UNIVERSITI TUN HUSSEIN ONN MALAYSIA

PEPERIKSAAN AKHIR
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NAMA MATAPELAJARAN	:	GEOLOGI KEJURUTERAAN
KOD MATAPELAJARAN	:	BFC 3013
KURSUS	:	3 BFC
TARIKH PEPERIKSAAN	:	APRIL 2009
JANGKA MASA	:	3 JAM
ARAHAN	:	JAWAB **SEMUA** SOALAN DARIPADA BAHAGIAN A DAN B, DAN **SATU (1)** SOALAN DARIPADA BAHAGIAN C.

KERTAS SOALAN INI MENGANDUNGI DUA PULUH LIMA (25) MUKA SURAT

BAHAGIAN A (25 markah)

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

(i) Berikan definisi Geologi dan Geologi Kejuruteraan.

(2 markah)

(ii) Nyatakan **dua (2)** perlaksanaan bidang Geologi Kejuruteraan dalam Kejuruteraan Awam yang melibatkan bumi atau bahan bumi.

(2 markah)

(iii) Apakah papak tektonik dan jelaskan **empat (4)** jenis sempadan papak.

(4 markah)

(b) Hakisan merupakan satu agen penting dalam mengangkut dan memindahkan bahan sedimen yang terhasil dari pemecahan batuan secara fizikal dan kimia oleh tindakbalas peluluhawaan.

(i) Berikan definisi tanah baki dan tanah terangkut.

(2 markah)

(ii) Nyatakan **tiga (3)** jenis beban berlainan yang dibawa oleh arus.

(4 markah)

(iii) Terangkan **empat (4)** jenis sedimen yang terkumpul di persekitaran benua bersama - sama kriteria pentingnya setiap satu.

(4 markah)

(c) Mekanik Batuan merupakan bidang sains gunaan dan telah dikenali sebagai salah satu daripada disiplin dalam bidang kejuruteraan sejak beberapa dekad yang lalu.

(i) Nyatakan bidang pengajian Mekanik Batuan.

(2 markah)

(ii) Senaraikan **empat (4)** jenis ujikaji yang dijalankan dalam ujikaji kekuatan terus.

(2 markah)

(iii) Berikan **tiga (3)** kebaikan ujikaji indeks.

(3 markah)

BAHAGIAN B (50 markah)

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

(2 markah)

(b) Satu bilik pemecah untuk lombong bawah tanah akan dikorek pada kedalaman 2100 m dari aras permukaan bumi. Kestabilan jasad batuan bergantung kepada dua set kekar tambah rawak. Kekar tersebut adalah kasar dan bersatah. Sentuhan dinding batuan dilapisi kelodak atau pasir, pecahan tanah liat kecil. Ujikaji makmal pada sampel korekan batuan sempurna memberikan nilai purata kekuatan mampatan satu paksi sebanyak 90 MPa. 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 sederhana. Dengan menggunakan nilai PMB daripada **S2 (a)**, kirakan nilai Q dengan berpandukan **Table 1**.

(8 markah)

(c) Sebuah terowong dibina melalui batupasir sederhana terluluhawa berkeadaan kekar dominan bersudut kemiringan 30° dan miring pada arah laluan masuk pembinaan terowong. Jurus ketakselanjaran adalah berserenjang dengan paksi terowong. Berdasarkan ujian beban titik, kekuatan batuan adalah 5 MPa. Kekar menunjukkan sifat permukaan sedikit kasar, panjang kekar berpurata 2 m, bukaan kekar berukuran antara 2 mm hingga 3 mm dengan bahan isian keras sebanyak 2 mm dan purata jarak antara kekar adalah 0.8 mm. Keadaan aras air bumi terowong adalah di dalam keadaan kering lengkap. Dengan menggunakan nilai PMB daripada **S2 (b)**, kirakan nilai *Rock Mass Rating* (RMR) dengan berpandukan kepada **Table 2**.

(15 markah)

S3 (a) Cadangan pembinaan jajaran lebuhraya adalah seperti yang diberikan dalam **Figure Q3**. Nilai sudut kemiringan bagi cerun potong A dan B telah diukur sebanyak 60°. 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
132°/81°	351°/59°	301°/37°
135°/70°	354°/54°	306°/46°
127°/79°	359°/60°	316°/42°
129°/68°	356°/66°	310°/34°

(i) Plotkan kesemua orientasi bagi setiap ketakselanjaran di atas secara plotan kutub dengan menggunakan jaringan stereo sama luas dalam **Figure Q3 (a)** 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 **Table 4**.

(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 **Table 5**.

(4 markah)

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

(2 markah)

(iii) Kajian set kekar mendapati kesemua nilai sudut geseran kekar batuan pada cerun tersebut adalah 35°. Lukiskan nilai sudut geseran tersebut pada kesemua cerun A dan B di atas kertas surih yang sama.

(2 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 **Table 6**.

(11 markah)

BAHAGIAN C (25 markah)

S4 (a) Semasa kajian tapak, didapati kedalaman retakan ketegangan adalah sepanjang 1.5 meter dan air telah memasuki retakan tegangan tersebut sebanyak separuh daripada kedalaman keseluruhan retakan tegangan tersebut. Nilai sudut geseran adalah sama seperti yang diberikan pada **S3 (b) (iii)**. 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 = 100 meter
Daya jelekitan kesemua satah ketakselanjaran = 50 kPa
Tetulang jenis Y_{25} = 10 ton = 100 kN

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

(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**.

(5 markah)

(c) Berikan penilaian untuk kategori tetulang jika stesen pemecah yang dibina adalah 15 m dan berada dalam kategori lombong terbuka tetap berpandukan jawapan **S2 (b), Table 1** dan **Figure 4(c)**.

(5 markah)

(d) Cadangkan jenis sistem sokongan dan pengorekan yang harus digunakan dengan nilai RMR yang diperolehi daripada jawapan **S2 (c)** berpandukan kepada **Table 7**.

(8 markah)

S5 (a) Diberikan data bahagian atas cerun ialah 054°/00°. Semasa kajian dilakukan, kedalaman retakan tegangan adalah sedalam 1.5 meter dan air telah memasuki retakan tegangan tersebut sebanyak separuh daripada kedalaman keseluruhan retakan tegangan tersebut. Nilai sudut geseran adalah sama seperti yang diberikan pada **S3 (c) (iii)**. 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 baji = 150 meter
Daya jelekitan kesemua satah ketakselanjaran = 50 kPa

Dengan menggunakan data cerun yang diperolehi daripada **S3 (c)**, kirakan faktor keselamatan kegagalan kegagalan baji bagi cerun B serta simpulkan kestabilannya berdasarkan keputusannya berpandukan **Figure Q5.**

(18 markah)

(b) Berikan penilaian untuk nilai kejelekitan dan sudut geseran batu pasir berpandukan dengan nilai RMR yang diperolehi dari **S2 (c)** berpandukan kepada **Table 2**.

(2 markah)

(c) Berikan penilaian mengenai ketahananan terowong tersebut tanpa sokongan dengan nilai RMR yang diperolehi dari soalan **S2 (c)** berpandukan kepada **Table 2**.

(2 markah)

(d) Berikan **tiga (3)** kelebihan peralatan Pembiasan Seismik.

(3 markah)

PART A (25 marks)

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

(i) Give the definition of Geology and Engineering Geology.

(2 marks)

(ii) Describe **two (2)** Engineering Geology practices in Civil Engineering projects which involved the earth or earth materials.

(2 marks)

(iii) Define tectonic plate and describe **four (4)** types of plate boundaries.

(4 marks)

(b) 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) Describe the definition of residual soil and transported soil.

(2 marks)

(ii) Describe **three (3)** different types of load carried by streams.

(4 marks)

(iii) Explain **four (4)** types of sediment that accumulate in continental environment with their each important characteristics.

(4 marks)

(c) Rock Mechanics is a field of applied science and has been recognized as a discipline in engineering since the last four decades.

(i) Describe the study of rock mechanics.

(2 marks)

(ii) List **four (4)** testing conducted in direct strength test.

(2 marks)

(iii) State **three (3)** advantages of index test.

(3 marks)

PART B (50 marks)

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

(2 marks)

(b) A crusher chamber for an underground mine is to be excavated at a depth of 2100 m below surface. The rock mass contains two joint sets plus random controlling stability. These joints are rough, planar and rock wall contact was silty - or sandy – clay coatings with small clay – fraction. Laboratory test on core samples of intact rock give an average uniaxial compressive strength of 90 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 mass is locally damp with medium inflow. By using the RQD value obtained from **Q2 (a)**, calculate Q based on data given in **Table 1**.

(8 marks)

(c) A tunnel is constructed and driven through moderately weathered sandstone with a dominant joint set dipping at 30° with the direction of the tunnel drive. The discontinuities strike perpendicular to the tunnel axis. Based on the point load test, the rock strength is 5 MPa. The joints are slightly rough and average length of joint is 2 m with a separation between 2 mm to 3 mm, with 2 mm hard infilling materials and spacing between joints is 0.8 mm. Groundwater of tunneling condition are anticipated to be completely dry. By using the RQD value obtained from **Q2 (a)**, calculate the Rock Mass Rating (RMR) value based on the data given in **Table 2**.

(15 marks)

Q3 (a) A proposed highway alignment is shown in **Figure Q3**. Dip angle at cut slope angles for slope A and B are 60°. A discontinuity survey was conducted along the proposed cut slope A and B and the results are given in **Table 3**.

Table 3

Joint set 1	Joint set 2	Joint set 3
132°/81°	351°/59°	301°/37°
135°/70°	354°/54°	306°/46°
127°/79°	359°/60°	316°/42°
129°/68°	356°/66°	310°/34°

(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)** 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 **Table 4**.

(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 **Table 5**.

(4 marks)

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

(2 marks)

(iii) A study of joint sets reveals that all joints have a friction angle of 35°. Draw the friction angle for slope A and B in the same tracing paper.

(2 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 **Table 6**.

(11 marks)

PART C (25 marks)

Q4 (a) During a site study, it was found that a tension crack was 1.5 meter deep and filled with water to half of its depth. The friction angle value is the same as given in **Q3 (c)**. 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 = 100 m
Cohesion of all discontinuities = 50 kPa
Bars for Y_{25} = 10 ton = 100 kN

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

(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) Evaluate the reinforcement category if the crusher station span was given in 15 m and falls into the category of permanent mine openings based on the Q value obtained from **Q2 (b)**, **Table 1** and **Figure Q4 (c)**.

(5 marks)

(d) Propose an appropriate excavation and support system based on the RMR value obtained from **Q2 (c)** and based on **Table 7**.

(8 marks)

Q5 (a) Given data for the upper slope is 054°/00°. During a site study, it was found that a tension crack was 1.5 meter deep and filled with water to half of its depth. The friction angle value is the same as given in **Q3 (b) (iii)**. 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 wedge = 150 m
Cohesion of all discontinuities = 50 kPa

By using cut slope data from **Q3 (c)**, calculate and conclude the safety factor for wedge failure for slope B based on the formula given in **Figure Q5**.

(18 marks)

(b) Determine the values of cohesion and friction angle for the sandstone according to RMR value obtained from **Q2 (c)** based on the values given in **Table 2**.

(2 marks)

(c) Assess the stand up time of the tunnel without support using the RMR value obtained from **Q2 (c)** based on the values given in **Table 2**.

(2 marks)

(d) Give **three (3)** advantages of Seismic Refraction equipment.

(3 marks)

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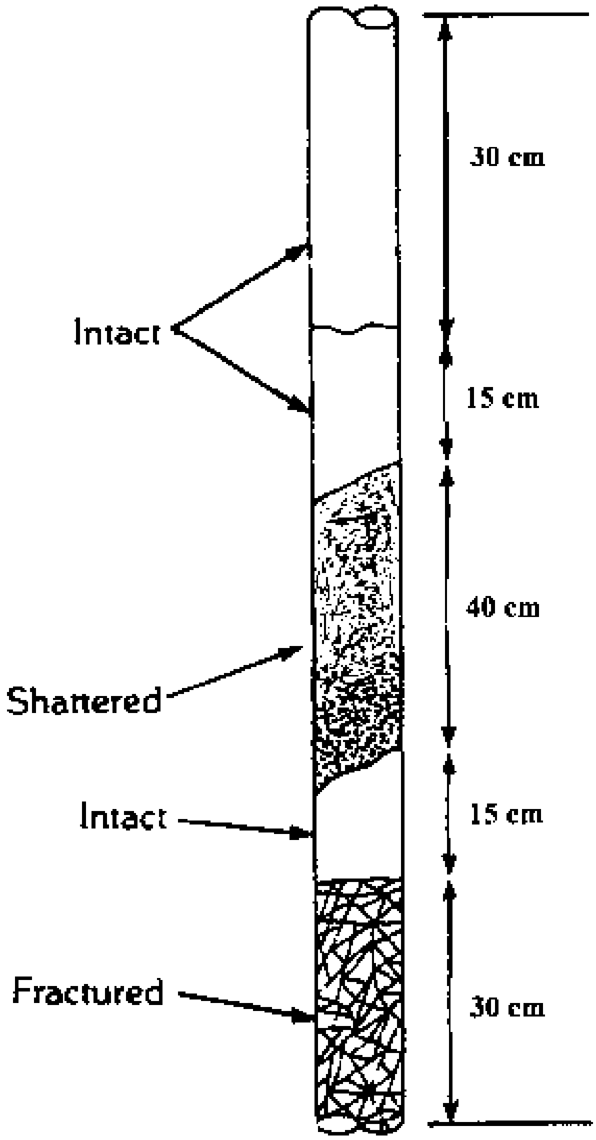

Figure Q2 : Discontinuities on surface of the tunnel wall viewed from the front and lateral.

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Table 1

DESCRIPTION	VALUE	ϕ_r degrees (approx.)	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 × 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 × 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	

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Table 1 continued

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 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 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	

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Table 1 continued

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.

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Table 1 continued

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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Table 2 : 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 continuous No separation Unweathered wall rock	Slightly rough surfaces. Separation <1mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided surfaces or Gouge<5 mm thick or Separation 1-5 mm continuous	Soft gouge>5 mm thick or Separation>5mm continuous
	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	Unfavourable	Very unfavourable
Rating	Tunnels and mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	-60

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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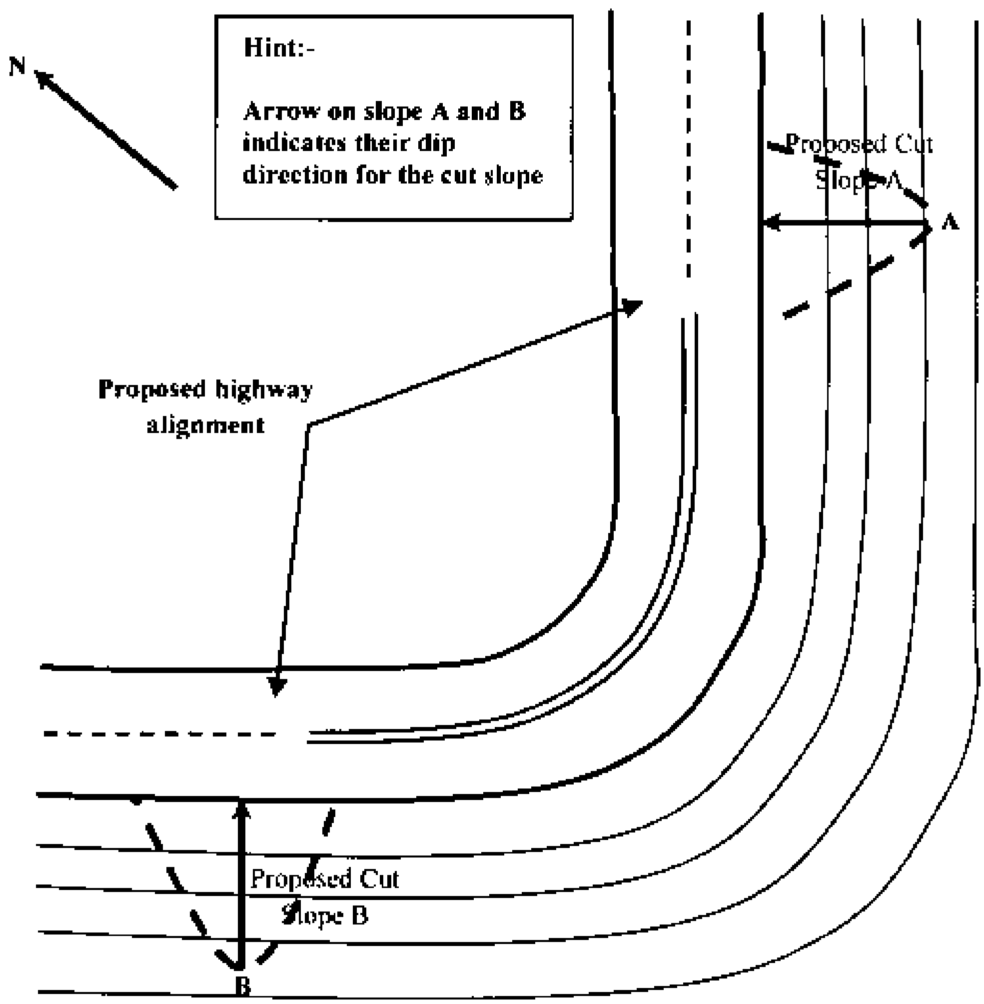

Figure Q3 : Proposed road alignment and the box cut of rock slope A side and B side from plan view

(Drawing: Not to scale)

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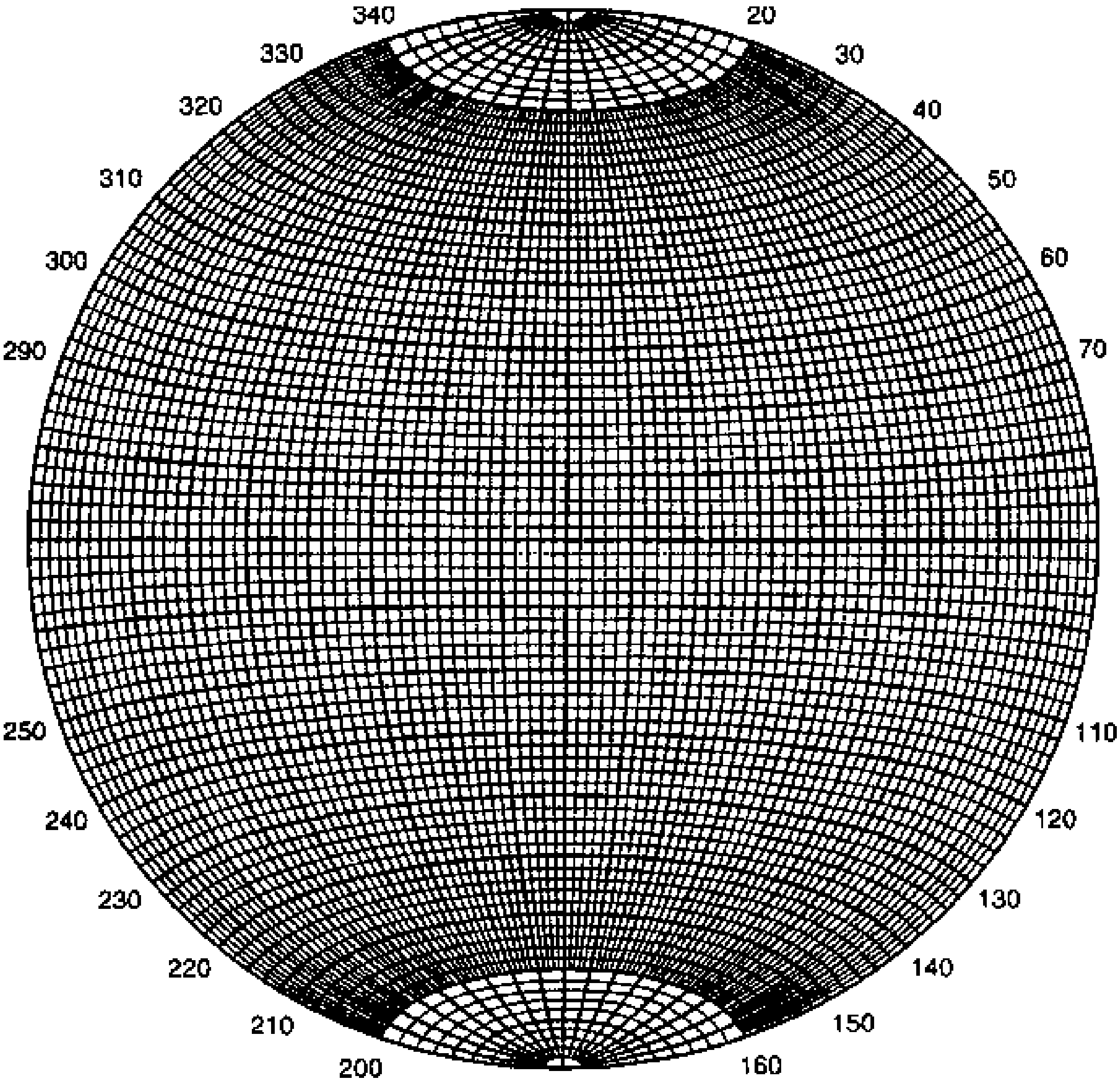

Figure Q3 (a) : Equal-area equatorial net for plotting poles and great circles
(DO NOT CHANGE THE SIZE)

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Table 4

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

Table 5

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

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Table 6

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

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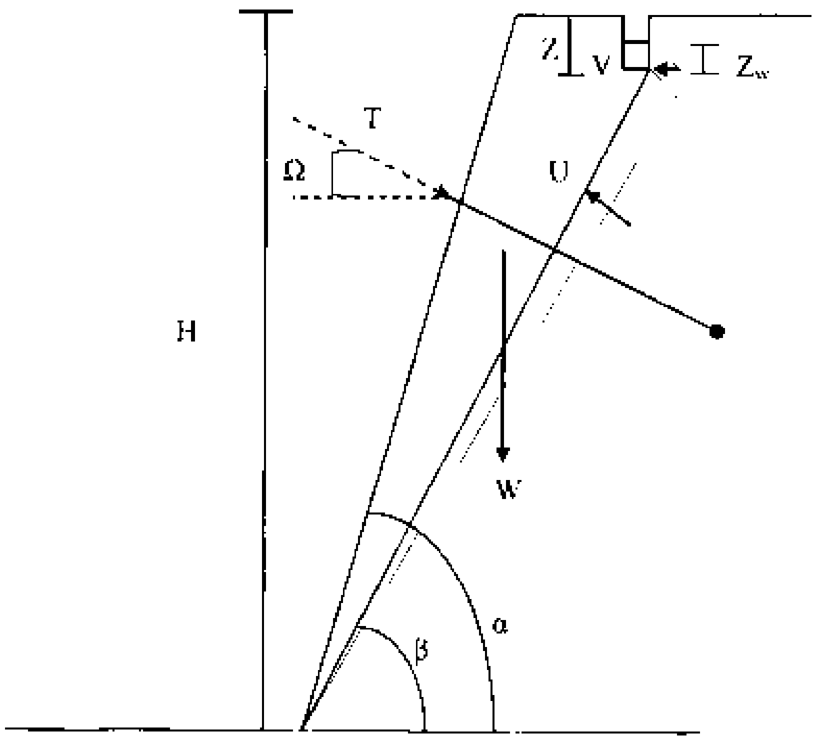

Given:

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

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

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

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

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

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

Figure Q4

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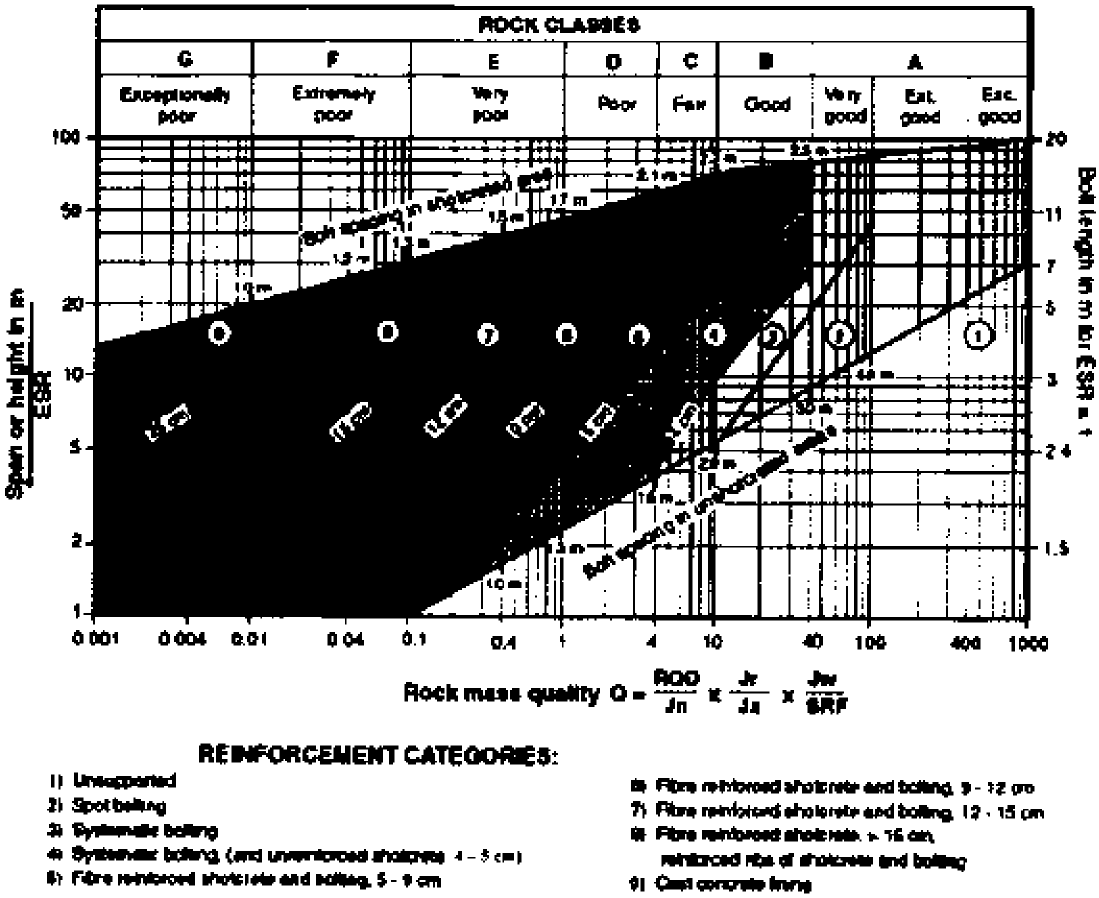

Figure Q4 (c) Estimated support categories based on the tunneling quality index, *Q* (After Grimstad and Barton, 1993, reproduced from Palmstrom and Broch, 2006)

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Table 7 : Guidelines for excavation and support of 10 m span rock tunnels in accordance with the RMR system (After Bieniawski, 1989)

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.

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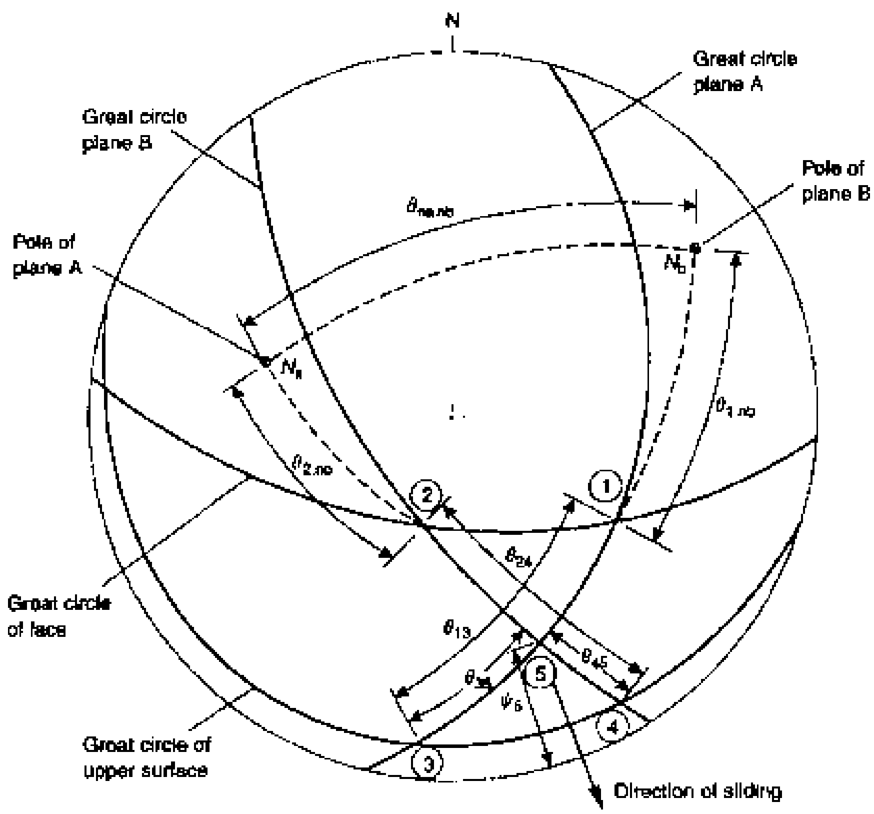

Given:

$$FOS = \frac{3}{\gamma H_t}(C_a X + C_b Y) + \left(A - \frac{\gamma_w}{2\gamma} X\right) Tan\varnothing_a + \left(B - \frac{\gamma_w}{2\gamma} Y\right) Tan\varnothing_b$$

$$X = \frac{Sin\ \theta_{24}}{Sin\ \theta_{45}\ Cos\theta_{2.na}} \qquad Y = \frac{Sin\ \theta_{13}}{Sin\ \theta_{35}\ Cos\ \theta_{1.nb}}$$

$$A = \frac{Cos\ \psi_a - Cos\ \psi_b\ Cos\ \theta_{na.nb}}{Sin\ \psi_5\ Sin^2\ \theta_{na.nb}} \qquad B = \frac{Cos\ \psi_b - Cos\ \psi_a\ Cos\ \theta_{na.nb}}{Sin\ \psi_5\ Sin^2\ \theta_{na.nb}}$$

Figure Q5