CHAPTER 1

Basic Concepts

CONTENTS

1. Basic Concepts

1.1 Introduction:

Structural Engineering

Analysis (SOM, SA)	Design (RCC, PSC, Steel)
- Equilibrium	- Safety
- Compatibility	- Serviceability
- Energy	- Durability
	- Economy
	- Asthetic

i) Safety:

A structure must be safe with appropriate factor of safety [FOS] for loading that may come on it during its intended life.

ii) Serviceability:

A structure should provide the service for which it is constructed.

iii) Durability:

A structure should sustain loading for which it was designed and should perform well with safety and serviceability upto its whole life

Durability without serviceability or less margin of safety [FOS] iv) has no meaning

iv) Economy:

Design and construction of any structure should be economical without affecting safety, serviceability and durability.

v) Asthetic:

If huge investment is involved in design and construction of a structure then asthetic also plays an important role.

Ex. Considering a beam:

i) Safety: Reinforcement is provided

ii) Serviceability: Doubly reinforced section instead of singly reinforced section to reduce depth of section.

iii) Durability: Nominal cover, selection of material.

iv) Economy: Monolythic casting of beam and slab designed as T-section.

v) Asthetic: Half round section instead of rectangular section.

1.2 Cement Concrete:

It is a mixture of binding material [cement], fine aggregate [sand], coarse aggregate, water and admixture in proper proportion to achieve concrete of desired properties at fresh state and hardened state.

1.2.1 Concrete Mix:

a) Nominal Mix:

- Based on experience.
- Mixing may be by weight or by volume. By weight is preferable
- Quantity of water is not fixed. It is provided as per site requirement.
- Nominal mix is allowed for M5 to M20.

	C	FA	CA
M10	1	3	6
M15	1	2	4
M20	1	1.5	3

b) Design Mix:

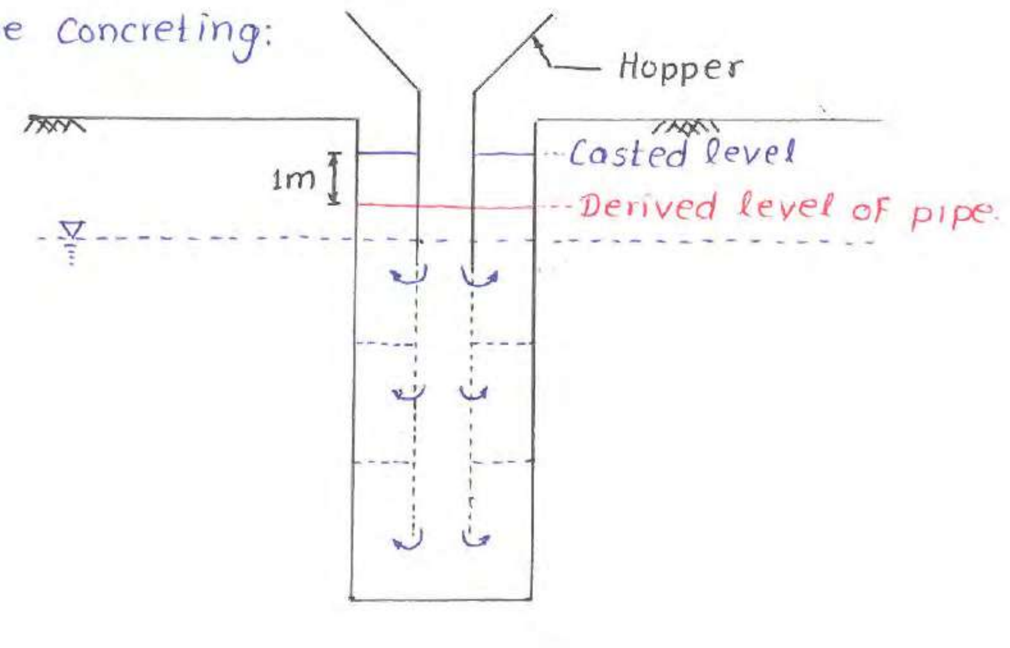
- Based on calculation as per IS10262 (2009)
- Proportioning must be by weight.
- Quantity of water is also fixed.
- Design mix is allowed for M10 to M100.

1.2.2 Fresh Concrete:

Workability is the most important property of fresh concrete which is simply defined as "Ease to work with."

Sr. No.	Degree of Workability	Use	Slump	Compacting Factor	Vee-bee time (sec)
1.	Very low	- Road Construction. - Shallow Section.	-	0.75 - 0.8	10 - 20
2.	Low	- Mass concreting. - Lightly reinforced section	25 - 75	0.8 - 0.85	5 - 10
3.	Medium	- Heavily reinforced section - Concreting by concrete pump.	50 - 100	0.85 - 0.92	2 - 5
4.	High	- Piling	100-150	0.92-above	-
5.	Very High	- Tremie pipe concreting.	-	0.92-above	-

* Tremie Pipe Concreting:



* Workability of Concrete can be measured by following methods.

1. Slump test
2. Compacting factor Test
3. Vee-bee Test
4. Flow Test

1.2.3 Hardened Concrete:

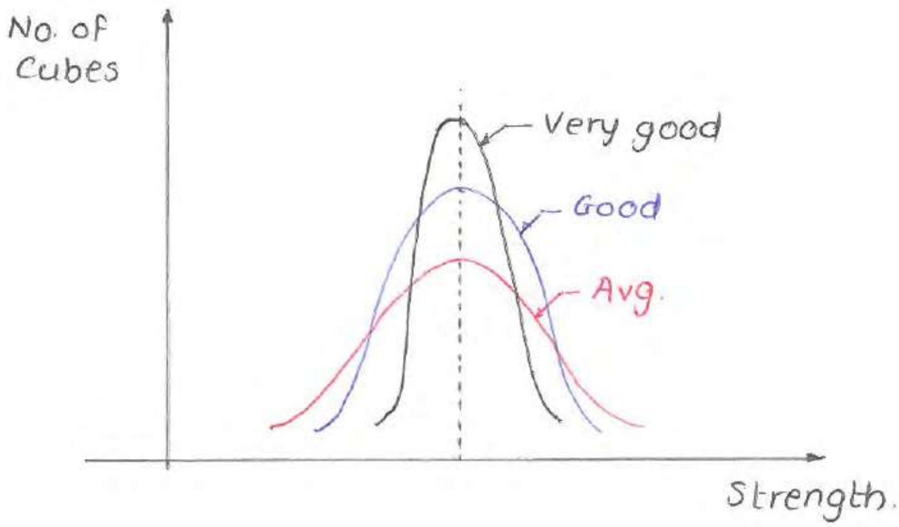
After final setting time, concrete is assumed to be hard and it keeps on gaining strength for very long time [1 to 5 years]

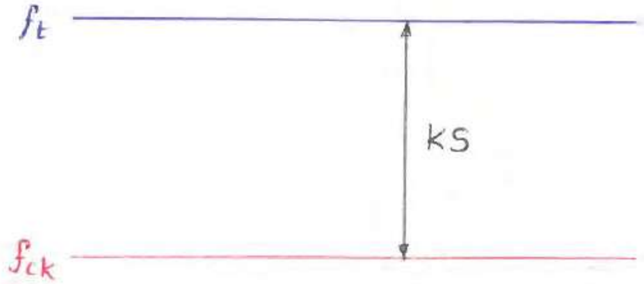
a) Compressive Strength of Cube:

This is the compressive strength of cube size 150 mm subjected to uniaxial compression after 28 days from day of casting.

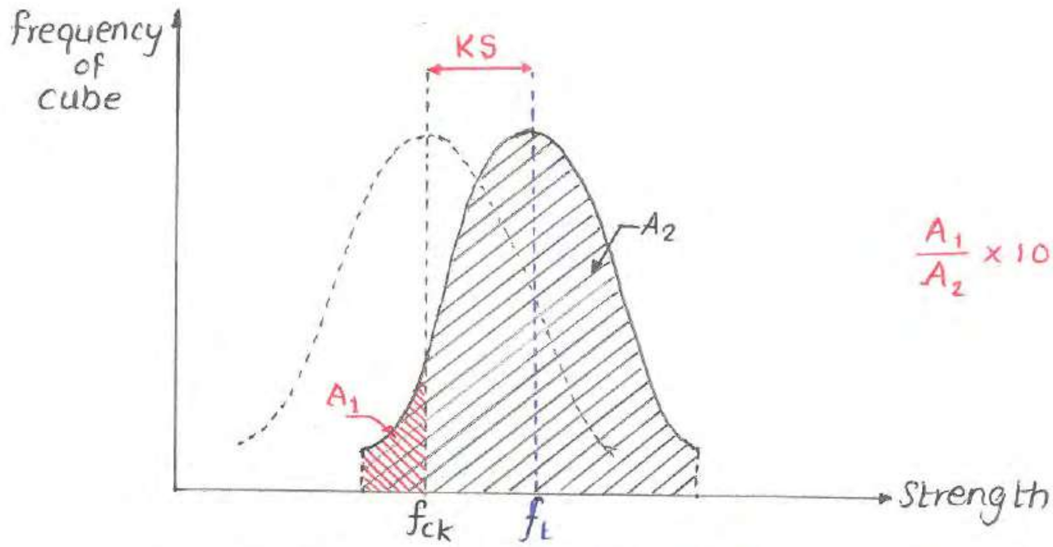
b) Characteristic Compressive Strength of Cube:

It is the strength below which not more than 5% test results are expected to fall.





$$f_t = f_{ck} + KS$$



$$\frac{A_1}{A_2} \times 100 \leq 5\%$$

Area under curve represents number of cubes.

K = 1.65 (for 5% of definition)

% of definition	K
0%	∞
5%	1.65
50%	0

S = Standard deviation that depends on quality control.

Ex. Uniaxial compression test results of 100 cubes are listed below in increasing order. Find f_{ck}

26, 26.5, 26.5, 27, 27.5,

28, 28.5, 29, 30, 30.5,

31, ...

.................., 42.5 N/mm²

$\Rightarrow$ As per definition, f_{ck} should be 28 N/mm². Since, f_{ck} always designated in multiple of 5, so answer should be 25 N/mm² or 30 N/mm².

In this case, 8 samples (more than 5%) are below 30 N/mm², so 30 N/mm² can not be f_{ck}

Now, 25 N/mm² can be considered as f_{ck} because zero test results (less than 5%) is below 25 N/mm²

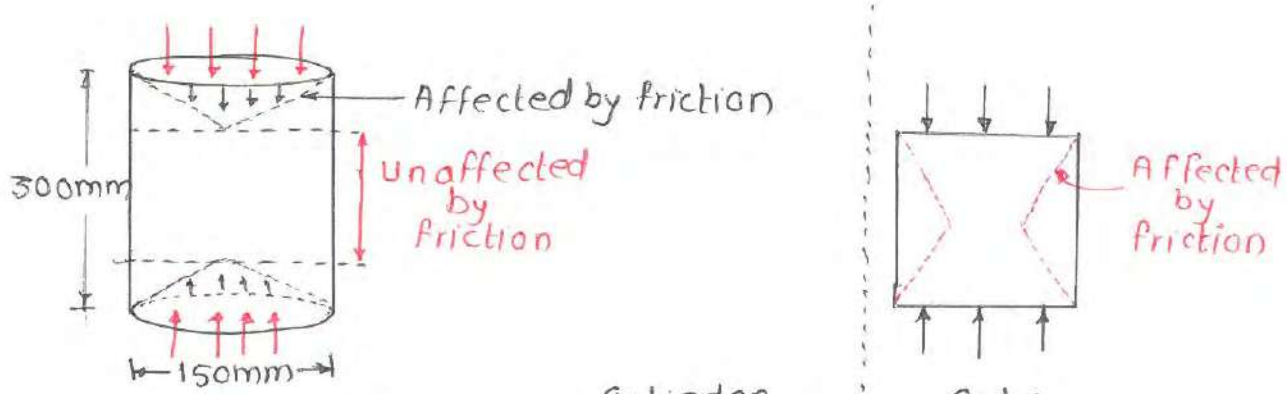
$$\Rightarrow f_{ck} = 25\ N/mm^2$$

c) Characteristic Compressive Strength of Concrete:

It is obtained by dividing characteristic compressive strength of cube by a factor 1.5 to account for variation in shape of concrete [other than cube] and variation in loading condition [other than uniaxial compression].

* Note:
- Factor 1.5 used here is not partial F.O.S.
- For general conversation, characteristic strength of concrete represents value obtained from characteristic strength of Cube.

1.2.4 Comparison between Cube and Cylinder:



	Cylinder	Cube
What should be used	✓	×
Actually Used.	×	✓

- Uniaxial compressive strength of concrete can be determined by using different shapes of spacimen. (Cube, cylinder, prism, etc)

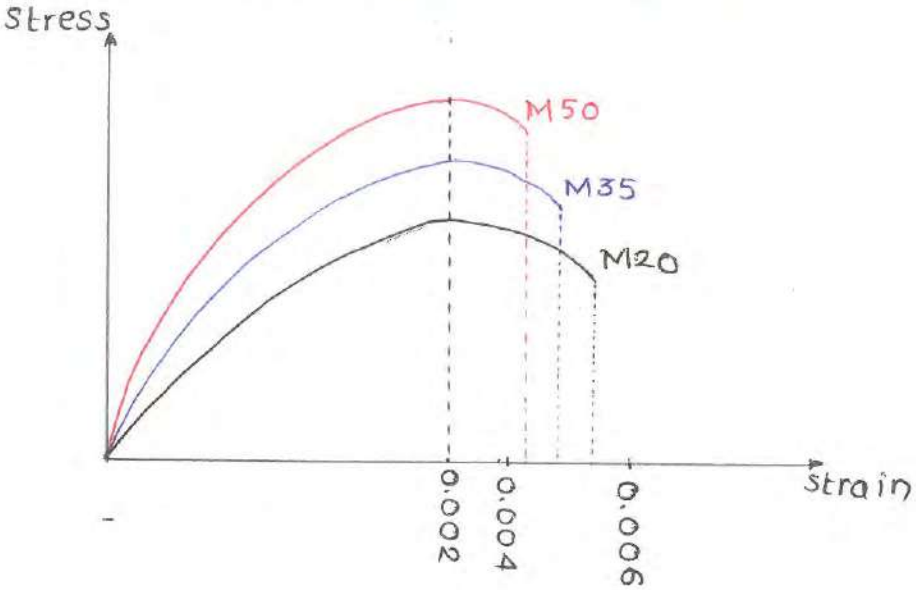
$$f_{cube} \approx 1.25\, f_{cylinder}$$

- Cylinder gives more appropriate results for uniaxial compressive strength of concrete because effect of friction between machine plates and specimen, is almost nil (zero).

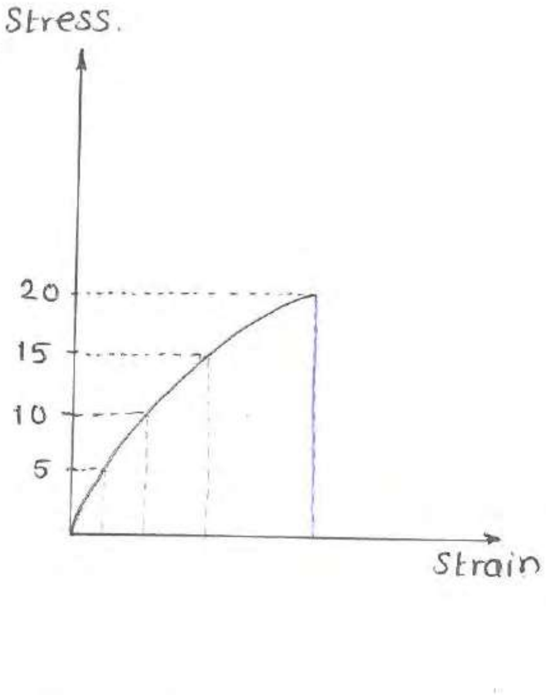
* Note:-

- Cube of smaller size (assuming 100mm) gives more strength than standard cube.
- A smaller cylinder also gives higher strength than standard cylinder, provided ratio of height to diameter remains constant
- These results are experimental.

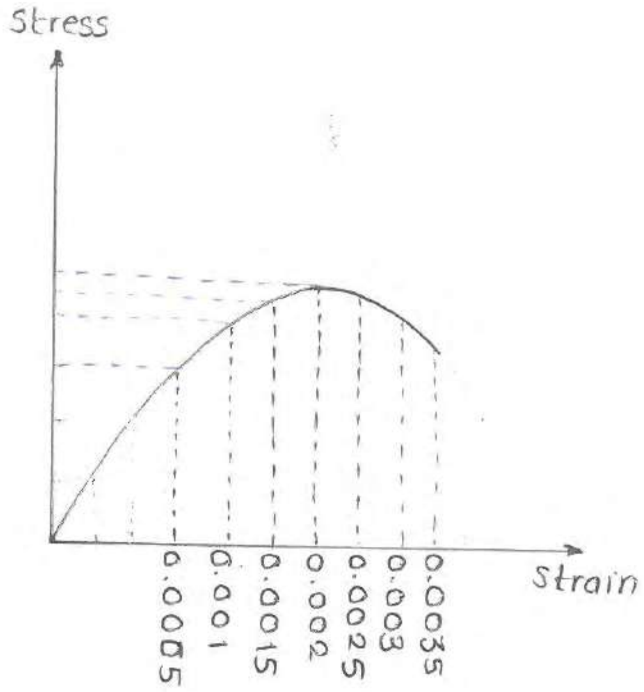
1.2.5 Stress-Strain diagram of Concrete under



- Stress-strain diagram is non-linear.
- Initial portion of stress-strain diagram can be considered as linear.
- Maximum compressive stress is corresponding to approx strain 0.002
- Ultimate strain lies between 0.004 to 0.006
- Modulus of elasticity increases with increase in grade of concrete.
- Brittleness increases with increase in grade of concrete.



Controlled Stress.



Controlled Strain

1.2.6 Grade of Concrete:

M - 25

Mix → M ; 25 → Characteristic compressive strength (N/mm^2)

M5 - M20 ⟶ Nominal Mix

M10 - M100 ⟶ Design Mix [as per ammendment (4)]

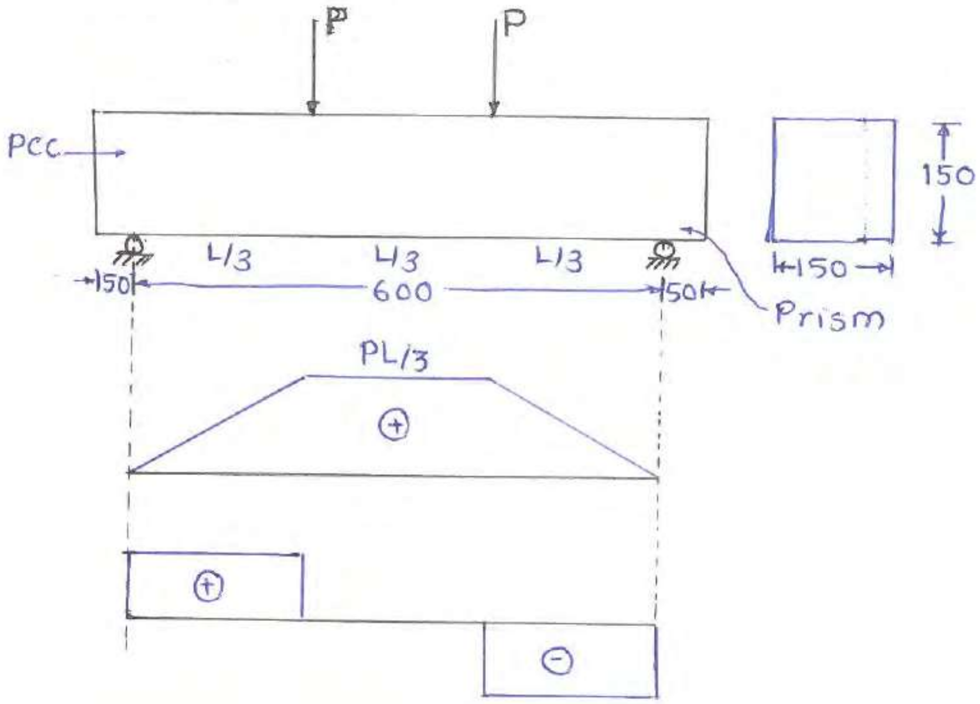
1.2.7 Tensile Strength of Concrete:

- It is approximately 10% (7% to 15%) of the compressive strength.
- Stress-strain diagram is almost linear.
- Ratio of compressive strength to tensile strength increases with increase in grade of concrete.
- Since tensile strength of concrete is ignored in RCC structure so it has very less importance. However, it is calculated to determine cracking moment.

1. Direct Tension Test:

Practically, it is very difficult to perform direct tension test because force never remains perfectly axial tension due to non-homogenity of concrete.

2. Flexure Test



Flexure Formula:

$$\underbrace{\frac{M}{I} = \frac{f}{y}}= \frac{E}{R}$$

$$\frac{P_{cr}\ L/3}{bD^3/12} = \frac{f_{cr}}{D/2}$$

$$f_{cr} = ??$$

- 3rd point loading is applied for pure bending condition. (Flexure).
- Value of P is increased from 0 to value corresponding to which 1st crack develops in extreme tension fibre.
- Corresponding to cracking load, bending moment is calculated in central portion and tensile strength is calculated as illustrated above.

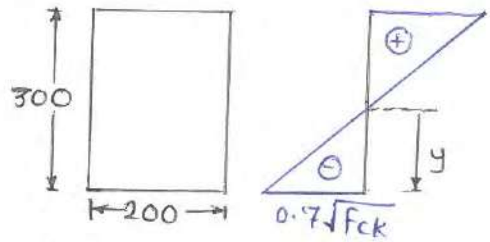
- IS 456 provides standard formula for flexure tensile Strength/Modulus of Rupture

$$f_{cr} = 0.7\sqrt{f_{ck}} \quad N/mm^2.$$

Ex. A PCC beam of section size 200 x 300 mm is made up of M30 concrete. Calculate cracking moment of section.

⇒

By Flexure Formula.



$$\frac{M_{cr}}{I} = \frac{f_{cr}}{y}$$

$$f_{cr} = 0.7\sqrt{f_{ck}}$$

$$f_{cr} = 0.7\sqrt{30} = 3.834\ N/mm^2$$

$$I = \frac{bD^3}{12} = \frac{200 \times 300^3}{12}$$

$$I = 450 \times 10^6\ mm^4$$

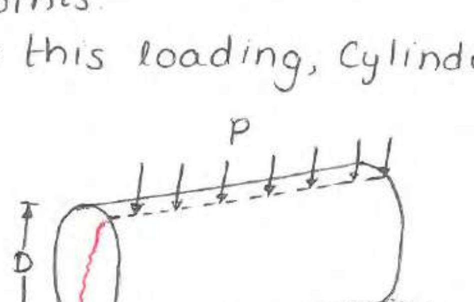
$$y = D/2 = 150\ mm$$

$$\frac{M_{cr}}{450 \times 10^6} = \frac{3.834}{150}$$

$$M_{cr} = 11.502\ kN\text{-}m$$

3. Cylinder Split Test:

- A line loading along length is applied at diametrically end points.
- Due to this loading, Cylinder splits into two parts.



$$f_{cr} = \frac{2P}{\pi DL}$$

$$f_{flexure} > f_{cylinder\ split} > f_{direct}$$

1.2.8 Shrinkage of Concrete:

Concrete has shrinkage property due to presence of cement. IS 456 provides a standard value of shrinkage strain of concrete for design of RCC structure.

$$\epsilon_{st} = 0.0003$$
$$= 0.03\%$$
$$= 3 \times 10^{-4}$$

1.2.9 Durability:

Exposure Condition	Description	Minimum Grade of Concrete	Minimum Nominal Cover	Minimum Cement content	Maximum W/C ratio
Mild	- Protected from rainfall	M20	20mm*	300 kg/m^3	0.55
Moderate	- Subjected to normal rainfall - Permanently submerged in normal water - Foundation in non aggressive soil.	M25	30mm	300 kg/m^3	0.5
Severe	- Coastal area - Subjected to Heavy rainfall - Permanently submerged in sea water - Alternate drying and wetting in normal water - Occasional freezing.	M30	45mm**	320 kg/m^3	0.45
Very Severe	- Subjected to sea spray (Alternate drying and wetting in sea water) - Permanent freezing.	M35	50mm	340 kg/m^3	0.45

Exposure Condition	Description	Minimum Grade of Concrete	Minimum Nominal Cover	Minimum Cement Content	Maximum W/C ratio
Extreme	- Tidal zone - Subjected to aggressive chemicals	M40	75mm	360kg/m^3	0.4

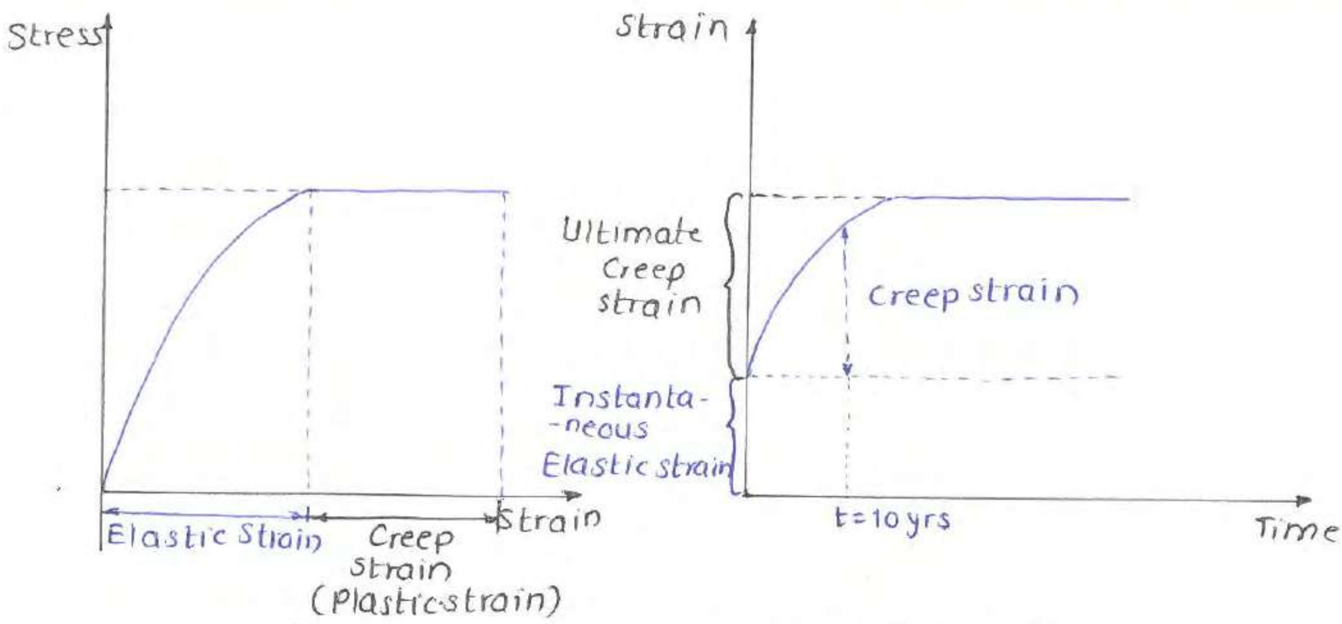
* - This can be reduced to 15mm for reinforcing bar dia. 12mm or less.

** - This can be reduced to 40mm for grade of concrete M35 or higher.

1.2.10 Creep of Concrete:

It is a time dependent strain in concrete due to sustained loading (permanent loading). Dead load and prestressing force are the examples of permanent loading.

The exact mechanism of creep in concrete is still not fully understood. It is generally attributed to internal movement of absorbed water, viscous flow or sliding between the gel particles, moisture loss and the growth in micro-cracks.

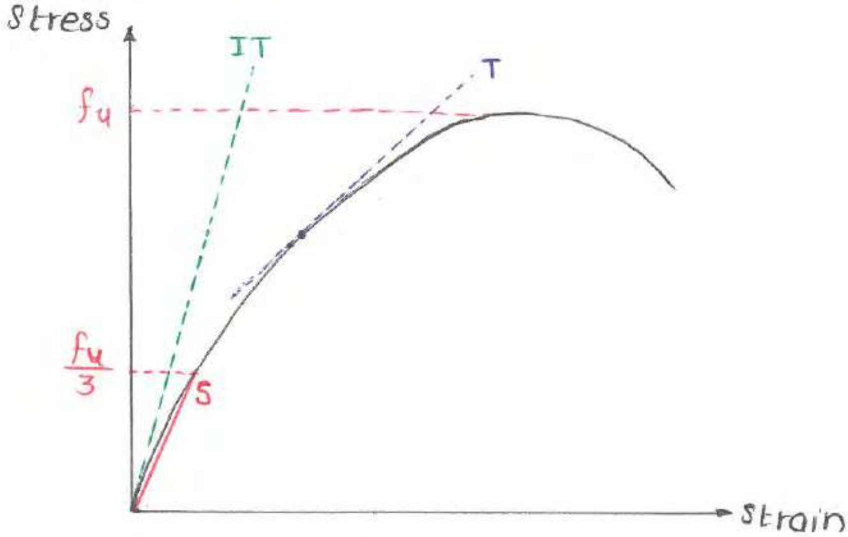


$$\text{Creep coefficient } (\theta) = \frac{\text{Ultimate Creep Strain}}{\text{Instantaneous Elastic Strain}}$$

Age of concrete at the time of loading	θ
7 days	2.2
28 days	1.6
1 Year	1.1

* Note:
- Higher value of θ represents higher creep strain
- Ultimate creep strain is more if load is applied at early age of concrete.

1.2.11 Modulus of Elasticity:



1. Initial Tangent Modulus (IT):

It is defined as slope of tangent drawn at a point of start of stress-strain diagram. This is also called as dynamic modulus of elasticity which is used for analysis due to dynamic loading. It is calculated using Resonance frequency test.

2. Secant Modulus (S):

It is defined as slope of line connecting point of start of stress-strain diagram to point with stress $\frac{1}{3}$rd of ultimate stress. It is also called as static modulus of elasticity. IS 456 provides standard formula for this modulus of elasticity.

$$E_c = 5000\sqrt{f_{ck}} \ N/mm^2.$$

This is also called as short term modulus of elasticity and it is not incorporating effect of creep.

After effect of creep.

$$E_{ce} = \frac{E_c}{1+\theta} = \frac{5000\sqrt{f_{ck}}}{1+\theta}$$

3. Tangent Modulus (T):

It is defined as slope of tangent drawn at any point of stress-strain diagram. It is used in incremental load analysis.

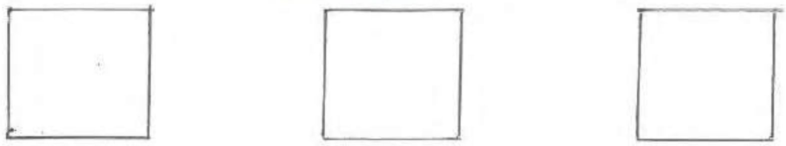
1.2.12 Acceptance of Concrete:

1.2.12.1 Acceptance Criteria of Sample:

- Specimen → 1 Cube
- Sample → Set of 3 cubes casted from same concrete at same time.

Quantity of Concrete	No. of Sample
1 - 5 m^3	1
6 - 15 m^3	2
16 - 30 m^3	3
31 - 50 m^3	4
51 - above	4 + 1 sample for each additional 50 m^3.

1 Sample



Compressive Strength of specimen	x	y	z

$$\text{Compressive strength of Sample} = \frac{x+y+z}{3}$$

Sample is acceptable only if compressive strength of no individual specimen (x, y, z) is falling beyond $\pm 15\%$ of compressive strength of sample $\left(\frac{x+y+z}{3}\right)$

1.2.12.2 Acceptance Criteria of Concrete

$V = 100\,m^3$

Day	Day 1	Day 2	Day 3	Day 4
Quantity	$20\,m^3$	$35\,m^3$	$25\,m^3$	$20\,m^3$
No. of Sample	3	4	3	3

Sample Number. 1 2 3 4 5 6 7 8 9 10 11 12 13

Avg. of 4 consecutive and non-overlapping $\geq$ Maximum
- $f_{ck} + (0.825 \times \text{Standard deviation})$
- $f_{ck} + 3$

In addition to above criteria, compressive strength of no individual sample (1 to 13) should be less than $f_{ck} - 3$

1.2.13 Testing of Hardened Concrete:

a) Distructive Testing:

Sample used for distructive testing can not be reused for service.

1. Load Test:

   Used in precast construction.

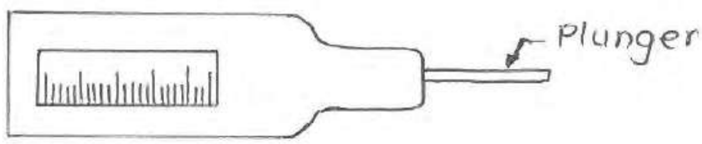
2. Core cut Test:

   Used in road construction.

b) Non-distructive Testing.

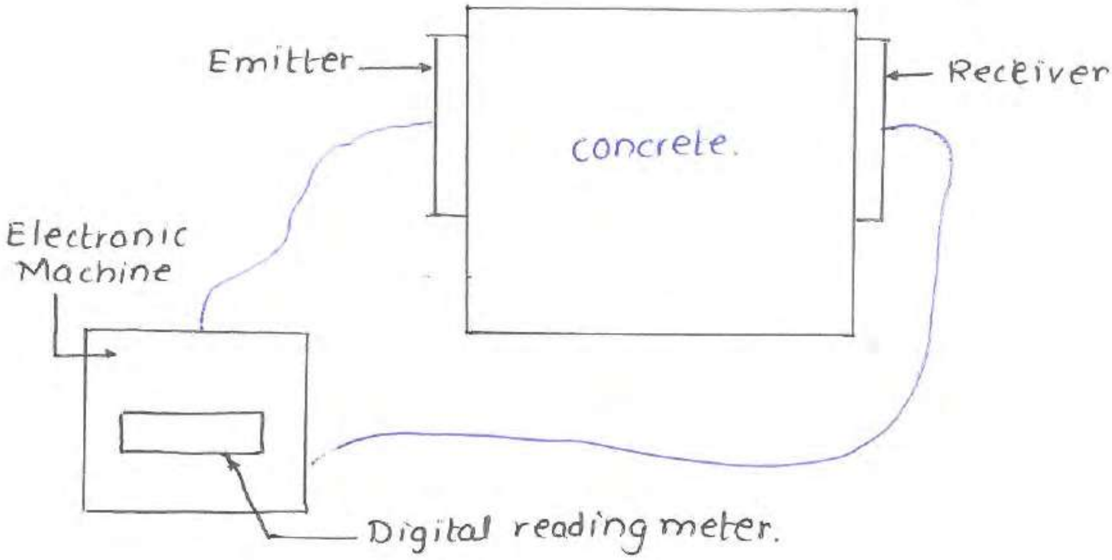
Sample used for NDT can be reused for service.

1. Rebound Hammer Test:



- Plunger of this apparatus is pressed against surface of concrete.
- Energy rebounded from concrete surface gives idea about strength of concrete.
- Reading meter installed with this apparatus gives a value which is multiplyied by a factor to get a compressive strength of concrete.
- This method of testing is vague because plunger pressed against mortar and aggregate gives different values.
- This test gives idea about surface of concrete only.

2. Ultrasonic Pulse Velocity Test:



- This is an electronic method in which emitter and reciever are connected on opposite surfaces of concrete.
- Time taken by ultrasonic waves to travel through concrete is measured.
- If time is less then concrete is dense. It means quality is good.
- This method is also used to detect cracking in RCC structure and to determine dynamic modulus of elasticity.

1.2.14 Concrete Mix Design:

Step 1: Calculate target mean strength

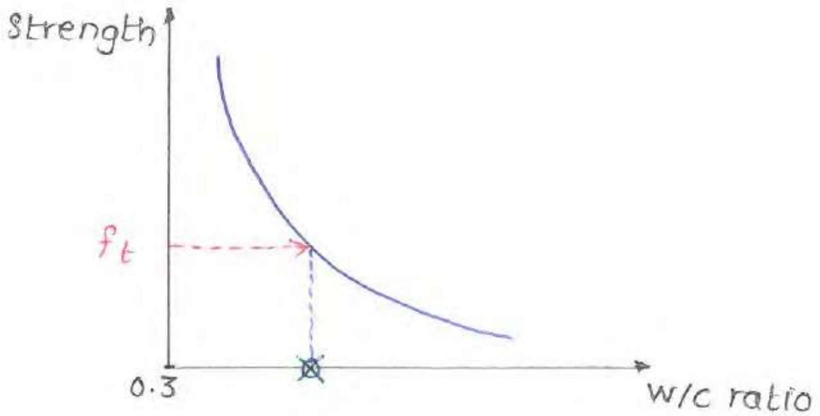
$$f_t = f_{ck} + K \cdot S$$

Where, K = 1.65 (for 5% of definition)

S = Standard deviation that depends on quality control.

Grade of concrete	S
M10 - M15	3.5
M20 - M25	4.0
M30 - M50	5.0

Step 2: Take value of water cement ratio corresponding to target mean strength from graph given in SP 23 [Special Publication]



W/C ratio should not be more than value obtained from above graph and corresponding to exposure condition.

Step 3: Take maximum water content from Table 2 of IS 10262, corresponding to nominal size of coarse aggregate and slump 25-50 mm

Nominal Size of Coarse Aggregate	Maximum Water Content
10 mm	205 kg/m^3
20 mm	186 kg/m^3
40 mm	165 kg/m^3

*Note:

- Maximum limit of water content is imposed to prepare economical and durable concrete with low shrinkage.
- As nominal size of C.A. increases, water requirement decreases because total surface area of larger size coarse aggregate is less than as of smaller size C.A.
- For each additional 25mm slump, above values are increased by 3%.
- Above values are reduced by 5-10% for plasticizers and 20% for super-plasticizers.
- Maximum limit of plasticizers and Super-plasticizers are 1% and 2% of quantity of cement respectively.

Step 4: Calculate Cement content:

$$\text{Weight of Cement} = \frac{W_w}{W/C}$$

This value should not be less than minimum cement content corresponding to exposure condition.

Step 5: Take proportion of volume of C.A. in volume of total aggregate (F.A.+C.A.) from Table 3 of IS 10262 for W/C ratio 0.5

$$\text{Proportion} = \frac{\text{Volume of Coarse Aggregate}}{\text{Volume of Total Aggregate}} \quad (\text{for } W/C = 0.5)$$

Nominal Size of C.A.	Zone IV	Zone III	Zone II	Zone I (Finest)
10 mm	0.50	0.48	0.46	0.44
20 mm	0.60	0.64	0.62	0.60
40 mm	0.75	0.73	0.71	0.69

For w/c ratio other than 0.5, above values are modified as given below –

± 0.01 in proportion for each ∓ 0.05 in w/c ratio.

*Step 6: Calculate quantity of F.A. and C.A.

Total volume of concrete = $1 m^3$.

(a) Volume of concrete mass = 1 − air content

(b) Volume of Cement = $\frac{W_c}{\text{density}} = \frac{W_c}{S_c \times \rho_w} = \frac{W_c}{S_c \times 1000}$

(c) Volume of Water = $\frac{W_w}{1000}$

(d) Volume of Admixture = $\frac{W_{adm}}{S_{adm} \times 1000}$

(e) Volume of Total aggregate = (a) − (b + c + d)

(f) Weight of Coarse Aggregate = Volume of C.A. × Density

= proportion × (e) × S_{CA} × 1000

* proportion = $\frac{\text{Volume of C.A}}{\text{Volume of T.A.}}$

⇒ Volume of C.A. = proportion × vol. of T.A.

(g) Weight of Fine Aggregate = Volume of F.A × Density

= [1 − proportion] × (e) × S_{FA} × 1000.

Ex. M40, CA = 20 mm, Severe exposure, slump 100 mm, 1% plasticizer, $S_c = 3.15$, $S_{CA/FA} = 2.74$, $S_{adm} = 1.145$, FA of zone I, Air content 1.5%

⇒

Step 1: Target Mean Strength:

$$f_t = f_{ck} + K \cdot S$$

$$= 40 + 1.65 \times 5$$

$$\Rightarrow \boxed{f_t = 48.25\ N/mm^2}$$

Step 2: W/c ratio:

$W/c = 0.4$ .... [from SP23, $f_t = 48.25\ N/mm^2$]

This is less than 0.45 (severe) so it is OK.

$$\Rightarrow \boxed{W/c = 0.4}$$

Step 3: Weight of Water:

$W_w = 186\ kg/m^3$ .... [from Table 2 of IS 10262, CA = 20 mm]

For 100 mm slump,

$$W_w = 186 + 186 \times \frac{6}{100}$$

$$W_w = 197.16\ kg/m^3$$

For use of plasticizer

$$W_w = 197.16 - 197.16 \times \frac{8}{100}$$

$$W_w = 181.37\ kg/m^3$$

This value is maximum limit, so taking

$\Rightarrow \boxed{W_w = 170\ kg/m^3}$ .... [Based on experience]

Step 4: Cement Content:

$$W_c = \frac{W_w}{W/C} = \frac{170}{0.4} = 425\ kg/m^3$$

This is greater than 320 kg/m³ (Severe) so, it is OK.

$$\Rightarrow \boxed{W_c = 425\ kg/m^3}$$

Step 5: Proportion:

Proportion = 0.6 .... [from Table 3 of IS 10262 C.A. = 20mm & zone I]

For W/C = 0.4,

$$\text{proportion} = 0.6 + (2 \times 0.01) = 0.62$$

$\Rightarrow$ **proportion = 0.62**

W/C	proportion
0.50	0.60
− 0.05	+ 0.01
− 0.05	+ 0.01
0.40 →	0.62

Step 6: Quantity of F.A. and C.A.

Total Volume of Concrete = 1 m^3

(a) Volume of concrete mass = 1 − air content

$$= 1 - 1 \times \frac{1.5}{100}$$

$$= 0.985\ m^3$$

(b) Volume of Cement $= \frac{W_c}{S_c \times 1000} = \frac{425}{3.15 \times 1000} = 0.135\ m^3$

(c) Volume of Water $= \frac{W_w}{1000} = \frac{170}{1000} = 0.170\ m^3$.

(d) Volume of Admixture $= \frac{W_{adm}}{S_{adm} \times 1000} = \frac{1\%\ W_c}{S_{adm} \times 1000}$

$$= \frac{1 \times \frac{425}{100}}{1.145 \times 1000}$$

$$= 0.0037\ m^3.$$

(e) Volume of Total Aggregate = (a) − (b + c + d)

$$= 0.985 - (0.135 + 0.170 + 0.0037)$$

$$= 0.6763\ m^3$$

(f) Weight of C.A = W_{CA} = proportion × (e) × S_{CA} × 1000

$= 0.62 \times 0.6763 \times 2.74 \times 1000$

$W_{CA} = 1148.89$ kg

(g) Weight of F.A. = W_{FA} = [1 − proportion] × (e) × S_{FA} × 1000

$= [1 - 0.62] \times 0.6763 \times 2.74 \times 1000$

$W_{FA} = 704.16$ kg.

⇒ Final Result :-

	C	FA	CA	W	Adm.
1 m^3	425	704.16	1148.89	170	4.25
Ratio	1	1.65	2.70	0.4	0.01
Per bag of cement	50	82.5	135	20	0.5

Ex. Calculate Standard deviation for the data given below.

Sample No.	Cube 1	Cube 2	Cube 3	Comp. strength of sample (x_i)	$(\bar{x}-x_i)$	$(\bar{x}-x_i)^2$
1	20.5	24.0	22.5	22.3	−2.1	4.41
2	18.5	22.5	19.0	20.0	0.2	0.04
3	19.5	20.5	21.5	20.5	−0.3	0.09
4	22.0	23.0	21.5	22.2	−2.0	4.0
5	18.5	21.5	21.5	20.5	−0.3	0.09
6	22.5	23.5	23.0	23.0	−2.8	7.84
7	24.0	23.5	21.5	23.0	−2.8	7.84
8	22.0	18.5	19.5	20.0	0.2	0.04
9	16.5	15.5	14.0	15.3	4.9	24.04
10	13.0	15.0	17.0	15.0	5.2	27.04
				$\bar{x} = 20.2$		$\Sigma = 75.4$

Standard deviation,

$$S = \sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{(n-1)}}$$

$$= \sqrt{\frac{75.4}{(10-1)}} = 2.85$$

$\Rightarrow$ $\boxed{S = 2.85}$

* Note:-

Test data of minimum 30 samples is required to calculate standard deviation.

1.3 Reinforcement:

Any material that can take tension may be used as reinforcement. For e.g. steel, copper, aluminium, plastic fibre, bamboo etc. Steel is most preferable because of following reasons –

i) Economical than other metals.

ii) High tensile strength

iii) Coefficient of thermal expansion is comparable to as of concrete.

1.3.1 Size of Reinforcement:

Diameter	Actual Area	Approx Area.
6	20.27	30
8	50.26	50
10	78.54	75
12	113.09	110
16	201.06	200
20	314.15	314
25	490.87	490 or 500
28	615.75	600
32	804.24	800
36	1017.87	1000
40	1256.63	1250
45	1590.43	1600
50	1963.49	2000

Ex. Provide 20mm and 12mm dia. bars for steel area $1285 mm^2$

⇒ $A_{st} = 1285 mm^2$

① $4-20\phi + 1-12\phi$

② $3-20\phi + 4-12\phi$

Ex. What will be the dia of bars if 3 bars are allowed for $A_{st} = 1450 mm^2$

⇒ $\text{Area of 1-bar} = \frac{1450}{3} = 483.33 mm^2$

① $3-25\phi$

② $2-28\phi + 1-20\phi$

1.3.2 Grade of Steel:

Yield Stress ↓

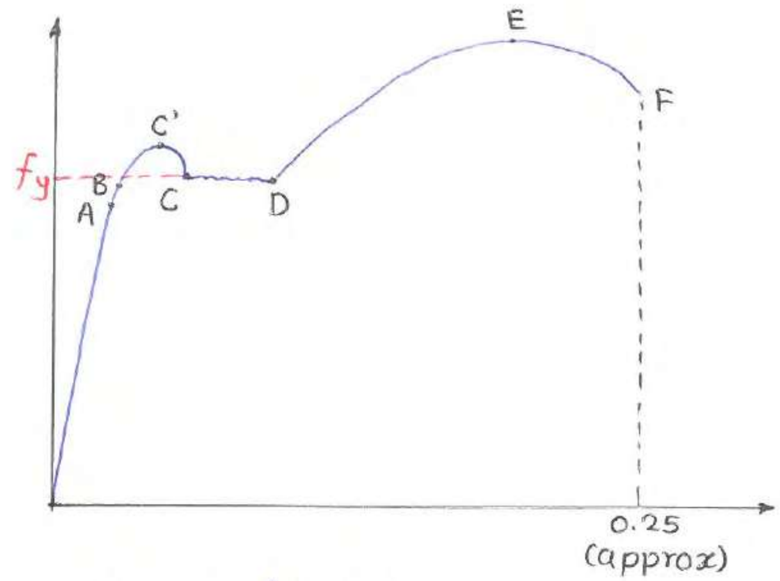
Fe 250 → Mild Steel

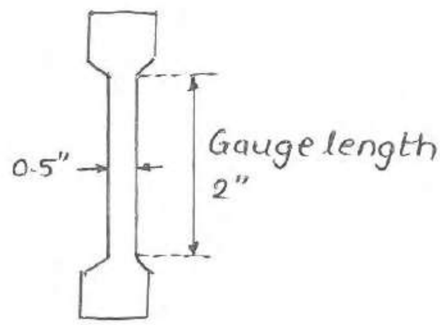
Fe 415 }
Fe 500 } HYSD

Recent Development {
Fe 500D → Ductility.
Fe 550
Fe 600

1.3.3 Types of Steel:

1. Mild Steel.





OA → Linear

A → Proportional Limit

AB → Non-linear

B → Elastic Limit

C' → Upper Yield Point

C → Lower Yield Point (Yield Stress)

CD → Yield Plateau

DE → Strain Hardening

E → Ultimate Point

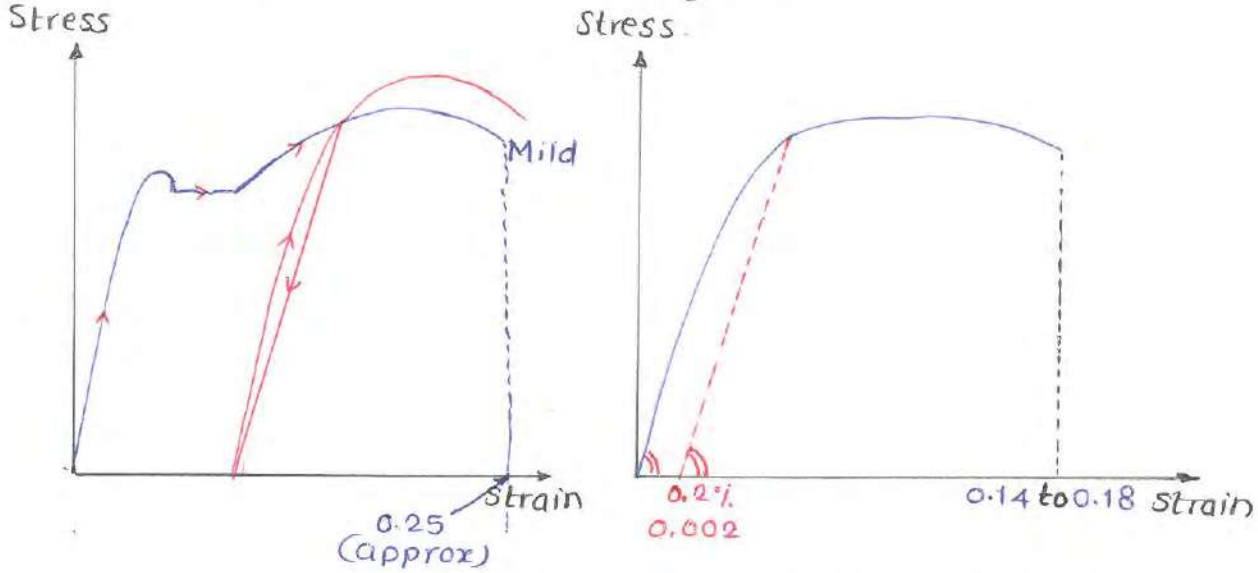
F → Fracture Point

2. HYSD/CTD/TOR

HYSD → High Yield Strength Deformed

CTD → Cold Twisted Deformed.

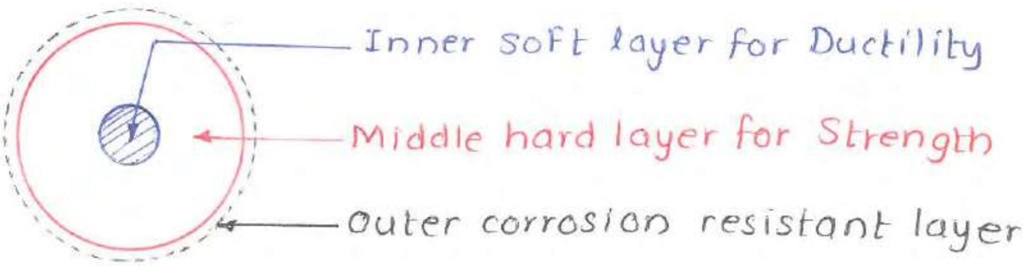
TOR → (Name of Company)



- It is obtained by straining mild steel beyond yield plateau by stretching and twisting at particular temperature and after that unloading is done. Above process of straining eliminates yield plateau from stress-strain diagram.
- HYSD steel is less ductile than mild steel
- In absence of definite yield point, 0.2% proof stress is considered as yield stress.

3. Thermo Mechanically Treated Bars (TMT)

- These bars are made by applying thermal and mechanical process simultaneously on steel.
- This combination process makes the steel relatively more corrosion resistant.
- TMT bars are relatively more ductile than HYSD
- TMT bars have all relevent features of HYSD.



TMT Bar

* Note:

- As carbon % increases, strength increases and ductility decreases.

.........Chapter1 Ends Here