First Semester Examination
2024/2025 Academic Session

February 2025

EBS417 – Geomechanics
(Geomekanik)

Duration : 3 hours
(Masa : 3 jam)

Please check that this examination paper consists of TWENTY (20) pages of printed material including SEVEN (7) pages APPENDIX before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi DUA PULUH (20) muka surat yang bercetak termasuk TUJUH (7) muka surat LAMPIRAN sebelum anda memulakan peperiksaan ini].

Instructions : Answer **FIVE (5)** questions. **Part A is COMPULSORY**. Answer THREE (3) questions from Part B. All questions carry the same marks.

*[**Arahan :** Jawab **LIMA (5)** soalan. **Bahagian A WAJIB dijawab**. Jawab TIGA (3) soalan daripada Bahagian B. Semua soalan membawa jumlah markah yang sama.]*

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah digunapakai].

PART A / *BAHAGIAN A*

(1). (a). The results of a sieve analysis on a soil sample are as shown in Table 1:
Keputusan analisa saringan suatu tanah adalah seperti di Jadual 1:

Table 1/ *Jadual 1*

Sieve size (mm)/ *Saringan saiz(mm)*	**Mass Retained (g)/** *Jisim dikekalkan (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, 2.30 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 2.30 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.*

(11 marks/*markah*)

(b). In a constant head permeameter test the following results were obtained:
Maklumat berikut diperolehi daripada ujian kebolehtelapan malar

- Duration of test
  Tempoh ujikaji = 5.0 min

- Quantity of water collected
  Kuantiti air diperolehi = 900 ml

- Head difference in manometer
  Perbezaan turus di dalam manometer = 50 mm

- Distance between manometer tappings
  Jarak antara torehan manometer = 100 mm

- Diameter of test sample
  Diameter sampel ujikaji = 120 mm

Determine the coefficient of permeability in m/s.
Tentukan pekali kebolehtelapan di dalam m/s.

(4 marks/*markah*)

(c). 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.*

(5 marks/*markah*)

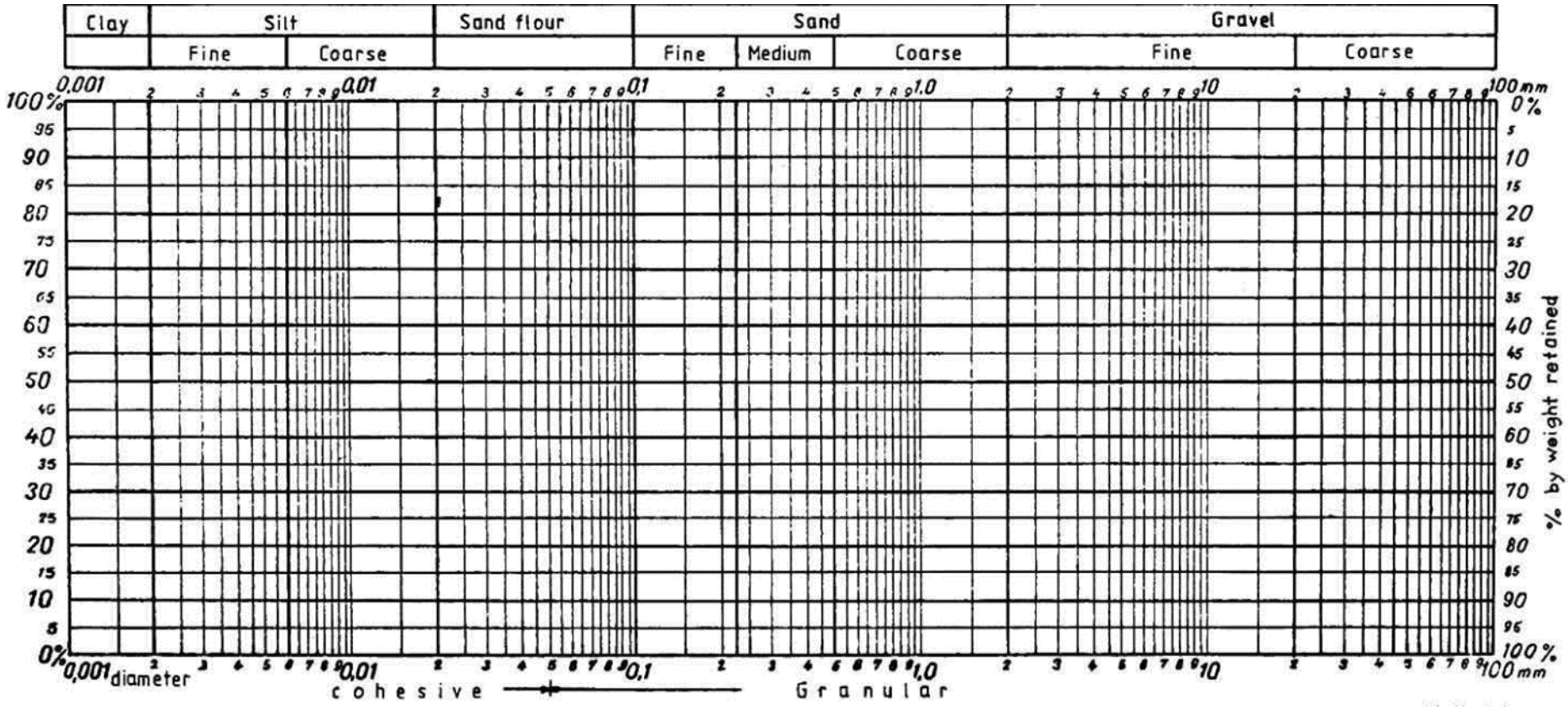

Figure 1/*Rajah 1*

(2). (a). Plot the poles of the following discontinuities, using Appendix 1:
Plot kutub-kutub ketakselanjaran berikut, menggunakan Lampiran 1:

(i). dip 67º towards 030º
miring 67º ke arah 030º

(ii). dip 34º towards 264º
miring 34º ke arah 264º

(iii). dip 35º towards 256º
miring 35º ke arah 256º

(iv). dip 36º towards 262º
miring 36º ke arah 262º

(v). dip 40º towards 268º
miring 40º ke arah 268º

(vi). dip 33º towards 270º
miring 33º ke arah 270º

(vii). dip 63º towards 100º
miring 63º ke arah 100º

(viii). dip 34º towards 259º
miring 34º ke arah 259º

Determine the estimate general dip and trend of these structures?
Tentukan anggaran kemiringan am dan tren struktur-struktur ini?

(10 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 100, and a dip of 60. Determine the plunge and trend of the line of the intersection between the two joint sets.

Berdasarkan anggaran min kutub yang diperolehi di atas (a), tentukan sudut di antara dua set min kutub bersama set kekar kedua pada arah kemiringan 100, dan miring sebanyak 60. Tentukan plun dan trend garis persilangan di antara dua set kekar.

(5 marks/*markah*)

(c). Rock stabilisation measures can be characterised on the basis of them offering either reinforcement or support to the rock. Commencing with a statement of the purpose of rock stabilisation, describe the fundamental behavioural differences between rock reinforcement and rock support, paying particular attention to how the differences are affected by the presence of discontinuous and continuous rock masses.

Langkah-langkah penstabilan batu boleh dicirikan berdasarkan apa yang ditawarkan sama ada tetulang atau sokongan kepada batu. Bermula dengan pernyataan tujuan penstabilan batuan, huraikan perbezaan perilaku asas antara penguatan batu dan sokongan batu, memberi perhatian khusus tentang bagaimana perbezaannya dipengaruhi oleh kehadiran ketakselanjaran dan jisim batuan berterusan

(5 marks/*markah*)

PART B / *BAHAGIAN B*

(3). (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:

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

Table 2/*Jadual 2*

Depth, m Kedalaman, m	Breakdown Pressure, MPa *Tekanan pecahan, MPa*	Shut-in Pressure, MPa *Tekanan kurungan, 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 must 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.

Memandangkan kekuatan tegangan daripada batu adalah 10 MPa, anggarkan dan senaraikan nilai-nilai σ_1, σ_2 dan σ_3 di kedua-dua kedalaman. Bincangkan semua andaian anda perlu buat untuk menghasilkan anggaran ini.
Menyatakan sama ada dua set keputusan adalah konsisten dengan satu sama lain, dan mewajarkan sebab-sebab bagi kenyataan itu.

(4 marks/*markah*)

(b). A geotechnical report has been written on the state of stress in a rock mass. The state of stress at various depths, determined in a vertical borehole, has been given in the report as follows:

Laporan geoteknik telah ditulis mengenai keadaan tekanan dalam jisim batu. Keadaan stres di pelbagai kedalaman, yang ditentukan dalam lubang lubang menegak, telah diberikan dalam laporan seperti berikut:

Table 3/*Jadual 3*

Depth, m *Kedalaman, m*	σ_1, MPa	Trend/Plunge *Tren/Tunjaman*	σ_2, MPa	Trend/Plunge *Tren/Tunjaman*	σ_3 MPa	Trend/Plunge *Tren/Tunjaman*
500	50.0	045/37	12.5	176/22	14.0	269/31
1000	70.0	060/42	25.0	180/15	18.0	280/50
1500	80.0	099/37	37.5	197/10	22.0	300/51

(i). State anything that is clearly wrong with the magnitudes of the stresses as presented above.

Nyatakan apa-apa yang jelas salah dengan magnitud tekanan seperti yang dinyatakan di atas.

(ii). For the state of stress at each of the three depths in the borehole, determine whether the principal stress components are mutually orthogonal

Untuk keadaan tekanan di setiap tiga kedalaman di lubang gerek, tentukan sama ada komponen tekanan utama adalah sama ortogonal

(iii). By reference to suitable sketches of stress vs. depth, show whether or not these data agree with collated world-wide trends

Dengan merujuk kepada lakaran tekanan yang sesuai berbanding kedalaman, tunjukkan sama ada data ini bersetuju dengan kesemua trend seluruh dunia.

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(iv). What evidence is there that these data were obtained using the hydraulic fracturing method? What evidence is there that techniques additional to hydraulic fracturing must have been used?

Bukti apa yang ada bahawa data-data ini diperoleh dengan menggunakan kaedah fraktur hidraulik? Adakah bukti bahawa teknik tambahan selain dari patah hidraulik telah digunakan?

(16 marks/*markah*)

(4). (a). **Explain** the following topics:
Jelaskan topik-topik *berikut:*

(i). Liquid Limit (LL)
Had Cecair

(ii). Plastic Limit (PL)
Had Plastik

(iii). Plasticity Index (PI)
Indeks Keplastikan

(iv). Type of soil classification analysis
Jenis-jenis analisis pengelasan tanah

(4 marks/*markah*)

(b). Distinguish between the fine sand, silt and clay.
Bezakan diantara pasir halus, kelodak dan lempung/tanah liat.

(6 marks/ *markah*)

(c). The following results were obtained from a liquid limit test:
Analisa berikut diperolehi daripada ujian had cecair:

Table 4/*Jadual 4*

Number of taps/ *Bilangan ketukan*	6	8	12	26	28	31
Water contents/ *Kandungan air* (%)	53.4	52.2	48.3	40.0	38.8	37.1

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

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

(10 marks/*markah*)

(5). (a). **Differentiate** between the drained and undrained shear strength.

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

(6 marks/*markah*)

(b). A granular soil has a saturated unit weight of 18.5kN/m^3 and an 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 18.5kN/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

(2 marks/*markah*)

(ii). If seepage occurs at and parallel to the surface of slope.
Jika tirisan muncul pada dan selari dengan permukaan cerun

(2 marks/ *markah*)

(c). **Discuss** any two corrective measures for failing slopes.
Bincangkan *mana-mana dua langkah pembetulan kegagalan cerun.*

(Note: Partial mark will be given for diagram)
(Nota: Sebahagian markah diberikan untuk gambarajah)

(10 marks/*markah*)

(6). (a). 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 < 1 L/min. The rock mass is easily broken by normal blow of hummer with the average UCS of is 45 MPa, and the horizontal stress is about 3.4 MPa.

10 m lebar dan 20 m tinggi bukaan janakuasa elektrik bawah tanah akan bina didalam 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 <1 L/min. Jisim batuan mudah pecah dengan pukulan biasa oleh tukul dengan purata UCS pada 45 MPa dan tekanan mendatar pada 3.4 MPa.

(i). Use the RMR and Q system (Appendix 2 & 3) to classify the rock mass.
Gunakan sistem klasifikasi RMR dan Q (Lampiran 2 & 3) untuk buat penilaian jisim batuan

(8 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 2 and 3.

Berdasarkan sistem pengelasan jisim batuan yang digunakan, jelaskan sistem sokongan yang diperlukan untuk menstabilkan jisim batuan yang telah digali dengan bantuan Lampiran 2 and 3.

(2 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.

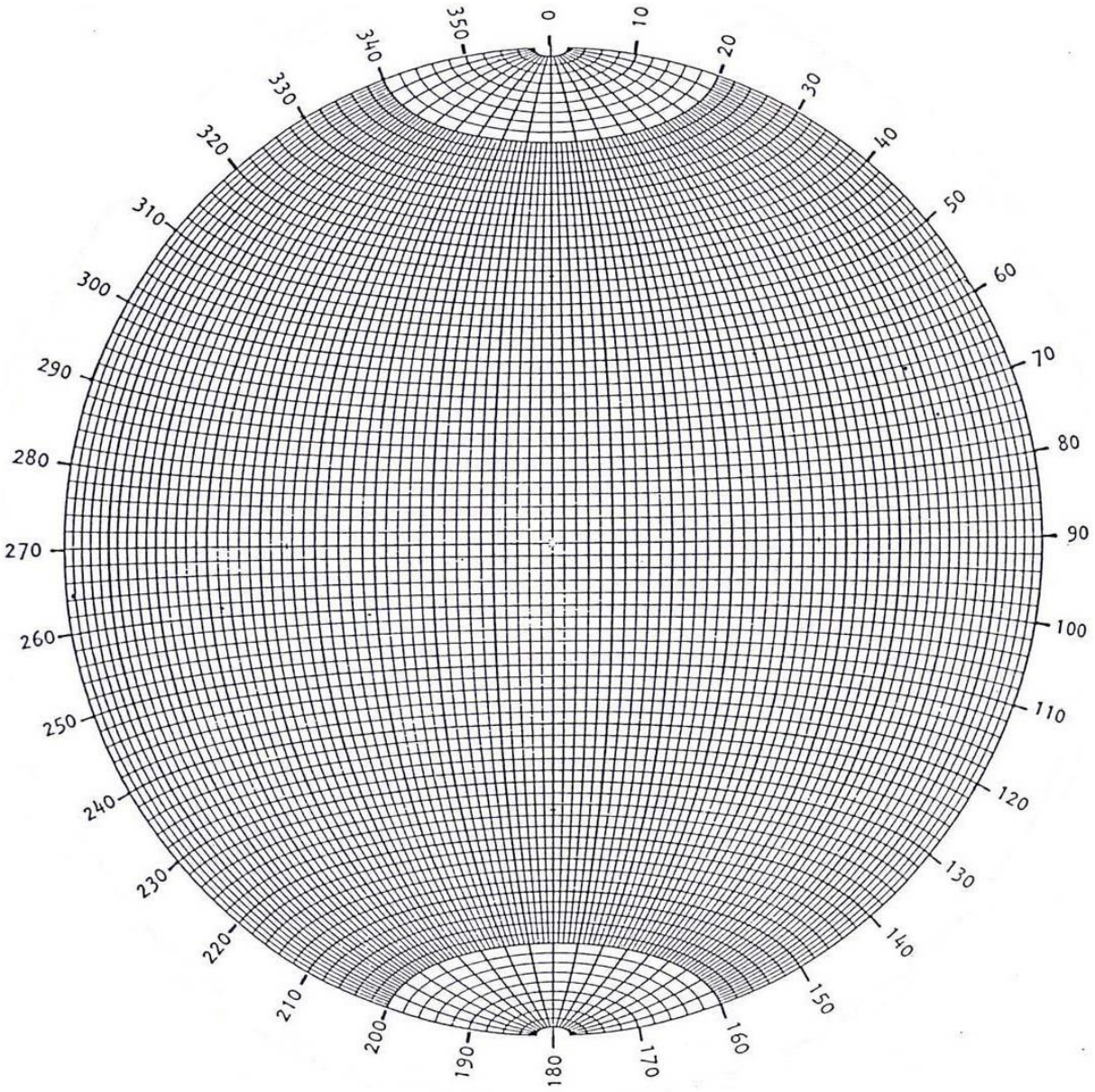
Sebahagian daripada 8 m bukaan, 6 km panjang terowong terletak di lapisan sub-mendatar batu pasir termetamof (σ_c = lebih kurang. 100 MPa). Kekar adalah ketat, licin dan rata dengan lapisan mika dan atau klorida sepanjang foliasi sering mempunyai panjang lebih dari 3 m. Selain daripada foliasi, terdapat 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.

Use the RMR and Q system (Appendix 2 & 3) to classify the rock mass. Based on the rock mass classification system used, describe the support system required to stabilize the excavated rock mass with help of Appendix 2 and 3.

Gunakan sistem klasifikasi RMR dan Q (Lampiran 2 & 3) 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 bantuan Lampiran 2 and 3.

(10 marks/*markah*)

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)

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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.

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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 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

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(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 ≤ 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.	

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(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:

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

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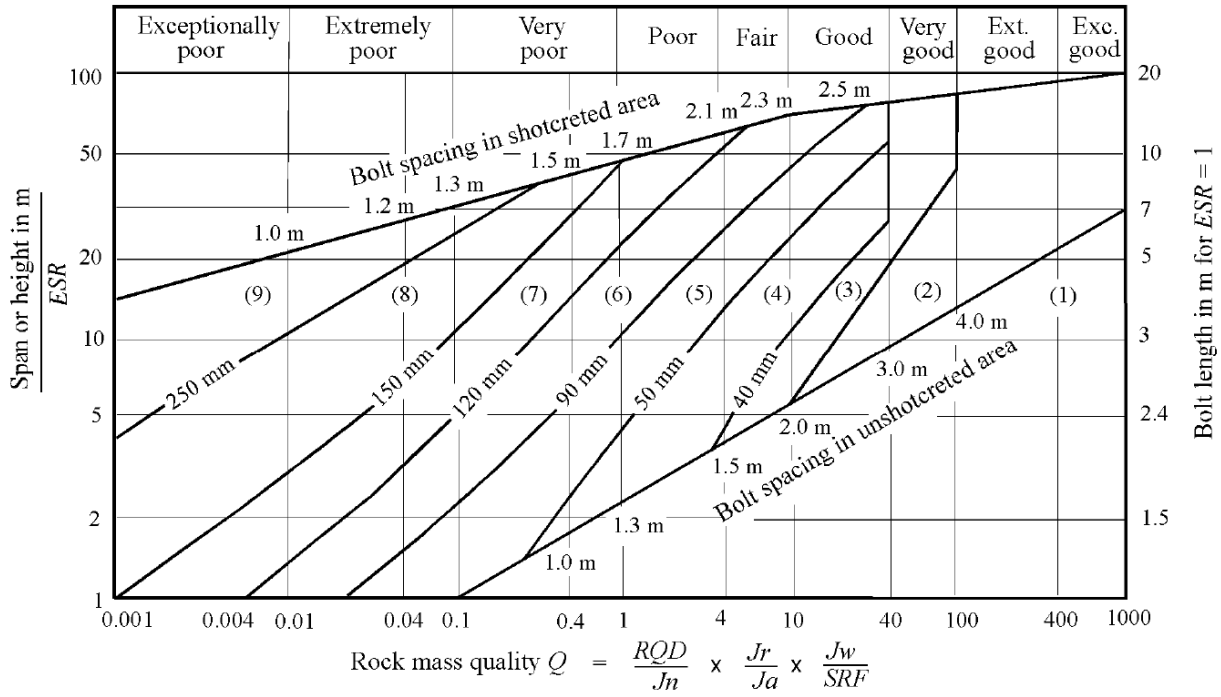
Tunnelling Quality Index *Q*: Estimated support categories based on the tunnelling quality index *Q*



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

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