Catalog

UNIT 1
INTRODUCTION
UNIT I

Objective of structural design-Steps in RCC Structural Design Process- Type of Loads on Structures and Load combinations- Code of practices and Specifications - Concept of Working Stress Method, Ultimate Load Design and Limit State Design Methods for RCC –Properties of Concrete and Reinforcing Steel - Analysis and Design of Singly reinforced Rectangular beams by working stress method - Limit State philosophy as detailed in IS code - Advantages of Limit State Method over other methods - Analysis and design of singly and doubly reinforced rectangular beams by Limit State Method.

1.1 Objective of Structural Design

The objectives of structural design are to design the structure for stability, strength and serviceability. It must also be economical and aesthetic.

The design of a structure must satisfy three basic requirements:

1) Stability to prevent overturning, sliding or buckling of the structure, or parts of it, under the action of loads,

2) Strength to resist safely the stresses induced by the loads in the various structural members; and

3) Serviceability to ensure satisfactory performance under service load conditions - which implies providing adequate stiffness and reinforcements to contain deflections, crack-widths and vibrations within acceptable limits, and also providing impermeability and durability (including corrosion-resistance), etc.

There are two other considerations that a sensible designer ought to bear in mind, viz., **economy and aesthetics**. One can always design a massive structure, which has more-than-adequate stability, strength and serviceability, but the ensuing cost of the structure may be exorbitant, and the end product, far from aesthetic. In the words of Felix Candela, the designer of a remarkably wide range of reinforced concrete shell structures, It is indeed a challenge, and a responsibility, for the structural designer to design a structure that is not only appropriate for the architecture, but also strikes the right balance between safety and economy.

1.2 Steps in RCC Structural Design Process

The process of structural design involves the following stages.

1. Structural planning
2. Action of forces and computation of loads
3. Methods of analysis
4. Member design
5. Detailing, Drawing and Preparation of schedules
6.

1. Structural Planning

After getting an architectural plan of the buildings, the structural planning of the building frame is done. This involves determination of the following.

- Position and orientation of columns
- Positioning of beams
- Spanning of slabs
- Layouts of stairs
- Selecting proper type of footing.

1.1 Positioning and orientation of columns Following are some of the building principles, which help in deciding the columns positions.

1. Columns should preferably be located at (or) near the corners of a building, and at the intersection of beams/walls.
2. Select the position of columns to reduce bending moments in beams.
3. Avoid larger spans of beams.
4. Avoid larger centre-to-centre distance between columns.
5. Columns on property line.

Orientation of columns

1. Avoid projection of columns: The projection of columns outside the wall in the room should be avoided as they not only give bad appearance but also obstruct the use of floor space, creating problems in placing furniture flush with the wall. The width of the column is required to be kept not less than 200mm to prevent the column from being slender. The spacing of the column should be considerably reduced so that the load on column on each floor is less and the necessity of large sections for columns does not arise.

2. Orient the column so that the depth of the column is contained in the major plane of bending or is perpendicular to the major axis of bending. This is provided to increase moment of inertia and hence greater moment resisting capacity. It will also reduce Leff/d ratio resulting in increase in the load carrying capacity of the column.

1.2 Positioning of Beams

1. Beams shall normally be provided under the walls or below a heavy concentrated load to avoid these loads directly coming on slabs. 2. Avoid larger spacing of beams from deflection and cracking criteria. (The deflection varies directly with the cube of the span and inversely with the cube of the depth i.e. L^3/D^3. Consequently, increase in span L which results in greater deflection for larger span).

1.3 Spanning of Slabs

This is decided by supporting arrangements. When the supports are only on opposite edges or only in one direction, then the slab acts as a one way supported slab. When the rectangular slab is supported along its four edges it acts as a one-way slab when $L_y/L_x < 2$. The two-way action of slab not only depends on the aspect ratio but also on the ratio of reinforcement on the directions. In one-way slab, main steel is provided along with short span only and the load is transferred to two opposite supports. The steel along the long span just acts as the distribution steel and is not designed for transferring the load but to distribute the load and to resist shrinkage and temperature stresses. A slab is made to act as a one-way slab spanning across the short span by providing main steel along the short span and only distribution steel along the long span

The provision of more steel in one direction increases the stiffness of the slab in that direction. According to elastic theory, the distribution of load being proportional to stiffness in two orthogonal directions, major load is transferred along the stiffer short span and the slab behaves as one way. Since, the slab is also supported over the short edge there is a tendency of the load on the slab by the side of support to get transferred to the nearer support causing tension at top across this short supporting edge. Since, there does not exist any steel at top across this short edge in a one way slab interconnecting the slab and the side beam, cracks develop at the top along that edge. The cracks may run through the depth of the slab due to differential deflection between the slab and the supporting short edge beam/wall. Therefore, care should be taken to provide minimum steel at top across the short edge support to avoid this cracking.

A two-way slab is generally economical compare to one-way slab because steel along both the spans acts as main steel and transfers the load to all its four supports. The two-way action is advantageous essentially for large spans (>3m) and for live loads (>3kN/m^2). For short spans and light loads, steel required for two way slabs does not differ appreciably as compared to steel for two way slab because of the requirements of minimum steel.

Structural Design of Foundations

The type of footing depends upon the load carried by the column and the bearing capacity of the supporting soil. The soil under the foundation is more susceptible to large variations. Even under one small building the soil may vary from soft clay to a hard murmur. The nature and properties of soil may change with season and weather, like swelling in wet weather. Increase in moisture content results in substantial loss of bearing capacity in case of certain soils, which may lead to differential settlements. It is necessary to conduct the survey in the areas for soil properties. For framed structure, isolated column footings are normally preferred except in case of exists for great depths, pile foundations can be an appropriate choice. If columns are very closely spaced and bearing capacity of the soil is low, raft foundation can be an alternative solution. For a column on the boundary line, a combined footing or a raft footing may be provided

The following are the assumptions made in the earthquake resistant design of structures:

- Earthquake causes impulsive ground motions, which are complex and irregular in character, changing in period and amplitude each lasting for small duration. Therefore resonance of the type as visualized under steady-state sinusoidal excitations, will not occur as it would need time to build up such amplitudes.
- Earthquake is not likely to occur simultaneously with wind or max. Flood or max. sea waves.
- The value of elastic modulus of materials, wherever required, maybe taken as per static analysis.

1.3 Type Of Loads On Structures And Load Combinations

A structural load is a force, deformation, or acceleration applied to structural elements. A load causes stress, deformation, and displacement in a structure. Structural analysis, a discipline in engineering, analyzes the effects of loads on structures and structural elements. An excess load may cause structural failure, so this should be considered and controlled during the design of a structure. Different types of loads can cause stress, displacement, deformation on a structure; which results in structural problems and even structural failure. Determining the total load acting on a structure is very important and complex.

Different types of loads

The loads in buildings and structures can be classified as vertical loads, horizontal loads and longitudinal loads. The vertical loads consist of dead load, live load and impact load. The horizontal loads consist of wind load and earthquake load. The longitudinal loads i.e. tractive and braking forces are considered in special cases of design. The estimation of various loads acting is to be calculated precisely. Indian standard code IS: 875–1987 and American Standard Code ASCE 7: Minimum Design Loads for Buildings and Other Structures specifies various design loads for buildings and structures.

1. **Dead load**

   Dead loads, also known as permanent or static loads, are those that remain relatively constant over time and comprise, for example, the weight of a building's structural elements, such as beams, walls, roof and structural flooring components. Dead loads may also include permanent non-structural partitions, immovable fixtures and even built-in cupboards. Dead loads comprise the weight of the structure or other fixed elements before any live loads are taken into consideration.

   Live loads are added to the dead load to give the total loading exerted on the structure. The calculation of dead loads of each structure is calculated by the volume of each section and multiplied by the unit material weight.

2. Live load

Live load is a civil engineering term that refers to a load that can change over time. The weight of the load is variable or shifts locations, such as when people are walking around in a building. Anything in a building that is not fixed to the structure can result in a live load since it can be moved around.

Live loads are factored into the calculation of the gravity load of a structure. They are measured in pounds per square foot. The minimum live-load requirements are based on the expected maximum load. A live load can be expressed either as a uniformly distributed load (UDL) or as one acting on a concentrated area (point load). It may eventually be factored into the calculation of gravity loads.

3. Wind load

The movement of air relative to a structure can apply wind loads, and analysis draws upon an understanding of meteorology and aerodynamics as well as structures. Wind load may not be a significant concern for small, massive, low-level buildings, but it gains importance with height, the use of lighter materials and the use of shapes that may affect the flow of air, typically roof forms.

Where the dead weight of a structure is insufficient to resist wind loads, additional structure and fixings may be required. Wind load is required to be considered in structural design especially when the heath of the building exceeds two times the dimensions transverse to the exposed wind surface.

The design wind loads for buildings and other structures shall be determined according to one of the following procedures:

Method 1 – Simplified procedure for low-rise simple diaphragm buildings

Method 2 – Analytical procedure for regular shaped building and structures

Method 3 – Wind tunnel procedure for geometrically complex buildings and structures

4. Snow load

This load can be imposed by the accumulation of snow and is more of a concern in geographic regions where snowfalls can be heavy and frequent. Significant quantities of snow can accumulate, adding a sizable load to a structure. The shape of a roof is a particularly important factor in the magnitude of the snow load. The code IS 875 (Part-

4):1987 deals with snow loads on roofs of the building. There are many variables involved in determining snow's weight:

5. Earthquake load

Earthquake load takes place due to the inertia force produced in the building because of seismic excitations. Inertia force varies with the mass. The higher mass of the structure will imply that the earthquake loading will also be high. When the earthquake load exceeds the moment of resistance offered by the element, then the structure will break or damage.

The magnitude of earthquake loading depends upon the weight or mass of the building, dynamic properties of the building and difference in stiffness of adjacent floors along with the intensity and duration of the earthquake. Earthquake load acts over the surface of a structure placed on the ground or with an adjacent building. Buildings in areas of seismic activity need to be carefully analysed and designed to ensure they do not fail if an earthquake should occur.

Earthquake load depends on the following factors;

- Seismic hazard
- Parameter of the structure
- Gravity load.

6. Load combination

A load combination results when more than one load type acts on the structure. Building codes usually specify a variety of load combinations together with load factors (weightings) for each load type to ensure the safety of the structure under different maximum expected loading scenarios.

7. Special loads

Thermal load – The loads occur when the materials expand or contract with temperature change and this can exert significant loads on a structure.

Settlement load – When one part of a building settles more than other parts this type of load occurs.

Flood load – These are caused by flood and water ingress in the foundation which results in corrosion.

Soil and fluid load – It is caused due to excessive flow of water in the soil which impacts the soil density.

1.4 CODE OF PRACTICES AND SPECIFICATIONS

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 is designed and constructed code specifies acceptable methods of design and construction to produce safe structures.

National building code have been formulated in different countries to lay down guidelines for the design and construction of structures. International code council located in USA has published international building code. 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 Reinforced 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.

1.5 CONCEPT OF WORKING STRESS METHOD, ULTIMATE LOAD DESIGN AND LIMIT STATE DESIGN METHODS FOR RCC

Various methods used for the design of R.C.C. structures are as follows:

(i) Working stress method.
(ii) Load factor or ultimate load method.
(iii) Limit state method.

Working Stress method

This method of design was the oldest one. It is based on the elastic theory and assumes that both steel and concrete and elastic and obey Hook's law. It means that the stress is directly proportional to strain up to the point of collapse. Based on the elastic theory, and assuming that the bond between steel and concrete is perfect, permissible stresses of the materials are obtained. The basis of this method is that the permissible stresses are not exceeded anywhere in the structure when it is subjected to worst combination of working loads.

In this method, the ultimate strength of concrete and yield strength or 0.2% proof stress of steel are divided by factors of safety to obtain permissible stresses. These factors of safety take into account the uncertainties in manufacturing of these materials. As per IS456, a factor of safety of 3 is to be used for bending compressive stresses in concrete and 1.78 for yield/proof strength of steel.

The main drawbacks of the working stress method of design are as follows :

(i) It assumes that concrete is elastic which is not true as the concrete behaves in-elastically even on low level of stresses.

(ii) It uses factors of safety for stresses only and not for loads. Hence, this method does not give true margin of safety with respect to loads because we do not know the failure load.

(iii) It does not use any factor of safety with respect to loads. It means, there is no provision for the uncertainties associated with the estimation of loads.

(iv) It does not account for shrinkage and creep, which are time dependent and plastic in nature.

(v) This method gives uneconomical sections.

(vi) It pays no attention to the conditions that arise at the time of collapse.

The working stress method is very simple and reliable but as per IS 456:2000 the working stress method is to be used only if it is not possible to use limit state method of design. Working stress method is the basic method and its knowledge is essential for understanding the concepts of design.

Load Factor Method or Ultimate Load Method

In this method, ultimate or collapse load is used as design load. The ultimate loads are obtained by increasing the working/service loads suitably by some factors. These factors, which are multiplied by the working loads to obtain ultimate loads, are called as load factors. These load factors give the exact margins of safety in terms of load. This method used the real stress-strain curve of concrete and steel and takes into account the plastic behavior of these materials.

Many designers feel that the load factor provides a clear margin of safety and one can easily tell the load at which the structure fails, which is not clear from the working stress concept of permissible stresses. This method was given in detail in IS 456-1964,

The advantages of Ultimate load method are listed below:

(i) The method is more realistic as compared to working stress method because ultimate load method taken into account the non-linear behavior of the concrete.

(ii) This method gives exact margin of safety in terms of load unlike working stress method which is based on the permissible stresses which do not give any idea about the failure/collapse load.

(iii) The sections designed by ultimate load method are thinner and require less reinforcement. Hence the method is economical as compared to WSM.

The main limitations of the ultimate load method are following:

(i) This method gives very thin sections which leads to excessive deformations and cracking, thus making the structure unserviceable.
(ii) No factors of safety are used for material stresses.

As the serviceability requirements are not satisfied at all in this method, the code replaced this method by limit state method which takes into account the strength as well as serviceability requirements.

Limit State Method

This is the most rational method which takes into account the ultimate strength of the structure and also the serviceability requirements. It is a judicious combination of working stress and ultimate load methods of design. The acceptable limits of safety and serviceability requirements before failure occurs is called a limit state. This method is based on the concept of safety at ultimate loads (ultimate load method) and serviceability at working loads (working stress method).

The two important limit states to be considered in design are :
(i) Limit state of collapse.
(ii) Limit state of serviceability.

Limit State of Collapse

This limit state corresponds to the strength of the structure and categorized into following types :

(a) Limit state of collapse: Flexure.

(b) Limit state of collapse: Shear and bond.

(c) Limit State of collapse: Torsion.

(d) Limit state of collapse: Compression.

(2) Limit State of Serviceability

This limit state corresponds to the serviceability requirements i.e., deformation, cracking etc. It is categorized into following types:

(a) Limit state of deflection.

(b) Limit state of cracking

(c) Limit state of vibration.

This method is based upon the probabilities variation in the loads and material properties. Limit state method takes into account the uncertainties associated with loads and material properties, thus uses partial factors of safety to obtain design loads and design stresses.

The limit state method is based on predictions unlike working stress method, which is deterministic in nature, assumes that the loads, factors of safety and material stresses are known accurately. In the limit state method, the partial safety factors are derived using probability and statistics and are different for different load combinations, hence giving a more rational and scientific design procedure.

1.6 PROPERTIES OF CONCRETE AND REINFORCING STEEL

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 pozzolona etc. High cement content give 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, metakoline 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 mixability, 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.

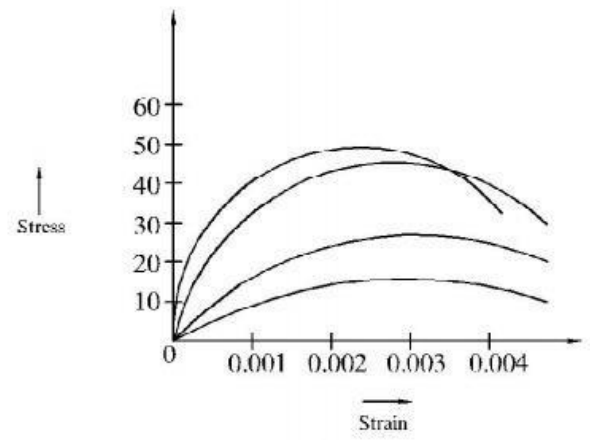
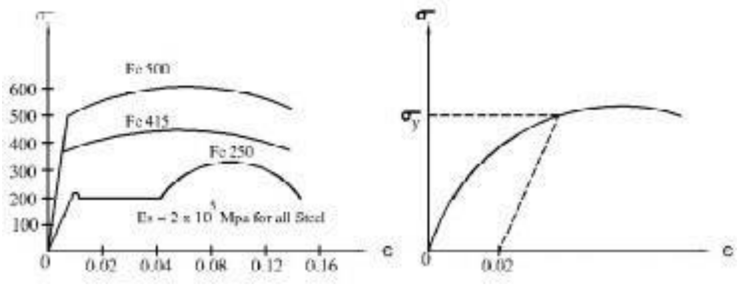


Fig 1.4

Reinforcing steel

Steel bars are often used in concrete to take case of tensile stresses. Often they are called as rebars, 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 tream (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. Fe followed by yield strength indicates steel grades. In the drawings of RCC, denotes MS bar and # denotes CTD or TMT bars.


Fe 500
Fe 415
Fe 250
600
500
400
300
200
100
0
0.02
0.04
0.08
0.12
0.16
Es = 2 x 10⁵ Mpa for all Steel

1.7 ANALYSIS AND DESIGN OF SINGLY REINFORCED RECTANGULAR BEAMS BY WORKING STRESS METHOD

1. **Design a R.C beam to carry a load of 6 kN/m inclusive of its own weight on an effect span of 6m keep the breath to be 2/3 rd of the effective depth .the permissible stressed in the concrete and steel are not to exceed 5N/mm² and 140 N/mm².take m=18**

Step 1: Design constants.

Modular ratio, m =18.

A Coefficient n = $\frac{m\sigma cbc}{m\sigma_{cbc}+\sigma_{st}}$ = 0.39

Lever arm Coefficient, j=1-(n/3) = 0.87

Moment of resistance Coefficient Q = $\frac{\sigma cbc}{2}$. n. j = 0.84 N/mm²

Step 2: Moment on the beam.

M = $(w.l^2)/8$

= $(6x6^2)/8$

= 27kNm

M = Qbd^2

d^2 = M/Qb

= $(27x10^6)/ (0.84x2/3xd)$

d = 245mm.

Step 3: Balanced Moment.

M_{bal} = Qbd^2

= $0.84x245x365^2$

= 27.41kNm. > M.

It can be designed as singly reinforced section.

Step 4: Area of steel.

Ast = M_{bal} / (σ_{st}.j.d)

= $616.72mm^2$

Use 20mm dia bars ast = $\pi/4\ (20^2) = 314.15mm^2$

No. of bars =Ast/ast

= 616.72/314.15

= 1.96 say 2nos.

Provide 2#20mm dia bars at the tension side

2. Design a beam subjected to a bending moment of 40kNm by working stress design. Adopt width of beam equal to half the effective depth. Assume the permissible stressed in the concrete and steel are not to exceed 5N/mm^2 and 140 N/mm^2.take m=18.

Step 1: Design constants.

Modular ratio, m =18.

A Coefficient n $= \frac{m\sigma cbc}{m\sigma_{cbc} + \sigma_{st}}$ = 0.39

Lever arm Coefficient, j=1-(n/3) = 0.87

Moment of resistance Coefficient Q $= \frac{\sigma cbc}{2}$. n. j = 0.84 N/mm^2

Step 2: Moment on the beam.

M = 40kNm

M = Qbd^2

d^2 = M/Qb

= (40x10^6)/ (0.84x1/2xd)

d = 456.2 say 460 mm.

b= 0.5 ,d = 0.5x460

= 230mm

Step 3: Balanced Moment.

M_{bal} = Qbd^2

= 0.84x230x460^2

= 40.88kNm. > M.

It can be designed as singly reinforced section.

Step 4: Area of steel.

Ast =M_{bal} / (σ_{st}.j.d)

= (40.88x10^6)/(140x0.87x460)

= 729.64mm^2

Use 20mm dia bars ast π/4 (20^2) = 314.15mm^2

No. of bars = Ast/ast

= 729.64/314.15

= 2.96 say 3nos.

Provide 3#20mm dia bars at the tension side.

3 Determine the moment of resistance of a singly reinforced beam 160X300mm effective section, if the stress in steel and concrete are not to exceed 140N/mm^2 and 5N/mm^2.effectve span of the beam is 5m and the beam carries 4 nos of 16mm dia bars. Take m=18.find also the minimum load the bam can carry. Use WSD method.

Step 1: Actual NA.

$b\,xa^2/2 = m.Ast.(d - xa)$

$160.\,xa^2/2 = 18 \times 804.24(300 - xa)$

$Xa = 159.42mm$

Step 2: Critical NA.

$xc = \sigma_{bc}.d/(\sigma_{st}/.m + \sigma_{cbc})$

$= 117.39mm$

$xc < Xa = 159.42mm$

it is Over reinforced Section.

Step 3: Moment of Resistance

$M = (b.\frac{xa}{2}.\sigma_{cbc})(d - xa/3)$

$= (160x159.42/2x5)(300-159.42/3)$

$= 15.74kNm$

Step 4: Safe load.

$M = (w.l^2)/8$

$W = (8 \times 15.74)/5^2$

$= 5.03$ kN/m

4. A reinforced concrete rectangular section 300 mm wide and 600 mm overall depth is reinforced with 4 bars of 25 mm diameter at an effective cover of 50 mm on the tension side. The beam is designed with M 20 grade concrete and Fe 415 grade steel. Determine the allowable bending moment and the stresses developed in steel and concrete under this moment. Use working stress method.

Step 1: Actual NA.

$b\,xa^2/2 = m.Ast.(d - xa)$

$300.\,xa^2/2 = 18 \times 1963.50(550 - xa)$

Xa = 117.81mm

Step 2: Critical NA.

Xc = σ_{bc}.d/(σ_{st}/.m + σ_{cbc})

= 194.66mm >Xa

= 117.81mm

it is Under reinforced Section.

Step 3: Moment of Resistance For steel:

M = (Ast.σ_{st})(d- xa/3)

= (1963.5x230)(550-117.81/3)

= 230.64kNm

For concrete:

M = (b.$\frac{xa}{2}$. σ_{cbc})(d- x_a/3)

= (300x117.81/2x7)(550-117.81/3)

= 63.17kNm

1.8 Limit State philosophy as detailed in IS code

DESIGN BASED ON LIMIT STATE METHOD:

Types of limit states:

Two categories of limit states are considered in design.

Limit states of collapse:

- Limit state of collapse in flexure
- Limit state of collapse in compression
- Limit state of collapse in compression and uniaxial bending.
- Limit state of collapse in compression and biaxial bending.
- Limit state of collapse in shear
- Limit state of collapse in bond
- Limit state of collapse in torsion
- Limit state of collapse in tension

Limit state of serviceability:

- Limit state of deflection
- Limit state of cracking
- Other limit states, such as vibration, fire resistance, durability etc.

1. **Limit state of collapse**:

The limit state of collapse of the structure or part of the structure could be assesses from rupture of one or more critical sections and from buckling due to elastic or plastic instability or overturning. The resistance to bending, shear, torsion and axial loads at every section shall not be less than the appropriate value at that section produced by the probable most unfavorable combination of loads on the structure using the appropriate partial safety factors.

2. **Limit state of serviceability**:

The limit state of serviceability relate to the performance or behavior of structure at working loads. Normally, design is based on the considerations of limit states of collapse on ultimate loads and on serviceability limit states of deflection and cracking under service loads. Durability is taken care of by prescribing appropriate grade of concrete, nominal cover for various exposure condition, cement content etc.

1.8 ADVANTAGES OF LIMIT STATE METHOD OVER OTHER METHODS

The advantages of limit state method over the other methods are the following

a) In the limit state method of analysis, the principles of both elastic as well as plastic theories used and hence suitable for concrete structures

b) The structure designed by limit state method is safe and serviceable under design loads and at the same time it is ensured that the structure does not collapse even under the worst possible loading conditions

c) The process of stress redistribution, moment redistribution etc., are considered in the analysis and more realistic factor of safety values are used in the design

d) Hence the design by limit state method is found to be more economical.

e) The overall sizes of flexural members (depth requirements) arrived by limit state method are less and hence they provide better appearance to the structures.

Working Stress Method	Limit State Method
The stress in a component is derived from the working load and compared with the permissible stress.	The stresses are derived from the design load and are compared with the design strength.
This method can also be referred to as the deterministic method as a result of the method assumes that the actual load, permissible stress and safety factors are identified.	This method can also be referred to as non-deterministic because the method is based on a probabilistic approach that relies on real data or experience.
The work stress method is based on elastic theory which assumes that concrete and steel are elastic and the stress-strain curve for both is linear.	The limit state method is based on the actual stress-strain curves of steel and concrete, The stress-strain curve for concrete is non-linear.
Physical capabilities are largely underestimated, Safety factors are used in the work stress method.	The capabilities of the material are not underestimated as much as they are in the working stress method. Partial protection factors

	are used in the limit state method.
The ultimate load-carrying capacity cannot be precisely predicted.	Ultimate stresses of the material themselves are used as allowable stresses.
Within the work stress method, the material follows Hooke's rule because the stress is not allowed to exceed the yield limit.	In the limit state method, stress is allowed to exceed the yield limit.
In working stress method, a section which is plane before bending remains plane after bending.	In LSM, a section normal to the axis of the structural element remains on the plane after bending.
In the work stress method, no safety factor is used for the load.	In the limit state method, the design load is obtained by multiplying the load's partial safety factors to the work load.
The working stress method is less economical as it gives thicker parts.	The limit state method is more economical because it gives thin sections.

1.9 Analysis and design of singly and doubly reinforced rectangular beams by Limit state method

The Concrete beam whose only tension zone of cross-section area is covered with steel rod is known as a **singly reinforced beam**.

ANALYSIS OF SINGLY REINFORCED BEAMS PROBLMS:

TYPE 1 PROBLEM:

GIVEN DATA: Ast in mm2 or number of bars with diameter, size of beam (b, D), type of concrete (fck), type of steel (fy), if load to be calculated then span is given. REQUIRED: Ultimate moment or factored moment or moment or resistance (Mu) or Mu & w.

Note:

1. Ultimate moment or factored moment (Mu) = 1.5 x working moment = 1.5 x M

2. Ultimate load or factored load (wu) = 1.5 x working load = 1.5 x w

DESIGN STEPS:

STEP 1: Note down the value for Xu,max/d by referring IS: 456-2000

F_y in N/mm^2	$X_{u,max}/d$
250	0.53
415	0.48
500	0.46

STEP 2: Determine depth of neutral axis Xu/d Xu/d = (0.87.fy.Ast)/(0.36.fck.b.d)

Where,

Xu = depth of neutral axis

Fy = characteristic tensile strength of steel in N/mm2 Ast = area of steel in tension in mm2

Fck = characteristic compressive strength of concrete in N/mm2 b = breadth or width of member

d = effective depth in mm

Effective depth (d) = overall depth (D) – effective cover (d’) Effective cover (d’) = clear cover + diameter of bar/2

Clear cover for beam = 25mm.

STEP 3: Compare Xu/d and Xu,max/d

If Xu/d < Xu,max/d, then section is under reinforced. The moment of resistance is calculated by

Mu = 0.87.fy.Ast.d. [1- (fy.Ast)/(fck.b.d)]

If Xu/d > Xu,max/d, then section is over reinforced. The moment of resistance is calculated by

Mu,lim = 0.149.fck.b.d2 for Fe250 steel.

Mu,lim = 0.138.fck.b.d2 for Fe415 steel.

Mu,lim = 0.133.fck.b.d2 for Fe500 steel.

If the section is balanced that is Xu/d = Xu,max/d then the limiting moment of resistance (Mu,lim) is calculated.

STEP 4: Working moment = M = Mu/1.5

The maximum bending moment for simply supported beam carrying UDL = wl2/8 Now equating maximum bending moment and working moment

$M = wl^2/8$, $w = 8M/ l^2$

Where w = total load = dead load + live load. DL

self-weight of beam= ρ.b.D =25.b.D kN/m

Live load = w-DL in kN/m.

PROBLEM 1.Find the depth of neutral axis of a singly reinforced R.C beam of 230mm width and 450mm effective depth. It is reinforced with 4 bars of 16mm diameter. Use M20 concrete and Fe415 bars. Also comment on the type of beam.

Given data: b=230mm,

d=450mm,

Ast=4-#16,

fck=20 N/mm2,

fy=415 N/mm2

Required: Xu

Solution:

Step1: As per IS: 456-2000 Xu,max/d = 0.48 for Fe415

Step2: Xu/d = (0.87.fy.Ast)/(0.36.fck.b.d)

Ast= no of bars x π(diameter)2/4 = 4x πx(16)2/4

= 504.24 mm^2

Xu/d = (0.87x415x804.24) / (0.36x20x230x450)

= 0.39

Xu = 0.39xd = 0.39x450 = 175.5mm.

Step3: By comparing Xu/d < Xu,max/d

Section is under-reinforced.

PROBLEM 2.A singly reinforced concrete beam 250mm width is reinforced with 4 bars of 25mm diameter at an effective depth 400mm. If M_{20} grade concrete and Fe_{415} bars are used. Compute moment of resistance of the section.

Given data: b=250mm, d=400mm, Ast=4-#25, fck=20 N/mm2, fy=415 N/mm^2 Required: Mu

Solution:

Step1: As per IS: 456-2000 Xu,max/d = 0.48 for Fe_{415}

Step2: Xu/d = (0.87.fy.Ast)/(0.36.fck.b.d)

Ast= no of bars x π(diameter)2/4

= 4x πx(25)2/4 = 1963.75 mm^2

Xu/d = (0.87x415x1963.75) / (0.36x20x250x400)

= 0.98

Step3: By comparing Xu/d > Xu,max/d

Section is Over-reinforced.

Step4:

Mu,lim=0.138.fck.bd^2

=0.138x20x250x400 ^{2}

= 110400000 N-mm = 110.4 kN-m

PROBLEM 3.A simply supported singly reinforced beam having 250mm wide and 500mm effective depth provided with Fe_{415} steel and M_{20} grade of concrete. Determine the ultimate moment of resistance of beam.

Given data: b=250mm,

d=500mm,

fck=20 N/mm2,

fy=415 N/mm^2

Required: Mu,lim

Solution:

Mu,lim=0.138.fck.bd^2

=0.138x20x250x500^2

= 172500000 N-mm

= 172.5 kN-m

PROBLEM 4.A rectangular section of 230x500mm is used as a simply supported beam for effective span of 6m. The beam consists of tensile reinforcement of 4000 mm2 and center of reinforcement is placed at 35mm from the bottom edge. What maximum total UDL can be allowed on the beam? Given M20 concrete and Fe415 steel.

Given data:

b=230mm,

D=500mm,

simply supported beam, l=6m,

Ast=4000mm2, d'=35mm,

fck=20 N/mm2,

fy=415 N/mm^2

Required: w

Solution:

Step1: As per IS: 456-2000

Xu,max/d = 0.48 for Fe415

Step2:

Xu/d = (0.87.fy.Ast)/ (0.36.fck.b.d)

d=D-d'=500-35=465mm

Xu/d = (0.87x415x4000) / (0.36x20x230x465)

= 1.875

Step3: by comparing Xu/d > Xu,max/d

Section is Over-reinforced.

Step4: Mu,lim=0.138.fck.bd^2 =0.138x20x230x465^2

= 137259630 N-mm

= 137.26 kN-m

Step5: M=Mu/1.5

=137.26/1.5=91.506kN-m

Maximum bending moment for simply supported beam with UDL

M=wl2/8,

w=8M/l2

=8.91.506/62=20.33kN-m

ANALYSIS OF DOUBLY REINFORCED BEAM

Definition: the RCC beam section in which steel reinforcement is provided to resist both compression and tension is called doubly reinforced beam.

The circumstances under which doubly reinforced sections are provided:

1. When there are architectural restrictions on the depth of otherwise singly reinforced section.

2. Restriction in the depth at the location of beam at plinth level, along with the provision of ventilator between the ground level and the bottom of plinth beam.

3. In a continuous beam floor system, where the beam acts as a T-beam in the midspan and acts as a rectangular beam at the supports where the B.M may be much greater than at the mid span.

4. Where it is required to increase the stiffness of the beam.

5. It is found that the compression steel increases the rotation capacity and ductility

TYPE I PROBLEMS (Mu):

Given data: Ast, Asc, size of beam, effective cover for compression steel (d'), type of concrete (fck) and steel (fy). If load to be calculated then span is given.

Required: ultimate moment or factored moment or moment of resistance (Mu) and super imposed load (w).

Solution:

Step1: calculate Asc= no of bars x π (ϕc)2/4 mm2, Ast= no of bars x π (ϕt)2/4 mm2 Where, ϕc= diameter of compression steel, ϕt= diameter of tension steel

Step2: Xu,max= 0.46d for Fe500

0.48d for Fe415

0.53d for Fe250

Step3: stress in compression (fsc): from the table F of SP16 by linear interpolation Calculate d'/d

For Fe250 fsc=0.87.fy

Step4: Ast_2= Asc.fsc / (0.87. fy)

Step5: Ast= Ast_1+ Ast_2

Ast1= Ast- Ast_2

Step 6: depth of neutral axis

Xu/d= (0.87.fy.Ast1) / (0.36.fck.b.d) or Xu= 0.87.fy.Ast-fsc.Asc / (0.36.fck.b)

If, Xu < Xu,max section is under reinforced.

Therefore, calculate the moment of resistance by the following expression Mu-Mu,lim=fsc.Asc.(d-d')

Mu= 0.36. fck.b.xu.(d-0.42.xu) + fsc.Asc(d-d') If, Xu > Xu,max section is over reinforced.

Put Xu = Xu,max value and calculate moment of resistance by the following expression, Mu= 0.36. fck.b.xu,max.(d-0.42.xu,max) + fsc.Asc(d-d')

To calculate safe udl of live load: follow same steps as in singly reinforced beams.

Poblem 1 A doubly reinforced beam section is 250mm wide and 450mm deep to center of the tensile reinforcement. It is reinforced with 2 bars of 16mm diameter as compressive reinforcement at an effective cover 50mm and 4 bars of 25mm diameter as tensile steel. Using M15 concrete and Fe250 steel. Calculate the ultimate moment of resistance of the beam.

Given data:

b=250mm,

d=450mm,

fck=15 N/mm2,

fy=250 N/mm2,

d'=50mm,

Asc= 2- #16, Ast=4-#25

Required: Mu Solution:

Step1: calculating Asc= no of bars x π (ϕc)2/4

=2 πx(16)2/4=402.12mm2 Ast

= no of bars x π (ϕt)2/4=4x πx(25)2/4=1963.49mm^2

Step2: Xu,max=0.53d for Fe250

=0.53x450=238.5mm

Step3: stress in compression (fsc)

fsc=0.87.fy=0.87x250=217.5 N/mm2

step4: Ast2=(Asc. fsc)/(0.87. fy)

=(402.12x217.5)/(0.87x250)=402.12mm2

step5: Ast=Ast1+Ast2, Ast1

=Ast-Ast2=1963.49-402.12=1561.37mm2

step6: depth of neutral axis (Xu)

Xu= 0.87.fy.Ast1/ (0.36.fck.b)

= 0.87x250x1561.37/ (0.36x15x250)

=251.5mm

Xu> Xu,max section is over reinforced.

Step7: Mu=0.149.fck.b.d2+fsc.Asc.

(d-d')= 0.149x15x250x4502+217.5x402.12x (450- 50) =148.13x106 N-mm

Mu=148.13 kN-m.

Problem 2 A doubly reinforced beam section is 250mm wide and 500mm deep to the center of the tensile reinforcement. It is reinforced with 2 bars of 18mm diameter as compression reinforcement at an effective cover of 40mm and 4 bars of 25mm diameter as tensile reinforcement using M15 concrete and Fe415 steel. Calculate MR of the section.

Given data:

b=250mm,

d=500mm,

fck=15 N/mm^2,

fy=415 N/mm^2,

d'=40mm,

A_{sc}= 2-#18,

A_{st}=4-#25

Required: M_u

Solution:

Step1: calculating,

Ast =no's.xπ.(ϕt)^2/4

= 4xπx(25)^2/4= 1963.49mm^2 Asc

= no of bars x π (ϕc)^2/4=2x πx(18)^2/4=508.93mm^2

Step2:

$X_{u,max}$=0.48d for Fe415

=0.48x500

=240mm

Step3: stress in compression (f_{sc})d'/d

=40/500

=0.08

By referring table –F of sp16d'/d fsc

0.05	355	Y1
0.08	?	Y
0.1	353	Y2

Y = Y1 + ((Y2-Y1)/(X2-X1))*(X-X1)

= 355+((353-355)/(0.1-0.05))*(0.08-0.05)=353.8 N/mm^2

F_{sc}= 353.8 N/mm^2

step4:

A_{st2} =(A_{sc}. f_{sc})/(0.87. f_y)

=(508.93x353.8)/(0.87x415)=498.71mm^2

step5:

A_{st} =A_{st1}+A_{st2},

A_{st1} =A_{st}-A_{st2}

=1963.49-498.71

=1464.78mm^2 step6: depth of neutral axis (X_u)

X_u = (0.87.f_y.A_{st}-f_{sc}.A_{sc})/ (0.36.f_{ck}.b)

= (0.87x415x1963.49-353.8x508.93)/(0.36x15x250)

=391.74mm

X_u> $X_{u,max}$ section is over reinforced.

Step7: M_u=0.138.f_{ck}.b.d^2+f_{sc}.A_{sc}. (d-d')

= 0.138x15x250x500^2+353.8x508.93x (500-40)

=212.2x10^6 N-mm

M_u=212.2 kN-m.