Ref. No. : Ex/PG/CE/T/112D/2024

M. E. CIVIL ENGINEERING FIRST YEAR FIRST SEMESTER EXAM – 2024

ROCK MECHANICS AND TUNNELING

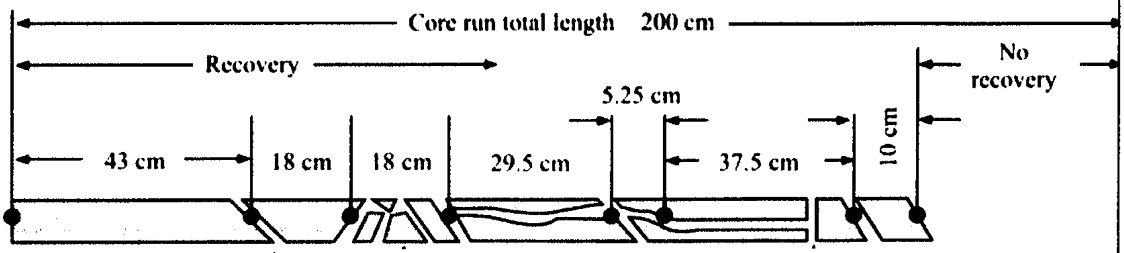
TIME: Three Hours **FULL MARKS: 100**

Answer all the questions

Assume any data if needed, reasonably

1.	(a) Write four key differences between rock and soil material.	(2)
	(b) How Intact rock and rock mass are different with respect to structural integrity and material properties?	(3)
	(c) Explain the terms 'strike', 'dip', and 'dip direction' with a neat sketch.	(5)
	(d) Plot stereonet projection of the following two discontinuity planes having strike, dip, and dip direction as given below: Discontinuity Plane 1: Strike: N55°E; Dip Direction: S45°E ; Dip: 65° Discontinuity Plane 2: Strike: N60°W; Dip Direction: S35°W ; Dip: 35° Also determine the dip and dip direction of the line of intersection.	(15)

<table>
<tr><td>2
.</td><td>(a) Define the followings:
(i) Orientation, (ii) Spacing, (iii) Persistence, and (iv) Aperture</td><td>(2)</td></tr>
<tr><td></td><td>(b) Find the RQD and core recovery ratio for the following borehole log.



</td><td>(3)</td></tr>
<tr><td></td><td>(c) A rock mass at a depth 200 m contains three fracture sets. One set comprises bedding planes which are highly weathered, slightly rough surface, and are continuous with an orientation of 180°/10° (fair). Another set of joints are slightly weathered, slightly rough, and have an orientation of 185°/75° (unfavourable). The third set of joints are slightly weathered, slightly rough, and have an orientation of 90°/80° (fair). The strength of intact rock has been assessed as 55 MPa. The values for the RQD and mean fracture spacing are reported as 60% and 0.4 m, respectively. Use the RMR system to classify the rock mass.</td><td>(10
)</td></tr>
<tr><td></td><td>(d) It is proposed to construct an underground tunnel 500 m below the ground. The drilled cores have an RQD of 85% and the number of joint sets is estimated to be 2. The joints are rough, undulating, and unweathered with minor surface staining. The average uniaxial compressive strength of the cores is 190 MPa. The mjor principal stress acts horizontally and is twice the vertical stress. The unit weight of rock is 30 kN/m^3. The excavation is relatively dry, with some dampness and negligible inflow. Estimate the Q-value and GSI.</td><td>(10
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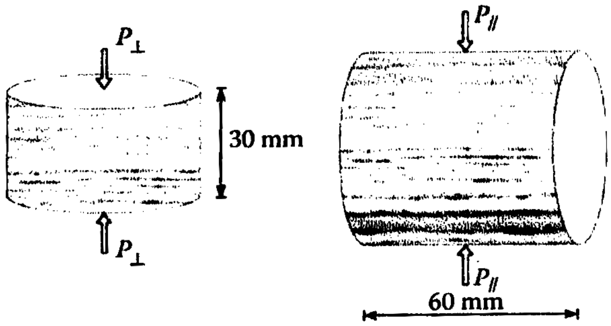
3.	(a) Explain different types of point load test. With neat sketch show the specimen shapes and loading direction.	(7)
	(b) What is slake durability index? Briefly explain the procedure of determining the slake durability index.	(7)
	(c) Point load tests were carried out on two sedimentary rock specimens of 54 mm diameter (NX core), as shown the following figure The loads $P_{\perp}$ and $P_{//}$ at failure are 6.28 kN and 4.71 kN, respectively. Find the point load strength index $I_{s(50)}$ in the two directions. 	(6)
	(d) A sandstone core has 82 mm diameter and 169 mm length. On saturation in water its wet weight is 21.42 N, after oven drying its weight is 20.31 N. Calculate its wet unit weight, dry unit weight, and porosity.	(5)

4.	(a) What are the conditions for plane state of stress to be valid?	(2)
	(b) Write the stress-strain relationship for plane strain case.	(3)
	(c) What is octahedral stress? Show that the octahedral shear stress can be expressed in terms of stress invariants only.	(10)
	(d) Determine the principal stresses, and principal axes for the following stress matrix $[\sigma_{ij}] = \begin{bmatrix} 18 & 0 & 24 \\ 0 & -50 & 0 \\ 24 & 0 & 32 \end{bmatrix}$ kPa	(10)

Use the following data as required

Rating Adjustment for Discontinuity Adjustments

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

Effect of Discontinuity Strike and Dip Orientation in Tunnelling

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

Classification Parameters and Their Ratings

	Parameter		*Range of values*						
1	Strength of intact rock material	Point-load strength index (MPa)	>10	4–10	2–4	1–2	For this low range uniaxial compressive test is preferred		
		Uniaxial compressive strength (MPa)	>250	100–250	50–100	25–50	5–25	1–5	< 1
	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 (mm)		> 2000	600–2000	200–600	60–200	< 60		
	Rating		20	15	10	8	5		
4	Condition of discontinuities (See Table 3.7E)		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	Slicken sided surfaces. Gouge < 5 mm thick; Separation 1–5 mm; Continuous	Soft gouge >5 mm thick; Separation > 5 mm; Continuous		
	Rating		30	25	20	10	0		
5	Ground water	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		

Guidelines for Classification of Discontinuity Condition

Discontinuity length (persistence)	< 1	1–3	3–10	10–20	> 20
Rating	6	4	2	1	0
Aperture (mm)	None	< 0.1	0.1–10	1–5	> 5
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
Rating	6	5	3	1	0

	Class	J_r
(a) Rock-wall contact, and (b) rock-wall before 10 cm shear		
A	Discontinuous joints	4
B	Rough or irregular, undulating	3
C	Smooth, undulating	2
D	Slicken sided, undulating	1.5
E	Rough or irregular, planar	1.5
F	Smooth, planar	1.0
G	Slicken sided, planar	0.5
(c) No rock-wall contact when sheared		
H	Zone containing clay minerals thick enough to prevent rock-wall contact	1.0
J	Sandy, gravely or crushed zone thick enough to prevent rock-wall contact	1.0

Note: (i) Descriptions refer to small-scale features and intermediate scale features, in that order. (ii) Add 1.0 if the mean spacing of the relevant joint set is greater than 3 m. (iii) $J_r = 0.5$ can be used for planar joints having lineations, provided the lineations are oriented for minimum strength. (iv) J_r and J_a 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, τ (where $t = \sigma_n \tan^{-1} (J_r/J_a)$).

	Class	$\varphi_r(°)$	J_a
(a) Rock-wall contact (no mineral fillings, only coatings)			
A	Tightly 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 coatings, 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 clay mineral coatings, i.e., kaolinite or mica. Also chlorite, talc, gypsum, graphite, etc., and small quantities of swelling clays	8–16	4.0
(b) Rock-wall contact 10 cm shear (thin mineral fillings)			
F	Sandy particles, clay-free disintegrated rock, 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-consolidation, 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 J_a depends on percent of swelling clay-size particles, and access to water, etc.	6–12	8–12
(c) No rock-wall contact when sheared (thick mineral fillings)			
KLM	Zones or bands of disintegrated or crushed rock and clay (see G, H, J for descriptions of clay conditions)	6–24	6, 8 or 8–12
N	Zones or bands of silty- or sandy-clay, small clay fraction (non-softening)	—	5.0
OPR	Thick, continuous zones or bands of clay (see G, H, J for description of clay condition)	6–24	10,13 or 13–20

	Class	*Approx. water pressure* (kg/cm^2)	J_w
A	Dry excavations or minor inflow, i.e., < 5 l/min locally	< 1	1.0
B	Rough or irregular, undulating	1–2.5	0.66
C	Smooth, undulating	2.5–10	0.50
D	Slickensided, undulating	2.5–10	0.33
E	Rough or irregular, planar	> 10	0.2–0.1
F	Smooth, planar	> 10	0.1–0.05

Note: (i) Factors C to F are crude estimates. Increase J_w if drainage measures are installed. (ii) Special problems caused by ice formation are not considered. (iii) For general characterization of rock masses distant from excavation influences, the use of J_w = 1.0, 0.66, 0.5, 0.33, etc. as depth increases from say 0–5, 5–25, 25–250 to >250 m is recommended, assuming that RQD/J_n is low enough (e.g., 0.5–25) for good hydraulic connectivity. This will help to adjust Q for some of the effective stress and water softening effects, in combination with appropriate characterization value of SRF. Correlations with depth-dependent static deformation modulus and seismic velocity will then follow the practise used when these were developed.

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	Class	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 zones containing clay or chemically disintegrated rock (depth of excavation ≤ 50 m)	5		
C	Single weakness zones containing clay or chemically disintegrated rock (depth of excavation > 50 m)	2.5		
D	Multiple shear zones in competent rock (clay-free), loose surrounding rock (any depth)	7.5		
E	Single shear zones in competent rock (clay-free), (depth of excavation ≤ 50 m)	5.0		
F	Single shear zones in competent rock (clay-free), (depth of excavation > 50 m)	2.5		
G	Loose, open joints, heavily jointed or 'sugar cube', etc. (any depth)	5.0		
(b) Competent rock, rock mass problems		σ_c/σ_1	σ_θ/σ_c	SRF
H	Low stress, favourable stress condition	> 200	< 0.01	2.5
J	Medium stress, favourable stress condition	200–10	0.01–0.3	1
K	High stress, very tight pressure. Usually favourable to stability, may be unfavourable for wall stability	10–5	0.3–0.4	0.5–2

	Class	SRF		
L	Moderate slabbing after > 1 h in massive rock	5–3	0.65–1	50–200
M	Slabbing and rock burst after a few minutes in massive rock	3–2	0.65–1	50–200
N	Heavy rock burst (strain–burst) and immediate dynamic deformation in massive rock	< 2	> 1	200–400
		σ_θ/σ_c	SRF	
(c) Squeezing rock: plastic flow of incompetent rock under the influence of high rock pressure				
O	Mild squeezing rock pressure	1–5	5–10	
P	Heavy squeezing rock pressure	> 5	10–20	
		SRF		
(d) Squeezing rock: chemical swelling activity depending on presence of water				
R	Mild swelling rock pressure	5–10		
S	Heavy swelling rock pressure	10–15		

Note: (i) Reduce the value of SRF by 25–50% if the relevant shear zones only influence but do not intersect the excavation. This will also be relevant for characterization. (ii) For strongly anisotropic virgin stress field (if measured): When, $5 \le \sigma_1/\sigma_3 \le 10$, reduce σ_c to 0.75 σ_c. When, $\sigma_1/\sigma_3 > 10$, reduce σ_c to $0.5\sigma_c$, where σ_c is the unconfined compressive strength, σ_1 and σ_3 are the major and minor principal stresses, and σ_θ the maximum tangential stress (estimated from elastic theory). (iii) Few case records available where depth below surface is less than span width, suggest as SRF increases from 2.5 to 5 for such case (see H). (iv) Cases L, M, and N are usually most relevant for support design of deep tunnel excavations in hard massive rock masses, with RQD/J_n ratios from about 50–200. (v) For general characterisation of rock masses distant from excavation influences, the use of SRF = 5, 2.5, 1.0, and 0.5 is recommended as depth increases from say 0–5, 5–25, 25–250 or > 250 m. This will help to adjust Q for some of the effects, in combination with appropriate values of J_w. Correlations with depth–dependent static deformation modulus and seismic velocity will then follow the practise used when these were developed. (vi) Cases of squeezing rock may occur for depth $H > 350Q^{1/3}$, Singh (1993). Rock mass compression strength can be estimated from $SIGMA_{cm} \approx 5\gamma Q_c^{1/3}$ (MPa) where γ is the rock density in t/m^3, and $Q_c = Q \times \sigma_c/100$, Barton (2000).

	Class	J_n
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, random, heavily jointed, 'sugar–cube', etc.	15
J	Crushed rock, earth like	20

Note: (i) For tunnel intersections, use $(3.0 \times J_n)$ (ii) For portals, use $(2.0 \times J_n)$.