RCC DESIGNS

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1 CHAPTER — INTRODUCTION

Basic Code for Design:

IS 456: 2000 - Plain and reinforced concrete - code of practice (IVth revision)

IS 875 (Part I - 5): 1987 : Code of practice for design loads (other than earthquake) for buildings and structures (2nd revision)

Part 1 : Dead loads

Part 2 : Imposed (lives) loads

Part 3 : Wind loads

Part 4 : Snow loads

Part 5 : Special loads and load combinations

IS 1893 : 2002 - Criteria for earthquake resistant design of structures (4th revision)

SP 16 : 1980 - Design aids(for reinforced concrete) to IS 456 : 1978

SP 34 : 1987 - Handbook on concrete reinforcement and detailing

SP 23 : 1982 - Design of concrete mixes

IS 13920 : 1993 - Ductile detailing of reinforced concrete structures subjected to seismic forces.

R.C.C. Structuree

- **1. Concrete**
- **2. Steel**

1. **Concrete :**
   - Mixture of cement, sand (fine aggregate), coarse aggregate and water.

   Main characteristics of concrete:
   - Durability under hostile environment.
   - Can be mound into variety of shapes
   - Relative economy and easy availability
   - Compression bearing capacity
   - Shows versatility
2. **Cement:** Various types of cement and tests on cements are dealt in detail in "**Building materials**"
   - **Aggregate :** Fine aggregate <4.75 mm. ; e.g. sand
     Coarse aggregate > 4.75 mm. ; e.g - Gravel and crushed rock
   - Generally, a maximum nominal size of 20mm is found to be satisfactory in RC structure elements.

Properties of Aggregates and Tests:

(i) **Particle size, shape and surface texture:** It influences the strength of concrete. Aggregate may be angular or round etc.

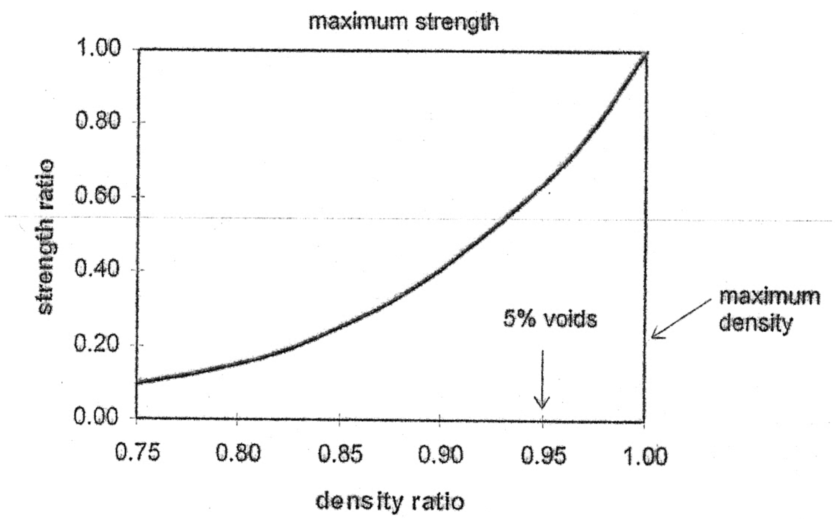
(ii) **Geological classification:** It is based on the mineral type of portent rock.

(iii) Specific gravity and bulk density

(iv) Moisture content, bulking of sand
(v) **Strength :-** Measured by Aggregate crushing value
(vi) **Toughness :** Resistance to impact measured by aggregate impact value
(vii) **Soundness :** It indicates about the volume changes due to alternate thermal change, wetting and drying, freezing and thawing etc.

Grading Requirement of Aggregates:

- Grading is the particle size distribution of aggregate and it is measured by sieve analysis and is generally described by means of a grading curve.
- The grading of aggregate is a major factor which influences the workability of fresh concrete and degree of compaction.



- **Water :** Potable water is suitable for concreting. Sea water is not recommended for concreting purpose.

S. No.	Type of solid	Permissible limit (maximum)
(i)	Organic	200 gm/1
(ii)	Inorganic	300 gm/1
(iii)	Sulphates (as SO_3)	400 mg/1
(iv)	Chlorides (as Cl)	2000 mg/l for concrete not containing embedded steel and 500 mg/l for reinforced concrete work
(v)	Suspended matter	20001

Note: Details about the water requirement is explained into "Building materials" Topic

Properties of Concrete

1. Durability of concrete:

It is the property by which concrete possesses same strength throughout its life time without much shrinkage and cracking.

Durability of concrete depends on:

(i) Permeability of concrete
(ii) Exposure conditions of concrete

(i) Permeability of Concrete:

- Chemical attack is caused by the ingress of water, oxygen, carbon dioxide, Chlorides, Sulphates etc. due to permeability of concrete. So impermeability of concrete is an important factor for durability of concrete
- **Permeability can be reduced by:**
  (a) Using low water-cement ratio
  (b) Providing high grade of concrete
  (c) Proper workmanship
  (d) Using well graded, dense aggregate, adequate cement ratio etc.

(ii) <u>Exposure conditions of concrete:</u>

Table: Exposure conditions and requirements for RC work with normal aggregate (20 mm nominal size)

Exposure e Category	Description	Min. grade	Min. cover (mm)	Min. Cement (kg/m^3)	Max. free w/e ratio
Mild	Protected against weather or aggressive conditions, except if located in coastal area	M 20	20*	300	0.55
Moderate	Sheltered from severe rain or freezing whilst wet, or Exposed to condensation and rain, or Continuously under water, or In contact with or buried under non-aggressive soil or ground water, or Sheltered from saturated 'salt air' in coastal area	M 25	30	300	0.50
Severe	Exposed to severe rain, alternate wetting and drying or occasional freezing whilst wet or severe condensation, or Completely immersed in sea water, or Exposed to coastal environment	M 30	45**	320	0.45
Very Severe	Exposed to sea water spray, corrosive fumes or severe freezing whilst wet, or In contact with or buried under aggressive sub-soil or ground water	M 35	50	340	0.45
Extreme	Members in tidal zone, or Members in direct contact with liquid/solid aggressive chemicals	M 40	75	360	0.40

2. Compressive Strength of Concrete:

- Compressive strength of concrete is measured by standard tests on concrete cube or cylinder specimen.
- The grade of concrete is designated in terms of M10, M15, M20, M25, etc., where 'M' denotes 'mix' and 10, 15, 20, 25 etc. denotes the characteristic compressive strength **OR** characteristic strength of the mix at 28 days expressed in N/mm^2.
- **Characteristic strength** is defined as the strength of material below which not more than 5% of the test results are expected to fall.

e.g., let the characteristic compressive strength of concrete be M 20. This means, if we perform 100 tests on cube specimen, then 95 cubes or more will show their compressive strength more than 20 MPa.

It is denoted by 'f_{ck}'

Mean compressive strength (f_{cm})at 28 days:

$$f_{cm} = f_{ck} + 1.65\sigma$$

Where, σ = standard deviation

- When the 'standard test cubes' of 150mm size is used to find the 28 days compressive strength of concrete, it is referred as **cube strength (f_c)** of concrete. While in some countries (such as USA),'standard test cylinders' of 150mm diameter and 300mm high are used to find the compressive strength of concrete, and it is referred as **cylinder strength (f'_c)** the cylinder strength is found to be invariably lower than the cube strength for the same grade of concrete.
- **<u>Influence of size of Test Specimen</u>:**

Compressive strength of concrete depends on height/width ratio and cross-sectional dimensions of the test specimen.

- A standard cylinder specimen size is: of 150mm in diameter and height/diameter =2.0

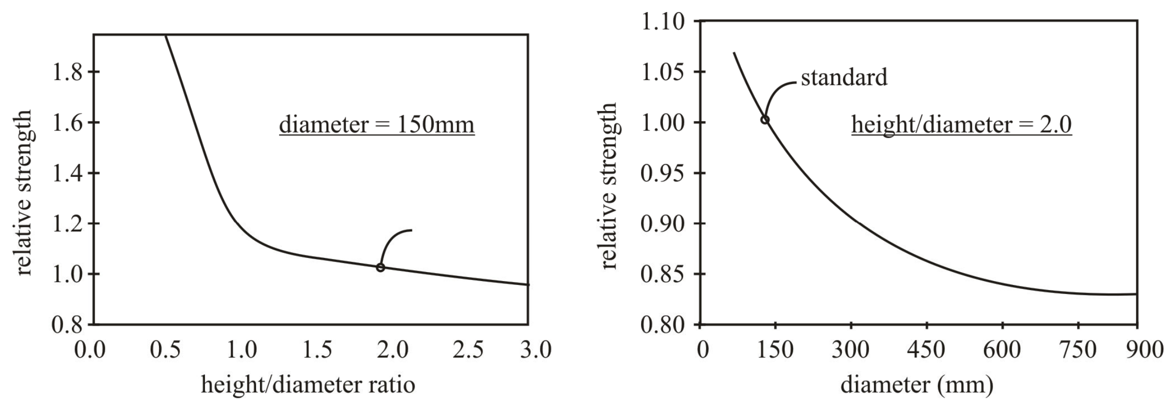
It height/diameter = 0.5, strength increases by 80% with diameter =150mm

Similarly, if height/diameter =2.0, with diameter=900mm, strength decreases by 17%

- End friction restrains the specimen from failure. In case of cube specimen, the end friction acts on the whole length, but in the case of cylinder, end friction acts only upto height of 0.85 times diameter of cylinder, so its compressive strength is lower

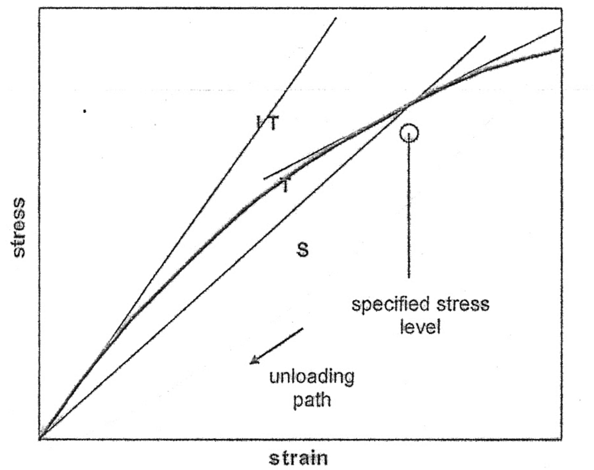
Cube (f_c) strength ≈ 1.25 × cylinder strength (f_c')

Where, $f_c' = 0.8 f_{ck}$; where f_{ck} is characteristic cube strength.



(a) (b)

3. Modules of Elasticity and Poisson's ratio :



- Initial tangent modulus, $\boxed{E_c = 5000\sqrt{f_{ck}}}$ (According to IS:456-2000)

OR (Short or term static modulus of elasticity)

However, earlier version of IS 456 had recommended $E_c = 5700\sqrt{f_{ck}}$, which is found to over-estimate the elastic modulus.

- Poisson's ratio varies between 0.1-0.2 ; for design purpose a value of about 0.2 is taken.

4. Modulus of rupture or flexural strength (f_{cr}):

$$\text{Modulus of rupture } \left(f_{cr}\right) = \frac{M}{Z}$$

where, M = bending moment

Z = section modulus

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

5. Splitting Tensile Strength :

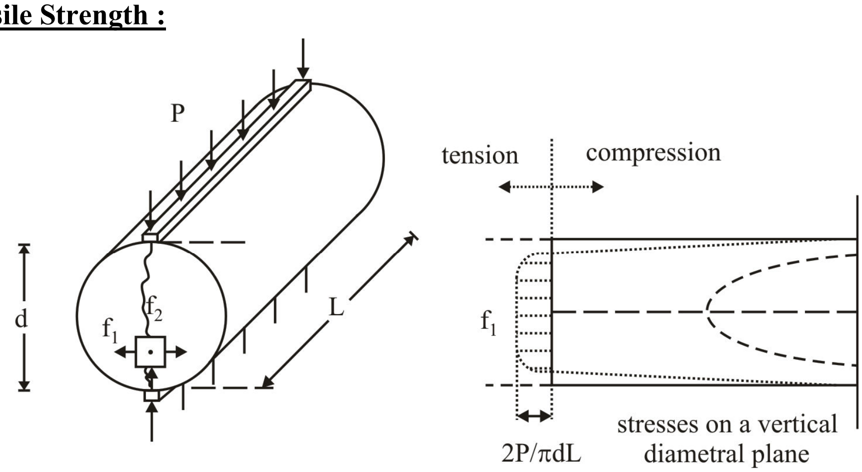


Figure: Cylinder splitting test for tensile strength

- Cylinder splitting test is performed to find splitting tensile strength of concrete In this test, a standard plain concrete cylinder (of 150mm diameter and 300mm height) is loaded in compression on its side along a diametral plane and failure occurs by the splitting of the cylinder along the loaded plane.

$\therefore$ Splitting tensile strength $\boxed{f_{ct} = \dfrac{2P}{\pi dL}}$

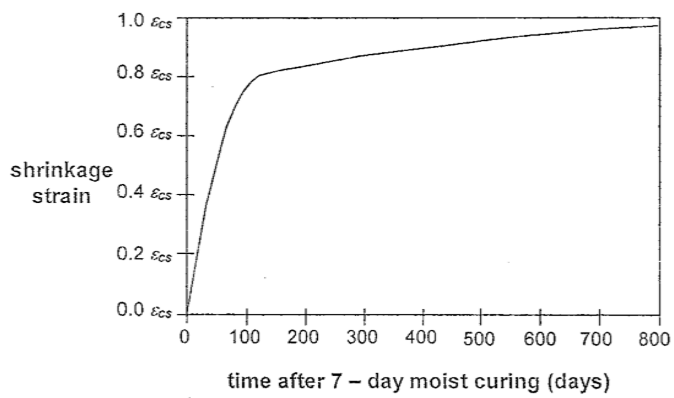
Where P = Maximum applied load d = Diameter L = Length

Generally, $f_{ct} \approx 0.6 f_{cr}$

6. Shrinkage:

- Shrinkage is the time dependent deformation, generally compressive in nature
- The factors on which the total shrinkage of concrete depends are:-
  (*i*) Constituents of concrete
  (*ii*) Size of member
  (*iii*) Environmental condition
- The total shrinkage, however, is mostly influenced by the total amount of water present in the concrete at the time of mixing for a given humidity and temperature.

The approximate value of total shrinkage strain for design is taken as 0.0003 in the absence of test data.



7. Creep:

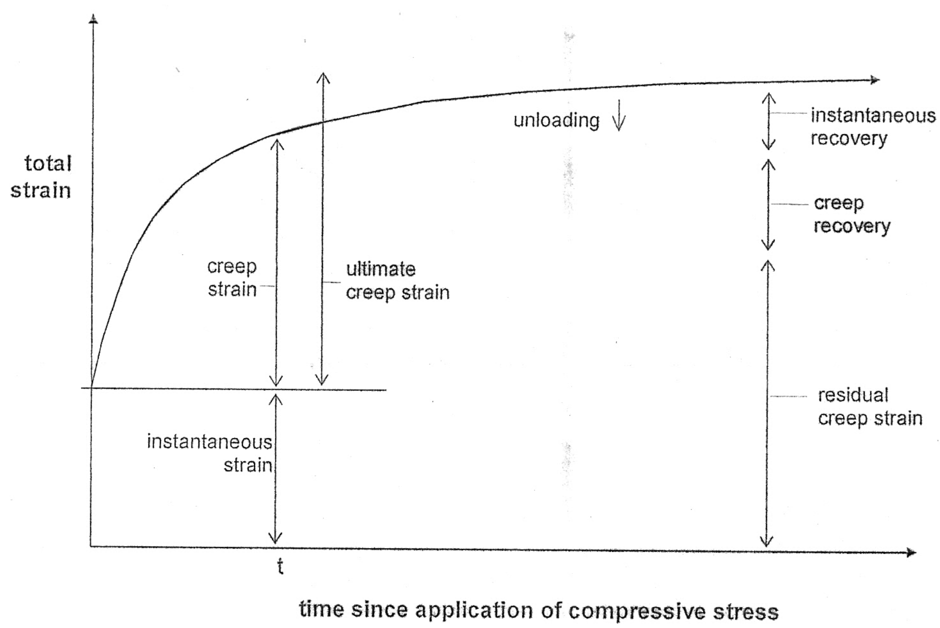


Figure: Typical strain-time curve for concrete in uniaxial compression

It is also a time dependent deformation of concrete usually under compressive stress. Factors affecting creep of concrete is:

- Properties of concrete
- W/C ratio
- Age of concrete at first loading
- Magnitude of stress and its duration
- Surface volume ratio of member

Creep of concrete results in following detrimental results in reinforced concrete structure:

(i) Increased deflection of beams and slabs
(ii) Increased deflection of slender columns
(iii) Loss of prestress in pre-stressed concrete

$$\text{Creep coeficient} = \theta = \frac{\varepsilon_{cr}}{\varepsilon_c}$$

Where, ε_{cr} =short term strain at the age of loading at a stress value of 'f_c'.

ε_{cr} =Ultimate creep strain

Age of loading	Creep coefficient (θ)
7 Days	2.2
28 Days	1.6
1 year	1.1

Also, total strain, $\varepsilon = \varepsilon_{cr} + \varepsilon_c$

- **Effective Modulus of concrete (E_{ce}):**

  Long term modulus of elasticity (E_{ce}),

  $E_{ce} = \frac{E_c}{1+\theta}$ Where, E_c = Short term elastic Modulus

Coefficient of thermal expansion:

The co-efficient of thermal expansion depends on nature of cement, aggregate, the relative humidity and the size of section.

Table: Values of coefficient of thermal expansion for concrete

Type of aggregate	Coefficient of thermal expansion for concrete/ºC
1. Quartzite	$1.2 \text{ to } 1.3 \times 10^{-5}$
2. Sandstone	$0.9 \text{ to } 1.2 \times 10^{-5}$
3. Granite	$0.7 \text{ to } 0.95 \times 10^{-5}$
4. Basalt	$0.8 \text{ to } 0.95 \times 10^{-5}$

5. Limestone	0.6 to 0.9 × 10^{-5}

Stress-strain curve for concrete:

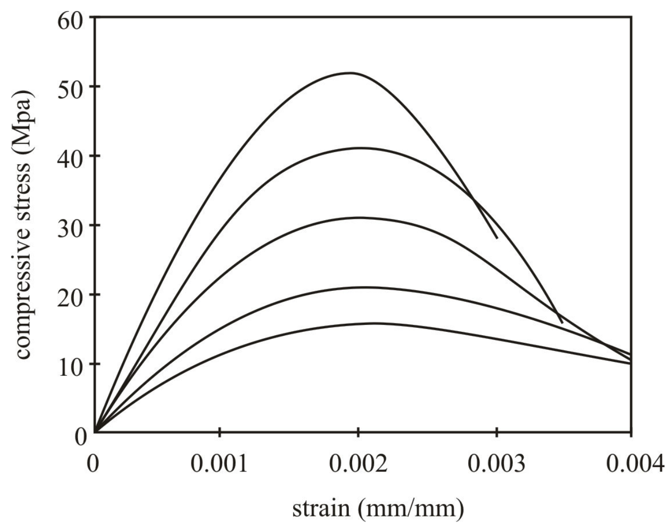


Figure: Typical stress-strain curves of concrete in compression

The curves are approximately linear in the very initial phase of loading and the non-linearity begins to gain significant when the stress level exceeds about one-third to one-half of the maximum

The maximum stress is reached at a strain approximately equal to 0.002 and beyond this point, an increase in strain is accompanied by a decrease in stress.

The higher the concrete grade, the steeper is the initial portion of stress-strain curve, the sharper the peak of the curve and a lesser the failure strain.
For low-strength grade, the curve has a relatively flat top and a high failure strain.

At a stress- level about 70-90% of the maximum stress internal cracks are initiated in the mortar throughout the concrete mass, roughly parallel to the direction the applied loading.

Types of Modulus:
1. Initial tangent modulus: Slope of stress strain curve at origin.
- This value is considered by IS 456

2. Tangent Modulus: Slope of tangent of any point on the curve.
3. Secant Modulus : Slope of line joining any point on curve to origin.

Permissible stresses in concrete
As per IS: 456-2000
1. Direct tensile stress:

Table : Permissible Direct Tensile Stress

Grade of concrete	M 10	M 15	M 20	M 25	M 30	M 35	M 40
Tensile stress N/mm^2	1.2	2.0	2.8	3.2	3.6	4.0	4.4

2. Compressive stress and bond stress:

Table: Permissible Stresses in Concrete (IS : 456-2000)

Grade of concrete	Permissible stress in compression (N/mm^2)		Permissible stress in Bond (Average) for plain bars in tention (N/mm^2) τ_{bd}
	Bending (σ_{cbc})	Direct (σ_{cc})	
M 10	3.0	2.5	_
M 15	5.0	4.0	0.6
M 20	7.0	5.0	0.8
M 25	8.5	6.0	0.9
M 30	10.0	8.0	1.0
M 35	11.5	9.0	1.1
M 40	13.0	10.0	1.2
M 45	14.5	11.0	1.3
M 50	16.0	12.0	1.4

3. Shear stress:

Table: Permissible Shear Stress In concrete (IS : 456-2000)

$\frac{100A_s}{bd}$	Permissible shear stress in concrete τ_c, N/mm^2 for grades of concrete					
	M 15	**M 20**	**M 25**	**M 30**	**M 35**	**M 40 and above**
≤ 0.15	0.18	0.18	0.19	0.20	0.20	0.20
0.25	0.22	0.22	0.23	0.23	0.23	0.23
0.50	0.29	0.30	0.31	0.31	0.31	0.32
0.75	0.34	0.35	0.36	0.37	0.37	0.38
1.00	0.37	0.39	0.40	0.41	0.42	0.42
1.25	0.40	0.42	0.44	0.45	0.45	0.46
1.50	0.42	0.45	0.46	0.48	0.49	0.49
1.75	0.44	0.47	0.49	0.50	0.52	0.52
2.00	0.44	0.49	0.51	0.53	0.54	0.55
2.25	0.44	0.51	0.53	0.55	0.56	0.57
2.50	0.44	0.51	0.55	0.57	0.58	0.60
2.75	0.44	0.51	0.56	0.58	0.60	0.62
3.00 and above	0.44	0.51	0.57	0.60	0.62	0.63

4. Modular ratio:

Modular ratio, $\boxed{m = \frac{280}{3\sigma_{cbc}}}$ (value considered by IS code)

Where, σ_{cbc} = Permissible compressive stress due to bending in concrete (N/mm^2)

Note: This value partially takes into account long term effect such as creep.

- This is the ratio of young modulus of steel and modulus of elasticity of concrete.

Table : Modular Ratio

Grade of concrete	M 10	M 15	M 20	M 25	M 30	M 35	M 40
Modular ration m	31 (31.11)	19 (18.67)	13 (13.33)	11 (10.98)	9 (9.33)	8 (8.11)	7 (7.18)

5. Increase of permissible stress:

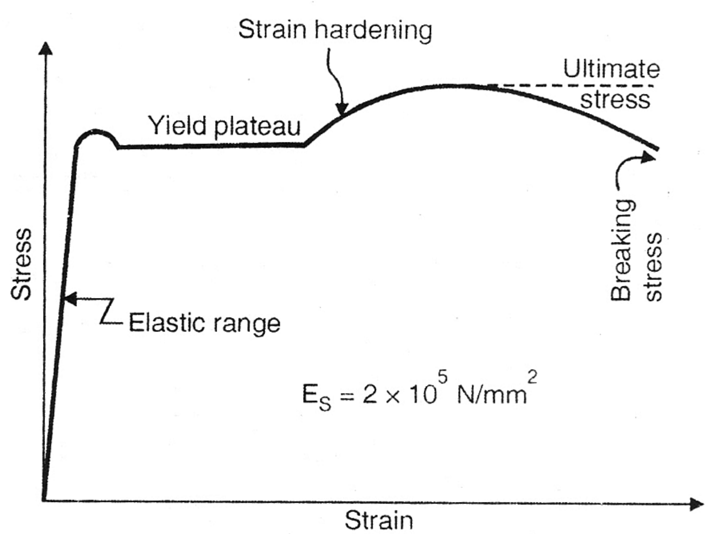
- Due to wind (or earthquake) and temperature effects, the above stresses (Direct tensile stress compressive stress, bond stress, and shear stress are increased by $33\frac{1}{3}\%$)
- Wind and seismic forces are not considered to act simultaneously

2. Steel

Steel reinforcement used in reinforced concrete are:

(i) Mild steel bar
(ii) Hot rolled mild steel deformed bar
(iii) Medium tensile steel
(iv) Hot rolled medium tensile steel
(v) Hot rolled high yield strength deformed bar (HYSD)
(vi) Cold worked steel high strength deformed bar or Tor steel (F_e 415 and F_e 500)

Stress-strain Curve for Mild Steel:



- Modulus of elasticity of steels as mentioned above is taken as $E = 2\times10^5 N/mm^2$.
- Fe 250 $\rightarrow$ yield stress = 250 N/mm^2
  Fe 415 = Yield stress = 415 N/mm^2 is equal to 0.2% proof stress or
  Tor 40
  Fe 500 $\rightarrow$ Yield stress =500 N/mm^2 is equal to 0.2% proof stress

OR
Tor 50

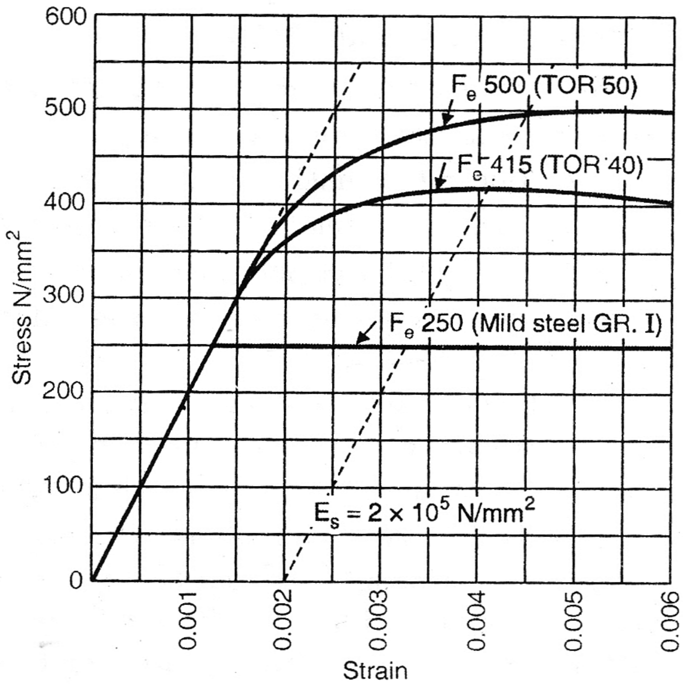


Figure: Stress Strain Curve for CTD Bars

Note-1 For HYSD (Fe 500), the permissible stress in direct tension and flexural tension shall be 0.55 f_y. The permissible stresses for shear and compression reinforcement shall be same as for grade F_e 415

	M.S. bars Grade I	**Medium tensile steel bars**	**Medium tensile steel bars**	**Medium steel deformed bars**	**HYSD and CTD bars**
Dia < 10 mm	20	17	23	20	14.5
Dia ≥ 10 mm	23	20	23	20	14.5

Characteristic strength of steel reinforcement (*fy*):

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

Type of reinforcement	**Yield stress or 0.2% proof stress (N/mm²)**	**Characteristic strength f_y (N/mm^2)**	**Permisible tensile strength σ_{st}**
1. Mild steel bars conforming to Grade I of IS : 432 (Part I) or deformed m.s. bars of I.S. 1139	250 (average)	250	140 (upto 20 mm dia.) 130 (over 20 mm dia.)
2. High yield strength deformed bars conforming to IS : 1109 or Grade Fe 415 of IS : 1786—1979	415	415	230
3. High yield strength deformed	500	500	275

bars of Grade Fe 500 of IS 1786—1979			

DESIGN CONCEPTS

METHODS OF DESIGN:

1. **Working Stress Method (WSM):**
   - In this method, structural materials are assumed to behave in a linear elastic manner.
   - The stresses in the members are considered for normal working load condition and the specified permissible (allowable) stresses are kept well below the material strength (i.e. in the initial phase of stress-strain curve)
   - Factor of safety (F.O.S.) $= \dfrac{\text{Yield stress of steel OR Cube strength of concrete}}{\text{Permissible OR working stress}}$
   - The stresses under the applied loads are analyzed by applying the methods of simple bending theory. In order to apply such methods to a composite material like reinforced concrete, strain compatibility is assumed, where by the strain in the reinforcing steel is assumed to be equal to that in the adjoining concrete.
2. **Ultimate load method (ULM): or Load Factor method:**
   - In this method, the stress condition at the state of impending collapse of the structure is analysed and the non linear stress-strain curve of concrete and steel are made use of.
   - The safety measure in the design is introduced by use of load factor which is defined as the ratio of the ultimate load (Design load) to the working load.

   $$\therefore \quad Load\ \ Factor = \frac{Ultimate\ Load}{Working\ Load}$$

   - This method generally results in more slender section and gives rise to excessive deformations and cracking.
3. **Limit state method (LSM):**
   - Unlike WSM, which is based on calculations on service load condition alone, and ULM, which is based on calculations on ultimate load condition alone, LSM takes into account not only the ultimate strength of the structure but also the serviceability and durability requirement
   - In LSM, a multiple safety factor format is used which attempts to provide adequate safety at ultimate loads as well as adequate serviceability at service load by considering all possible **'Limit states'.**
   - **Limit states:** It is a state of impending failure, beyond which a structure ceases to perform its intended function satisfactorily in terms of either safety or serviceability
   - There are two types of limit states:

(i) Limit state of collapse:

(a) Limit state of collapse in flexure

(b) Limit state of collapse in compression

(c) Limit state of collapse in shear

(d) Limit state of collapse in torsion

(ii) Limit state of serviceability:

(i) Excessive deflection
(ii) Excessive vibration
(iii) Loss of durability
(iv) Excessive cracking

As per IS 456: 2000 , design values for the limit state design:

Design strength of material, $$F_d = \frac{f}{\gamma_m}$$

Where, f = Characteristic strength of the material (f_{ck} for concrete or f_y for steel)
γ_m= Partial safety factor.

for concrete, $\gamma_m = 1.5$, $\therefore$ $$F_d = \frac{f_{ck}}{1.5} = 0.67 f_{ck}$$

for steel, $\gamma_m = 1.15$, $$F_d = \frac{f_y}{1.15} = 0.87 f_{ck}$$

Imposed load:

- **Characteristic load:** The value of load which has a 95% probability of not being exceeded during the life of the structure.
- **Design load : (F_d):**

$$F_d = F.\gamma_f$$

Where, F = Characteristic load
γ_f = Partial safety factor

Table: Partial Safety Factor γ_f for Loads

	Limit state of collapse			Limit state of serviceability		
	DL	LL	WL	DL	LL	WL
1	2	3	4	5	6	7
DL+LL	1.5	1.5	—	1.0	1.0	—
DL + WL	1.5 or 0.9*	—	1.5	1.0	—	1.0
DL + LL + WL	1.2	1.2	1.2	1.0	0.8	0.8

DL = Dead load, LL→ live load, WL→ wind load, EL→ Earthquake load
While considering earthquake effects, substitute EL for WL

Note: Earthquake load and wind load are not taken together as the probability of occurrence of both at the same time is very low.

Key Points

1. Durability of concrete depends on
(*i*) Permeability of concrete
(*ii*) Exposure conditions of concrete

2. Characteristic strength is defined as the strength of material below which not more than 5% of the test results are expected to fall.

3. Mean compressive strength (f_{cm}) at 28 days.

$$f_{cm} = f_{ck} + 1.65\,\sigma$$

where, $\sigma =$ Standard deviation

4. Cube strength $\approx$ 1.25 × cylinder strength

5. Short term static modulus of elasticity of concrete, $E_c = 5000\sqrt{f_{ck}}$

6. Modulus of rupture, $f_{cr} = 0.7\sqrt{f_{ck}}$

7. Splitting tensile strength, $f_{ct} = \dfrac{2P}{\pi d L}$

8. Long term elastic modulus, $E_{C_c} = \dfrac{E_c}{1+\theta}$

Where, $\theta =$ Creep coefficient

9. Modular ratio, $M = \dfrac{280}{3\,\sigma_{cbc}}$

Where, $\sigma_{cbc} =$ Permissible compressive strength due to bending in concrete.

10. Due to wind (or earthquake) and temperature effects the permissible stresses (*i.e.,* direct tensile stress, compressive stress, bond stress and shear stress) are increased by $33\frac{1}{3}\%$.

11. In limit state design, partial factor of safety for steel and concrete are taken as 1.15 and 1.5 respectively.

12. Load factor = $\dfrac{\text{Ultimate Load}}{\text{Working Load}}$

PROBLEM SET WITH SOLUTIONS

1. In relation to working stress method, the assumption of linear elastic behavior and stresses under working loads can be kept within the permissible stresses are not found to be realistic because of
(*i*) long term effects of creep (*ii*) long term effects of shrinkage
(*iii*) effect of stress concentration
Which of the above reason(s) is (are) correct ?
(*a*) All of these (*b*) (*i*) and (*ii*)
(*c*) (*i*) only (*d*) (*iii*) only

2. Examine the following statements:
(*i*) Factor of safety for steel should be based on its yield stress.
(*ii*) Factor of safety for steel should be based on its ultimate stress
(*iii*) Factor of safety for concrete should be based on its yield stress
(*iv*) Factor of safety for concrete should be based on its ultimate stress.
The correct statements are:
(*a*) (*i*) and (*iii*) (*b*) (*i*) and (*iv*)
(*c*) (*ii*) and (*iii*) (*d*) (*ii*) and (*iv*)

3. Stress strain curve of high tensile steel
(*a*) has a definite yield point
(*b*) does not show definite yield point but yield point is defined by 0.1% proof stress.
(*c*) does not show definite yield point but yield point but yield point is defined by 0.2% proof stress.
(*d*) does not show definite yield point but yield point is defined by 2% proof strength

4. For reinforced concrete exposed to sulphate attack minimum grade required is
(*a*) M 10 (*b*) M 15 (*c*) M 20 (*d*) M 25

5. The stress-stain curve of the concrete as per IS : 456 is
(*a*) a perfect straight line upto failure
(*b*) straight light upto 0.002 strain value and then parabolic upto failure
(*c*) parabolic upto 0.002 strain value than uniform upto failure
(*d*) linear upto 0.002 strain value of unifom upto failure.

6. The relation between modulus of rupture for, splitting strength for and direct tensile strength f_{ct} is given by
(*a*) $f_{cr} = f_{cs} = f_{ct}$ (*b*) $f_{cr} > f_{cs} > f_{ct}$
(*c*) $f_{cr} < f_{cs} < f_{ct}$ (*d*) $f_{cs} > f_{cr} > f_{ct}$

7. The compressive strength of 100 mm cube as compared to 150 mm cube is always
(*a*) less (*b*) more
(*c*) equal (*d*) none of the above

8. Ratio of compressive strength to tensile strength of concrete
(*a*) increases with age (*b*) remains constant
(*c*) decreases with age (*d*) none of the above

ANSWERS

1. **(*a*)** All of them
2. **(*b*)** A beam collapse when stress is equal to its yield strength and stress in concrete reaches its ultimate strength.
3. **(*c*)** **4. (*c*)** **5. (*c*)**

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