DEPARTMENT OF CIVIL ENGINEERING
IIT ROORKEE
TS-4; CE-433 : Rock Engineering, 2016-17

Q.1 The following triaxial test data is available from a testing programme

σ_3 (MPa)	0	7	14	20	28	34	41	48	55	62
σ_1 (MPa)	45	66	85	99	109	119	128	135	142	149

Plot failure envelopes in the form of i) τ_f vs σ_n , and ii) $(\sigma_{1f} - \sigma_{3f})$ vs σ_{3f} plots. Using these plots obtain instantaneous c and ϕ for σ_n = 10 MPa and σ_3 = 10 MPa.

Q2. The tensile strength of a rock specimen is 8 MPa. Use Griffith's criterion to generate σ_{1f} values for σ_3 = 0, 5, 10, 15 MPa respectively.

Q3. Obtain Hoek-Brown criterion parameters m and σ_c if only first four data points (including UCS) of Q1 are available.

Q4. Obtain Ramamurthy's (IITD) criterion parameters if only first four data points (including UCS) of Q1 are available.

Q5. Obtain MMC criterion parameter ϕ_0 if only first four data points (including UCS) of Q1 are available.

Q6. Obtain triaxial strength of the rock for confining pressures 28, 34, 41, 48, 55, and 62 MPa respectively by using the parameters obtained in Q3, Q4 and Q5 respectively.

$(\sigma_1 - \sigma_3) - \sigma_{ci}) \Rightarrow A(\sigma_{ci}^2 - 2\sigma_{ci}\sigma_3)$

$B = -2A\sigma_{ci}$

$-2A\sigma_{ci}$

Tutorial: (4)

Avinash Jain
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Answer: (2) Using Griffith Criterian

$$(\sigma_1 - \sigma_3)^2 = 8\sigma_t(\sigma_1 + \sigma_3)$$

$\sigma_t = 8$ MPa

$$\Rightarrow (\sigma_1 - \sigma_3)^2 = 8 \times 8 (\sigma_1 + \sigma_3)$$

$$\sigma_1^2 - 2\sigma_1\sigma_3 + \sigma_3^2 = 64\sigma_1 + 64\sigma_3$$

$$\Rightarrow \sigma_1^2 - \sigma_1(2\sigma_3 + 64) + \sigma_3^2 - 64\sigma_3 = 0$$

So, for $\sigma_3 = 0$ $\Rightarrow \sigma_1^2 - 64\sigma_1 + 0 = 0$

$\sigma_1(\sigma_1 - 64) = 0$ $\Rightarrow \boxed{\sigma_1 = 64}$

for $\sigma_3 = 5$ $\Rightarrow \sigma_1^2 - 54\sigma_1 - 295 = 0$

$(\sigma_1 - 5)(\sigma_1 + 59) = 0$

$\boxed{\sigma_1 = 5}$

for $\sigma_3 = 10$

$\Rightarrow \sigma_1^2 + 44\sigma_1 - 540 = 0$

$(\sigma_1 - 10)(\sigma_1 + 54) = 0$

$\Rightarrow \boxed{\sigma_1 = 10}$

for $\sigma_3 = 5$ $\Rightarrow \sigma_1^2 - 74\sigma_1 - 295 = 0$

$\boxed{\sigma_1 = 77.79 \text{ MPa}}$

for $\sigma_3 = 10$ $\Rightarrow \sigma_1^2 - 84\sigma_1 - 540 = 0$

$\boxed{\sigma_1 = 90 \text{ MPa}}$

for $\sigma_3 = 15$

$\Rightarrow \sigma_1^2 - 94\sigma_1 - 735 = 0$

$\boxed{\sigma_1 = 101.258 \text{ MPa}}$

Answer: (3) Data Points available

σ_3	σ_1
0	45
7	66
14	85
20	99

$$\sigma_1 = \sigma_3 + \sqrt{m\sigma_{ci}\sigma_3 + s\sigma_{ci}^2}$$

for intact Rocks $\Rightarrow$ $s = 1$

$$(\sigma_1 - \sigma_3)^2 = m\sigma_{ci}\sigma_3 + \sigma_{ci}^2$$

$$Y = A X + B$$

$$Y = AX + B$$

$$A = \frac{N\Sigma XY - (\Sigma X)(\Sigma Y)}{N\Sigma X^2 - (\Sigma X)^2}$$

$$A = \frac{\Sigma Y - B\Sigma X}{N}$$

σ_1	σ_3	$Y = (\sigma_1 - \sigma_3)^2$	$X = \sigma_3$
45	0	2025	0
66	7	3481	7
85	14	5041	14
99	20	6241	20

$A = 212.16$

$B = 2022.31$

$$Y = 212.16\,\sigma_3 + 2022.31$$

$$2022.31 = \sigma_{ci}^2$$

$$\boxed{\sigma_{ci} = 44.97 \text{ MPa}}$$

$$m(44.97) = 212.16$$

$$\boxed{m = 4.71}$$

Answer: (4) Using Ramamurthy's IIT Criterion (2)

$$\left(\frac{\sigma_1 - \sigma_3}{\sigma_3}\right) = \beta_i \left(\frac{\sigma_{ci}}{\sigma_3}\right)^{\alpha_i}$$

β_i & α_i $\Rightarrow$ Parameters

$\sigma_{ci} = 45$ MPa

$$\log\left(\frac{\sigma_1 - \sigma_3}{\sigma_3}\right) = \alpha_i \log\left(\frac{\sigma_{ci}}{\sigma_3}\right) + \log\beta_i$$

$$\log\left(\frac{\sigma_1}{\sigma_3} - 1\right) = \alpha_i \log\left(\frac{45}{\sigma_3}\right) + \log(\beta_i)$$

$$Y = B X + A$$

σ_1	σ_3	Y	X
45	0	–	–
66	7	0.925	0.808
85	14	0.705	0.507
99	20	0.596	0.3521

$Y = BX + A$

Using Straight Line Regression

$B = 0.7229$

$A = 0.3402$

So, $Y = 0.7229X + 0.3402$

$\boxed{\alpha_i = 0.7229}$

$\log \beta_i = 0.3402 \Rightarrow \boxed{\beta_i = 2.1887}$

Answer: (6) Using MMC Criterion

Hoek Brown

$(\sigma_1 - \sigma_3)^2 = 212.16\sigma_3 + 2022.31$

$\sigma_1 = \sqrt{212.16\sigma_3 + 2022.31} + \sigma_3$

σ_3	σ_1
28	117.23
34	130.10
41	144.54
48	158.48
55	172.00
62	185.19

(10)

Ramamurthy's IITD Criterion

$\left(\frac{\sigma_1 - \sigma_3}{\sigma_3}\right) = 2.1887\left(\frac{45}{\sigma_3}\right)^{0.7229}$

$\sigma_1 = \left[1 + 2.1887\left(\frac{45}{\sigma_3}\right)^{0.7229}\right]\sigma_3$

MM 10/3

σ_3	σ_1 (MPa)
28	144.35
34	125.13
41	136.98
48	148.26
55	159.12
62	169.63

Using MMC criterion

$$\sigma_1 - \sigma_3 = \sigma_{c_i} - 2A\sigma_{c_i}\sigma_3 + A\sigma_3^2$$

$$\sigma_1 = 45 + 2.187\sigma_3 - 0.0243\sigma_3^2$$

For $\sigma_3 > \sigma_{c_i} \Rightarrow \sigma_3 > 45$

$\sigma_1 = f(\sigma_3 = 45)$

$\sigma_1 = 45 + 2.187 \times 45 - 0.0243 \times 45^2$

$\boxed{\sigma_1 = 94.2075}$

σ_3	σ_1 (MPa)
28	87.184
34	91.267
41	93.818
48	94.2075
55	94.2075
62	94.2075

Answer:-(5)

Using MMC criterion

Case(1)

$$\sigma_1 - \sigma_3 = \sigma_{c_i} - 2A\sigma_{c_i}\sigma_3 + A\sigma_3^2$$

$$\Rightarrow (\sigma_1 - \sigma_3 - \sigma_{c_i}) = A(\sigma_3^2 - 2\sigma_{c_i}\sigma_3)$$

data Points Available

σ_1	σ_3
45	0
66	7
85	14
99	20

$\sigma_{c_i} = (\sigma_1 \text{ for } \sigma_3 = 0) \Rightarrow 45$ MPa

$\boxed{\sigma_3 < \sigma_{c_i}}$ for data Points

Case(2)

$$A = \frac{\Sigma(\sigma_1 - \sigma_3 - \sigma_c)}{\Sigma(\sigma_3^2 - 2\sigma_c\sigma_3)}$$

σ_3	σ_1	$(\sigma_1 - \sigma_3 - \sigma_c)$	$(\sigma_3^2 - 2\sigma_c\sigma_3)$
0	45	0	0
7	66	14	-581
14	85	26	-1064
20	99	34	-1400
		$\Sigma \Rightarrow 74$	Σ -3045

$$A = \frac{74}{(-3045)} = -0.0243$$

$$A = \frac{-1}{\sigma_{ci}} \frac{\sin\phi_0}{1-\sin\phi_0}$$

$$\Rightarrow -\frac{74}{3045} = \frac{-1}{45} \frac{\sin\phi_0}{1-\sin\phi_0}$$

$$\sin\phi_0 = 0.5223$$

$$\boxed{\phi_0 = 31.49^\circ}$$

$$\sigma_1 - \sigma_3 = \sigma_{ci} - 2A\sigma_c\sigma_3 + A\sigma_3^2$$

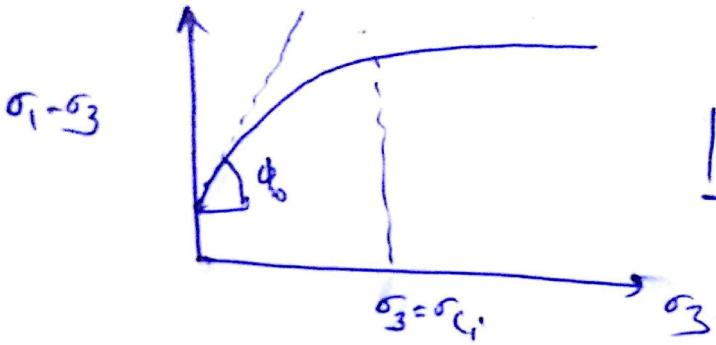
$$\Rightarrow \sigma_1 = 45 - 2 \times \left(\frac{-74}{3045}\right)(45)\sigma_3 + \left(\frac{-74}{3045}\sigma_3^2\right)$$

$$\boxed{\sigma_1 = 45 + 2.187\sigma_3 - 0.0243\sigma_3^2} \quad \text{for } \sigma_3 < 45$$

for $\sigma_3 > 45$

$$\sigma_1 = f(\sigma_3 = 45) = 45 + 2.187(45) - 0.0243(45^2)$$

$$\boxed{\sigma_1 = 94.2075 \text{ MPa}}$$



$$\boxed{\phi_0 = 31.49^\circ}$$

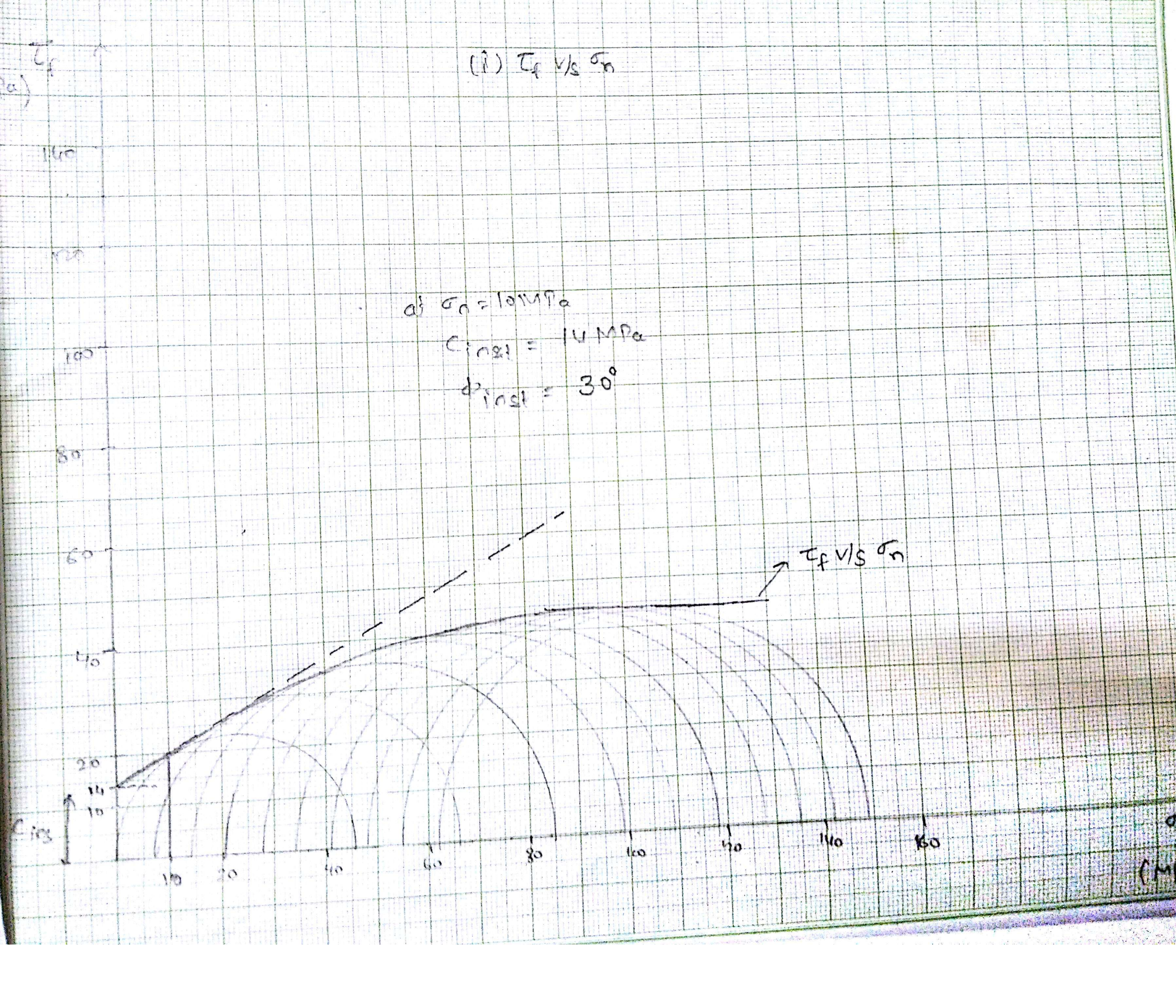
Answer:- (1)

(i) τ_f V/S σ_n Curve is drawn on the graph paper

(ii)

σ_{3f}	σ_{1f}	$\sigma_{1f} - \sigma_{3f}$	σ_{3f}	σ_{1f}	$\sigma_{1f} - \sigma_{3f}$
0	45	45	34	119	85
7	66	59	41	128	87
14	85	71	48	135	87
20	99	79	55	142	87
28	109	81	62	149	87

$(\sigma_{1f} - \sigma_{3f})$ V/S σ_{3f} Plot is drawn on the graph



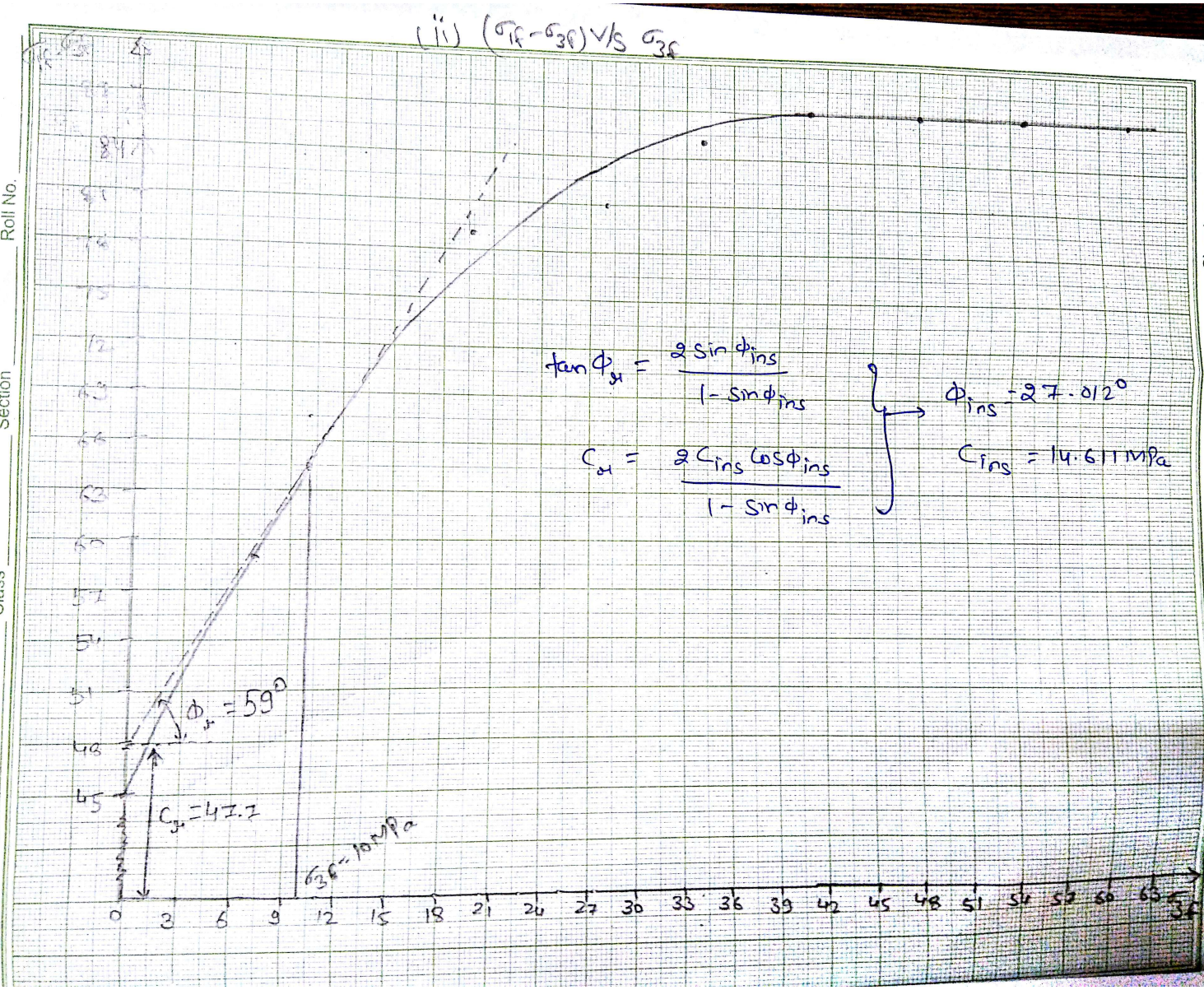
Measurement Chart of :

Remarks :

Signature :

4_{zf} = $C_{\sigma n}$ = $2 C_{ins} \cos\phi_{ins}$ => C_{inst} = 14.611 MPa

(ii) $(\sigma_{1f} - \sigma_{3f})$ V/S σ_{3f}



$$\tan\phi_d = \frac{2\sin\phi_{ins}}{1-\sin\phi_{ins}}$$

$$C_d = \frac{2C_{ins}\cos\phi_{ins}}{1-\sin\phi_{ins}}$$

$\Rightarrow \phi_{ins} = 27.012^\circ$

$C_{ins} = 14.611$ MPa

Name ____ Roll No. ____ Class ____ Section ____ Signature : ____ Remarks : ____ Measurement Chart of :

ii) for $\sigma_n = 10\ MPa$

for Calculation of C_{inst} and ϕ_{inst}

we will use τ_f V/S σ_n Curve.

at $\sigma_n = 10\ MPa$, we will draw a tangent.

$C_{inst} = 14\ MPa$

$\phi_{inst} = 30^\circ$

for $\sigma_3 = 10\ MPa$

$$\sigma_{1f} = \frac{2C_{inst}\cos\phi_{inst}}{1-\sin\phi_{inst}} + \frac{1+\sin\phi_{inst}}{1-\sin\phi_{inst}}\sigma_{3f}$$

$$(\sigma_{1f}-\sigma_{3f}) = \frac{2C_{ins}\cos\phi_{ins}}{1-\sin\phi_{ins}} + \frac{2\sin\phi_{ins}}{1-\sin\phi_{ins}}\sigma_{3f}$$

So, for Calculation of ϕ_{ins}, C_{ins} and ϕ_{inst}

we will draw a tangent

at $\sigma_{3f} = 10\ MPa$ on $\sigma_{1f}-\sigma_{3f}$ V/S σ_{3f} Curve.

$$(\sigma_{1f}-\sigma_{3f}) = C_R + \sigma_{3f}\tan\phi_R$$

$C_R = 47.7\ MPa$

$\phi_R = 59^\circ$

$$\tan\phi_R = \frac{2\sin\phi_{ins}}{1-\sin\phi_{ins}} = 1.664$$

$\sin\phi_{inst} = 0.4541$

$$\boxed{\phi_{inst} = 27.012^\circ}$$

$$47.7 = C_R = \frac{2C_{ins}\cos\phi_{ins}}{1-\sin\phi_{ins}} \Rightarrow \boxed{C_{inst} = 14.611\ MPa}$$