DEPARTMENT OF CIVIL ENGINEERING

I.I.T. ROORKEE

TS-3; CE-433 : Rock Engineering, 2016-17

Q1. Results of point load tests on rock specimens are given below. Estimate the average UCS of the rock in MPa. Also obtain standard deviation in strength.

d (mm)	50	44	46	48	55
p (kN)	2.2	1.8	1.9	2.1	2.6

Q2. A rectangular prism of an isotropic rock was tested under bending. Obtain tensile strength of the rock (in MPa) for the following data: Point load (at centre) at failure = 90 kN; distance between supports = 52 cm; thickness of prism = 2.0 cm, width of the prism = 6.5 cm.

Q3. Protodykonove test was conducted to obtain tensile strength of a rock. Following data was obtained; size of rectangular prism of rock = 70x30x300mm; vertical distance between end supports = 200 mm; Lever arm = 95 mm; Failure load = 2.6 kN. Obtain tensile strength of the rock.

Q4. Hydraulic extension test was conducted on a rock specimen. The internal and outer diameters of the cylindrical disc are 25mm and 75mm respectively. Vertical load required to maintain the fluid pressure is 4.5 kN. Draw variation of radial and circumferential stresses with the radial distance at appropriate interval. If failure occurs at load of 4.9 kN, what is the tensile strength of the rock?

Q5. Brazilian tests were conducted on rock specimens having diameter 54 mm. The output is given below. Compute tensile strength values, their average and standard deviation.

Thickness, mm	28	30	31	28	31	32	27
Failure load, kn	29	18	12	17	19	15	18

Q6. Oblique shear tests were conducted on rock specimens (54 mm dia, 108 mm length) and the following results were obtained:

Angle of shear plane with horizontal:	37	40	45	50
Failure load (kN):	675	270	135	90

i) Draw failure envelope in τ_f vs. σ_n space and obtain Mohr-Coulomb shear strength parameters.

ii) Obtain values and orientations of σ_3 and σ_1 at failure for all the tests and plot failure envelope in σ_1 vs. σ_3 space.

Q7. Following data is available for a rock: σ_{ci} = 80 MPa and σ_t = 8 MPa. Estimate Mohr-Coulomb shear strength parameters c and ϕ. Also generate failure envelopes for the range i) σ_3 = 0 to 50 MPa, and ii) σ_n = 0 to 50 MPa. Take interval of 10 MPa.

Name- Avinash Jain

Tutorial-3

CE-433

Rock Engineering

Ans ①

F = Correction Factor $= \left(\frac{d}{50}\right)^{0.45}$ $\qquad I_{s50} = \frac{FP}{d^2}$

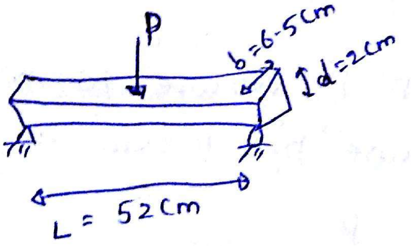
$\sigma_c = 24\, I_{s50}$

d (mm)	p (KN)	F	I_{s50} (N/mm^2)	σ_c (N/mm^2) (UCS)
50	2.2	1.000	0.880	21.120
44	1.8	0.944	0.877	21.048
46	1.9	0.963	0.864	20.736
48	2.1	0.981	0.894	21.456
55	2.6	1.043	0.896	21.515
			Σ	105.875

Average UCS value = $\frac{105.875}{5} \Rightarrow 21.175$ MPa

Standard Deviation in Strength (σ) = 0.285 MPa $= \sqrt{\frac{\Sigma(x-\bar{x})^2}{N}}$

Ans :- ②



P = 90KN

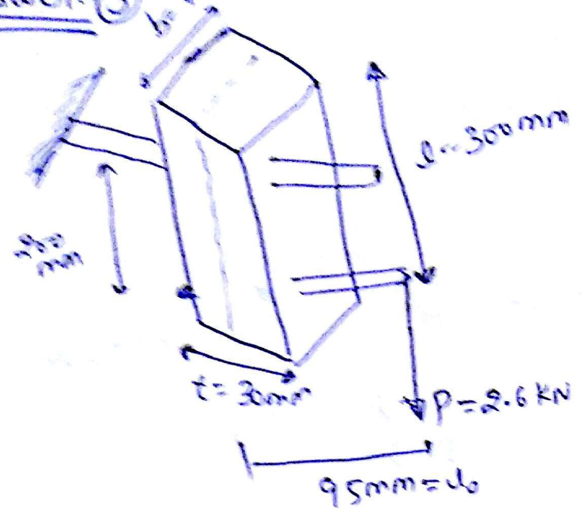
$\sigma_t = \frac{6M}{bd^2}$ where $M = \frac{PL}{4}$

$\sigma_t = \frac{6PL}{4bd^2} \Rightarrow \frac{3PL}{2bd^2}$

$\sigma_t = \frac{3 \times 90 \times 10^3 \times 520}{2 \times 650 \times 20^2} \Rightarrow 2700\ N/mm^2$

Answer:- (3)

Protodyakonov test



$M = P l_0$

$$\sigma_t = \frac{P}{A} + \frac{My}{I}$$

$$\sigma_t = \frac{P}{bt} + \frac{P l_0 (t/2)}{bt^3/12}$$

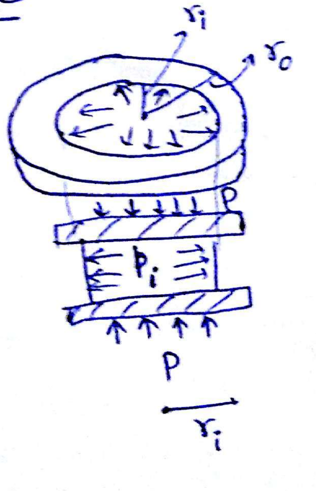
$$\sigma_t = \frac{P}{bt} + \frac{6 P l_0}{bt^2}$$

$$\sigma_t = \frac{2600}{70 \times 30} + \frac{6 \times 2600 \times 95}{70 \times 30^2} \Rightarrow 24.761 \text{ MPa}$$

Answer:- (4)

$r_i = \frac{25}{2} = 12.5$ mm

$r_o = \frac{75}{2} = 37.5$ mm



Vertical load 'P' required to maintain fluid Pressure 'P_i' inside the disc.

$$P_i = \frac{P}{\pi r_i^2}$$

(i) for P = 4.5 KN

$$P_i = \frac{P}{\pi r_i^2} \Rightarrow \frac{4500}{\pi (12.5)^2} \Rightarrow 9.167 \frac{N}{mm^2}$$

Variation of Radial Stress

$r_i \le r \le r_o$

$$\sigma_r = p_i \left(\frac{r_i^2}{r_o^2 - r_i^2}\right)\left(\frac{r_o^2}{r^2} - 1\right)$$

$$\sigma_r = 9.167\left(\frac{12.5^2}{37.5^2 - 12.5^2}\right)\left(\frac{37.5^2}{r^2} - 1\right)$$

$$\boxed{\sigma_r = \frac{1611.386}{r^2} - 1.145}$$

Variation of Circumferential Stress (Tensile stress)

$$\sigma_\theta = -p_i\left(\frac{r_i^2}{r_o^2 - r_i^2}\right)\left[\frac{r_o^2}{r^2} + 1\right)$$

$$\sigma_\theta = \frac{9.167 \times 12.5^2}{37.5^2 - 12.5^2}\left[\frac{37.5^2}{r^2} + 1\right]$$

$$\boxed{\sigma_\theta = -\left[\frac{1611.386}{r^2} + 1.145\right]}$$

r (mm)	σ_θ (N/mm²)	σ_r (N/mm²)
$r_i = 12.5$ mm	−11.457	9.167
17.5	−6.406	4.116
22.5	−4.327	2.037
27.5	−3.275	0.985
32.5	−2.670	0.380
$r_o =$ 37.5	−2.290	0.00087

(ii) At failure load

$P = 4.9$ kN

Failure is due to tension

at $r = r_i$, failure will occur.

$$P_i = \frac{P}{\pi r_i^2} \Rightarrow \frac{4900}{\pi(12.5^2)} = 9.982 \text{ N/mm}^2$$

Tensile strength = σ_θ at $r = r_i$

$$\sigma_t = -p_i \left(\frac{r_i^2}{r_o^2 - r_i^2}\right)\left(\frac{r_o^2}{r_i^2} + 1\right)$$

$$\sigma_t = -p_i \frac{(r_o^2 + r_i^2)}{(r_o^2 - r_i^2)}$$

$$\sigma_t = -9.982 \left(\frac{37.5^2 + 12.5^2}{37.5^2 - 12.5^2}\right)$$

$$\boxed{\sigma_t = 12.477 \text{ N/mm}^2}$$ Tensile strength.

Ans :- (5) Brazilian Test

$r_o = \frac{54}{2} = 27$ mm

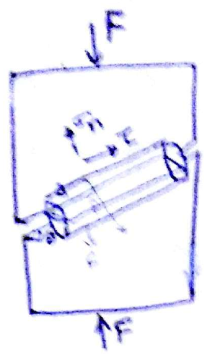
$\sigma_t = \frac{F}{\pi r_o t}$ N/mm² ; F = failure load in 'N', r_o and t are in mm

t (mm)	F (N)	σ_t (N/mm²)
28	29000	12.210
30	18000	7.073
31	12000	4.563
28	17000	7.157
31	19000	7.225
32	15000	5.526
27	18000	7.859

Average ~~UCS~~ Tensile Strength value => 7.373 N/mm²

Standard deviation => 2.239 N/mm²

Answer:- (6)



$\sigma_n = \frac{F\cos\theta}{DL}$ DL: Shear Area

$\tau = \frac{F\sin\theta}{DL}$ θ: Angle of Shear plane with Horizontal

D = 54mm, L = 108mm

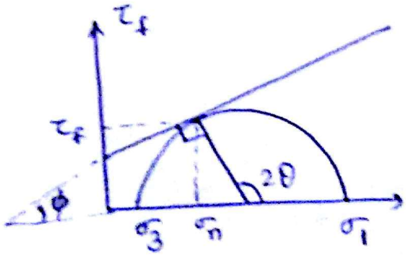
θ	F (failure load) (N)	τ_f (N/mm²)	σ_n (N/mm²)
37	675000	69.654	92.434
40	270000	29.758	35.465
45	135000	16.368	16.368
50	90000	11.821	9.919

(i) Failure envelope is drawn on the graph

from the graph

$\phi = 35^0$, $C = 5.00$ N/mm2

(ii)



$\left(\frac{\sigma_1 - \sigma_3}{2}\right)\sin(\pi - 2\theta) = \tau_f$

$\sigma_1 - \sigma_3 = \frac{2\tau_f}{\sin 2\theta}$ → (i)

$\frac{\sigma_1 + \sigma_3}{2} - \sigma_n = -\tau_f \cot 2\theta$

$\sigma_1 + \sigma_3 = 2\sigma_n - 2\tau_f \cot 2\theta$ → (ii)

From i) and ii)

$$\sigma_1 = \sigma_n + \tau_f \left[\frac{1-\cos 2\theta}{\sin 2\theta}\right] \Rightarrow \sigma_n + \tau_f \frac{2\sin^2\theta}{2\sin\theta\cos\theta}$$

$$\Rightarrow \sigma_n + \tau_f \tan\theta$$

$$\sigma_3 = \sigma_n - \tau_f \left[\frac{1+\cos 2\theta}{\sin 2\theta}\right] \Rightarrow \sigma_n - \tau_f \cot\theta$$

So, $\sigma_1 = \sigma_n + \tau_f \tan\theta$ where

$\sigma_3 = \sigma_n - \tau_f \cot\theta$

$\theta = 45 + \phi/2$

$\theta = 45 + 35/2 \Rightarrow 62.5^\circ$

So,

τ_f	σ_n	σ_{1f}	σ_{3f}
69.654	92.434	226.238	56.174
29.758	35.465	92.629	19.973
16.368	16.368	47.810	7.847
11.821	9.919	32.626	3.765

failure occurs at $\theta = 45 + \phi/2$

$\boxed{\theta \Rightarrow 62.5^\circ}$

Answer:- (7)

$\sigma_{c_i} = 80$ MPa ; $\sigma_t = 8$ MPa

$$\frac{\sigma_{c_i}}{\sigma_t} = \tan^2(45 + \phi/2) \Rightarrow \frac{80}{8} \Rightarrow 10$$

$$45 + \phi/2 = \tan^{-1}\sqrt{10} = 72.45$$

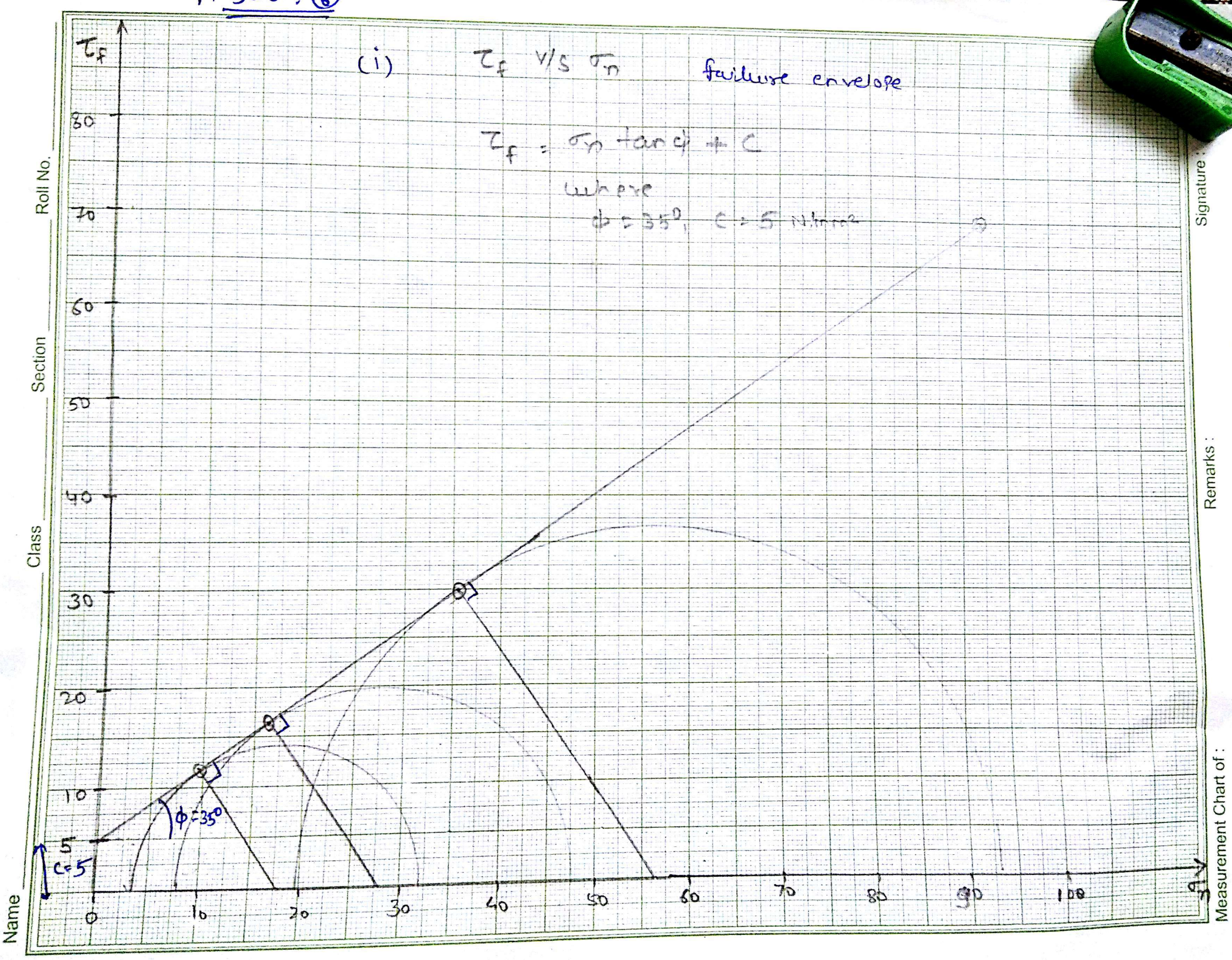
$$\boxed{\phi = 54.90^\circ}$$

$$\sigma_t = \frac{2c\cos\phi}{1+\sin\phi} \Rightarrow 8$$

$$\frac{2c\cos 54.90^\circ}{1+\sin 54.90^\circ} = 8$$

$$\boxed{c \Rightarrow 12.649 \text{ N/mm}^2}$$

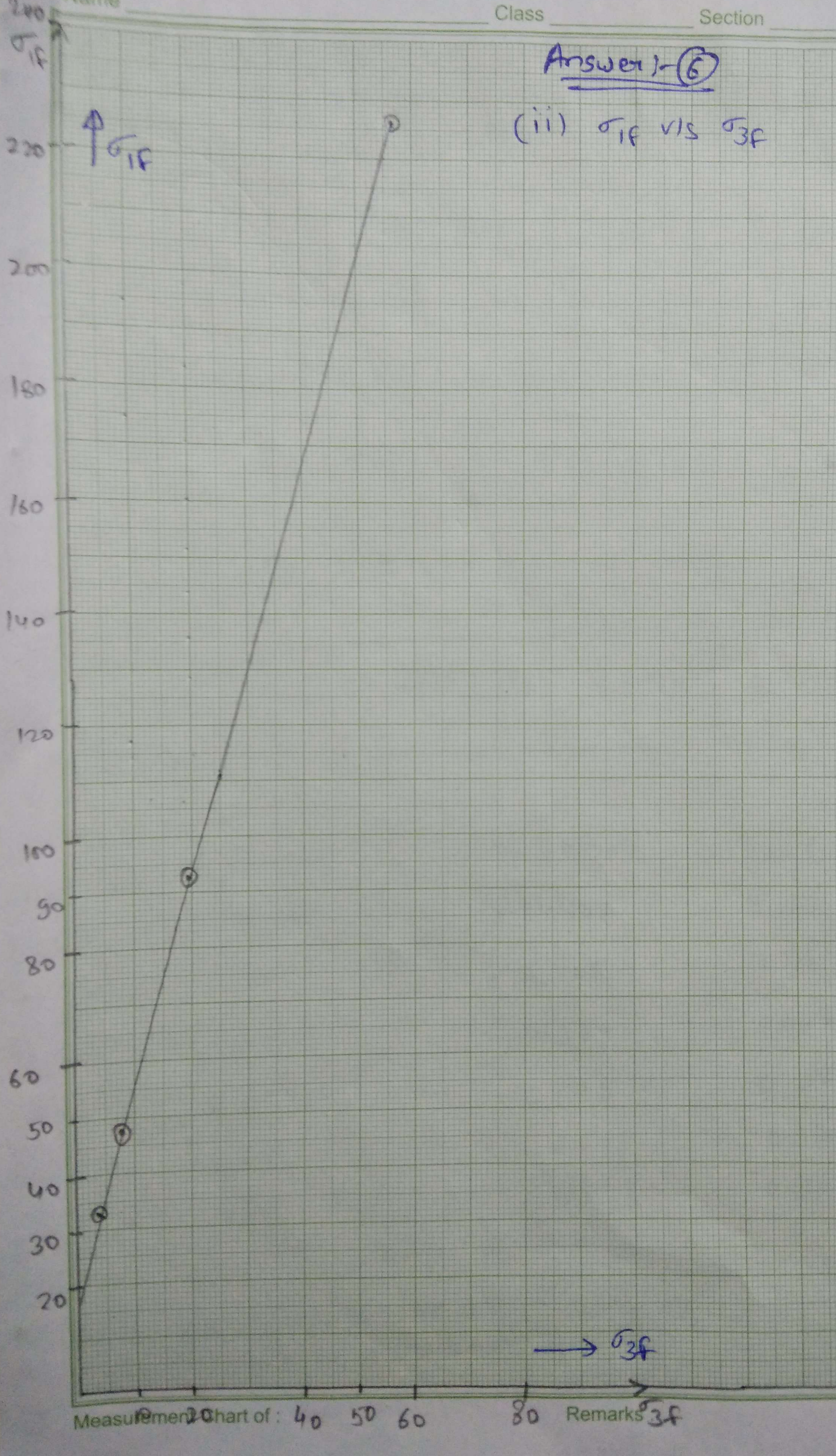
Answer:- 6


(i) τ_f v/s σ_n failure envelope
$\tau_f = \sigma_n \tan\phi + c$
where
$\phi = 35°$, $c = 5$ N/mm²
$\phi = 35°$
c=5
τ_f
0 10 20 30 40 50 60 70 80 90 100
5 10 20 30 40 50 60 70 80
Name
Class
Section
Roll No.
Signature
Remarks :
Measurement Chart of :

Name ______________ Class ________ Section ________ Roll No. ________

Answer :- (6)

(ii) σ_{1f} v/s σ_{3f}



Measurement Chart of : Remarks Signature :

$$\sigma_1 = \sigma_3 \left(\frac{1+\sin\phi}{1-\sin\phi}\right) + \frac{2c\cos\phi}{1-\sin\phi}$$

$$\sigma_1 = \sigma_3 \frac{\sigma_{ci}}{\sigma_t} + \sigma_t$$

$$\sigma_1 = 10\sigma_3 + 8$$

(i)

σ_3 (MPa)	σ_{1f}
0	8
10	108
20	208
30	308
40	408
50	508

(ii) $\sigma_n \tan\phi + c = \tau_f$

$$\sigma_1 = \sigma_n + \tau_f \tan(45+\phi/2)$$

$$\sigma_1 = \sigma_n + (\sigma_n \tan\phi + c)\tan(45+\phi/2)$$

σ_n	τ_f	σ_1
0	12.649	39.995
10	26.877	94.986
20	41.106	149.976
30	55.334	204.96
40	69.563	259.956
50	83.791	314.947