MPSC 2019

Maharashtra Public Service Commission

Assistant Engineer Examination

Civil Engineering

RCC & Pre-stressed Concrete

Well Illustrated **Theory** *with*
Solved Examples and **Practice Questions**

MADE EASY Publications

RCC & Pre-stressed Concrete

Contents

CHAPTER 01

Basic Design Concepts

1.1 Introduction

Concrete is one of the most common building material used for constructive civil engineering structures and is essential in the infrastructure development of any nation. Concrete is used in the construction of various types of structures which include buildings, bridges, piers, chimneys, pavements, dams, hydraulic structures, conveying pipes, liquid retaining tanks/structures, assembly halls, auditorium, swimming pools, bunkers etc. and the list goes on.

1.2 Types of Concrete

1.2.1 Plain Concrete

Concrete can be defined as a mass which is made from any cementing material and consists of sand, gravel and water. Mixing of such naturally occurring materials along with a cementing material result in a partial solid mass that can be molded in any shape and form, when wet, and which becomes hard on drying. Concrete is being used as a building material probably from the last 150 years.

Concrete is a highly successful building material and has gained wide popularity because of the following reasons:

1. Concrete is highly durable even under hostile environmental conditions.
2. It can be easily casted into any shape and size.
3. It is relatively cheaper and widely available.

The most important property of concrete is its compression resisting ability i.e. compressive strength, which supersedes any other building material. At present we have concrete grades ranging from 5 MPa to 100 MPa.

The major drawback of concrete is that it cannot resist significant tension. The tensile strength of concrete is about 10% of its compressive strength. Thus, the use of plain concrete as a building material is limited to places where tensile stresses/strains never develop. For example pedestals, mass concreting in dams etc.

1.2.2 Reinforced Concrete

Concrete has gained so much importance and popularity because of the development of **reinforced concrete**. Introducing the reinforcing bars in concrete makes the concrete an excellent composite building material which can resist significant amount of tensile stresses/strains also. Construction of load bearing building elements like beams, slabs etc. is made possible due to the reinforced concrete only. Steel bars embedded in the tension zone of concrete make it able to take tension.

In reinforced concrete, strain compatibility is assumed to exist i.e. there exists a perfect bond between the concrete and steel bars so that strain in concrete is equal to the strain in steel at the interface of concrete and steel.

Moreover, since the failure of concrete is brittle in nature which takes place without giving any warning, introduction of steel in concrete makes it a ductile material which gives sufficient warning before collapse.

Now tensile stresses occur either directly (e.g. direct tension, flexural tension) or indirectly (e.g. shear which causes tension along the diagonal planes). Temperature and shrinkage effects may also induce tensile stresses. At all such locations, steel is invariably provided which is in fact inevitable, that passes across the tensile cracks. Insufficient steel causes propagation of cracks which can lead to complete failure.

Embedding reinforcing bars in compression zone of concrete increases the compressive strength of member (e.g. In columns, doubly reinforced beams etc.).

1.2.3 Prestressed Concrete

Development of prestressed concrete took place along with the reinforced concrete. It is a high strength concrete with high tensile wires embedded in concrete and tensioned before the application of actual working load. While doing so, the concrete can be compressed to such an extent that when the structure is actually loaded, there is almost no tension developed in the beam section. Prestressed concrete is frequently used where, even a hair line crack is not admissible like, high pressure vessels, pipes, water tanks etc. and at locations which are subjected to fatigue loading like long span bridges or rail sleepers etc.

1.3 Importance of Design Codes in the Design of Structures

Different countries have formulated their own codes for laying down the guidelines for the design and construction of structures. These codes came into picture after a collaborative effort of highly experienced structural engineers, construction engineers, academicians and other eminent fellows of respective areas. These codes are revised periodically based on current research and trends (e.g. IS 456: 1978 and IS 456: 2000). Codes serve the following objectives/purposes:

1. They ensure structural stability/safety by specifying certain minimum design requirements.
2. They make the task of a designer rather simple by making available results in the form of tables and charts.
3. They ensure a consistency in procedures adopted by the various designers in the country.
4. They protect the designer against structural failures that are caused by improper site construction practices i.e. codes have legal sanctity and one can have a stand on the basis of these design codes.

Basic Indian Standard Codes for Structural Design

Some of the basic Indian Standard codes for reinforced concrete published by the BIS (Bureau of Indian Standards) are:

1. IS 456 : 2000 Plain and reinforced concrete-Code of practice.
2. IS 875 : 1987 (Part-I to V) Code of practice for design loads.
3. IS 1893 : 2002 Criteria for earthquake resistant design of structures.
4. IS 13920 : 1993 Ductile detailing of reinforced concrete structures subjected to seismic forces.
5. IS 1343 : 2012 Pre stressed concrete design
6. IS 3370 : 2009 Liquid retaining structure
7. IS 10262 Concrete mix design
8. IS 1642 Fire protection

1.4 Hardened Concrete

After final setting time (10 hr) from mixing concrete is assumed to be hard, from final setting time concrete starts gaining strength up to very long time (1 to 5 years).

1.4.1. Compressive Strength

(a) Compressive strength of cube: It is the compressive strength of cube of size 150 mm, subjected to uniaxial compression after 28 days from day of casting.

(b) Characteristics compressive strength of cube: It is the strength below which not more than 5% of the test results are expected to fail.

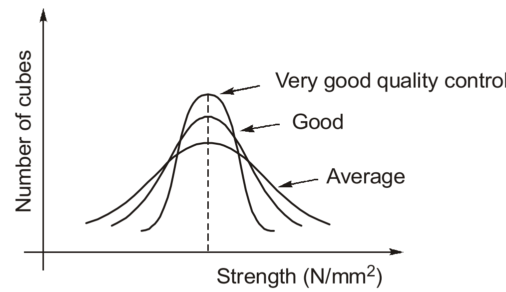


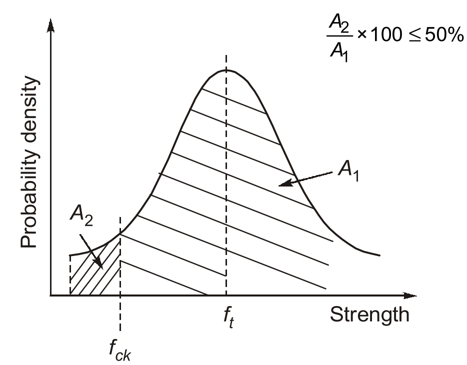
Fig. *Influence of quality control on the frequency distribution of concrete strength*

NOTE: Experimentally, it is found that probability distribution of concrete strength (for a particular concrete mix as found out by compressive strength tests in laboratory on a large number of specimens follow normal/ Gaussian distribution.

$f_t = f_{ck} + ks$

k = 1.65 (for 5% of definition)

s = Standard deviation that depends on grade of concrete



As per IS : 456-2000, clause 9.2.4.2 Assumed standard deviation	
Grade of Concrete	**Assumed Standard Deviation (N/mm^2)**
M10, M15	3.5
M20, M25	4.0
M30, M35, M40, M45, M50	5.0

f_t = Target mean strength

for 0% of definition; $k = \infty$

for 50% of definition; $k = 0$

Example-1.1 If the characteristics strength of concrete f_{ck} is defined as the strength below which not more than 50% of the test result are expected to fail, the expression for f_{ck} in terms of mean strength f_t and the standard deviation 's' would be

(a) $f_t - 0.1645s$
(b) $f_t - 1.645s$
(c) f_t
(d) $f_t + 1.645s$

Solution: (c)

We know that, $f_t = f_{ck} + ks$

for 50% of definition, $k = 0$

$\therefore$ $f_t = f_{ck}$

Example-1.2 Uniaxial compressive test, results of 100 cubes are listed below in increasing order. What is characteristics strength of concrete 26, 26.5, 27, 27, 28.5, 29, 29.5, 30, ..., 44.5

Solution:

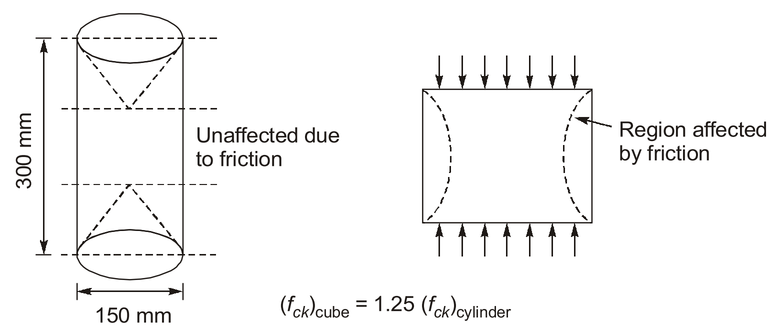
As per definition, characteristics strength should be 29 N/mm^2 since f_{ck} is designated in multiple of 5. So, f_{ck} should be either 25 or 30, in this case 7 samples (7%) are below 30 N/mm^2 so, 30 cannot be characteristics strength now, 25 is the characteristics strength of this concrete because zero sample (0% < 5%) is below 25 N/mm^2

$$\therefore \quad f_{ck} = 25 \text{ N/mm}^2$$

(c) Characteristics strength of concrete: It is obtained by dividing characteristics compressive strength of cube by a factor 1.5 to account for variation in loading condition (other than uniaxial compression) and variation in shape of concrete (other than cube of 150 mm).

(d) Characteristics strength of cylinder: Uniaxial compressive strength of concrete can be determined by using different types of shapes of specimen (cube, cylinder, prism).

- Cylinder gives more appropriate result for uniaxial compressive strength because effect of friction between machine plate and ends of specimen is least.
- Middle portion of cylinder remain unaffected of friction.

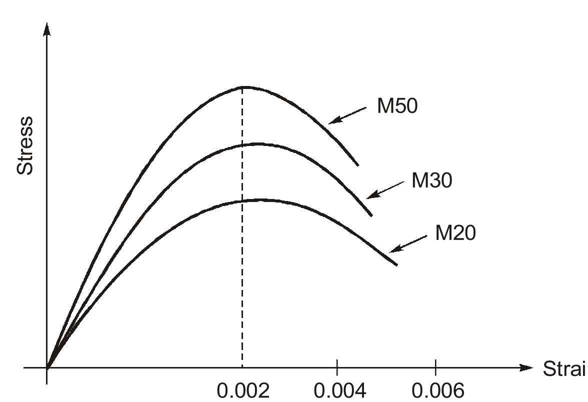


$(f_{ck})_{cube} = 1.25\ (f_{ck})_{cylinder}$

NOTE: In general, compressive strength of cube is used for characteristics strength of concrete for conversation purpose.

(e) Stress-strain diagram of concrete under uniaxial compression:

- Stress-strain diagram is non-linear.
- Maximum stress is corresponding to 0.002 strain (approximately).
- Ultimate strain lies between 0.004 to 0.006.
- Brittleness increases with increase in grade of concrete.
- Modulus of elasticity increases with increase in grade of concrete.
- Falling portion of stress-strain curve is obtained by controlled strain machine.



1.4.2 Grade of Concrete

Grade of concrete are based on characteristics strength. As per IS code (Amendment No. 4) the various grades of concrete are

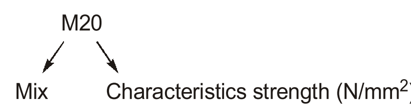
M10, M15, M20 } Ordinary grade

M25-M60] - Standard grade

M65-M100] - High strength concrete

where, M represents mix and number represents grade which is characteristics strength of 150 mm cube at 28 days.

Ex:



NOTE

- IS 456 : 2000 is not applicable to grade above M-60 (Amendment No. 4, May 2013)
- IS 456 : 2000 recommends the minimum grade as M-20 for reinforced concrete.
- Minimum grade of RCC and PCC used, depends on the exposure condition.

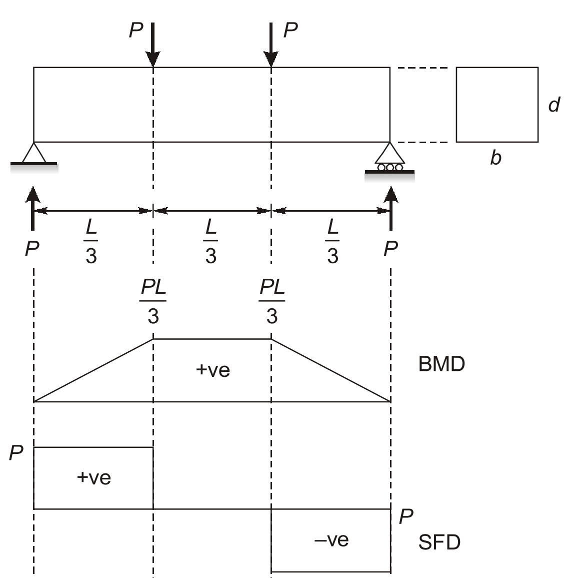
Exposure Condition	Minimum Grade (RCC)	Minimum Grade (PCC)
Mild	M20	–
Moderate	M25	M15
Severe	M30	M20
Very Severe	M35	M20
Extreme	M40	M25

1.4.3 Tensile Strength of Concrete

It is approximately 7 to 15% of compressive strength and stress-strain diagram is almost linear. Since, tensile strength of concrete is ignored in design so, it has vary less importance however it may be used to calculate cracking width and cracking moment.

(i) Direct tension test: Practically it is difficult to perform direct tension test due to stress concentration and non-homogeneity of material.

(ii) Flexure test:



Flexural formula, $$\frac{M}{I} = \frac{f}{y} = \frac{E}{R}$$

$$\frac{\left(\frac{PL}{3}\right)}{\left(\frac{bd^3}{12}\right)} = \frac{f_{cr}}{\left(\frac{d}{2}\right)}$$

$$f_{cr} = ?$$

- Third point loading is applied for pure bending condition.
- Value of P is increased from 0 to value corresponding to which first crack develops.
- Corresponding to cracking load, bending moment is calculated in central portion and tensile strength is calculated as shown above.
- IS : 456 provides a standard formula for flexure tensile strength/modulus of rupture as shown above:
- IS : 456 provides a standard formula for flexure tensile strength/modulus of rupture as shown below:

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

$$\downarrow \quad \downarrow$$

$$\text{N/mm}^2 = \text{N/mm}^2$$

(iii) Cylinder split test/splitting tensile strength of concrete: Owing to limitations of direct tensile strengthtest of concrete, cylinder splitting test is performed which gives more uniform results. In this test, a standard plain concrete cylinder (as used in compression test) is loaded on its sides along a diameter. Failure occurs by splitting of the cylinder along the plane of loading. This type of loading produces a uniform tensile stress across the plane of loading.

The splitting tensile strength (f_{ct}) is obtained as:

$$f_{ct} = \frac{2P}{\pi dL}$$

Where, P is the maximum load applied at failure, d is the diameter of the cylinder specimen, L is the length of the cylinder specimen.

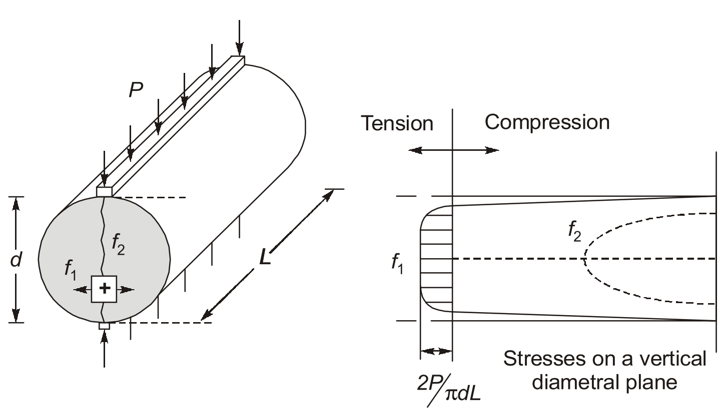


***Fig.** Cylinder splitting test for tensile strength*

Remember

IS 456: 2000 does not provide any empirical formula for splitting tensile strength (f_{ct}) as it does for modulus of rupture of concrete (f_{cr}). For normal density concrete, the **splitting tensile strength is about 2/3rd of the modulus of rupture of concrete**.

Example-1.3 Calculate cracking moment of plain cement concrete section of size 200 × 300 mm of M30 concrete.

Solution:

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

$$\therefore \quad \frac{M_{cr}}{\left(\frac{bd^3}{12}\right)} = \frac{f_{cr}}{\left(\frac{d}{2}\right)}$$

$$M_{cr} = 3.834 \text{ N/mm}^2 \times \frac{200 \times (300)^2}{6} \text{ mm}^3$$

$$= 11502000 \text{ N-mm} = 11.50 \text{ kN-m}$$

1.4.4 Creep of Concrete

Creep of concrete is covered in more detail in forth coming chapters. At present, it is worth to note that creep of concrete is having the following ill effects on concrete structures:

1. It increases the deflections of certain concrete elements like beams and slabs.
2. It increases the deflection of very long / slender columns.
3. It slowly transfers the load from concrete to reinforcing steel over a period of time.
4. It causes loss of prestress in prestressed concrete members.

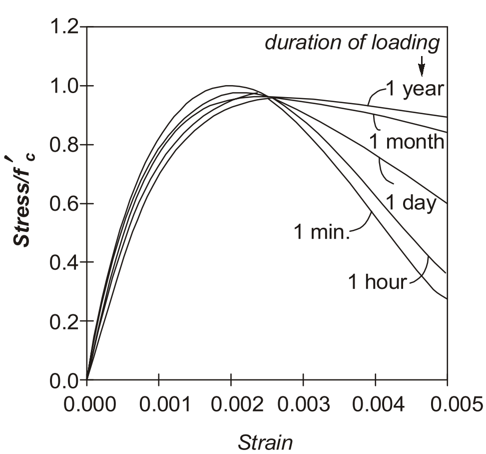


Fig. *Influence of duration of loading (strain-controlled) on the stress-strain curve of concrete*

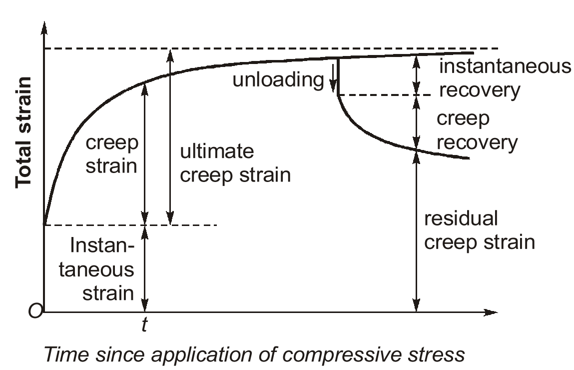


Fig. *Typical strain-time curve for concrete in uniaxial compression*

Following factors influence the creep of concrete:

1. High cement content increases the creep of concrete.
2. High water-cement ratio increases creep of concrete.
3. Creep increases when aggregate content is low.
4. It increases when air entrainment is high in concrete.
5. Low relative humidity increases creep.

6. Small size/thickness of members show large amount of creep.
7. Early loading of concrete members increases creep.
8. Long term sustained loading increases creep of concrete.

Long term sustained loading on concrete at a constant stress results in creep strains and a decrease in the compressive strength of concrete.

Creep Coefficient for Design

- As long as stress in concrete does not exceed one-third of its characteristics strength, creep may be assured to be proportional to stress.

$$\theta = \text{Creep coefficient} = \frac{\text{Ultimate creep strain}}{\text{Instantaneous elastic strain}}$$

Age of Loading	Creep Coefficient (θ)
7 Days	2.2
28 Days	1.6
1 Year	1.1

- Intermediate value of creep coefficient may be interpolarated by assuming that the creep coefficient decreases linearly with the log of time (in days). Thus, creep coefficient for age of loading at 15 days

$$\theta_{15} = 1.6 + \frac{0.6[\log_{10} 28 - \log_{10} 15]}{[\log_{10} 28 - \log_{10} 7]}$$

i.e. $\theta = C - \theta_0 \cdot \log t$

Effect of creep can be reduced by:

(i) Using high strength concrete.
(ii) Delaying the application of finishes, partition walls etc.
(iii) Adding reinforcement.
(iv) Steam curing under pressure.

1.4.5 Shrinkage of Concrete

Concrete is having shrinkage property due to presence of cement.

- Concrete undergoes volume changes as it changes phase from plastic to solid and this process is called shrinkage.
- Shrinkage is usually expressed as a linear strain (mm/mm).
- Unlike creep, shrinkage strains are independent of the stress condition of the concrete.
- Shrinkage is reversible to a greater extent.
- The total shrinkage of a concrete depends upon the constituents of concrete, size of member and environmental conditions etc.
- For a given humidity and temperature, the total shrinkage of concrete is most influenced by the total amount of water present in the concrete at the time of mixing and to a lesser extent by the cement content.
- Shrinkage has detrimental effects on the serviceability and durability of concrete. Shrinkage has been divided into five types as per different mechanisms:
  (a) Chemical shrinkage (b) Autogenous shrinkage (c) Plastic shrinkage
  (d) Drying shrinkage (e) Carbonation shrinkage

(a) Chemical shrinkage:

- This is due to the chemical reactions in concrete.
- In the plastic phase the chemical shrinkage results in overall reduction of specimen volume and at a later stage it creates pores within the mix structures.

(b) Autogenous shrinkage: It is a volume reduction of the concrete with no moisture transfer with the outer environment.

- It is mainly due to self-desiccation of cement resulting in rise in capillary suction pressure.

NOTE: Chemical shrinkage induces internal voids and autogenous shrinkage results in element shortening.

(c) Plastic shrinkage:

- This induce cracking on the top surface due to shortening of the concrete as sufficient tensile strength has not been developed in concrete.
- It is a short term process.

(d) Drying shrinkage: It is the contraction of a hardened concrete due to loss of water from concrete pores.

- It is similar to autogenous shrinkage as both occurs due to loss of water. However, in drying shrinkage the water is transferred to the outside and in autogenous shrinkage the water is transferred within the pore structure.
- Drying shrinkage is a long term process.

(e) Carbonation shrinkage: It is the result of reaction between calcium hydroxide $Ca(OH)_2$ present in the concrete and carbondioxide in atmosphere with the existence of moisture.

- Carbondioxide (CO_2) and moisture form carbonic acid (H_2CO_3)

$$H_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + 2H_2O$$

- The above reaction lower the pH in concrete and results in corrosions of reinforcement.
- The rate of carbonation shrinkage is low.
- A constant value of shrinkage strain is considered while designing RCC structure.

$$\varepsilon_s = 0.0003 = 3 \times 10^{-4} \simeq 0.03\%$$

1.4.6 Durability

Exposure Conditions	Description	Minimum grade of concrete	Minimum cement content	Minimum nominal cover	Maximum W/C ratio
Mild	Protected from rainfall	*M20	*300 kg/m^3	*20 mm	*0.55
Moderate	• Exposed to normal rain • Permanently submerged in normal water	M25	300 kg/m^3	30 mm	0.55
Severe	• Coastal area • Exposed to heavy rain • Footing in non-aggressive soil • Alternate drying and wetting in normal water • Permanently submerged in sea water	M30	320 kg/m^3	**45 mm	0.45
Very severe	• Exposed to sea spray • Footing in aggressive soil	M35	340 kg/m^3	50 mm	0.45
Extreme	• Tidal zone • Subjected to aggressive chemicals	M40	360 kg/m^3	***75 mm	0.40

* → It can be reduced to 15 mm when bar dia is 12 mm or less.
** → It can be reduced to 40 mm for grade M35 or above.

NOTE

- M20 is the minimum grade of concrete for any RCC structure.
- M20 and M30 are the minimum grade for PCC and RCC respectively in coastal areas (severe exposure conditions).

1.4.7 Modulus of Elasticity

1. **Initial tangent modulus of elasticity:** It is the slope of stress – strain curve of concrete at origin. It is the maximum value of modulus of elasticity of concrete (E_c). IS 456: 2000 defines this value as $5000\sqrt{f_{ck}}$.
2. **Tangent modulus of elasticity:** The slope of tangent at any point on the stress – strain curve is referred to as tangent modulus of elasticity.
3. **Secant Modulus of elasticity:** It is the slope of the line joining any point on stress – strain curve to the origin.
4. **Long term modulus of elasticity**: It considers the effect of creep and is defined as:

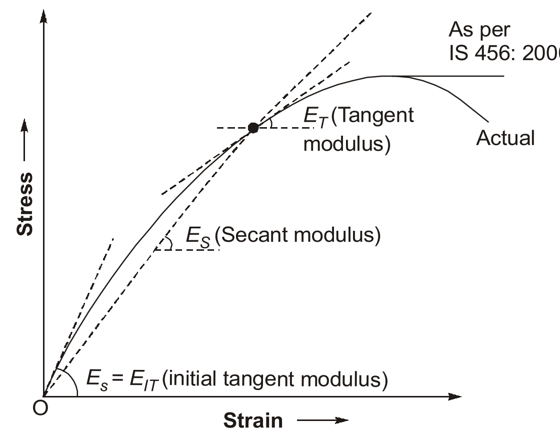


Fig. *Various Types of Modulus of Elasticity of Steel*

$$E_{long} = \frac{E_c}{(1+\theta)} = \frac{5000\sqrt{f_{ck}}}{(1+\theta)}$$

where, $$\theta = \text{Creep coefficient} = \frac{\text{Ultimate creep strain}}{\text{Elastic strain}}$$

1.5 Admixture

Any additional component of concrete that enhances property is called admixture.

1. **Accelerator:** It increases rate of setting of concrete and generally used in under water concreting and fast construction.
2. **Retarder:** It is used to reduce rate of hydration and generally used in RMC (Ready Mix Concrete) and mass concreting.
3. **Air entrainer:** It is used to improve workability and resistance against freezing and thawing condition. It also enhances soundness of concrete by introducing many air bubbles in concrete, subject to maximum 5% of its volume.
4. **Plasticizer and superplasticizer:** W/C = 0.4

	W	C	Hydration	Evaporate
Mix-1	20 kg	50 kg	12 kg (assumed)	8 kg
Mix-2	30 kg	75 kg	18 kg	12 kg

- Mix-2 is uneconomical because of more amount of cement.
- Mix-2 has more shrinkage properties because of higher water content.
- Mix-2 produces more porous concrete, because more water is left after hydration.
- Mix-1 has less workability so, plasticizer or superplasticizer is added to enhance workability.

NOTE: Quantity of admixture is always represented in proportion of cement content.

1.5.1 Mineral Admixture

- It is used to reduce quantity of cement because of its binding property.
- Replacement of cement by using flyash should not more than 35%.
- It enhances consistency and finally workability.
- Since, fineness of flyash is more than cement, so it produces dense concrete (durable concrete).
  Ex: Sluice fumes, rice husk

1.6 Water

- pH should not be less than 6.
- Sea water is not preferable.
- Water suitable for mixing is also suitable for curing.
- Curing water is not used for hydration. It is provided to maintain moisture content of concrete.

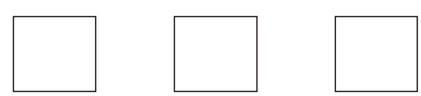
1.7 Acceptance Criteria of Concrete

1.7.1 Acceptance Criteria of Sample

(Specimen) – 1 cube of 150 mm size

(Sample) – set of 3 cubes casted from same concrete at same time

(1-sample)



Characteristics strength of cube x y z

Characteristics strength of sample $\left(\frac{x+y+z}{3}\right)$

- Sample is acceptable only when no individual compressive strength of specimen x, y and z should not fall beyond ±15% of compressive strength of sample $\left(\frac{x+y+z}{3}\right)$.
-

Quantity of concrete	Number of sample
1 – 5 m^3	1
6 – 15 m^3	2
16 – 30 m^3	3
31 – 50 m^3	4
50 – above	4 + 1 sample for each additional 50 m^3

1.7.2 Acceptance Criteria of concrete

Assume 100 m^3 of concrete

	Day 1	Day 2	Day 3	Day 4
	20 m^3	25 m^3	35 m^3	20 m^3
Number of sample	3	3	4	3

Sample number 1 | 2 3 4 5 | 6 | 7 8 9 10 | 11 12 13

(2–5 ✓, 7–10 ✓, 10–13 ×)

Average of 4 consecutive and non-overlapping $\geq$ maximum $\begin{cases} f_{ck} + 0.825s \\ f_{ck} + 3 \end{cases}$

In addition to that, compressive strength of no individual sample should be less than $f_{ck} - 3$.

1.8 Testing of Hardened Concrete

1.8.1 Destructive Testing

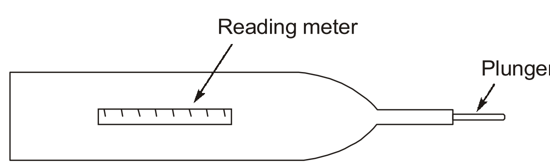
Sample used for destructive testing can not be used for service.

Load test: Used in precast element.

Corecut test: Used in road construction.

1.8.2 Non-destructive Testing

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 finally multiplied by a factor to get compressive strength of concrete.
- This method of testing is vague because of plunger can be pressed against aggregate and mortar.
- It gives idea about surface concrete only.

Ultrasonic Pulse Velocity Method

- It is an electronic method in which emitter and receiver are connected on opposite surface of concrete.
- Time taken by ultrasonic waves to travel through concrete is measured.
- If time is more than concrete is less dense this implies that quality is inferior.
- This method is used to detect cracking also.

1.9 Concrete Mix Design

Design of concrete mix for a particular grade of concrete involves proper selection of relative proportions of cement, sand and coarse aggregates. While designing a concrete mix, it is always tried to obtain a minimum strength which is equal to characteristic strength of concrete but concrete must also have the desired workability (when fresh/green), impermeability and durability (in hardened state). Table 1.3 depicts the various grades of concrete based on concrete mix design. Concrete mix design is classified as nominal mix design and the design mix.

Various grades of concrete as per IS 456: 2000

Concrete Grade	Type of Concrete
M10	Ordinary grade concrete
M15	
M20	
M25 - M55	Standard grade concrete
M60 - M100	High Strength concrete

Note: Provision of IS 456: 2000 do not apply to grades of concrete M60 and above.

1.9.1 Nominal Mix Design

Concrete mix design is a process that needs experience. Earlier, concrete mixes were specified in terms of fixed ratios like 1:2:4, 1:1.5:3 and so on for cement, sand and coarse aggregates respectively (by mass or by volume). This is a very rough method of concrete mix design which often gives wrong translations of concrete grades like M15, M20, M25, M30 etc.

Proportions of nominal mix concrete as per IS 456: 2000

Concrete Grade	Weight of FA and CA in 50 kg of cement	FA:CA	Weight of water (in kg) per 50 kg (1 bag) of cement
M5	800	Generally 1:2 but subject to an upper limit of 1:1.5 and a lower limit of 1:25	60
M7.5	625		45
M10	480		34
M15	330		32
M20	250		30

FA : Fine Aggregate, CA : Coarse Aggregate

IS 456: 2000 provides a more precise nominal mix proportions for M5, M7.5, M10, M15 and M20 grades of concrete in terms of total mass of aggregates, proportions of fine to coarse aggregates and volume of water to be used per 50 kg (i.e. 1 bag) of cement (which is in volume equal to 34.5 liters). Nominal mix concrete can only be used in ordinary concrete constructions involving concrete grade not higher than M20. For higher grades of concrete, design mix concrete is adopted.

Traditional nominal mix of 1 : 2 : 4 (cement : sand : coarse aggregate, by weight) with 33 grade of OPC conforms approximately to M15 concrete grade. This nominal mix with higher grades of cement (43, 53 grades) yields higher grades of concrete (M 20 and above).

1.9.2 Design Mix Concrete

Design mix concrete is based on the principles of "mix design" and is always preferred over nominal mix of concrete. It yields concrete of desired quality and is more economical than the nominal mix. The IS recommendations of the mix design are given in **IS 10262: 1982** and **SP 23: 1982**.

1.9.3 Steps Involved in Mix Design of Concrete as per IS Recommendation

Step 1. Determine the mean target strength (f_{cm}) from the desired characteristic strength (f_{ck}) as:

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

where, σ is the standard deviation that depends on quality control as listed in Table 8 of IS 456: 2000. The same table has been reproduced here as **Table (a)**.

Concrete Grade	Assumed Standard Deviation (N/mm^2)
M10	3.5
M15	
M20	4
M25	
M30	5
M35	
M40	
M45	
M50	

Table (a): *Standard deviation for various concrete grades*

Step 2. Determine the water-cement ratio based on 28 days strength of cement and the mean target strength of concrete. This ratio must not exceed the limits specified in Table 5 of IS 456: 2000 part of which is reproduced here as **Table (b)**.

Step 3. Determine the water content based on requirements of workability. Select the type of proportion of fine and coarse aggregate (by mass) based on aggregate grading and type. Water requirement is usually in the range of 170-200 litres per cubic metre of concrete (without admixtures) and ratio of fine and coarse aggregates is generally taken as 1:1.5, 1:2, or 1:2.5.

Exposure Condition	Minimum cement content (in kg/m^3)	Maximum free water cement ratio
Mild	300	0.55
Moderate	300	0.50
Severe	320	0.45
Very Severe	340	0.45
Extreme	360	0.40

***Table (b):** Minimum cement content and maximum water cement ratio based on exposure conditions*

Step 4. Determine the cement content (in kg/m^3) as:

$$\text{Cement Content} = \frac{\text{Water content}}{\text{Water-cement ratio}}$$

Cement content should not be less than that specified in Tables 4 and 5 of IS 456: 2000 for durability considerations.

Do you know? IS 456: 2000 restricts the use of cement beyond 450 kg/m^3 in order to control shrinkage and thermal cracks.

Step 5. Determine the masses of coarse and fine aggregates based on absolute volume principle as:

$$\frac{C}{\rho_c} + \frac{FA}{\rho_{FA}} + \frac{CA}{\rho_{CA}} + V_W + V_a = 1$$

Here C, FA and CA denotes the masses of cement, fine aggregates (sand) and coarse aggregates respectively and ρ_c, ρ_{FA} and ρ_{CA} denotes the mass densities of cement, fine aggregates (sand) and coarse aggregates respectively.

V_w = Volume of water and V_a = Volume of air voids.

Step 6. Determine the weight of ingredients per batch based on capacity of the concrete mixer.

Example-1.4 **Find the quantities of cement, fine aggregates (FA) and coarse aggregates (CA) for 1 m^3 of concrete. The void ratio in cement is 60%, in FA is 40% and in CA is 44%.**

Take Materials properties as:

Mix is 1 : 2 : 4 with water-cement ratio of 0.59. One bag of cement weighs 50 kg (neglecting the empty weight of bag) and density of cement is 1440 kg/m^3. Density of FA is 1780 kg/m^3 and coarse aggregate (CA) is 1650 kg/m^3. Volume of one bag of cement is 34.7 litres. Assume volume of air in concrete as 3% per m^3 of concrete.

Solution: (*)

Since the proportion specified is 1 : 2 : 4 without saying anything that whether it is 'by weight' or 'by volume'. In such cases, it is always recommended to use minimum proportions 'by weight'.

Thus 1 : 2 : 4 ⇒ 1 kg cement, 2 kg FA, 4 kg CA.

Now $\quad \text{Bulk density } (\gamma) = \frac{\text{Mass}}{\text{Total volume}} = \frac{M}{V}$

and $\quad \text{Mass density } (\gamma_m) = \frac{\text{Mass}}{\text{Volume of solid content}} = \frac{M}{V_s}$

$\therefore \quad \gamma = \frac{M}{V} = \frac{M}{V_s + V_v} \quad$ where, V_v = Volume of voids

$$= \frac{M/V_s}{1 + V_v/V_s} = \frac{\gamma_m}{1+e}$$

Now for cement, $\quad e = 0.6$

⇒ Mass density of cement, $\quad \gamma_{mc} = \gamma_c(1 + e) = 1440\,(1 + 0.6) = 2304$ kg/m^3

For fine aggregates, $\quad e = 0.4$

⇒ Mass density of fine aggregates, $\gamma_{mFA} = \gamma_{FA}(1 + e) = 1780(1 + 0.4) = 2492$ kg/ m^3

For coarse aggregates, e = 0.44

Mass density of coarse aggregates, $\gamma_{mCA} = \gamma_{CA}(1 + e) = 1650(1 + 0.44) = 2376 \text{ kg/m}^3$

Let Volume of concrete = 1 m^3 and mass of cement in 1 m^3 concrete = x kg

∴ Volume of air = 3% of volume of concrete = 0.03 m^3

Now Volume of concrete = Vol. of cement + Vol. of FA + Vol. of CA + Vol. of air + Vol. of water

$$\Rightarrow \quad 1 = \frac{x}{2304} + \frac{2x}{2492} + \frac{4x}{2376} + 0.03 + \frac{0.59x}{1000}$$

$$\Rightarrow \quad x = 276.35$$

∴ Mass of cement in 1 m^3 concrete = x = 276.35 kg

Mass of water in 1 m^3 concrete = $0.59x$ = 163.05 kg

Mass of fine aggregates in 1 m^3 concrete = $2x$ = 552.7 kg

Mass of coarse aggregates in 1 m^3 concrete = $4x$ = 1105.4 kg

Example-1.5 Find the quantities of cement, sand and coarse aggregates in 1 m^3 of concrete for a mix proportion of 1 : 1.15 : 2.5 (by volume). The water cement ratio required is 0.56 (by weight).

Bulk density of cement = 1500 kg/m^3

Bulk density of sand = 1780 kg/m^3

Bulk density of coarse aggregates = 1650 kg/m^3

Assume volume of entrained air per cubic meter of concrete as 3%.

Specific gravity of cement = 3.15

Specific gravity of sand = 2.65

Specific gravity of coarse aggregates = 2.3

Solution:

Mix proportion is 1 : 1.15 : 2.5 (by volume)

Let volume of cement per m^3 of concrete = x m^3

∴ Volume of cement : FA : CA = $x : 1.15x : 2.5x$ (m^3)

Also, Water-cement ratio = 0.56

$$\Rightarrow \quad \frac{\text{Mass of water}}{\text{Mass of cement}} = 0.56$$

Now, bulk density of cement, γ_c = 1500 kg/m^3

Bulk density of sand, γ_{FA} = 1780 kg/m^3

Bulk density of coarse aggregates, γ_{CA} = 1650 kg/m^3

∴ x m^3 of cement ≡ $1500x$ kg of cement

$1.15x$ m^3 of sand ≡ $1780(1.15x)$ kg of sand

$2.5x$ m^3 of coarse aggregates ≡ $1650(2.5x)$ kg of coarse aggregates

and Mass of water = 0.56 times of mass of cement

= $0.56\,(1500\,x)$ kg of water per m^3 of concrete

$$\therefore \quad \text{Volume of water} = \frac{0.56\,(1500\,x)}{1000}\,\text{m}^3 \qquad (\because \gamma_w = 1000 \text{ kg/m}^3)$$

Given, volume of air = 0.03 m^3 per m^3 of concrete

$\therefore$ Volume of concrete = Vol. of cement + Vol. of sand + Vol. of coarse aggregates + Vol. of air + Vol. of water

$$\Rightarrow \quad 1 = \frac{1500\,x}{3.15\times1000} + \frac{1780(1.15\,x)}{2.65\times1000} + \frac{1650(2.5\,x)}{2.3\times1000} + 0.03 + \frac{0.56(1500\,x)}{1000}$$

$$\Rightarrow \quad 0.97 = 0.4762x + 0.7725x + 1.793x + 0.84x$$

$$\Rightarrow \quad x = 0.25$$

$\therefore$ Weight of cement = $1500x = 375$ kg

Weight of sand = $1780\,(1.15x) = 511.75$ kg

Weight of coarse aggregates = $1650\,(2.5x) = 1031.25$ kg

Weight of water = $0.56\,(1500x) = 210$ kg

1.10 Properties of Reinforcement and its use in Reinforced Concrete Structures

The reinforcing steel is classified according to the yield strength of the steel that is to be used in construction for structural purposes. This specified yield strength is called as **grade of steel**. The grade of steel (e.g. Fe 250, Fe 415 etc.) represents yield strength of steel (expressed as N/mm^2 or MPa).

As stated earlier, for certain types of steel, yield point cannot be located distinctly on the stress strain curve. For such types of steel, the stress corresponding to 0.2% (or 0.002) offset strain is defined as yield point.

The slope of the elastic portion of stress strain curve is called as **modulus of elasticity** of steel (E_s) and for all types of steel it is taken as **2 x 10^5 N/mm^2**.

1.10.1 Types of Reinforcing Steel

1. **Mild Steel (Fe 250):** It can either be ORDINARY or HOT ROLLED with characteristic strength of 250 N/mm^2.
2. **Medium Tensile Steel:** It can also be either ORDINARY or HOT ROLLED.
3. **Cold Twisted Bar:** These are HYSD (HIGH YIELD STRENGTH DEFORMED) bars. e.g. Fe 415 and Fe 500 HYSD bars.
4. **TMT Bars:** These are THERMO MECHANICALLY TREATED (TMT) bars. e.g. Fe 415, Fe 500, Fe 550 TMT bars. Their outer shell has very high tensile strength but inner core is soft and ductile. These are usually coated with anticorrosive coating.

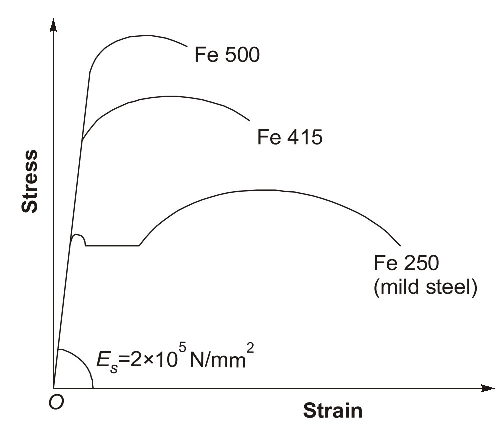


Fig. *Stress strain baheviour of mild and HYSD steel*

About Hot Rolled Mild Steel Reinforcement: In case of Hot Rolled mild steel reinforcement, an yield plateau is observed at upper yield point resulting in large deformation in steel and further resulting in large cracking of structure.

Yield Plateau: It can be eliminated by cold working.

Cold Working: Steel reinforcement is stressed beyond yield plateau either by stretching or by twisting and then it is unloaded. This process is called as cold working. Cold twisted bars are made by this process.

1.10.2 Yield Strength for HYSD Bars

Types of bar	Permissible Tensile Stress (N/mm^2)			
	Mild Steel (Fe 250)	Medium Tensile Steel	CTP/HYSD Steel	Fe 500
Tensile Strength				
Dia upto 20 mm	140	190	230	275
Dia > 20 mm	130	190	230	275
Compression bar in column	130	130	190	- -

Permissible tensile stresses of steel bars

For HYSD bars, yield stress is read at 0.2% proof strain i.e. at strain of 0.002 by drawing a line parallel to stress-strain curve.

Total strain at f_y, $$\varepsilon_y = 0.002 + \frac{f_y}{E_s}$$

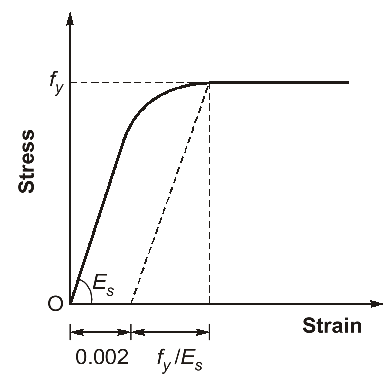


Fig. *Stress strain behaviour of HYSD/ CTP steel bars*

1.10.3 Reinforcement Bar Sizes available in India

The following bar sizes i.e. nominal bar diameters (in mm) are available in the Indian market viz.:

5, 6, 8, 10, 12, 16, 18, 20, 25, 28, 32, 36, 40, 45, 50. Among these, most commonly available bar sizes are 6, 8, 10, 12, 16, 20, 25, 32, 40.

1.10.4 Hot Rolled Versus Cold Worked Steel Bars

Hot rolled mild steel: The stress-strain curve of hot rolled mild steel is featured by an initially straight linear elastic part of the curve which is followed by the occurrence of an **yield plateau** (strain increases at constant stress) and followed by **strain hardening zone** wherein the stress increases with increasing strain till peak tensile strength is reached. Then this is followed by a decreasing limb of the stress strain curve till fracture occurs. For **Fe 250, ultimate tensile strength is 412 MPa and minimum percentage elongation is 20 to 22%.**

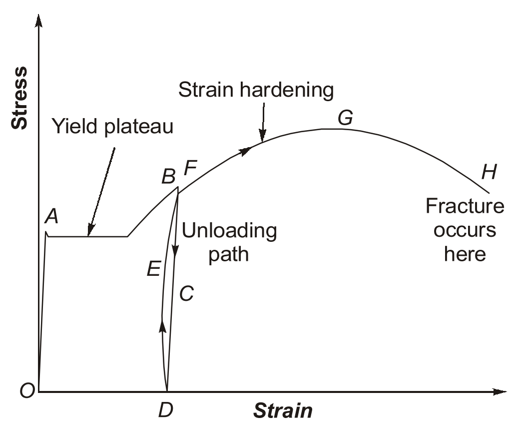


Fig. *Effect of cold-working of mild steel bars*

Cold worked bars involve the process of stretching and twisting of mild steel beyond the yield plateau which is followed by the release of load. This specimen on reloading will follow the path *DEF* as shown in the figure below. The process of unloading after the yield stress and then again reloading gives rise to a **hysteresis loop**. The unloading and reloading curves are nearly straight and parallel to *OA* as shown below. Thus the reloading process follows a linear elastic path (with the same modulus of elasticity E_s as that of mild steel) till the point where the unloading process started. Then the material (steel) enters into the strain hardening stage. The process of cold working increases the yield strength of steel but at the same time, it reduces the ductility of steel. **Cold working also decreases the margin between the yield strength and the ultimate strength of steel.**

Do You Know?

Some Interesting Facts about Mild Steel (Fe250):

1. In LSM, mild steel (Fe 250) which has a clearly defined yield point, the steel yields i.e. reaches the stress 'f_y' even at strains less than $\left(\frac{0.87f_y}{E_s}+0.002\right)$ and thus at values of x_u which are slightly greater than $x_{u\,lim}$, the stress in mild steel remains $0.87f_y$.
2. Ductility requirement may be partially satisfied with the use of Fe 250 steel even if x_u is slightly greater than $x_{u\,lim}$.
3. Due to the ability of mild steel to yield even at strains less than $\left(\frac{0.87f_y}{E_s}+0.002\right)$, the actual under-reinforced behavior gives values of percentage of tensile reinforcement (p_t) greater than $p_{t\,lim}$. But **IS 456: 2000** limit the use of p_t values greater than $p_{t\,lim}$ for design purposes.

1.11 Design Philosophies for the Design of Reinforced Concrete Structures

Numerous design philosophies have been proposed in the last century for the design of reinforced concrete structures. Every **design philosophy** is based on certain assumptions.

Cl. 18.2 of IS 456: 2000 accepts three methods of design of reinforced concrete structures viz. *Limit State Method, Working Stress Method* and *Method based on experimental approach.* **Working Stress Method** is the earliest codified design philosophy which is based on linear elastic theory. This method is now out dated and in the latest version of IS 456: 2000, the provisions of *working stress method* of design has been shifted from the main text of the code to **Annexure 'B'** so as to have larger emphasis on *Limit State Method.*

Ultimate Load Method of design is based on the strength of concrete at ultimate loads. This method was in fact a replacement of traditional WSM of design which was incorporated in the **IS: 456** in the year 1964.

Later on it was realized that there involves a lot of uncertainty in the precise estimation of loads and material properties. Every time designing a structure for the most possible severe combination of loads make the structure highly safe which in fact may not be subjected to that much loads in actual life and at the same time it increases the cost and works out to be uneconomical. However, these uncertainties can be handled by the **theory of probability.** The risk associated with the design of structure was quantified in terms of **probability of failure** of the structure. This type of probability based method is called as **reliability based method.** The major drawback of these methods is that they are highly complicated in terms of mathematical calculations.

In order to overcome the above stated problem of reliability based methods, instead of determining the actual **probability of failure** of the structure, we introduce **many (partial) safety factors**. The European Committee for Concrete **(CEB)** and the International Federation of Prestressing **(FIP)** were among the first to introduce the concept of **Limit State Method of Design,** which is a **reliability based method.** Later on, based on the recommendations of **CEB-FIP,** the limit state method of design got introduced in the British Code (BS-8110-1997) and in the **Indian Code (IS 456:1978)**.

1.11.1 The Working Stress Method (WSM) of Design

It is the most traditional method for the design of **reinforced concrete, structural steel and timber.** The basic design philosophy of this method is:

1. The material behaves in a linear elastic manner.
2. Adequate safety can be ensured by restricting the stresses in the materials that are induced due to the application of working loads/service loads.

Now the question arises:

"How to justify the assumption that material behaves in a linear elastic manner?"

The answer to the above question lies in the second assumption, where the allowable stresses are kept well below the strength of material i.e. the allowable stresses lie in the linear phase of stress-strain curve so the assumption of linear elastic behavior of material is justified.

The second assumption as stated above also introduces the concept of **factor of safety** which is expressed as:

$$\text{Factor of safety} = \frac{\text{Strength of the material}}{\text{Allowable stress in the material}}$$

The stresses induced due to the application of service or working loads are determined using the principles of **Strength of Materials.** But reinforced concrete is a **composite material** having two altogether different materials viz. concrete and steel. To apply the principles of Strength of Materials to a composite structure like reinforced concrete, the concept of **strain compatibility** is employed wherein it is assumed that there exists a perfect bond between the two materials (steel and concrete) and that the strain in steel is equal to the strain in the surrounding concrete due to that perfect bond.

It is quite evident that the stress is related to the strain and thus it follows that stress in steel is related to the strain in steel. But strain in steel is equal to the strain in surrounding concrete. Therefore, the stress in steel is indirectly related to the strain in the surrounding concrete. This indirect relation (between the steel and concrete) is expressed in terms of **modular ratio (m)** as:

$$\text{Modular Ratio} = \frac{\text{Stress in steel } (f_s)}{\text{Stress in concrete } (f_c)}$$

$$= \frac{\text{Strain in steel } (\varepsilon_s) \times \text{Modulus of elasticity of steel } (E_s)}{\text{Strain in concrete } (\varepsilon_c) \times \text{Modulus of elasticity of concrete } (E_c)}$$

$$= \frac{E_s}{E_c} \qquad (\text{Since } \varepsilon_c = \varepsilon_s)$$

Limitations of WSM of design

1. It fails to give relative importance to the different types of loads that act on a structure i.e. dead loads, live loads, snow load, seismic loads, temperature load etc. All of these act on the structure with different uncertainties. This often leads to over conservative designs and sometimes under conservative designs (when two loads are acting oppositely i.e. dead and wind loads, live and seismic loads etc.).
2. WSM of design gives large sections (compared to LSM and ULM) of the designed reinforced concrete members.

Remember

Although WSM of design has been put at annexure in IS 456: 2000 and superseded by LSM, it still remains the accepted method of design for certain type of structures like reinforced concrete water tanks **(IS 3370)**, chimneys **(IS 4998)** and bridges **(IRC-21).**

1.11.2 The Ultimate Load Method (ULM) of Design

This method is an improvement over the traditional WSM of design and takes into account the shortcomings of the earlier method. The ULM is also called as the **load factor method** or the **ultimate strength method.** In this method, the non-linear stress strain behavior of steel and concrete are accounted for and stresses induced in the structure at the verge of failure at ultimate loads are considered. The problems associated with the modular ratio (m) are entirely avoided in this method. The safety in the design of structure is taken care by the concept of **load factor** which is expressed as:

$$\text{Load Factor} = \frac{\text{Ultimate or design load}}{\text{Working or service load}}$$

This concept of load factor makes it possible to assign different factors of safety (in terms of load factors) to different types of loads (like dead loads, live loads, seismic loads, wind loads, snow loads etc.) and can be suitably combined; which was a major drawback in the WSM of design.

Limitations of ULM of design

1. The major drawback of this method is that, one cannot say with 100% assurance that if a structure performs well at ultimate loads (**strength**), the same structure will perform its function satisfactorily at service loads also (**serviceability**).
2. Another drawback of this method is that, the assumed nonlinear stress strain behavior of concrete and steel is relevant only if nonlinear analysis is performed on the structure. But nonlinear analysis of structures is too cumbersome to be done for routine type of structures.

For assessing the distribution of stresses at ultimate loads, we use the stress distribution at service loads magnified by the load factor, but this approach is NOT correct owing to the fact that as the loading is increased from the service load level to the ultimate load level, significant inelastic and nonlinear behavior of materials comes in with considerable stress redistribution.

1.11.3 The Limit State Method (LSM) of Design

The earlier design methods includes the working stress method (WSM) and the ultimate load method (ULM) of design. **WSM is based on service loads conditions** alone whereas the **ULM is based on ultimate load conditions** alone. However, LSM takes into account the safety at ultimate load and serviceability at service loads. LSM employs different safety factors at ultimate loads and service loads. These multiple safety factors are based on probabilistic approach with separate approaches for each type of failure, type of materials and types of loads.

Limit State: Limit state is the state of 'about to collapse' or 'impending failure', beyond which, the structure is not of any practical use i.e. either the structure collapses or becomes unserviceable. In LSM, two types of limit states are defined which are:

1. **Limit state of collapse**: This limit state deals with the strength of the structure in terms of collapse, overturning, sliding, buckling etc.

   Various limit states of collapse are:

   - Flexure
   - Compression
   - Shear
   - Torsion

2. **Limit state of serviceability**: This limit state deals with the deformation of the structure to such an extent that the structure becomes unserviceable due to excessive deflection, cracks, vibration, leakage etc.

   Various limit states of serviceability are:

   - Deflection
   - Excessive vibrations
   - Corrosion
   - Cracking (Do not consider the tensile strength of concrete)

1.12 Necessity of Designing Reinforced Concrete Structures

The principal aim of structural design is that the structures should perform its intended function *safely* at ultimate loads within their life time and also *serviceable* at service or working loads.

The term '**safety'** includes the following parameters:

1. Reserve strength of the material of the structure.
2. Limited or permissible deformation(s) in the structure.
3. Durability of the structure in the long run.

Thus, **safety** implies that the possibility of the failure of the structure (partial or complete failure) is very low even at **ultimate loads** considering appropriate factor of safety.

Serviceability implies that the structure should perform its intended function very well at **working loads.** It includes deflection, vibration, crack widths, durability, permeability, acoustics, thermal insulation etc.

Thus, the basic objectives to fulfil serviceability criteria can be summarized as:

1. Properly designed structures should perform its intended function at service loads quite satisfactorily.
2. Structure should bear all the loads and should deform within the permissible limits.
3. The structures should be durable enough against the adverse environmental conditions.
4. The designed structure must adequately resist the probable hazardous effects of structural misuse and fire.

Remember

Increasing the **factor of safety** in the design of structures increases the safety and serviceability of the structure but at the same time it increases the cost of structure also. Here comes the role of **economy** in the design of structures. While considering the overall economy of a structure, the increased cost associated with the increased factor of safety must be properly weighed against the possibility of structural failure.

1.12.1 Objectives of Structural Design

The rational design of a structure must satisfy the following requirements:

1. **Stability:** The structure must be stable enough to resist the failure of structure in terms of overturning, sliding, buckling of the structure or parts thereof under the severe action of loads viz. both permanent (dead load) and temporary (superimposed live load etc.).
2. **Strength:** The structure must be able to carry safely the stresses induced by the severe most possible combination of loads acting on the structure.
3. **Serviceability:** The structure must perform its intended function i.e. it must be serviceable. This implies that the deflections, vibrations, crack-widths, permeability to water etc. are within the permissible limits.
4. **Aesthetics:** The structure must be in harmony with the surroundings and should look pleasing. It is purely an architectural consideration.
5. **Economy:** At last, economy plays the most important role in structural design. The cost of the structure and its associated facilities must not be so gargantuan that it may dictate the overall functional requirement of the structure.

1.13 Major Reasons of Structure Failure

There are so many reasons for a building failure. By the term '**failure**', it implies failure in terms of either **collapse or serviceability or both**. Some of the major reasons of structure failure are as follows:

Failure during construction or soon after	Failure after a long time of construction
Design fault/significant shift from actual design	Collapse/failure of primary load carrying member by accident or otherwise
Poor detailing	Change in use of the structure leading to over loading
Inferior quality of materials	Factors which are beyond human control like fire, earthquake, blast etc.
Inferior construction quality	Lack of proper repair and maintenance
Substandard formwork and/or scaffolding	Exposure to adverse environment which was not envisaged in design

1.14 Major Challenges for a Structural Designer

In order to design a structure economically , a structural designer faces the following challenges:

1. Analysing a structure on the basis of **highly simplified structural analysis theories** which are far from actual material (steel, concrete) behavior.
2. Construction of structure by the unorganized sector of construction workers and there always exists a possibility of human error.
3. Structure subjected to a completely unpredictable natural environment.

STUDENT'S ASSIGNMENTS

Q.1 A reinforced concrete structures has to be constructed along sea coast. The minimum grade of concrete to be used as per IS 456 : 2000 is
(a) M15 (b) M20
(c) M25 (d) M30
[GATE-2008]

Q.2 The characteristics strength of concrete is defined as that compressive strength below which not more than
(a) 10% of result fail (b) 5% of result fail
(c) 2% of result fail (d) None of above
[GATE-1999]

Q.3 The cylinder strength of the concrete is less than the cube strength because of
(a) The difference in the shape of the cross-section of the specimens.
(b) The difference in the slenderness ratio of the specimens.
(c) The frictional between the concrete specimens and the steel plate of the testing machine.
(d) The cubes are tested without capping but the cylinders are tested with capping.
[GATE-1997]

Q.4 The flexural strength of M30 concrete as per IS 456 : 2000 is ________.
(a) 3.83 MPa (b) 5.47 MPa
(c) 21.43 MPa (d) 30.0 MPa
[GATE-2005]

Q.5 In a random sampling procedure for cube strength of concrete, one sample consist of X number of specimens. These specimens are tested at 28 days and average strength of these X specimens is considered as test result of the sample, provided the individual variation in the strength of specimens is not more than ±Y percent of the average strength. The value of X and Y as per IS 456 : 2000 are
(a) 4 and 10 respectively
(b) 3 and 10 respectively
(c) 4 and 15 respectively
(d) 3 and 15 respectively
[GATE-2005]

Q.6 The modulus of rupture of concrete in terms of its characteristics cube compressive strength (f_{ck}) in MPa according to IS 456 : 2000 is
(a) $5000\, f_{ck}$ (b) $0.7\, f_{ck}$
(c) $5000\sqrt{f_{ck}}$ (d) $0.7\sqrt{f_{ck}}$
[GATE-2009]

Q.7 The modulus of elasticity, $E = 5000\sqrt{f_{ck}}$ where f_{ck} is the characteristics compressive strength of concrete, specified in IS 456 : 2000 is based on
(a) Tangent modulus
(b) Initial tangent modulus
(c) Secant modulus
(d) Chord modulus
[GATE-2014]

Q.8 The target mean strength f_{cm} for concrete mix design obtained from the characteristics strength f_{ck} and standard deviation σ, as defined in IS 456 : 2000 is