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RPSC - A.En.

Assistant Engineering

CIVIL

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Volume - 10

Reinforced Concrete Structures (RCC)

SIERRA
INNOVATIONS

1

INTRODUCTION

THEORY

1.1 PLAIN CONCRETE

It is a mixture of sand, gravel, cement, and water which results in a solid mass. Concrete is strong in compression but weak in tension. Its tensile strength is approx. One tenth of compressive strength. Plain concrete is mostly used in mass concrete work. (As in dams).

1.2 REINFORCED CONCRETE

It is a concrete with reinforcement embedded in it. The embedded reinforcement makes it capable of resisting tension also.

Steel bars embedded in the tension zone of concrete, relieves concrete of any tension and takes all tension without separating from concrete.

The bond between steel and surrounding concrete ensures strain compatibility i.e., the strain at any point in the steel is equal to that in the adjoining concrete.

Reinforcing steel imparts ductility to concrete which is otherwise brittle material.

Here ductility means large deflection owing to yielding of steel, thereby giving ample warning of impending collapse.

Tensile stress in concrete arises on account of direct tension, flexural tension, diagonal tension (due to shear), temperature and shrinkage effect and restraint to deformation.

Under these conditions, reinforcements must be provided across potential tensile crack.

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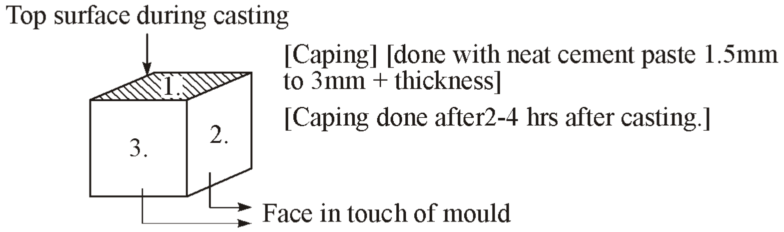
1.3 GRADE OF CONCRETE

Compressive strength of concrete is the most important property of concrete. Because other properties like tensile strength, shear strength, bond strength, density, impermeability, durability etc. can be inferred from the compressive strength using established correlations.

Compressive strength can be measured by standard test on concrete cube, (or cylinder) specimen.

Strength of concrete in uniaxial compression is determined by loading standard test cube (150 mm size) to failure in compression testing machine.

The test specimen is generally tested 28 days after casting (and continuous curing)

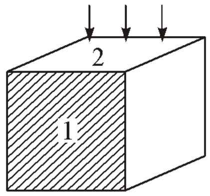


Top surface during casting

[Caping] [done with neat cement paste 1.5mm to 3mm + thickness]

[Caping done after2-4 hrs after casting.]

Face in touch of mould



Cube is always tested on sides i.e., face in touch with mould.

Strength of cube is expressed to the nearest of 0.5 N/mm^2

As per IS 456 : 2000, three specimen of a sample is taken.

Additional samples may be required for various purposes such as to determine the strength of concrete at 7 days or at the time of striking of the foam work, or to determine the duration of curing, or to check the testing error. Additional specimen may also be required for testing samples cured by accelerated methods

To report, strength of cube, we take average of three specimen of a sample.

Individual variation should not be more than ±15% of average if variation is more, test results of the sample are invalid.

1.4 ACCEPTANCE CRITERIA

Compressive Strength : The concrete shall be deemed to comply with the strength requirements when both the following condition are met:

(a) The mean strength determined from any group of four non–overlapping consecutive test results compiles with the appropriate limits in col. 2 of table shown below

(b) Any individual test result complies with the appropriate limits in col 3 of table shown below

Characteristic compressive strength compliance requirement (Clauses 16.1 and 16.3)

Specified grade (1)	Mean of the group of 4 non-overlaping consecutive test results in N/mm^2 (2)	Individual test result in N/mm^2 (3)
M 15	≥ f_{ck} + 0.825 × established standard deviation (rounded off to nearest 0.5 N/mm^2) or f_{ck} + 3 N/mm^2, whichever is greater	f_{ck} – 3N/mm^2
M20 or above	≥ f_{ck} + 0.825 × established standard deviation (rounded off to nearest 0.5 N/mm^2) or f_{ck} + 4N/mm^2, whichever is greater	f_{ck} – 4N/mm^2

Flexural Strength : When both the following conditions are met, the concrete complies with the specified flexural strength.

(a) The mean strength determined from any group of four consecutive test results exceeds the specified characteristic strength by at least 0.3 N/mm^2.

(b) The strength determined from any test result is not less than the specified characteristic strength less 0.3 N/mm^2.

Variation in strength : No material is truly homogeneous, so the strength of similar concrete varies in different testing.

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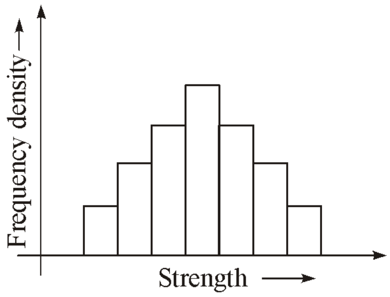
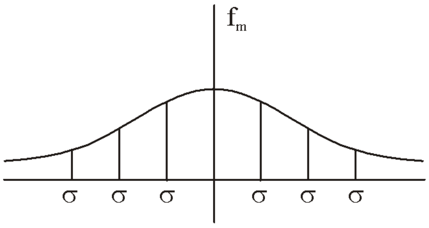
$$\text{Frequency density} = \frac{\text{No. of samples in an interval}}{\text{Total no. of samples}}$$

If the number of sample are increased indefinitely, the histogram becomes probability distribution curve. For most of the engineering material, probability is symmetrical about mean and such a curve is called ***Normal Probability distribution curve***.





$$\text{Mean strength } (f_m) = \frac{\Sigma f \longleftarrow \text{Strength of sample}}{m \longleftarrow \text{No. of sample}}$$

$$\sigma = \sqrt{\frac{\Sigma(f - f_m)^2}{m}}$$

$f - f_m$ = deviation from mean,

σ = standard deviation.

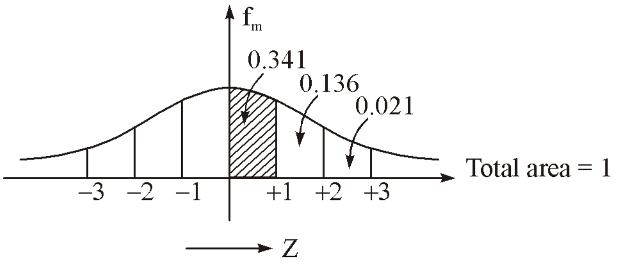
Spread of σ is the measure of quality control.

(Large σ) ⇒ (more strength variation) ⇒ poor quality control.

(Small σ) ⇒ (less strength variation) ⇒ high quality control.

Taking mean as origin. Let $Z = \frac{f - f_m}{\sigma}$. then probability density (or frequency density)

$$\boxed{y = \frac{1}{\sqrt{2\pi}} e^{-z^2/2}}$$



Probability of strength failing below $(f_m - \sigma)$

$= 1 - (0.5 + 0.341) = 0.159 = 15.9\%$

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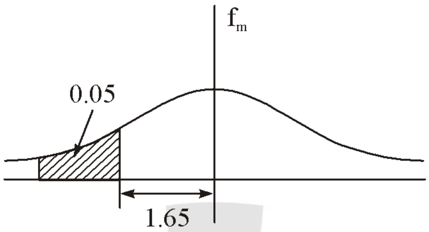
1.5 CHARACTERISTIC STRENGTH (f_{ck})

It is that strength below which not more than 5% of test results are expected to fail

$$\boxed{f_{ck} = f_m - 1.65\sigma}$$



Note :

For no. of test samples ≥ 30, $\sigma = \sqrt{\dfrac{\Sigma(f - f_m)^2}{m}}$

If no, of test samples < 30, $\sigma = \sqrt{\dfrac{\Sigma(f - f_m)^2}{m - 1}}$

Concrete is designated by characteristic cube strength of concrete at 28 days.

As cement hydrates, it gains strength over a long period. Hence we need to specify the strength after some particular time.

Note :

At 28 days curing, if strength = 1 = Reference strength, then

At 6 month curing, strength = 1.2 ie 20% more

At 7 days curing, strength = 0.7 ie 30% less

[exact values depend on mix properties and type of cement]

If the concrete is cured for less than 7 days, strength at 28 days will be quite less. Hence, min curing period is 7 days for OPC.

Grades of concrete are based on characteristic strength. As per IS code the various grades of concrete are

$$\left.\begin{array}{l} M10 \\ M15 \\ M20 \end{array}\right\} \text{ ordinary grade concrete}$$

$$M25 - M55\} \ - \text{ standard grade concrete}$$

$$M60 - M90\} \ - \text{ High strength concrete}$$

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

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Note :

IS 456 : 2000 is not applicable to M60 & above.

IS 456 : 2000 recommends the minimum grade as M20 for reinforced concrete.

Minimum grade of RCC used, depends on the exposure conditions.

Exposure condition	**Minimum grade**
Mild	M20
Moderate	M25
Severe	M30
Very Severe	M35
Extreme	M40

1.6 CONCRETE MIX DESIGN

Design of concrete mix involves economical selection of relative proportions of various ingredients of concrete.

Apart from meeting the criteria for characteristic strength, the concrete must be workable in fresh state and impermeable and durable in hardened state.

Nominal mix concrete : Nominal mix concrete is permitted only in ordinary concrete (i.e. upto M20 grade). For higher grade, design mix is adopted.

In Nominal mix, the mix is specified in terms of total mass of aggregate, properties of fine aggregate to coarse aggregate and vol. of water to be used per 50 kg of cement [i.e, per bag of cement]

Note :

Vol of 1 bag of cement is normally 34.5 litres in sealed condition in the bag.

As per IS 456 : 2000 : Proportion of Nominal mix concrete are as under given in Table below.

Grade of concrete	**(Wt of FA + CA) in kg 50 kg of cement**	**FA : C.A.**	**Wt of water (in kg) per 50 kg of cement**
M5	800	Generally	60
M7.5	625	1:2	45
M10	480	but can be	34
M15	330	in the range of	32
M20	250	1 : 1.5 to 1 : 2.5	30

Note :

For FA : CA = 1 : 2, the proportion of cement : fine aggregates : coarse aggregate will be an given below

Cement : FA : CA

$$M5 \rightarrow 50 : \frac{800}{3} : \frac{1600}{3} = 1 : 5.33 : 10.67 \qquad \text{w/c ratio} = 1.2$$

$$M7.5 \rightarrow 50 : \frac{625}{3} : \frac{1250}{3} = 1 : 4.16 : 8.33 \qquad 0.9$$

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$M10 \rightarrow 50 : \frac{480}{3} : \frac{960}{3} = 1 : 3.2 : 6.4$	0.68
$M15 \rightarrow 50 : \frac{330}{3} : \frac{660}{3} = 1 : 2.2 : 4.4$	0.64
$M20 \rightarrow 50 : \frac{250}{3} : \frac{500}{3} = 1 : 1.67 : 3.33$	0.60

Design mix concrete : Various steps in the IS code method of design mix (IS : 10262–1982)

(1) Determine target mean strength (fm)

$$\boxed{f_m = f_{ck} + 1.65\sigma}$$

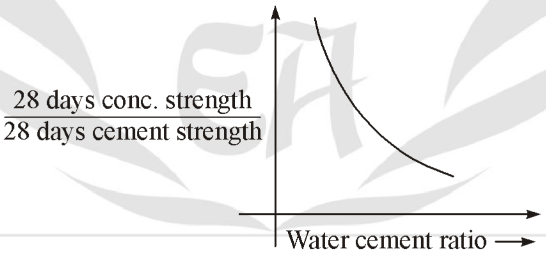
f_{ck} = characteristic strength

σ = standard deviation

σ is calculated from the previous records or may be assumed as per table given below

Grade of Concrete	Assumed σ(N/mm^2)
M10 – M15	3.5
M20 – M25	4.0
M30 – M50	5.0

(2) Determine water–cement ratio from the charts available as shown below :



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This water cement ratio obtained, however should not exceed the limits given in table [from durability consideration].

For RCC with 20 mm aggregate, the minimum cement content and max water cement ratio from durability consideration are given as under.

Exposure	Mix cement content kg/m^3	Max 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

Note:

(1) Free water means water excluding that absorbed by aggregate.

(2) For purely chemical requirement (i.e., for complete hydration of cement), w/c ratio required is 0.25.

(3) Determine the water content (V_w) based on workability requirement and select ratio of fine aggregate and coarse aggregate by mass based on type and grading of aggregate.

Normally water content = 180 – 200 *l*/m^3 of concrete

$$\frac{\text{F.A.}}{\text{C.A.}} = 1:2 \quad \text{[Normally in the range of 1 : 1.5 to 1 : 2.5]}$$

(4) Find cement content M_c (kg/m^3) from water content and water cement ratio.

$$\boxed{M_C = \frac{V_w}{(w/c)}}$$

Cement content should not be less than that obtained from durability consideration from table above

(5) Mass of fine aggregate and coarse aggregate should be calculated from absolute volume principle.

$$\boxed{\frac{M_C}{\rho_c} + \frac{M_{fa}}{\rho_{fa}} + \frac{M_{c.a}}{\rho_{c.a}} + V_w + V_v = 1.0}$$

ρ_c, ρ_{fa}, $\rho_{c.a}$ are the mass density of cement, fine aggregate and coarse aggregate.

V_w = vol. of water per m^3 of concrete

V_v = vol. of voids per m^3 of concrete [Normally 2%]

(6) Determine the wt of ingredients per batch, based on capacity of concrete mixer.

Example :

Calculate the quantities of cement, sand and coarse aggregate required to produce one cubic meter of concrete for mix proportions of 1 : 1.40 : 2.80 (by volume) with water cement ratio of 0.48 (by mass). Bulk densities of cement, sand and coarse aggregates are 14.7, 16.66 and 15.68 kN/m^3, respectively. Percentage of entrained air is 2.0. Specific gravities of cement, sand and coarse aggregate are 3.15, 2.6 and 2.5, respectively.

Solution :

Cement : F.A. : CA $\qquad x\text{m}^3 : 1.4x\ \text{m}^3 : 2.8 \times \text{m}^3$

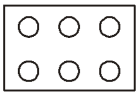
$$\frac{\text{weight of water}}{\text{weight of cement}} = 0.48$$

$$\frac{\text{Weight}}{\text{Volume}} = \text{Absolute density } (e_s) = \frac{W_s}{V_s}$$

$$e_{\text{bulk cement}} = 14.7 \text{ kN/m}^3$$

$$e_{\text{bulk F.A.}} = 16.66 \text{ kN/m}^3$$

$$e_{\text{bulk C.A.}} = 15.68 \text{ kN/m}^{3.}$$



$$\frac{\text{Weight}}{\text{Volume}} = \frac{\text{Weight of solid}}{V_s + V_{air}} = \text{bulk density}$$

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$$\therefore \quad \text{Cement : FA : CA} = (14.7\text{ x kN}) : (1.4 \times 16.66\text{ x kN}) : (15.68 \times 2.8\text{x})$$

$$\text{Weight of water} = 0.48 \times \text{weight of cement}$$

$$= 0.48 \times 14.7\text{ x kN}$$

$$\text{Volume of water} = \frac{0.48 \times 14.7\text{x}}{\gamma_w}\text{m}^3$$

$$\text{Vol. of air} = 0.02\text{ m}^2$$

$$\therefore \quad \frac{14.7\text{x}}{3.15\gamma_w} + \frac{1.4 \times 16.66\text{x}}{2.6\gamma_w} + \frac{15.68 \times 2.8\text{x}}{2.5\gamma_w} + \frac{0.48 \times 14.7\text{x}}{\gamma_w} + 0.02 = 1\text{m}^3$$

$$\therefore \quad \text{x} = 0.257\text{ m}^3$$

Now,

$$\text{Weight of cement} = 14.7\text{ x} = 3.777\text{ kN} = 377.7\text{ kg } [1\text{ kN} = (100\text{ kg})]$$

$$\text{Weight of FA} = 1.4 \times 16.66\text{ x} = 5.994\text{ kN} = 599.4\text{ kg}$$

$$\text{Weight of CA} = 15.68 \times 2.8\text{ x} = 11.283\text{ kN} = 1128.3\text{ kg}$$

$$\text{Weight of water} = 0.48 \times 14.7\text{ x} = 0.48 \times 377.7 = 181.296\text{ kg}$$

Example :

Estimate the quantities of cement, fine aggregate and coarse aggregate per cubic metre of concrete if the void ratio in cement is 62%, fine aggregate is 41% and coarse aggregate is 45%. The material properties are as follows :

1 : 2 : 4 with a w/c of 0.55, one bag of cement contains 50 kg of cement and its density is 1440 kg/m^3. The density of fine aggregate is 1700 kg/m^3 and coarse aggregate is 1600 kg/m^3 respectively. One bag of cement is equal to 34.7 litres.

Solution :

When the mix proportion is given like 1:2:4, and it is not mentioned whether it is by volume or by weight, we should always take it as by weight like 1 kg cement: 2 kg fine aggregate : 4 kg coarse aggregate

Also, bulk density or simply density of cement means

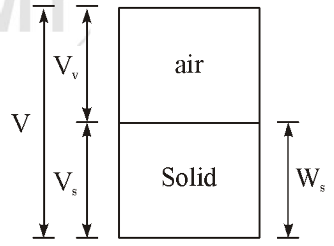
$$\text{Bulk density or density of cement} = \frac{\text{Mass of cement}}{\text{Vol. of cement}}$$

on the other hand, absolute density or mass density means

$$\text{Absolute density or mass density of cement} = \frac{\text{Mass of cement}}{\text{Vol. of cement solid}}$$

$$\text{Mass density} = \frac{W_s}{V_s}$$

$$\text{Bulk density} = \frac{W_s}{V} = \frac{W_s}{V_s + V_v} = \frac{W_s/V_s}{1 + \frac{V_v}{V_s}}$$



$$\boxed{\text{Bulk density} = \frac{\text{Mass density}}{1 + \text{e}}}$$

where,

$$\text{e} = \text{Void ratio}$$

$$\text{e}_{\text{cement}} = 0.62$$

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Bulk density of cement = 1440 kg/m^3

$e_{\text{fine aggregate}} = 0.41$

Bulk density of fine aggregate =1700 kg/m^3

$e_{\text{coarse aggregate}} = 0.45$

Bulk density of coarse aggregate = 1600kg/m^3

$\Rightarrow$ Mass density of cement,

$$\rho_c = (\text{Bulk density of cement}) \times (1 + e_c)$$

$$\rho_c = 1440 \times 1.62 = 2332.8 \text{ kg/m}^3$$

Similarly, $\rho_{fa} = 1700 \times 1.41 = 2391 \text{ kg/m}^3$

$$\rho_{ca} = 1600 \times 1.45 = 2320 \text{ kg/m}^3$$

Let the volume of air in 1m^3 of concrete = 0.02 m^3

Sum of vol. of all ingredients =Vol. of concrete

Let the mass of cement in m^3 of concrete be x kg.

$\Rightarrow$ x kg of cement is to be mixed with 2x kg fine aggregate and 4x kg coarse aggregate and as $\frac{W}{C}$ ratio is 0.55 wt of water is 0.55x.

$$\Rightarrow \frac{x}{2332.8} + \frac{2x}{2397} + \frac{4x}{2320} + \frac{0.55x}{1000} + 0.02 = 1$$

$\Rightarrow$ x = 277.06 kg

$\Rightarrow$ Wt. of cement for 1m^3 Concrete = 277.06kg

$\Rightarrow$ Wt. of F.A for 1m^3 Concrete = 554.12kg

$\Rightarrow$ Wt. of C.A for 1m^3 Concrete = 1108.24kg

$\Rightarrow$ Wt. of water for 1m^3 Concrete = 152.383kg

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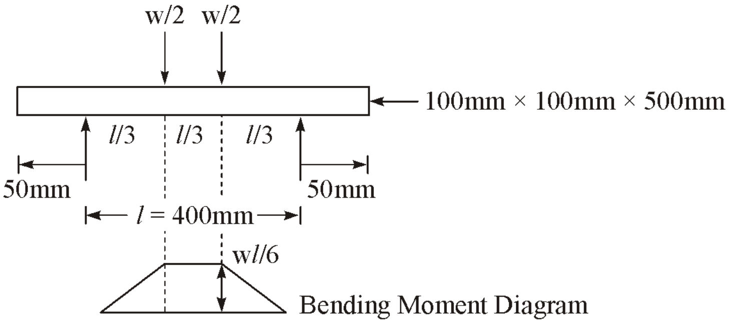
1.7 COMPRESSIVE STRENGTH OF CONCRETE IN STRUCTURES

Strength of concrete is found to decrease with increase in the size of the specimen. However, beyond 450mm size, there is no decrease in the compressive strength of concrete.

Thus, compressive strength of concrete in structure is taken as 0.67 f_{ck}

1.8 FLEXURAL STRENGTH OF CONCRETE (MODULUS OF RUPTURE)

Tensile strength of concrete in flexure is called flexural strength.



$$\frac{M}{Z} = \frac{W \times 400}{\frac{w \times 400 \times (100)^2}{6}} \times 10^3 \ \text{N/mm}^2$$

[If W is in kN] [Assuming linear stress strain curve and contribution of steel area to be negligible]

$$\boxed{f_{cr} = 0.4W \ \text{N/mm}^2 \ \text{[For onset of cracking.]}}$$

However, stress strain variation is not linear hence as per IS code

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

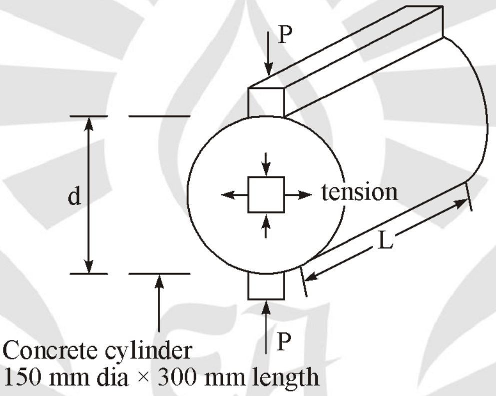
$$\downarrow \qquad \downarrow$$

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

Flexural strength is used to determine the onset of cracking or the loading at which cracking starts in a structure.

1.9 TENSILE STRENGTH OF CONCRETE

Tensile strength of plain concrete is obtained by the splitting test.



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

f_{ct} = splitting tensile strength = 0.66 f_{cr}

Direct tensile strength = [0.5 to 0.625] f_{cr}

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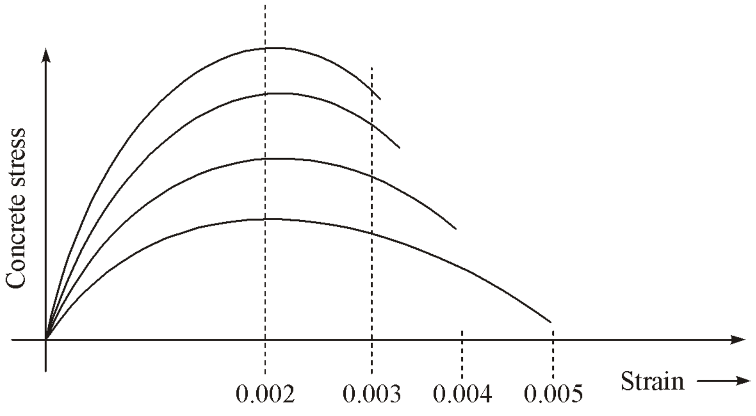
1.10 STRESS-STRAIN CURVE OF CONCRETE

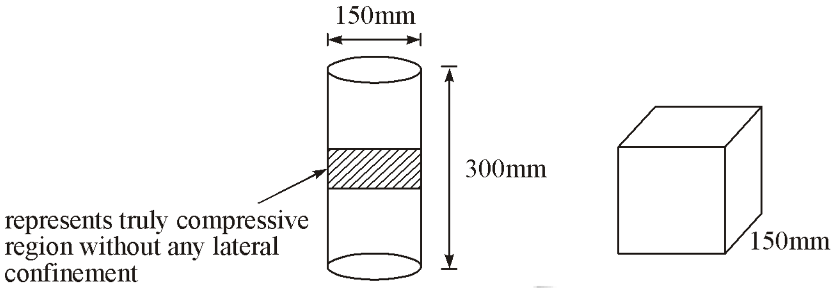


It is found by testing cylinder under compression. The max. strength obtained in the cylinder strength, test.

Cylinder strength = 0.8 × cube strength
↓ ↓
(150 mmϕ, 300 long) (150 mm cube).

Cylinder is tested to obtain stress strain curve, because, we have to obtain condition for uniaxial stress condition. In case of cubes, due to friction between the concrete surface and the steel plate of testing machine, lateral restraints occurs.

The effect of this lateral restraint is to increase the compressive strength in longitudinal direction. This effect lies down with increasing distance from the friction surface [called platen restraint surface]. Thus as the distance from the friction surface increases (i.e., as height/width ratio increases), compressive strength decreases



From the above stress-strain curve, following points must be noted.

(1) Max compressive stress occurs at a strain value of 0.002. i.e., 0.2%. The value of stress at 0.002 strain is called compressive strength of concrete.

(2) Lower strength concrete has greater deformability i.e. ductility than high strength concrete.

(3) Decending part of high strength concrete is steeper.

(4) High strength concrete gets crushed at smaller strain.

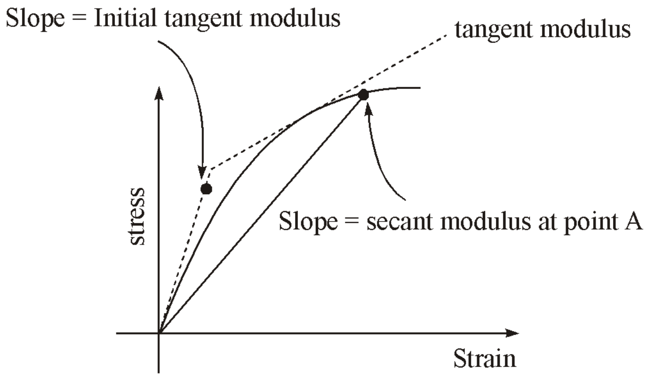
(5) The point where curve ends is called crushing strain

(6) High strength concrete is more brittle as compared to low strength concrete. (Crushing strain is 0.3%-0.5%.)

(7) Curves, are generally linear upto a stress of 0.6 times the peak stress.

(8) Modulus of elasticity of concrete for all practical purpose is taken as secant modulus at a stress of around 0.33 f_{ck}.

This E_c *is generally found acceptable in representing an average value of* E_c *under service load condition (static loading).*



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Modulus of elasticity is primarily influenced by the elastic properties of aggregate and to a lesser extent by the conditions of curing, age of concrete, mix proportion and type of cement.

As per IS code : $E_C = 5000\sqrt{f_{ck}}$ (E_c and f_{ck} are in N/mm^2)

↓

Short term modulus of elasticity of concrete

Long term modulus of elasticity including creep $E_{ce} = \dfrac{E_c}{1+\theta}$

where,

θ = creep coefficient

E_C = short term modulus of elasticity

θ = creep coefficient

$$= \frac{\text{ultimate creep strain}}{\text{elastic strain at the age of loading}}$$

Age at loading	Creep coefficient
7 days	2.2
28 days	1.6
1 year	1.1

1.11 | CONCRETE STRAIN AT ULTIMATE STRENGTH

If a concrete cylinder is axially loaded the ultimate strength is at 0.2% strain.

For flexure, crushing is assumed to occur at 0.35% strain

Note:

Actually it is seen that, if the stress distribution is

(a) rectangular, strain = 0.2%

(b) Triangular, strain = 0.35%

(c) Trapezoidal, strain = 0.2 – 0.35%

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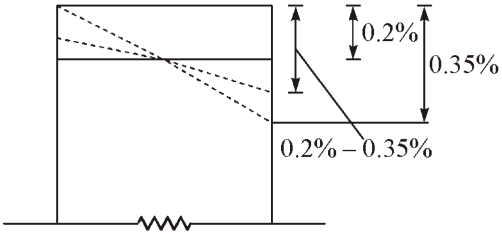


Design Stress-Strain Curve :

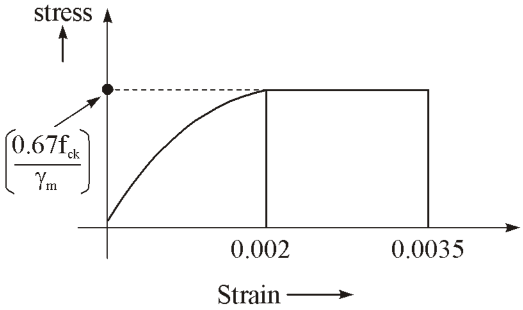
Ascending part is taken as 2nd degree parabola.

$0.67\ f_{ck}$ = Strength of concrete in structure

γ_m = partial safety factor for material strength.

γ_m = 1.5 for limit state of collapse

γ_m = 1.0 for limit state of serviceability.

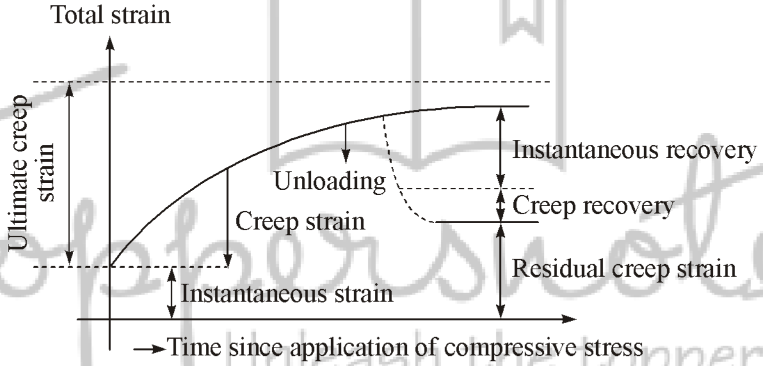


1.12 SHRINKAGE & CREEP IN CONCRETE

1.12.1 *Creep*

When concrete is subjected to sustained compressive loading, its deformation keeps on increasing with time, even though the stress level is not altered.

Time dependent component of total strain is called creep.



Creep is thought to occur due to :

(1) Internal movement of absorbed water

(2) Viscous flow or sliding between concrete gel particles

(3) Moisture loss

(4) Growth in microcracks

Effects of creep are :

(1) Increase in deflection of beams and slabs

(2) Increased deflection of slender column that may lead to buckling

(3) Gradual transfer of load from concrete to reinforcing steel in comp. members

(4) Loss of prestress

Beneficial effects of creep are :

(1) Reduction in stress induced by restrained shrinkage resulting in reduction in cracking

(2) In indeterminate structures, stress induced due to settlement of support is reduced due to creep. Factors influencing creep

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Creep increases when :

(a) Cement content is high (b) W/c ratio is high (c) Aggregate content is low (d) Air entrainment is high (e) Relative humidity is low (f) Temperature (causing moisture loss) is high (g) Size/thickness of member is small (h) Loading occurs at early age (i) Loading sustained over a long period.

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

Thus under service load condition, creep will be proportional to stress. This concept can be used to compute total deflection (initial + creep) by usual linear elastic analysis with reduced modulus of elasticity. The reduced modulus of elasticity

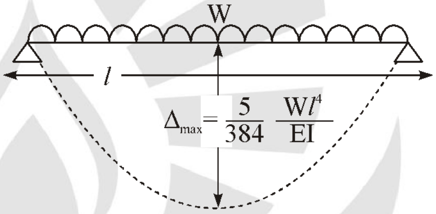
$$E_{c_s} = \frac{E_c}{1+\theta}$$

where E_{cc} = reduced modulus of elasticity taking into account long term effect of creep

E_c = short term modulus of elasticity

θ = creep coefficient

Age at loading	
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 in

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

i.e., $\boxed{\theta = C - \theta_0 \log t}$

Effect of creep can be reduced by :

(1) using high strength concrete

(2) Delaying the application of finishes, partition walls etc.

(3) Adding reinforcement

(4) Steam curing under pressure

Note:

Steam curing under pressure reduces drying shrinkage and moisture movement.

1.12.2 *Shrinkage*

The shortening in length of a member or contraction of the concrete per unit length due to drying when concrete sets is known as shrinkage.

Shrinkage can be classified as

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(a) Plastic shrinkage (b) Drying shrinkage

Plastic Shrinkage : This type of shrinkage manifests itself soon after the concrete is placed in the form while the concrete is still in plastic state. Loss of water by evaporation from the surface of concrete or by absorption by aggregate or subgrade, is believed to be the reason for plastic–shrinkage.

As aggregate & steel restrain this effect, cracks appear at the surface or internally around aggregate. This shrinkage is prevented by using aluminium powder and expanding cement.

Drying Shrinkage : It is an ever lasting process and occurs mainly due to loss of water held in the gel pores when concrete is kept in drying condition.

The finer the gel, the more is the shrinkage.

Harder aggregate leads to lower shrinkage but higher shrinkage stress. Reverse is true for softer aggregate.

Shrinkage decreases with increase in size of member.

Concrete made with smaller size aggregate shrinkage more than concrete made with larger size aggregate

Shrinkage produces tensile cracks in any member which is restrained.

For a given environment, the total shrinkage depends more on the total amount of water present in concrete at the time of mixing and to a lesser extent on the cement content.

In the absence of test data, an approx value of total shrinkage strain for design may be taken as 0.0003

Shrinkage decreases with increase in relative humidity.

1/2 of total shrinkage assumed in 1st month and 3/4th in 1st 6 months.

1.13 MORE ON REINFORCED CONCRETE

Reinforced concrete is a combination of steel and concrete which effectively uses the tensile strength of steel and compressive strength of concrete.

For the two materials to act together, it is necessary that the bond between concrete and steel bars should be strong enough so that no slip occurs.

A good bond between concrete and steel is ensured by proper detailing of reinforcements.

Except in case of water retaining structure and where cracking is not desired, we generally allow concrete to crack on tension side (as in flexure).

This is because prior to cracking in concrete, strain in steel is very small and hence stress in steel is very small. Thus if we donot allow the concrete to crack, the costlier material steel will not be economically utilized.

Stress at cracking in concrete = $0.7\sqrt{f_{ck}}$

Strain at cracking in concrete $\dfrac{0.7\sqrt{f_{ck}}}{5000\sqrt{f_{ck}}} = 1.4 \times 10^{-4}$

Strain at cracking in steel = 1.4×10^{-4} (from strain compatibility)

$\Rightarrow$ Stress in steel = $1.4 \times 10^{-4} \times 2 \times 10^{5} \dfrac{N}{mm^2} = 28\,N/mm^2$

Thus if concrete is not allowed to crack, the max. stress that steel bar can take is 28N/mm^2. However, it is capable of taking much larger stress. Thus without allowing cracking, steel will not be economically utilized.

Beam can also be reinforced on compression face to strength the beam in compression.

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Besides strength requirement of RCC, an important point of design is that the member must have ductile failure.

A beam has ductile failure, if the tension steel yields before failure.

Note :

If beam is over–reinforced, the beam will not have ductile failure.

1.14 REINFORCEMENT

Reinforcement: generally used are

$$\text{IS456 : 2000}\left|\begin{array}{l}\text{Fe250 – yield strength} = 250\dfrac{\text{N}}{\text{mm}^2}\\ \text{Fe415 – yield strength} = 415\dfrac{\text{N}}{\text{mm}^2}\\ \text{Fe500 – yield strength} = 500\dfrac{\text{N}}{\text{mm}^2}\end{array}\right.$$

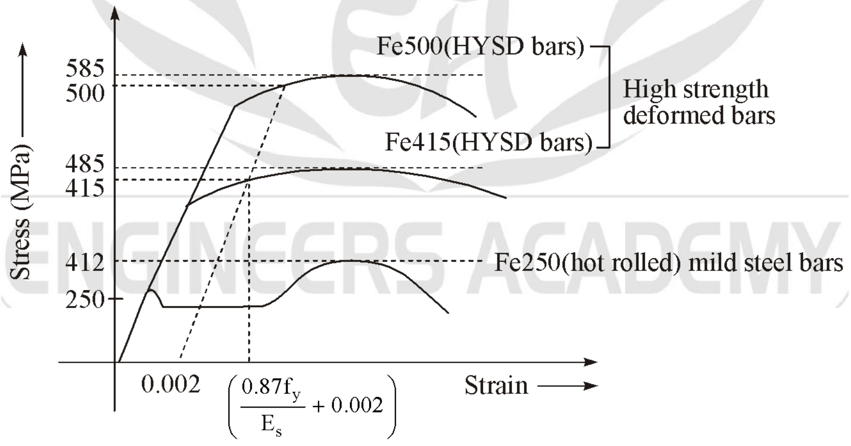
$$\left.\begin{array}{l}\text{Fe415D}\\ \text{Fe500D}\\ \text{Fe550D}\\ \text{Fe550D}\\ \text{Fe600}\end{array}\right\}$$ has been introduced in IS 1786 : 2008. Here, D means more ductility.

In Fe 250, Fe 415, Fe 500, 250, 415 and 500 are specified yield strength

Specified yield strength is the guaranteed minimum

Actual yield strength can be somewhat higher

Specified yield strength may be treated as characteristic strength of reinforcing steel.



1. $E_s = 2 \times 10^5$ MPa for all steel.
2. By cold working on the steel (starching and twisting) f_y increases but ductility falls.
3. For cold worked steel which does not have a well defined yield stress, 0.2% proof stress is taken as the yield stress for calculation purposes.
4. For MS bar, % elongation at failure = 23%

   For HYSD Fe 415 bar, elongation at failure =14.5%

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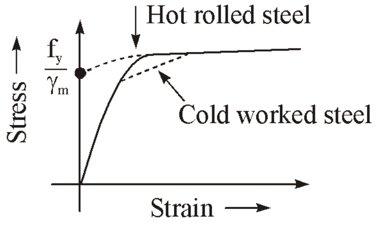
1.15 DESIGN STRESS STRAIN CURVE FOR STEEL

γ_m = Factor of safety

γ_m = 1 for limit state of serviceability

= 1.5 for limit state of collapse



Increase of stress in strain hardening region is neglected

In RCC, steel never reaches its ultimate strength because strain at which ultimate strength is reaches will never be reached.

Concrete will get crushed before steel reaches its ultimate strength.

Note :

Failure of RCC beam always occurs due to curshing of concrete. It never occurs due to failure of steel, (i.e., snapping of steel)

We may use same curve for tension and compression for both grades of steel (Hot rolled or cold worked). This may lead to insignificant error, (in case of compression)

1.16 DESIGN METHODS

1.16.1 *Working Stress Method*

Material is assumed to behave linearly elastic manner.

Stresses within the material is not allowed to exceed the permissible stress.

$$\text{Permissible stress} = \frac{\text{Strength of material}}{\text{Factor of safety}}$$

In RCC design, permissible stress in tension steel : $\boxed{0.55f_y = \sigma_{st}}$

⇒ F.O.S = 1.8

Permissible compressive stress in concrete in bending

$$\boxed{\sigma_{cb} = 0.33f_{ck}}$$

⇒ FO.S = 3

Deficiency in WSM : It may not be possible to keep the stress within permissible stresses. This is because of

(a) long term effect of shrinkage and creep

(b) effect of stress concentration and other secondary effects. All such effects result in significant local increase in stresses into inelastic range and redistribution of the calculated stress.

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In working stress method of design, Actual margin of safety is not equal to factor of safety used in WSM because stress–strain curve is not linear upto collapse.

$$\text{Actual margin of safety} = \frac{\text{Collapse load}}{\text{Working load}}$$

WSM fails to discriminate between different types of loads that act simultaneously, but, have different degree of uncertainty.

1.16.2 *Ultimate Load Method (Introduced in 1960)*

In this method stress condition at the state of impending failure of section is analyzed and Non–linear stress strain curve, of steel and concrete are made use of.

Safety measure is introduced by an appropriate choice of load factor.

$$\text{Load factor} = \frac{\text{Ultimate load}}{\text{Working load}}$$

In ultimate load method distribution of stress resultants at ultimate load is taken as distribution at service loads magnified by load factor. This is clearly in error because significant inelastic behaviour and redistribution of stress resultant takes place as loading is increased from service loads to ultimate loads.

1.16.3 *Limit State Method of Design : (Introduced in 1970)*

We know that there is uncertainty in the loading and the material properties. Besides this uncertainty also occur in dimension of member, uncertainty due to simplifying assumptions used in analysis & design, etc.

To overcome this reliability based analysis was performed and factors of safety were established both for loading and material properties. These factors of safety are called partial safety factors.

Analysis based on the above concept was called limit state method.

LSM provides adequate safety at ultimate load and adequate serviceability at service loads by considering all possible limit states.

Selection of various partial safety factors has sound probabilistic basis.

Limit state is a state in which the structure becomes unfit for use.

There are two type of limit states.

(a) **Limit state of serviceability :** satisfactory performance under service load. Like discomfort caused by excessive deflection, crack width, vibration, leakage, loss of durability etc.

(b) **Limit state of collapse :** Adequate margin of safety for normal over loads. These include limit state of strength, overturning, sliding, buckling, fatigue etc.

Note :

If a structure has reached a limit state of serviceability and loads are removed, the structure will return to its original state.

However, structure reaching limit state of collapse, doesnot recover its original shape.

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