SRIMAAN COACHING CENTRE-TRICHY-TNMAWS- MUNICIPAL ADMINISTRATION & WATER SUPPLY DEPARTMENT-CIVIL ENGINEERING STUDY MATERIAL -TO CONTACT:8072230063.

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TNMAWS

MUNICIPAL ADMINISTRATION & WATER SUPPLY DEPARTMENT-(MAWS)

CIVIL ENGINEERING(DIPLOMA STANDARD)

UNIT-IX: STRUCTURAL ENGINEERING

TN-MAWS STUDY MATERIALS

CIVIL/ MECHANICAL /ELECTRICAL / TOWN PLANNING/ ARCHITECTURE / PUBLIC HEALTH & SANITATION

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UNIT-IX: STRUCTURAL ENGINEERING
(DIPLOMA STANDARD)

Reinforced cement concrete structure

INTRODUCTION

Concrete is a mixture of cement, aggregates, water and admixtures in an adequate proportion. It is a rock like material. Concrete is a product obtained artificially by hardening of the mixture of cement, sand, gravel and water in predetermined proportions. It has *enough strength in compression*, but has *little strength in tension*. Due to this, *concrete is weak in bending, shear and torsion*. Hence to overcome the issues *reinforcement in concrete* was obtained to withstand the properties required for a structure.

Properties of Fresh Concrete

Concrete should be such that it can be transported, placed, compacted and finished without harmful segregation. The mix should maintain its uniformity and not bleed excessively; these two are collectively called as workability .Bleeding is movement and appearance of water at the surface of freshly-placed concrete, due to settlement of heavier particles. Consistency is a measure of its wetness and fluidity .Measured by the slump test and Workability dependent on water content, fineness of cement, and surface area of aggregates.

Properties of Hardened Concrete:

The important properties of concrete are

a. Compressive strength

b. Tensile strength   c.Shear strength

d. Bond strength   e. Density

f. Impermeability   g. Durability   h. Ductility

Among these properties, compressive strength of concrete is the most valuable and can be easily tested in laboratory.

This is generally measured on concrete cubes or cylinders.

- ❖ Many of the properties of concrete can be inferred from compressive strength, using correlation that has been established.
- ❖ Quality of concrete depends on the compressive strength.
- ❖ Dependent on strength (compressive, tension and flexure), Modulus of elasticity, Durability, Creep and shrinkage
- ❖ Concrete is classified under different grades depending upon its characteristic strength.

"Characteristic strength is defined as the strength of material below which not more than 5 percent of the test results are expected to fall".

- ❖ Strength of concrete varies for the same concrete mix, which give different compressive strength in laboratory tests.
- ❖ Variability in strength evidently depends on degree of quality control.
- ❖ Variability in strength is measured in terms of either the "Standard Deviation" or the Coefficient of
  Variation (COV), which is the ratio of standard deviation to mean strength.
- ❖ Due to significant variability in strength, it is necessary to ensure that the designer has a reasonable assurance of a certain minimum strength of concrete.
- ❖ Characteristic strength provides minimum guaranteed strength.

What is a stress-strain diagram?

- ➢ It is a tool for understanding **material behavior under load.**
- ➢ A stress strain diagram **help engineers to select the right materials for specific loading conditions**. In other words, It is a graph that represents how a part behaves under an increasing load, and used by engineers when selecting materials for specific designs
- ➢ A stress-strain diagram generally contains three regions: ❖ **Elastic region**: This portion is generally represented as a linear relationship between stress and
  strain. If the load is released the specimen will return to its original dimensions.

❖ **Plastic region**: In this portion, the specimen begins to yield. The maximum strength of the specimen occurs in this zone. The specimen endures some permanent deformation that remains after the load is released.

Diagram of concrete

- Concrete is mostly used in compression that is why **its compressive stress strain curve is of major attention**.
- The stress and strain of concrete is **obtained by testing concrete cylinder specimen at age of 28 days**, using compressive test machine.
- The stress strain curve of concrete allows designers and engineers to **anticipate the behavior of concrete** used in building constructions.
- Stress strain curve of concrete is a graphical representation of concrete behavior under load.
- It is produced by plotting **concrete compressive strain at various interval of concrete compressive stress** (which is the loading).
- The S-S curve for hardened concrete is **almost linear**.
- The aggregate is more rigid than the cement paste and will therefore deform less(that is it will have lower strain) under same applied stress.
- The **S-S curve of concrete lies between the aggregate and the cement paste**.
- However, this relationship is **non-linear over the most of the range**, that is why micro cracks are formed.
- The cracks are formed
- at the interface between aggregate particles and cement paste as a result of the differential movement between the two phases
- Within the cement paste.
- These cracks are formed as result of **changes in temperature, moisture and application of load.**
- The experimental or actual stress strain curve for concrete is very difficult to use in design. Therefore, IS code 456:2000 has simplified as below.
- For design purpose, the compressive strength of concrete in the structure in taken as 0.67 times the characteristic strength.
- The 0.67 factor is introduced to account for the difference in the strength indicated by a cube test and the strength of concrete in actual structure.
- The partial safety factor equal to 1.5 is applied in addition to this 0.67 factor.
- The initial portion of the curve is parabolic. After a strain of 0.002 (0.2%), the stress becomes constant with increasing load, until a strain of 0.0035 is reached and here the concrete is assumed to have failed.

- **As per IS specifications, for M30 grade concrete.**
- **Up to 0.002 of strain the curve will be parabolic for a concrete cube** ❖ **And then the slope becomes zero up to ultimate strain of 0.0035** **<u>As per IS specifications</u>**

a) The earlier given was for the characteristic strength of a standard 150x150x150 mm size of concrete cube.

b) But when the design is for a entire structure then the compressive strength of the concrete will get reduced due to the influence of the soil as given in the figure.

c) For design purpose Limit state method is adopted as in IS codes. So a partial safety factor of 1.5 is considered.

d) Therefore the design stress of concrete is taken as $[(0.67*f_{ck})/ 1.5] = 0.45 f_{ck}$

e) Hence for the design problems the design stress of concrete is taken as $0.45 f_{ck}$ and the ultimate strain of concrete is taken as 0.0035.

f) Thus finally results in a design curve as shown in figure.

Stress - Strain diagram of mild steel

- If the force is considerably large the material will experience elastic deformation but the ratio of stress and strain will not be proportional. (Point A to B). This is the elastic limit.
- Beyond that point the material will experience plastic deformation.
- The point where plastic deformations starts is the yield point which is shown in the figure as point B. 0-B is the upper yield point.
- Resulting graph will not be straight line anymore. C is the lower yield point.
- D is the maximum ultimate stress.
- E is the breaking stress. It is the area of the whole curve (point 0-E). Energy absorbed at unit volume up to breaking point.
- If tensile force is applied to a steel bar it will have some extension.
- If the force is small the ratio of the stress and strain will remain proportional

Stress - Strain diagram HYSD (High Yield Strength Deformed) bars

- There is no specified yield point for HYSD bars, the code gives the characteristic curve as given above.
- So considering the strain value of 0.002 the yield stress is noted.
- The design curve almost same as mild steel and the design stress is also $0.87 f_y$.
- But the strain at this point is different as given above.

Analysis and design of singly and Doubly reinforced rectangular and T-beam sections

DESIGN PHILOSOPHIES

- A design philosophy is a set of assumptions and procedures which are used to meet the conditions of serviceability, safety, economy and functionality of the structure. Some of the design philosophies that has been used by engineers are
  1. Working Stress Method (WSM)
  2. Ultimate Load Method (ULM)
  3. Limit State Method (LSM)

Working Stress Method

- The sections of the members of the structure are designed assuming straight line stress-strain relationships ensuring that at service loads the stresses in the steel and concrete do not exceed the allowable working stresses.
- The allowable stresses are taken as fixed proportions of the ultimate or yield strength of the materials.
- The B.Ms and forces that act on statically indeterminate structures are calculated assuming linear – elastic behaviour.
- Reinforced concrete sections behave in elastically at high loads. Hence elastic theory cannot give a reliable prediction of the ultimate strength of the members because inelastic strains are not taken into account.
- For structures designed by the working stress method, the exact load factor is unknown and varies from structures to structure.

Ultimate Load Method:

- Sections of members of the structures are designed taking inelastic strains into account to reach ultimate (maximum) strength when an ultimate load, equal to the sum of each service load multiplied by its respective load factor, is applied to the structure.
- The beginning moments and forces that act as statically indeterminate structures at the ultimate load are calculated assuming non linear elastic behaviour of the structure up to the ultimate load. i.e., redistribution of same actions is taking place due to nonlinear relationship between actions and deformations.
- Ultimate strength design makes more efficient use of high strength reinforcement and smaller beam depths can be used without compression steel.

- If the sections are designed based on ultimate strength design, there is a danger that although the load factor is adequate. The cracking and the deflections at the service loads may be excessive.
- Cracking may be excessive if the steel stresses are high or if the bars are badly distributed.
- Deflections may be critical if the shallow sections, which are possible in USD, are used and the stresses are high.
- To ensure a satisfactory design, the crack widths and deflections at service loads must be checked to make sure that this lies within reasonable limiting values, as per functional requirements of the structure. This is done by use of elastic theory.

Limit state method of design

The object of the design based on the limit state concept is to achieve an acceptable probability, that a structure will not become unsuitable in its lifetime for the use for which it is intended i.e. it will not reach a limit state

- A structure with appropriate degree of reliability should be able to withstand safely.
- All loads that are reliable to act on it throughout its life and it should also satisfy the sustainability requirements, such as limitations on deflection and cracking.
- It should also be able to maintain the required structural integrity, during and after accident, such as fires, explosion & local failure i.e. limit sate must be consider in design to ensure an adequate degree of safety and serviceability
- The most important of these limit states, which must be examine in design are as follows Limit state of collapse - Flexure, Compression, Shear and Torsion Limit state of serviceability
- This state corresponds to the maximum load carrying capacity.

Deflection Criteria

Deflection of structure or part thereof shall not adversely affect the appearance or efficiency of structure or finishes or partitions.

<u>Deflection shall generally be limited to the following:</u>

i. Final deflection due to all loads including the effects of temperature, creep and shrinkage and measured from as-cast level of supports of floors, roofs and all other horizontal members should not normally exceed span/250.

ii. Deflection including effects of temperature, creep and shrinkage occurring after erection of partitions and application of finishes should not normally exceed (span/350) or 20mm whichever is less.

Factors influencing limits on deflection in flexural members

- Aesthetic/psychological discomfort
- Crack width limitation
- Effect on attached structural and non structural elements
- Ponding in (roof) slabs

DESIGN FOR BOND IN RC

- **Bond stress**: stress developed between surface of steel reinforcement and surrounding concrete by which slip occurs when concrete and steel act together in structural member by transferring stress between each other.
- **Slip**: relative displacement between reinforcement and surrounding concrete.
- Bond stresses are, in effect, longitudinal shearing stresses developed on surface between steel and surrounding concrete wherever stress in a bar changes.
- Importance of determining bond stress in tensile reinforcing bars has increased due to the following reasons
  - ✓ More frequent use of high grade steel with larger bar diameter and
  - ✓ Adopting refined ultimate strength design procedures

DISTRIBUTION OF BOND STRESS

- Bond stress in a beam or wall is neither uniform nor gradually varying from point to point
- Very large bond stresses develop adjacent to tension crack
- Essentially ultimate bond stresses exist close by on the same bar, even reversed in direction in many cases.
- Thus there is a practical problem as to how to describe or measure or evaluate such a fluctuating stress condition.

BOND MECHANISM

Bond can be thought of as shearing stress or force between a bar and surrounding concrete Bond resistance is offered by

- ✓ Chemical Adhesion – gel like hydration products
- ✓ Friction–surface roughness and concrete shrinkage
- ✓ Mechanical Interaction - ribs in deformed bars Importance of Bond

Ultimate Limit State

- Anchorage of Reinforcement
- Control of Hinge rotations in flexural members
- Maintenance of Composite action Serviceability Limit State
- Control of Flexural Cracking

– Control of Member Deformations

Factors affecting bond strength

- Type of Reinforcement – Plain or Deformed
- Diameter of bars
- Grade of Concrete
- Cover to reinforcement
- Confinement of Concrete
- Direction of Casting
- Top bar effect
- Spacing of bars
- Relative rib area of bars
- Quality of reinforcement
- Coating to reinforcement

Types of Bond

- Flexural bond: arises in flexural members on account of shear or variation in bending moment-critical at points where shear is significant.
- Anchorage bond: arises over a length of anchorage provided for a bar or near the end of a reinforcing bar and resists pulling out of bar in tension.

Table 1 Difference between three lengths

Development length	Anchorage length	Lap length
Development length must be provided for the required amount of reinforcement(as per moment) on either sides of every section in the mem-ber so that the reinforcement doesn't slip as it approaches the ultimate stress at that	Anchorage is the length of reinforcement that needs to be embedded into the support for complete stress transfer. **Anchorage bars** are different for bars in tension and compression. **Bends** are taken ***as 4 times the diameter of the bar for 45 degree bend, 8 times the diameter of the bar for 90 degree bend, 16 times the diameter of the bar for 135 degree bend. U-hooks shall be taken 16 times the dia-meter of the bar***.	Lap is required when a reinforcement bar needs to be spliced at a section. This is again to ensure sufficient development length at every section. The bar that ends midway lacks the sufficient development length at the sec-tions closer to its end and the bar that begins midway lacks the development length at the beginning sections. In order to satisfy both the requirements the bars are overlapped for a sufficient length on either sides of the intended splice point.

BEAMS

Doubly reinforced rectangular and T-beam sections

BEAM

- A Beam is an inevitable horizontal or sloping structural element to resist the load of the structure.
- The main function of the beam is designed to resist the external or internal load such as wall, slab and floors of the building and distribute the load to the foundation through the column.
- The horizontal beam carries an only transverse (vertical) load and the sloping beams carry both transverse and axial load.

LIMIT STATE METHOD OF DESIGN

- The object of the design based on the limit state concept is to achieve an acceptable probability, that a structure will not become unsuitable in it's lifetime use for which it is intended.
- A structure with appropriate degree of reliability should be able to withstand safety.
- It should also be able to maintain the required structural integrity, during and after accident, such as fires, explosion & local failure. i.e. limit sate must be consider in design to ensure an adequate degree of safety and serviceability

- The most important of these limit states, which must be examine in design are as follows Limit state of collapse
    - **Flexure**
    - **Compression**
    - **Shear**
    - **Torsion**
- This state corresponds to the maximum load carrying capacity.

Limit State :

The acceptable limit for the safety and serviceability requirements before failure occur.

Types of limit state

1. Limit state of **collapse or failure**:
    - Flexural (Bending)
    - Compression
    - Shear
    - Torsion

    } Based on *imaginary behaviour* of structure

2. Limit state of **serviceability**:
    - Deflection
    - Cracking
    - Vibration
    - Fire resistance
    - Etc.

    } Based on *actual behaviour* of structure

WHAT IS DEPTH OF NEUTRAL AXIS?

- Neutral axis is the axis at which the stresses are zero and it is situated at the centre of gravity of the section, **which is neither compression nor tension.**
- The maximum depth of neutral axis is limited to ensure that tensile steel will reach its yield stress before concrete fails in compression, thus a brittle failure is avoided.

WHAT IS EFFECTIVE DEPTH?

- The effective depth of the beam is the **distance from the tension steel to the edge of the compression fiber**.
- Therefore, we can say that the effective depth of a beam section is a distance as measured from top fiber of beam to centroid of steel reinforcement.

WHAT IS EFFECTIVE COVER?

- Effective cover is taken as distance taken from bottom concrete fiber section from the center level of the reinforcement.

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

WHAT IS CLEAR COVER?

- Clear cover is the distance measured from the exposed concrete surface (Without plaster and other finishes) to the nearest surface of the reinforcing bar.

WHY EFFECTIVE COVER IS PROVIDED?

- To protect the steel reinforcement bars (rebars) from environmental effects to prevent their corrosion;
- To provide thermal insulation, which protects the reinforcement bars from fire, and;
- To give reinforcing bars sufficient embedding to enable them to be stressed without slipping.

FLEXURE OF RCC BEAMS OF RECTANGULAR SECTION

- Flexural members are **slender members that deform primarily by bending moments** caused by concentrated couples or transverse forces.
- In modern construction, these **members may be** joists, **beams**, girders, lintels, and other specially named elements.
- But their **behavior** in every case **is essentially the same**.
- Unless otherwise specified in a problem, **flexural members will be referred to as beams** here.

Assumptions to determine Moment of resistance of Reinforced concrete beams

1. **Plane sections remain plane before and after bending**. This means that strains are proportional to distance from the neural axis.
2. Ultimate limit state of bending failure is assumed to have been reached when the strain in the concrete at the extreme bending compression fiber reaches 0.0035.
3. The stress distribution across compression face will correspond to the stress-strain diagram for concrete in compression.
4. The **tensile strength of concrete is neglected as the section is assumed to be cracked up to the neutral axis**.
5. **The stress in steel will correspond to the corresponding strain in the steel**
6. As given in assumption 2 above **that the reinforced concrete section in bending is assumed to fail when the compression strain in concrete reaches the failure strain** in bending compression equal to 0.0035.

TYPES OF REINFORCED CONCRETE BEAMS

- Singly reinforced beam
- Doubly reinforced beam
- Singly or doubly reinforced flanged beams
- Continuous beams

SINGLY REINFORCED BEAM

- The beam that is longitudinally reinforced only in tension zone, it is known as singly reinforced beam.
- In such beams, the final bending moment and the stress because of bending are carried by the reinforcement, while this compression is carried by the concrete.
- But it is not possible to provide reinforcement only in the tension zone, because we need to tie the stirrups.
- Therefore, two rebars/ holding bars are used in the compression zone to tie the stirrups, and the rebars act as false members only to hold the stirrups

DOUBLY REINFORCED BEAM

- The beam that is reinforced with steel in the tension and compression zone is known as the doubly reinforced beam.
- The doubly reinforced beams have compression reinforcement in addition to the tension reinforcement, and this compression reinforcement can be on both sides of the beam (top or bottom face), depending on the type of beam, that is, simply supported or cantilever, respectively

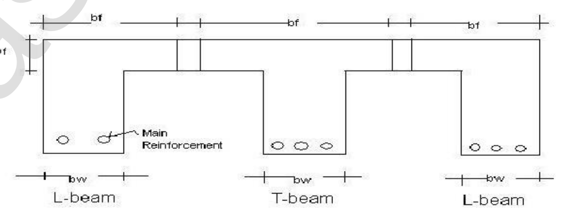
WHY A DOUBLY REINFORCED BEAM?

- This type of beam will be considered necessary when, due to the consideration of headroom or architecture, the depth of the beam is restricted.
- And when the singly reinforced section is insufficient to resist the bending moment on the section additional tension and compression reinforcement are designed based on steel beam theory.
- The doubly reinforced beam (DRB) section is used where the span is more, where cross section will also be increased.
- Depth can be reduced and the A_{st} can be increased.
- In DRB, the top and bottom reinforcement must be designed.

SINGLY OR DOUBLY REINFORCED FLANGED BEAMS

- The flanged beam may be considered as a rectangular beam of width b_f and effective depth d, if the neutral axis is in the flange as the concrete in tension is ignored. However, if the neutral axis is in the web, the compression is taken by the flange and a part of the web

Combination of T and L-beams



CONTINUOUS BEAMS

- Beams are made continuous over the supports to increase structural integrity.
- A continuous beam provides an alternate load path in the case of failure at a section.
- In regions with high seismic risk, continuous beams and frames are preferred in buildings and bridges.
- A continuous beam is a statically indeterminate structure.

Balanced, Under-Reinforced and Over-Reinforced Beam Sections

Balanced Beam Section:

- Reinforced concrete beam sections in which the **tension steel also reaches yield strain simultaneously as the concrete reaches the failure strain in bending** are called balanced sections.
- Steel bars, inside fail first and then the concrete (i.e.,) Steel failure to concrete failure

Under-Reinforced Beam Section

- Reinforced concrete beam sections in which the **steel reaches yield strain at loads lower than the load at which the concrete reaches failure strain** are called under-reinforced sections.

- The concrete has maximum yield strain (i.e.,) steel reaches yield strain at lower load than concrete

Over-Reinforced Beam Sections

- Reinforced concrete beam sections, in which **the failure strain in concrete is reached earlier than the yield strain of steel is reached**, are called over-reinforced beam sections.
- The concrete fails first then the steel (i.e.,) concrete failure to steel failure

Depth of Neutral axis

Consider a rectangular beam section,

b- Width of section

d- Effective depth

A_{st}- Area of steel reinforcement = $\pi d^2/4$

X_u- depth of neutral axis

For equilibrium of forces at the limit state of collapse Pg. No. 96

Limiting values of (X_{umax}/d) for different grades of steel forming table Ref Pg. no. 70

Grades of steel	$X_{u,max}/d$	Expression for Mu limit
Fe250	0.53	$0.149 f_{ck}.b.d^2$
Fe415	0.48	$0.138 f_{ck}.b.d^2$
Fe500	0.46	$0.149 f_{ck}.b.d^2$

Steps to calculate Mu:

Find d

Step 1; to find Mu, find depth, d.

To find d, we have to equate compression force = tension force (i.e) So equate C =T

$0.36 f_{ck} b X_u = 0.87 f_y A_{st}$

Find neutral axis co-efficient which is X_u/d $X_u = (0.87 f_y A_{st}) / (0.36 f_{ck} b)$

Divide both sides by d = $\frac{Xu}{d} = \frac{0.87 .fy .Ast}{(0.36.fck.b.d)}$

Step 2; From table in IS 456-2000 Pg No. 96

To find $\left(\frac{Xu}{d}\right)$max, Fe250 = 0.53

Fe415 = 0.48

Fe500 = 0.46

From this we can get that whether beam is under reinforced or over reinforced or balanced.

i. $\left(\frac{Xu}{d}\right)_{max} < 0.48$
ii. $\left(\frac{Xu}{d}\right)_{max} = 0.48$
iii. $\left(\frac{Xu}{d}\right)_{max} > 0.48$

For Fe415:

If Xu/d is equal to 0.48, then it is balanced section [Mu = Mu,lim]

If Xu/d is less than limiting value 0.48, under reinforced section [Mu<Mu,lim]

If Xu/d is greater than 0.48, than it is over reinforced section [Mu >Mu,lim]

Analysis Problems

Q1. A rectangular reinforced concrete beam of width 200 mm & it is reinforced with 2 steel bars of 20 mm diameter and effective depth of 400 mm. If M20 grade concrete and Fe 415 steel as used. Estimate the ultimate moment of resistant.

Given Data:

b=200mm,

d=400mm,

f_{ck} = 20 N/mm²

A_{st} = = 2 * [(π*20²)/4] = 628.32 mm² Ast = 628.32 mm²

Solution:

Depth of Neutral axis:

$$\frac{Xu}{d} = \frac{0.87 .fy .Ast}{(0.36.fck.b.d)}$$

$$= \frac{0.87*415*628.32}{(0.36*20*200*400)}$$

=0.39

$\frac{Xu}{d}$ = 0.394 $\left(\frac{Xu}{d}\right)$ max =0.48

$\left(\frac{Xu}{d}\right) < \left(\frac{Xu}{d}\right)$max = 0.394 < 0.48

Therefore section is under reinforced section

Moment of resistance

$$Mu = 0.87 . fy. Ast . d \left[1 - \left(\frac{Ast.fy}{b.d.fck}\right)\right]$$

$$= 0.87 * 415 * 628.32 * 400 \left[1 - \frac{628.32*415}{200*400*20}\right]$$

= 75.95*10⁶ N.mm = 75.95 KN.m

Q2. A reinforced concrete beam of rectangular section 200mm wide and 550mm deep. It is reinforced with the 4 bars of 25mm diameter at effective depth of 500mm. Using M20 grade concrete and Fe415 HYSD bars. Calculate the safe moment of resistance of section.

Given Data:

b =200mm, d = 500mm, fck = 20N/mm² f_y = 415 N/mm²

Ast = n$\left[\frac{\pi d^2}{4}\right]$

Ast = 4[π*25²/4] = 1963.49 mm²

Solution:

Depth of neutral axis

$$\frac{Xu}{d} = \frac{0.87.fy.Ast}{(0.36.fck.b.d)}$$

$$= \frac{0.87*415*1963.49}{0.36*20*200*500}$$

$$= 0.98$$

$\left(\frac{Xu}{d}\right) > \left(\frac{Xu}{d}\right)_{max}$ (i.e) 0.98 > 0.48

(i.e) It is over reinforced concrete

Moment of Resistance, Mu:

$M_u = 0.138*f_{ck}*b*d^2$ (or) $M_u = 0.36(X_{umax}/d)\,[1-0.42(X_{umax}/d)]\,b*d^2*f_{ck}$

$M_u = 0.138*20*200*500^2$ (or) $M_u = 0.36*0.48[1-(0.42*0.48)]\,20*200*500^2$

$M_u = 138*10^6$ N mm (or) $M_u = 138*10^6$ N mm

M_u =138 KN.m

Q3. A reinforced concrete beam of 300mm wide is reinforced with 1436mm² of Fe415 HYSD bars at an effective depth of 500mm, if M20 grade concrete is used estimate the moment of resistance of the section.

Given Data:

b =300mm, d = 500mm, f_{ck} = 20N/mm² f_y = 415 N/mm² A_{st}=1436mm²

Solution:

Depth of Neutral axis

$$\frac{Xu}{d} = \frac{0.87.fy.Ast}{(0.36.fck.b.d)}$$

$$= \left[\frac{(0.87*415*1436)}{(0.36*20*300*500}\right]$$

$$=0.48$$

$\left(\frac{Xu}{d}\right) = \left(\frac{Xu}{d}\right)_{max}$ => it is a balanced section

Moment of resistance, Mu:

$M_u = 0.138*f_{ck}*b*d^2$ (or) $M_u = 0.36(X_{umax}/d)[1-0.42(X_{umax}/d)]\ b*d^2 *f_{ck}$ $M_u= 0.138*20*300*500^2$ (or) $M_u = 0.36*0.48[1-(0.42*0.48)]\ 20*300*500^2$ $M_u = 207*10^6$ N mm (or) $M_u = 206.9 *10^6$ N mm

M_u=207 KN.m

Q4. Determine area of reinforced steel required for singly reinforced concrete section having a breadth of 300mm, effective depth of 600mm to resist a factor moment of 200KN.m. Adopt fck=20N/mm² and fy = 415 N/mm².

Given Data:

b =300mm, d = 600mm, fck = 20N/mm² fy = 415 N/mm², Mu (factor moment)= 200KN.m

Solution:

Limiting Moment of resistance, Mu,lim:

Mu,lim = 0.138*fck*b*d²

=0.138*20*300*600² =298KNm Here Mu<Mu,lim = 200< 298KNm

i. If Mu<Mu,lim = under reinforced section
ii. If Mu=Mu,lim = Balanced reinforced section
iii. If Mu>Mu,lim = Over reinforced section Therefore here it is under reinforced section.

[IS 456-2000 pg.no 96, For Mu]

$$* \text{Mu} = 0.87 \,.\text{fy}.\text{Ast}\,.\text{d}\left[1 - \left(\frac{\text{Ast.fy}}{\text{b.d.fck}}\right)\right]$$

$$200*10^6 = 0.87*415*Ast*600[1 - \frac{Ast*415}{300*600*20}]$$

$$200*10^6 = 216630\ Ast – 24.91\ Ast^2$$

$$Ast = -b \pm (\sqrt{b^2} - 4ac)/2a$$

$$= -216630 \pm (\frac{\sqrt{216630^2 - 4*24.9*200*10^6)}}{(2*24.9)}$$ Ast = 7649.4 mm² (+ve) (or) 1050.5 mm² (-ve)

DOUBLY REINFORCED SECTION: Problem:

Q1. A doubly reinforced section/beam having a rectangular section 250mm wide and 540mm over all depth is reinforced with 2 bars of 12mm φ in the compression side and 4bars of 20mm φ in the tension side. The effective cover to bar 40mm using M20 grade concrete and Fe415 steel. Estimate the flexural strength of the section using IS 456-2000

Given Data:

b =250mm, D = 540mm, fck = 20N/mm² fy = 415 N/mm²

Step 1:-

Asc – area of steel in compression side $= 2*\pi*12^2 / 4$ = 226.08 mm²

Ast – area of steel in tension side

Ast = $[\frac{\pi d^2}{4}]$ 2 = 2*π*20² / 4 = 1256 mm²

Effective cover, d' = 40mm

Step 2:- Effective depth d = D-d' = 540 – 40 = 500mm

Xumax/d = 0.48 (constant)

Xumax/d = 0.48*500 = 240mm

Step 3:- $fsc = 0.0035\left\{\frac{[Xumax - d']}{Xumax}\right\} * Es$

=0.0035{[240 – 40]/240 } *2*10^5

= 583.33 N/mm² fsc value

should not be greater than 0.87fy

fsc= 583.33 > 0.87 fy

fsc= 0.87*415 = 361.05 N/mm²

Step 4:- $Ast^2 = \frac{Asc.fsc}{0.87.fy} =$ 226.08 mm²

Ast = $Ast_1 + Ast_2$

$Ast_1 = Ast - Ast_2$ = 1256 – 226.08 = 1029.92

Ast_1 = 1030 mm²

Step 5:- Check for Xu, $\frac{fy.Ast}{(0.36.fck.b.d)}$

Xu = $\left[\frac{(0.87*415*1030)}{(0.36*20*250)}\right]$

= 206.6 < 240mm

= 191 KNm

Q2. A doubly reinforced concrete section has width of 300mm & it is reinforced with tension steel area of 2455mm² at an effective depth of 600mm. Compression steel area 982mm² is provided at an effective cover of 60mm using M20 grade concrete & Fe415 steel. Estimate the ultimate moment capacity of the section.

Given Data:

b =300mm, d = 600mm, fck = 20N/mm² fy = 415 N/mm²

Ast = 2455 mm² (tension), Asc = 982 mm²(compression), d' = 600mm

Solution:

Step 1:- Xumax/ d = 0.48

Xumax = 0.48 *600 = 288mm *Step 2:-*

$fsc = 0.0035\left\{\frac{[Xumax - d']}{Xumax}\right\} * Es$

=0.0035{[288 – 60]/288 } *2*10^5

= 554.16 N/mm² fsc should not be greater than 0.87fy

0.87 * fy = 361.05 N/mm²

fsc=554 is greater than 0.87 fy, so take 361 N/mm² as fsc fsc = 361 N/mm²

Step 3:- $Ast_2 = \frac{Asc.fsc}{0.87.fy}$ = 982 mm²

$Ast = Ast_1 + Ast_2$

$Ast_1 = Ast - Ast_2$ = 2455 – 982 = 1473 mm²

Step 4:- Check Xu

$\frac{Xu}{d} = \frac{0.87\ .fy\ .Ast}{(0.36.fck.b.d)}$

$Xu = \left[\frac{0.87*415*1473}{0.36*20*300}\right]$ = 246.21 mm

Xu< Xumax = 246.21 < 288

It is under reinforced.

Step 6:-

Mu = 0.87 .fy. Ast_1 (d-0.42.Xu) + F_{sc}. Asc (d-d')

= 455 KN.m

ULTIMATE SHEAR STRENGTH OF RC SECTION

RC members are generally subjected to max shear forces normally near the support section of simply supported flexural members. In continuous beams the support section are subjected to shear couple with moments. The types of shear failure absorbed in RC members are:

i. Shear tension (or) Diagonal tension failure

ii. Flexure shear failure

iii. Shear compression failure iv. Shear bond failure

PROBLEMS

Q1. A RCB has a support section with a width of 250mm and effective depth of 500m. The support section is reinforced with 3 bars of 20mm on tension side 8mmφ. 2 legged stirrups are provided at a spacing of 200mm centre using M20 grade concrete of Fe415 steel bars. Calculate the shear strength of the support section.

Given Data:

b =250 mm, d = 500 mm, fck = 20 N/mm² fy = 415 N/mm²

Ast = $[\frac{\pi d^2}{4}]$ n, Ast =3*π*20²/4 = 942.48mm²

$A_{SV} = 2*\pi*8^2/4 = 100.53mm^2$,

$S_v = 200mm$

To find: V_u

Step 1:- Percentage of tension [refer Pg No. 73]

$Pt = \frac{100Ast}{bd} = \frac{100*942.48}{250*500}$ = 0.75 [refer table 19 IS 456-2000 & read out the design shear strength of concrete Ʈc corresponding to M20 grade concrete]

Ʈc = 0.56 N/mm^2

Step2:- Shear resisted by concrete

V_{uc} = Ʈc*b*d [refer Pg No. 72]

= 0.56*250*250 = 70*10^3 N or 70KN

Step 3:- Shear resisted by Vertical links/ stirrups

$Vus = \frac{Asv\ (0.87\ fy)\ d}{Sv}$ [Refer Pg No. 73]

= 100.53(0.87*415)500]/200

= 90.74 KN

Step 4:- Total shear resistance

$V_u = V_{us} + V_{us}$ = 70 + 90 = 160 KN

Common width of beams are 150, 200, 230, 250 & 300mm [Pg No. 37]

Space range	Loading	Span(depth ratio L/d)
3 to 4m	Light	15 to 20
5 to 10m	Medium/heavy	12 to 15
5 to 10m	Heavy	10 to 12