CHAPTER 01

Introduction

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.

1.3.1 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.

1.4 Characteristic Strength of Concrete

Due to wide variation in the characteristics of concrete constituents (sand, coarse aggregates etc.), concrete is subjected to considerable variation in strength. Also, due to non-homogeneous nature of concrete, specimens taken from the same mix may give different compressive strengths in tests. This variation can be controlled by strict quality control and quality assurance.

Table 1.1: *Characteristic compressive strength compliance requirement (as per Cl. 16.1 and 16.3 of IS 456: 2000)*

Specified Grade	Mean of the Group of 4 Non-Overlapping Consecutive Test Results in N/mm²	Individual Test Results in N/mm²
M20 or above	$\geq f_{ck}$ + 0.825 × Established standard deviation (rounded off to nearest 0.5 N/mm²) or f_{ck} +4 N/mm², whichever is greater	$\geq f_{ck}$ -4 N/mm²

Statistically, the variation in concrete strength is studied in terms of **standard deviation** and/or **coefficient of variation.**

$$\text{Coefficient of variation} = \frac{\text{Standard deviation}}{\text{Mean strength}}$$

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) follows **normal/Gaussian distribution. The coefficient of variation varies generally in the range of 0.01 to 0.02.** With higher degree of quality control, this variation can be reduced.

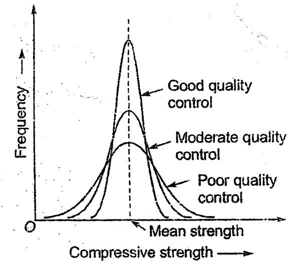

Fig.1.1 *Influence of quality control on the frequency distribution of concrete strength*

1. Strength of concrete in uniaxial compression is determined by testing a standard cube of 150 mm size and is loaded till its failure.
2. The cube specimen is tested after 28 days of casting and curing.
3. The strength of cube is always expressed nearest to 0.5 N/mm².
4. As per IS 456: 2000, there should be three specimens in a sample.
5. Strength of sample is expressed as an average of three specimens of the sample.
6. Individual variation in the strength of cubes should not vary by more than ±15% of average strength and if the variation is more then the test results are discarded.

Do You Know?

Why it is needed to define characteristic strength of concrete?

Due to significant variation in the compressive strength of concrete (tested on concrete cube/cylinder specimens), it is quite essential to ensure that a certain minimum strength of concrete can always be obtained from a given mix. This is obtained by defining **Characteristic Strength** of concrete (which is applicable for other materials also).

Characteristic Strength is defined as that strength of the material below which not more than 5% of the tests results are expected to fall. This is shown in the Fig.1.2.

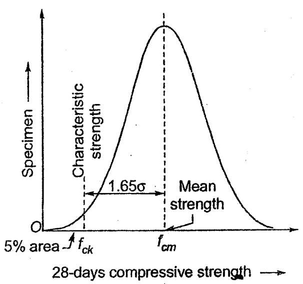

Fig.1.2 *Idealised normal distribution of concrete strength*

Thus, mean strength of concrete has to be significantly greater than the characteristic strength of concrete.

1.5 Grade of Concrete

The desired properties of concrete are its compressive strength, tensile strength, shear strength, bond strength, density, durability, impermeability etc. Among these properties, the most important property is the compressive strength of concrete. This is measured by standard tests on concrete cube/cylinder specimens. Many other properties of concrete can be inferred from its compressive strength.

The grade of concrete is expressed in terms of its characteristic compressive strength (of 150 mm cube at 28 days) expressed in N/mm^2 or MPa. e.g. Different grades of concrete are M20, M25, M30, M40 and so on.

Do You Know? In the recent revised version of IS 456: 2000, minimum grade of concrete is based on considerations of durability and the type of environment that the structure is exposed to. Minimum concrete grade in RCC has been upgraded from M15 to M20 in IS 456: 2000. Minimum grade of concrete as per exposure conditions is shown in Table 1.2.

Table 1.2: *Minimum grade of concrete based on exposure conditions as per IS: 456*

Exposure Condition	Minimum Concrete Grade
Mild	M20
Moderate	M25
Severe	M30
Very Severe	M35
Extreme	M40

1.6 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.

Table 1.3: *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.

1.6.1 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.

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.

Table 1.4: *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

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).

1.6.2 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.

1.7 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 1.5.

Table 1.5: *Standard deviation for various concrete grades*

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

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 1.6.

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.

Table 1.6: Minimum cement content and maximum water cement ratio based on exposure conditions

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

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

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

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

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

Now for cement, $e = 0.6$

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

For fine aggregates, $e = 0.4$

⇒ 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, $\gamma_{mCA} = \gamma_{CA}(1+e) = 1650(1+0.44) = 2376$ 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

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

⇒ $x = 276.35$

∴ 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 1.2 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

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

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

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

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

∴ Volume of concrete = Vol. of cement + Vol. of sand + Vol. of coarse aggregates + Vol. of air + Vol. of water

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

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

$$\Rightarrow \quad x = 0.25$$

$\therefore$ 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

1.8 Behaviour of Concrete under Uniaxial Compression

Strength of concrete is determined by the compressive strength test on a standard 150 mm concrete cube in a compression testing machine as per **IS 516: 1959**. The test specimens are generally tested after 28 days of casting and continuous curing. The loading is **strain-controlled** and load is generally applied at a uniform **strain rate of 0.001 mm/mm/minute**. The maximum stress attained in this loading process is called as **cube strength** of concrete.

Remember In USA, instead of 150 mm cubes, standard test cylinders of height to diameter ratio of 2, e.g. 150 mm diameter and 300 mm height cylinders are used. **Cylinder strength comes out to be lower than the cube strength of concrete** for the same quality of concrete.

1.8.1 Influence of Specimen Size on Strength of Concrete

Height to width ratio of the specimen and the cross sectional dimensions of the specimen affects the compressive strength (maximum stress attained) obtained from compression testing machine.

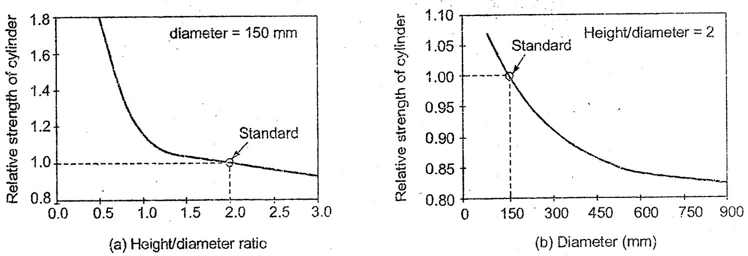

Fig.1.3 *Influence of (a) height/diameter ratio and (b) diameter on cylinder strength*

In case of cylindrical test specimen of 150 mm diameter and height to diameter ratio of 2, the compressive strength of the concrete specimen increases to about 80% as the height/diameter ratio is reduced from 2 to 0.5. With the same height/diameter ratio being equal to 2, the strength decreases by about 17% as the diameter of the cylindrical specimen is increased from 150 mm to 900 mm.

The loading plates and the top/bottom surface of the concrete specimen offers some frictional resistance called as **platen restraint** which introduces shear stress at the top and bottom surfaces of the specimen and this effect diminishes as the distance between the platen surfaces increases.

For this reason, standard concrete cube (height/diameter ratio equal to 1) specimen gives higher compressive strength than the cylindrical specimen (height/diameter ratio equal to 2).

Remember: Cube strength of concrete is nearly 1.25 times the cylinder strength.

1.8.2 Stress Strain Curve of Concrete in Compression

These stress strain curves of concrete for various grades are somewhat linear in the initial phase of loading. The non-linearity in the curve becomes quite significant when the stress in concrete reaches to about one third to one half of the maximum value.

For concrete, the maximum stress is reached at a strain which is approximately equal to 0.002, beyond which an increase in strain is accompanied by a decrease in stress. Usually at failure, the strain in concrete ranges from 0.003 to 0.005.

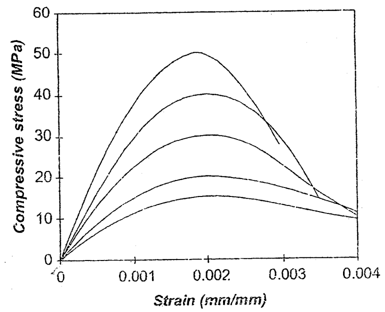

Fig.1.4 *Typical stress-strain curves of concrete in compression*

1.9 Behaviour of Concrete in Tension

Concrete is quite weak in tension and is not supposed to and also not designed to take any direct tension. But tensile stresses occur in concrete due to flexure, shear, shrinkage and temperature stresses etc. Pure shear causes tension on diagonal planes for which sufficient knowledge of direct tensile strength of concrete is important for assessing the shear strength of beams with unreinforced webs. For assessing the moment at first crack, the knowledge of flexural tensile strength of concrete is necessary. The direct tensile strength of concrete is about 7 to 15 % of the compressive strength of concrete.

It is difficult to have direct tension test on concrete as it requires pure axial tensile stress free from any secondary stresses and misalignment in the tension testing machine. Thus indirect tension tests are performed using **flexure test** or **cylinder splitting test**.

1.9.1 Modulus of Rupture of Concrete

While performing flexure test, a standard simply supported plain concrete beam of square or rectangular section is used, which is subjected to three points loading until failure. For a linear stress distribution across the section, the theoretical maximum tensile stress which is developed in the extreme fiber is called as **modulus of rupture** (f_{cr}) of concrete. It is given by,

$$f_{cr} = \frac{M}{Z}$$

Where, M is the bending moment that causes failure and Z is the section modulus.

But the actual stress distribution across the section is not linear. IS 456: 2000 recommends the use of following formula for modulus of rupture of concrete (f_{cr}):

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

where, stress units are in MPa or N/mm^2.

1.9.2 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:

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

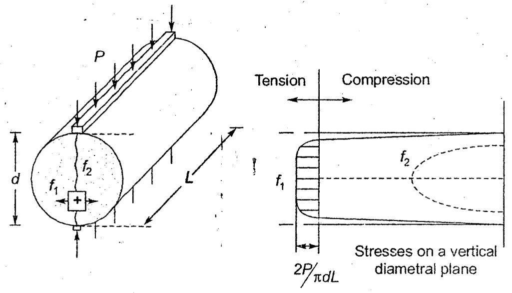

Fig.1.5 *Cylinder splitting test for tensile strength*

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.

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.

1.9.3 Stress Strain Curve of Concrete in Tension

Concrete is very weak in tension and thus has low failure strain in uniaxial tension, being in the range of 0.001 to 0.002. The stress - strain curve of concrete in tension is approximated as a straight line from origin to the point of failure. The modulus of elasticity of concrete in tension is taken to be the same as that of compression. Since the tensile strength of concrete is very low and is invariably ignored in design, the tensile stress-strain relationship of concrete is of very minimal practical value.

1.10 Modulus of Elasticity and Poisson's Ratio of Concrete

Concrete is not a truly elastic material i.e. it cannot regain its original shape from the deformed shape after removal of loading. It is not only **inelastic**, it is **non-linear** also i.e. stress – strain relationship is not linear. Thus, conventional elastic constants (like modulus of elasticity, Poisson's ratio etc.) cannot be defined for a non-linear, inelastic material like concrete. Even though we have to define these constants for concrete in order to make possible the analysis of structures which are in fact based on linear elastic analysis.

The Young's modulus of elasticity is the ratio of axial stress to axial strain under uniaxial loading within the linear elastic range and it is a constant. For concrete under uniaxial compression, this is valid only in the very initial portion of the stress - strain curve which is nearly linear i.e. loading is of low intensity and of short duration. Sustained loading introduces the effect of **creep** even at low loading intensities.

In situations, where long term effects of loading on the structure are negligible like wind or earthquake loading, we define **initial tangent modulus** which is in fact a measure of **dynamic modulus of elasticity** of concrete. In the usual linear static analysis, we define **static modulus of elasticity**. When loads on the structure are of long duration (dead and live loads), the long term effects of **creep decreases the effective modulus of elasticity of concrete**.

It is difficult to separate the long term strains due to creep and shrinkage from short term elastic strains. Thus, while estimating deflection of reinforced concrete beam, the total deflection is assumed to be the sum of instantaneous elastic deflection (due to loads) and long term deflections due to creep and shrinkage. Short term static modulus of elasticity of concrete (E_c) is used in computing the instantaneous elastic deflection.

Various definitions of *modulus of elasticity of concrete* (E_c) are there. Some of them are initial tangent modulus, tangent modulus (at specified stress level), secant modulus (at specified stress level) etc. Secant modulus at a stress level of about 1/3rd the cube strength of concrete is generally found acceptable in expressing the average value of E_c under the usual service load conditions.

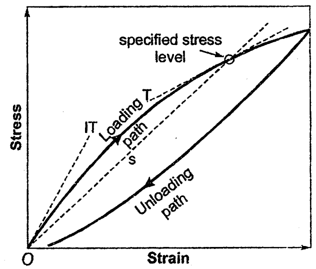

Fig.1.6 *Various descriptions of modulus of elasticity of concrete*

(IT = Initial tangent, T = tangent, s = secant)

As per IS 456: 2000, short term static modulus of elasticity of concrete (E_c, in MPa) is given in terms of characteristic strength of concrete as:

$$E_c = 5000\sqrt{f_{ck}}$$

Do you know? Earlier version of code i.e. IS 456:1978 gave this value as $5700\sqrt{f_{ck}}$, which was an over estimation of the elastic modulus.

1.10.1 Poisson's Ratio

It is the ratio of lateral strain to the longitudinal strain under uniform uniaxial stress. For concrete, a wide range of values of Poisson's ratio are obtained which range from 0.1 to 0.3. For design purposes, a value of 0.15 or 0.2 is considered.

1.11 Effect of Duration of Loading on Stress Strain Curve

The standard compression test gets over within 10 minutes with loading being applied at a uniform strain rate of 0.001 mm/mm/minute. When load is applied at a faster strain rate (as impact loading), the modulus of elasticity and strength of concrete increase but the failure strain decreases. When the load is applied at a slower rate (duration greater than 10 minutes to as long as 1 year or more) then there is a slight decrease in the modulus of elasticity and significant increase in the failure strain.

1.12 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.

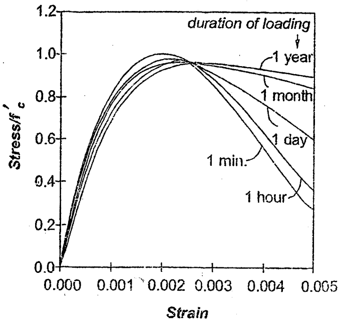

Fig.1.7 *Influence of duration of loading (strain-controlled) on the stress-strain curve of concrete*

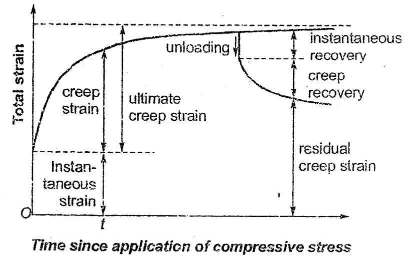

Fig.1.8 *Typical strain-time curve for concrete in uniaxial compression*

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.

1.13 Compressive Strength of Concrete in the Design of Structures

The compressive strength of concrete in an actual structure cannot be exactly same as compressive strength obtained by uniaxial compression test in laboratory even for the samples obtained from the concrete mix which is used in actual construction. This is because of the effect of loading duration, member sizes and strain gradient.

The maximum strength of concrete is taken as 0.85 times the specified cylinder strength for the design of RCC members (for both in compression and flexure/bending). This comes out to be approximately equal to 0.67 times the characteristic cube strength. IS 456: 2000 also limits the failure strain to 0.002 in direct compression and 0.0035 in flexure.

Remember When the predominant loading on the structure is of short term nature (like wind or earth quake loading on towers, chimneys etc.) and NOT the sustained loading then it is too conservative to limit the compressive strength of concrete to 0.85 times the cylinder strength or 0.67 times the characteristic cube strength. In such cases, a suitable higher value of compressive strength is taken.