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TS-2; CE-433 : Rock Engineering, 2016-17

Q1. Following data is available for UCS tests conducted on rock cores extracted from site. The diameter of the core is 54 mm and height is 100 mm.

Load (kN)	0.0	2.8	8.5	13.9	22.6	31.2	42.0	54.0	110	51
Def. (mm)	0.0	0.1	0.20	0.3	0.4	0.5	0.6	0.7	0.9	0.92

i) Draw axial-stress vs axial-strain curve and get the UCS.
ii) Obtain secant modulus, E_{t0} and E_{t50}.
iii) Calculate modulus ratio. Assess the elastic strain at failure.
iv) Estimate the UCS value for a specimen with height of 105 mm and diameter 50mm. Use both methods.

Q.2 Draw Deere-Miller classification chart and show the position of the rock given in Q1 on this chart.

Q3. The following UCS values were obtained for a project site: 30, 39, 46, 33, 20, 26, 38, 29, 27, 35, 34, 31, 22, 17, 24, 43, 36, 41 MPa respectively. Draw CDF and get the probability for i) UCS is less than or equal to 30 MPa, ii) UCS is greater than 30 MPa and less than or equal to 45MPa.

Q4. Fit Weibull distribution curve in the data given in Q 3 and hence obtain the probabilities.

Q5. Discuss factors affecting UCS of intact rocks.

Tutorial-2
Avinash Jain
CE-433 (Rock Engineering)

Answer: (3)

Following UCS value
30, 39, 46, 33, 20, 26, 38, 29, 27, 35, 34, 31, 22, 17, 24, 43, 36, 41

→ assume σ_u = 12.5 M

Order (m)	Values (σ)	Probability P = (m/N+1)	Y	X
1	17	1/19	-2.917	1.504
2	20	2/19	-2.196	2.014
3	22	3/19	-1.761	2.251
4	24	4/19	-1.442	2.442
5	26	5/19	-1.186	2.602
6	27	6/19	-0.968	2.674
7	29	7/19	-0.777	2.803
8	30	8/19	-0.604	2.862
9	31	9/19	-0.443	2.917
10	33	10/19	-0.291	3.020
11	34	11/19	-0.145	3.068
12	35	12/19	-0.001	3.113
13	36	13/19	0.142	3.157
14	38	14/19	0.288	3.238
15	39	15/19	0.443	3.277
16	41	16/19	0.612	3.349
17	43	17/19	0.811	3.417
18	46	18/19	1.079	3.511

So, From Graph b/w Probability v/s Strength value

(i) Probability of UCS is less than or equal to 30 MPa

$= \frac{7.5}{19} \Rightarrow 0.3947$

(ii) Probability of UCS > 30 MPa and < 45 MPa

$\Rightarrow \frac{17.8}{19} - \frac{7.5}{19} \Rightarrow \frac{10.3}{19} \Rightarrow 0.5421$

Answer: (4)

Fitting Weibull Distribution

$$P = 1 - e^{-\left(\frac{\sigma - \sigma_u}{\sigma_0}\right)^m}$$

$$\ln\ln\left(\frac{1}{1-P}\right) = m\ln(\sigma - \sigma_u) - m\ln\sigma_0$$

$$Y = AX + B$$

assume. $\sigma_u = 12.5$ MPa (from previous question)

As $Y = \ln\ln\left(\frac{1}{1-P}\right)$

$X = \ln(\sigma - 12.5)$

After calculating Y and X, we will calculate A and B.

From Linear Line Regression analysis

$$A = \frac{N\sum XY - (\sum X)(\sum Y)}{N\sum X^2 - (\sum X)^2}, \quad B = \frac{\sum Y - A\sum X}{N}$$

where, $N = 18$

$\sum X = 51.219$ $\quad \sum X^2 = 150.458$

$\sum Y = -9.356$ $\quad \sum Y^2 = 24.621$

$\sum XY = -17.053$

$$A = \frac{18(-17.053) - 51.219 \times (-9.356)}{18(150.458) - (51.219)^2} = +2.0294$$

~~$A = \frac{\sum Y - B\sum X}{N} \Rightarrow \frac{-9.356 - B(51.219)}{18} = 2.0294$~~

~~$B = -6.2946$~~

$$\Rightarrow B = \frac{-9.356 - (2.0294)(51.219)}{18} \Rightarrow -6.294$$

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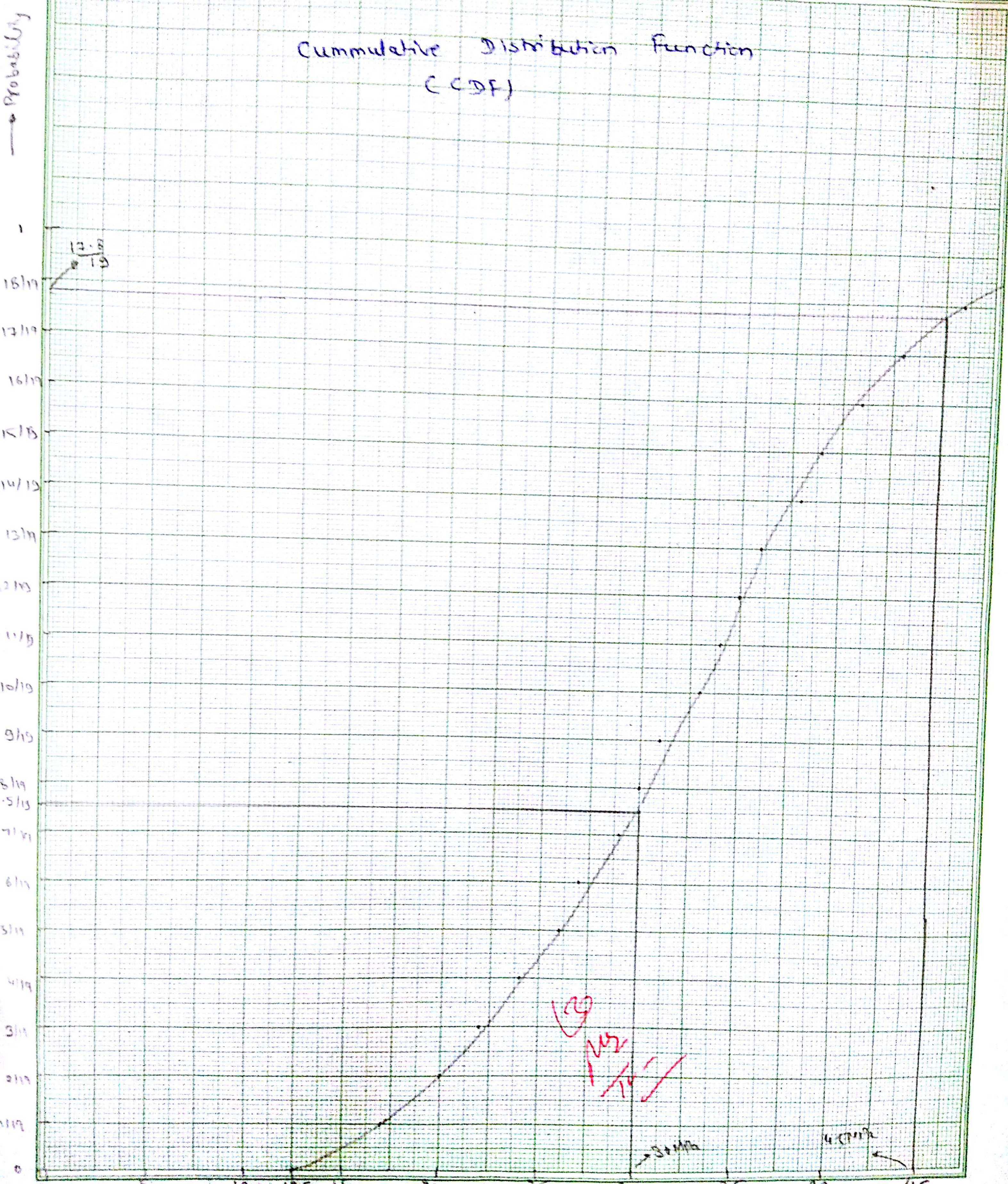
Cummulative Distribution Function (CDF)



Measurement Chart of : Remarks : Signature :

(1) End ...

So, $m = A = 2.0294$

and $-m \ln \sigma_0 = B = -6.294$

$$\ln \sigma_0 = \frac{6.294}{2.0294}$$

$$\sigma_0 = 22.229$$

So, Weibull Distribution :-

$$P = 1 - e^{-\left(\frac{\sigma - \sigma_u}{\sigma_0}\right)^m}$$

$$\Rightarrow \boxed{P = 1 - e^{-\left(\frac{\sigma - 12.5}{22.229}\right)^{2.0294}}}$$

So, Probability of UCS less than 30 MPa is

$$P_{30} = 1 - e^{-\left(\frac{30 - 12.5}{22.229}\right)^{2.0294}}$$

$$P_{30} = 0.4595$$

Probability of UCS is greater than 30 MPa and less than 45 MPa

$$P_{45} - P_{30}$$

$$\Rightarrow \left\{1 - e^{-\left(\frac{45 - 12.5}{22.229}\right)^{2.0294}}\right\} - 0.4595$$

$$\Rightarrow 0.8848 - 0.4595$$

$$\Rightarrow 0.4253$$

(1)

Answer:- (5) Factors affecting UCS of Intact Rocks

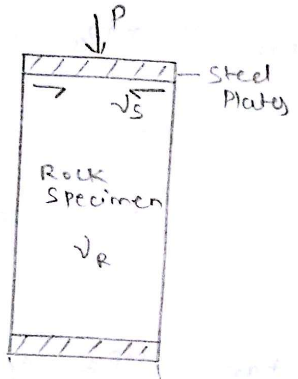
UCS of Intact Rocks depends on the following factors

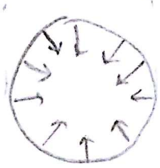
(i) End effect (end friction)

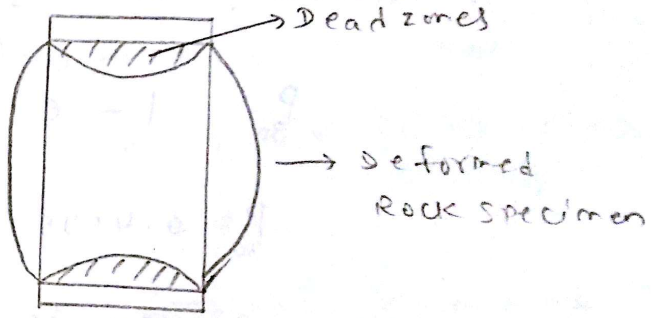
→ When load is applied on the specimen, lateral deformation takes place but as the poisson's ratio is higher for rocks i.e. $\nu_R > \nu_s$, steel plates will try to restrict its lateral expansion creating frictional stresses.

→ This will create zones in which stresses will be triaxial instead of uni-axial, these zones are called Dead zones.

→ End effect is minimized by using "Teflon Sheets" which have very low effect of friction.





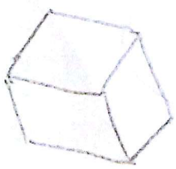


(ii) Geometry of specimen

a) Shapes

• Cubical

• Cylindrical

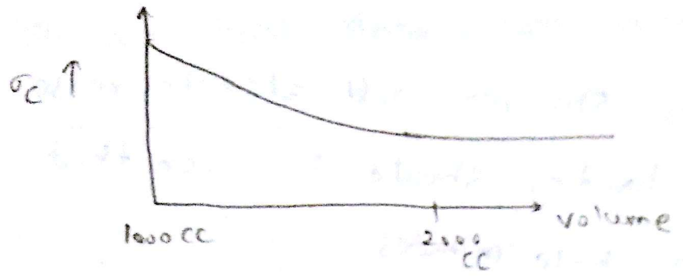


(2)

- Sharp edges of cubical specimen attracts stress concentration, which result in premature failure.

- Therefore these are less preferred.

(b) Sizes



- Theoritically strength of a material (stresses) should not depend on the volume of its specimen. However, it is observed that strength value decreases as volume increases upto a certain value and it becomes constant afterward
- This is because of the boundary cracks (also called "Griffith" cracks") align more and more towards the failure surface which is at $45+\phi/2$ from cylindrical face.
- Volume at which it becomes constant is around 52-53 mm which is why 54mm (N_x) is suggested as minimum specimen size for project works.

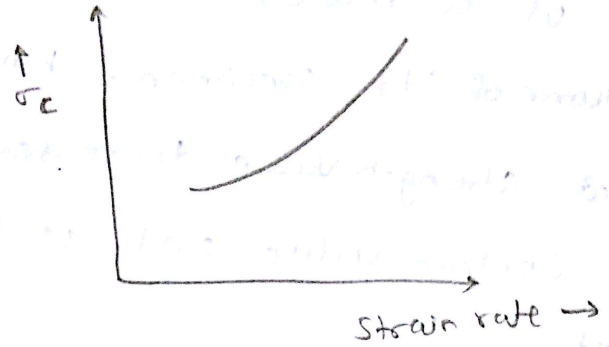
(c) h/d ratio

→ As $\frac{h}{d}$ ratio decreases, strength increases

- If $\frac{h}{d}$ is small, the two dead zones will intersect and specimen will be almost under tri-axial loading condition. (9)
- If $\frac{h}{d}$ is large, the specimen will fail prematurely under buckling.

(iii) loading Rate

- If loading Rate increases strength will also increase.
- For testing Purpose loading should be such that failure occurs within 5-10 minutes.



(iv) Environmental Factors.

- **Moisture Content :-** If moisture content is high strength will be low and vice versa.
- **Type of liquids :-** Different chemicals that may affect Rocks.
- **Temperature:-** Higher Temperature will result in low strength and vice versa. As we go deep into the earth temperature increases.

(V) In-situ stresses !-

- When a rock (before excavation) is subjected to stresses from its surroundings, upon excavation these stresses are released.
- As a result, this rock will try to expand and during this process cracks get induced resulting in lower strength.

(vi) Mineralogy:-

Strength will depend on minerals, grain size distribution

Porosity etc.

5

① UCS Test   d = 54mm, h = 100 mm $A_0 = \frac{\pi}{4} d^2 \Rightarrow 2290.22\ mm^2$

Load (KN)	Deformation (mm)	Stress (MPa)	Strain (ε)	Corrected area (mm²)	Corrected Stress (MPa)
0	0	0	0	2290.22	0
2.8	0.1	1.22	0.001	2292.51	1.22
8.5	0.2	3.71	0.002	2294.81	3.70
13.9	0.3	6.07	0.003	2297.11	6.05
22.6	0.4	9.87	0.004	2299.42	9.83
31.2	0.5	13.6	0.005	2301.73	13.56
42	0.6	18.3	0.006	2304.04	18.23
54	0.7	23.6	0.007	2306.37	23.41
110	0.9	48	0.009	2311.02	47.60
51	0.92	22.3	0.0092	2311.49	22.06

i) Peak stress value from axial stress v/s axial strain curve

σ_{ci} = UCS = 47.60 MPa (Uniaxial Compression stress value)

(ii) Tangent Modulus at strain = 0 = stress

$$E_{t_0} = \frac{3.2\ MPa}{0.003} \Rightarrow 1066.67\ MPa$$

Secant Modulus

$$E_s = \frac{47.6\ MPa}{0.009} \Rightarrow 5288.89\ MPa$$

$E_{t_{50}}$ = at 50% UCS value

$$= \frac{(34 - 13.6)\ MPa}{0.088 - 0.085} \Rightarrow 6800\ MPa$$

iii) $E_{t_{50}} = \frac{\sigma_{ci}}{\epsilon_e}$ ϵ_e = elastic strain at failure

$$\Rightarrow 6800 = \frac{47.6}{\epsilon_e}$$

$$\epsilon_e = 0.007$$

$$\text{Modulus Ratio} = \frac{1}{\epsilon_e} = \frac{1}{0.007} = 142.85$$

iv) <u>Using ASTM Method</u>

Given $\frac{h}{d} = \frac{100}{54} = 1.85 \Rightarrow \sigma_{ci} = 47.6\ MPa$

$\Rightarrow \frac{h}{d} = \frac{105}{50} \Rightarrow 2.1$

$$\sigma_{c_1} = \frac{\sigma_{c_{1.85}}}{0.778 + \frac{0.222}{1.85}} = \frac{\sigma_{c_{2.1}}}{0.778 + \frac{0.222}{2.1}}$$

$$\Rightarrow \sigma_{c_{2.1}} = 46.84\ MPa$$

<u>Using Protodyakonov Method</u>

$$\sigma_{c_2} = \frac{8\sigma_{c_{1.85}}}{7 + \frac{2}{1.85}} = \frac{8\sigma_{c_{2.1}}}{7 + \frac{2}{2.1}}$$

$$\sigma_{c_{2.1}} = 46.84\ MPa$$

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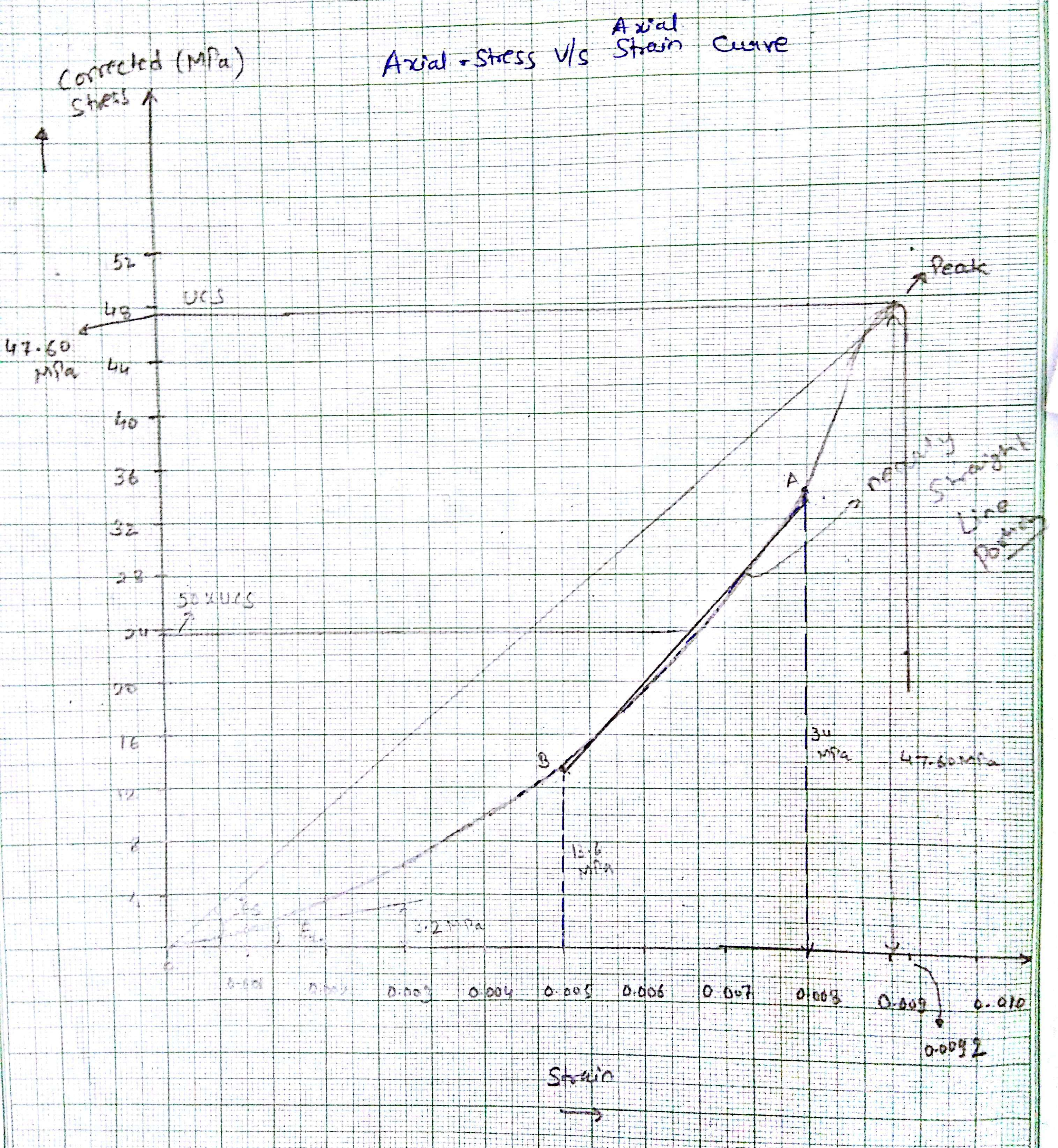

A_c = Corrected area

$= \frac{A_o}{1-\epsilon}$ $\Rightarrow A_o = 2290.22\ mm^2$

Measurement Chart of : Remarks : Signature :

(2) Deere-Miller Classification Chart

Rock Classification is based on its UCS value and modulus Ratio

XY X → UCS

Y – Modulus Ratio

UCS (MPa)			Modulus Ratio		
A –	Very High	> 200	H	– High	> 500
B –	High	100–200	M	– Medium	200–500
C –	Medium	50–100	L	– Low	< 200
D –	Low	25–50			
E –	Very low	< 25			

		Modulus Ratio		
		H	M	L
UCS (MPa)	A	AH	AM	AL
	B	BH	BM	BL
	C	CH	CM	CL
	D	DH	DM	DL
	E	EH	EM	EL

⇒ Deere Miller Rock Classification Chart

in question 1. UCS = 47.6 MPa

So, Category = C ⇒ Medium

Modulus Ratio = 142.85

So, Category = L ⇒ Low

Shaded Portion in the chart is the type of Rock given in Question 1.

Rock Type = CL