R.C.C

Unit - 1

Introduction

P.C.C ⇒ Plain Cement Concrete :-

Plain cement concrete is a hardened mass obtained from a mixture of cement, fine aggregate (sand), coarse aggregate (gravel) & water in definite proportion.

R.C.C ⇒ Reinforced Cement Concrete :⇒

The cement concrete reinforced with steel bars is known as reinforced cement concrete.

Uses of R.C.C :⇒

(i) Beams, columns & slabs in residential, commercial & industrial building.
(ii) Tunnels (iii) Water retaining structure (iv) Irrigation works
(v) Electric poles (vi) chimneys & towers (v) Power plants.

Advantages & Disadvantages of R.C.C ⇒

Advantages :⇒

1. Strength ⇒ R.C.C has very good strength in tension as well as in compression.
2. Durability ⇒ R.C.C structures are durable as these can withstand the action of weathering agencies.
3. Economy : ⇒ R.C.C is cheap in the long run. as its maintenance cost is very low.
4. Transportation ⇒ The raw materials required for R.C.C can be transported easily from one place to another

... shape easily by properly designing the form work

6. Fire Resistance
7. Permeability
8. Seismic Resistance
9. Aesthetic
10. compact section

Disadvantage ⇒ 1.) Initial cost of R.C.C work is high

(ii) R.C.C structures are heavier than other structural materials. Therefore, dead load of the structures is increased.

iii) Skilled labour is required for construction of R.C.C structures.

iv) R.C.C structures take time to attain its full strength.

v) R.C.C needs lot of formwork, centering & shuttering to be fixed, thus require lot of site space & skilled workforce to handle it

Grades of Cement :⇒ OPC is commonly used in concrete structures. The BIS has classified OPC in three grades:-

(i) 33 Grade
(ii) 43 Grade
(iii) 53 Grade

Grade Number indicate the minm compressive strength of Cement sand mortar cubes in N/mm^2 at 28 days.
The face area of these cubes should be $50 cm^2$

50 kg = 1 bag

1 bag volume is 34.5 litres.

As per IS 456:2000, the max^m cement content used for R.C.C constructions is 450 kg/m^3

Grades of Concrete :⇒

As per IS 456:2000 Concrete mixes are designated into 15 Grades.

① Ordinary Concrete M_{10} to M_{20}

② Standard concrete M_{25} to M_{55}

③ High strength Concrete M_{60} to M_{80}

M refers to Mix & No. represents the characteristic compressive strength of 150mm Concrete cube at 28 days after mixing in N/mm^2.

The characteristic compressive strength of concrete is defined as that strength below which not more than 5% of the test results are expected to fall.

∴ ⇒ (i) The strength of concrete after 28 days is about 75-80% of the strength of concrete after one year.

(ii) Min^m grades of Concrete for various structure are

→ for R.C.C work - M_{20}
→ for Post-tensioned prestressed concrete - M_{30}
→ for pre-tensioned prestressed " - M_{40}

iii) Concrete of grade lower than M_{20} may be used only for P.C.C works; lean concrete, Simple foundations, masonary walls & other simple construction work

Reinforcing Materials ⇒

The material which develops a good bond with concrete to increase its tensile strength is called Reinforcing Material.

Purpose of Providing Reinforcement :⇒

(i) It takes all the tensils stresses developed in the structure.

(ii) It increase the strength of concrete sections.

(iii) Due to reinforcement, sections become thinner as compared to plain concrete sections.

(iv) Reinforcement prevents the propagation of cracks developed due to temperature & shrinkage stresses in concrete structure.

characteristics of a Reinforcing Material ⇒

(i) The reinforcing material should develop a perfect bond with concrete so that stresses are easily transferred from one material to another.

ii) It should have high tensile strength.

iii) It should be cheap & easily available in market.

iv) It should be durable.

v) It should be easily workable i.e easy to cut, bend and join

vi) It should have high modulus of elasticity.

Suitability of steel As a Reinforcing Material :⇒

steel fulfills alomost all the characteristics required for an ideal reinforcing material. Hence it is most suitable reinforcing material.

... is used as a most reinforcing material because of the following reasons:

(i) Steel develops very good bond with concrete. And due to introduction of deformed bars this property has increased further

ii) Steel is very strong in tension, compression, shear & torsion.

iii) The steel bars can be cut, bent, welded or lifted easily with commonly available tools & machines.

iv) Steel is easily available throughout India.

v) Steel has longer life.

vi) Steel is a ductile material i.e there is more elongation of steel before failure. Hence steel gives sufficient warning time before failure.

(vii) The co-efficient of thermal expansion of steel ($11.7 \times 10^{-6}/°C$) is nearly equal to that concrete ($9.9 \times 10^{-6}/°C$). Therefore there are no temperature stresses with steel as reinforcing material in concrete.

Disadvantage:- (limitations)

(i) Rusting of steel is the biggest disadvantage. If concrete is porous or if cover to the reinforcement is not sufficie steel get rusted & loose strength.

ii) Steel looses its strength at high temperature.

Forms of steel Reinforcement :⇒

Steel Reinforcement shall be any of the following types.

(a) Mild steel & medium tensile steel bars.
(conforming to IS. 432-1982)

(b) High strength deformed bars
(Conforming to IS: 1786-2008)

(c) Hard-drawn steel wire fabric
(Conforming to IS: 1566-1982)

(d) Structural steel
(conforming to Grade A of IS: 2062-1992)

(a) Mild steel & medium tensile steel bars: ⇒

Properties of mild steel: ⇒

(i) Mild steel bars are also known as Fe 250 because the yield strength of this steel is 250 N/mm^2.
ii) This is most ductile amongest all types of steel due to less percentege of carbon.
iii) The mild steel bars are plain round & hot rolled bars.
iv) Although these bars have sufficient bond with concrete yet hooks and bends are provided at their ends for proper anchorage.
v) These can be easily bent and weldable.
vi) Mild steel has a definite yield point.
vii) Mild steel bars give sufficient warning time before failure

(b) HYSD Bars ⇒ High Yield strength deformed bars:

Properties ⇒ (i) As the name indicates the HYSD bars have much high yield point, but the yield point is not defined.

(ii) The yield stress is generally given by 0.2% proof stress.

(iii) These bars have projections on the surface which act as a key for the concrete and check the slipping of bars. These bars do not need hooks & bends at the ends for anchorage.

(iv) HYSD bars require less length of overlaps & hence these bars are economical.

(V) HYSD bars have high tensile strength.

<u>Different Grades of HYSD Bars</u> :-

HYSD bars are available in the following grades.

(i) Fe 415 (ii) Fe 500 (iii) Fe 550 (iv) Fe 600

Fe refers to ferrous metal & number refers to yield strength of steel in N/mm^2.

In deformed bars (TOR steel), the following are improved:

(i) Increase in tensile strength.

ii) Increase in yield stress (50% more than plain M.S bars)

iii) " " bond strength (60% more than " " ")

) Nowdays TMT & CRS bars also available in the market.

<u>Advantage of HYSD bars</u> :- ⇒

(i) HYSD bars have yield strength higher than of plain mild steel bars. Due to this the amount of steel required is considerably reduced.

(ii) The HYSD bars have better bond with concrete due to corrugations or ribs on surface of the bars.

As per IS 456-2000, the bond strength of HYSD bars is 60 percent greater than plain mild steel bars.

iii) During the twisting process the defects, if any in HYSD bars noticed & they are rejected.

<u>Disadvantages</u> :⇒

(i) With increase in stresses the cracking tendency increase. Hence Fe 500 or higher grade of steel it becomes necessary to use higher grade of concrete.

ii) Due to use of reduced amount of tension steel, the design shear strength of concrete is reduced.

<u>Nominal dia of bars</u> :⇒

Nominal dia. may be defined as the dimension of the dia (in mm) of round bar. In use of defomed bars, the nominal dia. is taken equivalent to that of a plain bar having the same mass per Unit length as the deformed bars.

Dia. of bars is usually represented with a symbol ϕ.

The reinforcing bars are generally available in following sizes 4mm, 5mm, 6mm, 8mm, 10mm, 12mm, 16mm, 20mm, 25mm, 28mm, 32mm, 36mm, 40mm

Note :⇒

(i) The weight of steel is taken as 7850 kg/m3

(ii) Wt. of bar (in kg) per meter length = $\frac{(\text{Dia of bar})^2}{162.2}$

Loading on structures (As per IS:875)

The various types of loads likely to act on a structure are

(i) Dead loads
ii) Live loads
iii) Wind loads
iv) Snow loads
v) Seismic loads

(i) Dead loads ⇒ Dead loads are due to self wt. of the structure. These are permanent loads which are always present. Dead loads depend upon the unit weight of material. dead loads include self wt. of wall, floors, beams etc. & also the permanent fixtures present in the structure.

Live load ⇒ (superimposed loads) ⇒ Live lods on floors & roofs consist of all the loads which are temporarily placed on structure e.g. loads of people, furniture, machine etc. These loads keep changing from time to time. These are also called as superimposed loads. Roofs of buildings used for incidental assembly are designed for a min^m live load of $4 kN/m^2$.

iii) Wind load: ⇒ The force exerted by the horizontal component of wind is to be considered in the design of building. It depends upon the velocity of wind, shape & size of the building. Wind loads have to be considered in the design of multistorey building, towers & poles. upto ht of 30m, the wind pressure is considered to act uniformly

Above 30m height the wind pressure increases.

iv) Snow loads: ⇒ The building which are located in the regions where snowfall is very common are to be designed for snow loads.

(V) Earthquake loads: ⇒ Now it is mandatory to follow the recommendations regarding seismic loads in the design of structures, if the structure is situated in the seismic areas. Seismic areas are the regions which have experienced earthquake in the past & are likely to experience in future.

Unit = 2

Introduction to Following methods of RCC design

Introduction ⇒

The main purpose of structural design is safety, serviceability & economy of the structure. The structure should be safe under worst combination of loading conditions. It should fulfill the purpose for which it has been designed during its whole life span. All the structure should be economical with regard to its initial cost & maintenance cost.

Method of R.C.C Design: ⇒

The design of any R.C.C structure comprises of the following

(i) To decide the size of the member & amount of steel reinforcement required.

(ii) To check whether the designed structure will perform safely & satisfactorily during its life span.

Various method used for the design of R.C.C structure are as follows

(i) Working stress method

(ii) Limit state method

(i) Working stress method (WSM) ⇒

Working stress method is the oldest one. The salient features of this method are:-

(i) This method is based on the linear elastic theory & assumes that both steel and concrete are elastic & obey Hooke's law. Therefore, this method is also known as Elastic method of design or Modular ratio method.

(ii) The working stress is based on the behaviour of structure at working loads. It is assumed that the stresses in steel & concrete donot exceed their permissible value at working loads.

The permissible stresses in steel & concrete are obtained by dividing the characteristic strength of the material by the factor of safety (FOS). FOS allows for uncerteinies in the estimation of working loads & variation in properties of materials

F.O.S = 1.78 for steel

F.O.S = 3 for Concrete.

iii) This method is referred to as Deterministic because it is assumed that loads, permissible stresses & F.O.S are known accurately.

iv) In this method, the permissible stresses are kept much below the Ulimate strength of the material.

v) This method gives no indication of the actual margin of safety against collapse as the Ultimate load carrying cannot be predict accurately.

Limitation of WSM ⇒

following are the main drawbacks of the WSM of design.

(i) This method assumes that both concrete & steel are elastic which is not true. Concrete is not elastic. The mild steel behaves as an elastic material but HYSD bars do not behave elastically.

ii) This method uses factor of safety for stresses only which does not give true margin of safety because we dont known the failure load

iii) This method does not account for shrinkage & creep which are time dependent in nature.

iv) The method does not use any F.O.S with respect to loads. It means there is no provision for uncertainties associated with the load.

v) This method is Uneconomical because comparatively large section with higher quantities of steel reinforced are obtained

Limit State method (LSM) ⇒

This is most rational method which is based on safety at Ultimate loads & serviceability at working loads.
The acceptable limit of safety & serviceability requirements before failure of a structure takes place is known as a limit state. A limit state is a state at which one condition relating to a structure attains a limiting value.

The important limit states which are to be considered in design are:-

(i) Limit state of collapse

ii) Limit state of serviceability

Limit state method is referred to as 'Non-deterministic', because it is based on predictions which depend upon experience.

Unit 3 (WSM)

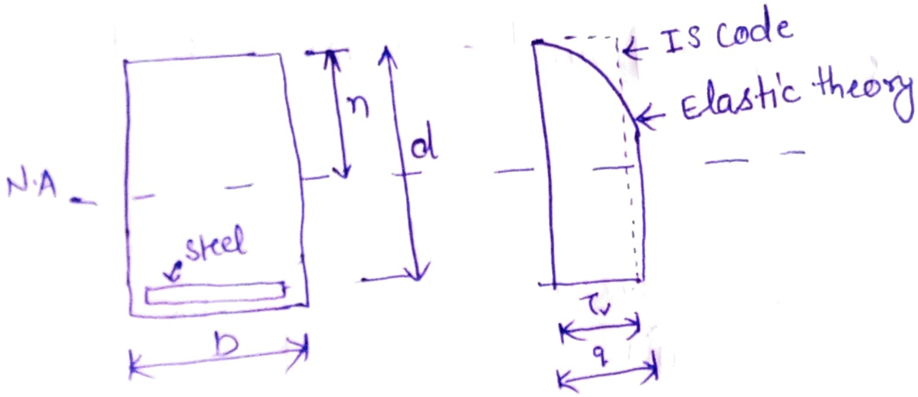
Shear & development length

Introduction :⇒

A beam loaded with transverse loads is subjected to shear force and bending moment. The shear force at any section of beam is equal to the rate of change of bending moment at that section.

Shear stress in R.C.C Beams (IS:456-2000)

As per IS code (456:2000), shear stress obtained from elastic theory does not represent the true behaviour of the R.C.C beam in shear. IS code has introduced the concept of nominal shear stress (τ_v) for R.C.C beam.



formula calculating nominal shear stress in beams or slabs of uniform depth specified by the IS code is

$$\tau_v = \frac{V}{bd}$$

τ_v = Nominal shear stress

V = shear force in beam at critical

b = Breadth of the beam

d = effective depth of beam.

Nominal shear stress in beams of Uniform width $ varying depth (e.g cantilever beams, footing etc.)

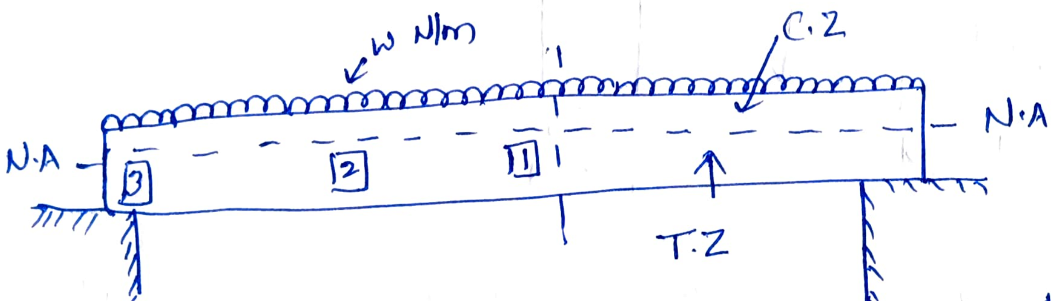
$$\tau_v = \frac{V \pm \frac{M \tan \beta}{d}}{bd}$$

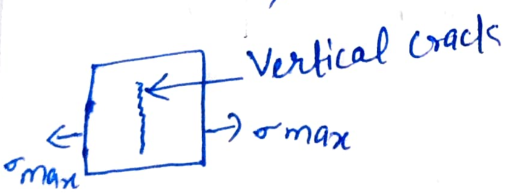
M = Bending Moment

β = Angle b/w the top $ bottom edges of the beam

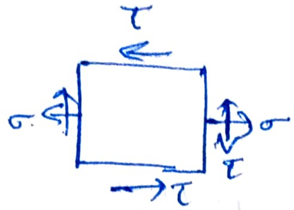
Effects of shear (Diagonal Tension) :⇒

Consider a simply supported beam AB subjected to uniformly distributed load over the whole span. The maxm bending Moment in this beam will be at midspan and maxm shear force will be at supports. The beam is subjected to bending $ shear stresses across the X-section. Let us consider three small elements 1, 2, $ 3 from the tensile zone of the beam



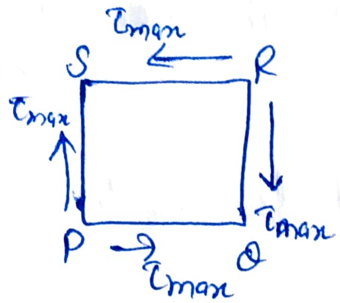


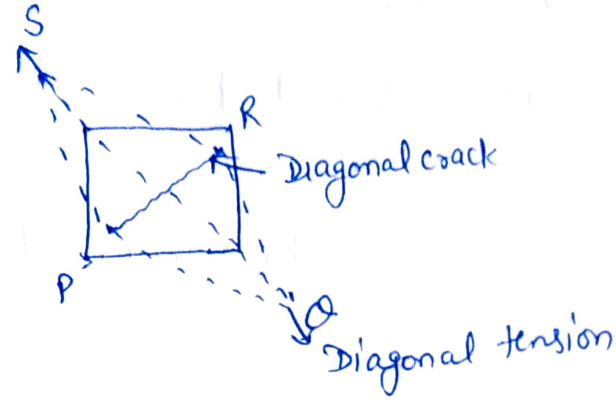
The element 1 is at mid-span of the beam Here B.M is maxm $ S.F is zero. Thus this element is subjected to only maxm tensile bending stress (σmax). This stress tries to pull apart the element $ develops the vertical crack.



Element [2]

The element [2] is b/w support & mid-span. There will be bending moment & shear force. Thus this element is subjected to tensile bending stress (σ) as well as shear stress (τ)



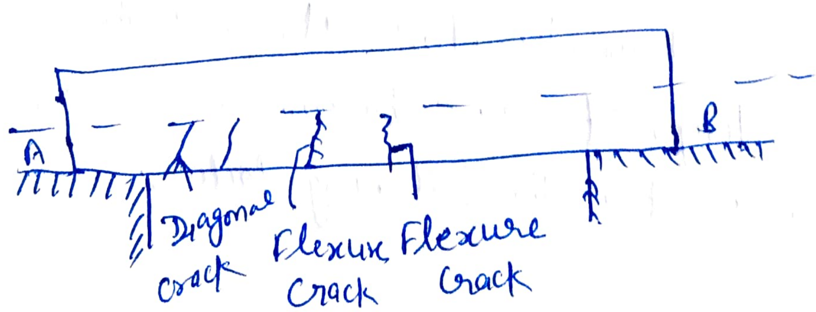


Element [3]

The element [3] is at the support. At the support, the bending moment is zero & the shear force is max^m. Thus this element is subjected to max^m shear stress & no bending stress. Due to this stress condition the diagonal QS is subjected to tensile stresses. As the concrete is very weak in tension, it splits along the diagonal & develops crack.

This tension which is caused in tensile zone of the beam due to shear, at or near the supports is called as diagonal tension. This diagonal tension results in cracks at 45°.

The crack pattern for a simply supported beam



(i) At or near the mid-span, the cracks are vertical (flexure crack due to bending alone)

ii) At or near the supports, the cracks are inclined at 45°.

(Diagonal tension crack due shear alone)

iii) In b/w the support & mid-span, the cracks are inclined at 45° to 90° gradually.

(flexure shear crack due to combined effect of flexure & shear both.)

To avoid such cracks, reinfocement called shear reinforcemen can be provided. shear reinforcement can be provided in any of the following forms.

(i) In the form of vertical bars known as stirrups.

ii) In the form of bent-up bars inclined at an angles to the plane of diagonal tension.

iii) In the form of combination of stirrups & inclined bars.

Critical sections for shear design :⇒ (As per IS 456:2000)

shear strength of concrete (without shear Reinforcement) :⇒

concrete is good in shear, therefore its strength is to be considered in the design of R.C.C beam. The shear strength of concrete depends upon the following factors.

(i) Grade of concrete :⇒ The shear strength of concrete increase with the increase grade of Concrete. Higher the grade of Concrete, higher is the shear strength of concrete

ii) Percentage of Tensile Reinforcement :→

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Unit ⇒ 4

Concept of Limit State Method

Concept of LSM ⇒

The aim of LSM is that the structure should be designed to:-

(a) Withstand safely all the loads that are liable to act on it throughout it life

(b) It should also satisfy the serviceability of limiting deflection and cracking.

LSM of design, collapse of a structure will not take place because it is based on safety at Ultimate loads. Also the failure of a structure will not occur due to excessive deflection or cracking etc at working loads.

Limit state :⇒

The acceptable limit for the safety & serviceability requirements before failure occurs called a limit state.

The most important limit states which are considered in design are:

1. Limit state of collapse
2. Limit state of serviceability

1) Limit state of collapse ⇒ Limit state of collapse is also known as Ultimate limit state as it corresponds to the maxm load carrying capacity. The limit state of collapse is reached when the structure as a whole or part of

structure collapses under the following

i) Limit state of collapse in flexure
ii) Limit state of " " compression
iii) " " " " " shear
iv) " " " " in torsion

2 Limit state of serviceability :⇒ A structure is of no use if it is not serviceable. Thus this limit state is introduced to prevent excessive deflection & cracking. Limit state of serviceability ensures the satisfactory performance of the structure at working loads.

The two important limit state of serviceability are:

i) Limit state of deflection
ii) " " " collapse.

Comparison b/w working stress Method & LSM ⇒

WSM	LSM
① This method is based on the elastic theory which assumes that concrete & steel are elastic & the stress strain curve is linear for both materials.	① This method is based on non-linear stress distribution taking inelastic strain into consideration.
2) This method is based on the behaviour of structure under service load.	2) In this method the structure is designed on the basis of most critical limit state & checked for other limit states.

WSM	LSM
3) This method assumes that all the loads permissible stresses & factor of safety are known. So it is called deterministic Method.	3) This method is known as non-deterministic because loads and stresses are predicted based upon experience & field data.
4) In this method the F.O.S are applied to the yield stresses to get permissible stresses. No F.O.S is used for loads	4) In this method partial safety factors are applied to stress as well as to working loads to get design stresses & design loads.
5) In this method safety against Ultimate loads is not known.	5) It satisfies all the limit states of collapsed & serviceability.

characteristic strength of materials :⇒

The characteristic strength means that value of the strength of the material below which not more than 5 percent of the test results are expected to fall.

It means that the characteristic strength has 95% reliability or there is only 5% probability of actual strength being less than the characteristic strength.

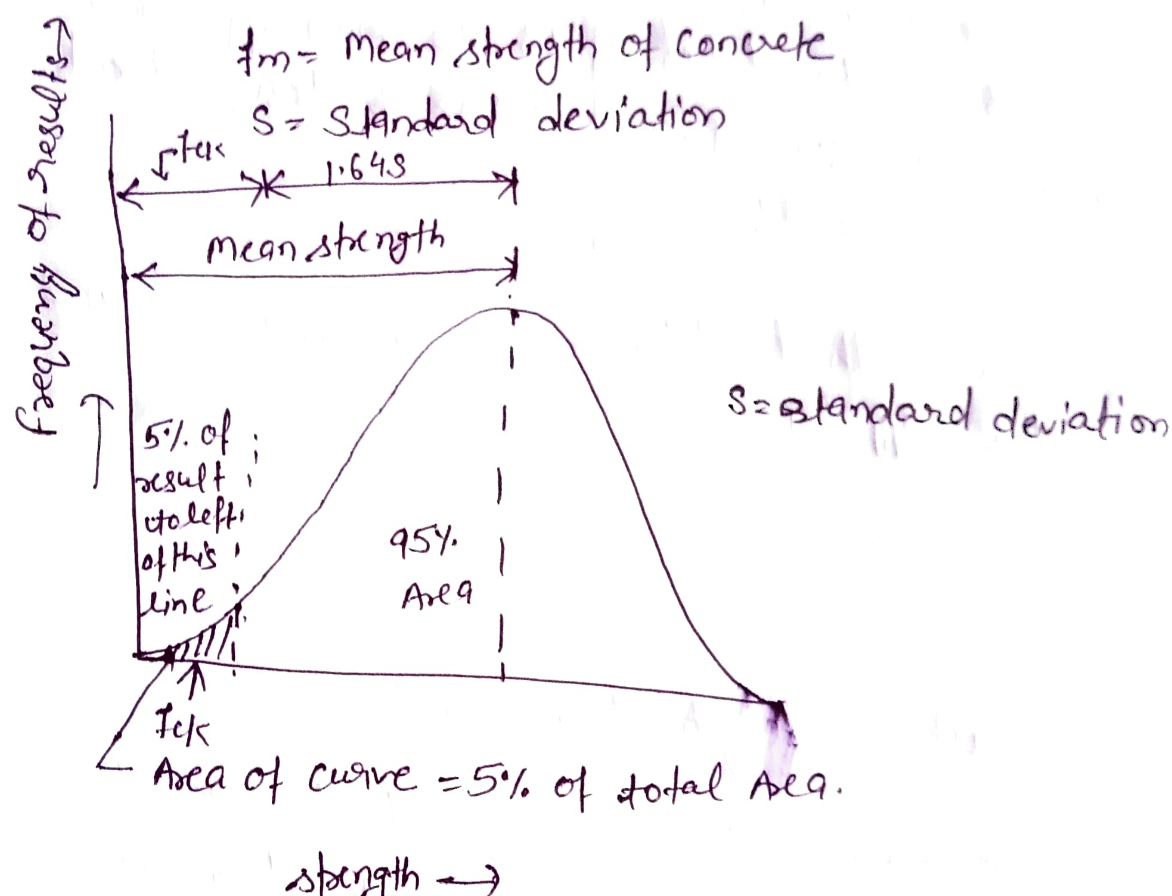
a) characteristic strength of concrete (f_{ck})

The characteristic strength of concrete (f_{ck}) is defined as the compressive strength of 150mm cube at 28 days expressed in N/mm^2 below not more than 5% of the test results are expected to fall.

characteristic strength of concrete (f_{ck}) = $f_m - 1.64s$

f_m = Mean strength of concrete

S = Standard deviation



Frequency Distribution Curve for strength

characteristic strength of steel (f_y):- The characteristic strength of steel (f_y) is defined as that value of yield stress in the case of mild steel or 0.2% proof stess in the case of HYSD bars below which not more than 5% of the test specimens are expected to fall.

(a) Partial safety factor strength of material (γ_m) :→

The partial safety factor for strength of materials is the factor by which the characteristic strength of the material is divided to get the design value for materials.

Values of Partial safety factor (γ_m) for strength of materials.

Material	Limit state of collapse	Limit state of serviceability	
		Deflection	cracking
concrete	1.5	1.0	1.3
Steel	1.15	1.0	1.0

(b) Partial safety factor for loads :→ (γ_f)

The partial safety factor for the loads is the factor by which the characteristic loads are multiplied to get the design values for loads

Value of partial safety factor (γ_f) for loads

Load combinations	Limit state of collapse			Limit state of serviceability		
	DL	LL	WL	DL	LL	WL
DL+LL	1.5	1.5	—	1.0	1.0	—
DL+WL	1.5 or 0.9	—	1.5	1.0	—	1.0
DL+LL+WL	1.2	1.2	1.2	1.0	0.8	0.8

Design Values :→ Design value are obtained when partial safety factors are applied to characteristic strength of material and characteristic loads.

(a) Design Value for strength of Materials (fd)

The design value for strength of materials (fd) is given by

$$fd = \frac{f}{\gamma_m}$$

fd = Design strength of material
f = charatteristic strength of the material
γ_m = Partial safety factor.

(b) Design value for load (Fd): ⇒

$$Fd = F \times \gamma_f$$

Fd = design load
F = characteristic load
γ_f = Partial safety factor appropriate to the nature of loading and the limit state being considered.

Assumptions in limit state of collapse in flexure :-

According. (IS 456 : 2000) Code Page No. - 69.

Design stress-strain curves ⇒

IS 456 : 2000 - 69

12 DESIGN OF R.C.C. BEAMS (Limit State Method)

12.1 INTRODUCTION

Beams are the flexural members which are provided in the structures to resist bending, caused due to external loading. Beams may be singly reinforced or doubly reinforced.

The R.C.C. beams in which the steel reinforcement is provided only in tension side, are known as singly reinforced beams. But in case of doubly reinforced beams, the main reinforcement is provided in the tension zone as well as compression zone, *i.e.* above and below the neutral axis of the beam.

12.2 BASIC RULES FOR DESIGN OF BEAMS

We have already discussed the theory of singly and doubly reinforced beams. While designing R.C.C. beams, the following rules as per I S : 456 – 2000 must be kept in mind.

1. **Effective Span :** Unless otherwise specified, the effective span of a beam shall be as follows :

(*a*) Simply supported beam : The effective span of a simply supported beam (that is not built integrally with its supports) is taken as the least of the following :

(*i*) centre to centre distance between supports

(*ii*) clear span + effective depth of beam

(*b*) Cantilever beam : The effective span of a cantilever beam shall be taken as

— length of the overhang plus half the effective depth

— except where it forms the end of a continuous beam where the length upto the centre of support shall be taken

(*c*) Continuous beam :

If the width of support is less than $\frac{1}{12}$th of the clear span

In this case the effective span of the beam shall be taken as given in case of simply supported beams.

If the width of support is greater than $\frac{1}{12}$th of the clear span or 600 mm whichever is less

In this case the effective span of the beam shall be taken as under :

(i) For end span with one end fixed and the other continuous or for intermediate spans, the effective span shall be the clear span between supports.

(ii) For end span with one end free and other continuous, the effective span shall be equal to the clear span plus half the effective depth of the beam or the clear span plus half the width of the discontinuous support, whichever is less.

2. **Control of Deflection :** The deflection of a structure or part thereof shall not adversely affect the appearance or efficiency of the structure.

The vertical deflection limits may generally be assumed to be satisfied provided that the span to depth ratios are not greater than the values obtained as below :

(a) Basic values of span to effective depth ratios for span upto 10 m

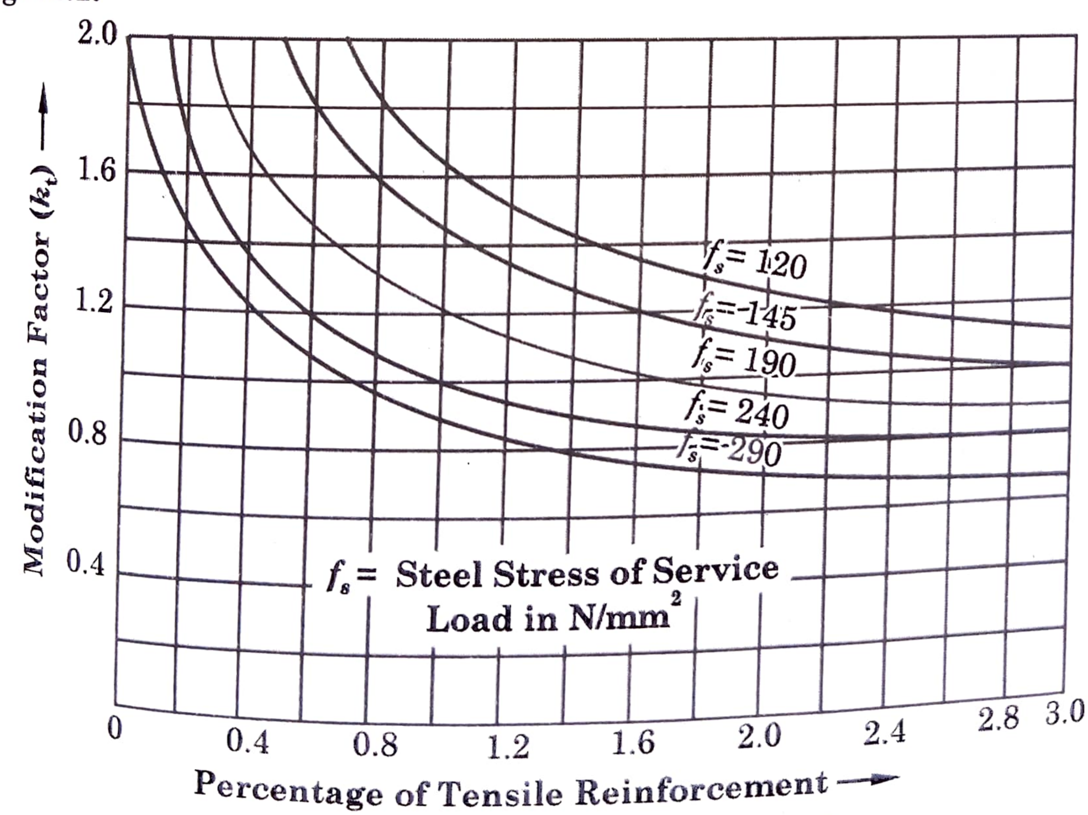
Cantilever beam = 7

Simply supported beam = 20

Continuous beam = 26

(b) For span above 10m, the values in (a) may be multiplied by 10/span in meters, except for cantilever in which case deflection calculations should be made.

(c) Depending on the area and the stress of steel for tension reinforcement, the values in (a) or (b) shall be modified by multiplying with the modification factor (k_t) obtained from **Fig. 12.1.**



$$f_s = 0.58\, f_y \left[\frac{\text{Area of steel required}}{\text{Area of steel provided}}\right]$$

Fig. 12.1 : Modification Factor for Tensile Reinforcement

(*d*) Depending on the area of compression reinforcement, the values in (*a*) or (*b*) shall be further modified by multiplying with the modification factor (k_c) obtained from **Fig. 12.2**.

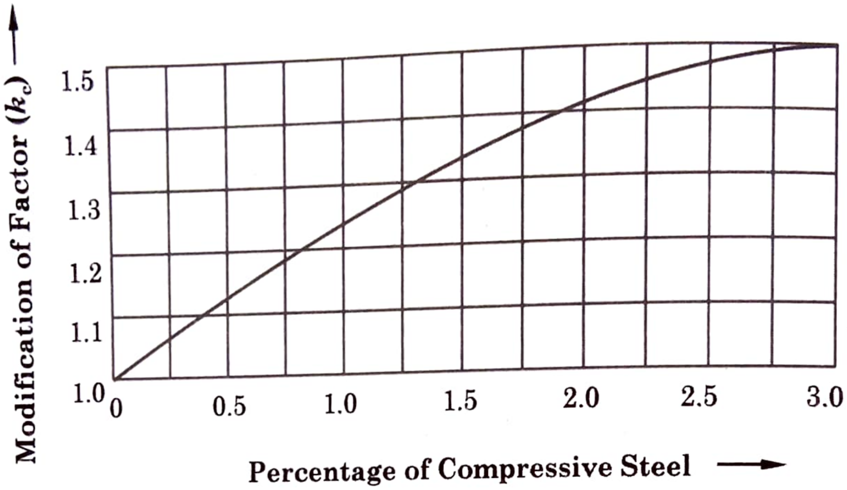


Fig. 12.2 : Modification Factor for Compressive Reinforcement

3. Slenderness Limits for Beams to Ensure Lateral Stability

(*a*) For a simply supported or continuous beam : The beam shall be so proportioned that the clear distance between the lateral restraints does not exceed 60 *b* or $\frac{250b^2}{d}$ whichever is less,

where *d* is the effective depth of the beam

and *b* is the breadth of the compression face midway between the lateral restraints

(*b*) For a cantilever beam : For a cantilever beam, the clear distance from the free end of the cantilever to the lateral restraint shall not exceed 25 *b* or $\frac{100b^2}{d}$ whichever is less.

4. Beam Dimensions : The rough estimate of self weight of beam is made by assuming dimensions of the beam *i.e.* breadth and depth.

Breadth : The breadth of the beam should be sufficient to accommodate the required reinforcement. Generally the breadth of the beam is kept $\frac{1}{2}$ to $\frac{2}{3}$ of its total depth.

i.e. $$b = \frac{D}{2} \text{ to } \frac{2D}{3}$$

Effective Depth : The effective depth of the beam may be assumed as $\frac{1}{10}$th of the span of the beam.

Hence effective depth of beam (d) = $\frac{1}{10}$ of span

Total depth of beam (D) = d + Effective cover

(Effective cover is assumed as 40 mm to 50 mm)

5. **Reinforcement in Beams**

(*a*) **Tension reinforcement**

(*i*) **Minimum reinforcement :** The minimum area of tension reinforcement shall be not ...s than that given by the following :

$$\frac{A_s}{bd} = \frac{0.85}{f_y}$$

where A_s = Minimum area of tension reinforcement

b = Breadth of beam or breadth of the web of T-beam

d = Effective depth of beam

f_y = Characteristic strength of reinforcement

(*ii*) **Maximum reinforcement :** The maximum area of tension reinforcement shall not exceed 0.04 *b* D (*i.e.*, 4% of the cross-sectional area of beam).

NOTE : *IS : 456 – 2000 has recommended the following amendment –*

"The use of 4 percent reinforcement may involve practical difficulty in placing and compacting concrete, hence lower percentage is recommended."

(*b*) **Compression reinforcement :** The maximum area of compression reinforcement shall not exceed 0.04 *b* D (*i.e.*, 4% of the cross-sectional area of beam).

Compression reinforcement in beams shall be enclosed by stirrups for effective lateral restraint.

NOTE : *IS : 456 – 2000 has recommended the following amendment –*

"The use of 4 percent reinforcement may involve practical difficulty in placing and compacting concrete, hence lower percentage is recommended."

(c) **Side face reinforcement :** When the depth of the web in a beam exceeds 750 mm, side face reinforcement shall be provided along the two faces.

The total area of such reinforcement shall be not less than 0.1 percent of the web area and shall be distributed equally on two faces at a spacing not exceeding 300 mm or web thickness whichever is less.

(*d*) **Shear reinforcement :** The shear reinforcement in beams shall be taken around the outermost tension and compression bars. The design of shear reinforcement has been discussed in Chapter-10.

6. **Spacing of Reinforcement**

(*a*) **Horizontal distance between bars :** The clear horizontal distance between two adjacent parallel main bars shall be not less than the maximum of the following :

(*i*) Diameter of the bar if diameters are equal

(*ii*) Diameter of the largest bar if diameters are unequal

(*iii*) 5 mm more than the nominal maximum size of coarse aggregates

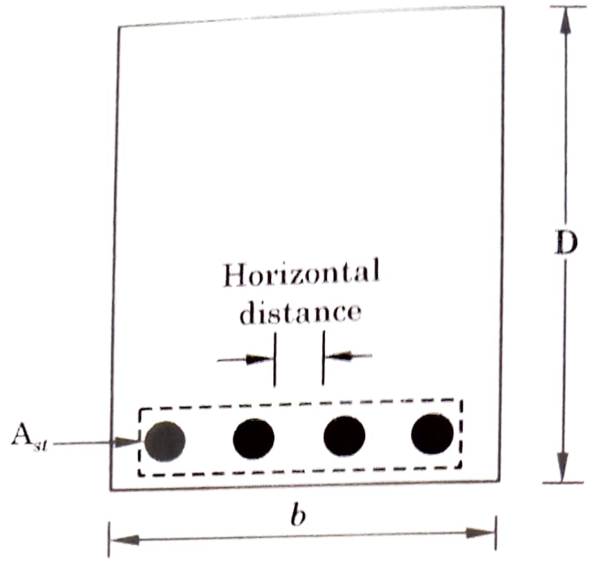


Fig. 12.3 : Horizontal Distance Between Bars

(*b*) **Vertical distance between bars :** When number of longitudinal bars are large and cannot be accommodated in a single row, then the longitudinal bars are provided in horizontal rows by providing minimum vertical distance with the help of a spacer bar. Normally spacer bars are provided @ 1 m c/c. Longitudinal bars in upper layer are provided exactly over the bottom layer.

The minimum vertical distance between two rows of longitudinal bars should be maximum of the following :

(*i*) 15 mm

(*ii*) $\frac{2}{3}$ rd of nominal maximum size of aggregates

(*iii*) Maximum diameter of the longitudinal bar

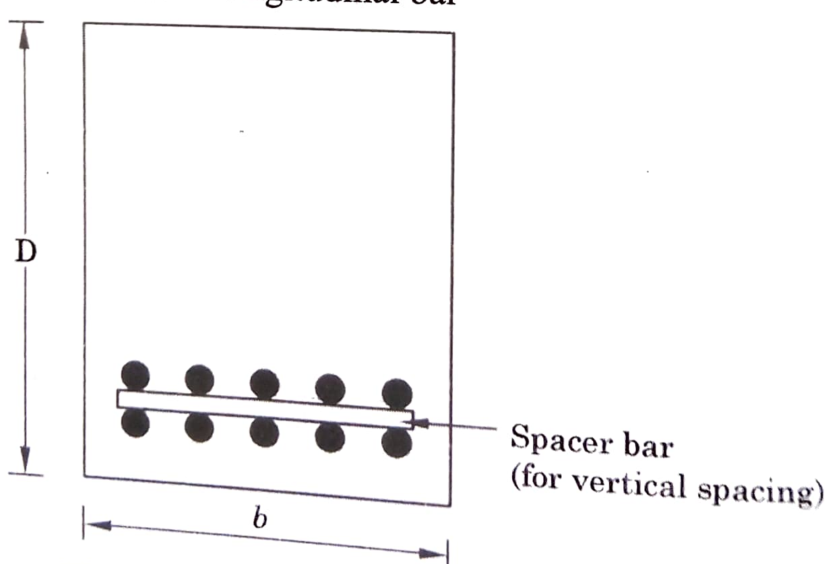


Fig. 12.4 : Vertical Distance Between Bars

7. Nominal Cover to Reinforcement

Nominal cover : Nominal cover is the design depth of the concrete cover to all steel reinforcements including shear stirrups or column ties.

It is the dimension used in design and indicated in the drawings. It shall be not less than the diameter of the bar in any case.

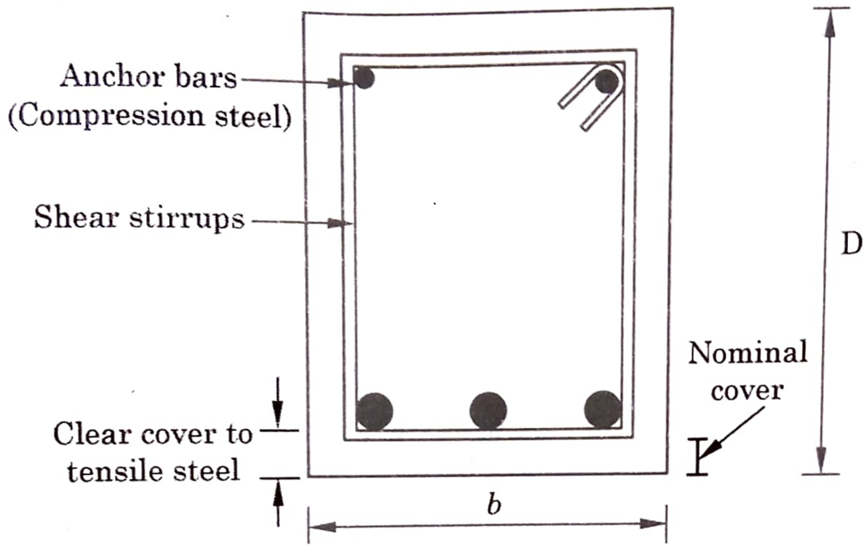


Fig. 12.5 : Nominal Covers to Reinforcement

Nominal cover is provided in R.C.C. structures for the following reasons :

(*i*) To protect the reinforcement against corrosion and fire.

(*ii*) To develop the desired strength of the steel bar by ensuring proper bond between concrete and steel.

Nominal Cover to meet Durability Requirement : Minimum values for the nominal cover of normal weight aggregate concrete which should be provided to all reinforcement, including links depending on the condition of exposure shall be as given in **Table – 12.1**.

Table – 12.1 : Nominal Cover to meet Durability Requirements

Exposure Conditions	Nominal Concrete Cover (in mm) not less than
Mild	20
Moderate	30
Severe	45
Very Severe	50
Extreme	75

NOTES :

(*i*) *For main reinforcement upto 12 mm diameter bar for mild exposure the nominal cover may be reduced by 5 mm.*

(*ii*) *Unless specified otherwise, actual concrete cover should not deviate from the required nominal cover by + 10 mm and – 0 mm.*

(*iii*) *For exposure condition 'sever' and 'very severe' reduction of 5 mm may be made, where concrete grade is M 35 and above.*

(*iv*) *For a longitudinal reinforcing bar in a column nominal cover shall in any case not be less than 40 mm, or less than the diameter of such bar. Such a large cover is provided in concrete column so as to prevent buckling of the main longitudinal bars in compression.*

In the case of columns of minimum dimension of 200 mm or under, whose reinforcing bars do not exceed 12 mm, a nominal cover of 25 mm may be provided.

(*v*) *For footings minimum cover shall be 50 mm.*

8. Curtailment of Tension Reinforcement : For curtailment, reinforcement shall extend beyond the point at which it is no longer required to resist flexure for a distance equal to the effective depth of the member or 12 times the diameter of the bar, whichever is greater except at simple supports or end of cantilever.

The detailed procedure has been discussed in Chapter-11.

9. Unit weight of concrete : The unit weight of plain cement concrete (P.C.C.) is taken as 24000 N/m^3 and for reinforced concrete (R.C.C.) it is taken as 25000 N/m^3

12.3 DESIGN STEPS FOR SINGLY REINFORCED BEAMS

For the design of singly reinforced beam generally following steps are taken :

Step 1. Assume approximate dimensions (*b*, D) of the beam

$$\text{Effective depth } (d) = \frac{\text{span}}{10} \text{ to } \frac{\text{span}}{8}$$

$$\text{Total depth (D)} = d + \text{Effective cover}$$

(Effective cover is assumed as 40 mm to 50 mm)

$$\text{Breadth } (b) = \frac{D}{2} \text{ to } \frac{2}{3}D$$

Step 2. Calculate the effective span (*l*)

Assume width of support (or bearing of beam), if not given. Calculate the effective span of the beam.

Step 3. Calculate the factored design load (w_u)

Calculate the self weight (Dead load) of the beam per metre

Self weight of the beam/m = $b \times D \times 1 \times 25000$ N/m

(Here b and D are in meters)

Total *u.d.l.* (w)/m = Self weight/m + Live load/m

Factored design load (w_u)/m = 1.5 w/m

Step 4. Calculate the factored bending moment (M_u)

$$M_u = \frac{w_u l^2}{8}$$

Step 5. Design the beam section

Design the beam section as a balanced section

By equating M_u to $M_{u,lim}$, find effective depth of beam.

$$M_{u,lim} = 0.148 f_{ck} bd^2 \quad \text{(For Fe 250 steel)}$$
$$= 0.138 f_{ck} bd^2 \quad \text{(For Fe 415 steel)}$$
$$= 0.133 f_{ck} bd^2 \quad \text{(For Fe 500 steel)}$$

Equate $M_u = M_{u,lim}$ (depending upon the type of steel used)

Calculate the value of 'd'.

Compare this 'd' with the assumed value of 'd' in step 1.

⇒ If d (calculated) is slightly less than or equal to d (assumed), then proceed further. and If d (calculated) is more than d (assumed), then redesign.

⇒ Redesign of the beam means assume the new increased dimensions of beam in step 1 and repeat all the steps till the calculated value of 'd' comes to be slightly less than or equal to assumed value of 'd'.

Step 6. Calculate the area of tensile steel (A_{st})

For a balanced section,

$$A_{st} = \frac{0.36 f_{ck} b x_{u,max}}{0.87 f_y}$$

where

$$x_{u,max} = 0.53\,d \quad \text{(For Fe 250 steel)}$$
$$= 0.48\,d \quad \text{(For Fe 415 steel)}$$
$$= 0.46\,d \quad \text{(For Fe 500 steel)}$$

b = Breadth of beam (in mm)

f_{ck} = Characteristics strength of concrete (in N/mm^2)

f_y = Characteristics strength of steel (in N/mm^2)

Step 7. Check for minimum and maximum area of tensile steel

(*i*) Calculate minimum area of tensile steel $(A_s) = \dfrac{0.85bd}{f_y}$

(*ii*) Calculate maximum area of tensile steel = $0.04bD$

Check that the actual area of steel provided (A_{st}) satisfies both these limiting conditions.

Step 8. Check for shear and design shear reinforcement

The detailed procedure has been discussed in Chapter-10.

Step 9. Check for development length

The detailed procedure has been discussed in Chapter-11.

Step 10. Check for depth of beam from deflection consideration

(*i*) Calculate the percentage of steel $(p_t) = \dfrac{100A_{st}}{bd}$

(*ii*) Calculate $f_s = 0.58 f_y \left(\frac{\text{Area of steel required}}{\text{Area of steel provided}}\right)$

(*iii*) Calculate the values of modification factors k_t, k_c and k_f.

k_t = Modification factor for tension reinforcement corresponding to the values of p_t and f_s from Fig. **Fig. 12.1**.

k_c = Modification factor for compression reinforcement from **Fig. 12.2**.

(And $k_c = 1$, if no compression reinforcement is provided)

k_f = Modification factor for flanged section

(And $k_f = 1$, for rectangular beam section)

(*iv*) $\left(\frac{l}{d}\right)_{max} = 20. k_t. k_c. k_f$

(*v*) Find $\left(\frac{l}{d}\right)_{provided}$

(*vi*) $\left(\frac{l}{d}\right)_{provided}$ should be less than $\left(\frac{l}{d}\right)_{max}$

This will satisfy the limit state of serviceability.

Step 11. Provide side face reinforcement along the two faces (if required)

If depth of beam exceeds 750 mm then provide side face reinforcement along the two faces.

$$\text{Calculate } A_s = 0.1\% \text{ of web area}$$

$$= \frac{0.1}{100} \times bD$$

⇒ Calculate the number of bars and distribute them equally on two faces at a spacing not exceeding 300 mm or web thickness whichever is less.

Step 12. Draw neat sketches (Drawings)

Draw a neat sketch (longitudinal section and cross section) showing all the designed parameters.

EXAMPLE. 12.1. *Design a simply supported rectangular beam with the following data :*

Clear span = *4.5 m*

Superimposed load = *15 kN/m*

Live load = *12 kN/m*

Use Fe-415 grade steel and M-20 grade concrete.

SOLUTION.

Given

Clear span of beam (L) = 4.5 m = 4500 mm

Superimposed load = 15 kN/m

Live load = 12 kN/m

f_y = 415 N/mm² (For Fe 415 steel)

f_{ck} = 20 N/mm² (For M 20 concrete)

Assume nominal cover = 20 mm

Effective cover = 40 mm

Width of support at each end = 300 mm

Step 1. Assume approximate dimensions (*b*, D) of beam

$$\text{Effective depth } (d) = \frac{\text{span}}{10} \text{ to } \frac{\text{span}}{8}$$

$$= \frac{4500}{10} \text{ to } \frac{4500}{8}$$

$$= 450 \text{ mm to } 560 \text{ mm}$$

Take effective depth (d) = 500 mm

∴ Total depth of beam (D) = Effective depth + Effective cover

= 500 + 40 = 540

$$\text{Breadth of beam } (b) = \frac{D}{2} \text{ to } \frac{2}{3}D$$

$$= \frac{540}{2} \text{ to } \frac{2}{3} \times 540$$

$$= 270 \text{ mm to } 360 \text{ mm}$$

Take breadth of beam (b) = 300 mm

Step 2. Calculate the effective span (l) of the beam

Effective span of the beam will be the least of the following :

(*i*) c/c distance between supports $= 4.5 + \frac{0.30}{2} + \frac{0.30}{2}$

= 4.8 m

(*ii*) clear span of beam + effective depth = 4.5 + 0.5 = 5.0 m

Hence effective span of beam = 4.8 m

Step 3. Calculate the factored design load (w_u)

Self weight of the beam/m = (b × D×1) × 25000 N/m

$$= \left(\frac{300}{1000} \times \frac{540}{1000} \times 1\right) \times 25000$$

= 4050 N/m

Superimposed load/m = 15 kN/m = 15000 N/m

Live load/m = 12 kN/m = 12000 N/m

Total *u.d.l.* per m run of the beam (w) = 4050 + 15000 + 12000 = 31050 N/m

Factored design load (w_u)/m = 1.5 × w

= 1.5 × 31050 = 46575 N/m

Step 4. Calculate the factored bending moment (M_u)

$$M_u = \frac{w_u l^2}{8} = \frac{46575 \times 4.8^2}{8} = 134136 \text{ N-m}$$

$$= 134136 \times 10^3 \text{ N-mm}$$

Step 5. Design the beam section

Design the beam as a balanced section.

$\therefore$ $M_{u,\,lim} = 0.138 f_{ck} bd^2$ (For Fe 415 steel)

Equating M_u and $M_{u,\,lim}$,

$$M_u = M_{u,\,lim}$$

$$134136 \times 10^3 = 0.138 \times 20 \times 300 \times d^2$$

$$\therefore \quad d = \sqrt{\frac{134136 \times 10^3}{0.138 \times 20 \times 300}} = 402.49 \text{ mm}$$

$\simeq$ 410 mm (say)

< 500 mm (Assumed 'd')

Hence O.K.

Hence adopt the following dimensions of the beam.

Effective depth (d) = 410 mm

Total depth (D) = 410 + 40 = 450 mm

Breadth (d) = 300 mm

Step 6. Calculate the area of tensile steel (A_{st})

For a balanced section,

$$A_{st} = \frac{0.36 f_{ck} b.x_{u,max}}{0.87 f_y}$$

where $x_{u,max} = 0.48d$ (For Fe 415 steel)

$$A_{st} = \frac{0.36 \times 20 \times 300 \times 0.48 \times 410}{0.87 \times 415}$$

$$= 1177.36 \text{ mm}^2$$

Hence required area of tensile steel (A_{st}) = 1177.36 mm^2

Provide 20 mm diameter longitudinal steel bars.

Area of one 20 mm diameter bar $= \frac{\pi (20)^2}{4} = 314 \text{ mm}^2$

$\therefore$ Number of bars required $= \frac{A_{st}}{\text{Area of one bar}}$

$$= \frac{1177.36}{314} = 3.75 \simeq 4 \text{ bars}$$

Area of steel provided $= 4 \times 314 = 1256 \text{ mm}^2$

Step 7. Check for minimum and maximum area of tensile steel

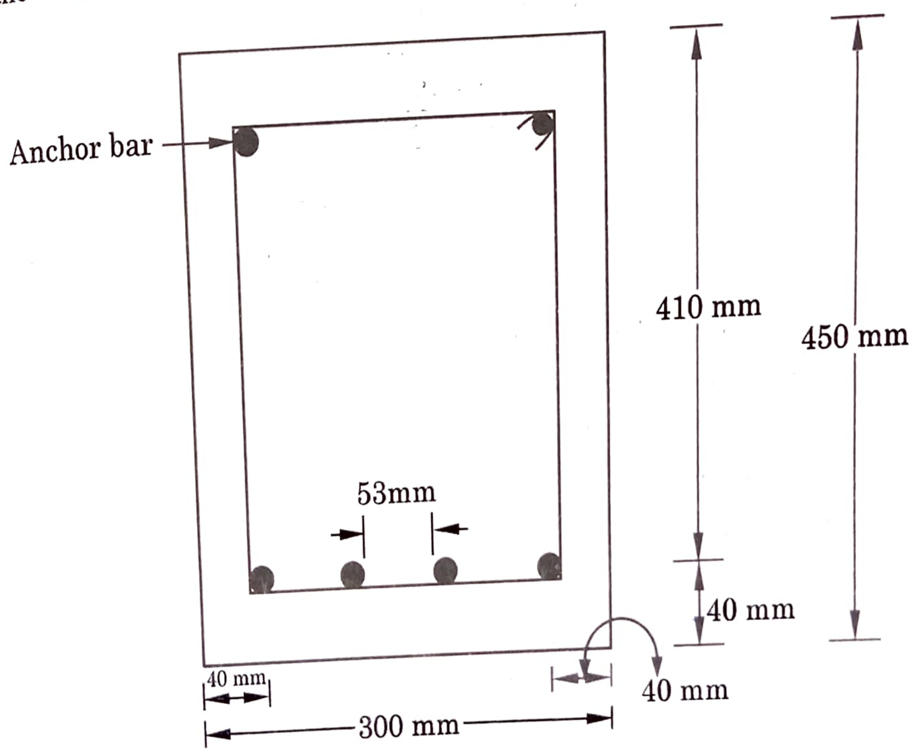
(*i*) Minimum area of tensile steel (A_s) $= \dfrac{0.85bd}{f_y}$

$$= \frac{0.85 \times 300 \times 410}{415} = 252 \text{ mm}^2$$

(*ii*) Maximum area of tensile steel $= 0.04\, b\, D$

$$= 0.04 \times 300 \times 450 = 5400 \text{ mm}^2$$

Thus the actual area of steel provided (A_{st} = 1256 mm^2) satisfies both these limiting conditions.



Horizontal distance (clear distance) between adjacent steel bars

$$= \frac{\text{Breadth of beam} - 2\,(\text{effective cover}) - 3\,(\text{dia. of bar})}{\text{Number of spacings}}$$

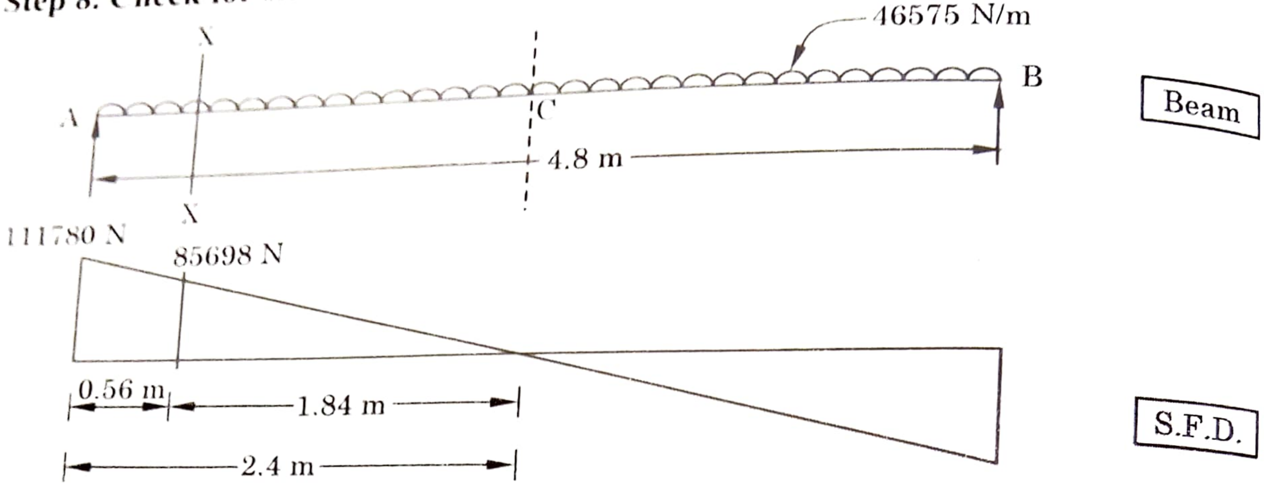
$$= \frac{300 - 2 \times 40 - 3 \times 20}{3} = 53 \text{ mm}$$

It should be more than the following

(*i*) Diameter of bar = 20 mm

(*ii*) Size of aggregate + 5 mm = 20 + 5 = 25 mm Hence O.K.

Step 8. Check for shear and design of shear reinforcement



The critical section (X-X) for shear is at a distance d (*i.e.* 410 mm) from the inner face of support

(or)

$$0.41 + \frac{0.30}{2} = 0.56 \text{ m from the centre of support}$$

(or)

$$2.4 - 0.56 = 1.84 \text{ m from the centre of beam}$$

Factored shear force (S.F.) at centre of support $= \dfrac{w_u l}{2}$

$$= \frac{46575 \times 4.8}{2} = 111780 \text{ N}$$

Factored shear force at critical section X-X, (V_u)

$$= \frac{111780}{2.4} \times 1.84 = 85698 \text{ N}$$

Nominal shear stress $(\tau_v) = \dfrac{V_u}{bd} = \dfrac{85698}{300 \times 410} = 0.696 \text{ N/mm}^2$

$\tau_{c,\max} = 2.8 \text{ N/mm}^2$ (For M 20 concrete)

Thus $\tau_v < \tau_{c,\max}$

Hence O.K.

Shear strength of concrete (τ_c) depends upon the grade of concrete and percentage of tension steel.

Assuming no longitudinal steel bar is bent-up or curtailed and all the bars are available at supports.

$$p = \frac{100A_s}{bd} = \frac{100 \times 1256}{300 \times 410} = 1.02\% \quad \text{(Assume 1.00\%)}$$

For $p = 1.00\ \%$ and M 20 grade concrete, from **Table – 10.1**

$\tau_c = 0.62 \text{ N/mm}^2$

$\because$ $\tau_v (0.696 \text{ N/mm}^2) > \tau_c (0.62 \text{ N/mm}^2)$

Hence shear reinforcement is required.

Design shear stress $(\tau_{us}) = \tau_v - \tau_c$

$= 0.696 - 0.62 = 0.076 \text{ N/mm}^2$

Shear force for shear reinforcement $(V_{us}) = \tau_{us}\, bd$

$= 0.076 \times 300 \times 410 = 9348 \text{ N}$

Provide 6 mm ϕ 2 legged vertical stirrups of Fe 415 grade steel.

$$A_{sv} = 2 \times \frac{\pi}{4} \times 6^2 = 56.54 \text{ mm}^2$$

$$\text{Spacing of vertical stirrups } (S_v) = \frac{0.87 f_y A_{sv} d}{V_{us}}$$

$$= \frac{0.87 \times 415 \times 56.54 \times 410}{9348} = 895 \text{ mm}$$

Maximum spacing as per minimum shear reinforcement,

$$S_v = \frac{0.87 A_{sv} f_y}{0.4 b} = \frac{0.87 \times 56.54 \times 415}{0.4 \times 300}$$

$$= 170 \text{ mm}$$

Maximum spacing is also given by least of the following

(*i*) $0.75\, d = 0.75 \times 410 = 307$ mm

(*ii*) 300 mm

∴ Provide 6 mm ϕ 2 legged stirrups @ 170 mm c/c throughout the length of the beam.

Step 9. Check for development length

$$\text{Development length } (L_d) = \frac{0.87 f_y \phi}{4 \tau_{bd}} = \frac{0.87 \times 415 \times 20}{4 \times 1.92}$$

$$= 940 \text{ mm}$$

From Table – 11.1,

$\tau_{bd} = 1.2 \text{ N/mm}^2$ for M 20 concrete and plain mild steel bars

and $\tau_{bd} = 1.2 \times 1.6 = 1.92 \text{ N/mm}^2$ for M 20 and Fe 415 steel

As per I S : 456 – 2000, at the simple supports, the longitudinal steel bars must extend beyond the face of support by a distance not less than $\frac{L_d}{3} = \frac{940}{3} = 313$ mm

Length available from face of support = Support width – end cover

$= 300 - 20 = 280 \text{ mm} < 313 \text{ mm}$

Therefore, there is need to increase the embedded length of steel bar.

Provide 90° standard bend having a total anchorage value of $8\phi = 8 \times 20 = 160$ mm

Now available length from centre of support, (L_0)

$$= \left(\frac{300}{2} - 20 - 5\phi\right) + 160$$

$$= (150 - 20 - 5 \times 20) + 160 = 190 \text{ mm}$$

$\therefore$ Embedded length provided from the inner face of support

$$= \frac{300}{2} + 190 = 340 \text{ mm} > \frac{L_d}{3}$$

As the beam is simply supported, the compressive reaction will confine the reinforcement.

Hence

$$L_d \ngtr \frac{1.3M_1}{V} + L_0$$

where

M_1 = Moment of resistance provided by 4 – 20 mm ϕ bars

$$= 0.87 f_y A_{st_1}\left(d - \frac{f_y A_{st_1}}{f_{ck} b}\right)$$

$$= 0.87 \times 415 \times 1256\left(410 - \frac{415 \times 1256}{20 \times 300}\right)$$

$$M_1 = 146531 \times 10^3 \text{ N-mm} \qquad \left(A_{st_1} = 4 \times \frac{\pi}{4} \times 20^2 = 1256 \text{ mm}^2\right)$$

V = Factored shear force at the centre of support

$$= \frac{46575 \times 4.8}{2} = 111780 \text{ N}$$

$$\frac{1.3M_1}{V} + L_0 = \frac{1.3 \times 146531 \times 10^3}{111780} + 190 = 1895 \text{ mm}$$

Thus

$$940 \ngtr 1895$$

Hence development length requirements are satisfied.

Step 10. Check for deflection

$$p_t = \frac{100A_s}{bd} = \frac{100 \times 1256}{300 \times 410} = 1.02\%$$

$$f_s = 0.58 f_y\left(\frac{\text{Area of steel required}}{\text{Area of steel provided}}\right)$$

$$= 0.58 \times 415 \times \left(\frac{1177}{1256}\right) = 225 \text{ N/mm}^2$$

Modification factors

$k_t = 1.0$ (For $p_t = 1.02\%$ and $f_s = 225$ N/mm² from **Fig. 12.1**)

$k_c = 1.0$ ($\because$ No compression reinforcement is provided)

$k_f = 1.0$ ($\because$ Beam is rectangular)

$$\therefore \quad \left(\frac{l}{d}\right)_{max} = 20 . k_t . k_c . k_f = 20 \times 1 \times 1 \times 1 = 20$$

and

$$\left(\frac{l}{d}\right)_{provided} = \frac{4800}{410} = 11.7 < 20$$

Hence the beam satisfies the limit state of serviceability