilization measures would you propose if the slope must always have;

(a) A factor of safety of about 1.2.

(b) If the factor of safety must be more than 1.7.

(2 marks)

(b) Give an assessment on the Rock Quality Designation (RQD) value obtained from question **Q2(a)** and propose the appropriate excavation and support system based on the Q value obtained from **Q2(b)** according to the Figure **Q4(b)** and Figure **Q4(c)**.

(3 marks)

(c) Explain the different among these parameters: Q, c, ϕ, RQD.

(3 marks)

(d) Explain two differences between intact rock and rock mass.

(4 marks)

(e) Explain two differences of bearing capacity from building code of practice and data resulted from direct test result.

(3 marks)

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

Data of rock: RMR value = 25; c = 2 Mpa ; $\phi = 30^{\circ}$
Uniaxial compressive strength = 60 MPa

Data of loading from tower: Vertical load = 150 ton
Moment load = 10 ton-meter
Horizontal load = 0 ton

(i) Calculate the compressive strength of the rock by using Figure **Q5(a)** and Figure **Q5(a)(i)**.

(3 marks)

(ii) Calculate the tensile strength of the rock by using Figure **Q5(a)** and Figure **Q5(a)(i)**.

(3 marks)

(iii) Design a suitable square footing foundation to support this electrical tower with an approved Safety Factor of bearing capacity = 2. The strength parameter cohesion and friction angle are 20 kPa and 35° respectively *Cf1* for the square footing = 1.25 based on Figure **Q5(a)(i)** and use the formula below.

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

(4 marks)

(b) A 36 in (900 mm) diameter drilled pile is supported on weathered rock socketting 3 m into rock, the sizes and spacing of discontinuities are 2 mm and 50 mm respectively. The rock was sandstone with core of σ_c = 90 MPa. Estimate the allowable BC and allowable load of this socketted pile. Use Figure **Q5(b)** and formula:

$$q_a = (\sigma_c)\, K_{sp}\, d\ ;\ d = [0.8 + 0.2(L_s / B)] \leq 2$$

(4 marks)

(c) According to the RMR value obtained from question **Q2(c)**:

(i) Determine the values of cohesion and friction angle for the sandstone based on Figure **Q2(c)**.

(2 marks)

(ii) Assess the stand up time of the tunnel without support based the on Figure **Q2(c)**.

(1 mark)

(iii) Propose the appropriate excavation and support system based on Figure **Q5(c)**.

(4 marks)

(d) Explain is the concept behind and the benefits in the use of the two different types of equal area stereographic nets that are used in rock slope engineering.

(2 marks)

(e) Determine the accuracy of the field observations and the subsequent stereographic net analysis.

(2 marks)

BAHAGIAN A (75 markah)

S1 (a) Hakisan merupakan salah satu agen penting bagi mengangkut dan memindah bahan endapan yang merupakan hasil luluhawa fizikal dan kimia batuan.

(i) Senaraikan **EMPAT (4)** jenis sedimen yang terkumpul di kawasan persekitaran benua.

(2 markah)

(ii) Berikan **TIGA (3)** faktor yang mendatangkan kesan kepada hakisan air larian.

(3 markah)

(iii) Senaraikan pergerakan sedimen dalam:

(a) Air
(b) Angin

(3 markah)

(b) Sejak berjuta tahun sejarah bumi dahulu, kerak bumi sentiasa bergerak dan mengalami pencacatan seperti penindihan, keterikan, mahupun pecahan.

(i) Berikan definisi kekar, sesar dan lipatan.

(3 markah)

(ii) Nyatakan kesemua jenis lipatan.

(3 markah)

(iii) Terangkan maksud *competent* dan *incompetent* yang terdapat dalam lipatan batuan.

(2 markah)

(c) Penyiasatan tapak dan ujikaji batuan merupakan perkara penting dalam bidang geologi kejuruteraan. Jurutera perlu mempraktikkan kemahiran geologi terhadap penyelesaian masalah kejuruteraan secara praktikal.

(i) Berikan **DUA (2)** had data lubang jara dalam penyiasatan tapak.

(2 markah)

(ii) Berikan **TIGA (3)** kelemahan penggunaan pembiasan seismik dalam penyiasatan tapak dengan menggunakan kaedah geofizikal.

(3 markah)

(iii) Terangkan ujikaji jenis indek dalam ujikaji batuan.

(4 markah)

S2 (a) Kirakan nilai Penanda Mutu Batuan (PMB) seperti yang ditunjukkan dalam Rajah **Q2(a)**.

(2 markah)

(b) Sebuah laluan terowong sepanjang 12 m rentangan untuk lombong bawah tanah akan dikorek pada kedalaman 2100 m dari aras permukaan bumi. Kestabilan jasad batuan bergantung kepada pecahan batuan. Kekar tersebut adalah kasar atau tidak sekata, bersatah dan sentuhan dinding batuan adalah bersifat lembut atau dilapisi lapisan mineral tanah liat geseran rendah. Ujikaji makmal pada sampel korekan batuan sempurna memberikan nilai purata kekuatan mampatan satu paksi sebanyak 60 MPa. Arah tegasan prinsip adalah dianggarkan mendatar dan pugak dan magnitud tegasan prinsip mendatar adalah dianggarkan sebanyak 1.5 lebih daripada tegasan prinsip pugak. Batuan mengalami masalah tegasan bersifat kompeten berada dalam keadaan basah dengan pengaliran air yang banyak dan bertekanan tinggi. Dengan menggunakan nilai PMB daripada **S2(a)**, kirakan nilai Q dengan berpandukan Rajah **Q2(b)**.

(8 markah)

(c) Sebuah terowong dibina melalui batupasir terluluhawa tinggi di mana kekar dominannya bersudut kemiringan 40° dan miring searah dengan arah laluan masuk pembinaan terowong. Jurus ketakselanjaran adalah berserenjang dengan paksi terowong. Berdasarkan ujian beban titik, kekuatan batuan adalah 2.5 MPa. Kekar menunjukkan sifat permukaan sedikit kasar, panjang kekar berpurata 4 m, bukaan kekar berukuran antara 2 mm hingga 4 mm dengan bahan isian keras sebanyak 2 mm dan purata jarak antara kekar adalah 0.3 m. Keadaan aras air bumi terowong adalah dijangka berkeadaan menitis. Dengan menggunakan nilai PMB daripada **S2(a)**, kirakan nilai Penilaian Jasad Batuan (*RMR*) dengan berpandukan kepada Rajah **Q2(c)**.

(15 markah)

S3 Bagi memenuhi sebahagian daripada pelanjutan lesen kuari batuan, adalah menjadi satu keperluan bagi menjalankan pemeriksaan berkenaan tahap kestabilan cadangan permukaan cerun kuari baru seperti yang diberikan dalam Rajah **Q3(a)**. Data permukaan cerun A, B dan D telah diukur sebanyak 65°/040°, 75°/138° and 60°/345° bagi setiap satu. Singkapan batuan di kawasan ini adalah batuan jenis batukapur dengan sifat ketakselanjaran seperti ketat, bersih dan kering dan tiada tanda-tanda berlakunya pengaliran resipan air. Data yang diperolehi daripada tinjauan ketakselanjaran di kawasan tapak cadangan telah diplot dalam bentuk kutub pada jaringan stereo sama luas seperti yang diberikan dalam Rajah **Q3(b)**. Sudut geseran permukaan ketakselanjaran telah diukur sebanyak 32°.

(a) Berikan data sudut miring dan arah miring untuk setiap set ketakselanjaran yang diberikan dalam Rajah **Q3(b)** dan jadualkan data tersebut dalam Rajah **Q3(c)**.

(5 markah)

(b) Dengan menggunakan jaringan stereo sama luas dengan jelas beserta lebel seperti yang diberikan dalam Rajah **Q3(d)**, lukiskan bulatan besar bagi kesemua set ketakselanjaran yang telah dijadualkan dalam Rajah **Q3(c)** dalam kertas surih yang diberikan.

(5 markah)

(c) Lukis dan labelkan dengan jelas bulatan besar bagi cadangan pengorekan cerun potong A, B dan D pada kertas surih yang sama digunakan dalam soalan **Q3(b)** atau baru.

(4 markah)

(d) Lukiskan dan labelkan dengan jelas sudut geseran ketakselanjaran di atas kertas surih yang sama digunakan dalam soalan **Q3(c)**.

(2 markah)

(e) Analisis dan tentukan kesemua potensi mod kegagalan cerun batuan yang boleh berlaku pada cadangan pengorekan cerun potong A dan B bersama-sama kriterianya sebagai bukti. Jadualkan keputusan tersebut pada Rajah **Q3(e)**.

(9 markah)

PERINGATAN: Pelajar **MESTI** menghantar Rajah **Q3(b)**, **Q3(c)**, **Q3(e)** dan kesemua kertas surih yang digunakan untuk proses menjawab soalan yang berkaitan.

BAHAGIAN B (25 Markah)

S4 (a) Pemerhatian yang diperolehi daripada penilaian kajian tapak cerun batuan adalah seperti Jadual **1** dan Jadual **2**.

Jadual **1**: Maklumat jasad batuan

Jenis kegagalan	**Kegagalan satah**
Satah kelemahan ketakselanjaran utama (kemungkinan besar kegagalan jenis satah)	32° pada arah 120°
Kedalaman retakan tegangan	4 m
Sudut geseran satah ketakselanjaran dominan	25°
Kejelekitan isian jenis tanah liat ketakselanjaran	70 kPa
Berat unit batuan	26 kN/m^3

Jadual 2: Maklumat cadangan cerun batuan

Ketinggian cerun	50 m
Maklumat arah dan sudut kemiringan muka cerun	55° in a direction bearing 128°
Kedalaman air memasuki retakan tegangan selepas hujan lebat	3 m
Berat unit air	9.81 kN/m^3

(i) Siasat keselamatan cadangan cerun batuan apabila retakan tegangan berada dalam keadaan kering dan basah melalui pengiraan nilai faktor keselamatan berdasarkan persamaan yang diberikan dalam Rajah **Q4(a)**.

(6 markah)

(ii) Berikan penilaian cerun selepas keadaan hujan lebat dengan pengiraan semula nilai faktor keselamatan apabila nilai retakan tegangan dimasuki air pada kedalaman 3 m berdasarkan persamaan yang diberikan dalam Rajah **Q4(a)**.

(4 markah)

(iii) Apakah pengukuran kestabilan yang dapat dicadangkan jika cerun sentiasa berada dalam keadaan;

(a) Jika nilai faktor keselamatan ialah 1.2.

(b) Jika nilai faktor keselamatan melebihi 1.7.

(2 markah)

(b) Berikan penilaian mengenai sample korekan batuan yang ditunjukkan berdasarkan nilai Petanda Mutu Batuan (PMB) yang diperolehi dari soalan **S2(a)** berpandukan kepada Rajah **Q4(b)** dan cadangkan jenis sistem sokongan dan pengorekan yang perlu digunakan berdasarkan nilai Q yang diperolehi daripada jawapan soalan **S2(b)** berpandukan kepada Rajah **Q4(c)**.

(3 markah)

(c) Jelaskan perbezaan parameter berikut : Q, c, ϕ , RQD

(4 markah)

(d) Jelaskan perbezaan antara batuan segar dengan batuan tak segar (massa batuan).

(3 markah)

(e) Terangkan dua perbezaan antara keupayaan galas yang diperoleh daripada piawaian bangunan dengan data daripada uji terus.

(3 markah)

S5 (a) Asas sebuah jambatan akan dibina di atas batuan jenis batupasir. Data dari siasatan tapak dan kerja makmal diberi seperti berikut :

Data batuan : Nilai RMR = 25 ; c = 2 Mpa ; $\phi = 30^\circ$
Kekuatan mampatan satu paksi = 60 MPa

Data dari jambatan : Beban pugak = 150 ton
Beban momen = 10 ton-meter
Beban mengufuk = 0 ton

(i) Kira kekuatan tekan batuan tersebut menggunakan Rajah **Q5(a)** dan **5(a)(i)**.
(3 markah)

(ii) Kira kekuatan regangan batuan tersebut menggunakan Rajah **Q5(a)** dan **Q5(a)(i)**.
(3 markah)

(iii) Rekabentuk suatu asas cetek sama segi yang sesuai bagi menampung jambatan tersebut dengan nilai faktor keselamatan yang telah ditetapkan sebanyak 2.0 dan Cf_l sebanyak 1.25 bagi asas cetek sama segi berpandukan Rajah **Q5(a)(i)** dan rumus di bawah.

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

$$SF_{horizontal} = \frac{V \tan\delta + c_{adhesion} A}{H}$$

(4 markah)

(b) Sebuah cerucuk tergerudi dengan saiz 36 in (900 mm) disokong dalam batuan sedalam 3 m, saiz dan ruang ketakselanjaran adalah 2 mm dan 50 mm. Batuan tersebut adalah sandstone dengan nilai σ_c = 90 MPa. Kira keupayaan galas yang dibenarkan dari asas tersebut. Guna Rajah **Q5(b)** dan rumus:

$$q_a = (\sigma_c)\, K_{sp}\, d \; ; \; d = [0.8 + 0.2(L_s / B)] \leq 2$$

(4 markah)

(c) Berdasarkan nilai RMR yang diperolehi daripada soalan S2(c).

(i) Berikan penilaian untuk nilai kejelekitan dan sudut geseran batupasir tersebut berpandukan kepada Rajah **Q2(c)**.
(2 markah)

(ii) Berikan penilaian mengenai ketahananan terowong tersebut tanpa sokongan berpandukan kepada Rajah **Q2(c)**.
(1 markah)

(iii) Cadangkan jenis sistem sokongan dan pengorekan yang perlu digunakan berpandukan kepada Rajah **Q5(c)**.

(4 markah)

(d) Berikan konsep dan kebaikan penggunaan dua jenis jaringan stereo sama luas yang berbeza dalam kejuruteraan cerun batuan.

(2 markah)

(e) Berikan ketepatan analisis melalui data pemerhatian lapangan dan juga jaringan stereo sama luas.

(2 markah)

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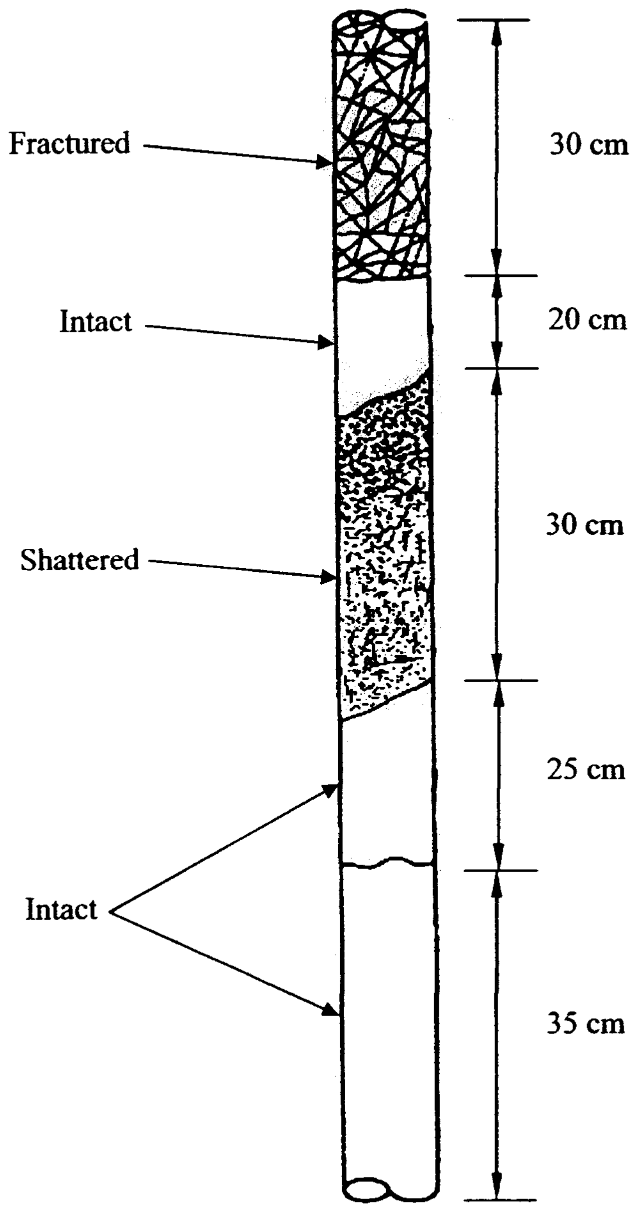

FIGURE Q2(a): Discontinuities on surface of the tunnel wall viewed from the front and lateral

(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), 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 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, are intended as an approximate guide to the mineralogical properties of the alteration products, if present.
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	

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 (if measured): when $5 \le \sigma_1/\sigma_3 \le 10$, 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.

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

FIGURE Q2(b) 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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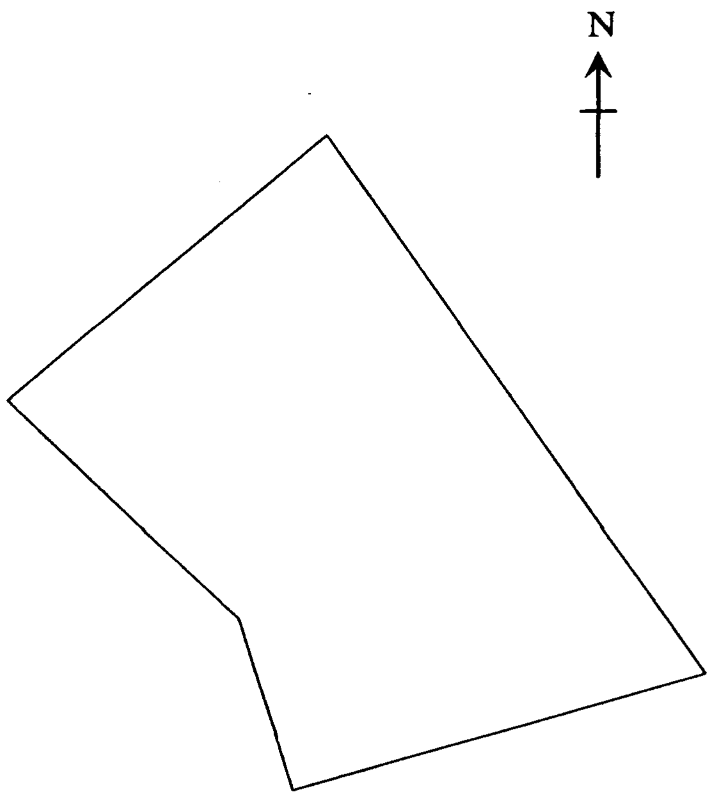

FIGURE Q3(a) : Sketch plan of proposed quarry (NOT TO SCALE)

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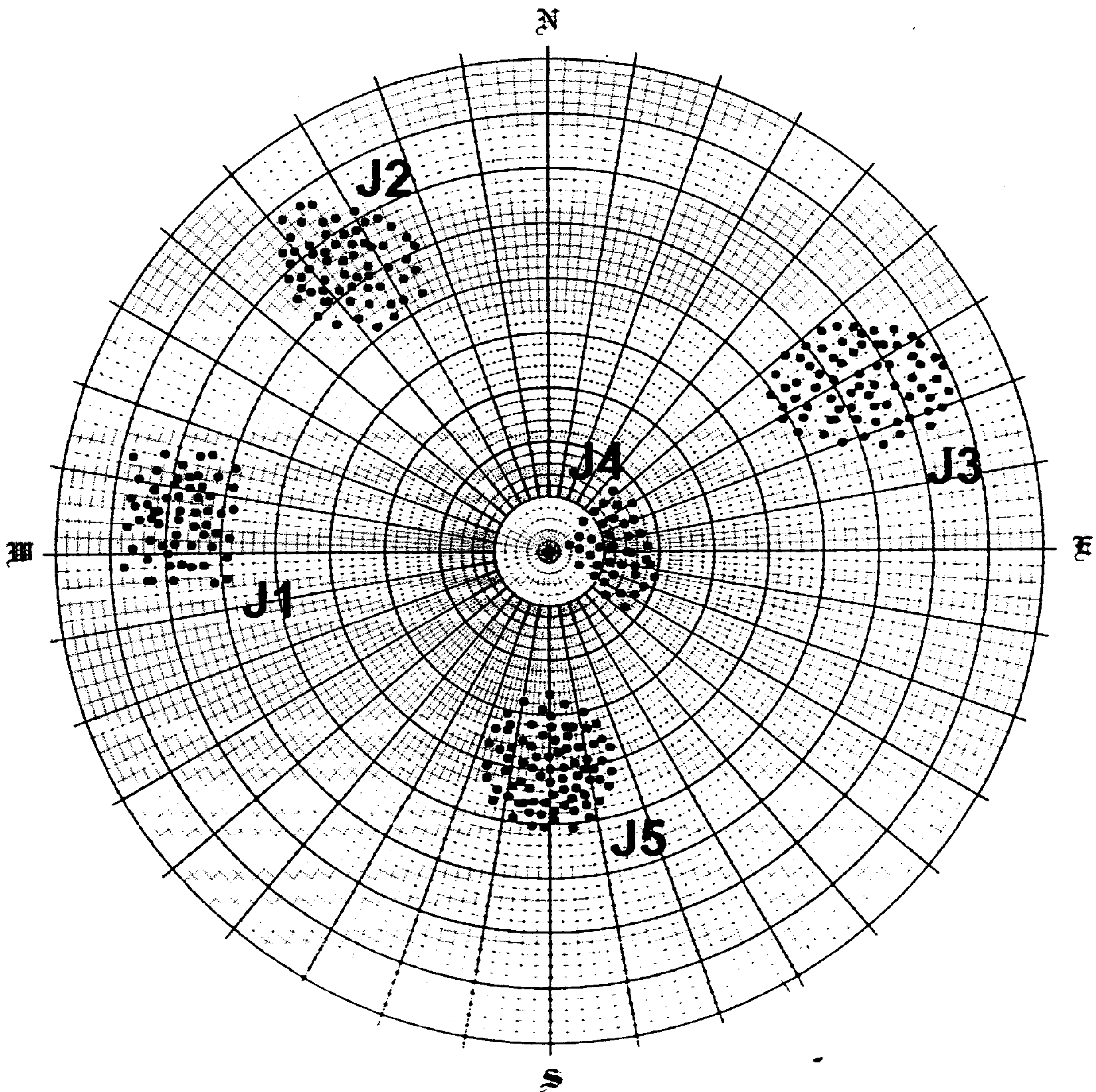

FIGURE Q3(b) : Lower hemisphere, equal area polar stereo - net marked in 2° intervals

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Discontinuity	Dip direction, ° Bearing	Dip angle, °
J1		
J2		
J3		
J4		
J5		

FIGURE Q3(c) : Dip and dip directions of the discontinuities

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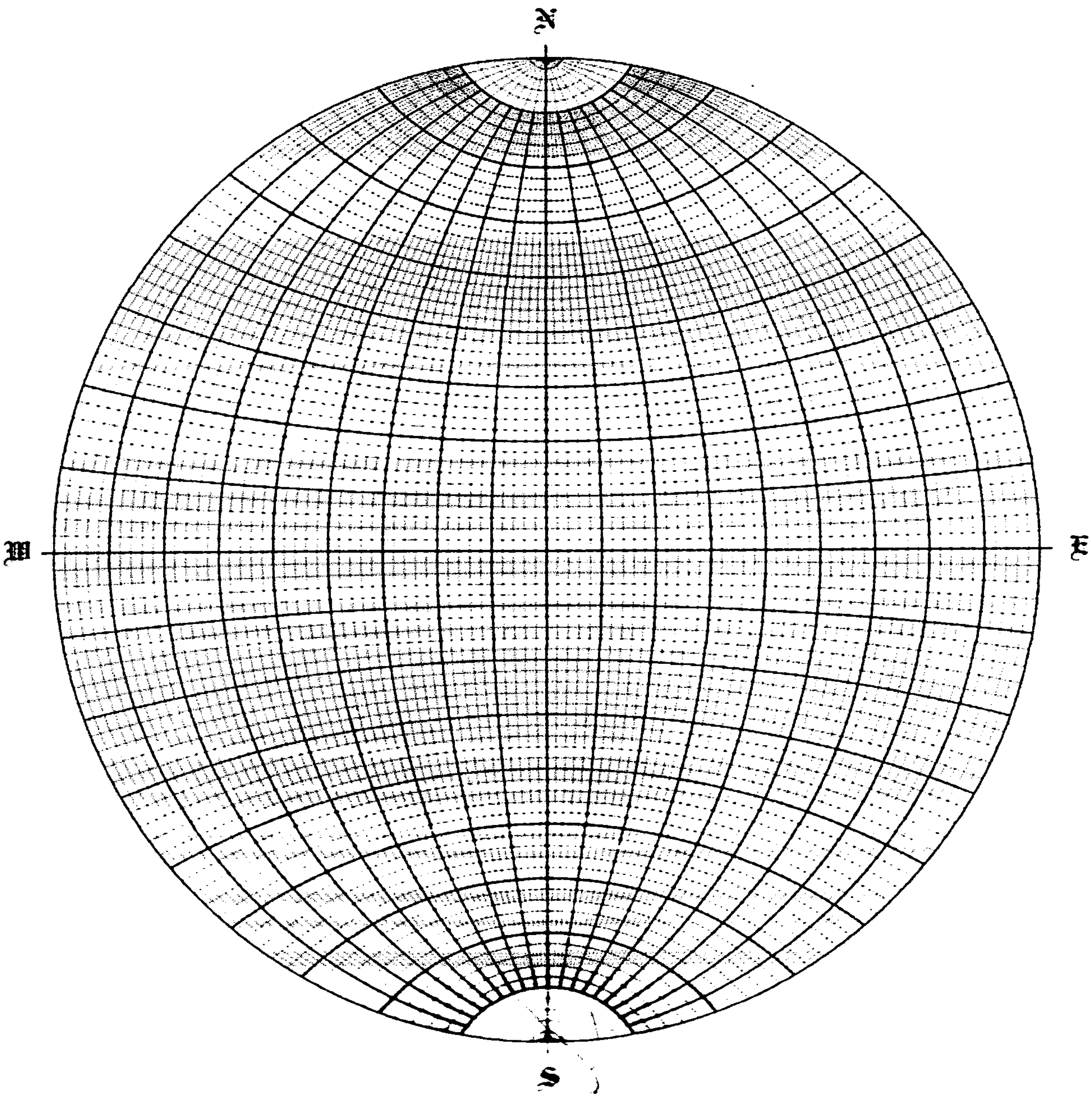

FIGURE Q3(d) : Equatorial equal-area stereo-net marked in 2° intervals

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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(e)

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

FIGURE Q3(e) : continued

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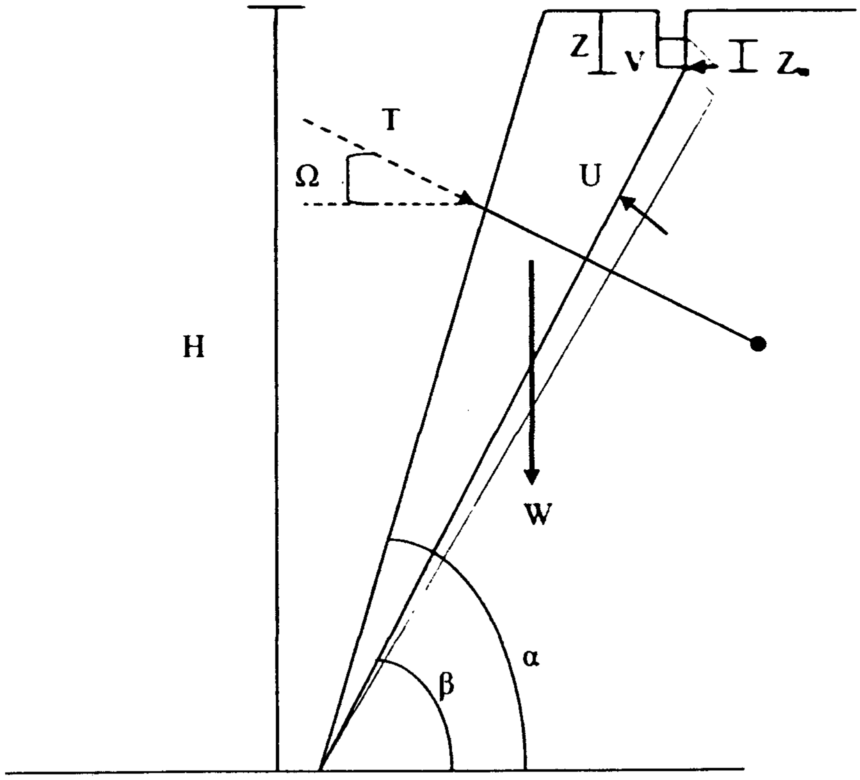

Given:

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

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

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

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

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

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

FIGURE Q4(a)

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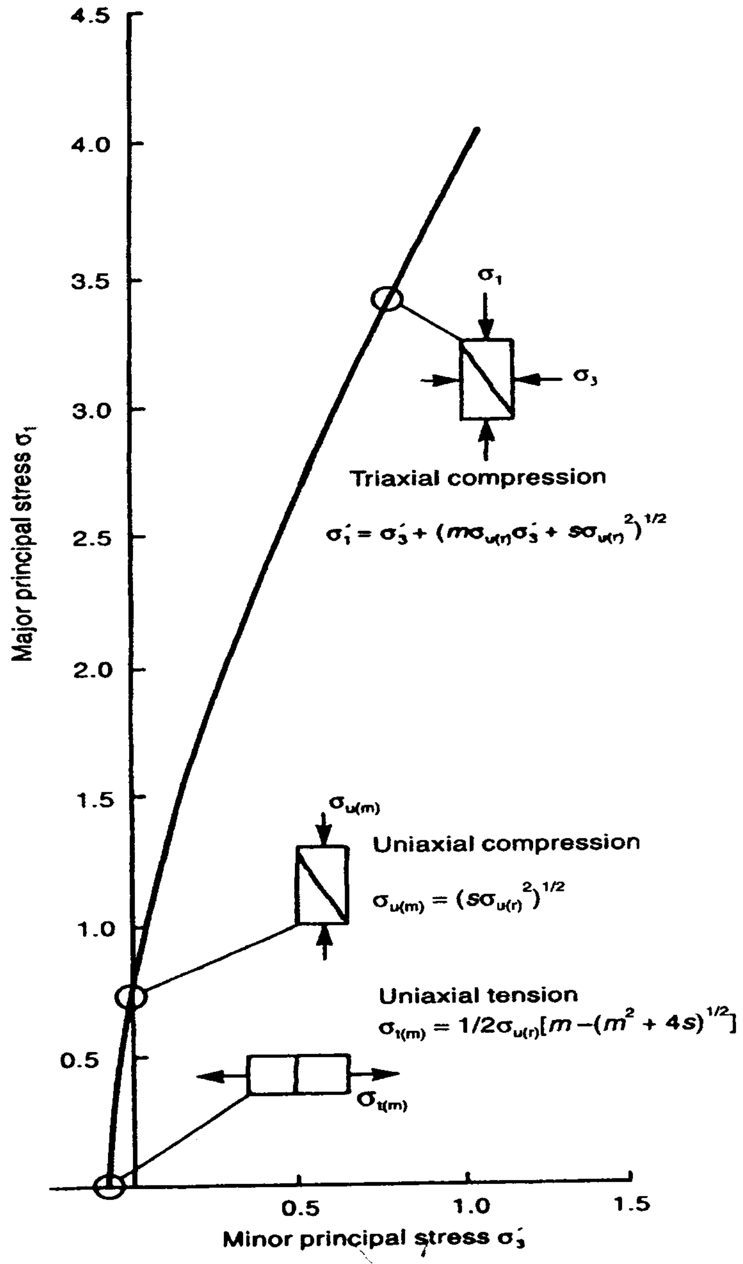

FIGURE Q5(a) : Strength of fractured rock (Hoek. 1983)

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Empirical failure criterion:
$\sigma'_1 = \sigma'_3 + \sqrt{m\sigma_c \sigma'_3 + s\sigma_c^2}$
σ'_1 = major principal effective stress
σ'_3 = minor principal effective stress
σ_c = 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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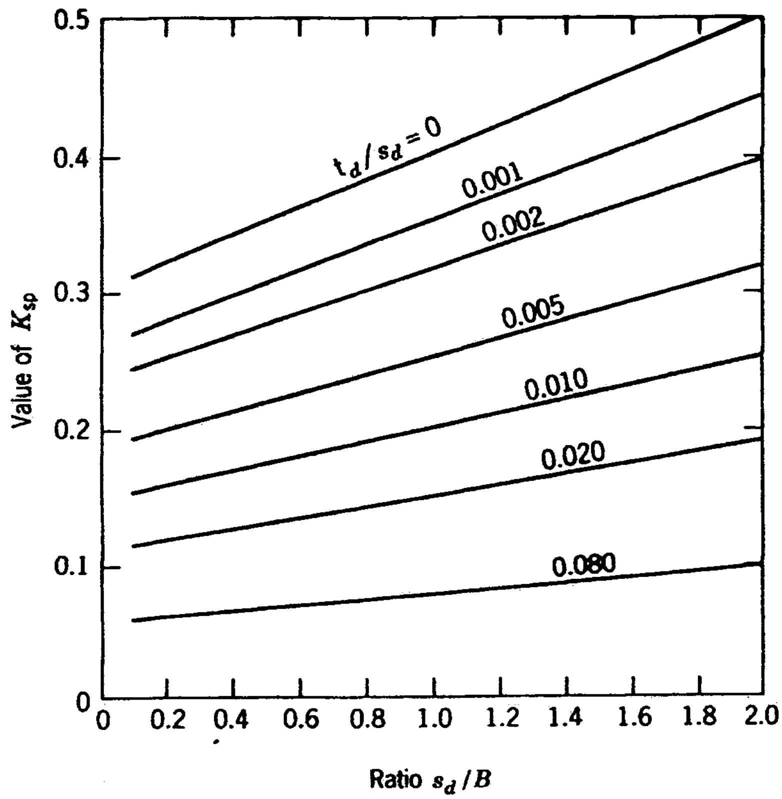

$$K_{sp} = \frac{3 + s_d/B}{10\sqrt{1 + 300\, t_d/s_d}}$$

s_d = spacing of discontinuities
t_d = thickness of discontinuities
B = Pile width or diameter

FIGURE Q5(b) : Values of empirical coefficient, Ksp. The coefficient Ksp takes into account the size effect and presence of discontinuities and contains a nominal factor of safety of three against general foundation failure. (Canadian Foundation Engineering Manual, 1985)

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