UNIVERSITI SAINS MALAYSIA

First Semester Examination
Academic Session 2012/2013

January 2013

EBS 417/3 – Geomechanics
[Geomekanik]

Duration : 3 hours
[Masa : 3 jam]

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

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

Instruction: Answer FIVE questions. Answer **ALL** questions from PART A and **THREE** questions from PART B. If 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, the English version shall be used.
[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai.]

…2/-

PART A / *BAHAGIAN A*

1. [a] The results of a sieve analysis on a soil sample were:

Keputusan analisa saringan suatu tanah adalah seperti berikut:

Sieve size (mm) ***Saiz saringan (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

It was also found that about 2.30 g mass of soil sample passing the 63 µm sieve. Using the particle size distribution chart provided (**APPENDIX 1**), **plot** the particle size distribution curve. **Determine** the uniformity coefficient (C_u) and **classify** the soil sample based on the chart provided.

*Sebanyak 2.30 g jisim sampel tanah melepasi saringan saiz 63 µm. Berdasarkan carta taburan saiz zarah yang disediakan (**LAMPIRAN 1**), **plotkan** lengkungan taburan saiz zarah. **Tentukan** pekali keseragaman (C_u) dan **kelaskan** sampel tanah ini menggunakan carta yang dibekalkan.*

(50 marks/*markah*)

[b] **Explain** the terms:

(i) Liquid Limit (LL).

(ii) Plastic Limit (PL).

(iii) Plasticity Index (PI).

Jelaskan *istilah berikut:*

(i) Had Cecair (LL).

(ii) Had Plastik (PL).

(iii) Indeks Keplastikan (PI).

(15 marks/*markah*)

[c] The following results were obtained from a liquid limit test:

Number of taps	6	8	12	26	2831	
Water content (%)	53.4	52.2	48.3	40.0	38.8	37.1

Plot the water content against the log of number of taps. **Determine** the liquid limit and the plasticity index if the plastic limit was 18%.

Analisa berikut diperolehi daripada ujian had cecair:

Bilangan ketukan	*6*	*8*	*12*	*26*	*2831*	
Kandungan air (%)	*53.4*	*52.2*	*48.3*	*40.0*	*38.8*	*37.1*

Plotkan *graf kandungan air lawan log bilangan ketukan.* ***Tentukan*** *had cecair dan indeks keplastikan jika had plastik adalah 18%.*

(35 marks/*markah*)

2. [a] Write short notes about the common rock slope failures illustrating with the help of sketches of the slope and the stereographic projection of each failure.

Tulis secara ringkas mengenai kegagalan cerun batuan yang biasa berlaku dengan bantuan lakaran cerun dan unjuran stereografik untuk setiap kegagalan.

(50 marks/*markah*)

[b] Discuss briefly the failure criterion used in rocks.

Secara ringkas bincangkan kriteria kegagalan yang digunakan dalam batuan.

(50 marks/*markah*)

PART B / *BAHAGIAN B*

3. Figure 1 below gives details of an embankment made of cohesive soil with $\phi_u = 0$ and C_u = 23 kN/m². The unit weight of the soil is 19 kN/m^3. The weight of sliding sector is 398 kN acting at the eccentricity of 5.7m from the center of rotation.

Note: In both cases assume that no tension crack develops.

Rajah 1 menunjukkan benteng yang diperbuat daripada tanah berjelekit dengan $\phi_u = 0$ dan C_u = 23 kN/m². Jisim unit tanah adalah 19 kN/m^3. Berat sektor gelinciran adalah 398 kN bertindak terhadap keeksentrikan 5.7m daripada pusat putaran.

Nota: Anggapkan tiada keretakan di dalam kedua-dua situasi.

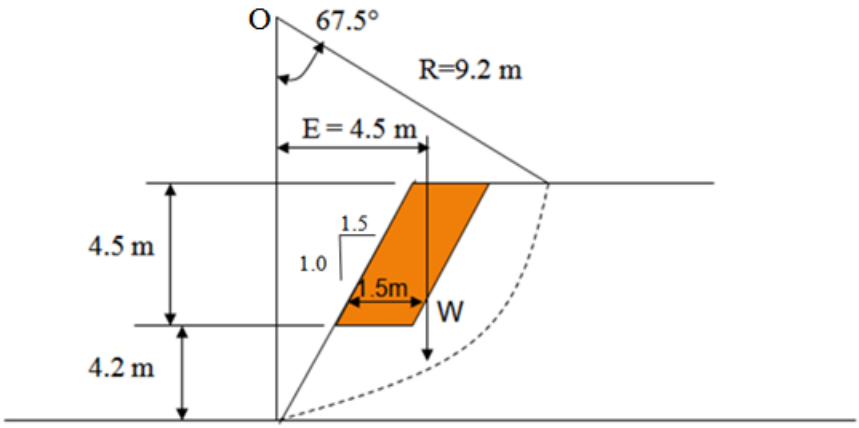


Figure 1: Embankment made of cohesive soil

Rajah 1: Benteng yang diperbuat daripada tanah berjelekit

[a] For the trial circle shown, **determine** the factor of safety against sliding.

*Berdasarkan cubaan bulatan seperti yang ditunjukkan di bawah, **tentukan** faktor keselamatan terhadap gelinciran.*

(30 marks/*markah*)

[b] **Determine** and analyse the factor of safety if the shaded portion of the embankment were removed.

Tentukan *dan analisa faktor keselamatan yang baharu sekiranya bahagian yang berlorek dikeluarkan.*

(50 marks/*markah*)

[c] **Calculate** the increases between the factor of safety for the case of [3a] and [3b] above. Provide a **comment** on this.

Kirakan peningkatan peratusan faktor keselamatan antara kedua-dua situasi [3a] dan [3b] di atas. Berikan ***komen*** *anda.*

(20 marks/*markah*)

4. [a] Briefly **discuss** the best practice for the ground investigation of an existing slope, or the ground onto which a slope is to be built.

Secara ringkas ***bincangkan*** *langkah praktikal terbaik untuk menjalankan penyiasatan lapangan terhadap cerun siap dibina ataupun lapangan yang akan dibina cerun.*

(30 marks/*markah*)

[b] **Distinguish** the difference between the “short term” and “long term” stability of a slope.

Bezakan *di antara kestabilan cerun “jangka pendek” dan “jangka panjang”.*

(30 marks/*markah*)

[c] Explain what is meant by the flow net.

Jelaskan maksud jaringan aliran.

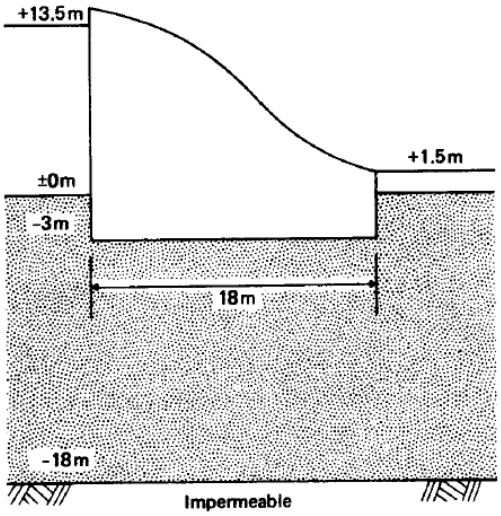
(20 marks/*markah*)

[d] Figure 2(a) shows the cross section of a concrete dam founded on slightly permeable soil, below which there is an impermeable stratum while Figure 2(b) illustrates the completed flow net for the concrete dam.

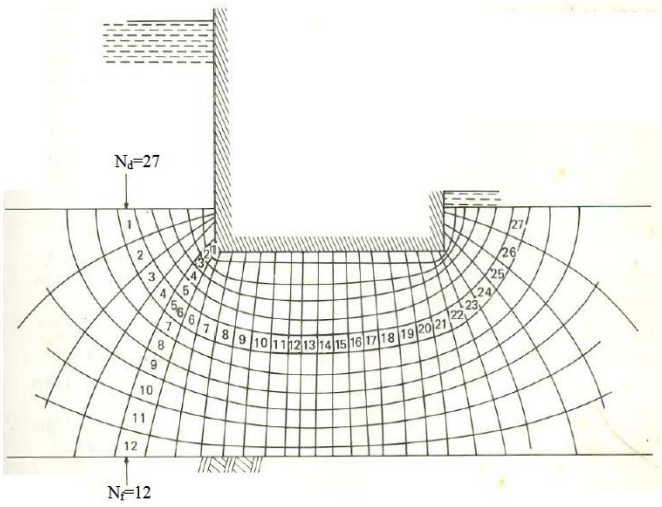
Assuming the soil to be isotropic, determine the rate of seepage of water under the dam. Given k for the soil =12.5 x 10^{-3} mm/s.

Rajah 2(a) menunjukkan keratan rentas empangan konkrit yang dibina di atas tanah separa telap manakala terdapat kewujudan stratum tidak boleh telap pada bahagian dasar. Rajah 2(b) pula menunjukkan jaringan aliran penuh bagi empangan konkrit tersebut.

Dengan mengandaikan tanah tersebut adalah isotropi, tentukan kadar kuantiti aliran air di bawah empangan. Diberikan nilai k untuk tanah=12.5 x 10^{-3} mm/s.



(a) Cross section of a concrete dam.
Keratan rentas empangan konkrit



(b) Flow net for the concrete dam.
Jaringan aliran penuh bagi empangan konkrit

Figure 2 / *Rajah 2*

(20 marks/*markah*)

5. [a] Plot the poles of the following discontinuities:

(i) dip 57º towards 200º.

(ii) dip 64º towards 195º.

(iii) dip 45º towards 045º.

(iv) dip 55º towards 220º.

(v) dip 60º towards 190º.

(vi) dip 53º towards 205º.

From the plot obtained, estimate and determine the general dip and trend of these structures.

Plot kutub-kutub ketakselanjaran berikut:

(i) miring 57º ke arah 200º.

(ii) miring 64º ke arah 195º.

(iii) miring 45º ke arah 045º.

(iv) miring 55º ke arah 220º.

(v) miring 60º ke arah 190º.

(vi) miring 53º ke arah 205º.

Dari plot yang diperolehi, anggarkan dan tentukan kemiringan am dan tren struktur-struktur ini.

(40 marks/*markah*)

[b] A new bench of an open pit mine is going to cut through a granite hill. The rock slope of the bench is going to dip towards 300º. The rock has two sets of joint as follow:

Set 1: dips 52º towards 258º.

Set 2: dips 60º towards 333º.

The angles of the bench cut are being considered at the following angles:

- 60º.
- 52º.
- 40º.

(i) Give your comments on the type of failures (if any) that may occur on each proposed slope.

(ii) What is the steepest slope that you would recommend and why? Attach all tracing papers used with your answers.

Sebuah jalan raya akan dibina dan akan memotong sebahagian daripada sebuah bukit granit. Cerun di tepi jalan raya ini miring ke arah 300º. Batuan yang akan dipotong ini terdapat dua kekar iaitu :

Set 1: miring 52º ke arah 258º.

Set 2: miring 60º ke arah 333º.

Sudut muka cerun potongan ini sedang dipertimbangkan seperti berikut:

- *60º.*
- *52º.*
- *40º.*

(i) Beri komen anda mengenai jenis kegagalan (jika ada) yang mungkin terjadi pada setiap sudut muka cerun yang dicadangkan.

(ii) Apakah sudut muka cerun yang paling curam yang anda syorkan dan nyatakan mengapa? Jawapan anda hendaklah disertakan dengan kertas surih yang anda gunakan.

(60 marks/*markah*)

6. [a] A 30 m high face slope has been excavated East-South direction into a rock mass. Extensive geotechnical drilling programme has revealed the following information:

Plane A: dips 40º towards 106º, Ø of 35.

Plane B: dips 65º towards 250º, Ø 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 40º, a dip direction of 012º and a Ø of 31º; Plane C is also planar, smooth and has zero cohesion. Very shortly after this intersection day lighted out of its slope, the wedge failed.

Using the design charts as in **APPENDIX 2 & 3**, 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 Timur-Selatan di dalam jisim suatu batuan. Program penggerudian geoteknikal telah menghasilkan maklumat yang berikut:

Satah A: miring 40º ke arah 106º, dengan Ø 35.

Satah B: miring 65º ke arah 250º, dengan Ø 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 40º, arah miring 012º dan Ø bernilai 31º; sesar ini 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 dalam **LAMPIRAN 2 & 3**, tentukan faktor keselamatan baji yang dibentuk oleh satah A, B dan C.*

(50 marks/*markah*)

[b] During the exploration programme for a proposed open pit mine, the mine planning engineer responsible for the pit layout has requested guidance on the maximum safe angles which may be used for the design of the overall pit slopes. Extensive geological mapping of outcrops on the site together with a certain amount of core logging has established that there are four sets of geological discontinuities in the rock mass surrounding the ore body. The scatter in the dip and dip direction measurements should be taken into account in the analysis considering the mapping covers the entire alignment that extends over several kilometres.

Using the stereonet and accompanying design charts (**APPENDIX 2 & 3**), determine the factor of safety for each of the wedge formed, assuming a friction of angle of 30°. The dips and dip directions of these discontinuities are as follows:

Joints Set	Dip direction	Dip
1	150°	60°
2	140°	68°
3	180°	65°
4	256°	57°
5	298	49°

Semasa operasi penerokaan bagi membuka sebuah lombong dedah, jurutera perancangan lombong yang bertanggungjawab bagi susun atur pit telah meminta bimbingan berkaitan sudut maksimum yang selamat digunakan untuk reka bentuk keseluruhan cerun pit. Pemetaan geologi singkapan di kawasan lombong bersama-sama dengan rekod telah memperlihatkan bahawa terdapat empat set ketidakselanjaran geologi dalam jisim batu yang mengelilingi badan bijih. Serakan ukuran miring dan arah kemiringan perlu diambil kira di dalam analisis ini memandangkan pemetaan meliputi kawasan yang menjangkau lebih daripada beberapa kilometer.

*Menggunakan stereonet dan carta reka bentuk yang disertakan (**LAMPIRAN 2 & 3**), tentukan faktor keselamatan untuk setiap baji dibentuk dengan menganggapkan sudut geseran adalah 30°. Miring dan arah kemiringan ketidakselanjaran adalah seperti berikut:*

Set Kekar	***Arah kemiringan***	***Miring***
1	*150°*	*60°*
2	*140°*	*68°*
3	*180°*	*65°*
4	*250°*	*57°*
5	*298*	*49°*

(50 marks/*markah*)

7. A 5.5 m diameter tunnel is to be driven through a sequence of brecciated schist, phyllite and gneiss rock at a minimum depth of 1, 200 m. The rock strata dip towards the East, and being cut by two major discontinuities orientated at N285° and N250°. The bedding dips between 15° and 20°, the faults dip at 70° and 60° respectively. The faults are smooth planar to slickenside planar, moderately narrow, highly weathered, healed with clay infilling and has average discontinuity spacing of 4 cm, hence overall the rock is described as 'highly weathered and weak'. The groundwater level is about 10 m below the ground surface and recorded at < 1L/min. The rock mass is easily broken by normal blow of hammer with the average UCS of 45 MPa, and values of the RQD as 50%.

   Use the RMR and Q system (**APPENDIX 4 & 5**) to classify this rock, and access the stability of the tunnel as its being driven from northeast to southwest.

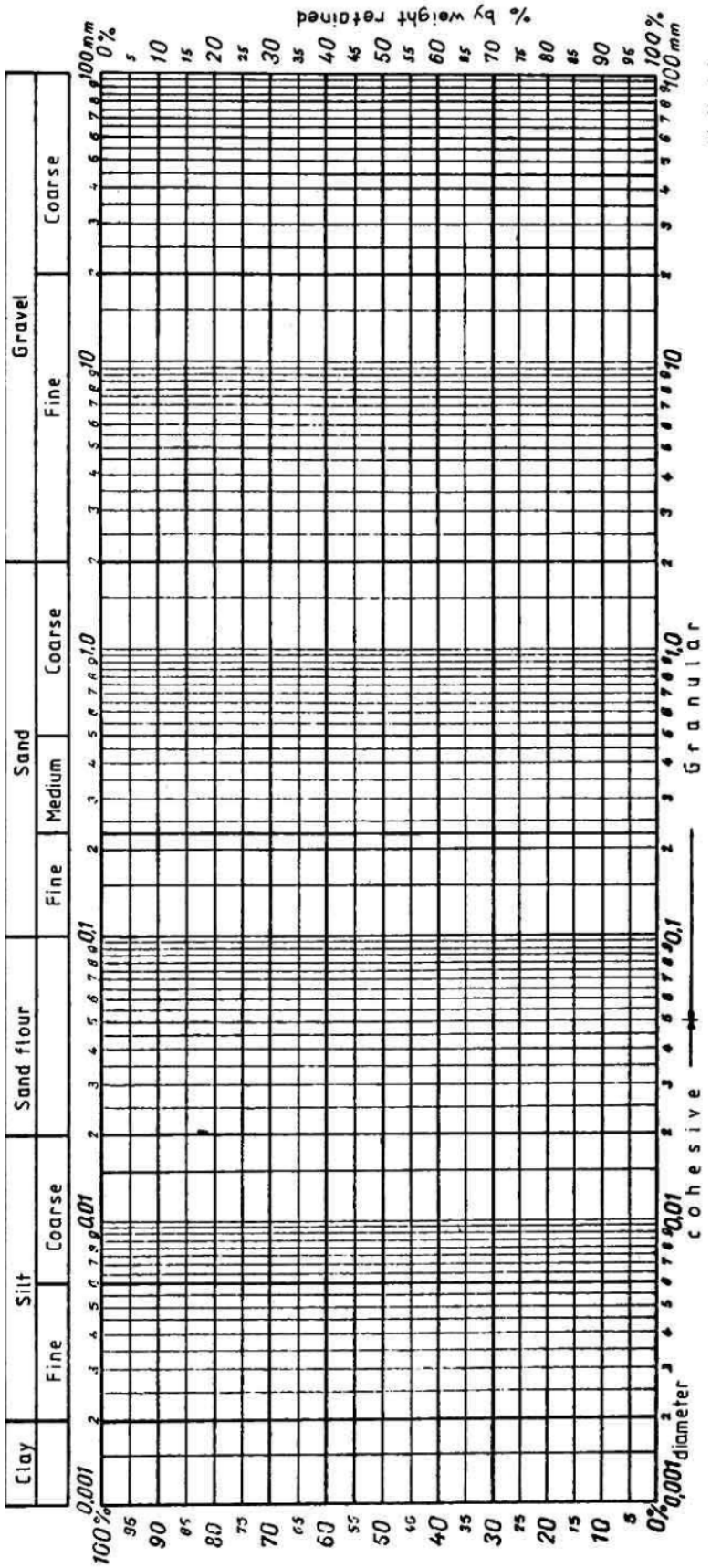
   5.5 diameter terowong sedang di bina di dalam urutan batuan syis berbreksia, filit dan gneis pada kedalaman tidak kurang dari 1, 200 m. Strata batuan ini miring ke arah Timur, dan dipotong oleh dua ketakselanjaran utama yang berorientasi pada arah N285° dan N250°. Perlapisan batuan miring di antara 15° dan 20°, sesar miring masing-masing pada 70° dan 60°. Sesar adalah satah licin kepada upaman, sederhana sempit, ditutupi oleh lumpur dan mempunyai purata jarak ketakselanjaran 4 cm, oleh itu secara keseluruhan batuan digambarkan sebagai 'sangat terluluhawa dan lemah'. Air bawah tanah ditemui pada 10 m di bawah permukaan tanah dan direkod pada <1L/min. Jisim batuan mudah pecah dengan pukulan biasa oleh tukul dengan tegasan pada batuan utuh pada 45 MPa dan nilai bagi RQD sebagai 50%.

   *Gunakan sistem klasifikasi RMR dan Q (**Lampiran 4 & 5**) untuk batuan ini dan buat penilaian kestabilan terowong ini sekiranya proses pengorekan dilakukan dari utara timur ke selatan barat.*

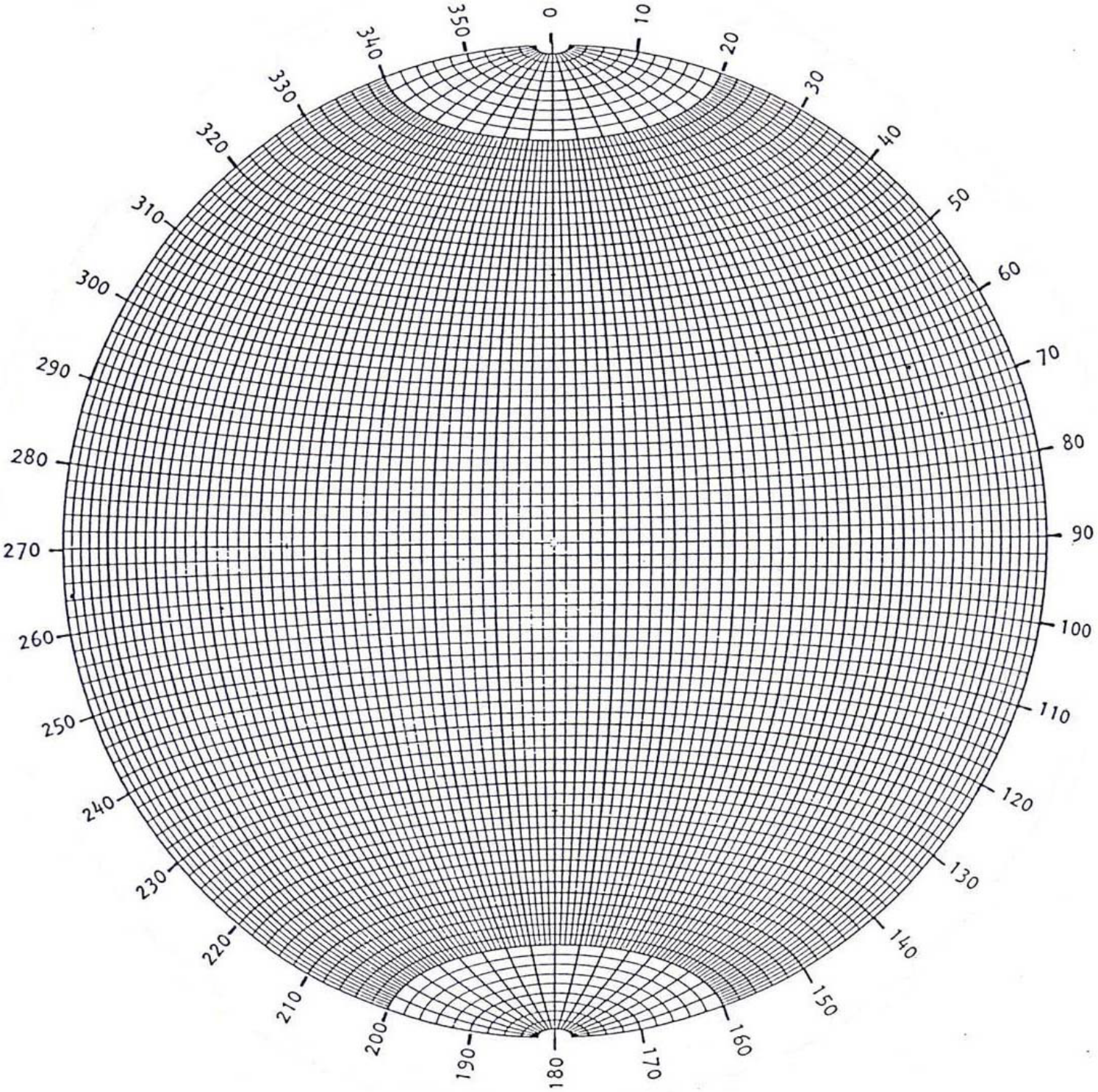
   (100 marks/*markah*)

- oooOooo -

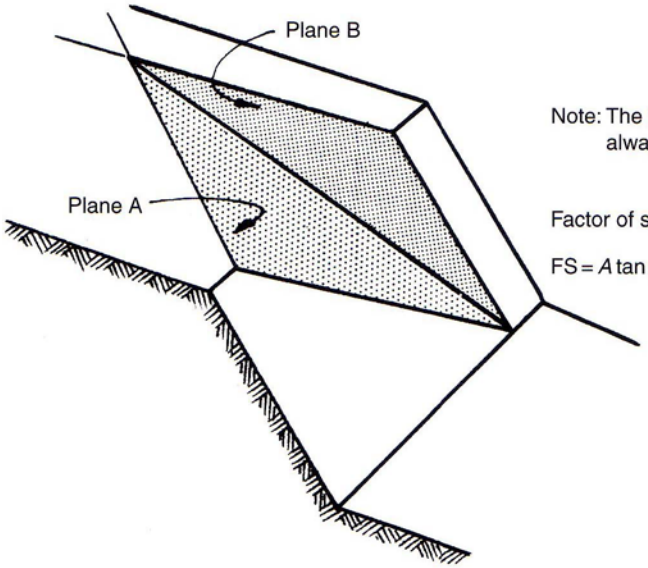
APPENDIX 1 / ***LAMPIRAN 1***

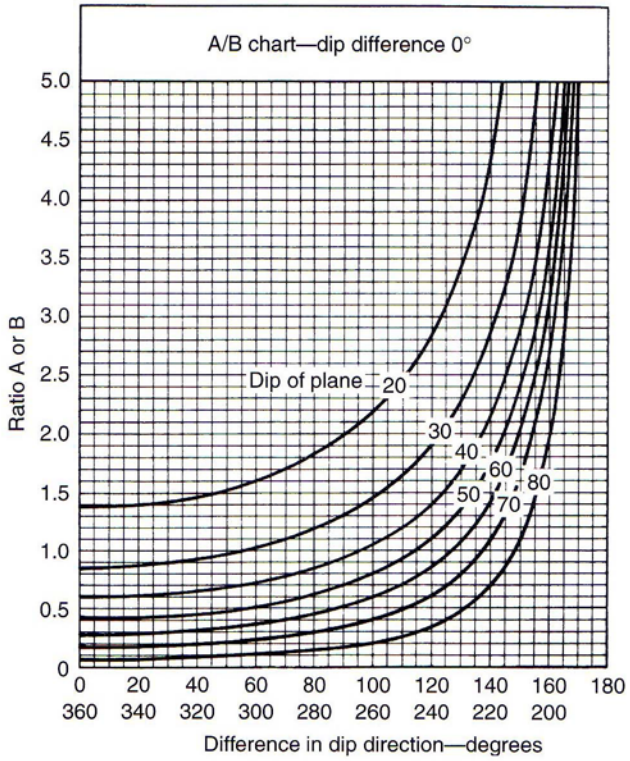


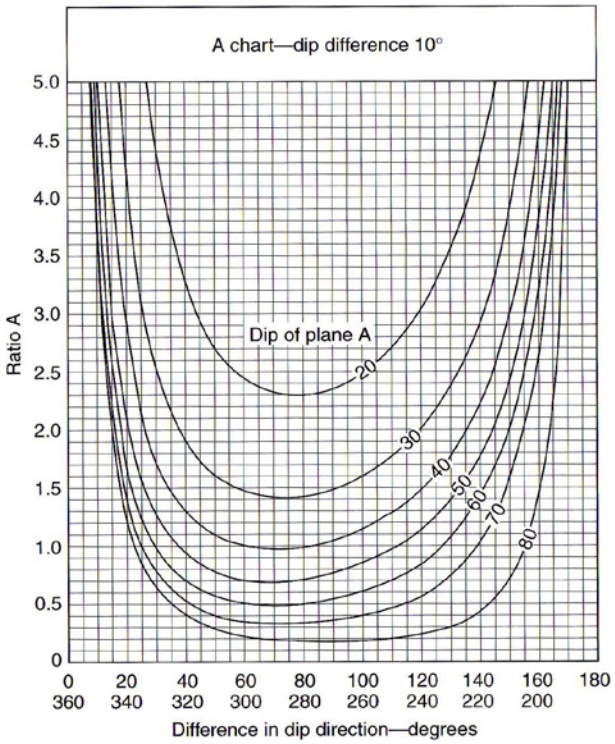
APPENDIX 2 / ***LAMPIRAN 2***

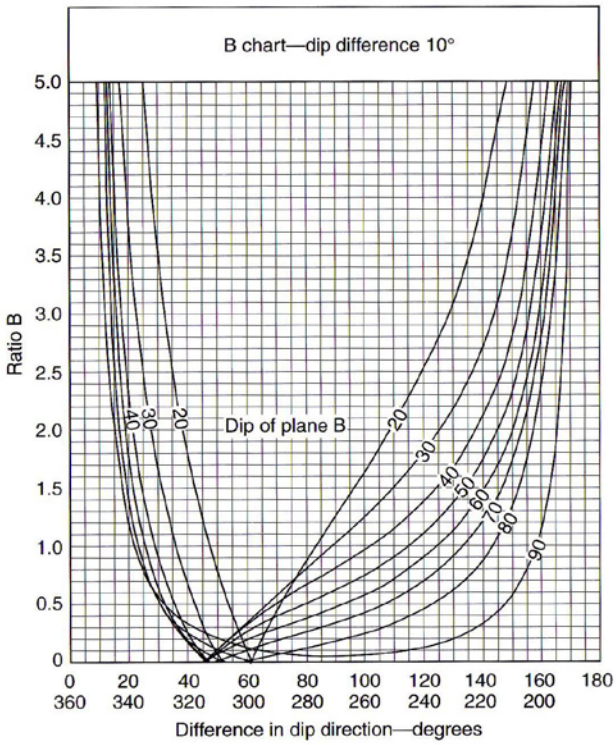


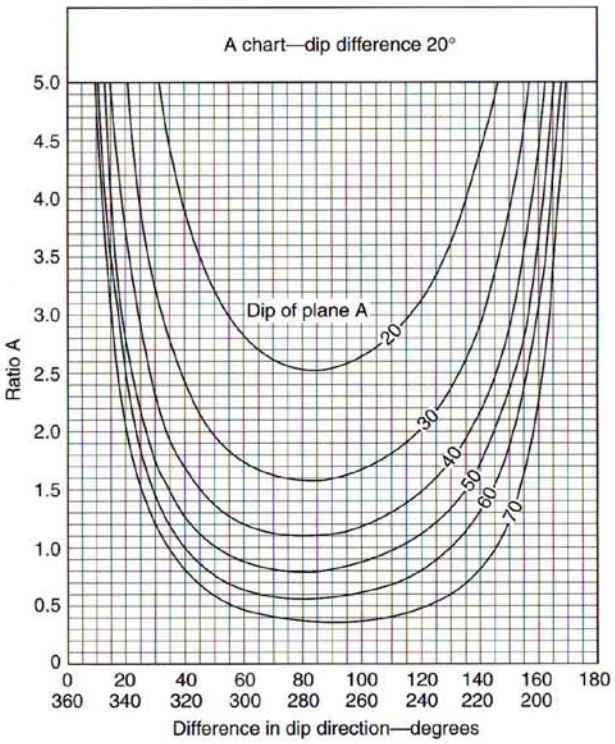
APPENDIX 3 */ LAMPIRAN 3*

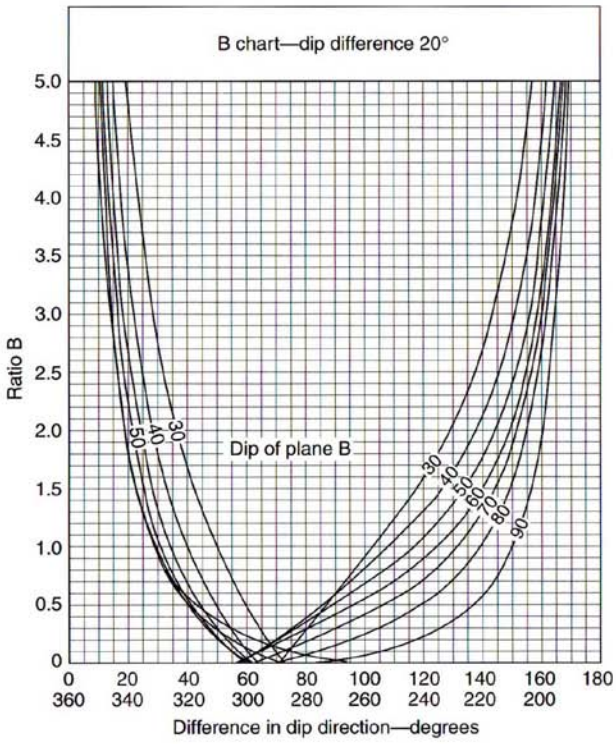


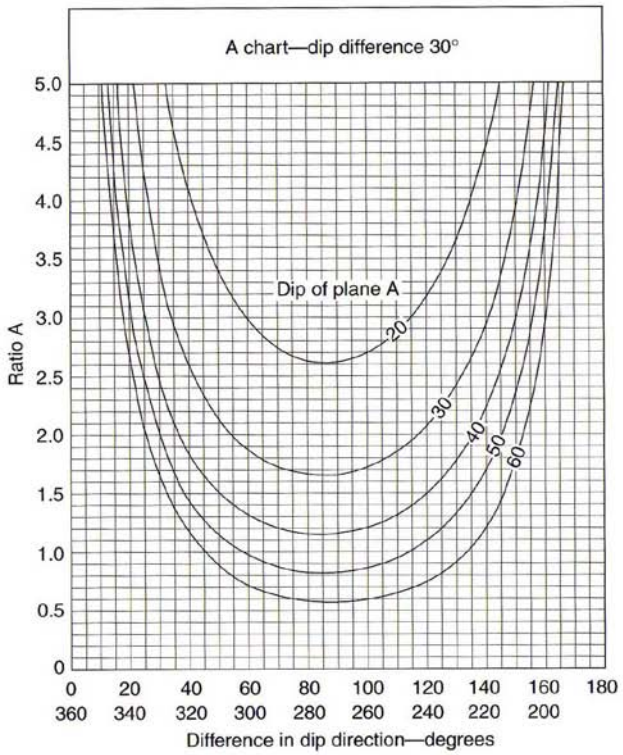


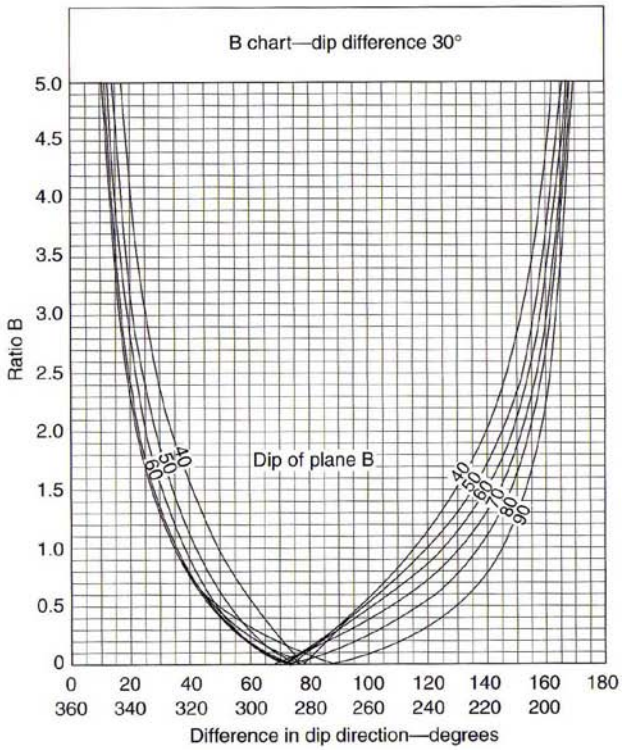

A chart—dip difference 10°
Ratio A
Dip of plane A
20
30
40
50
60
70
80
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees

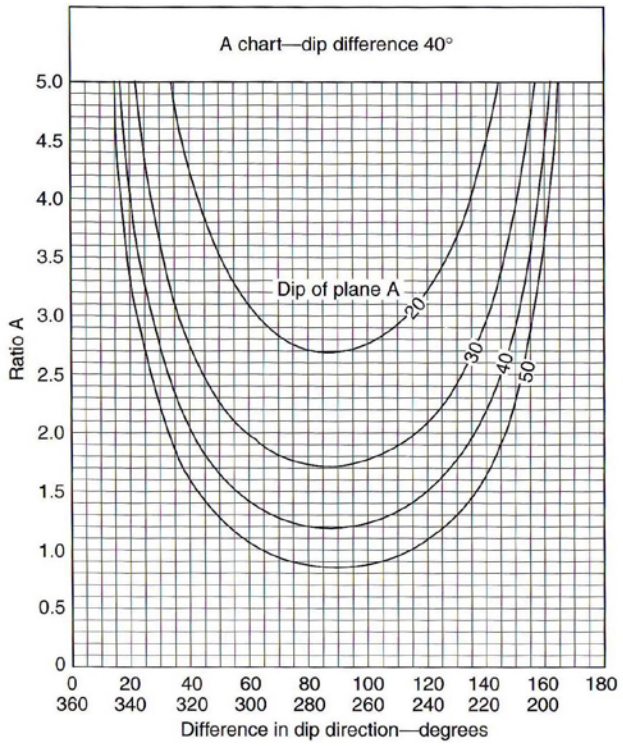

B chart—dip difference 10°
Ratio B
Dip of plane B
20
30
40
50
60
70
80
90
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees

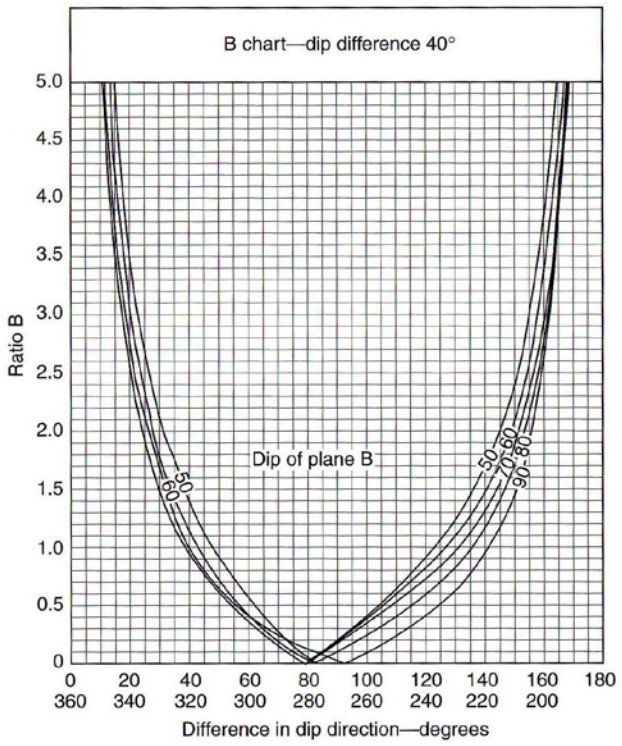

A chart—dip difference 20°
Ratio A
Dip of plane A
20
30
40
50
60
70
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees

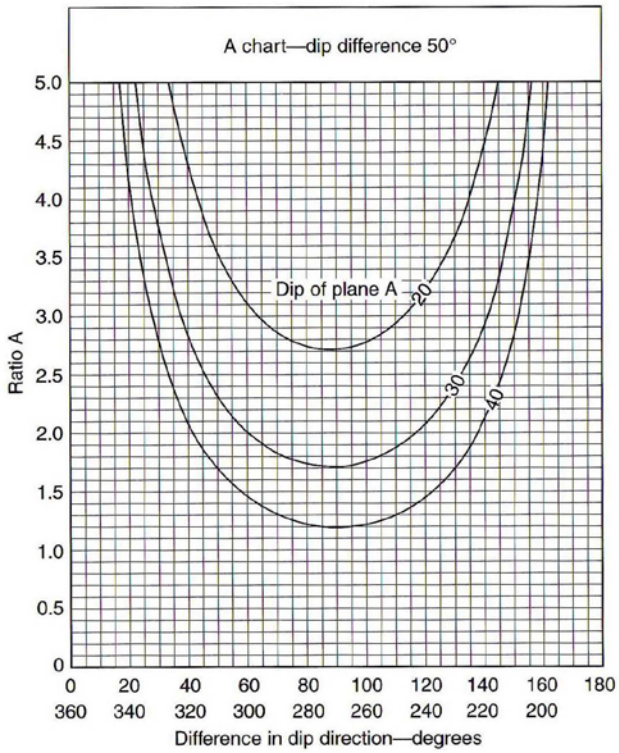

B chart—dip difference 20°
Ratio B
Dip of plane B
30
40
50
60
70
80
90
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees

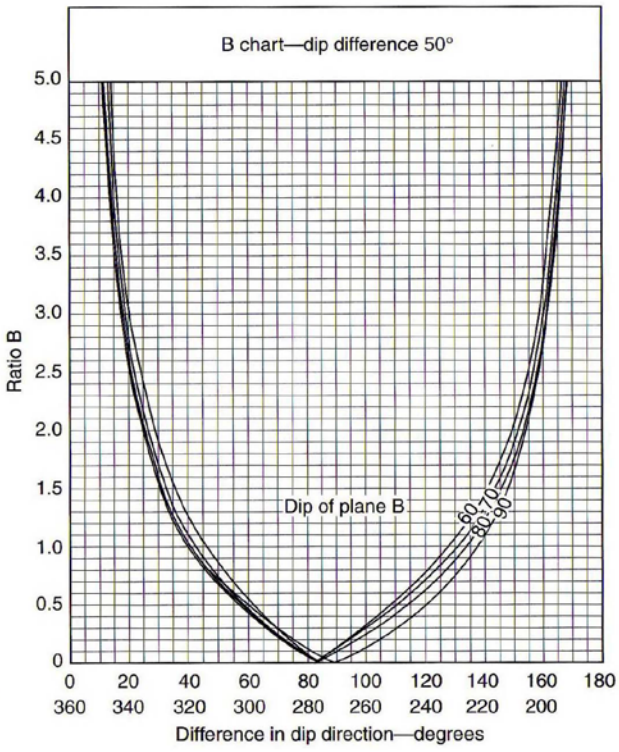

A chart—dip difference 30°
Ratio A
Dip of plane A
20
30
40
50
60
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees

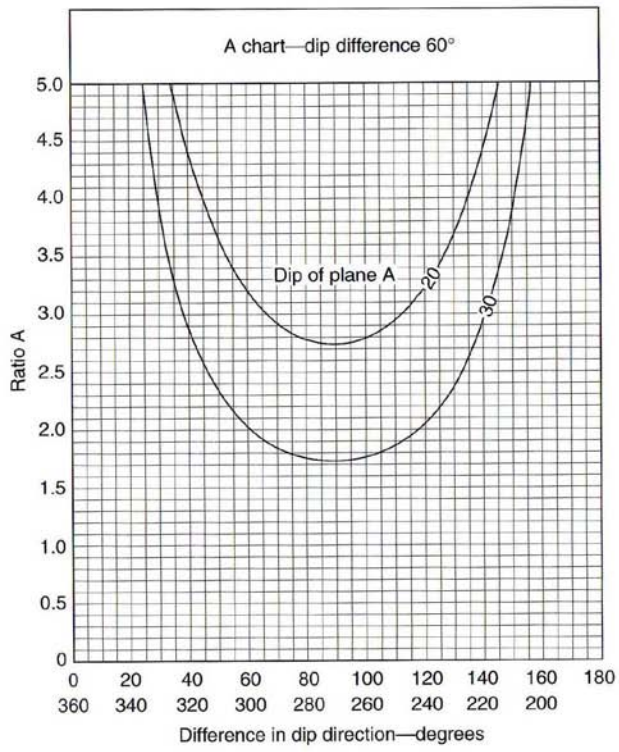

B chart—dip difference 30°
Ratio B
Dip of plane B
40
50
60
70
80
90
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees

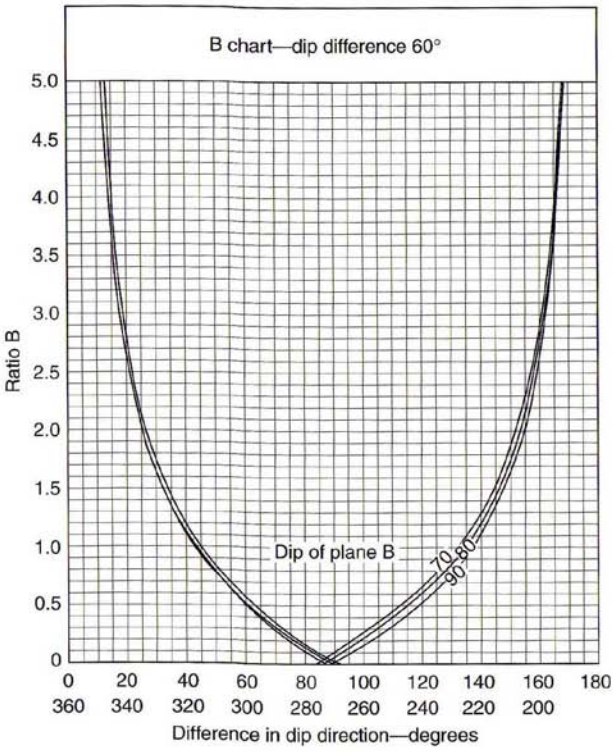

A chart—dip difference 40°
Ratio A
Dip of plane A
20
30
40
50
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees

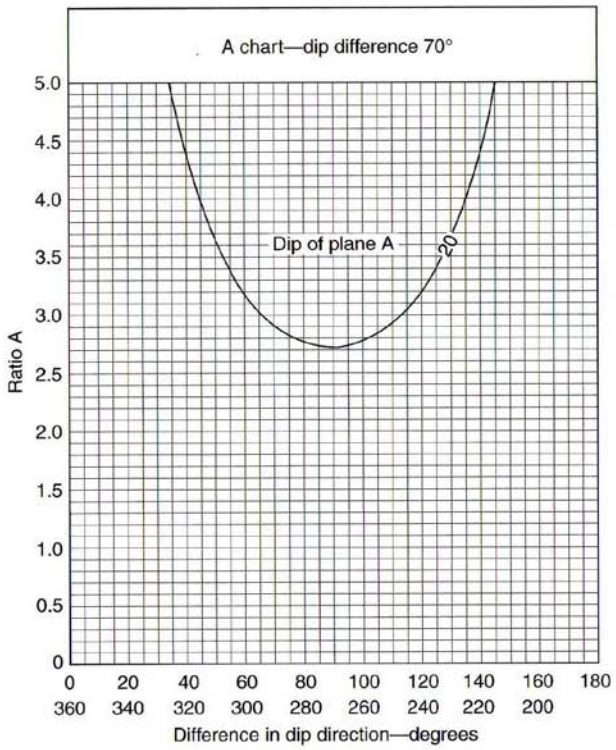

B chart—dip difference 40°
Ratio B
Dip of plane B
50
60
70
80
90
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees

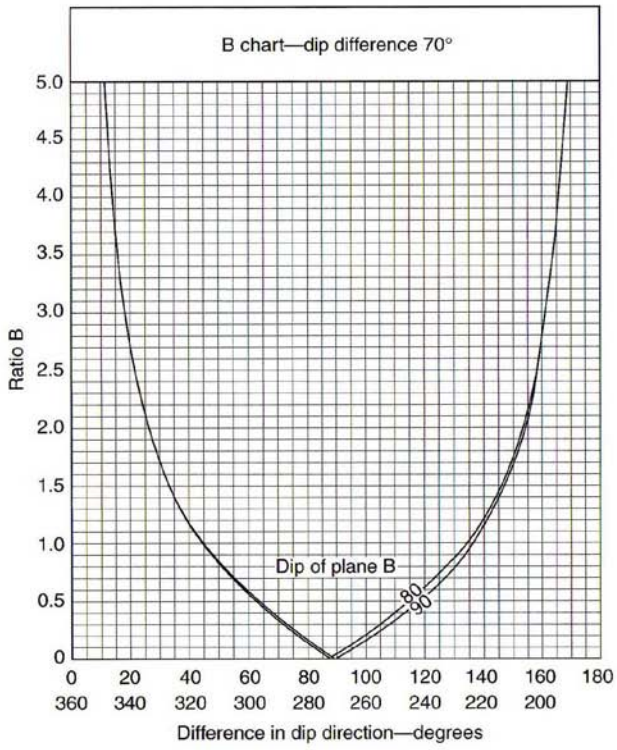

A chart—dip difference 50°
Ratio A
Dip of plane A
20
30
40
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees


B chart—dip difference 50°
Ratio B
Dip of plane B
60
70
80
90
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 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 60°
Ratio A
Dip of plane A
20
30
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 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 60°
Ratio B
Dip of plane B
70
80
90
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 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 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
20
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

APPENDIX 4: Rock Mass Rating System (After Bieniawski, 1989)

LAMPIRAN 4: Sistem Penarafan Massa Rock (Selepas Bieniawski, 1989)

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).

APPENDIX 5 / *LAMPIRAN 5*

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 º	1.0
C	Slightly altered joint walls. Non-softening mineral coating, sandy particles, clay-free disintegrated rock, etc.	25 – 30 º	2.0
D	Silty-or sandy-clay coating, small clay fraction (non-softening)	20 – 25 º	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 º	4.0

(b)	***Rock-wall contact before 10 cm shear (thin mineral fillings)***		
F	Sandy particles, clay-free disintegrated roock, etc.	25 – 30 º	4.0
G	Strongly over-consolidated non-softening clay mineral fillings (continuous, but < 5 mm thickness)	16 – 24 º	6.0
H	Medium or low over-consolidated softening clay mineral fillings (continuous, but < 5 mm thickness)	12 – 16 º	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 º	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 º	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 º	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/cm^2)	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/cm^2)	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 $\leq$ 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 $\leq$50 m)	7.5
E	Single shear zone in competent rock (clay-free) (depth of excavation $\leq$ 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**