

MPSC

2023

Maharashtra Public Service Commission
Assistant Engineer Examination

Civil Engineering

RCC & Pre-stressed Concrete

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



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RCC & Pre-stressed Concrete

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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

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.

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.).

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).

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.

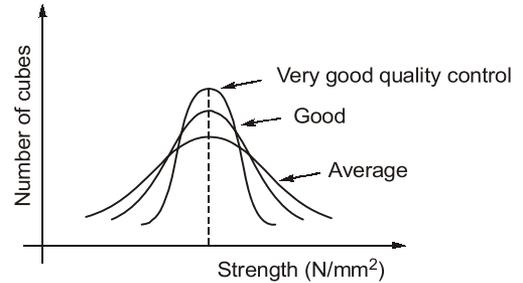


Fig. Influence of quality control on the frequency distribution of concrete strength

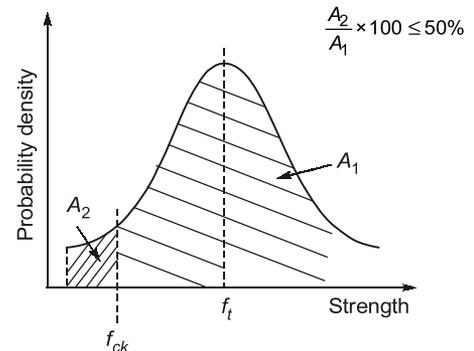
NOTE: Experimentally, it is found that probability distribution of concrete strength (for a particular concrete mix as found out by compressive strength tests in laboratory on a large number of specimens follow normal/Gaussian distribution.

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

$$k = 1.65 \text{ (for 5\% of definition)}$$

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



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,
for 50% of definition,
 \therefore

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

$$k = 0$$

$$f_t = f_{ck}$$

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:

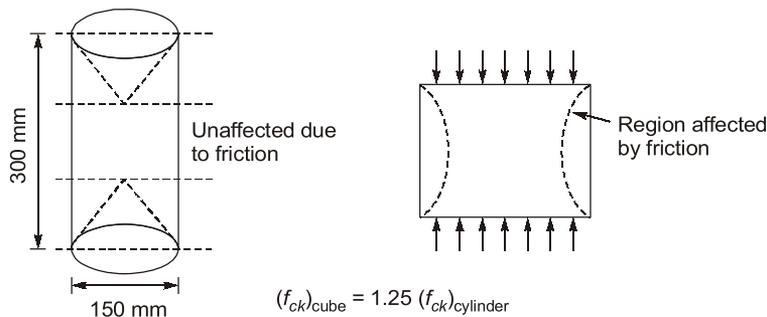
As per definition, characteristics strength should be 29 N/mm² since f_{ck} is designated in multiple of 5. So, f_{ck} should be either 25 or 30, in this case 7 samples (7%) are below 30 N/mm² so, 30 cannot be characteristics strength now, 25 is the characteristics strength of this concrete because zero sample (0% < 5%) is below 25 N/mm²

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

(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).

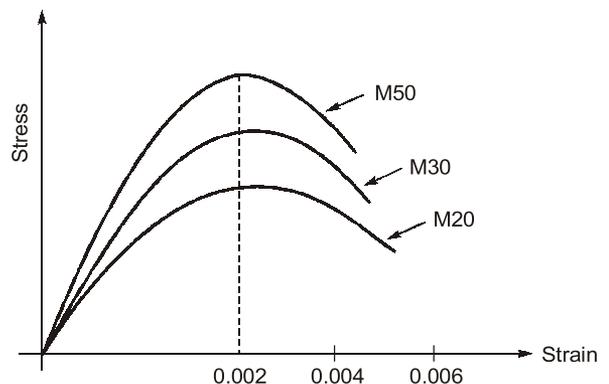
- Cylinder gives more appropriate result for uniaxial compressive strength because effect of friction between machine plate and ends of specimen is least.
- Middle portion of cylinder remain unaffected of friction.



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.

**Grade of Concrete**

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

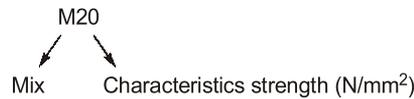
M10 }
M15 } Ordinary grade
M20 }

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:



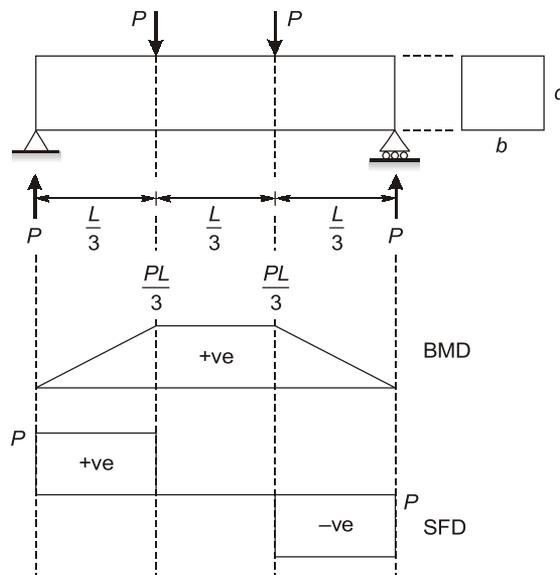
- IS 456 : 2000 is not applicable to grade above M-60 (Amendment No. 4, May 2013)
- IS 456 : 2000 recommends the minimum grade as M-20 for reinforced concrete.
- Minimum grade of RCC and PCC used, depends on the exposure condition.

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

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:

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

↓ ↓

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

(iii) Cylinder split test/splitting tensile strength of concrete: Owing to limitations of direct tensile strength test 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.

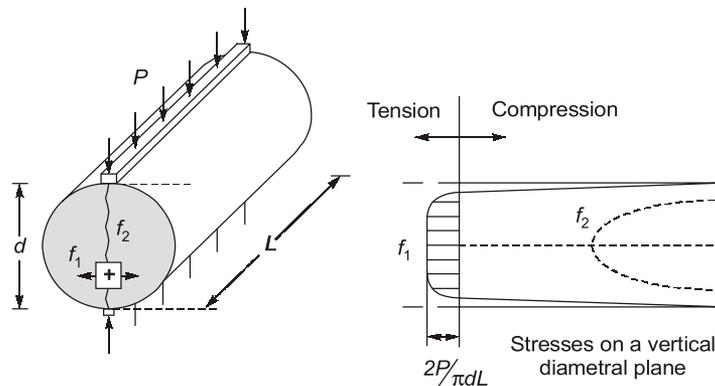


Fig. Cylinder splitting test for tensile strength



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 $2/3^{rd}$ 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

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

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

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

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.

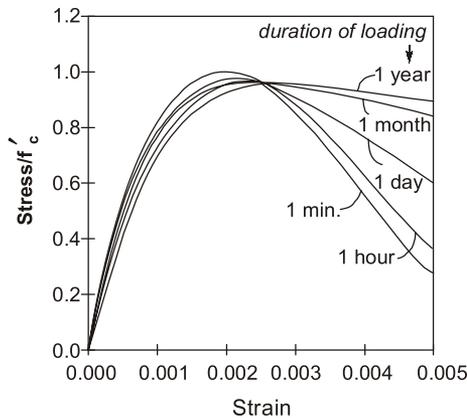


Fig. Influence of duration of loading (strain-controlled) on the stress-strain curve of concrete

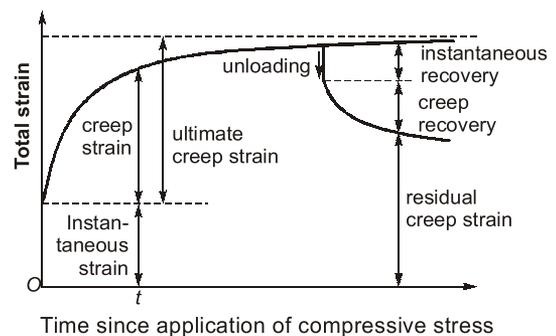


Fig. Typical strain-time curve for concrete in uniaxial compression

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 interpolated 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.

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:

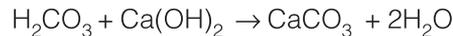
- This induce cracking on the top surface due to shortening of the concrete as sufficient tensile strength has not been developed in concrete.
- It is a short term process.

(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)



- 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.**

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

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	<ul style="list-style-type: none"> • Exposed to normal rain • Permanently submerged in normal water 	M25	300 kg/m ³	30 mm	0.55
Severe	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Exposed to sea spray • Footing in aggressive soil 	M35	340 kg/m ³	50 mm	0.45
Extreme	<ul style="list-style-type: none"> • 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).

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:

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

where,

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

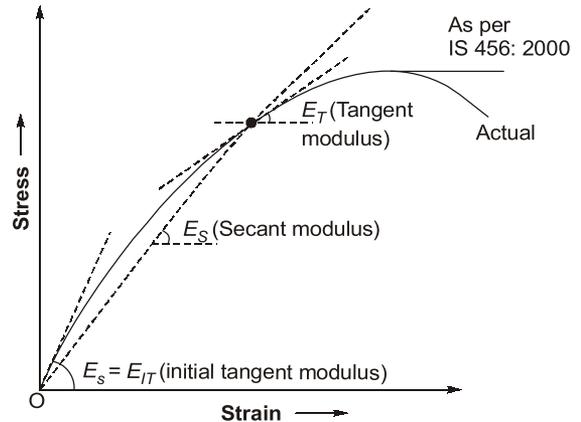


Fig. Various Types of Modulus of Elasticity of Steel

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.

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

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 $\pm 15\%$ 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

Acceptance Criteria of concrete

Assume 100 m³ 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

Average of 4 consecutive and non-overlapping \geq maximum $\begin{cases} f_{ck} + 0.825s \\ f_{ck} + 3 \end{cases}$ (S = Standard deviation)

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

1.8 Testing of Hardened Concrete

Destructive Testing

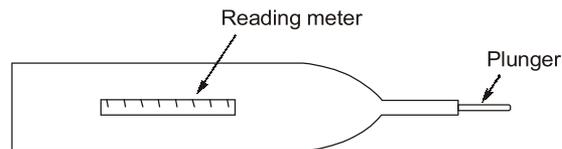
Sample used for destructive testing can not be used for service.

Load test: Used in precast element.

Corecut test: Used in road construction.

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.

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. 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

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 1:2.5	60
M7.5	625		45
M10	480		34
M15	330		32
M20	250		30
FA : Fine Aggregate, CA : Coarse Aggregate			

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).

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**.

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)**.

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.

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

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/m³) 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/m³ 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 m³ 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/m³. Density of FA is 1780 kg/m³ and coarse aggregate (CA) is 1650 kg/m³. Volume of one bag of cement is 34.7 litres. Assume volume of air in concrete as 3% per m³ 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 \Rightarrow 1 kg cement, 2 kg FA, 4 kg CA.

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

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

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

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

Now for cement,

$$e = 0.6$$

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

For fine aggregates,

$$e = 0.4$$

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

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 = $x \text{ kg}$
 \therefore 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
 $\Rightarrow 1 = \frac{x}{2304} + \frac{2x}{2492} + \frac{4x}{2376} + 0.03 + \frac{0.59x}{1000}$
 $\Rightarrow x = 276.35$
 \therefore Mass of cement in 1 m^3 concrete = $x = 276.35 \text{ kg}$
 Mass of water in 1 m^3 concrete = $0.59x = 163.05 \text{ kg}$
 Mass of fine aggregates in 1 m^3 concrete = $2x = 552.7 \text{ kg}$
 Mass of coarse aggregates in 1 m^3 concrete = $4x = 1105.4 \text{ kg}$

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 = $x \text{ m}^3$

\therefore Volume of cement : FA : CA = $x : 1.15x : 2.5x \text{ (m}^3\text{)}$

Also, Water-cement ratio = 0.56

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

Now, bulk density of cement, $\gamma_c = 1500 \text{ kg/m}^3$

Bulk density of sand, $\gamma_{FA} = 1780 \text{ kg/m}^3$

Bulk density of coarse aggregates, $\gamma_{CA} = 1650 \text{ kg/m}^3$

$\therefore x \text{ m}^3$ of cement $\equiv 1500x \text{ kg}$ of cement

$1.15x \text{ m}^3$ of sand $\equiv 1780(1.15x) \text{ kg}$ of sand

$2.5x \text{ m}^3$ of coarse aggregates $\equiv 1650(2.5x) \text{ kg}$ of coarse aggregates

and Mass of water = 0.56 times of mass of cement
 = $0.56 (1500 \cdot x) \text{ kg}$ of water per m^3 of concrete

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

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

$$\begin{aligned} \therefore \text{Volume of concrete} &= \text{Vol. of cement} + \text{Vol. of sand} + \text{Vol. of coarse aggregates} \\ &\quad + \text{Vol. of air} + \text{Vol. of water} \\ \Rightarrow 1 &= \frac{1500x}{3.15 \times 1000} + \frac{1780(1.15x)}{2.65 \times 1000} + \frac{1650(2.5x)}{2.3 \times 1000} + 0.03 \\ &\quad + \frac{0.56(1500x)}{1000} \\ \Rightarrow 0.97 &= 0.4762x + 0.7725x + 1.793x + 0.84x \\ \Rightarrow x &= 0.25 \\ \therefore \text{Weight of cement} &= 1500x = 375 \text{ kg} \\ \text{Weight of sand} &= 1780(1.15x) = 511.75 \text{ kg} \\ \text{Weight of coarse aggregates} &= 1650(2.5x) = 1031.25 \text{ kg} \\ \text{Weight of water} &= 0.56(1500x) = 210 \text{ kg} \end{aligned}$$

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/mm² 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 2×10^5 N/mm².

Types of Reinforcing Steel

- Mild Steel (Fe 250):** It can either be ORDINARY or HOT ROLLED with characteristic strength of 250 N/mm².
- Medium Tensile Steel:** It can also be either ORDINARY or HOT ROLLED.
- Cold Twisted Bar:** These are HYSD (HIGH YIELD STRENGTH DEFORMED) bars. e.g. Fe 415 and Fe 500 HYSD bars.
- 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.

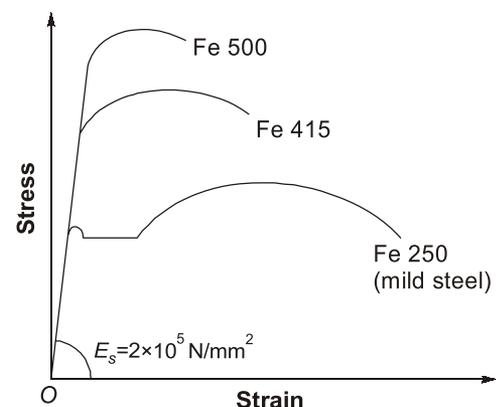


Fig. Stress strain behaviour of mild and HYSD steel

About Hot Rolled Mild Steel Reinforcement: In case of Hot Rolled mild steel reinforcement, a 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.

1.14 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 $\pm Y$ 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
- (a) $f_{ck} + 1.35\sigma$ (b) $f_{ck} + 1.45\sigma$
(c) $f_{ck} + 1.55\sigma$ (d) $f_{ck} + 1.65\sigma$
- [GATE-2014]

- Q.9** Limit state of serviceability of prestressed concrete sections should satisfy
 (a) cracking deflection and maximum compression
 (b) cracking only
 (c) deflection and cracking
 (d) deflection and maximum compression
- Q.10** Mild steel used in RCC structures conforms to
 (a) IS : 432 (b) IS : 1566
 (c) IS : 1786 (d) IS : 2062
- Q.11** The value of ultimate creep coefficient for concrete
 (a) increases with age of loading
 (b) decreases with age of loading
 (c) remains constant
 (d) is taken as 0.0003
- Q.12** The cover to reinforcement in a RC beam shall not be less than
 (i) 25 mm
 (ii) diameter of the bar (ϕ)
 (iii) spacing between the bars
 (iv) 5 mm
 Which of the above statement(s) is/are true?
 (a) (i) and (ii) (b) (i) only
 (c) (ii) only (d) (i) and (iii)
- Q.13** Minimum grade of concrete that can be used in structures as per IS 456: 2000 is
 (a) M15 (b) M20
 (c) M25 (d) M30
- Q.14** Which of the following reinforced concrete design philosophy do not distinguish between the different load cases?
 (a) Limit State Method
 (b) Working Stress Method
 (c) Ultimate Load Method
 (d) All of the above
- Q.15** The number of concrete cube samples required to be taken for 35 m³ of concreting work as per IS 456 : 2000 is:
 (a) 1 (b) 2
 (c) 3 (d) 4
- Q.16** Which of the following curve is NOT covered by **IS 456 : 2000**?
 (a) Stress strain curve of concrete in tension.
 (b) Stress strain curve for mild steel.
 (c) Stress strain curve of concrete in compression.
 (d) Stress strain curve for cold worked steel.
- Q.17** Flexure strength of concrete is determined as
 (a) modulus of rigidity
 (b) modulus of rupture
 (c) modulus of plasticity
 (d) modulus of elasticity
- Q.18** Why are steel reinforcing rods used in concrete beams
 (a) to make it carry compression
 (b) to make it carry tension
 (c) to make it carry tension as well as compression
 (d) none of these
- Q.19** As per IS 456 : 2000, in absence of test data approximate value of total shrinkage strain for design may be taken as
 (a) 0.004 (b) 0.001
 (c) 0.002 (d) 0.0003
- Q.20** Characteristics strength of concrete measured at
 (a) 14 days (b) 28 days
 (c) 91 days (d) 7 days

ANSWER KEY // **STUDENT'S ASSIGNMENTS**

- | | | | | |
|----------------|----------------|----------------|----------------|----------------|
| 1. (d) | 2. (b) | 3. (c) | 4. (a) | 5. (d) |
| 6. (d) | 7. (c) | 8. (d) | 9. (c) | 10. (b) |
| 11. (b) | 12. (a) | 13. (b) | 14. (b) | 15. (d) |
| 16. (a) | 17. (b) | 18. (b) | 19. (d) | 20. (b) |

