UNIVERSITI SAINS MALAYSIA

First Semester Examination
2015/2016 Academic Session

December 2015 / January 2016

EBS 417/3 – Geomechanics
[Geomekanik]

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains THIRTEEN printed pages and FOURTEEN pages APPENDIX before you begin the examination.
[Sila pastikan bahawa kertas peperiksaan ini mengandungi TIGA BELAS muka surat beserta EMPAT BELAS muka surat LAMPIRAN yang bercetak sebelum anda memulakan peperiksaan ini.]

This paper consists of SEVEN questions. TWO questions in PART A and FIVE questions in PART B.
[Kertas soalan ini mengandungi TUJUH soalan. DUA soalan di BAHAGIAN A dan LIMA soalan di BAHAGIAN B.]

Instruction: Answer **FIVE** questions. Answer **ALL** questions from PART A and **THREE** questions from PART B. If a candidate answers more than five questions only the first five questions answered in the answer script would be examined.
***[Arahan**: Jawab **LIMA** soalan. Jawab **SEMUA** soalan dari BAHAGIAN A dan **TIGA** soalan dari BAHAGIAN B. Jika calon menjawab lebih daripada lima soalan hanya lima soalan pertama mengikut susunan dalam skrip jawapan akan diberi markah.]*

The answers to all questions must start on a new page.
[Mulakan jawapan anda untuk semua soalan pada muka surat yang baru.]

You may answer a question either in Bahasa Malaysia or in English.
[Anda dibenarkan menjawab soalan sama ada dalam Bahasa Malaysia atau Bahasa Inggeris.]

In the event of any discrepancies in the examination questions, the English version shall be used.
[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah digunapakai.]

PART A / *BAHAGIAN A*

1. [a] By the aid of a diagram, **distinguish** between:

(i) the active earth pressure

(ii) the passive earth pressure

Dengan bantuan rajah, ***bezakan*** *di antara:*

(i) tekanan aktif bumi

(ii) tekanan pasif bumi

(30 marks/*markah*)

[b] The results of a sieve analysis on a soil sample were shown in Table 1:

Keputusan analisa saringan suatu tanah adalah seperti Jadual 1:

Table 1 - Particle size distribution

Jadual 1 - Taburan saiz partikel

Sieve size (mm) *Saiz ayak (mm)*	**Mass Retained (g)** *Jisim tertahan (g)*
10.00	0.0
6.00	5.5
2.00	25.7
1.00	23.1
0.60	22.0
0.30	17.3
0.15	12.7
0.063	6.9

In addition, 2.10 gram was found to pass the 63 μm sieve size. Using the particle size distribution chart provided, **plot** the particle size distribution curve. **Determine** the uniformity coefficient (C_u) and **classify** the soil sample based on the chart provided.

Selain itu, sebanyak 2.10 gram didapati melepasi saringan saiz 63 μm. Berdasarkan carta taburan saiz zarah yang disediakan, ***plotkan*** *lengkungan taburan saiz zarah.* ***Tentukan*** *pekali keseragaman (C_u) dan* ***kelaskan*** *sampel tanah ini menggunakan carta yang dibekalkan.*

(70 marks/*markah*)

2. [a] A rock mass is characterised by three main sets of discontinuities:

Satu jisim batuan dicirikan oleh tiga set ketakselanjaran utama:

Plane *Satah*	**Dip direction** *Arah kemiringan*	**Dip** *Kemiringan*	**Angle of friction ϕ** *Sudut geseran, ϕ*
1	120°	74°	26°
2	250°	60°	32°
3	030°	45°	36°

(i) Plot the great circles of all planes using the stereographic projection (Appendix 1).

Plot bulatan besar bagi kesemua kekar menggunakan unjuran stereografi (Lampiran 1).

(20 marks/*markah*)

(ii) Determine the direction of the line of intersection between the two planes of three sets discontinuities.

Tentukan arah garis persilangan antara dua satah bagi tiga set ketakselanjaran.

(20 marks/*markah*)

(iii) An open pit mine is to be built in the rock mass. Using the stereographic projection, determine the maximum safe slope angle for slopes with the following dip directions: 0°, 70°, 120°, 190°, 260° and 300°. Indicate the type of potential failure for each case (e.g. sliding on plane 1, wedge of plane 2).

Lombong dedah terbuka akan dibina dalam jisim batuan. Menggunakan unjuran stereografik, tentukan sudut cerun maksimum yang selamat bagi cerun pada arah kemiringan berikut: 0°, 70°, 120°, 190°, 260° dan 300°. Nyatakan jenis kegagalan yang berpotensi bagi setiap kes (seperti planar pada satah 1, baji pada satah 2).

(60 marks/*markah*)

PART B / *BAHAGIAN B*

3. [a] Briefly **discuss** the use of Factor of Safety (FoS) in slope stability analysis.

Secara ringkas, ***bincangkan*** *kegunaan Faktor Keselamatan (FoS) dalam analisis kestabilan cerun.*

(20 marks/*markah*)

[b] **Compare** between these remedial measures for failing slopes.

(i) **Loading the Toe** vs **Regrading the Slope**.

Beban Kaki lawan Penarahan Cerun.

(30 marks/*markah*)

(ii) **Soil Anchors** vs **Sheet piling** and retaining structures.

Penambat Tanah lawan Cerucuk keping dan struktur penahan.

(30 marks/*markah*)

(iii) **Geo-textiles** vs **"Grassing-over" the slope**.

Geo-tekstil lawan Tanaman litup cerun.

(20 marks/*markah*)

(Note: Partially marks will be given for diagram)

(Nota: Sebahagian markah diberikan untuk gambarajah)

4. [a] **Explain** what is meant by the flow net.

Jelaskan *maksud jaringan aliran.*

(30 marks/*markah*)

[b] Base on the flownet in Figure 1, **determine** the water rise (in meter) if a piezometer was placed at point:

(i) A

(ii) B

(iii) C

Berdasarkan jaringan alir di dalam Rajah 1, ***tentukan*** *kenaikan air (di dalam meter) jika piezometer diletakkan di titik berikut:*

(i) A

(ii) B

(iii) C

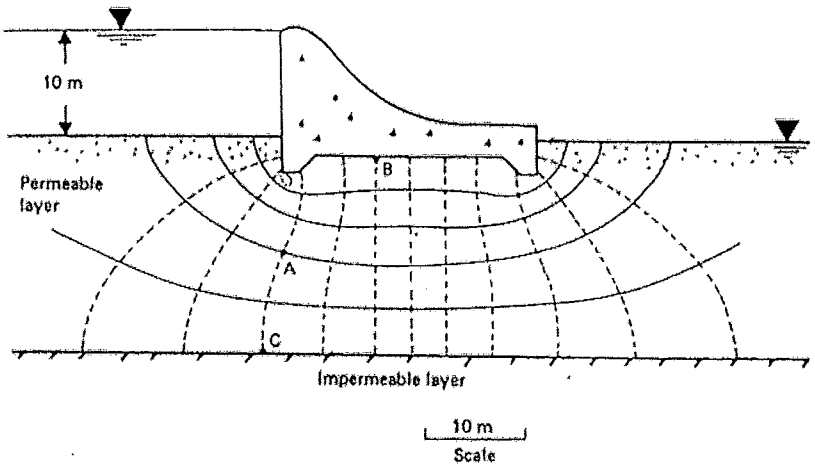

Figure 1

Rajah 1

(50 marks/*markah*)

[c] Based on Figure 1, if the k = 0.02 mm/s, **determine** the seepage lost of the dam in m^3/day.

Berdasarkan Rajah 1, jika k = 0.02 mm/s, ***tentukan*** *kehilangan turus empangan di dalam m^3/hari.*

(20 marks/*markah*)

5. [a] Plot the poles of the following discontinuities, using Appendix 1:

(i) dip 83° towards 310°
(ii) dip 79° towards 320°
(iii) dip 30° towards 035°
(iv) dip 80° towards 305°
(v) dip 82° towards 315°
(vi) dip 45° towards 130°

Determine the estimate general dip and trend of these structures.

Plot kutub-kutub ketakselanjaran berikut, menggunakan Lampiran 1:

(i) 83° miring ke arah 310°
(ii) 79° miring ke arah 320°
(iii) 30° miring ke arah 035°
(iv) 80° miring ke arah 305°
(v) 82° miring ke arah 315°
(vi) 45° miring ke arah 130°

Anggarkan kemiringan am dan tren struktur-struktur ini.

(30 marks/*markah*)

[b] In open pit mine operations, methods exist to stabilize sliding wedge failure through application of tensioned anchors across potential planes of sliding. Discuss one scenario under which placement of tensioned anchors might create a reduction in stability for a potential sliding wedge.

Dalam operasi lombong dedah, kaedah-kaedah wujud untuk menstabilkan gelonsoran oleh kegagalan baji melalui penggunaan penambat tuju yang ditegangkan keseluruhan satah yang berpotensi untuk gagal. Bincangkan satu senario di mana penggunaan penambat tuju-ditegangkan mungkin dapat mengurangkan potensi ketidakstabilan bagi kegagalan baji untuk berlaku.

(40 marks/*markah*)

[c] Describe different methods of rock reinforcement and support for tunnels and rock slopes; you may use sketches for illustration. Discuss the fundamental difference between prestressed and unstressed reinforcement. Also discuss the concept of stiff and deformable support.

Huraikan kaedah yang berbeza bagi tetulang batu dan sokongan untuk terowong dan cerun batuan; anda boleh menggunakan lakaran untuk ilustrasi. Bincangkan perbezaan asas antara tetulang prategasan dan ditegaskan. Juga bincangkan konsep sokongan kaku dan ubah bentuk.

(30 marks/*markah*)

6. [a] A 10 m diameter tunnel is to be bored through granite of 200 m BGL; the tunnel axis is horizontal with a trend of 330°. Two sets of joints were presents, J1 of dips 20° towards 23° and J2 of dips 45° towards 47°. It was found that several small fracture zones (clay-free) were found in core logs. Zones range from 100 mm to 0.3 m in thickness, with some random joints present. The rock mass are described as the following:

10 m diameter terowong akan dikorek melalui granit 200 m BGL; paksi terowong adalah mendatar dengan trend 330°. Dua set kekar hadir, J1 dengan kemiringan 20° ke arah 23° dan J2 dengan kemiringan 45° ke arah 47°. Telah didapati bahawa terdapat beberapa zon keretakan kecil (bebas tanah liat) dalam log gerudi. Zon berkisar dari 100 mm hingga 0.3 m tebal, dengan beberapa kekar hadir. Jisim batuan digambarkan sebagai berikut:

	Parameter ***Parameter***		**Range of values** ***Julat nilai***	
(1)	Strength of intact rock material *Tegasan pada batuan utuh*		Moderate low: 25 - 50 MPa of UCS *Sedikit rendah: 25 - 50 MPa UCS*	
(2)	Drill core Quality, RQD *Kualiti lubang gerudi, RQD*		50% - 75%	
(3)	Spacing of discontinuities *Jarak ketakselanjaran*		200 - 600 mm	60 - 200 mm
(4)	Condition of discontinuities *Keadaan ketakselanjaran*	Persistence *Kekerapan*	J1 3 - 10	J2 1 – 3 m
		Aperture *Bukaan*	0.1 - 1.0 mm	0.1 - 1.0 mm
		Roughness *Kekasaran*	Rough *Kasar*	Rough Kasar
		Infilling *Isian*	None *Tiada*	Soft infilling < 5 mm *Isian lembut < 5 mm*
		Weathering *Luluhawa*	Slightly weathered *Sedikit terluluhawa*	Slightly weathered *Sedikit terluluhawa*
(5)	Groundwater *Air bawah tanah*		25 - 125 l/m	

Classify the quality of the rock mass using RMR system (Appendix 2) and the Tunnelling Quality Index Q (Appendix 3). Consider the Excavation Support Ratio (ESR) to be equal 1.0. Use your judgement in case of any ambiguities and comment on your decisions.

Kelaskan kualiti jisim batuan menggunakan sistem RMR (Lampiran 2) dan Terowong Kualiti Indeks Q (Lampiran 3). Pertimbangkan Nisbah Sokongan Excavation (ESR) sebagai sama dengan 1.0. Gunakan pertimbangan anda jika terdapat sebarang kemusykilan dan beri ulasan mengenai keputusan anda.

(60 marks/*markah*)

[b] Discuss the recommendations associated with both classification systems to design a support system for the tunnel considering the excavation method. Also give recommendations for the excavation procedure. Discuss any differences of support design derived from the two classification systems.

Bincangkan cadangan yang berkaitan dengan kedua-dua sistem pengelasan untuk merekabentuk sistem sokongan bagi terowong berdasarkan kaedah penggalian. Juga memberikan cadangan untuk prosedur penggalian. Bincangkan perbezaan reka bentuk sokongan yang diperolehi daripada kedua-dua sistem pengelasan.

(40 marks/*markah*)

7. [a] A 30 m high face slope has been excavated northward into a rock mass. Extensive geotechnical drilling programme has revealed the following information:

Plane A:	dips 32° towards 158°, ϕ of 35
Plane B:	dips 60° towards 333°, ϕ of 20

The intersection of the two planes will daylight on the slope face, and the water table has been identified as located a few meters below the proposed excavation. At the opposite site of the slope, plane A formed a wedge intersection with Plane C having a dip of 40°, a dip direction of 012° and a ϕ of 31°; Plane C is also planar, smooth and has zero cohesion. Very shortly after this intersection daylighted out of its slope, the wedge failed.

Using accompanying design charts (Appendix 4), determine the factor of safety of the wedge formed by Plane A, B and C

Satu muka cerun setinggi 30 m telah dikorek ke arah utara di dalam jisim suatu batuan. Program penggerudian geoteknikal telah mendedahkan maklumat yang berikut:

Satah A	*miring 32° ke arah 158°, dengan ϕ 35*
Satah B	*miring 60° ke arah 333°, dengan ϕ 20*

Persilangan kedua-dua satah akan terdedah di muka cerun, dan air di dalam tanah telah dikesan berada beberapa meter di bawah aras tempat pengorekan yang dicadangkan. Di kawasan bertentangan cerun tersebut, satah A membentuk persilangan baji dengan satah C yang mempunyai kemiringan 40°, arah miring 012° dan Ø bernilai 31°; sesar pada satah C juga berbentuk planar dan licin dan mempunyai kejeleketan kosong. Baji ini gagal tidak lama setelah persilangan terdedah di muka cerun.

Dengan menggunakan carta yang disediakan (Lampiran 4), tentukan faktor keselamatan baji yang dibentuk oleh satah A, B dan C

(30 marks/*markah*)

[b] A 30 m concrete dam is to be built across a valley that runs along the bottom of a syncline, wherein rocks have been folded downward and dip into the valley from both sides. The rocks are mostly limestones, but some are intricately interbedded with sands and clays. These sand and clay layers form bedding planes that parallel the syncline structure, dipping steeply into the valley from both sides. Fracture systems in the rocks run both parallel and perpendicular to bedding planes which are characterized by 3 sets of major discontinuities (See below). The angle of friction of all discontinuities is approximately ϕ = 30°.

Set 1 dip 10° towards 030°

Set 2 dip 20° towards 015°

Set 3 dip 21° towards 122°

The rock slopes having different orientation will be cut during the construction of the dam. Kinematical method analysis was performed for the West and North dipping slopes.

(i) Angles of the slope is being considered at the following:

1. 45°
2. 55°

Determine and give your comments on the most likely mode of failures that may occur on each of proposed slope angle.

(ii) Identify the discontinuity set or sets which sliding would occur on each slope.

(iii) Determine the steepest possible slope angle that you would recommend. Attach all tracing papers used with your answer.

30 m empangan konkrit akan dibina di sebuah lembah yang memanjang di sepanjang bahagian bawah sinklin, di mana batu-batu telah dilipat ke bawah dan miring ke arah lembah dari kedua-dua belah pihak. Batu-batu kebanyakannya batu kapur, tetapi ada perlapisan halus di antara pasir dan tanah liat. Lapisan pasir dan tanah liat membentuk satah perlapisan yang selari dengan struktur sinklin, bermiringan curam ke lembah dari kedua-dua belah pihak. Sistem sesar dalam batu adalah kedua-duanya selari dan bersudut tepat dengan satah perlapisan yang disifatkan oleh 3 set sesar utama (Lihat di bawah). Sudut geseran untuk semua kegagalan adalah lebih kurang $\varphi = 30$

Set 1 10° *miring ke arah* 030°

Set 2 20° *miring ke arah* 015°

Set 3 21° *miring ke arah* 122°

Cerun batu mempunyai orientasi yang berbeza akan dipotong semasa pembinaan empangan. Analisis kaedah kinematik dilakukan bagi tebing mencerun kearah Barat dan Utara.

(i) Sudut cerun akan dipertimbangkan adalah berikut:

1. 45°
2. 55°

Tentukan dan berikan komen anda tentang mod kegagalan yang berkemungkinan besar akan berlaku pada setiap sudut cerun yang dicadangkan.

(ii) Kenalpasti ketakselanjaran atau set setakselanjaran yang mana gelongsoran akan berlaku pada setiap cerun.

(iii) Tentukan sudut cerun paling curam yang mungkin anda akan syorkan. Lampirkan semua kertas surih yang digunakan dengan jawapan anda.

(70 marks/*markah*)

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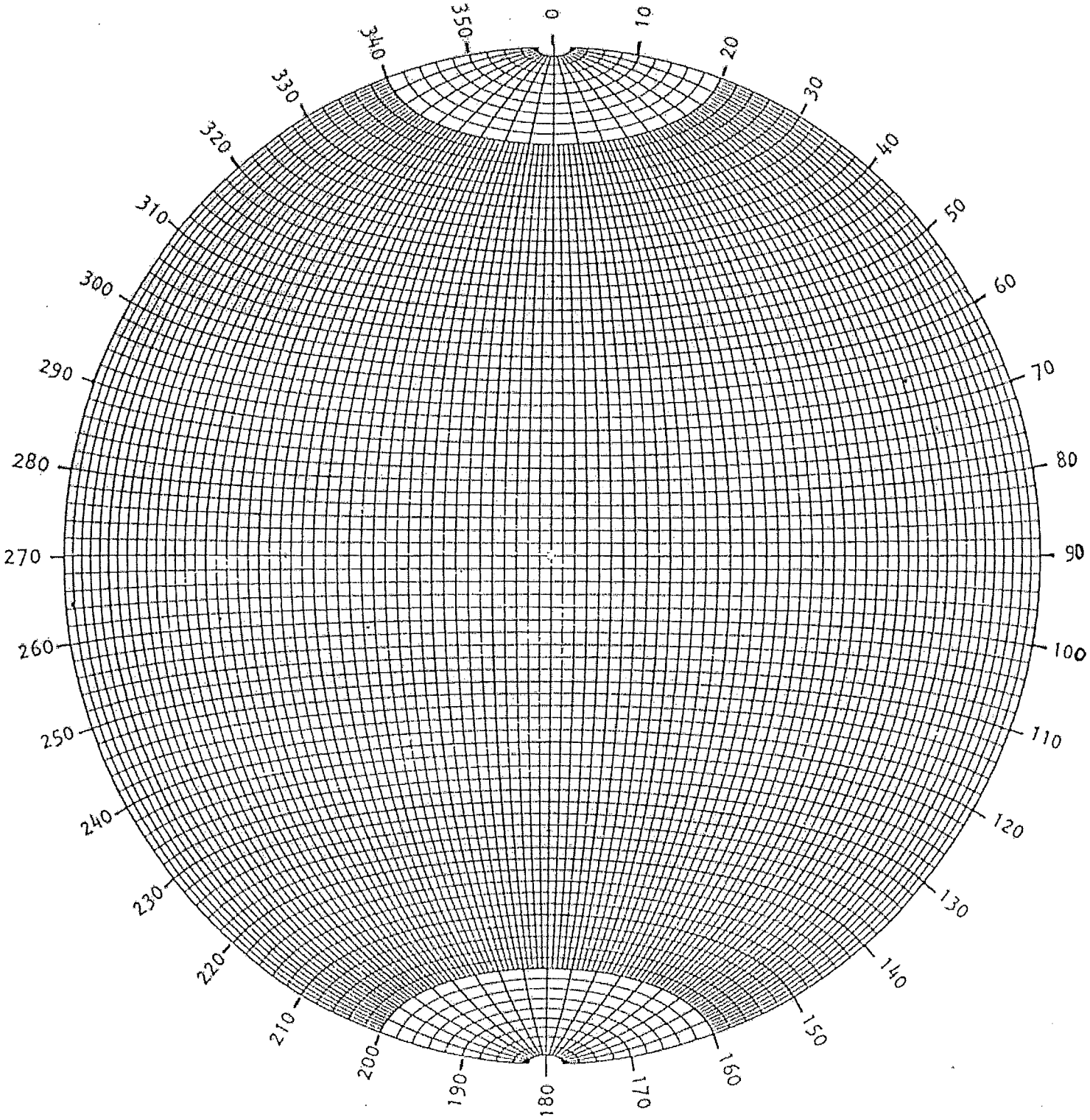
APPENDIX 1

LAMPIRAN 1



APPENDIX 2

LAMPIRAN 2

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

Parameter			Range of values						
1	Strength of intact rock material	Point-load strength index	>10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred		
		Uniaxial comp. strength	>250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa	1 - 5 MPa	< 1 MPa
	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		> 2 m	0.6 - 2 . m	200 - 600 mm	60 - 200 mm	< 60 mm		
	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 < 1 mm 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 > 5 mm Continuous		
	Rating		30	25	20	10	0		
5	Groundwater	Inflow per 10 m tunnel length (l/m)	None	< 10	10 - 25	25 - 125	> 125		
		(Joint water press)/ (Major principal σ)	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 ORIENTATIONS (See F)

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

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

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 OF ROCK CLASSES

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

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions

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

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING**

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

* Some conditions are mutually exclusive . For example, if infilling is present, the roughness of the surface will be overshadowed by the influence of the gouge. In such cases use A.4 directly.

** Modified after Wickham et al (1972).

Rock Mass Rating (RMR) System: Guidelines for excavation and support of 10 m span rock tunnels in accordance with the RMR system (after Bieniawski, 1989)

These guidelines have been published for a 10 m span horseshoe shaped tunnel, constructed using drill and blast methods, in a rock mass subjected to a vertical stress < 25 MPa (equivalent to a depth below surface of ≈ 900 m).

Rock mass class	Excavation	Rock bolts (20 mm diameter, fully grouted)	Shotcrete	Steel sets
I = Very good rock RMR: 81-100	Full face, 3m 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 1.5-2 m in crown and walls with wire mesh in crown	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 4-5 m long, spaced 1-1.5 m 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 1-1.5 m 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 forepoling if required. Close invert.

APPENDIX 3

LAMPIRAN 3

Tunnelling Quality Index Q: Classification of individual parameters (after Barton et al 1974).

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

2.	Joint Set Number	Jn
A	Massive, no or few joints	0.5 – 1
B	One joint set	2
C	One joint set plus random joints	3
D	Two joint set	4
E	Two joint set plus random joints	6
F	Three joint set	9
G	Three joint set plus random joints	12
H	Four or more joint sets, heavily jointed	15
J	Crushed rock, earthlike	20
Note:	(i) For intersections, use (3.0 x Jn). (ii) For portals, use (2.0 x Jn)	

3.	Joint Roughness Number	Jr
(a)	**Rock-wall contact, and (b) Rock wall contact before 10cm shear**	
A	Discontinuous joints	4
B	Rough or irregular, undulating	3
C	Smooth, undulating	2
D	Slickensided, undulating	1.5
E	Rough or irregular, planar	1.5
F	Smooth, planar	1.0
G	Slickensided, planar	0.5
Note:	(i) Descriptions refer to small and intermediate scale features, in that order.	
(c)	**No rock-wall contact when sheared**	

H	Zone containing clay minerals thick enough to prevent rock-wall contact	1.0
J	Sandy, gravelly or crushed zone thick enough to prevent rock-wall contact	1.0
Note :	(ii) Add 1.0 if the mean spacing of the relevant joint set ≥ 3m. (iii) Jr = 0.5 can be used for planar slickensided joints having lineations are oriented for minimum strength.	

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

O,P, R	Thick, continuous zones or bands of clay (see G, H, J for clay condition description)	6 – 24 °	10, 13, or 13 - 20

5.	Joint Water Reduction Factor	Water pressure	Jw
A	Dry excavation or minor inflow, i.e., < 5 l/min locally	<1 (kg/cm²)	1.0
B	Medium inflow or pressure, occasional outwash of joint fillings	1 – 2.5	0.66
C	Large inflow or high pressure in competent rock with unfilled joints	2.5 – 10	0.5
D	Large inflow or high pressure, considerable outwash of joints fillings	2.5 – 10	0.33
E	Exceptionally high inflow or water pressure at blasting, decaying with time	>10	0.2 – 0.1
F	Exceptionally high inflow or water pressure continuing without noticeable decay	>10 (kg/cm²)	0.1 – 0.05
Note:	(i)Factors C to F are crude estimates. Increase Jw if drainage measures are installed. (ii)Special problems caused by ice formation are not considered.		

6.	Stress Reduction Factor	SRF
(a)	**Weakness zones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated**	
A	Multiple occurrences of weakness zones containing clay or chemically disintegrated rock, very loose surrounding rock (any depth)	10
B	Single weakness zone containing clay or chemically disintegrated rock (depth of excavation ≤ 50 m)	5
C	Single weakness zone containing clay or chemically disintegrated rock (depth of excavation > 50 m)	2.5
D	Multiple shear zones in competent rock (clay-free) (depth of excavation ≤50 m)	7.5
E	Single shear zone in competent rock (clay-free) (depth of excavation ≤ 50 m)	5
F	Single shear zone in competent rock (clay-free) (depth of excavation > 50 m)	2.5
G	Loose, open joint, heavily jointed (any depth)	5
Note:	(i)Reduce SRF value by 25-50% if the relevant shear zones only influence but not intersect the excavation.	

(b)	Competent rock, rock stress problems	σ_c / σ_1	σ_θ / σ_c	SRF
H	Low stress, near surface, open joints	>200	<0.01	2.5
J	Medium stress, favourable stress condition	200 – 10	0.01 – 0.03	1
K	High stress, very tight structure. Usually favourable to stability, may be unfavourable to wall stability	10 – 5	0.3 – 0.4	0.5 – 2
L	Moderate slabbing after >1 hour in massive rock	5 – 3	0.5 – 0.65	5 – 50
M	Slabbing and rock burst after a few minutes in massive rock	3 – 3	0.65 – 1	50 – 200
N	Heavy rock burst (strain-burst) and immediate dynamic deformation in massive rock	<2	>1	200 – 400
Note:	(ii)For strongly anisotropic virgin stress field (if measured): when $5 \leq \sigma_1 / \sigma_3 \leq 10$, reduce σ_c to 0.75 σ_c; when $\sigma_1 / \sigma_3 > 10$, reduce σ_c to 0.5 σ_c; where σ_c is unconfined compressive strength, σ_1 and σ_3 are major and minor principal stresses, and σ_θ is maximum tangential stress (estimated from elastic theory). (iii) Few cases 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 in incompetent rock under the influence of high rock pressure**		σ_θ / σ_c	SRF
O	Mild squeezing rock pressure		1 – 5	5 – 10
P	Heavy squeezing rock pressure		5	10 – 20
Note:	(vi) Cases of squeezing rock may occur for depth $H > 350\ Q^{1/3}$. Rock mass compressive strength can be estimated from $Q = 7\ \gamma\ Q^{1/3}$ (MPa), where γ = rock density in g/cm^3.			
(d)	**Swelling rock: chemical swelling activity depending on presence of water**			SRF
R	Mile swelling rock pressure			5 – 10
S.	Heavily swell rock pressure			10 – 15

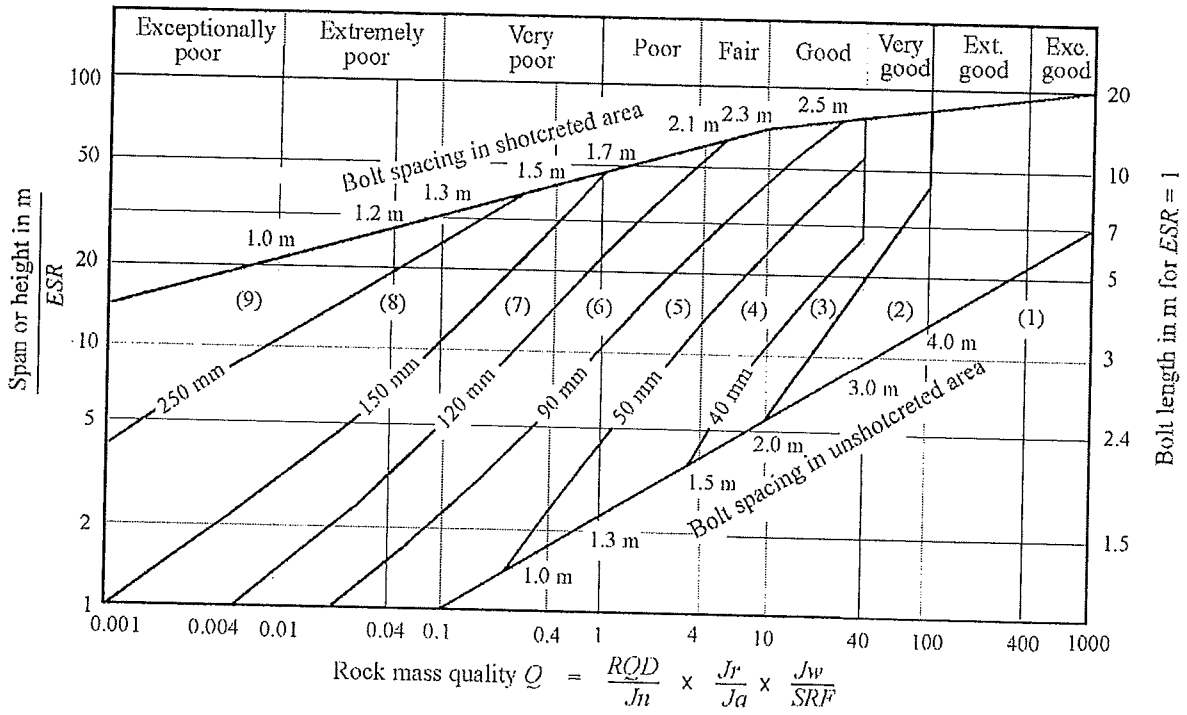
Note:	Jr and Ja classification is applied to the joint set or discontinuity that is least favourable for stability both from the point of view of orientation and shear resistance.

Q-value	Class	Rock mass quality
400 ~ 1000	A	Exceptionally Good
100 ~ 400	A	Extremely Good
40 ~ 100	A	Very Good
10 ~ 40	B	Good
4 ~ 10	C	Fair
1 ~ 4	D	Poor
0.1 ~ 1	E	Very Poor
0.01 ~ 0.1	F	Extremely Poor
0.001 ~ 0.01	G	Exceptionally Poor

Tunnelling Quality Index:

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

Tunnelling Quality Index Q: Estimated support categories based on the tunnelling quality index Q



Recommended support for reinforcement categories based on the tunnelling quality index Q:

(1) Unsupported

(2) Spot bolting

(3) Systematic bolting

(4) Systematic bolting with 40-100mm unreinforced shotcrete

(5) Fibre reinforced shotcrete, 50-90mm and bolting

(6) Fibre reinforced shotcrete, 90-120mm and bolting

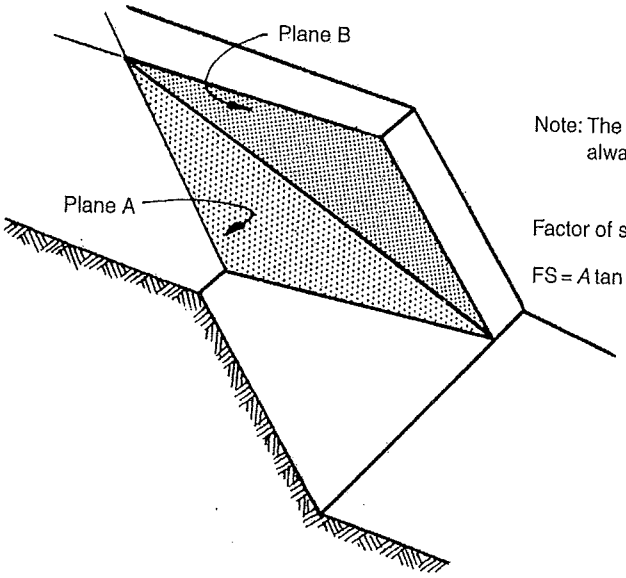
(7) Fibre reinforced shotcrete, 120-150mm and bolting

(8) Fibre reinforced shotcrete, >150mm, with reinforced ribs of shotcrete and bolting

(9) Cast concrete lining

APPENDIX 4

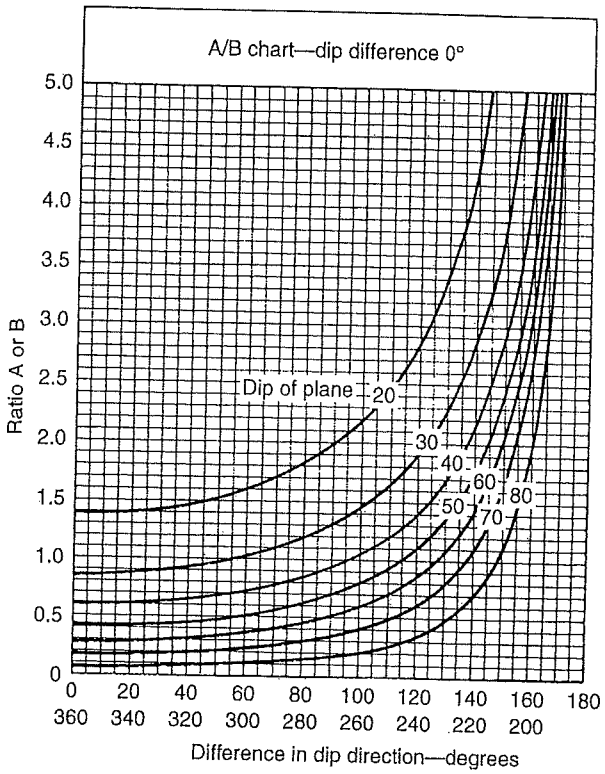
LAMPIRAN 4

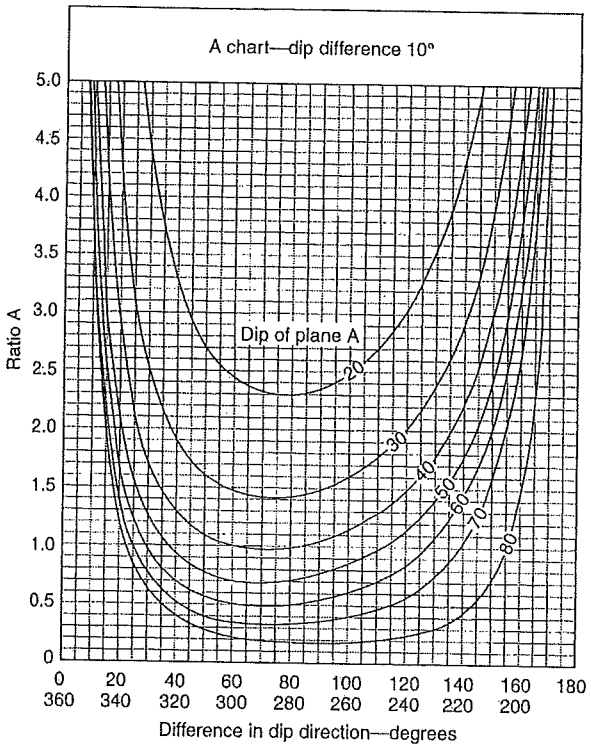


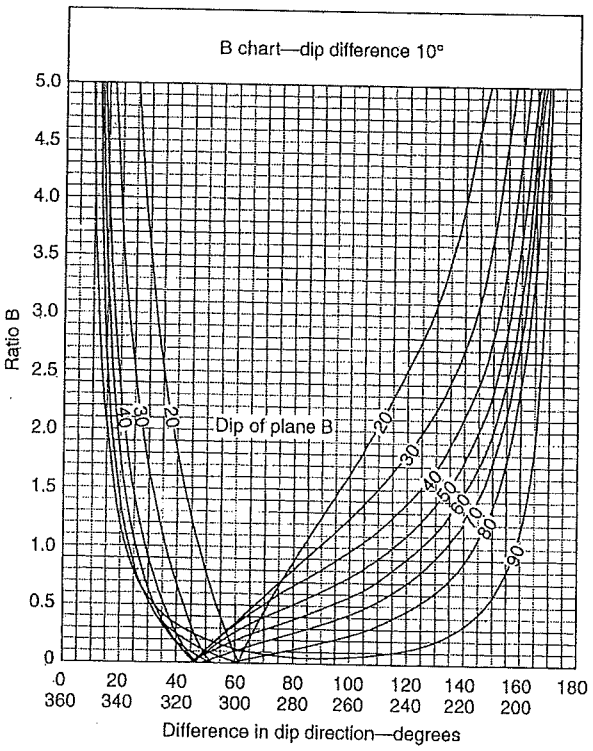
Note: The flatter of the two planes is always called plane A.

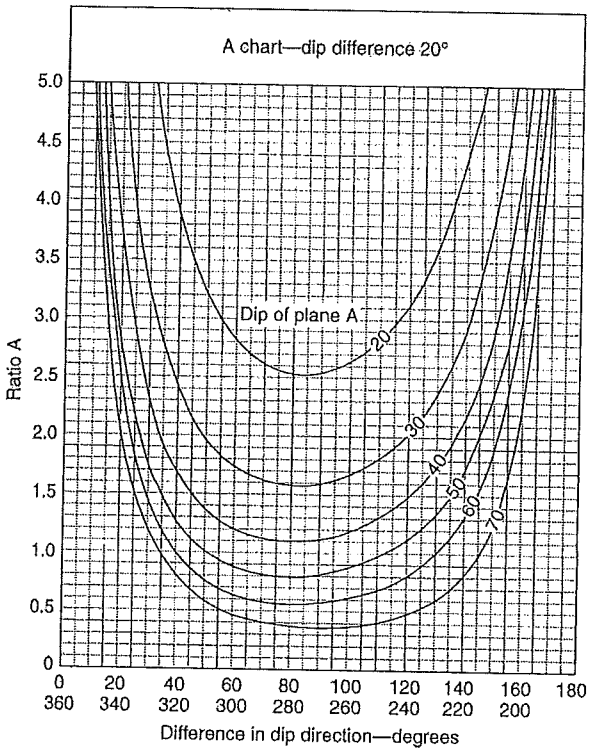
Factor of safety

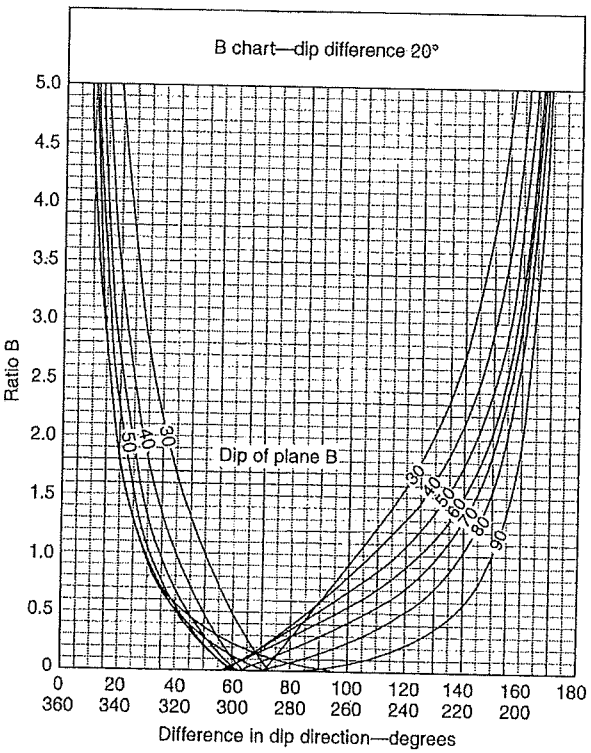
$FS = A \tan \phi_A + B \tan \phi_B$

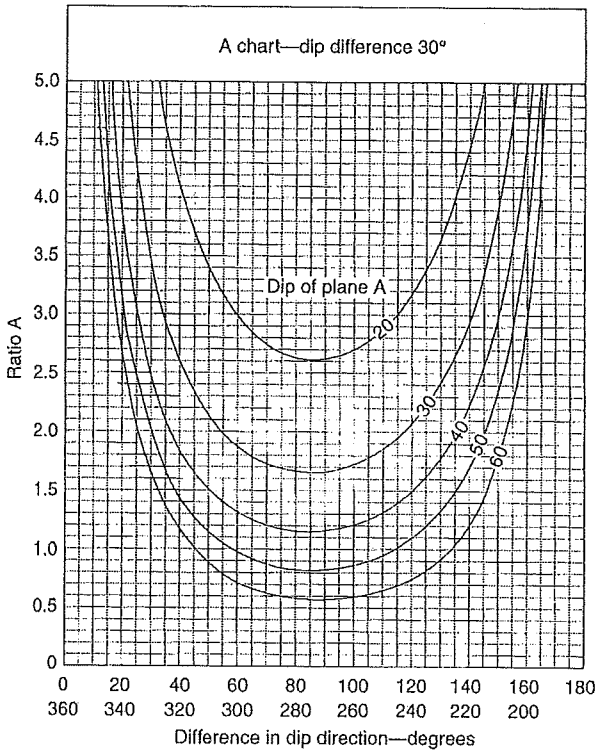


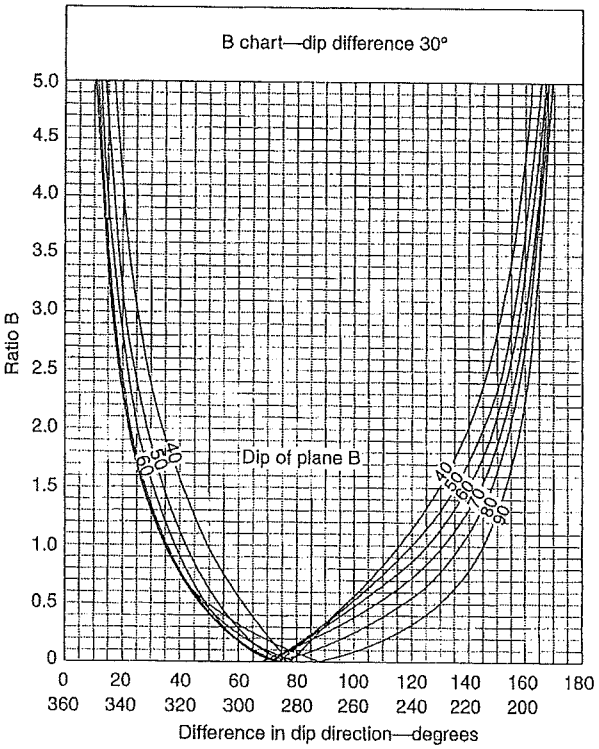

A chart—dip difference 10°
Ratio A
Dip of plane A
20
30
40
50
60
70
80
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees

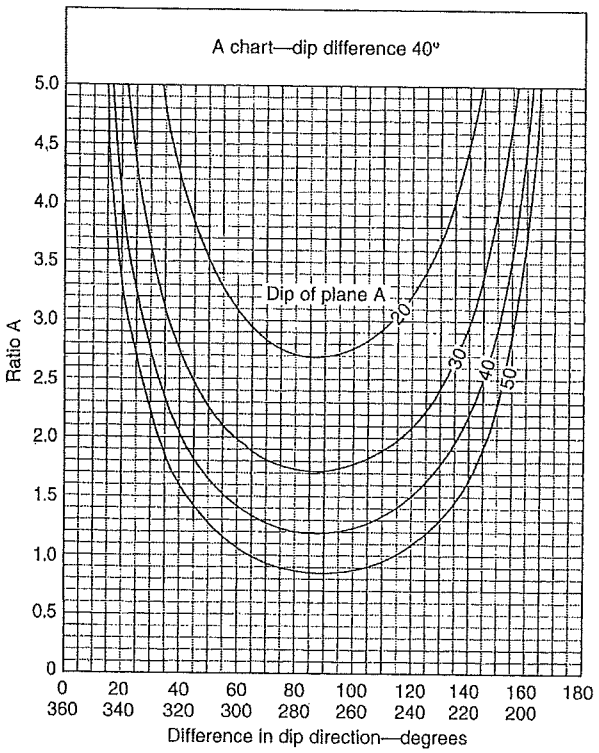

B chart—dip difference 10°
Ratio B
Dip of plane B
20
30
40
50
60
70
80
90
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees

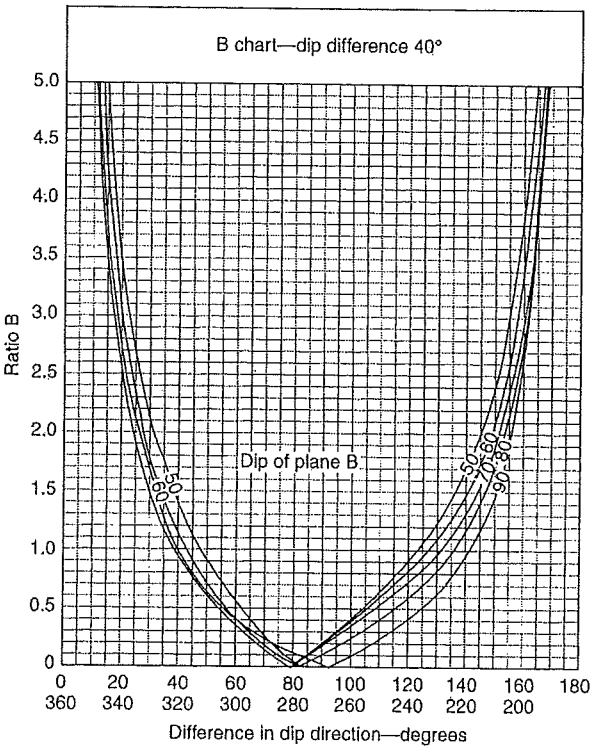

A chart—dip difference 20°
Ratio A
Dip of plane A
20
30
40
50
60
70
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees

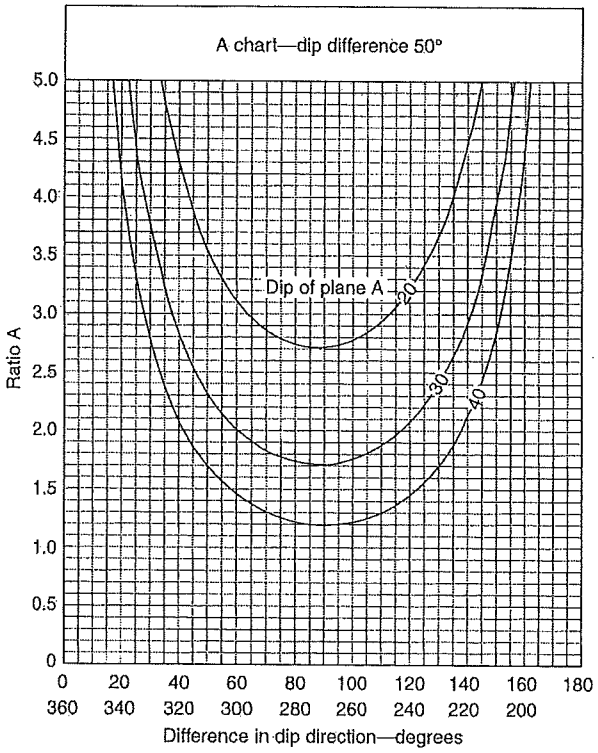

B chart—dip difference 20°
Ratio B
Dip of plane B
30
40
50
60
70
80
90
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees

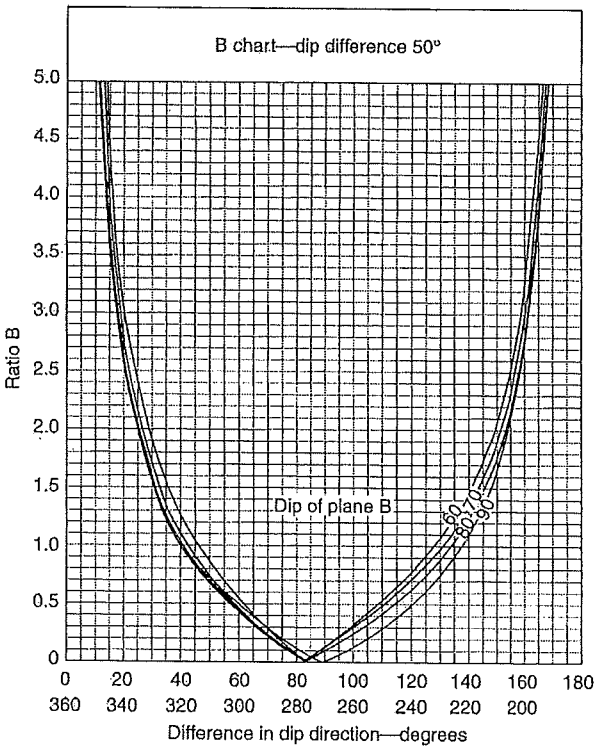

A chart—dip difference 30°
Ratio A
Dip of plane A
20
30
40
50
60
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees

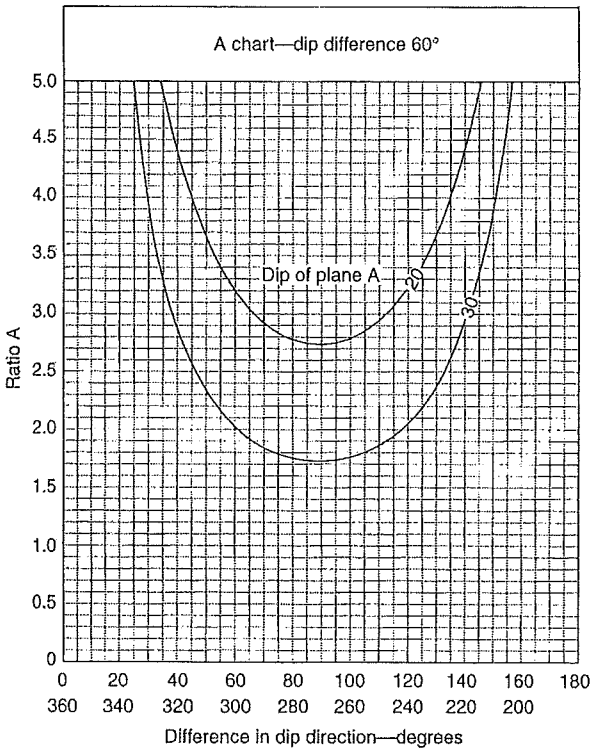

B chart—dip difference 30°
Ratio B
Dip of plane B
50
60
40
50
60
70
80
90
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees

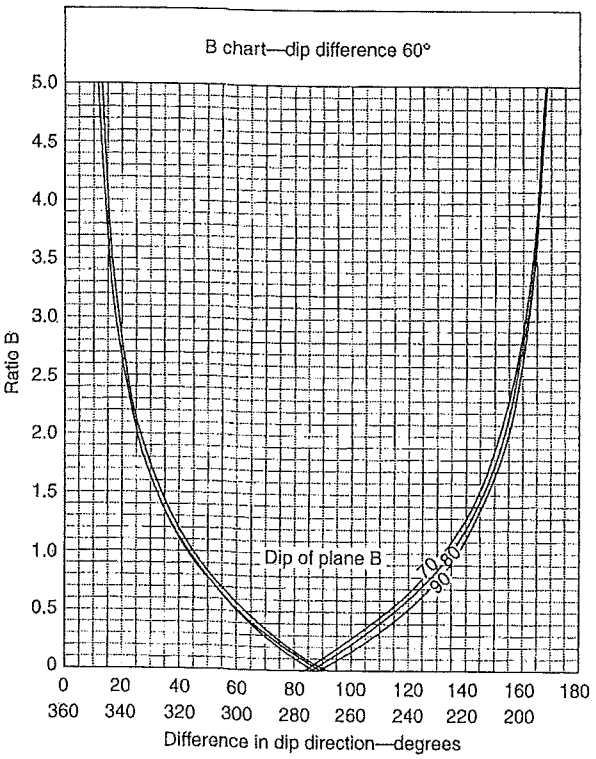

A chart—dip difference 40°
Ratio A
Dip of plane A
20
30
40
50
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees

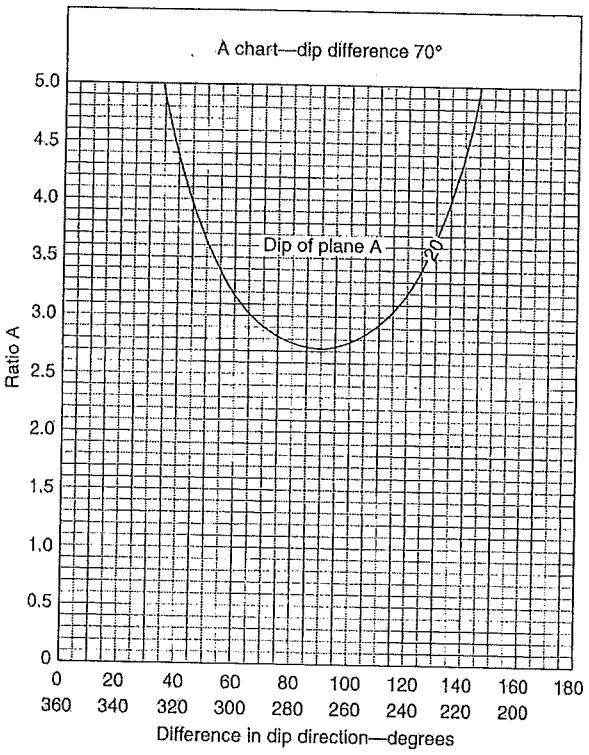

B chart—dip difference 40°
Ratio B
Dip of plane B
50
60
50
60
70
80
90
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees

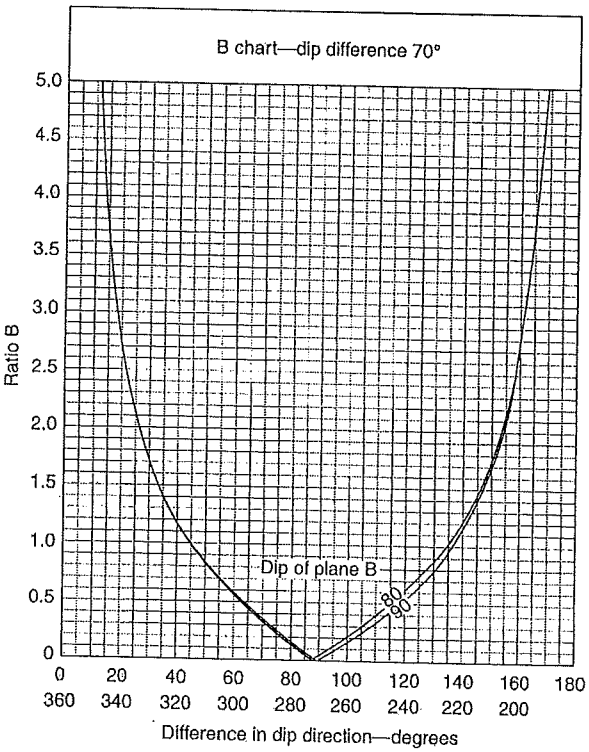

A chart—dip difference 50°
Ratio A
Dip of plane A
20
30
40
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees


B chart—dip difference 50°
Ratio B
Dip of plane B
50
70
90
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees


A chart—dip difference 60°
Ratio A
Dip of plane A
20
30
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees


B chart—dip difference 60°
Ratio B
Dip of plane B
70
90
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees


A chart—dip difference 70°
Ratio A
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
Dip of plane A
90
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees


B chart—dip difference 70°
Ratio B
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
Dip of plane B
80
90
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees