LAMPIRAN D3

Untuk Kegunaan Seksyen Peperiksaan dan Pengijazahan	
Nombor Sampul	
Tarikh Peperiksaan	
Sesi Peperiksaan	PAGI / PETANG

PENYEMAKAN KERTAS SOALAN PEPERIKSAAN
Proof-reading of Examination Question Paper

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I/We have checked the typed copies of the Examination Paper stated below :

Kod Kursus / *Course Code* : EBS 419/3
Tajuk Kursus / *Course Title* : Geomechanics / Geomekanik

Jangka Masa Peperiksaan / *Duration of Examination* : 3 Jam / *Hours*
Bilangan Muka Surat Bertaip / *Number of typed pages* : 18 + 12 Muka Surat / *Pages*
Bilangan Soalan Yang Perlu Dijawab / *Number of questions required to be answered* : 5 Soalan / *Questions*

Soalan-soalan dijawab atas : *Questions to be answered in :* Sila (√) *Please (√)*	BUKU JAWAPAN *Answer Book*	OMR *OMR Form*	JAWAB DALAM KERTAS SOALAN *Answer In Question Paper*
	√		

DENGAN INI DISAHKAN BAHAWA KERTAS SOALAN PEPERIKSAAN INI ADALAH TERATUR, BETUL DAN SEDIA UNTUK DICETAK.
Certified that this question paper is in order, correct and ready for printing.

Nama Pemeriksa / *Name of Examiner(s)* : MOHD HAFIZAN
Huruf Besar / *In Block Capitals* : DR. HAREYANI ZABIDI
Tandatangan / *Signature* :
Tarikh / *Date* : 27/10/16 ; 31/10/2016

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NOTA / *NOTE* : Pemeriksa-pemeriksa yang menyediakan kertas soalan peperiksaan adalah bertanggungjawab atas ketepatan isi kandungan kertas soalan peperiksaan berkenaan.
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UNIVERSITI SAINS MALAYSIA

First Semester Examination
2016/2017 Academic Session

December 2016 / January 2017

EBS 417/3 - Geomechanics
[Geomekanik]

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains EIGHTEEN printed pages and TWELVE pages APPENDIX before you begin the examination.
[Sila pastikan bahawa kertas peperiksaan ini mengandungi LAPAN BELAS muka surat beserta DUA 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 di 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] Based on the information given in Figure 1:

(i) **Compute** an approximate value for the coefficient of permeability (*k*) for the sample above. Note: The sample consist of clean sand

(ii) **Determine** the uniformity coefficient (C_u)

(iii) **Classify** the soil sample based on the chart provided.

Berdasarkan maklumat di dalam Rajah 1:

(i) ***Kirakan*** *anggaran nilai pekali kebolehtelapan (k) bagi sampel tersebut. Nota: Sampel adalah pasir bersih.*

(ii) ***Tentukan*** *pekali keseragaman (C_u)*

(iii) ***Kelaskan*** *sampel tanah ini menggunakan carta yang dibekalkan.*

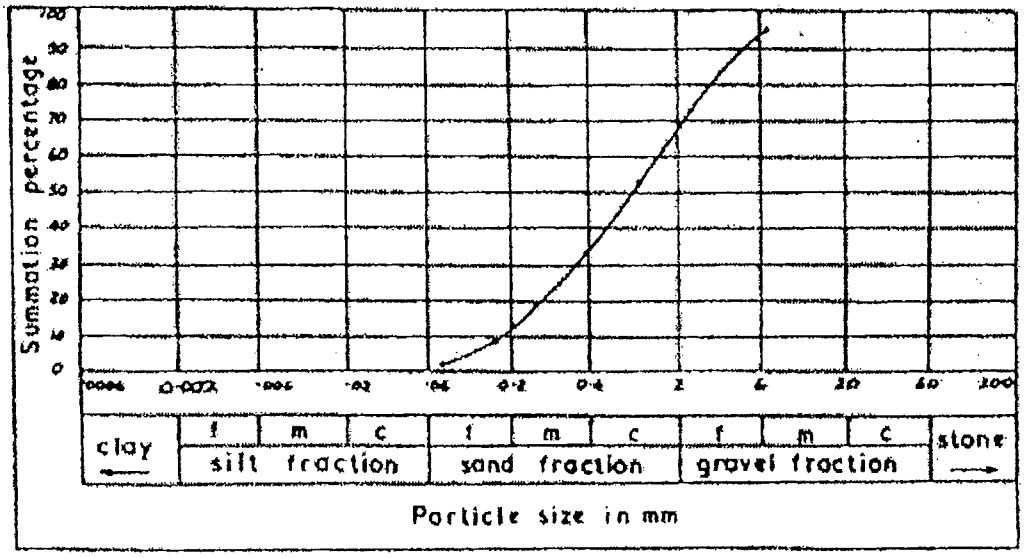


Figure 1: Particle size distribution curve

Rajah 1: Lengkung taburan saiz partikel

(60 marks/ *markah*)

[b] Water flows through the soil sample under a head which is kept constant by means of the overflow arrangement as shown in Figure 2. The head loss, h, between two points along the length of the sample, distance, l, apart is measured by means of a manometer.

By the mean of the Darcy's law, q = Aki and assuming that the area of sample is A, **derive** the expression of coefficient of permeability, k.

Aliran air melalui sampel tanah secara malar adalah seperti yang ditunjukkan di dalam Rajah 2. Kehilangan turus malar, h, adalah di antara dua titik disepanjang sampel yang panjangnya, l, dan diukur menggunakan manometer.

Dengan menggunakan Hukum Darcy, q=Aki dan mengandaikan luas sampel adalah A, ***terbitkan*** *persamaan pekali kebolehtelapan, k.*

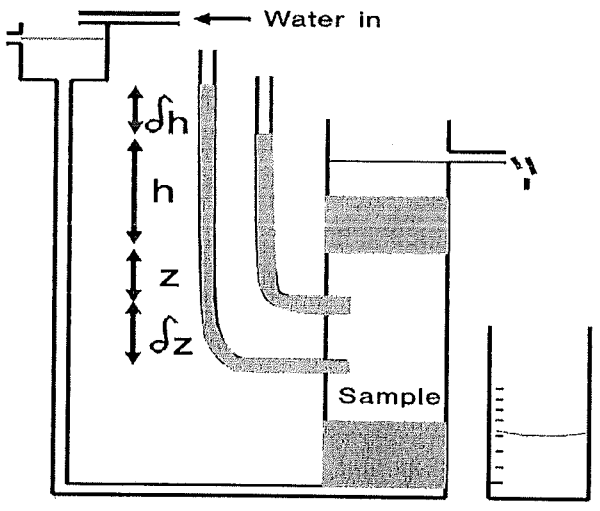


Figure 2 : Constant head permeability test

Rajah 2: Ujian kebolehtelapan malar

(20 marks/ *markah*)

[c] In a constant head permeability test the following results were obtained:

- Duration of test = 5.0 min
- Quantity of water collected/ = 900 ml
- Head difference in manometer = 50 mm
- Distance between manometer tappings/ = 100 mm
- Diameter of test sample/ = 120 mm

Determine the coefficient of permeability in m/s.

Maklumat berikut diperolehi daripada ujian kebolehtelapan malar:

- *Tempoh ujikaji* = *5.0 min*
- *Kuantiti air diperolehi* = *900 ml*
- *Perbezaan turus di dalam manometer* = *50 mm*
- *Jarak antara manometer* = *100 mm*
- *Diameter sampel ujikaji* = *120 mm*

Tentukan pekali kebolehtelapan di dalam m/s.

(20 marks/ *markah*)

2. [a] 10 m wide and 20 m height underground hydropower cavern is to be built in a sequence of brecciated schist, phyllite and gneiss rock at a minimum depth of 600 m. The rock strata dip towards the South, and being cut by three major joint sets orientated at N285°, N080° and N250°. In addition, some random joints occur. The bedding dips between 15° and 20°, the joints dip at 70°, 55° and 60° respectively. RQD value ranges from 70% to 80%. The joints are slightly rough, slightly weathered walls, tight and mostly longer than 3 m and overall the rock is described as 'slightly weathered'. 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 is 45 MPa, and the horizontal stress is about 3.4 MPa.

Sebuah janakuasa elektrik bawah tanah (10 m lebar, 20 m tinggi) akan dibina di dalam jujukan batuan syis berbreksia, filit dan gneis pada kedalaman sekurang-kurangnya 600 m. Strata batuan ini miring ke arah Selatan, dan dipotong oleh tiga ketakselanjaran utama yang berorientasi pada arah N285°, N080° dan N250°. Tambahan dengan kehadiran beberapa kekar rawak. Perlapisan batuan miring di antara 15° dan 20°, kekar miring masing- masing pada 70°, 55° dan 60°. Nilai RQD bermula dari 70% kepada 80%. Kekar adalah sedikit kasar, dinding sedikit terluluhawa, ketat dan kebanyakannya lebih dari 3 m dan secara keseluruhan batuan digambarkan sebagai 'sedikit terluluhawa'. 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 tekanan mendatar pada 3.4 MPa.

...6/-

(i) Use the RMR and Q system (Appendix 1 & 2) to classify the rock mass.

Gunakan sistem klasifikasi RMR dan Q (Lampiran 1 & 2) untuk penilaian jisim batuan

(30 marks/*markah*)

(ii) Based on the rock mass classification system used, describe the support system required to stabilize the excavated rock mass with helps of Appendix 1 and 2.

Berdasarkan sistem pengelasan jisim batuan yang digunakan, jelaskan sistem sokongan yang diperlukan untuk menstabilkan jisim batuan yang telah digali dengan bantuan Lampiran 1 dan 2.

(20 marks/*markah*)

(b) Half of this 8 m span, 6 km long tunnel is located in sub-horizontal layers of meta-sandstone (σ_c = approx. 100 MPa). The tight, smooth and planar joints with coating of mica and/or chlorite along the foliation are often longer than 3 m. In addition to these foliation joints, it is a set of vertical joints and some random joints. However, the rock splits easily into smaller pieces, because of tiny, irregular (often partly welded) cracks, which are easily activated from the blasting. The result is a block volume of V_b = 0.0005 – 0.005 m^3 (representative V_b = 0.001m^3 is used), RQD = 10, joint spacing mostly 5 - 20cm. The main joint set has fair orientation with regard to the tunnel. The rock overburden along the tunnel is 40 – 100 m medium stress level) and there was no or minor water inflows.

Use the RMR and Q system (Appendix 1 & 2) to classify the rock mass. Based on the rock mass classification system used, describe the support system required to stabilize the excavated rock mass using Appendix 1 and 2.

Separuh daripada 8 m bukaan, 6 km panjang terowong terletak di lapisan sub-mendatar batu pasir termetamof (σ_c = lebih kurang. 100 MPa). Kekar adalah ketat, licin dan rata dengan lapisan mika dan atau klorida sepanjang foliasi sering mempunyai panjang lebih dari 3 m. Selain daripada foliasi, terdapat kekar menegak dan beberapa kekar rawak. Walau bagaimanapun, batu mudah terpisah kepada batuan yang lebih kecil, kerana retakan kecil, tidak teratur (sering sebahagiannya dikimpal) yang mudah diaktifkan dari letupan. Hasilnya ialah jumlah blok V_b = ,0005-0,005 m^3 (wakil V_b = 0.001m^3 digunakan), RQD = 10, jarak antara kekar kebanyakannya 5 - 20cm. Set kekar utama mempunyai orientasi sederhana dengan terowong. Batu beban sepanjang terowong ialah 40 - 100 m (tahap tekanan yang sederhana) dan tidak ada atau aliran masuk air adalah kecil.

Gunakan sistem klasifikasi RMR dan Q (Lampiran 1 & 2) untuk buat penilaian jisim batuan. Berdasarkan sistem pengelasan jisim batuan yang digunakan, jelaskan sistem sokongan yang diperlukan untuk menstabilkan jisim batuan yang telah digali dengan menggunakan Lampiran 1 and 2.

(50 marks/*markah*)

PART B/*BAHAGIAN B*

3. [a] **Differentiate** between the drained and undrained shear strength

Bezakan *di antara kekuatan tegasan tersalir dan kekuatan tegasan tak tersalir*

(30 marks/ *markah*)

[b] A granular soil has a saturated unit weight of 18.5 space kN/m^3 and angle of shearing resistance of 33^0. A slope is to be made of this material. If the factor of safety is to be 1.25, **determine** the safe angle of the slope.

Satu tanah granul mempunyai berat unit tepu 18.5 kN/m^3 dan sudut rintangan ricih 33^0. Sebuah cerun dibina menggunakan tanah tersebut. Andaikan faktor keselamatan yang diperlukan adalah 1.25, ***tentukan*** *sudut selamat bagi cerun tersebut jika*

(i) The slope is in dry condition

Cerun dalam keadaan kering

(10 marks/ *markah*)

(ii) If seepage occurs at and parallel to the surface of slope.

Jika resipan muncul pada dan selari dengan permukaan cerun

(10 marks/ *markah*)

(c) **Discuss** any two corrective measures for failing slopes.
(Note: Partially marks will be given for diagram)

Bincangkan *mana-mana dua langkah pembaikan kegagalan cerun.*
(Nota: Sebahagian markah diberikan untuk gambarajah)

(50 marks / *markah*)

4. Figure 1 below gives details of an embankment of made cohesive soil with $\phi_u = 0$ and $C_u = 23$ kN/m². The unit weight of the soil is 19 kN/m³. The weight of sliding sector is 398 kN acting at the eccentricity of 5.7 m from the center of rotation .

Rajah 1 menunjukkan benteng yang diperbuat daripada tanah berjelekit dengan $\phi_u = 0$ and $C_u = 23$ kN/m². Jisim unit tanah adalah 19 kN/m³. Berat sektor gelinciran adalah 398 kN bertindak terhadap keeksentrikan 5.7 m daripada pusat putaran.

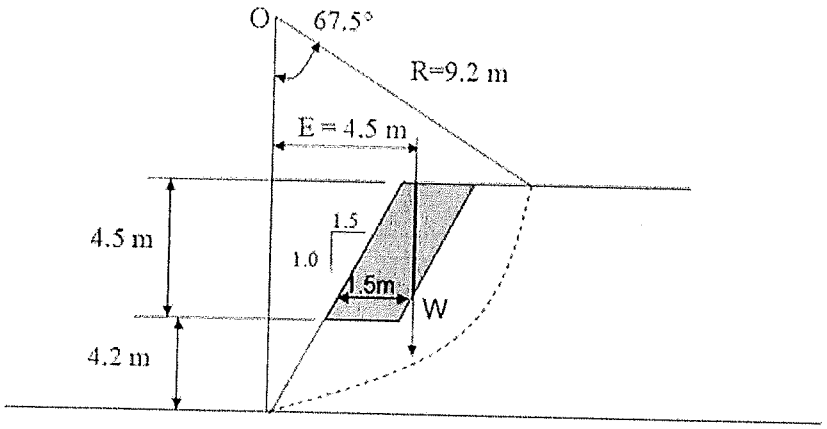


Figure 3 / *Rajah 3*

(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) **Examine** the factor of safety if the shaded portion of the embankment were removed.

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 (4a) and (4b) above. Provide a **comment** on this.

Kirakan peningkatan peratusan faktor keselamatan antara kedua-dua situasi (4a) dan (4b) di atas. Berikan ***komen*** *anda.*

(20 marks/ *markah*)

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

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

5. [a] Plot the poles of the following discontinuities, using Appendix 3:

(i) dip 83° towards 160°
(ii) dip 39° towards 015°
(iii) dip 77° towards 163°
(iv) dip 80° towards 171°
(v) dip 82° towards 157°
(vi) dip 45° towards 332°

Determine the estimate general dip and trend of these structures

Plot kutub-kutub ketakselanjaran berikut, menggunakan Lampiran 3:

(i) miring 83° ke arah 160°
(ii) miring 39° ke arah 015°
(iii) miring 77° ke arah 163°
(iv) miring 80° ke arah 171°
(v) miring 82° ke arah 157°
(vi) miring 45° ke arah 332°

Anggarkan kemiringan am dan tren struktur-struktur ini?

(30 marks/*markah*)

[b] Following the obtained estimated mean pole above (a), determine the angle between two mean poles of second joint set at a dip direction of 250, and a dip of 42. Determine the plunge and trend of the line of the intersection between the two joint sets.

Berikutan daripada anggaran min kutub yang diperolehi di atas (a), tentukan sudut di antara dua set min kutub bersama set kekar kedua pada arah kemiringan 250, dan miring sebanyak 42. Tentukan plun dan trend garis persilangan di antara dua set kekar.

(20 marks/*markah)*

[c] A proposed highway on a north-south alignment passes through a ridge of rock in which a through-cut is required to keep the highway on grade. Diamond drilling and mapping shows that the geological conditions in the ridge are consistent so that the same structure will be exposed in each face. The investigation identified four sets of discontinuities in the rock mass through which the road will pass.

Using the stereonet and accompanying design charts (Appendix 4), determine the factor of safety for each of the wedge formed, assuming that the slope is drained, there is zero cohesion on both the slide planes and a friction of angle of 30°. The dips and dip directions of these discontinuities are as follows:

Satu cadangan lebuh raya pada jajaran utara-selatan melalui rabung batuan di mana potongan dikehendaki untuk memastikan lebuh raya pada gred. Penggerudian berlian dan pemetaan menunjukkan bahawa keadaan geologi di rabung konsisten dengan struktur yang sama akan didedahkan dalam setiap muka. Siasatan mengenal pasti empat set ketakselanjaran dalam jisim batuan di mana jalan akan melaluinya.

Menggunakan stereonet dan carta reka bentuk yang disertakan (Lampiran 4), tentukan faktor keselamatan untuk setiap baji dibentuk, menganggap sudut geseran adalah 30°. Miring dan arah kemiringan ketidak selanjaran adalah seperti berikut:

Joints/*Kekar*	**Dip direction/ *Arah kemiringan***	**Dip/*Miring***
Plane 1/*satah 1*	120°	60°
Plane 2/ *satah 2*	357°	70°
Plane 3/ *satah 3*	78°	59°
Plane 4/ *satah 4*	299°	68°

(50 marks/*markah*)

6. [a] 13 m high rock slope with a face angle of 60° has been excavated in a wide range of geological environments. At the bottom of the stratigraphic sequence are thick interbedded Jurasic age sandstone and siltstones and these were overlain by Early Cretaceous carbonaceous measures rocks comprises of limestone and minor dolomite.

These strata form bedding planes dipping 45° into the excavation and had been cut by several set of discontinuites with the major discontinuity strike at an angle of 55° to bedding planes. The 6.5 m deep tension crack is found 5 m behind the crest, and is filled with water to a height of 4 m above the sliding surface.

The slope has the following dimensions:

- Height of the ground water level: $H_W = 10.5$ m
- Angle of friction of the plane: $\phi = 35°$
- Cohesion of the plane: $c = 25$ kN/m^2
- Unit weight of the rock: $\gamma_r = 27$ kN/m^3
- Unit weight of water: $\gamma_w = 9.81$kN/m^3

13 m cerun batuan dengan sudut muka 60° telah digali di pelbagai persekitaran geologi. Di bahagian bawah urutan stratigrafi terdapat lapisan tebal antara batu pasir dan batu lodak berusia Jurasic dan ini dilapisi oleh arang karbon Awal Cretaceous yang mengandungi batu kapur dan sedikit dolomit.

Strata ini membentuk satah perlapisan miring 45° ke dalam penggalian dan telah dipotong oleh beberapa set ketakselanjaran dengan jurus ketakselanjaran utama pada sudut 55° ke satah perlapisan. Retak ketegangan pada kedalaman 6.5 m didapati pada 5 m di belakang puncak, dan diisi dengan air dengan ketinggian 4 m di atas permukaan gelonsoran.

Cerun tersebut mempunyai dimensi berikut:

- *Ketinggian paras air bawah tanah:* $H_W = 10.5\ m$
- *Sudut geseran satah:* $\varphi = 35°$
- *Kejeleketan satah:* $c = 25\ kN/m^2$
- *Berat unit batuan:* $\gamma r = 27\ kN/m^3$
- *Berat unit air:* $\gamma w = 9.81 kN/m^3$

(i) Please illustrate the slope profile based on the above given details and derive an equation for the factor of safety of the slope that includes all forces acting on the rock mass above the plane.

$$FoS = \frac{cA + \Sigma N \tan \phi}{\Sigma S}$$

$A = (H + b \tan\Psi_s - z) \operatorname{cosec}\Psi_p$

$U = 1/2\gamma_w z_w (H + b \tan \Psi_s - z) \operatorname{cosec}\Psi_p$

$V = 1/2\gamma_w z^2_w$

$W_a = \gamma_r [(1 - \cot\Psi_f \tan\Psi_p) (bH + 1/2H^2 \cot\Psi_f + 1/2b2 (\tan\Psi_s - \tan\Psi_p)]$

$W_b = 1/2\gamma_r H^2 [(1 - z/H)^2 \cot\Psi_p \times (\cot\Psi_s \tan\Psi_p - 1)]$

...16/-

Sila gambarkan profil cerun berdasarkan butir-butir yang diberikan di atas dan terbitkan persamaan untuk faktor keselamatan cerun yang merangkumi semua daya yang bertindak pada jasad batuan di atas satah tersebut.

(40 marks/*markah*)

(ii) Determine the factor of safety if the tension crack were completely filled with water due to run-off collecting on the crest of the slope.

Tentukan faktor keselamatan jika retak ketegangan telah dipenuhi dengan air kerana air larian terkumpul di puncak cerun.

(20 marks/*markah*)

(iii) Determine the factor of safety if the slope were completely drained.

Tentukan faktor keselamatan cerun jika cerun tersebut telah disalirkan sepenuhnya

(20 marks /*markah*)

(iv) Determine the factor of safety of the slope if the slope was reinforced with prestressed bolts that are installed with a plunge of 10°.

Tentukan faktor keselamatan cerun jika cerun diperkukuhkan dengan bolt prategasan yang dipasang dengan tunjaman 10°.

(20 marks/*markah*)

7. [a] The stress in a rock mass has been measured by the hydraulic fracturing technique. Two tests were conducted in a vertical borehole: one test at a depth of 500 m; and the other test at a depth of 1000 m. The results were as follows:

Depth, m	Breakdown Pressure, MPa	Shut-in Pressure, MPa
500	14.0	8.0
1000	24.5	16.0

Given that the tensile strength of the rock is 10 MPa, estimate and list the values of σ_1, σ_2 and σ_3 at the two depths. Discuss all the assumptions you have to make in order to produce these estimations.
State whether the two sets of results are consistent with each other, and justify the reasons for the statement.

Tegasan dalam jisim batuan telah diukur dengan teknik keretakan hidraulik. Dua ujian telah dijalankan dalam lubang telaga menegak: satu ujian pada kedalaman 500 m; dan ujian yang lain pada kedalaman 1000 m. Keputusan adalah seperti berikut:

Kedalaman, m	*Pecahan tekanan, MPa*	*Shut-dalam tekanan, MPa*
500	*14.0*	*8.0*
1000	*24.5*	*16.0*

Memandangkan kekuatan tegangan daripada batu adalah 10 MPa, anggarkan dan menyenaraikan nilai-nilai σ1, σ2 dan σ3 di kedua-dua kedalaman. Bincangkan semua andaian anda perlu membuat untuk menghasilkan anggaran ini.
Menyatakan sama ada dua set keputusan adalah konsisten dengan satu sama lain, dan nyatakan justifikasi kenyataan tersebut.

(40 marks/*markah*)

(b) 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 stereographic untuk setiap kegagalan

(30 marks/ *markah*)

(c) As an alternative to back analysis to determine the strength of rock masses, an empirical method has been developed. Discuss briefly the failure criterion used in rocks to provide input data for the analyses required for the design of an open pit mine and underground excavation in hard rock.

Sebagai alternatif untuk analisis semula untuk menentukan kekuatan jasad batuan, kaedah empirikal telah dibangunkan. Secara ringkas bincangkan kriteria kegagalan yang digunakan di dalam batuan untuk menyediakan data input untuk analisis yang diperlukan untuk reka bentuk lombong dedah dan penggalian bawah tanah di dalam batuan keras.

(30 marks/ *markah*)

APPENDIX 1

LAMPIRAN 1

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, 1-1.5m advance, Complete support 20 m from face	Locally bolts in crown 3 m long, spaced 2.5 m with occasional wire mesh.	50mm 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	100mm in crown and 30mm 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, 10m from face	Systematic bolts 4-5 m long, spaced 1-1.5 m in crown and walls with wire mesh	100-150mm in crown and 100mm 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.	150-200mm in crown, 150mm in sides and 50mm on face.	Medium to heavy ribs spaced 0.75 m with steel lagging and forepoling if required. Close invert.

APPENDIX 2

LAMPIRAN 2

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/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 ≤ 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.		

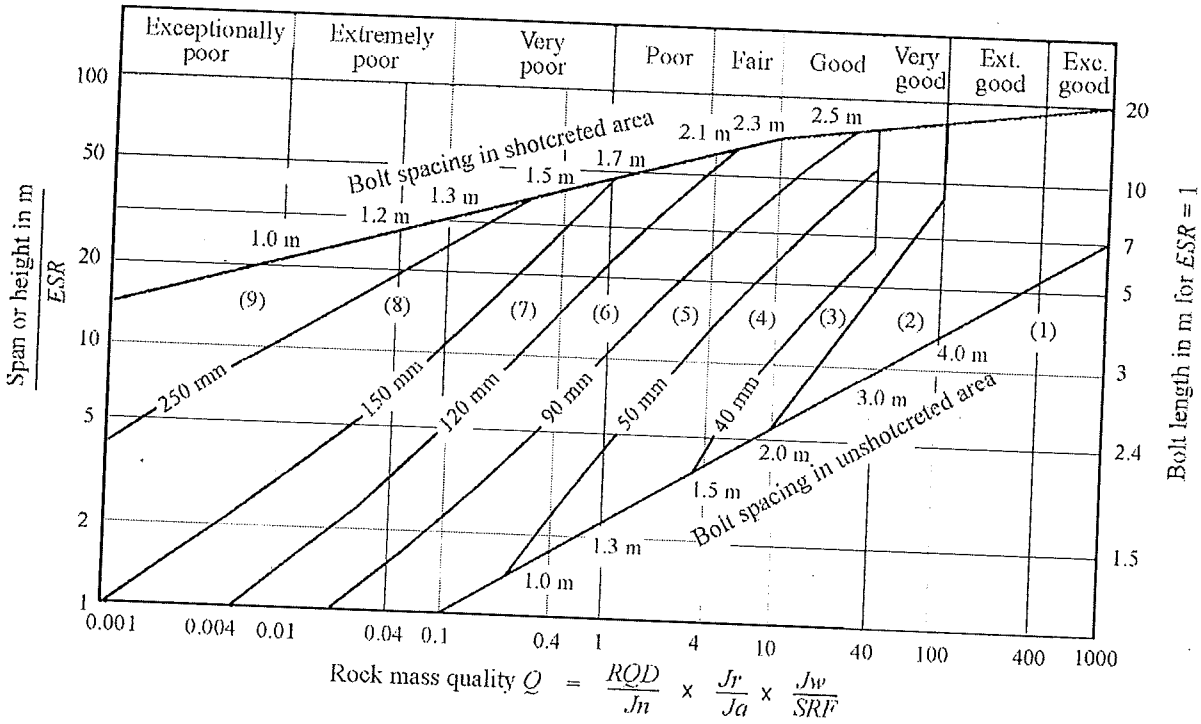
(d)	*Swelling rock: chemical swelling activity depending on presence of water*	SRF
R	Mile swelling rock pressure	5 – 10
S	Heavily swell rock pressure	10 – 15

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

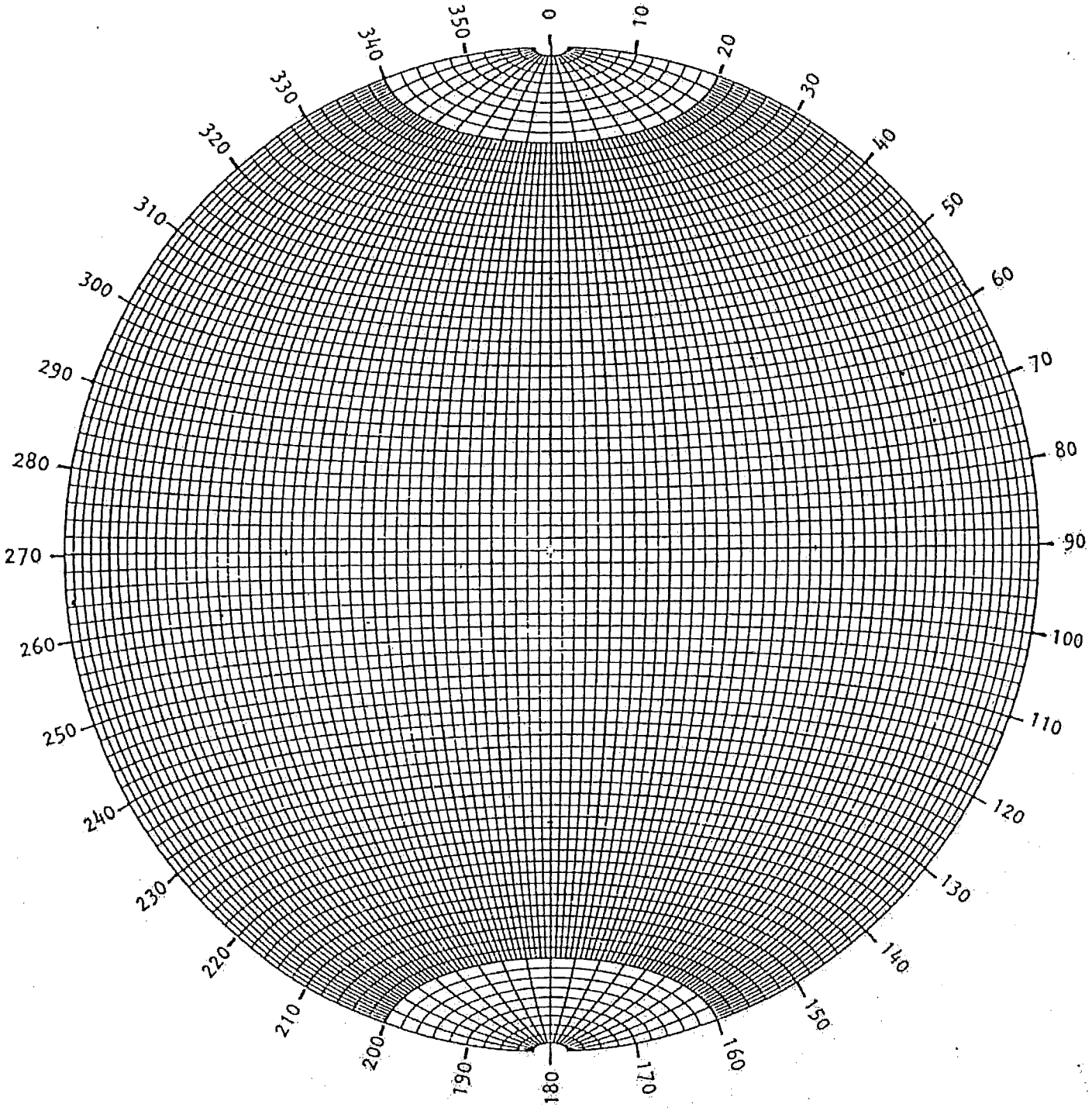
(7) Fibre reinforced shotcrete, 120-150mm and bolting

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

(9) Cast concrete lining

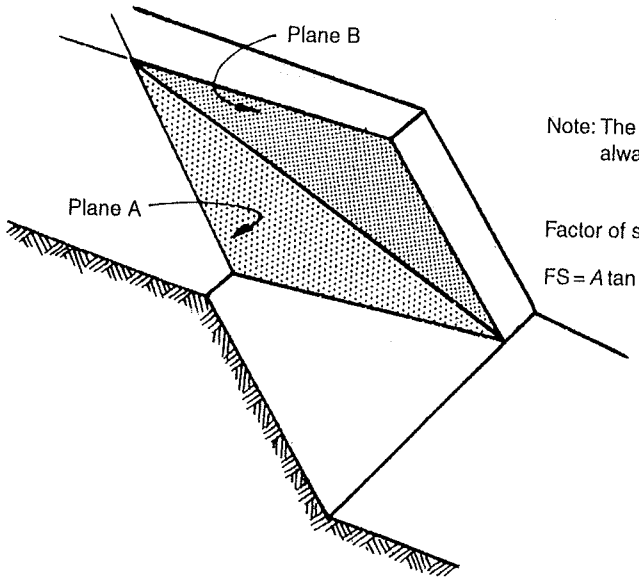
APPENDIX 3

LAMPIRAN 3



APPENDIX 4

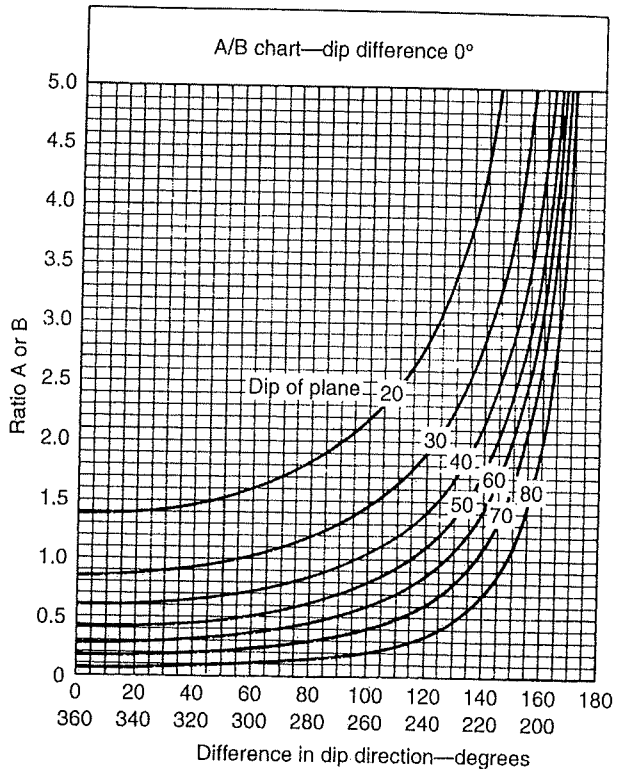
LAMPIRAN 4

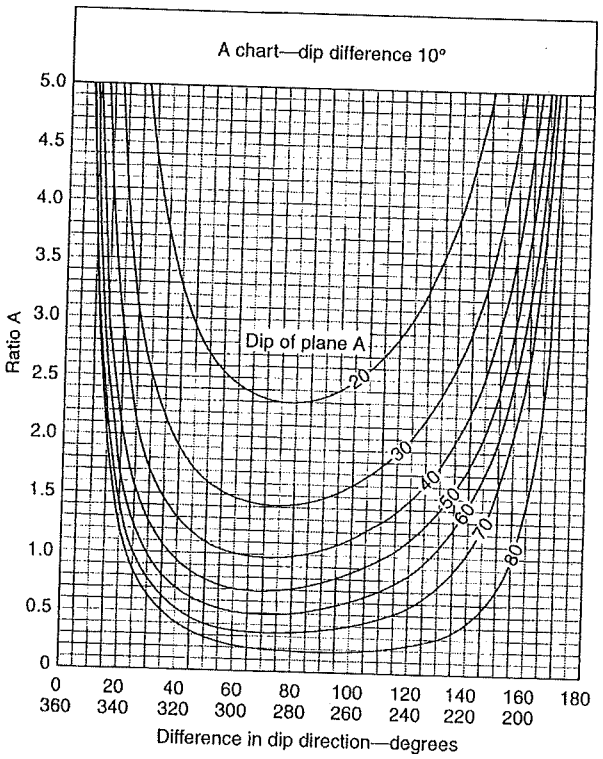


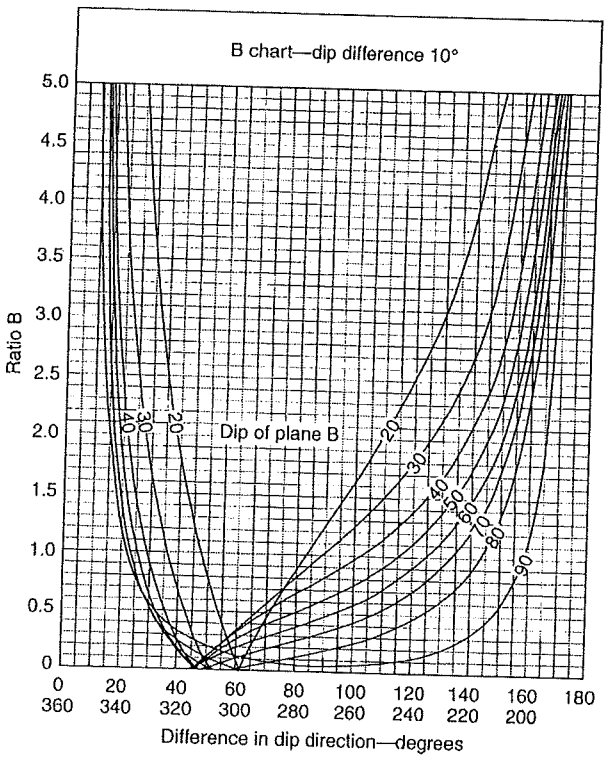
Note: The flatter of the two planes is always called plane A.

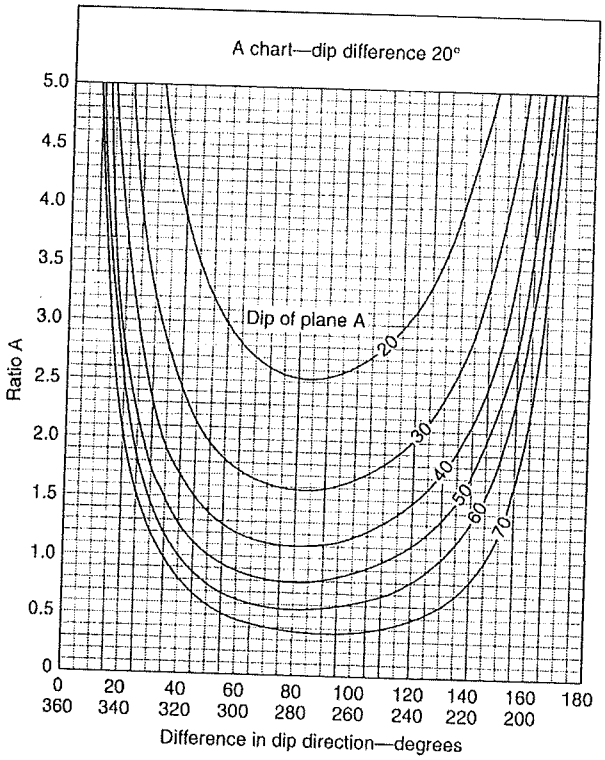
Factor of safety

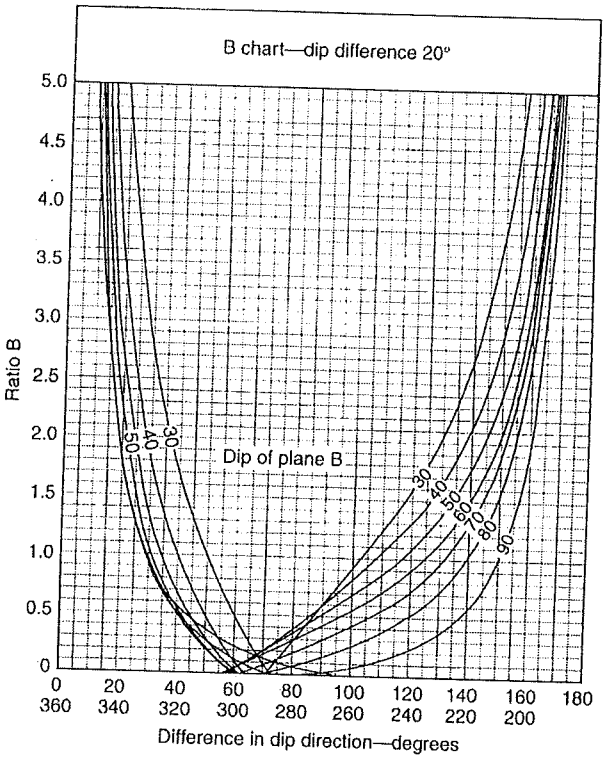
$FS = A \tan \phi_A + B \tan \phi_B$

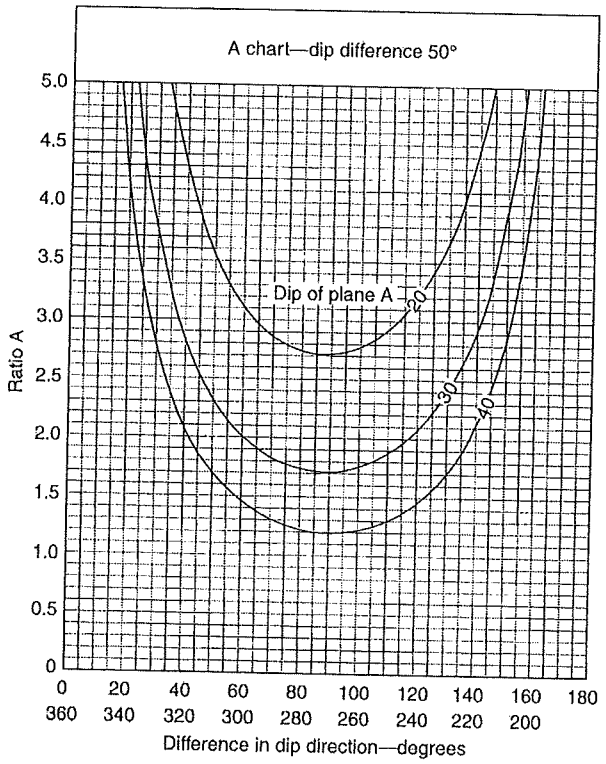


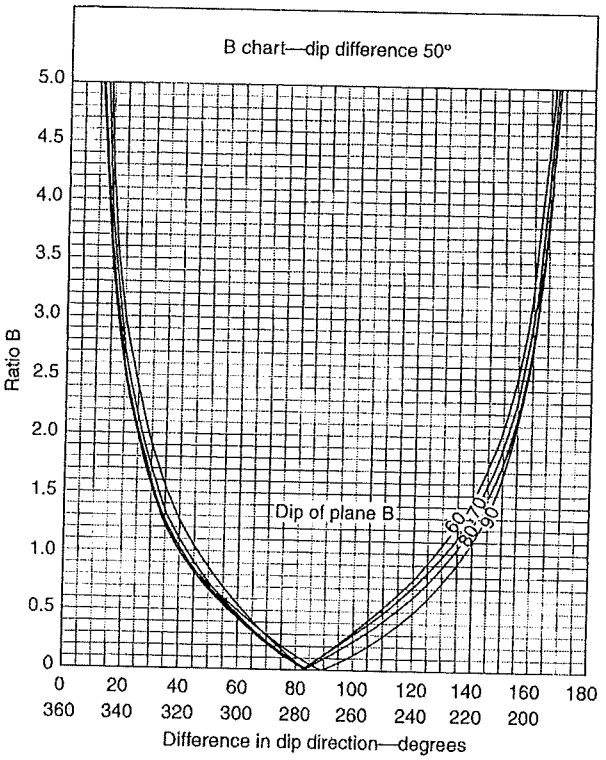

A chart—dip difference 10°
Ratio A
Dip of plane A
20
30
40
50
60
70
80
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees

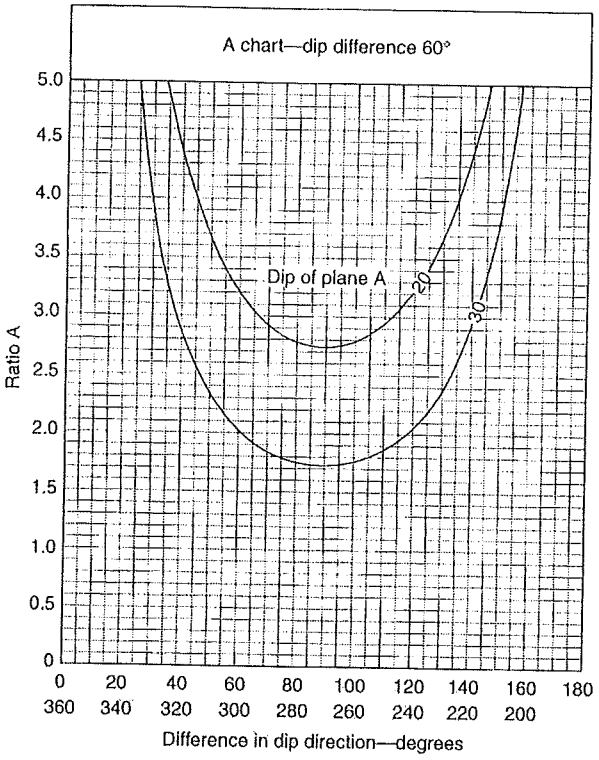

B chart—dip difference 10°
Ratio B
Dip of plane B
20
30
40
50
60
70
80
90
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees

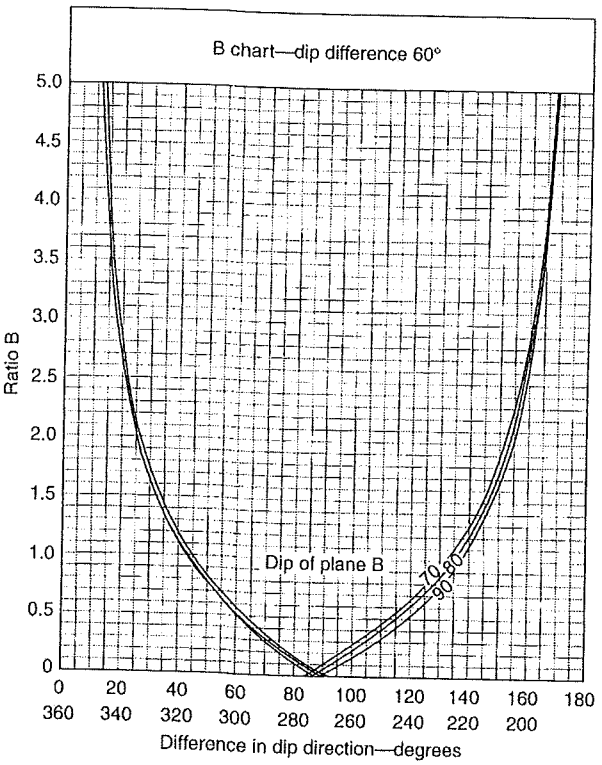

A chart—dip difference 20°
Ratio A
Dip of plane A
20
30
40
50
60
70
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees

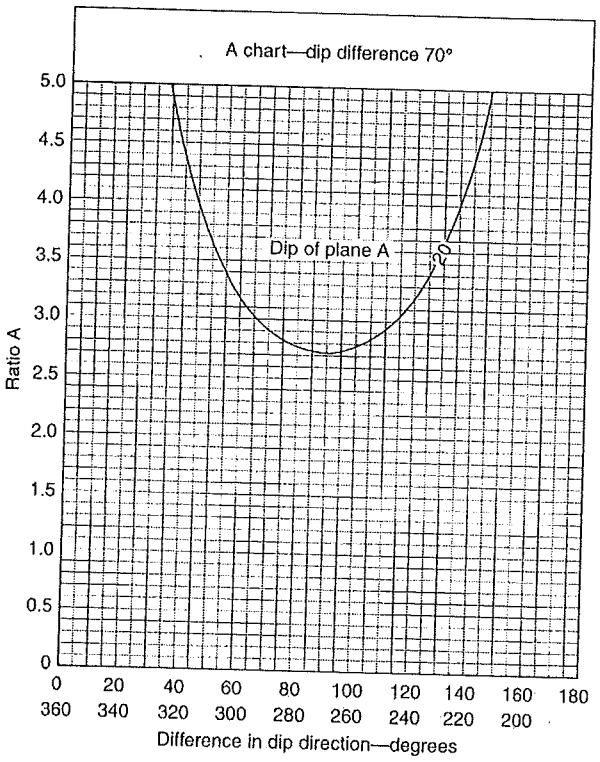

B chart—dip difference 20°
Ratio B
Dip of plane B
30
40
50
60
70
80
90
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees

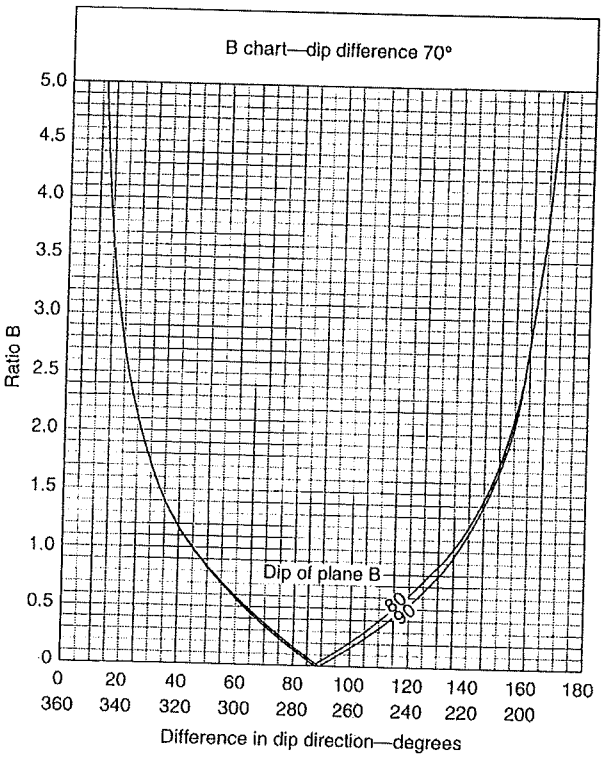

A chart—dip difference 50°
Ratio A
Dip of plane A
20
30
40
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0 20 40 60 80 100 120 140 160 180
360 340 320 300 280 260 240 220 200
Difference in dip direction—degrees


B chart—dip difference 50°
Ratio B
Dip of plane B
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 60°
Ratio A
Dip of plane A
20
30
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 60°
Ratio B
Dip of plane B
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 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