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New Scheme Based On AICTE Flexible Curricula

Civil Engineering, VI-Semester

CE601- Structural Design & Drawing (RCC-I)

Structural Design & Drawing (RCC-I)
Unit - I
Basic Principles of Structural Design: Assumptions, Mechanism of load transfer, Various properties of concrete and reinforcing steel, Introduction to working stress method and limit state methods of design, partial safety factor for load and material. Calculation of various loads for structural design of singly reinforced beam, Partial load factors.

Unit - II
Design of Beams: Doubly reinforced rectangular & Flanged Beams, Lintel, Cantilever, simply supported and continuous beams, Beams with compression reinforcement: Redistribution of moments in continuous beams, Circular girders: Deep beams. Design of beam for shear and bond.

Unit-III
Design of Slabs: Slabs spanning in one direction. Cantilever, Simply supported and Continous slabs, Slabs spanning in two directions, Circular slabs, Waffle slabs, Flat slabs, Yield line theory.

Unit -IV
Columns & Footings: Effective length of columns, Short and long cloumns- Square, Rectangular and Circular columns, Isolated and combined footings, Strap footing, Columns subjected to axial loads and bending moments (sections with no tension), Raft foundation.

Unit -V
Staircases: Staircases with waist slab having equal and unequal flights with different support conditions,Slabless tread-riser staircase.

NOTE :- All the designs for strength and serviceability should strictly be as per the latest version of IS:456. Use of SP-16 (Design aids)

Laboratory Work: Laboratory work will be based on the above course as required for engineering projects.

Reference Books: -

1. Plain & Reinforced Concrete Vol. I & II – O.P. Jain & Jay Krishna
2. Limit State Design by P.C.Varghese ; Prentice Hall of India, New Delhi
3. Design of Reinforced Concrete Elements by Purushothman; Tata McGraw Hill, New Delhi
4. Reinforced Cement Concrete by Gupta & Mallick, Oxford and IBH

5. Reinforced Cement Concrete by P. Dayaratnam, Oxford and IBH
6. Plain & reinforced concrete - Rammuttham
7. Plain & reinforced concrete – B.C. Punnia
8. Structural Design & Drawing by N.K.Raju.

Unit – I

Basic Principles of Structural Design : Assumptions, Mechanism of load transfer, Various properties of concrete and reinforcing steel, Introduction to working stress method and limit state methods of design, partial safety factor for load and material. Calculation of various loads for structural design of singly reinforced beam, Partial load factors.

Introduction to RCC

RCC is concrete reinforced with steel. Concrete is strong in compression and weak in tension and cannot take high tensile stress. Layers below the NA are in tension. Initially the tensile stress is distributed equally between concrete and reinforcement.

Different method of design of RCC

1. **Working stress method:**
   The following assumptions are made for this method. Concrete and reinforcement behaves in a linearly elastic manner. Plane sections before bending remains same even after bending. Strain is proportional to distance from NA.
2. **Limit state method**
   Design of the structure should be such that it should safely with stand all loads liable to act on it through its life. Satisfy serviceability requirements.
3. **Ultimate load method**
   Load factor= Ultimate load/Working load
   Advantages of this method are slender sections, requires less reinforcement etc.

General features of reinforced concrete:

A structure refers to a system of connected parts used to support forces (loads). Buildings, bridges and towers are examples for structures in civil engineering. In buildings, structure consists of walls floors, roofs and foundation. In bridges, the structure consists of deck, supporting systems and foundations. In towers the structure consists of vertical, horizontal and diagonal members along with foundation.

A structure can be broadly classified as (i) sub structure and (ii) super structure. The portion of building below ground level is known as sub-structure and portion above the ground is called as super structure. Foundation is sub structure and plinth, walls, columns, floor slabs with or without beams, stairs, roof slabs with or without beams etc are super structure.

Many naturally occurring substances, such as clay, sand, wood, rocks natural fibres are used to construct buildings. Apart from this many manmade products are in use for building construction. Bricks, tiles, cement concrete, concrete blocks, plastic, steel & glass etc are manmade building materials. Cement concrete is a composites building material made from combination of aggregates (course and fine) and a binder such as cement. The most common form of concrete consists of mineral aggregate (gravel & sand), Portland cement and water. After mixing, the cement hydrates and eventually hardens into a stone like material. Recently a large number of additives known as concrete additives are also added to enhance the quality of concrete. Plasticizers, super plasticizers, accelerators, retarders, pazolonic materials, air entertaining agents, fibres, polymers and silica furies are the additives used in concrete. Hardened concrete has high compressive strength and low tensile strength. Concrete is generally strengthened using steel bars or rods known as rebar in tension zone. Such elements are "reinforced concrete" concrete can be moulded to any complex shape using suitable form work and it has high durability, better appearance, fire resistance and economical. For a strong, ductile and durable construction the reinforcement shall have high strength, high tensile strain and good bond to concrete and thermal compatibility. Building components like slab walls, beams, columns foundation & frames

are constructed with reinforced concrete. Reinforced concreted can be in-situ concreted or precast concrete.

For understanding behaviour of reinforced concrete, we shall consider a plain concrete beam subjected to external load as shown in Fig. 1.1. Tensile strength of concrete is approximately one-tenth of its compressive strength.

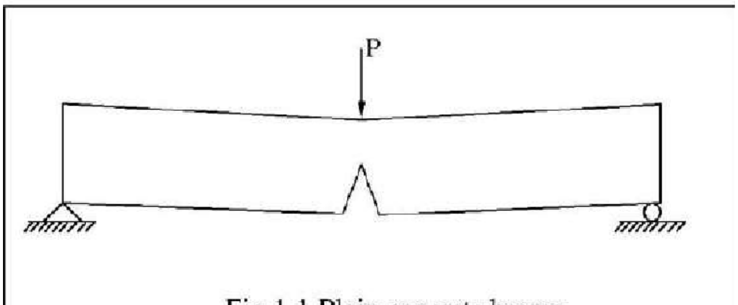


Fig 1.1 Plain concrete beams

Hence use of plain concrete as a structural material is limited to situations where significant tensile stresses and strains do not develop as in solid or hollow concrete blocks , pedestal and in mass concrete dams. The steel bars are used in tension zone of the element to resist tension as shown in Fig 1.2 The tension caused by bending moment is chiefly resisted by the steel reinforcements, while concrete resist the compression. Such joint action is possible if relative slip between concrete and steel is prevented. This phenomenon is called "bond". This can be achieved by using deformed bass which has high bond strength at the steel-concrete interface. Rebar imparts "ductility" to the structural element, i.e. RC elements has large deflection before it fails due to yielding of steel, thus it gives ample warning before its collapse.

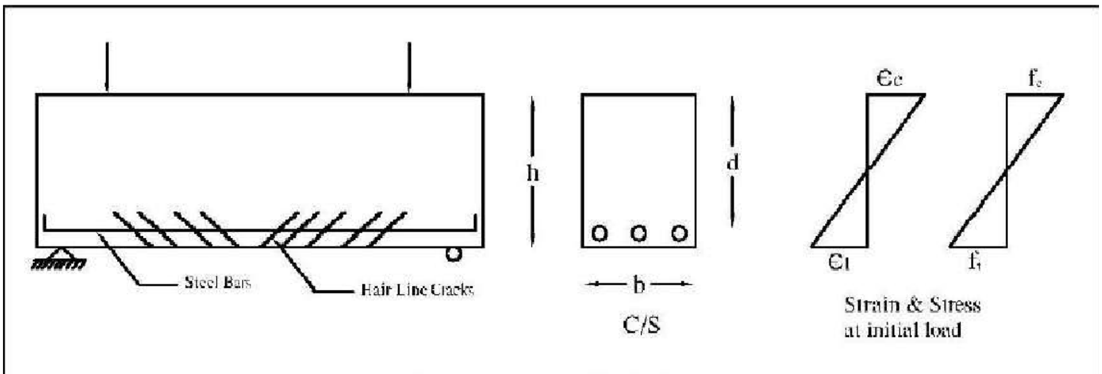


Fig 1.2 Longitudinal elevation & C/S of RC beam

Design Loads

For the analysis and design of structure, the forces are considered as the "Loads" on the structure. In a structure all components which are stationary, like wall, slab etc., exert forces due to gravity, which are called as "Dead Loads". Moving bodies like furniture, humans etc exert forces due to gravity which are called as "Live Loads". Dead loads and live loads are gravity forces which act vertically down ward. Wind load is basically a horizontal force due to wind pressure exerted on the structure. Earthquake load is primarily a horizontal pressure exerted due to movement of the soil on the foundation of a structure. Vertical earthquake force is about 5% to 10% of horizontal earthquake force. Fig. 1.3 illustrates the loads that are considered in analysis and design.

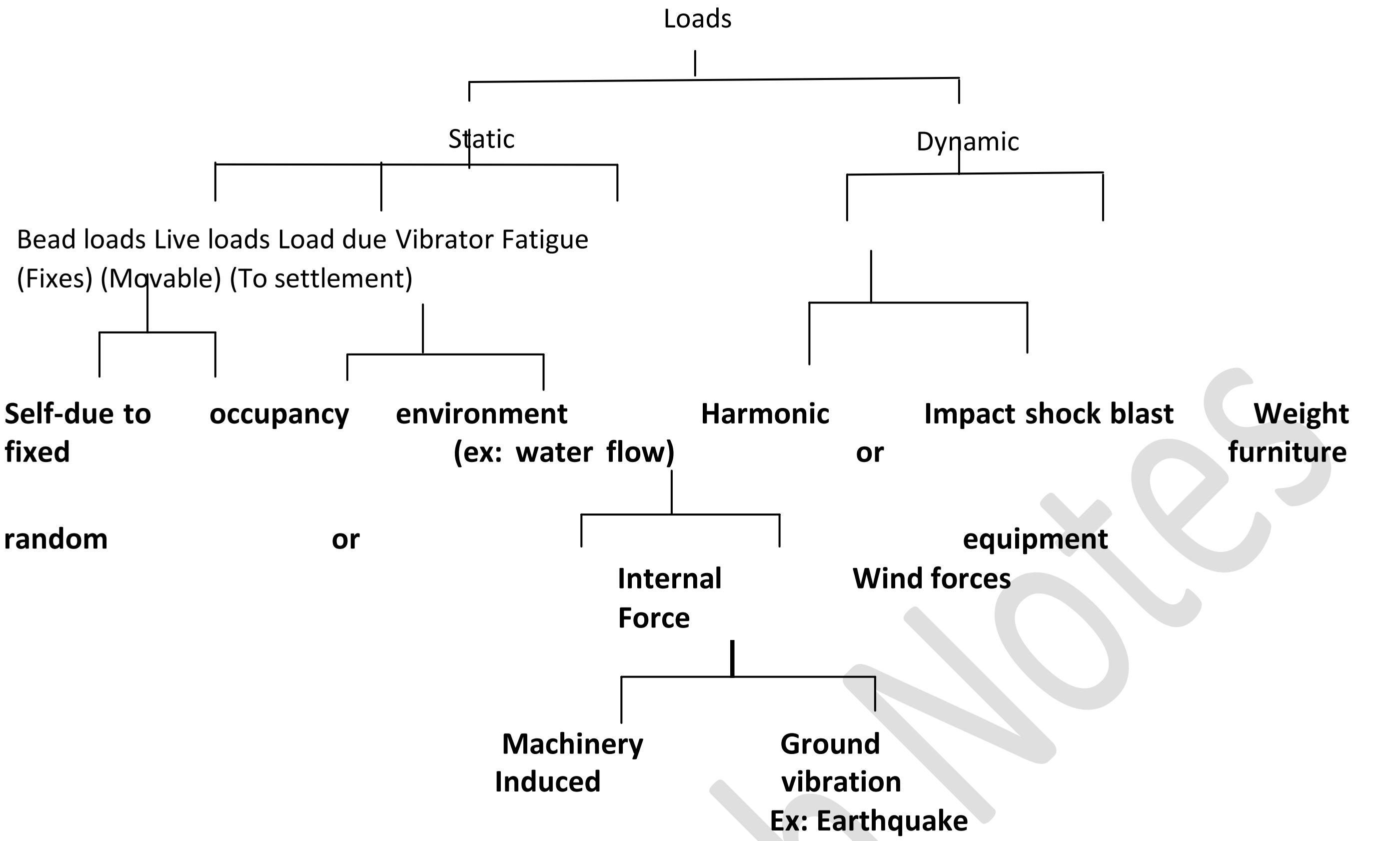


Fig 1.3 Types of loads on Structure

IS875 -1987 part 1 gives unit weight of different materials, Part – 2 of this code describe live load on floors and roof. Wind load to be considered is given in part 3 of the code. Details of earthquake load to be considered are described in 1893 – 2002 code and combination of loads is given in part 5 of IS875 – 1987.

Materials for Reinforced Concrete

Concrete

Concrete is a composite material consists essentially of

a) **A binding medium cement and water called cement paste**
b) **Particles of a relatively inert filler called aggregate**

The selection of the relative proportions of cement, water and aggregate is called "mix design"

Basic requirement of a good concrete are workability, strength, durability and economy. Depending upon the intended use the cement may be OPC (33, 43& 53 Grade), Rapid hardening cements Portland slag, Portland pazolonic etc. High cement content gives rise to increased shrinkage, creep and cracking. Minimum cement content is 300Kg/m^3 and maximum being 450Kg/m^3 as per Indian code. Mineral additives like fly ash , silica fume, rice husk ash, metabolize and ground granulated blast furnace slag may be used to reduce micro cracks . The aggregate used is primarily for the purpose of providing bulk to the concrete and constitutes 60 to 80 percent of finished product. Fine aggregates are used to increase the workability and uniformly of concrete mixture. Water used for mixing and curing shall be clean and free from oil, acids, alkalis, salts, sugar etc. The diverse requirements of mix ability, stability, transportability place ability, mobility, compatibility of fresh concrete are collectively referred to as workability.

Compressive strength of concrete on 28th day after casting is considered as one of the measure of quality. At least 4 specimens of cubes should be tested for acceptance criteria.

Grade of concrete

Based on the compressive strength of concrete, they are designated with letter H followed by an integer number represented characteristic strength of concrete, measured using 150mm size cube. Characteristic strength is defined us the strength of material below which not more than 5% of test results are expected to full. The concrete grade M10, M15 and M20 are termed as ordinary concrete and those of M25 to M55 are termed as standard concrete and the concrete of grade 60 and above are termed as high strength concrete. The selection of minimum grade of concrete is dictated by durability considerations which are based on kind of environment to which the structure is exposed, though the minimum grade of concrete for reinforced concrete is specified as M20 under mild exposure conditions, it is advisable to adopt a higher grade. For moderate, severe, very severe and extreme exposure conditions, M25, M30, M35 & M40 grades respectively are recommended. Typical stress-strain curves of concrete are shown.

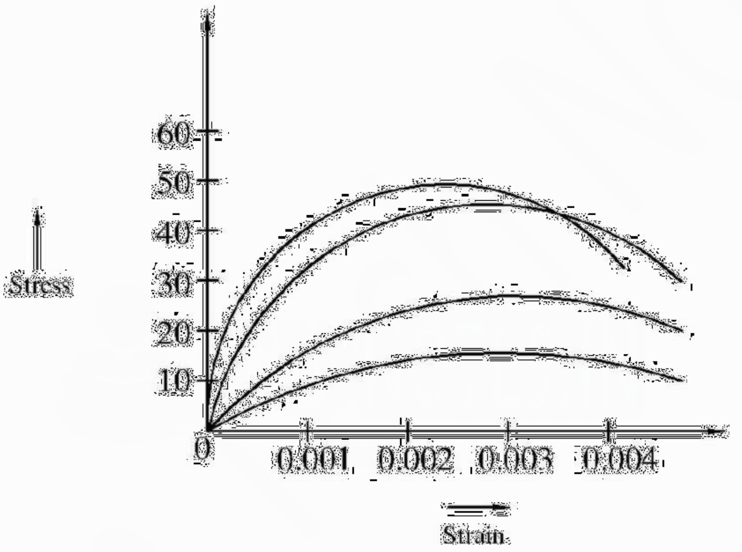
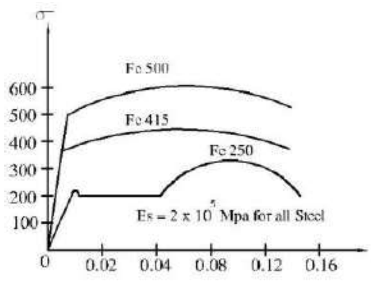
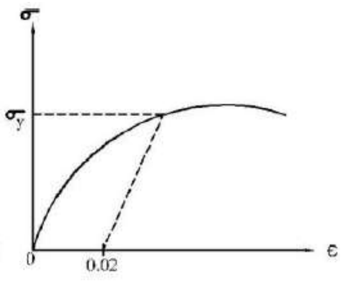


Fig 1.4

Reinforcing steel

Steel bars are often used in concrete to take case of tensile stresses. Often they are called as rears, steel bar induces ductility to composite material i.e. reinforced concrete steel is stronger than concrete in compression also. Plain mild steel bars or deformed bars are generally used. Due to poor bond strength plain bars are not used. High strength deformed bars generally cold twisted (CTD) are used in reinforced concrete. During beginning of 21st century, Thermo mechanical treated (TMT) bars which have ribs on surface are used in reinforced concrete. Yield strength of steel bars are denoted as characteristic strength. Yield strength of mild steel is 250MPa; yield strength of CTD &TMT bars available in market has 415 MPa or 500 MPa or 550MPa. TMT bars have better elongation than CTD bars. Stress-strain curve of CTD bars or TMT bars do not have definite yield point, hence 0.2% proof stress is used as yield strength. Fig 1.5 shows stress strain curve of different steel grades. Steel grades are indicated by Fe followed by yield strength. In the drawings of RCC, ϕ denotes MS bar and # denotes CTD or TMT bars





stress –strain curve

Design codes and Hand books

A code is a set of technical specifications intended to control the design and construction. The code can be legally adopted to see that sound structure are designed and constructed code specifies acceptable methods of design and construction to produce safe and sound structures.

National building code have been formulated in different countries to lay down guidelines for the design and construction of structures. International building code has been published by international code council located in USA. National building code (NBC – 2005) published in India describes the specification and design procedure for buildings.

For designing reinforced concrete following codes of different countries are available

India – IS456 – 2000 – Plain and reinforced concrete code practice.

USA - ACI 318-2011 – Building code requirements for Structural concrete (American concrete institute)

UK - BS8110 –part1 –structural use of concrete –code of practice for design and construction. (British standard Institute)

Europe – EN 1992(Euro code 2) - Design of concrete structures

Canada – CAN/CSA – A23.3-04 - Design of concrete structures (Reaffirmed in 2010),

Australia – As 3600 -2001 – concrete structures.

Germany – Din 1045 – Design of concrete structures

Russia – SNIP

China - GB 50010 -2002 code for design of concrete structures to help the designers, each country has produced “handbook”. In India following hand books called special publication are available.

SP – 16-1980- Design Aid for Reformed concrete to IS456-1978

SP – 23-1982- Hand book on concrete mixes

Sp – 24 -1983 – Explanatory hand book on IS456 – 1978

SP – 34-1987 - Hand book on concrete reinforcement and detailing.

Design Philosophies

Structural design is process of determining the configuration (form and proportion) of a structure subject to a load carrying performance requirement. Form of a structure describes the shape and relative arrangements of its components. The determination of an efficient form is basically a trial and error procedure.

In the beginning of 20th century (1900 to 1960) to late 50’s of this century, members were proportioned so that stresses in concrete and steel resulting from service load were within the allowable stresses. Allowable stresses were specified by codes. This method of design is called “working stress method” (WSM). This method of design resulted in conservative sections and was not economical. This design principle satisfies the relation

Where R is resistance of structural element, RS is factor of safety and L is applied external load.

In 1950’s ultimate load method or load factor method was developed. In this method, using nonlinear stress – strain curve of concrete and steel, the resistance of the element is computed. The safety measure in the design is introduced by an appropriate choice of the load factor (ultimate load/working

load). Different load factors are assigned for different loads. Following equations are used for finding ultimate load as per IS456 – 1964.

$$U = 1.5\ DL + 2.2\ LL$$

$$U = 1.5\ DL + 2.2LL \text{ to } 5WL \text{ or } 1.5\ DL + 0.5LL + 2.2\ WL$$

Here DL = Dead load, LL = Live load WL= wind load or earthquake load. The design principle should satisfy R≥LF etc or R ≥ U, Where, R= Resistance, LF= Load factor, L= load. Ultimate load method generally results in more slender section, but leads to larger deformation. Due to the disadvantage of larger deflection, this method was discontinued. To overcome the disadvantages of working stress method and ultimate method, a probabilistic design concept called as "Limit state method, was developed during 1970's. IS456 -1978 recommended this method and is continued in 2000 version also. This method safe guards the risk of both collapse and unserviceability. Limits state method uses multiple safety factory format, which attempt to provide adequate safety at ultimate loads or well as a denote serviceability at service loads by considering all limit states, The acceptable limit for safety and serviceability requirements before failure or collapse is termed as "Limit state" Two principal limit states are considered i.e. 1. Limit state of collapse 2. Limit state of serviceability. The limit state of collapse include one or more of i) flexure, II) shear, III) torsion and IV) compression the limit state of collapse is expressed as $\mu R > \Sigma X_i L_i$ Where, μ and λ are partial safety factors, Here μ<1 &λ>1. The most important limit state considered in design are of deflection, other limit state of serviceability are crack and vibration. For deflection $\delta_{max} \le \frac{l}{\propto}$where δ_{max} is maximum deflection, l=span 4 ∝ is an integer numbers. For over all deflection ∝ is 250 and for short term deflection ∝ =350.

Partial safety factor

To account for the different conditions like for material strength, load etc. Different partial factors are used for material and load. M indicate safety factor for material & for load

Design strength =_____γm

Design load = γm x characteristic load

As per clause 36.4.2 page 68 of IS 456, γ_m= 1.5 for concrete and γ_m =1.15 for steel. Similarly clause 36.4.1 page 68 of code gives γ_f in table 18 for different values for different load combinations and different limit states.

IS 456 – 2000 Recommendations

(i) Partial safety factors for materials to be multiplied with characteristic Strength is given below.

Values of partial safety factor rm

Material	Limit state		
	Collapse	Deflection	Cracking
Concrete	1.5	1.0	1.3
Steel	1.15	1.0	1.0

Design strength =_______

γ

(ii) Partial safety factors for loads to be multiplied with characteristic load is given below.

Value of partial safety factors γ_f

Load combination	Ultimate limit state	Serviceability limit state
1)Dead load & live load	1.5(DL+LL)	DL+LL
2)Dead seismic/wind load a) Dead load contributes to Stability b) Dead load assists overturning	0.9DL+1.5(E2/WL) 1.5(DL+E2/WL)	 DL + EQ/WL DL+EQ/wL
3)Dead, live load and Seismic/wind load	1.2(DL+LL+EQ/WL)	Dl+0.LL+0.8EQ/WL

DL-Dead load, LL- Live load WL- Wind load EQ- Earthquake load

(iii) The code has suggested effective span to effective depth ratios as given below

Basic effective span to effective depth ratio (l/l) basic

Type of beam one /slab	Span≤10m	Span>10m
1)Cantilever	7	Deflection should be Be calculated
2) Simply supported	20	(20X10)/span
3)continuous beam	26	(26X10)/span

The above values are to be modified for (i) the type and amount of tension steel (Fig 4 page 38 of T5456-2000)
(ii) The amount of compression steel (Fig 5 page 39 of I5456-2000)
(iii) The type of beam i.e. flanged beams etc (Fig 6 page 39 of I5456 – 2000).

For slabs spanning in two directions, the l/d ratio is given below.
For slabs spanning in two directions, the l/d ratio is given below

Type of slab	l/d for grade of steel	
	Fe250	Fe415
1)Simply supported	35	28
2) Continuous	40	32

Characteristic strength and loads

Limit state method is based on statistical concepts. Strength of materials and loads are highly variable in a range of values. The test in laboratory on compressive strength of concrete has indicated coefficient of variation of ±10%. Hence in reinforced concrete construction, If is not practicable to specify a precise cube strength. Hence in limit state design uses the concept of "characteristic strength" fck indicates characteristics strength of concrete & by characteristic strength of steel. In general fck indicates the characteristic strength of material.

$$\therefore f_{ck} = F_M - 1.646$$

here F_M = mean strength.

Similarly "characteristic load" is that value of load which has an accepted probability of not being exceeded during the life span of structure. In practice the load specified by IS875 – 1987 is considered as characteristic load. Equation for characteristic load is

$$L_k = L_m + 1.64.$$

Unit – II

Design of Beams: Doubly reinforced rectangular & Flanged Beams, Lintel, Cantilever, simply supported and continuous beams, Beams with compression reinforcement: Redistribution of moments in continuous beams, Circular girders: Deep beams. Design of beam for shear and bond.

Introduction:

A beam experiences flexural stresses and shear stresses. It deforms and cracks are developed. ARC beam should have perfect bond between concrete and steel for composites action. It is primarily designed as flexural member and then checked for other parameters like shear, bond, deflection etc. In reinforced concrete beams, in addition to the effects of shrinkage, creep and loading history, cracks developed in tension zone effects its behaviour. Elastic design method (WSM) do not give a clear indication of their potential strengths. Several investigators have published behaviour of RC members at ultimate load. Ultimate strength design for beams was introduced into both the American and British code in 1950's. The Indian code ES456 introduced the ultimate state method of design in 1964. Considering both probability concept and ultimate load called as "Limit state method of design" was introduced in Indian code from 1978.

Behaviour of Reinforced concrete beam

To understand the behaviour of beam under transverse loading, a simply supported beam subjected to two point loading as shown in Fig. 2.1 is considered. This beam is of rectangular cross-section and reinforced at bottom.

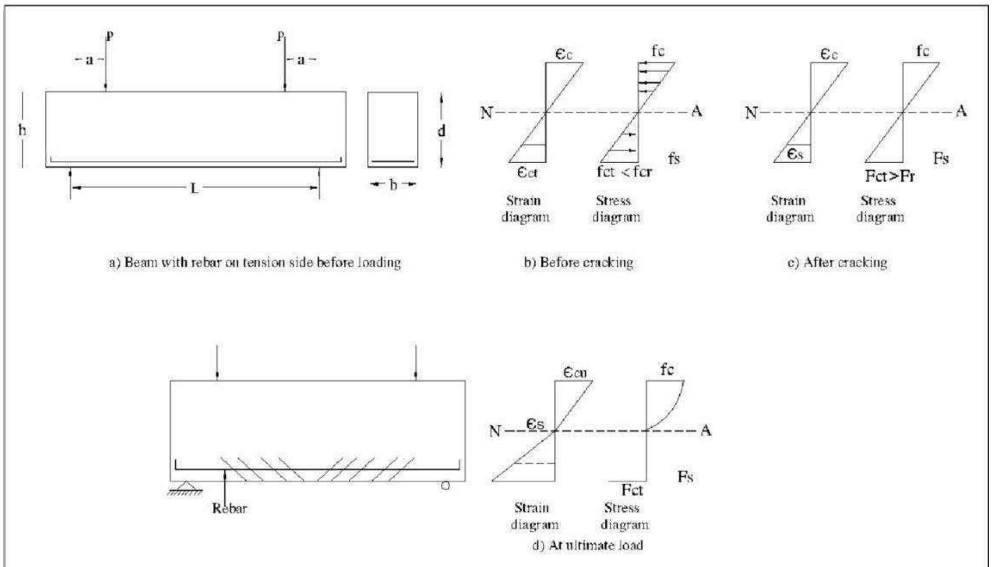


Fig 2.1 Behaviour of RC beam

When the load is gradually increased from zero to the ultimate load value, several stages of behaviour can be observed. At low loads where maximum tensile stress is less than modulus of rupture of concrete, the entire concrete is effective in resisting both compressive stress and tensile stress. At this stage, due to bonding tensile stress is also induced in steel bars.

With increase in load, the tensile strength of concrete exceeds the modulus of rupture of concrete and concrete cracks. Cracks propagate quickly upward with increase in loading up; to neutral axis. Strain and stress distribution across the depth is shown in Fig 4.1c. Width of crack is small. Tensile stresses developed are absorbed by steel bars. Stress and strain are proportional till fc<_. Further increase in load, increases strain and stress in the section and are no longer proportional. The distribution of stress – strain curve of concrete. Fig 41d shows the stress distribution at ultimate load.

Failure of beam depends on the amount of steel present in tension side. When moderate amount of steel is present, stress in steel reaches its yielding value and stretches a large amount with tension crack in concrete widens. Cracks in concrete propagate upward with increases in deflection of beam. This induces crushing of concrete in compression zone and called as "secondary compression failure". This

failure is gradual and is preceded by visible signs of distress. Such sections are called "under reinforced" sections.

When the amount of steel bar is large or very high strength steel is used, compressive stress in concrete reaches its ultimate value before steel yields. Concrete fails by crushing and failure is sudden. This failure is almost explosive and occur without warning. Such reactions are called "over reinforced section"

If the amount of steel bar is such that compressive stress in concrete and tensile stress in steel reaches their ultimate value simultaneously, then such reactions are called "Balanced Section".

The beams are generally reinforced in the tension zone. Such beams are termed as "singly reinforced" section. Some times rebars are also provided in compression zone in addition to tension rebars to enhance the resistance capacity, then such sections are called "Doubly reinforce section.

Assumptions

Following assumptions are made in analysis of members under flexure in limit state method

Plane sections normal to axis remain plane after bending. This implies that strain is proportional to the distance from neutral axis.

Maximum strain in concrete of compression zone at failure is 0.0035 in bending.

Tensile strength of concrete is ignored.

The stress-strain curve for the concrete in compression may be assumed to be rectangle, trapezium, parabola or any other shape which results in prediction of strength in substantial agreement with test results. Design curve given in IS456-2000 is shown in Fig. 2.2

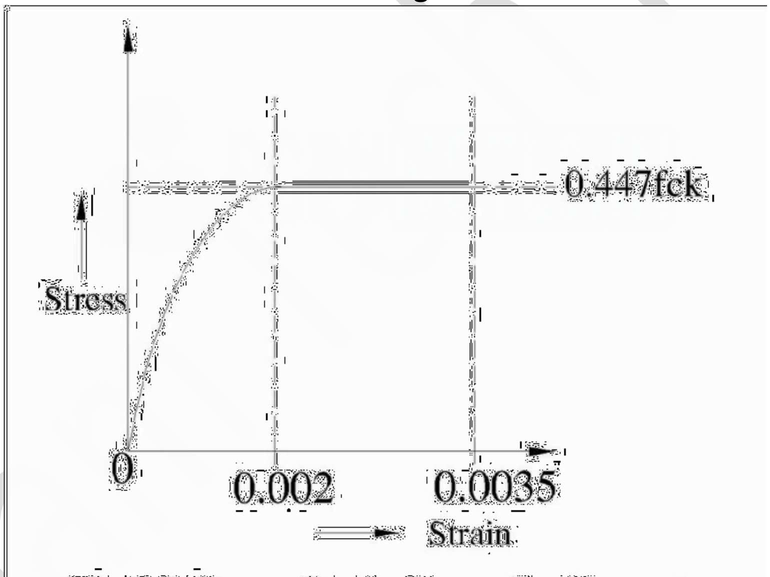
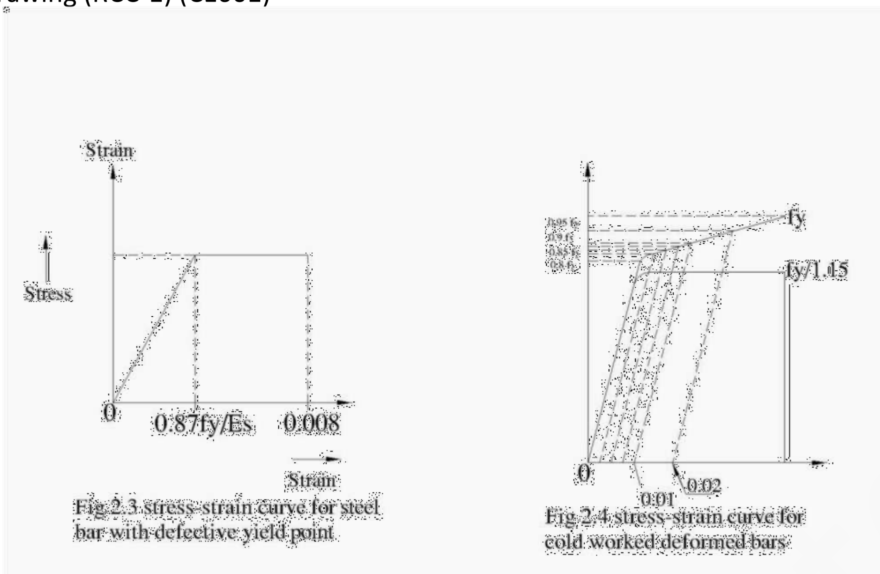


Fig 2.2 Stress-Strain Curve for Concrete

Stress – strain curve for steel bar with definite yield print and for cold worked deformed bars is shown respectively.



To ensure ductility, maximum strain in tension reinforcement shall not be less than. + 0.002.

Perfect bond between concrete and steel exists.

Analysis of singly reinforced rectangular sections

Consider a rectangular section of dimension b x h reinforced with A_{st} amount of steel on tension side with effective cover Ce from tension extreme fiber to C.G of steel. Then effective depth d=h-ce, measured from extreme compression fiber to C.G of steel strain and stress distribution across the section is shown in Fig.2.4. The stress distribution is called stress block.

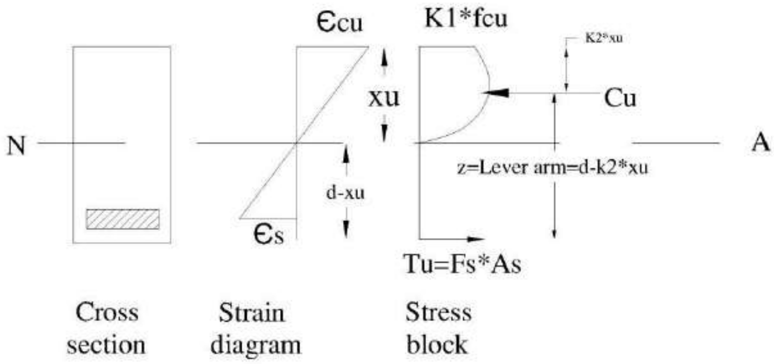


Fig 2.5 Stress Block

From similar triangle properly applied to strain diagram

$$\frac{\varepsilon cu}{xu} = \frac{\varepsilon s}{d - xu} \rightarrow (1)$$

$$\in s = \in cu \times \frac{d - xu}{xu} \rightarrow (2)$$

For the known value of x4 & 6cu the strain in steel is used to get the value of stress in steel from stress-strain diagram. Equation 4.4-1 can be used to get the value of neutral axis depth as

$$xu = \frac{\in cu}{\in s} \times (d - xu) = \frac{\in cu}{\in s} \times d - \frac{\in cu}{\in s} \times$$

$$1 + \frac{\in cu}{\in s}) = \frac{\in cu}{\in s} \times$$

$$xu\left(\frac{\in s+\in cu}{\in s}\right) = \frac{\in cu}{\in s} \times d$$

$$\therefore \quad xu = \frac{\in cu}{\in cu+\in s} \times d - (3)$$

Here $\in^{\in}$ $\in$is called neutral axis factor

For equilibrium Cu = Tu.

K_1, k_3 f_{cu} b x_u = f_sA_s

$$\therefore fs = \frac{K1,k3fcubxu}{As} = \frac{k1k3fcub}{As} \times \frac{\in cu}{\in cu+\in s}$$

$$fs = k1k3fcu \times \frac{Ecu}{Ecu+Es} \times \frac{bd}{As} \; Let\ p = steel\ raio = \frac{As}{bd}$$

$$\therefore fs = \frac{k1k3fcu}{p} \times \frac{Ecu}{Ecn+Es} \; or \; \frac{Ecu}{Ecu+Es} = \frac{fsp}{k1k3fcu} - (4) \quad \times$$

Value of fs can be graphically computed for a given value of P as shown in Fig2.6

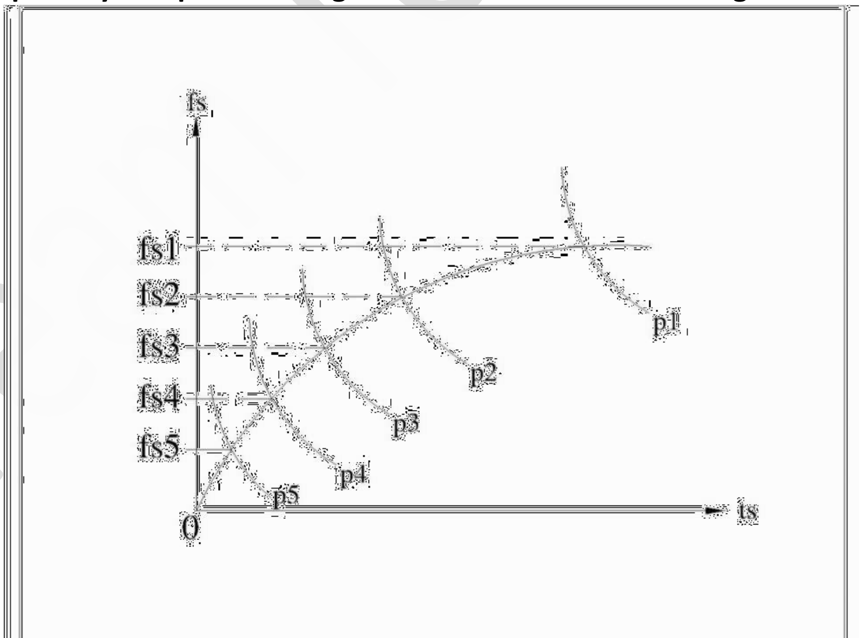


Fig 2.6

After getting fs graphically, the ultimate moment or ultimate moment of resistance is calculated as

Mu = T_u x Z = f_sA_s(d-$k_2$xu)

Mu= Cu x Z = $k_1k_2f_{cu}bx_u$ x (d-$k_2$xu)

Consider

Mu = f_sA_s(d-k2 x $\frac{\epsilon cu}{\epsilon cu+\epsilon s}$ d) = fsAsd(1-kz $\frac{\epsilon cu}{\epsilon cu+\epsilon s}$)

From (4) $\frac{Ecu}{Ecu+Es} = \frac{f_s\, p}{k1k3fcm}$

$\therefore\ Mu = fsAsd\left(1-\frac{k2fsp}{k1k3fcu}\right) - \ (5)$

Here the term $1 - \frac{k2fsp}{k1k3fcu}$ is called lever arm factor———

Using As=pad in (5), the ultimate moment of resistance is computed as

; = ! (0+) 1 –)1)3!)2! 0

-./ ? = (1 –$\frac{Jsp}{fcu} \times \frac{K\angle}{k1k3}$)

&A@ B = 0! ?

Dividing both sides by fcu we get or

$\frac{Mu}{bd^2} = p \times \frac{fs}{fcu}$ **× ? – (6)**

A graph plotted between @&AB ______as shown in fig 2.7 and can be used for design

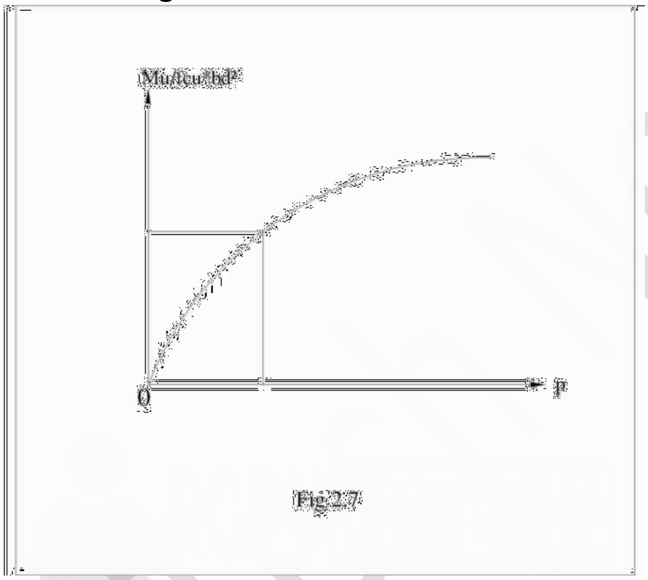


Fig.2.7

2.5 Stress Blocks

Stress blocks adopted by different codes are based on the stress blocks proposed by different investigators. Among them that proposed by Hog nested and Whitney equivalent rectangular block are used by most of the codes. Stress block of IS456-2000 is shown in Fig 2.8. Code recommends ultimate strain ε_{cu}=0.0035 & strain at which the stress reaches design strength ε_0=0.002. Using similar triangle properties on strain diagram

Case 1: Balanced section

Balanced section is considered when the ultimate strain in concrete and in steel are reached simultaneously before collapse.

For equilibrium Cu=Tu

$\therefore$ 0.36$f_{ck}x_{umax}$ b = 0.87f_yAst$_{max}$.

$\frac{xumax}{d} = \frac{0.87fy}{0.36fck}\ \frac{Astmax}{bd}$ but $\frac{Ast\ max}{bd}$ **= pt$_{masc}$.**

$$\therefore pt_{max} = \left(\frac{xumax}{d}\right) \times \frac{0.36fck}{0.87fy}$$

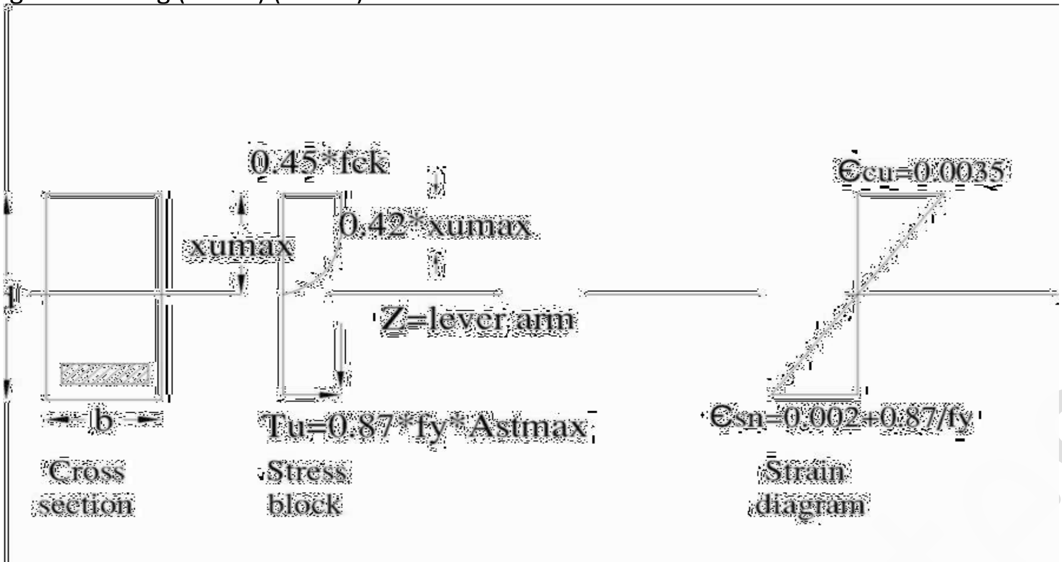


Fig 2.9

Grade of steel this value is given in note of clause 38.1 as (pp70) Values of ':H'A is obtained from equation (12). This value depends on grade of steel. Based on
FyXumax/d

250	**0.53**
415	**0.48**
500	**0.46(0.456)**

Ptmax given in equation (11) is called limiting percentage steel and denoted as pt lim.
To find moment of resistance, the internal moment of Cu &Tu is computed as
Mulim = Cu x Z = 0.36$f_{ck}x_{ulim}$ b (d-0.42 x_{ulim}) from equation (11) ':H'A= 2.42
Mulim = Tu x Z = 0.87fyAst [d-0.42xulim]
Mulim = 0.87fyAst [d-0.42 x 2.42 $_0/: H']

Table 2.1 Limiting Moment resistance & limiting steel

FY	**250**	**415**	**500**
	0.149	**0.138**	**0.133**

Where p_{tlim} is in%

Now considering M_{ulim} = C_u x Z.
Mulim = 0.36$f_{ck}x_{ulim}$ b x (d-0.42x_{ulim})

Value of $&A@] I: B is available in table C ~~of SP16~~ & Value of ~~@] I:~~ &AB for different grade of concrete and steel is given in Tables. Value of ptlim for different grade of concrete and steel is given in @] I: &AB Table E of SP –'6'. Term is termed as limiting moment of resistance factor and denoted as Qlim
∴Mulim = $Q_{lim}bd^2$.

Case 2: Under reinforced section
In under reinforced section, the tensile strain in steel attains its limiting value first and at this stage the strain in extreme compressive fiber of concern is less than limiting strain as shown in Fig 2.10

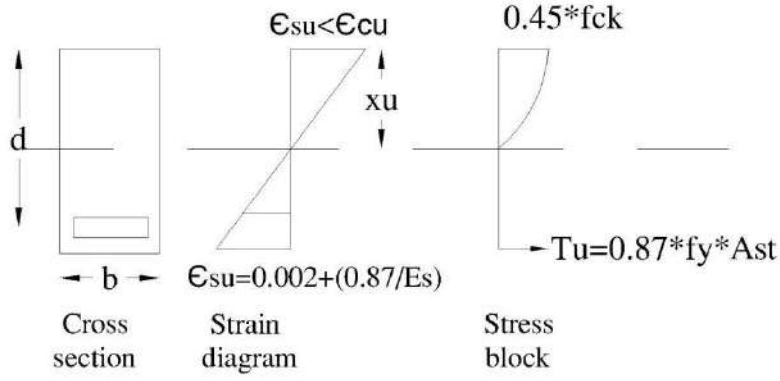


Fig 2.10

The neutral axis depth is obtained from equilibrium condition Cu=Tu

∴ $0.36f_{ck}x_{ub}$ = 0.87fyAst

xu = $\frac{0.87 fyAst}{0.36fck\ b} = 2.41\ \frac{fy}{fck}$ **(&Q or 'A**

$= 2.41\ \frac{fy}{fck}\ \frac{Ast}{bd} - \ (16)$

Moment of resistance is calculated considering ultimate tensile strength of steel ∴M_{uR} = T_u x Z or M_{ur} = 0.87fy Ast X (d-0.42xu) = 0.87ftAst d (1-0.42 'A)

= 0.87fyAst d (1-0.42 x 2.41 $ (&AQ)

Considering p_t = 100 (&A expressed as % we get

M_{uR} = 0.87fyAst d(1-1.0122 $\frac{fy}{fck}(\frac{pt}{100}))$

Or $\frac{MuR}{0.87\ fybd^2} = \frac{Ast}{bd}$ (1-1.0122 $\frac{fy}{fck}(\frac{pt}{100})$, taking 1.0122 ≈ 1

$$\frac{MuR}{0.87\ fybd^2} = \left(\frac{pt}{100}\right) - \frac{fy}{fck}\left(\frac{pt}{100}\right)^2$$

Or $\frac{fy}{fck}\ \left(\frac{pt}{100}\right)^2 - \frac{pt}{100} + \frac{MuR}{0.87\ fybd^2} = 0 - (17)$

Equation (17) is quadratic equation in terms of (pt/100)

Solving for pt, the value of pt can be obtained as

Pt = 50

Case 3: Over reinforced section in over reinforced section, strain in extreme concrete fiber reaches its ultimate value. Such section fail suddenly hence code does not recommend to design over reinforced section. Depth of neutral axis is computed using equation 4.5-6. Moment of resistance is calculated using concrete strength.

M_{uR} = Cu x Z

= 0.36 fckxub (d-0.42xu) – 19

$\frac{xu}{d} > \frac{xulim}{d}$

Position of neutral axis of 3 cases is compared in Fig. 2.11

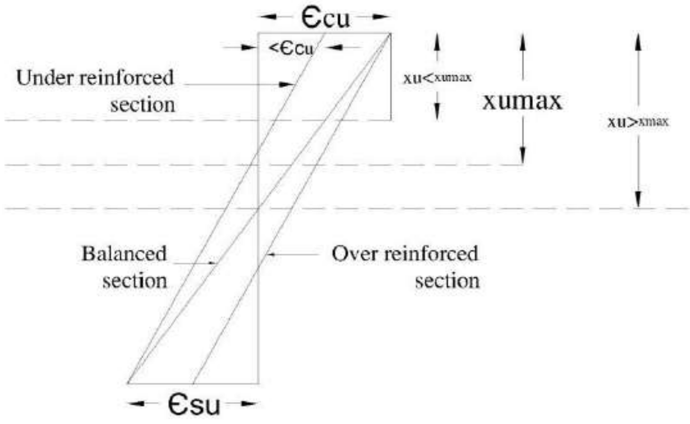


Fig 2.11

Unit – III

Design of Slabs: Slabs spanning in one direction. Cantilever, simply supported and Continuous slabs, Slabs spanning in two directions, Circular slabs, Waffle slabs, Flat slabs, Yield line theory

General

A slab is a flat two dimensional planar structural element having thickness small compared to its other two dimensions. It provides a working flat surface or a covering shelter in buildings. It primarily transfer the load by bending in one or two directions. Reinforced concrete slabs are used in floors, roofs and walls of buildings and as the decks of bridges. The floor system of a structure can take many forms such as in situ solid slab, ribbed slab or pre-cast units. Slabs may be supported on monolithic concrete beam, steel beams, walls or directly over the columns.
Concrete slab behave primarily as flexural members and the design is similar to that of beams.

Classification of Slabs
Slabs are classified based on many aspects
Based of shape: Square, rectangular, circular and polygonal in shape.
Based on type of support: Slab supported on walls, Slab supported on beams, Slab supported on columns (Flat slabs).
Based on support or boundary condition: Simply supported, Cantilever slab, Overhanging slab, Fixed or Continues slab.
Based on use: Roof slab, Floor slab, Foundation slab, Water tank slab.
5) Basis of cross section or sectional configuration: Ribbed slab /Grid slab, Solid slab, Filler slab, folded plate
6) Basis of spanning directions:
One way slab – Spanning in one direction
Two way slab _ spanning in two directions
In general, rectangular one way and two way slabs are very common and are discussed in detail.

Methods of Analysis
The analysis of slabs is extremely complicated because of the influence of number of factors stated above. Thus the exact (close form) solutions are not easily available. The various methods are:
Classical methods – Levy and Navies solutions (Plate analysis)
Yield line analysis – Used for ultimate /limit analysis
Numerical techniques – Finite element and Finite difference method.
Semi empirical – Prescribed by codes for practical design which uses coefficients.

GENERAL GUIDELINES

Effective span of slab:
Effective span of slab shall be lesser of the two

l = clear span + d (effective depth)
l = Centre to centre distance between the support

Depth of slab:
The depth of slab depends on bending moment and deflection criterion. the trail depth can be obtained using:
Effective depth d= Span / ((l/d)$_{Basic}$ x modification factor)
For obtaining modification factor, the percentage of steel for slab can be assumed from 0.2 to 0.5%
The effective depth d of two way slabs can also be assumed using cl.24.1,IS 456 provided short span is ≤ 3.5m and loading class is < 3.5KN/m^2

Type of support	Fe-250	Fe-415
Simply supported	l/35	l/28
continuous	l/40	l/32

The following thumb rules can be used
One way slab d= (l/22) to (l/28).
Two way simply supported slab d= (l/20) to (l/30)
Two way restrained slab d= (l/30) to (l/32)

Load on slab:
The load on slab comprises of Dead load, floor finish and live load. The loads are calculated per unit area (load/m^2).

Dead load = D x 25 kN/m^2 (Where D is thickness of slab in m)
Floor finish (Assumed as) = 1 to 2 kN/m^2
Live load (Assumed as) = 3 to 5 kN/m^2 (depending on the occupancy of the building)

Detailing Requirements As Per Is 456: 2000
Nominal Cover:
For Mild exposure – 20 mm
For Moderate exposure – 30 mm
However, if the diameter of bar do not exceed 12 mm, or cover may be reduced by 5 mm. Thus for main reinforcement up to 12 mm diameter bar and for mild exposure, the nominal cover is 15 mm

Minimum reinforcement: The reinforcement in either direction in slab shall not be less than
0.15% of the total cross sectional area for Fe-250 steel
0.12% of the total cross sectional area for Fe-415 & Fe-500 steel.

Spacing of bars: The maximum spacing of bars shall not exceed
Main Steel – 3d or 300 mm whichever is smaller
Distribution steel –5d or 450 mm whichever is smaller
Where'd' is the effective depth of slab.

Note: The minimum clear spacing of bars is not kept less than 75 mm (Preferably 100 mm) though code do not recommend any value.

Maximum diameter of bar: The maximum diameter of bar in slab, shall not exceed D/8,
Where D is the total thickness of slab.

Behaviour of One Way Slab

When a slab is supported only on two parallel apposite edges, it spans only in the direction perpendicular to two supporting edges. Such a slab is called one way slab. Also, if the slab is supported on all four edges and the ratio of longer span(l_y) to shorter span (l_x) i.ely/lx > 2, practically the slab spans across the shorter span. Such a slabs are also designed as one way slabs. In this case, the main reinforcement is provided along the spanning direction to resist one way bending.

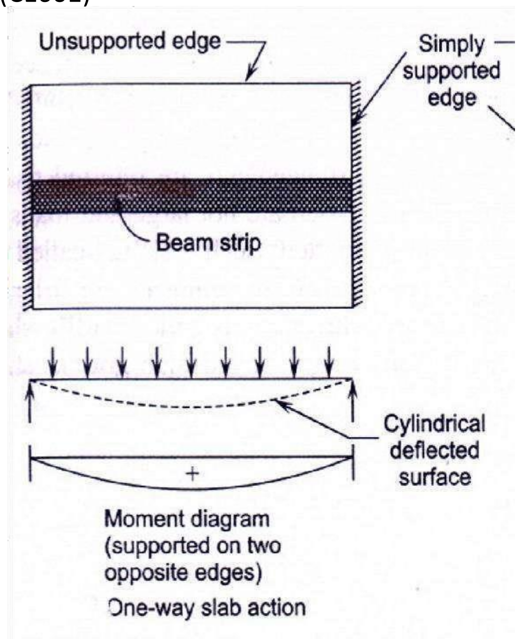


Fig.1: Behaviour of one way slab

Behaviour Of Two Way Slabs

A rectangular slab supported on four edge supports, which bends in two orthogonal directions and deflects in the form of dish or a saucer is called two way slabs. For a two way slab the ratio of ly/lx shall be ≤2.0 .

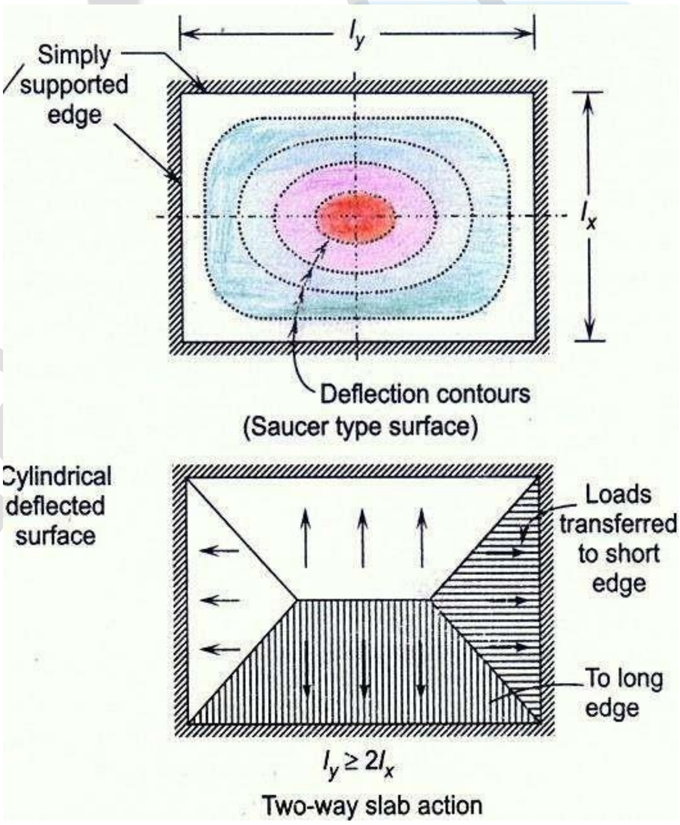


Fig. 2: Behaviour of Two way slab

Since, the slab rest freely on all sides, due to transverse load the corners tend to curl up and lift up. The slab loses the contact over some region. This is known as lifting of corner. These slabs are called two way simply supported slabs. If the slabs are cast monolithic with the beams, the corners of the slab are restrained from lifting. These slabs are called restrained slabs. At corner, the rotation occurs in both the

direction and causes the corners to lift. If the corners of slab are restrained from lifting, downward reaction results at corner & the end strips gets restrained against rotation. However, when the ends are restrained and the rotation of central strip still occurs and causing rotation at corner (slab is acting as unit) the end strip is subjected to torsion.

Types of Two Way Slab

Two way slabs are classified into two types based on the support conditions:

Simply supported slab

Restrained slabs

Two way simply supported slabs

The bending moments M_x and M_y for a rectangular slabs simply supported on all four edges with corners free to lift or the slabs do not having adequate provisions to prevent lifting of corners are obtained using

Mx = αx W l2x

$M_y = \alpha_y W l^2_x$

Where, α_x and α_y are coefficients given in Table 1 (Table 27,IS 456-2000) W- Total load /unit area l_x & l_y – lengths of shorter and longer span.

Table 1 Bending Moment Coefficients for Slabs Spanning in Two Directions at Right Angles, Simply Supported on Four Sides (Table 27:IS 456-2000)

l_y/l_x	1.0	1.1	1.2	1.3	1.4	1.5	1.75	2.0	2.5	3.0
α_x	0.062	0.074	0.084	0.093	0.099	0.104	0.113	0.118	0.122	0.124
α_y	0.062	0.061	0.059	0.055	0.051	0.046	0.037	0.029	0.020	0.014

Note: 50% of the tension steel provided at mid span can be curtailed at $0.1l_x$ or $0.1l_y$ from support.

Two way restrained slabs

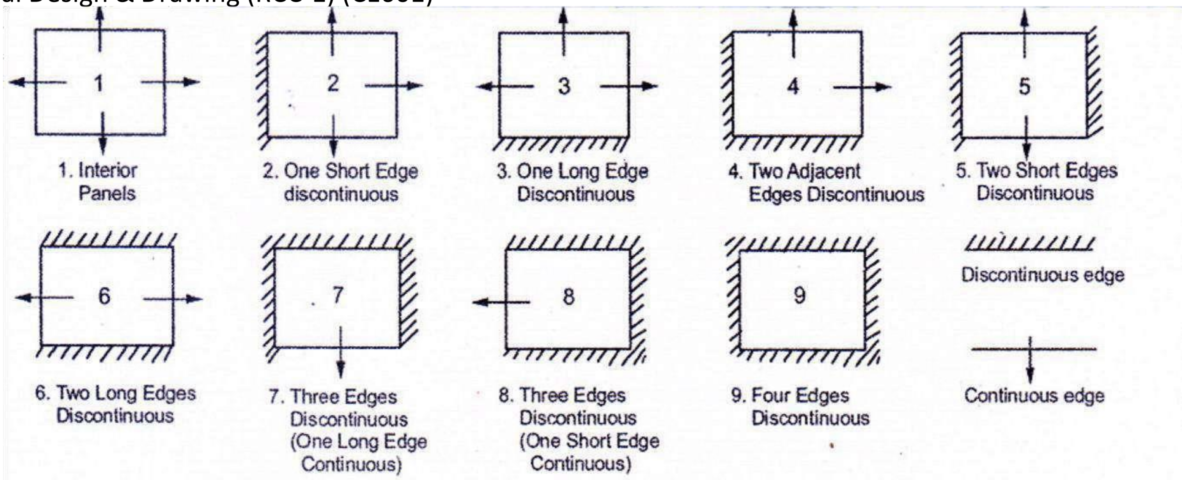
When the two way slabs are supported on beam or when the corners of the slabs are prevented from lifting the bending moment coefficients are obtained from Table 2 (Table 26, IS456-2000) depending on the type of panel shown in Fig. 3. These coefficients are obtained using yield line theory. Since, the slabs are restrained; negative moment arises near the supports. The bending moments are obtained using;

Mx (Negative)=αx (-) W l2x

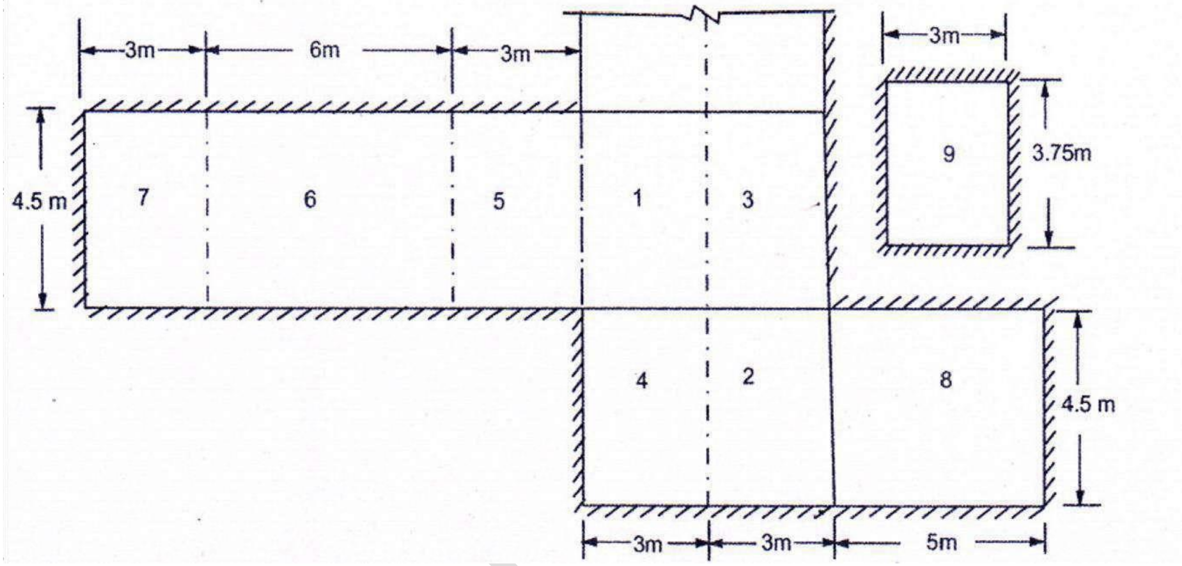
Mx (Positive)=αx (+) W l2x

My (Negative)=αy (-) W l2x

My (Positive)=αy (+) W l2x



Different Types of Support Conditions for Rectangular Two - way Slabs



Different Boundary conditions of two way Restrained slabs

Bending moment coefficients for two way restrained slabs (Table 26, IS 456-2000)

Case No.	Type of Panel and Moments Considered	Short Span Coefficients α_x (Values of l_y/l_x)								Long Span Coefficients α_y for All Values of l_y/l_x
		1.0	1.1	1.2	1.3	1.4	1.5	1.75	2.0	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	*Interior Panels*:									
	Negative moment at continuous edge	0.032	0.037	0.043	0.047	0.051	0.053	0.060	0.065	0.032
	Positive moment at mid-span	0.024	0.028	0.032	0.036	0.039	0.041	0.045	0.049	0.024
2	*One Short Edge Continuous*:									
	Negative moment at continuous edge	0.037	0.043	0.048	0.051	0.055	0.057	0.064	0.068	0.037
	Positive moment at mid-span	0.028	0.032	0.036	0.039	0.041	0.044	0.048	0.052	0.028
3	*One Long Edge Discontinuous*:									
	Negative moment at continuous edge	0.037	0.044	0.052	0.057	0.063	0.067	0.077	0.085	0.037
	Positive moment at mid-span	0.028	0.033	0.039	0.044	0.047	0.051	0.059	0.065	0.028
4	*Two Adjacent Edges Discontinuous*:									
	Negative moment at continuous edge	0.047	0.053	0.060	0.065	0.071	0.075	0.084	0.091	0.047
	Positive moment at mid-span	0.035	0.040	0.045	0.049	0.053	0.056	0.063	0.069	0.035
5	*Two Short Edges Discontinuous*:									
	Negative moment at continuous edge	0.045	0.049	0.052	0.056	0.059	0.060	0.065	0.069	—
	Positive moment at mid-span	0.035	0.037	0.040	0.043	0.044	0.045	0.049	0.052	0.035
6	*Two Long Edges Discontinuous*:									
	Negative moment at continuous edge	—	—	—	—	—	—	—	—	0.045
	Positive moment at mid-span	0.035	0.043	0.051	0.057	0.063	0.068	0.080	0.088	0.035
7	*Three Edges Discontinuous (One Long Edge Continuous)*:									
	Negative moment at continuous edge	0.057	0.064	0.071	0.076	0.080	0.084	0.091	0.097	—
	Positive moment at mid-span	0.043	0.048	0.053	0.057	0.060	0.064	0.069	0.073	0.043
8	*Three Edges Discontinuous (One Short Edge Continuous)*:									
	Negative moment at continuous edge	—	—	—	—	—	—	—	—	0.057
	Positive moment at mid-span	0.043	0.051	0.059	0.065	0.071	0.076	0.087	0.096	0.043
9	*Four Edges Discontinuous*:									
	Positive moment at mid-span	0.056	0.064	0.072	0.079	0.085	0.089	0.100	0.107	0.056

Detailing requirements as per IS 456-2000

Slabs are considered as divided in each direction into middle and end strips as shown below

The maximum moments obtained using equations are apply only to middle strip.

50% of the tension reinforcement provided at midspan in the middle strip shall extend in the lower part of the slab to within 0.25l of a continuous edge or 0.15l of a discontinuous edge and the remaining 50% shall extend into support.

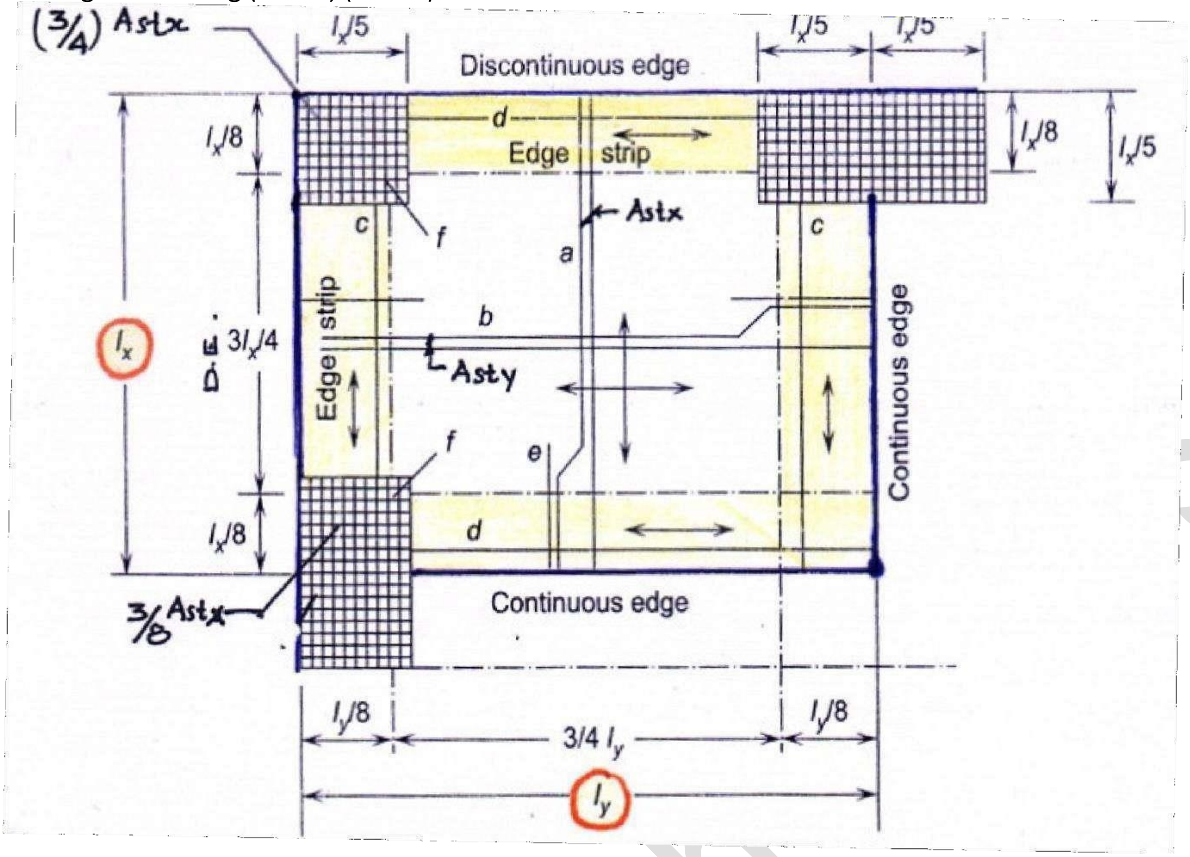
50% of tension reinforcement at top of a continuous edge shall be extended for a distance of 0.15l on each side from the support and at least 50% shall be provided for a distance of

0.3l on each face from the support.

At discontinuous edge, negative moment may arise, in general 50% of mid span steel shall be extended into the span for a distance of 0.1l at top.

Minimum steel can be provided in the edge strip

Tension steel shall be provided at corner in the form of grid (in two directions) at top and bottom of slab where the slab is discontinuous at both the edges. This area of steel in each layer in each direction shall be equal to ¾ the area required (A_{st}) for maximum mid span moment. This steel shall extend from the edges for a distance of l_x/5. The area of steel shall be reduced to half (3/8 A_{st}) at corners containing edges over only one edge is continuous and other is discontinuous.



Reinforcement details and strips in two way restrained slabs

The slabs spanning in one direction and continuous over supports are called one way continuous slabs. These are idealised as continuous beam of unit width. For slabs of uniform section which support substantially UDL over three or more spans which do not differ by more than 15% of the longest, the B.M and S.F are obtained using the coefficients available in Table 12 and Table 13 of IS 456-2000. For moments at supports where two unequal spans meet or in case where the slabs are not equally loaded, the average of the two values for the negative moments at supports may be taken. Alternatively, the moments may be obtained by moment distribution or any other methods.

Table 3: Bending moment and Shear force coefficients for continuous slabs (Table 12, Table 13, IS 456-200)

IS 456 : 2000

Table 12 Bending Moment Coefficients
(*Clause* 22.5.1)

Type of Load	Span Moments		Support Moments	
	Near Middle of End Span	At Middle of Interior Span	At Support Next to the End Support	At Other Interior Supports
(1)	(2)	(3)	(4)	(5)
Dead load and imposed load (fixed)	$+\frac{1}{12}$	$+\frac{1}{16}$	$-\frac{1}{10}$	$-\frac{1}{12}$
Imposed load (not fixed)	$+\frac{1}{10}$	$+\frac{1}{12}$	$-\frac{1}{9}$	$-\frac{1}{9}$

NOTE — For obtaining the bending moment, the coefficient shall be multiplied by the total design load and effective span.

Table 13 Shear for Coefficients
(*Clauses* 22.5.1 *and* 22.5.2)

Type of Load	At End Support	At Support Next to the End Support		At All Other Interior Supports
		Outer Side	Inner Side	
(1)	(2)	(3)	(4)	(5)
Dead load and imposed load (fixed)	0.4	0.6	0.55	0.5
Imposed load (not fixed)	0.45	0.6	0.6	0.6

NOTE — For obtaining the shear force, the coefficient shall be multiplied by the total design load.

DESIGN EXAMPLES

1. Design a simply supported one –way slab over a clear span of 3.5 m. It carries a live load of 4 kN/m^2 and floor finish of 1.5 kN/m^2. The width of supporting wall is 230 mm. Adopt M20 concrete & Fe-415 steel.

1) Trail depth and effective span

Assume approximate depth d =L/26

3500/26 = 134 mm

Assume overall depth D=160 mm & clear cover 15mm for mild exposure d = 160-15 (cover) -10/2 (dia of Bar/2) =140 mm

Effective span is lesser of the two

l =3.5 + 0.23 (width of support) = 3.73 m

l= 3.5 + 0.14 (effective depth) =3.64 m effective span = 3.64 m

2) Load on slab

Self-weight of slab = 0.16 x 25 = 4.00

Floor finish = 1.50

Live load = 4.00

= 9.5 kN/m^2

Ultimate load W_u = 9.5 x 1.5 = 14.25 kN/m^2

3) Design bending moment and check for depth

$$M_u = W_u l^2/8 = \frac{14.25 X 3.64^2}{8} \; 23.60 \text{ kN/m}$$

Minimum depth required from BM consideration

d=$\sqrt{\frac{Mu}{0.138 f_{ck} b}} = \sqrt{\frac{23.60X10^6}{0.138X20X1000}}$ = 92.4 > 140 (OK)

4) Area of Reinforcement

Area of steel is obtained using the following equation

Mu= $0.87 f_y A_{st} d\left(1-\frac{f_y A_{st}}{f_{ck} bd}\right)$

23.60X10^6= $0.87X415XA_{st}X140\left(1-\frac{415XA_{st}}{20X1000X140}\right)$

23.60X10^6=50547A_st-749 A_{st}^2

Solving Ast =504mm²

OR

A_st= $\frac{0.5 f_{ck}}{f_y}\left[1-\sqrt{1-\frac{4.6M_u}{f_{ck} bd^2}}\right] bd$

A_st = $\frac{0.5X20}{415}\left[1-\sqrt{1-\frac{4.6X23.60X10^6}{20X1000X140^2}}\right] 1000X140$

=505 mm²

Spacing of 10mm S_V= $\frac{a_{st}}{A_{st}} X1000$

S_V= $\frac{78}{505} X1000$ **=154 mm**

Provide 10mm @ 150 C/C ($< 3d\ or\ 300$ **)**

(420 or 300) OK

Provided steel (A_st=524mm², Pt=0.37%)

Distribution steel@ 0.12% of the Gross area.

$\frac{0.12}{100} X1000X160$ **=192 mm²**

Spacing of 8 mm S_V= $\frac{50}{192} X1000$ **=260 mm**

Provide 8 mm @260 mm C/C (<5d or 450)

(700 or 450) OK

5) Check for shear

Design shear V_u= $W_u l/2$

= $14.25X\frac{3.64}{2}$ **= 25.93 KN**

$\tau_v = \frac{25.93X10^3}{1000X140} = 0.18\ N/mm^2$ **(<** $\tau_{c\,max} = 2.8\ N/mm^2$ **)**

Shear resisted by concrete $\tau_c = 0.42\ for\ p_t = 0.37$ **(Table 19, IS 456-2000)**

However for solid slab design shear strength shall be

= $\tau_c k$

Where, K is obtained from Cl.40.2.1.1, IS 456 -2000

$\tau_{cd} = 0.42X1.28 = 0.53\ N/mm^2$

$\tau_{cd} > \tau_v$ **OK**

6) Check for deflection

$\left(\frac{l}{d}\right)_{Actual} < \left(\frac{l}{d}\right)_{Allowable}$

$\left(\frac{l}{d}\right)_{Allowable} = \left(\frac{l}{d}\right)_{Basic} Xk_1Xk_2Xk_3Xk_4.$

K1-Modification factor for tension steel K2 – Modification factor for compression steel

k_3 – Modification factor for T-sections **k_4-Only if span exceeds 10 m (10/span)**

$k_1 = 1.38\ for\ P_t = 0.37$ $\left(\frac{l}{d}\right)_{Allowable}$ **(Fig. 4, cl.32.2.1)**

=20X1.38=27.6

$\left(\frac{l}{d}\right)_{Actual}$ **=3630/140=25.92**

$\left(\frac{l}{d}\right)_{Actual} < \left(\frac{l}{d}\right)_{Allowable}$ **(OK)**

7) Check for Development length

Development length

$$L_d = \frac{\phi \sigma_s}{4 \tau_{bd}}$$

L_d = (0.87x415x10) / (4x1.2x1.6) =470 mm

At simple support, where compressive reaction confines the bars, to limit the dia. of bar

$$L_d \leq 1.3\left(\frac{M_1}{V}\right) + L_o$$

Since alternate bars are cranked M_1=M_u/2 = 23.2/2 = 11.8 kN.m

V_1 = 5.93 KN, providing 90o bend and 25 mm end cover

L_o = 230/2 – 25 + 3(dia of bar) = 120

470 < (1.3x11.8x106) / (25.9x103) + 120 = 711 mm O. K. However, from the end anchorage requirement

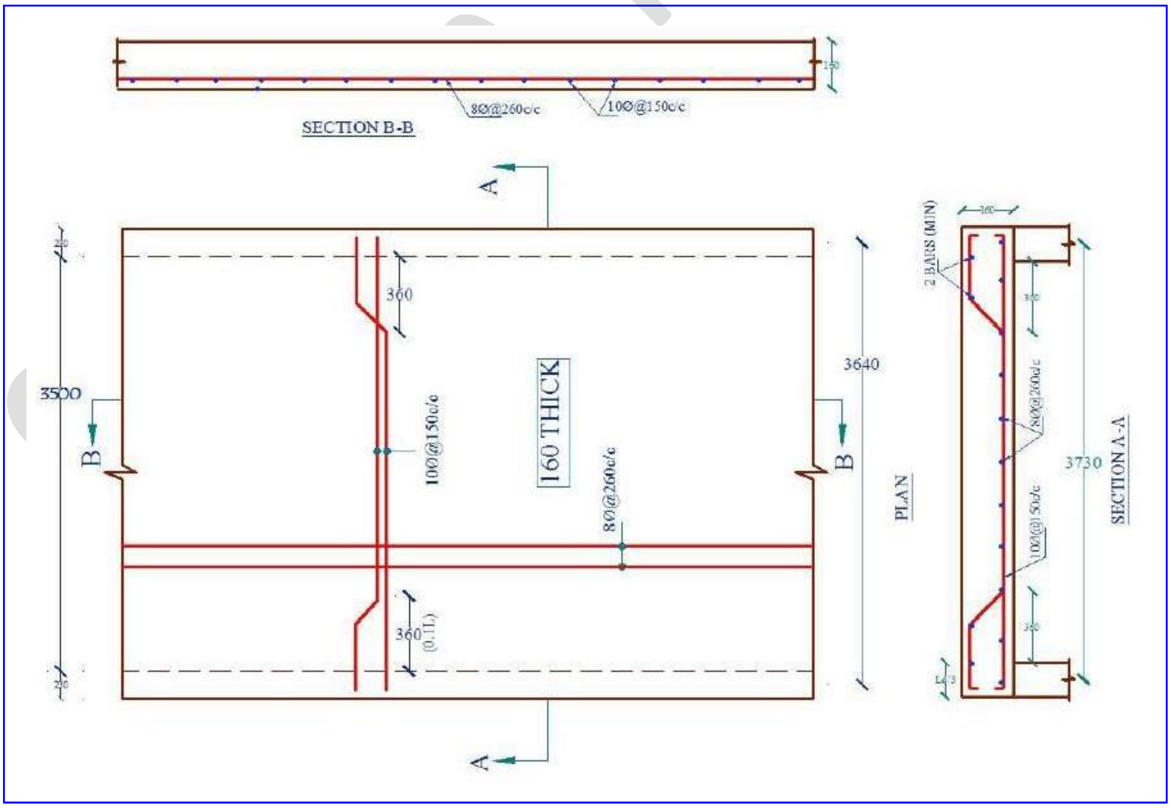
Extend the bars for a length equal to ld./3 = 156 mm from inner face of support

8) Check for cracking

Steel is more than 0.12% of the gross area.

Spacing of steel is < 3d

Diameter of bar used is < 160/8=20mm Check for cracking is satisfied.



Reinforcement Detail of One way slab

Unit – IV

Columns & Footings: Effective length of columns, Short and long columns- Square, Rectangular and Circular columns, Isolated and combined footings, Strap footing, Columns subjected to axial loads and bending moments (sections with no tension), Raft foundation

Introduction: A column is defined as a compression member, the effective length of which exceeds three times the least lateral dimension. Compression members, whose lengths do not exceed three times the least lateral dimension, may be made of plain concrete. A column forms a very important component of a structure. Columns support beams which in turn support walls and slabs. It should be realized that the failure of a column results in the collapse of the structure. The design of a column should therefore receive importance.

A column is a vertical structural member supporting axial compressive loads, with or without moments. The cross-sectional dimensions of a column are generally considerably less than its height. Columns support vertical loads from the floors and roof and transmit these loads to the foundations.

The more general terms compression members and members subjected to combined axial load and bending are sometimes used to refer to columns, walls, and members in concrete trusses or frames. These may be vertical, inclined, or horizontal. A column is a special case of a compression member that is vertical. Stability effects must be considered in the design of compression members.

Classification of columns

A column may be classified based on different criteria such as:

Based on shape

Rectangle

Square

Circular

Polygon

L type

T type

+ type

Based on slenderness ratio or height

Short column and Long column or Short and Slender Compression Members

A compression member may be considered as short when both the slenderness ratios namely l_{ex}/D and l_{ey}/b are less than 12: Where l_{ex}= effective length in respect of the major axis, D= depth in respect of the major axis, l_{ey}= effective length in respect of the minor axis, and b = width of the member.

It shall otherwise be considered as a slender or long compression member.

The great majority of concrete columns are sufficiently stocky (short) that slenderness can be ignored. Such columns are referred to as short columns. Short column generally fails by crushing of concrete due to axial force. If the moments induced by slenderness effects weaken a column appreciably, it is referred to as a slender column or a long column. Long columns generally fail by bending effect than due to axial effect. Long column carry less load compared to long column.

Based on pattern of lateral reinforcement

Tied columns with ties as laterals

Columns with Spiral steel as laterals or spiral columns

Majority of columns in any buildings are tied columns. In a tied column the longitudinal bars are tied together with smaller bars at intervals up the column. Tied columns may be square, rectangular, L-shaped, circular, or any other required shape. Occasionally, when high strength and/or high ductility are required, the bars are placed in a circle, and the ties are replaced by a bar bent into a helix or spiral. Such

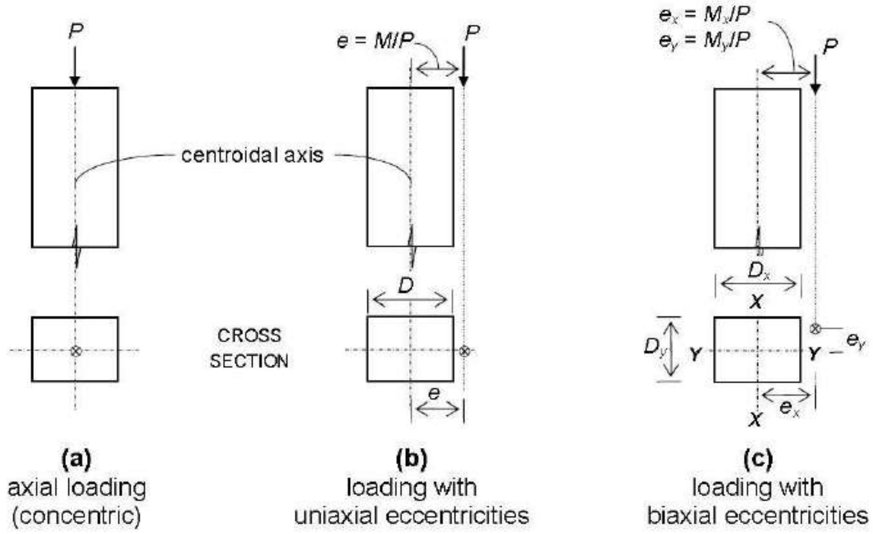
a column, called a spiral column. Spiral columns are generally circular, although square or polygonal shapes are sometimes used. The spiral acts to restrain the lateral expansion of the column core under high axial loads and, in doing so, delays the failure of the core, making the column more ductile. Spiral columns are used more extensively in seismic regions. If properly designed, spiral column carry 5% extra load at failure compared to similar tied column.

Based on type of loading

Axially loaded column or centrally or concentrically loaded column (P_u)

A column subjected to axial load and unaxial bending ($P_u + M_{ux}$) or ($P + M_{uy}$)

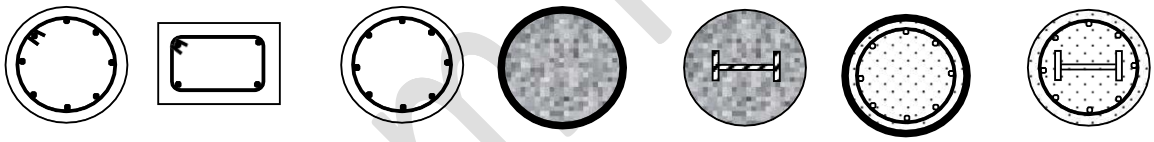
A column subjected to axial load and biaxial bending ($P_u + M_{ux} + M_{uy}$)



Different loading situations in columns

Based on materials

Timber, stone, masonry, RCC, PSC, Steel, aluminium, composite column



RCC-Tied **RCC spiral** **Composite columns**

Behaviour of Tied and Spiral Columns

Figure shows a portion of the core of a spiral column. Under a compressive load, the concrete in this column shortens longitudinally under the stress and so, to satisfy Poisson's ratio, it expands laterally. In a spiral column, the lateral expansion of the concrete inside the spiral (referred to as the core) is restrained by the spiral. This stresses the spiral in tension. For equilibrium, the concrete is subjected to lateral compressive stresses. In a tied column in a non seismic region, the ties are spaced roughly the width of the column apart and, as a result, provide relatively little lateral restraint to the core. Outward pressure on the sides of the ties due to lateral expansion of the core merely bends them outward, developing an insignificant hoop-stress effect. Hence, normal ties have little effect on the strength of the core in a tied column. They do, however, act to reduce the unsupported length of the longitudinal bars, thus reducing the danger of buckling of those bars as the bar stress approaches yield. Load deflection diagrams for a tied column and a spiral column subjected to axial loads is shown in figure. The initial parts of these diagrams are similar. As the maximum load is reached, vertical cracks and crushing develop in the concrete shell outside the ties or spiral, and this concrete spalls off. When this occurs in a tied column, the capacity of the core that remains is less than the load on the column. The concrete core is crushed, and the reinforcement buckles outward between ties. This occurs suddenly, without warning,

in a brittle manner. When the shell spalls off a spiral column, the column does not fail immediately because the strength of the core has been enhanced by the triaxial stresses resulting from the effect of the spiral reinforcement. As a result, the column can undergo large deformations, eventually reaching a second maximum load, when the spirals yield and the column finally collapses. Such a failure is much more ductile than that of a tied column and gives warning of the impending failure, along with possible load redistribution to other members. Due to this, spiral column carry little more load than the tied column to an extent of about 5%. Spiral columns are used when ductility is important or where high loads make it economical to utilize the extra strength. Both columns are in the same building and have undergone the same deformations. The tied column has failed completely, while the spiral column, although badly damaged, is still supporting a load. The very minimal ties were inadequate to confine the core concrete. Had the column ties been detailed according to ACI Code, the column will perform better as shown.

Specifications for covers and reinforcement in column
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. 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 used. For footings minimum cover shall be 50 mm.

Nominal Cover in mm to meet durability requirements based on exposure

Mild 20, Moderate 30, Severe 45, Very severe 50, Extreme 75

Nominal cover to meet specified period of fire resistance for all fire rating 0.5 to 4 hours is 40 mm for columns only

Effective length of compression member
Column or strut is a compression member, the effective length of which exceeds three times the least lateral dimension. For normal usage assuming idealized conditions, the effective length of in a given plane may be assessed on the basis of Table 28 of IS: 456-2000. Following terms are required.

Following are the end restraints:

Effectively held in position and restrained against rotation in both ends

Effectively held in position at both ends, restrained against rotation at one end

Effectively held in position at both ends, but not restrained against rotation

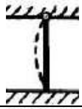
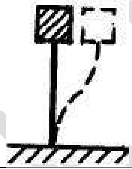
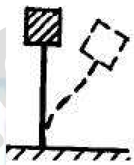
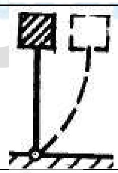
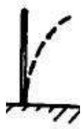
Effectively held in position and restrained against rotation at one end, and at the other restrained against rotation but not held in position

Effectively held in position and restrained against rotation in one end, and at the other partially restrained against rotation but not held in position

Effectively held in position at one end but not restrained against rotation, and at the other end restrained against rotation but not held in position

Effectively held in position and restrained against rotation at one end but not held in position nor restrained against rotation at the other end

Table. Effective length of compression member

Sl. No.	Degree of End Restraint of Compression Members	Figure	Theo. Value of Effective Length	Recon. Value of Effective Length
1	Effectively held in position and restrained against rotation in both ends		0.50 l	0.65l
2	Effectively held in position at both ends, restrained against rotation at one end		0.70 l	0.80l
3	Effectively held in position at both ends, but not restrained against rotation		1.0 l	1.0l
4	Effectively held in position and restrained against rotation at one end, and at the other restrained against rotation but not held in position		1.0 l	1.20l
5	Effectively held in position and restrained against rotation in one end, and at the other partially restrained against rotation but not held in position		-	1.5l
6	Effectively held in position at one end but not restrained against rotation, and at the other end restrained against rotation but not held in position		2.0 l	2.0l
7	Effectively held in position and restrained against rotation at one end but not held in position nor restrained against rotation at the other end		2.0 l	2.0l

Unsupported Length

The unsupported length, l, of a compression member shall be taken as the clear distance between end restraints (visible height of column). Exception to this is for flat slab construction, beam and slab construction, and columns restrained laterally by struts (Ref. IS: 456-2000),

Slenderness Limits for Columns

The unsupported length between end restraints shall not exceed 60 times the least lateral dimension of a column.

If in any given plane, one end of a column is unrestrained, its unsupported length, l, shall not exceed $100b^2/D$, where b = width of that cross-section, and D= depth of the cross-section measured in the plane under consideration.

Specifications as per IS: 456-2000

Longitudinal reinforcement

The cross-sectional area of longitudinal reinforcement shall be not less than 0.8 percent nor more than 6 percent of the gross cross sectional area of the column.

NOTE - The use of 6 percent reinforcement may involve practical difficulties in placing and compacting of concrete; hence lower percentage is recommended. Where bars from the columns below have to be lapped with those in the column under consideration, the percentage of steel shall usually not exceed 4 percent.

In any column that has a larger cross-sectional area than that required to support the load, the minimum percentage of steel shall be based upon the area of concrete required to resist the direct stress and not upon the actual area.

The minimum number of longitudinal bars provided in a column shall be four in rectangular columns and six in circular columns.

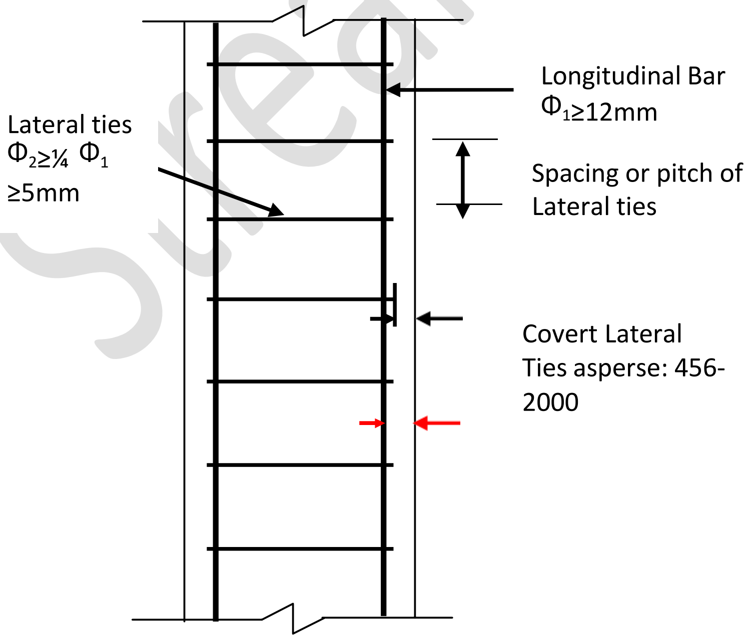
The bars shall not be less than 12 mm in diameter

A reinforced concrete column having helical reinforcement shall have at least six bars of longitudinal reinforcement within the helical reinforcement.

In a helically reinforced column, the longitudinal bars shall be in contact with the helical reinforcement and equidistant around its inner circumference.

Spacing of longitudinal bars measured along the periphery of the column shall not exceed 300 mm.

In case of pedestals in which the longitudinal reinforcement is not taken in account in strength calculations, nominal longitudinal reinforcement not less than 0.15 percent of the cross-sectional area shall be provided.



Transverse reinforcement

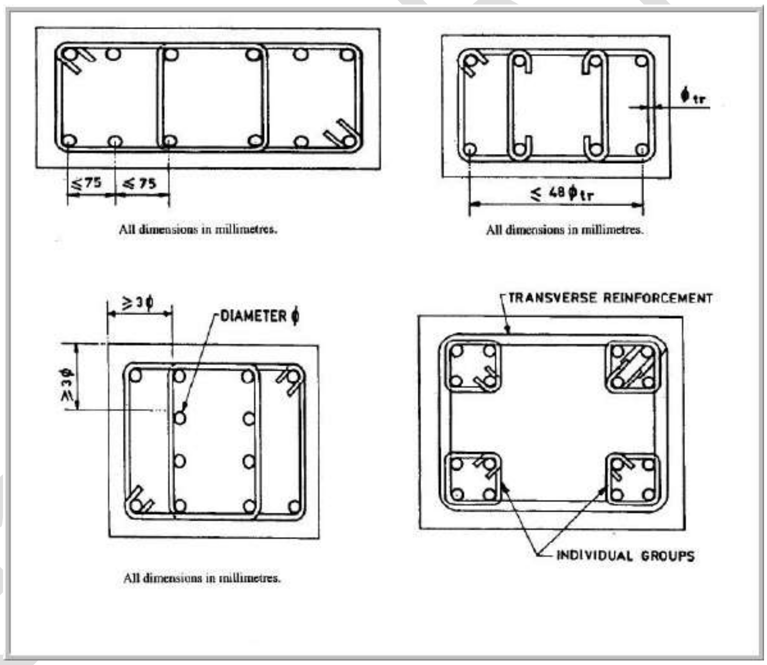
A reinforced concrete compression member shall have transverse or helical reinforcement so disposed that every longitudinal bar nearest to the compression face has effective lateral support against buckling.

The effective lateral support is given by transverse reinforcement either in the form of circular rings capable of taking up circumferential tension or by polygonal links (lateral ties) with internal angles not exceeding 135°. The ends of the transverse reinforcement shall be properly anchored.

Arrangement of transverse reinforcement

If the longitudinal bars are not spaced more than 75 mm on either side, transverse reinforcement need only to go round corner and alternate bars for the purpose of providing effective lateral supports (Ref. IS:456).

If the longitudinal bars spaced at a distance of not exceeding 48 times the diameter of the tie are effectively tied in two directions, additional longitudinal bars in between these bars need to be tied in one direction by open ties (Ref. IS:456).



Pitch and diameter of lateral ties

1) Pitch-The pitch of transverse reinforcement shall be not more than the least of the following distances:
i) The least lateral dimension of the compression members; ii) Sixteen times the smallest diameter of the longitudinal reinforcement bar to be tied; and iii) 300 mm.

2) Diameter-The diameter of the polygonal links or lateral ties shall be not less than one fourth of the diameter of the largest longitudinal bar, and in no case less than 6 mm.

Helical reinforcement

1) Pitch-Helical reinforcement shall be of regular formation with the turns of the helix spaced evenly and its ends shall be anchored properly by providing one and a half extra turns of the spiral bar. Where an increased load on the column on the strength of the helical reinforcement is allowed for, the pitch of helical turns shall be not more than 7.5 mm, nor more than one sixth of the core diameter of the column, nor less than 25 mm, nor less than three times the diameter of the steel bar forming the helix.

LIMIT STATE OF COLLAPSE: COMPRESSION

Assumptions

The maximum compressive strain in concrete in axial compression is taken as 0.002.

The maximum compressive strain at the highly compressed extreme fibre in concrete subjected to axial compression and bending and when there is no tension on the section shall be 0.0035 minus 0.75 times the strain at the least compressed extreme fibre.

In addition the following assumptions of flexure are also required

Plane sections normal to the axis remain plane after bending.

The maximum strain in concrete at the outermost compression fibre is taken as 0.0035 in bending.

The relationship between the compressive stress distribution in concrete and the strain in concrete may be assumed to be rectangle, trapezoid, parabola or any other shape which results in prediction of strength in substantial agreement with the results of test.

An acceptable stress strain curve is given in IS: 456-200. For design purposes, the compressive strength of concrete in the structure shall be assumed to be 0.67 times the characteristic strength. The partial safety factor y of 1.5 shall be applied in addition to this.

The tensile strength of the concrete is ignored.

The stresses in the reinforcement are derived from representative stress-strain curve for the type of steel used. Typical curves are given in IS: 456-2000. For design purposes the partial safety factor equal to 1.15 shall be applied.

Minimum eccentricity

As per IS:456-2000, all columns shall be designed for minimum eccentricity, equal to the unsupported length of column/ 500 plus lateral dimensions/30, subject to a minimum of 20 mm. Where bi-axial bending is considered, it is sufficient to ensure that eccentricity exceeds the minimum about one axis at a time.

Short Axially Loaded Members in Compression

The member shall be designed by considering the assumptions given in 39.1 and the minimum eccentricity. When the minimum eccentricity as per 25.4 does not exceed 0.05 times the lateral dimension, the members may be designed by the following equation:

$$P_u = 0.4\, f_{ck}\, A_c + 0.67\, f_y A_{sc}$$

P_u = axial load on the member, f_{ck}= characteristic compressive strength of the concrete, A_c = area of concrete, FY $_=$characteristic strength of the compression reinforcement, and A_s = area of longitudinal reinforcement for columns.

Compression Members with Helical Reinforcement

The strength of compression members with helical reinforcement satisfying the requirement of IS: 456 shall be taken as 1.05 times the strength of similar member with lateral ties.

The ratio of the volume of helical reinforcement to the volume of the core shall not be less than

$$V_{hs} / V_C > 0.36 (A_g/A_c - 1) f_{ck}/f_y$$

A_g = gross area of the section,
A_c = area of the core of the helically reinforced column measured to the outside diameter of the helix,
Fck = characteristic compressive strength of the concrete, and FY= characteristic strength of the helical reinforcement but not exceeding 415 N/mm.

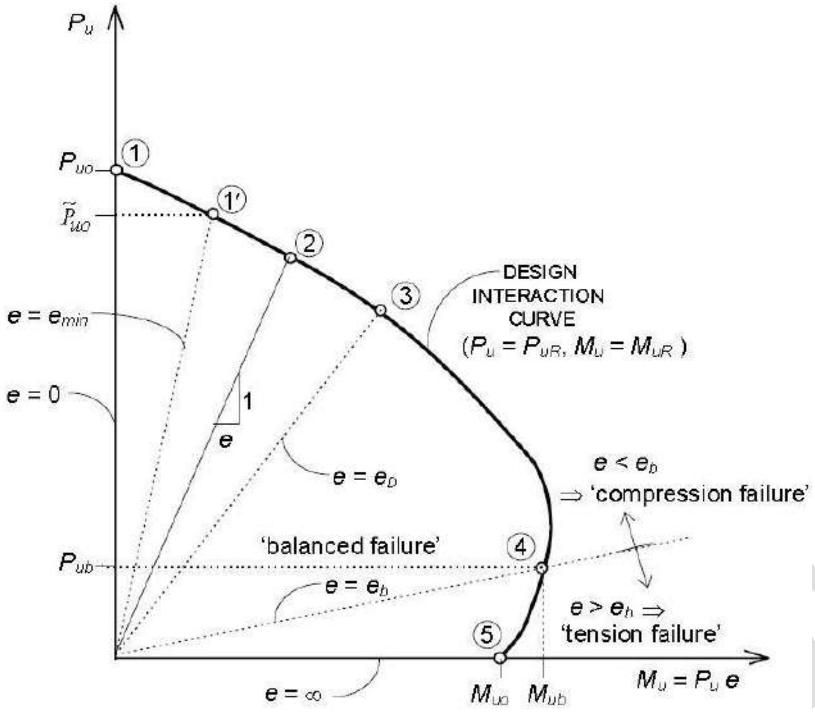
Members Subjected to Combined Axial Load and Uni-axial Bending

Use of Non-dimensional Interaction Diagrams as Design Aids
Design Charts (for Uniaxial Eccentric Compression) in SP-16
The design Charts (non-dimensional interaction curves) given in the Design Handbook, SP:16 cover the following three cases of symmetrically arranged reinforcement:
Rectangular sections with reinforcement distributed equally on two sides (Charts 27 – 38): the 'two sides' refer to the sides parallel to the axis of bending; there are no inner rows of bars, and each outer row has an area of 0.5A this includes the simple 4–bar configuration. s
Rectangular sections with reinforcement distributed equally on four sides (Charts 39 –
50): two outer rows (with area 0.3A each) and four inner rows (with area 0.1A each) s s
Have been considered in the calculations; however, the use of these Charts can be extended, without significant error, to cases of not less than two inner rows (with a minimum area 0.3A in each outer row).
Circular column sections (Charts 51 – 62): the Charts are applicable for circular sections with at least six bars (of equal diameter) uniformly spaced circumferentially.

Corresponding to each of the above three cases, there are as many as 12 Charts available covering the 3 grades of steel (Fe 250, Fe 415, Fe 500), with 4 values of d^1/ D ratio for each grade (namely 0.05, .0.10, 0.15, 0.20). For intermediate values of d^1/ D, linear interpolation may be done. Each of the 12 Charts of SP-16 covers a family of non-dimensional design interaction curves with p/f values ranging from 0.0 to 0.26. ck

From this, percentage of steel (p) can be found. Find the area of steel and provide the required number of bars with proper arrangement of steel as shown in the chart.

Typical interaction curve



Typical P_u — M_u interaction diagram

Salient Points on the Interaction Curve

The salient points, marked 1 to 5 on the interaction curve correspond to the failure strain profiles, marked 1 to 5 in the above figure.

The point 1 in figure corresponds to the condition of axial loading with e = 0. For this case of 'pure' axial compression.

The point 1^1 in figure corresponds to the condition of axial loading with the mandatory minimum eccentricity e prescribed by the Code. Min

The point 3 in figure corresponds to the condition x = D, i.e., e = e. For e <e, the Entire section is under compression and the neutral axis is located outside the section (x > D), with 0.002 <ε < 0.0035. For e >e , the NA is located within the section u cu D (x < D) and ε = 0.0035 at the 'highly compressed edge'. u cu

Procedure for using of Non-dimensional Interaction Diagrams as Design Aids to find steel

Given:

Size of column, Grade of concrete, Grade of steel (otherwise assume suitably)
Factored load and Factored moment

Assume arrangement of reinforcement: On two sides or on four sides
Assume moment due to minimum eccentricity to be less than the actual moment
Assume suitable axis of bending based on the given moment (xx or yy)
Assuming suitable diameter of longitudinal bars and suitable nominal cover

Find d^1/D from effective cover d^1
Find non dimensional parameters $P_u/f_{ck}bD$ and $M_u/f_{ck}bD^2$
Referring to appropriate chart from S-16, find p/f_{ck} and hence the percentage of reinforcement, p
Find steel from, A_s = p bD/100
Provide proper number and arrangement for steel
Design suitable transverse steel
Provide neat sketch

Members Subjected to Combined Axial Load and Biaxial Bending

The resistance of a member subjected to axial force and biaxial bending shall be obtained on the basis of assumptions given in IS: 456 with neutral axis so chosen as to satisfy the equilibrium of load and moments about two axes. Alternatively such members may be designed by the following equation:

[Mux/Mux1]αn + [Muy/Muy1]αn ≤ 1, where
M_{ux} and M_y= moments about x and y axes due to design loads,

M_{ux1} and M_{y1} = maximum uni-axial moment capacity for an axial load of P_u bending about x and y axes respectively, and αn is related to P_u /$P_{uz,}$ where P_{uz} = 0.45 f_{ck} .A_c + 0.75 f_yA_{sc}

For values of P_u /P_{uz} = 0.2 to 0.8, the values of αn vary linearly from 1 .0 to 2.0. For values less than 0.2 and greater than 0.8, it is taken as 1 and 2 respectively

NOTE -The design of member subject to combined axial load and uniaxial bending will involve lengthy calculation by trial and error. In order to overcome these difficulties interaction diagrams may be used. These have been prepared and published by BIS in SP:16 titled Design aids for reinforced concrete Corresponding minimum eccentricities as per IS: 456-2000
Assume a trial section for the column (square, rectangle or circular).
Determine *M* and *M* , corresponding to the given *P* (using appropriate curve from *ux*1 *uy*1 *u* SP-16 design aids)
Ensure that *M* and *M* are significantly greater than *M* and *M* respectively; *ux*1 *uy*1 *ux* *uy* Otherwise, suitably redesign the section.
Determine *P* and hence α*uz* *n*
Check the adequacy of the section using interaction equation. If necessary, redesign the section and check again.

Slender Compression Members: The design of slender compression members shall be based on the forces and the moments determined from an analysis of the structure, including the effect of deflections on moments and forces. When the effects of deflections are not taken into account in the analysis, additional moment given in 39.7.1 shall be taken into account in the appropriate direction.

Unit – V

Staircases: Staircases with waist slab having equal and unequal flights with different support conditions, Slab less tread-riser staircase

Stairs

Stairs consist of steps arranged in a series for purpose of giving access to different floors of a building. Since a stair is often the only means of communication between the various floors of a building, the location of the stair requires good and careful consideration.

In a residential house, the staircase may be provided near the main entrance. In a public building, the stairs must be from the main entrance itself and located centrally, to provide quick accessibility to the principal apartments. All staircases should be adequately lighted and properly ventilated.

The staircase is an important component of a building, and often the only means of access between the various floors in the building. It consists of a flight of steps, usually with one or more intermediate landings provided between the floor levels. The horizontal top portion of a step is termed tread and the vertical projection of the step is called riser. Generally tread of 300 mm and Riser of 150 mm are ideally suited for public buildings. For residential and factory buildings lower values of tread up to 250 mm combined with higher values of riser up to 190 mm are preferred. The width of the stair is generally around 1.1 – 1.5m, and in any case, should normally not be less than 850 mm. The horizontal projection (plan) of an inclined flight of steps, between the first and last risers, is termed going of flight. Generally, risers in a flight should not exceed about 12 in number.

Types of stair cases

Geometric classification

Straight stairs (with or without intermediate landing)
Quarter-turn stairs
Dog-legged stairs
Open well stairs
Spiral stairs
Helicoidally stairs
Slab less stair case
Free standing stair case

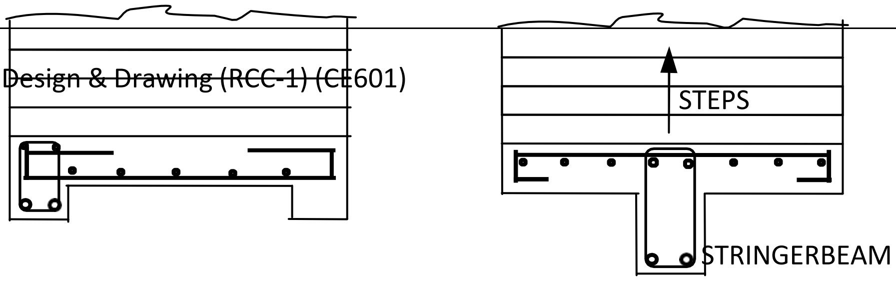
Structural Classification

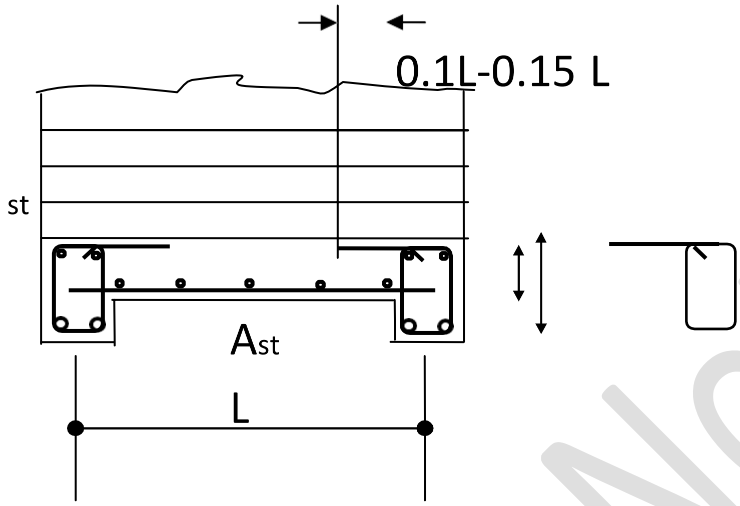
Stairs with cantilever steps
Stair slab spanning transversely
(or horizontally between stringer beams or walls)
Stair slab spanning longitudinally
Slabless or raiser and tread type
Spiral stair case
Helicoidal slab stair case
3D or free standing stair slab

- **Classification based on span**

Based on type of span, following are the two types of stair cases;

Horizontally spanning or transversely spanning stairs. Figure 1
Longitudinally spanning stairs. For details refer IS: 456-2000 and SP (34).





Transversely spanning stair cases can be seen in figure 1. Here the main steel is provided transversely and the distribution steel is in the longitudinal direction.
STRINGER BEAMS
0.5 A
Transversely spanning stair cases

Longitudinally spanning stair cases:
Here the main steel in provided longitudinally and the distribution steel is in the transverse direction. Refer problem.

Effective span
The effective span is defined as follows based on the type of support.

Where flight supported at the ends of the landings in such a way that both landing and flight spans in the same direction, the effective span is the distance between the center to center of the supporting beams or wall. Refer Figure 2.

Where spanning on the edge of a landing slab which spans parallel with the riser, the effective span is the distance equal to the going of the stairs plus at each end either half the width of the landing or one meter, whichever is smaller. Refer Figure 3.

Where supported at top and bottom riser by beams spanning parallel with the riser, the distance center to center of the beams is the effective span. Refer Figure 4.

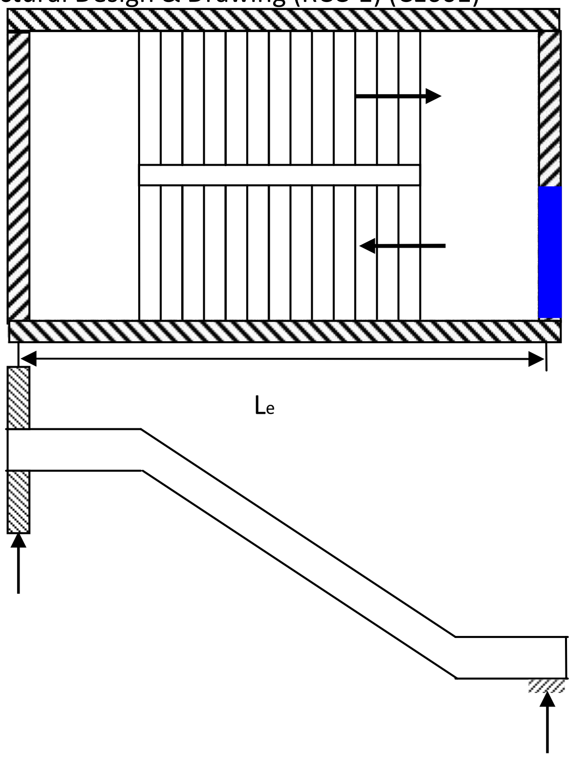
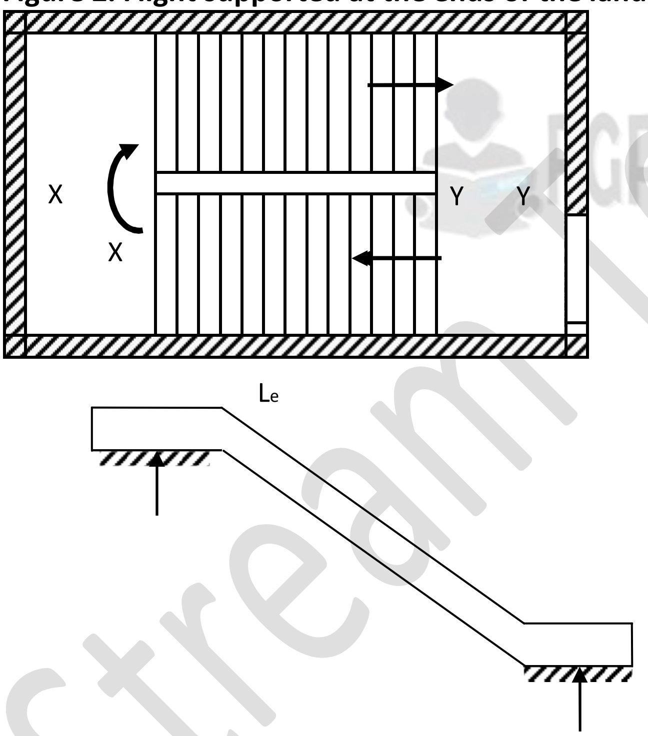
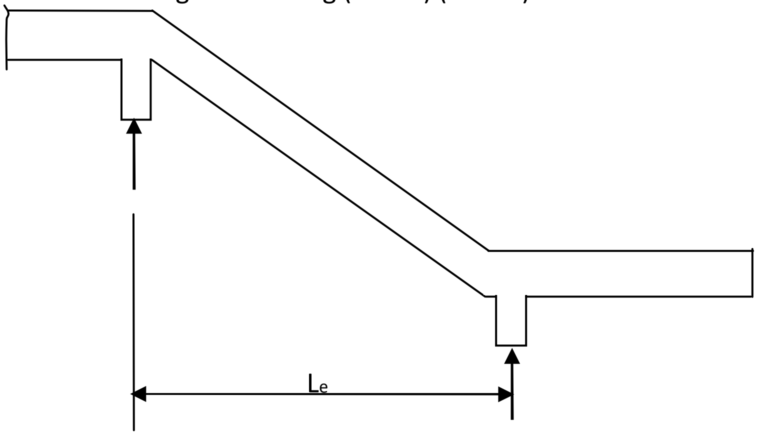


Figure 2. Flight supported at the ends of the landings on walls



Flight supported at the sides of the landings on walls



Flight supported on landing beams

Guide lines

Guide lines to be followed for fixing the dimensions of component parts of stair.

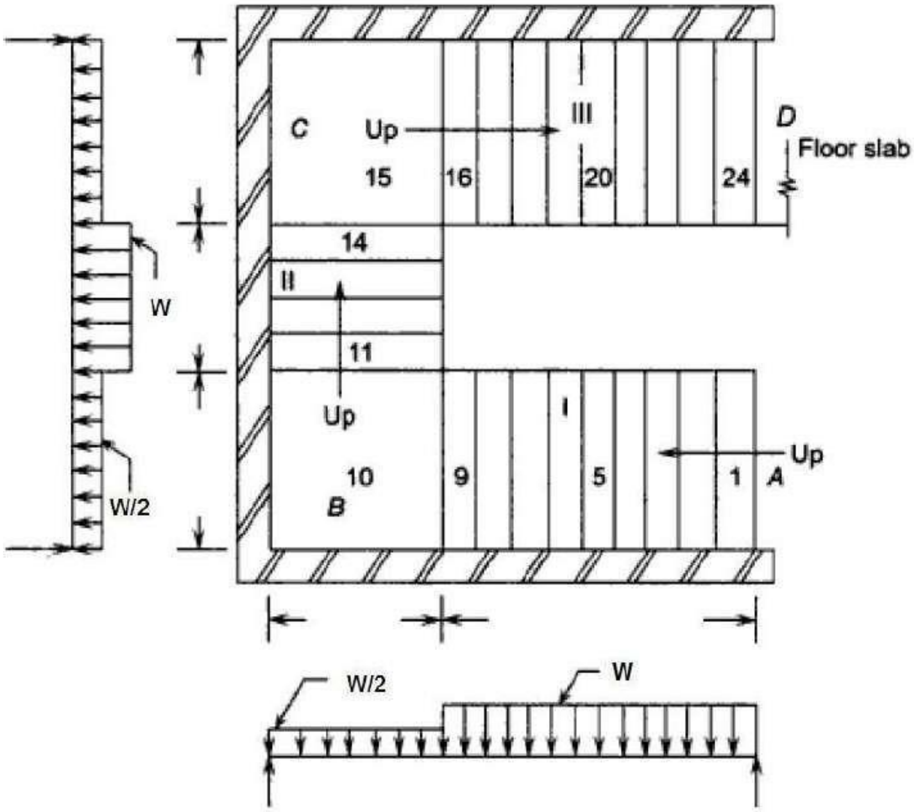
Rise (R) is 150mm to 180mm and tread (T) is 220 mm to 250 mm for a residential building.
For public building rise is kept between 120 to 150 mm and tread between 250 to 300 mm
Sum of tread (T) and twice the rise (2R) should be between 500 mm to 650 mm
The width of the stair is dependent on the usage and is between 0.8 m to 1 m for residential building and 1.8 m to 2 m for public building.
The width of the landing is equal to the width of stairs.
The number of steps in each flight should not be greater than 12
The pitch of the stair should not be more than 38 degrees.
The head room measured vertically above any step or below the mid landing shall not be less than 2.1 m.

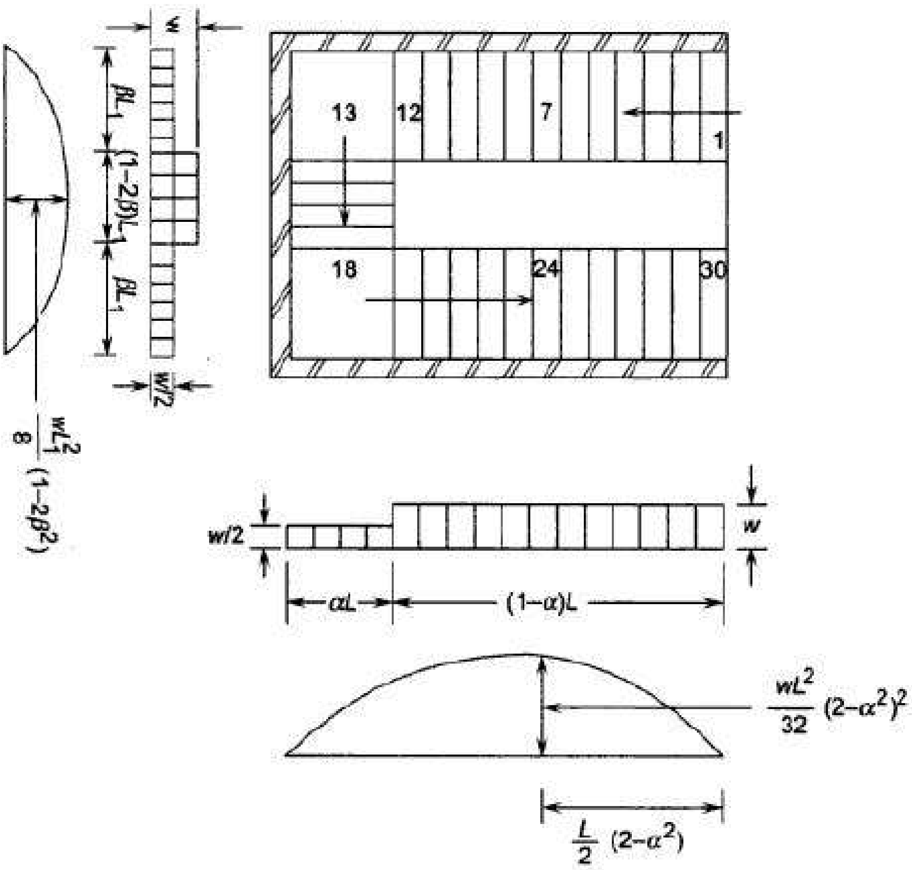
Distribution of Loading on Stairs

In the case of stairs with open wells, where spans partly crossing at right angles occur, the load on areas common to any two such spans may be taken as one half in each direction as shown in Fig. 5. Where flights or landings are embedded into walls for a length of not less than 110 mm and are designed to span in the direction of the flight, a 150 mm strip may be deducted from the loaded area and the effective breadth of the section increased by 75 mm for purposes of design (see Fig. 6).

Depth of Section

The depth of section shall be taken as the minimum thickness perpendicular to the soffit of the staircase.





Load distribution and bending moments

RCC design of a Dog-legged staircase

In this type of staircase, the succeeding flights rise in opposite directions. The two flights in plan are not separated by a well. A landing is provided corresponding to the level at which the direction of the flight changes.

Design of Dog-legged Stairs

Based on the direction along which a stair slab span, the stairs maybe classified into the following two types.

Stairs spanning horizontally

Stairs spanning vertically

Stairs spanning horizontally

These stairs are supported at each side by walls. Stringer beams or at one side by wall or at the other side by a beam.

Loads

Dead load of a step = ½ x T x R x 25

Dead load of waist slab = b x t x 25

Live load = LL (KN/m^2)

Floor finish = assume 0.5 kN/m

Stairs spanning longitudinally

In this, stairs spanning longitudinally, the beam is supported by top and at the bottom of flights.

Loads

Self-weight of a step = 1 x R/2 x 25

Self-weight of waist slab = 1 x t x 25

Self-weight of plan = 1 x t x 25[(R^2 + T^2)/T]

Live load = LL (KN/m^2)

Floor finish = assume 0.5 KN/m

For the efficient design of an RCC stair, we have to first analyse the various loads to be imposed on the stair.

The load calculations will help us determine, how much strength is required to carry the load. The strength bearing capacity of a staircase is determined on the amount of steel and concrete used.

The ratio of steel to concrete has to be as per standards. Steel in the staircase will take the tension imposed on it and the concrete takes up the compression

Design of RCC Stair case