Nilachal Polytechnic

Bhubaneswar

Sem. : 6th Subject : [redacted]

Branch: Civil Engineering

Name of the Faculty : Dipika Samal

Text Book to be followed by Student / Faculty

Book- : A.K. Jain(ALL)

Chapter-3: Analysis and design of singly and double reinforced sections (LSM)

1.Learning Objectives

Student will learn –
i).Define the characteristic load,

ii).Explain the situations when doubly reinforced beams are designed,

iii).State the assumptions of analysis and design of doubly reinforced beams,

iv).Derive the governing equations of doubly reinforced beams,

v). state the basis of determining the combination of different loads acting on the structure

2. Essential Questions (Fundamental Question)

i).Establish comparison between WSM & LSM. 2016,2015

ii). Write short notes on limit state of collapse and limit state of serviceability.

iii). Write the minimum and maximum tension and compression reinforcement for beams. Also minimum reinforcement and maximum diameter of bars for slab as IS specification.

iv). Establish comparison between WSM & LSM. 2016,2015

v). Write short notes on limit state of collapse and limit state of serviceability.

vi). Derive the stress block parameters for limit state analysis for flexure.

3. Hours Required

Theory	2hr
Problems	4hr
Question & Answer Theory	2hr
Total	**8hr**

4. Question for Teaching / Assignment / Self Practice

Question sets	02 Marks	05 Marks	10Marks
Teaching	02	02	04
Assignment	nill	02	03
Self Practice	nill	nill	02
Total	02	04	09

Lesson Description

Construction of concrete structures involves at least two different main materials: concrete and steel. Design of these structures should be based on cost rather than weight minimization. In this work, least cost design of singly and doubly reinforced beams is done by applying of the Lagrangian multipliers method (LMM) under ultimate design constraint beside other constraints. Cost objective functions and moment constraints are derived and implemented within the optimization method. The optimum solution comparisons with conventional design methods are performed and the result reported, showing that the LMM can be successfully applied to the minimum cost deign of reinforced concrete beams without need for iterative trials. Optimum design solution surfaces have been developed. Good and reliable results have been obtained and confirmed by using standard design procedures. The artificial neural networks (ANN) has been trained with design data obtained from optimal design formulas. After successful trials, the model predicted the optimum depth of the beam sections a

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ultimate design constraint beside other constraints. Cost objective functions and moment constraints are derived and implemented within the optimization method. The optimum solution comparisons with conventional design methods are performed and the result reported, showing that the

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- The doubly reinforced concrete beam design may be required when a beam’s cross-section is limited because of architectural or other considerations. As a result, the concrete cannot develop the compression force required to resist the given bending moment. In that case, steel bars are added to the beam's compression zone to improve it at compression.
- Therefore, a beam reinforced with tension steel and compression steel is called a doubly reinforced concrete beam. The moment of resistance of a doubly reinforced

concrete beam is greater than that of a singly reinforced concrete beam for the same cross-section, steel grade, and concrete.

Enclosed :

Course Material.

Analysis and design of singly and double reinforced sections (LSM)

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 for the use for which it is intended, limit state

• A structure with appropriate degree of reliability should be able to withstand safely.

• All loads, that are reliable to act on i requirements, such as limitations on deflection and cracking.

• The most important of these limit states, which must be examine in design are as follows state of collapse This state corresponds to the maximum load carrying capacity.

- Flexure

- Compression

- Shear

- Torsion

This state corresponds to the maximum load carrying capacity.

Types of reinforced concrete beams

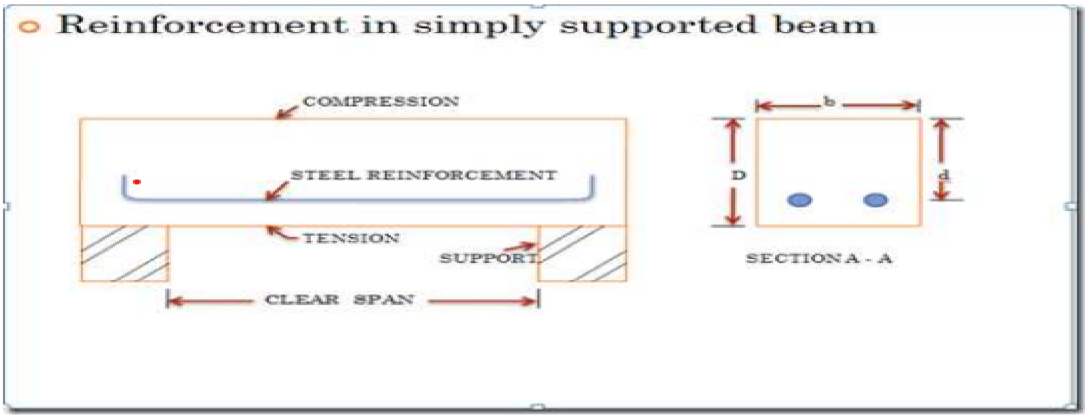
A)Singly reinforced beam

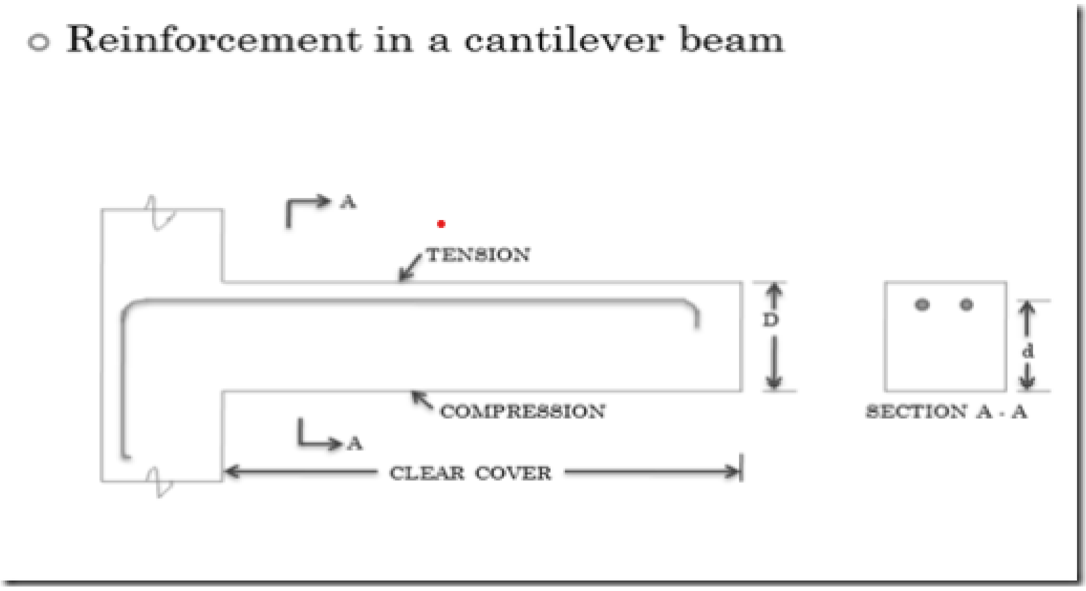
B)Doubly reinforced beam

C)Singly or Doubly reinforced flanged beams Singly reinforced beam

A)Singly reinforced beam

In singly reinforced simply supported beams or slabs reinforcing steel bars are placed near the bottom of the beam or slabs where they are most effective in resisting the tensile stresses.





2.2 Basic concept of design of single reinforced members

The following types of problems can be encountered in the design of reinforced concrete members.

(A) Determination of Area of Tensile Reinforcement

The section, bending moment to be resisted and the maximum stresses in steel and concrete are given.

Steps to be followed:

(i) Determine k, j, Q (or Q') for the given stress.

(ii) Find the critical moment of resistance, $M = Q.b.d^2$ from the dimensions of the beam.

(iii) Compare the bending moment to be resisted with M, the critical moment of resistance.

(a) If B.M. is less than M, design the section as under reinforced.

$$M = \sigma_{st}.A_s.\left(d - \frac{x}{3}\right)$$

To find A_s in terms of x, take moments of areas about $N.A.$

$$b.x.\frac{x}{2} = m.A_s.(d - x)$$

$$A_s = \frac{b.x^2}{2(m)(d - x)} \therefore \quad M = \frac{\sigma_{st}.b.x^2}{2.m.(d - x)}\left(d - \frac{x}{3}\right) = B.M. \text{ to be resisted}$$

Solve for 'x', and then A_s can be calculated.

(b) If *B.M.* is more than *M*, design the section as over-reinforced.

$M = \frac{\sigma_{cbc}}{2}.b.x\left(d - \frac{x}{3}\right) = B.M.$ to be resisted. Determine 'x'. Then A_s can be obtained by taking moments of areas (compressive and tensile) about using the following expression.

$$A_s = \frac{b.x^2}{2.m.(d - x)}$$

(B) Design of Section for a Given loading

Design the section as balanced section for the given loading.

Steps to be followed:

(i) Find the maximum bending moment (*B.M.*) due to given loading.

(ii) Compute the constants k, j, Q for the balanced section for known stresses.

(iii) Fix the depth to breadth ratio of the beam section as 2 to 4.

(iv) From $M = Q.b.d^2$, find 'd' and then 'b' from depth to breadth ratio.

(v) Obtain overall depth 'D' by adding concrete cover to 'd' the effective depth.

(vi) Calculate A_s from the relation

$$A_s = \frac{B.M.}{\sigma_{st}.j.d}$$

(C) To Determine the Load carrying Capacity of a given Beam

The dimensions of the beam section, the material stresses and area of reinforcing steel are given.

Steps to be followed:

(i) Find the position of the neutral axis from section and reinforcement given.

(ii) Find the position of the critical *N.A.* from known permissible stresses of concrete and steel.

$$x = \frac{1}{1 + \frac{\sigma_{st}}{m.\sigma_{cbc}}}.d$$

(iii) Check if (i) > (ii)- the section is over-reinforced

(i)<(ii)- the section is under-reinforced

(iv) Calculate M from relation

$$M = b.x.\frac{1}{2}.\sigma_{cbc}.\left(d - \frac{x}{3}\right) \text{for over-reinforced section}$$

and $M = \sigma_{st}.A_s.\left(d - \frac{x}{3}\right)$ for under-reinforced section.

(v) If the effective span and the support conditions of the beam are known, the load carrying capacity can be computed.

(D) To Check The Stresses Developed In Concrete And Steel

The section, reinforcement and bending moment are given.

Steps to be followed:

(i) Find the position of *N.A.* using the following relation.

$$b.\frac{x^2}{2} = m.A_s.(d - x))$$

(ii) Determine lever arm, $z = d - \frac{x}{3}$

(iii) $B.M. = \sigma_{st}.A_s.z$ is used to find out the actual stress in steel σ_{sa}.

(iv) To compute the actual stress in concrete σ_{cba}, use the following relation.

$$BM = \frac{\sigma_{cba}}{2}.b.x.z$$

TYPES OF BEAM SECTIONS

SECTIONS Section in which, tension steel also reaches yield strain simultaneously as the concrete reaches the failure strain in bending are called, 'Balanced Section'.

Section in which, tension steel also reaches yield strain at loads lower than the load at which concrete reaches the failure strain in bending are called, 'Under Reinforced Section'.

Section in which, tension steel also reaches yield strain at loads higher than the load at which concrete reaches the failure strain in bending are called, ‘Over Reinforced Section’.

Sr. No.	Types of Problems	Data Given	Data Determine
1.	Identify the type of section, balance, under reinforced or over reinforced	Grade of Concrete & Steel, Size of beam & Reinforcement provided	If $\frac{X_u}{d} = \frac{X_{u\max}}{d} \Rightarrow$ Balanced If $\frac{X_u}{d} < \frac{X_{u\max}}{d} \Rightarrow$ Under Reinforced If $\frac{X_u}{d} > \frac{X_{u\max}}{d} \Rightarrow$ Over Reinforced $\frac{X_u}{d} = \frac{0.87 f_y.A_{st}}{0.36 b.d f_{ck}}$ f_y — $\frac{X_{u\max}}{d}$ 250 — 0.53 415 — 0.48 500 — 0.46

<table>
<tr>
<td rowspan="3">2</td>
<td rowspan="3">Calculate Moment of Resistance</td>
<td rowspan="3">Grade of Concrete &

Steel, Size of beam &

Reinforcement

Provided</td>
<td>1) If $\frac{x_u}{d} = \frac{x_{u,max}}{d}, balanced$

$M.R = M_u = 0.36.\frac{x_{u,max}}{d}(1-0.42\frac{x_{u,max}}{d})b.d^2.f_{ck}$</td>
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<td>2) If $\frac{X_u}{d} < \frac{X_{u\,max}}{d}$ Under Reinforced

M.R=M_u=

$0.87 f_y.A_{st}.d(1-\frac{A_{st}.f_y}{b.d.f_{ck}}) or\ M.R = 0.87 f_y.A_{st}.d(1-0.42\frac{x_u}{d})$</td>
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<tr>
<td>3) If

$\frac{X_u}{d} > \frac{X_{u\,max}}{d}$ $\Rightarrow$ over reinforced, Revise the depth</td>
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<tr>
<td>3</td>
<td>Design the beam. Find out the depth of Beam D & Reinforcement required A_{st}.</td>
<td>Grade of Concrete &

Steel, width of beam & Bending Moment or loading on the beam with the span of the beam

Reinforcement

Provided</td>
<td>We have to design the beam as a 'Balanced Design'.

For finding 'd' effective depth use the equation;

$M.R = M_u = 0.36.\frac{x_{u,max}}{d}(1-0.42\frac{x_{u,max}}{d})b.d^2.f_{ck}$

For finding A_{st} use the equation

$0.87 f_y.A_{st}.d(1-\frac{A_{st}.f_y}{b.d.f_{ck}}) or\ M.R = 0.87 f_y.A_{st}.d(1-0.42\frac{x_u}{d})$</td>
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Where

D = effective depth of beam in mm.

B = width of beam in mm

Xu = depth of actual neutral axis im mm from extreme compression fibre.

Xu, max = depth of critical neutral axis in mm from extreme compression fibre.

Ast = area of tensile reinforcement

Ƒck = characteristic strength of concrete in mpa.

Ƒy = characteristic strength of steel in mpa.

Mu, lim = Limiting Moment of Resistance of a section without compression reinforcement.

EXAMPLE 3.1 Calculate the area of steel of grade Fe 415 required for section of 250mm wide and overall depth 500mm with effective cover 40mm in M20, if the limit state of moment be carried by the section is

A) 100 KN b) 146 KN c) 200KN

SOLUTION:

For f_y =415N/mm^2, $\frac{X_{u\max}}{d} = 0.48$

$$M_{u,\lim} = 0.36.\frac{x_{u,\max}}{d}(1-0.42\frac{x_{u,\max}}{d})b.d^2.f_{ck}$$

$$= 0.36 \text{ X } .48(1\text{-}0.42 \text{ X } 0.48) \text{ X } 250 \text{ X } 460^2 \text{ X } 20$$

$$= 146 \text{ X } 10^6 \text{N.mm}$$

a) For M_u = 100 KN.m < 146 KN.m

Area of steel required is obtained from , $M_u = 0.87 f_y.A_{st}.d(1-\frac{A_{st}.f_y}{b.d.f_{ck}})$

$100 \text{ X } 10^6 = 0.87 \text{ X } 415 \text{ X } A_{st} \text{ X}460 \text{ (1- } \frac{A_{st} X 415}{250 X 460 X 20} \text{)}$

A_{st} =686 or 4850 mm^2, taking minimum steel 686mm^2

b) M_u = 146 KN.m =$M_{u,lim}$= 146 KN.m

$x_u = x_{u,max}$

Area of tension reinforcement required

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

$$A_{st} = \frac{0.48 X 0.36 X 20 X 250 X 460}{0.87 X 415} = 1100 mm^2$$

c) M_u = 200 KN.m >$M_{u,lim}$= 146 KN.m

Reinforcement is to be provided in the compression zone also along with the reinforcement in tension zone.

$M_u = M_{u,lim} = f_{sc}.A_{sc}(d - d')$

f_{sc} is stress corresponding to strain of $\dfrac{0.0035(x_{u,max} - d')}{x_{u,lim}} = \dfrac{0.0035(0.48 X 460 - 40)}{0.48 X 460} = 0.002866$

$f_{sc} = 360.8 N/mm^2$

(200-146) X 10^6 = 360.8. A_{sc}(460-40)

A_{sc}= 356mm^2

A_{st1}= Area of tension reinforcement corresponding to $M_{u,lim}$

$$146 X 10^6 = 0.87 X 460 X 415 A_{st1}(1 - \frac{A_{st} X 415}{250 X 460 X 20})$$

A_{st1} = 1094mm^2

$A_{st2} = A_{sc}. f_{sc} / 0.87 X415$ =356mm^2

$A_{st} = A_{st1} + A_{st2}$ = 1094 + 356 = 1450mm^2

EXAMPLE: 3.2 Design a rectangular beam which carries a maximum limiting bending moment of 65 KN.m. Use M20 and Fe 415 as reinforcement.

At balanced failure condition

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

$$M_{u,\lim} = 0.36.\frac{x_{u,\max}}{d}(1-0.42\frac{x_{u,\max}}{d})b.d^2.f_{ck}$$

$$M_{u,lim} = 0.36 \text{ X } 0.48 \text{ X } 20(1\text{-}0.42 \text{ X } 0.48) \text{ bd}^2$$

$$= 2.759\text{b d}^2$$

Assuming width of beam as 250 mm

$$d = \sqrt{\frac{65X10^6}{2.759X250}} = 307\text{mm}$$

Area of reinforcement

$$\frac{X_{u,\max}}{d} = \frac{0.87f_y.A_{st}}{0.36b.df_{ck}}$$

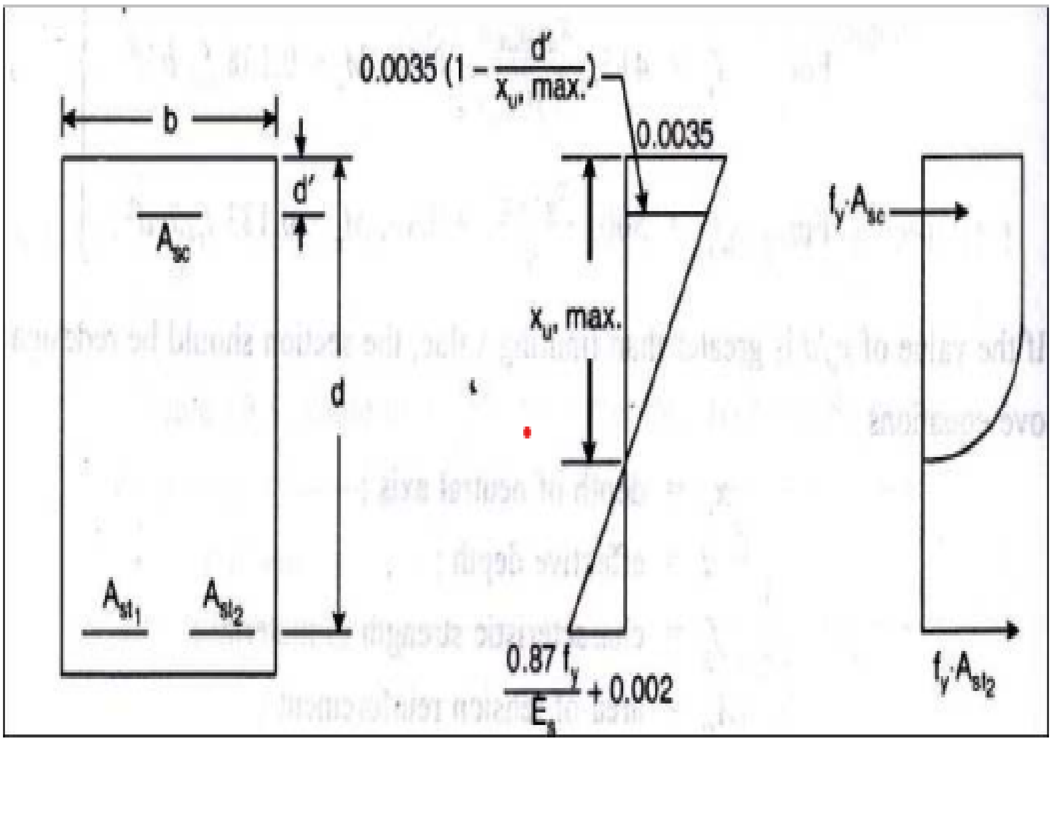
$$0.48 = \frac{0.87X415XA_{st}}{0.36X20X250X307}$$

$$A_{st} = 734.66 \text{ mm}^2$$

Doubly Reinforced Section or sections with Compression Reinforcement

Doubly Reinforced Section sections are adopted when the dimensions of the beam have been predetermined from other considerations and the design moment exceeds the moment of resistance of a singly reinforced section. The additional moment of resistance is carried by providing compression reinforcement and additional reinforcement in tension zone. The moment of resistance of a doubly reinforced section is the sum of the limiting moment of resistance Mu,lim of a single reinforced section and the additional moment of resistance Mu2.

Mu2 = Mu – Mu,lim



The lever arm for the additional moment of resistance is equal to the distance between the centroids of tension and compression reinforcement, (d – d').

$M_{u2} = 0.87\, f_y . A_{st2}(d - d') = A_{sc}.(f_{sc} - f_{cc})(d - d')$

Where : A_{st2} = Area of additional tensile reinforcement

A_{sc} = Area of compression reinforcement

f_{sc} = Stress in compression reinforcement

f_{cc} = Compressive stress in concrete at the level of compression reinforcement

Since the additiona reinforcement is balanced by the additional compressive force.

$A_{sc}.(f_{sc} - f_{cc}) = 0.87\, f_y . A_{st2}$

The strain at level of compression reinforcement is $0.0035\,(1 - \frac{d'}{x_{u,\,max}})$

Total area of reinforcement shall be obtained by

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

A_{st1} = Area of reinforcement for a singly reinforced section for $M_{u,lim}$

$$A_{st2} = \frac{A_{sc}\,(f_{sc} - f_{cc})}{0.87 f_y}$$

MOMENT OF RESISTANCE OF DOUBLY REINFORCED SECTIONS

Consider a rectangular section reinforced on tension as well as compression faces as shown in Fig.2.4 (a-c)

Let b = width of section,

d = effective depth of section,

D = overall depth of section,

d' = cover to centre of compressive steel,

M = Bending moment or total moment of resistance,

M_{bal} = Moment of resistance of a balanced section with tension reinforcement,

A_{st} = Total area of tensile steel,

A_{st1} = Area of tensile steel required to develop M_{bal}

A_{st2} = Area of tensile steel required to develop M_2

A_{sc} = Area of compression steel,

σ_{st} = Stress in steel, and

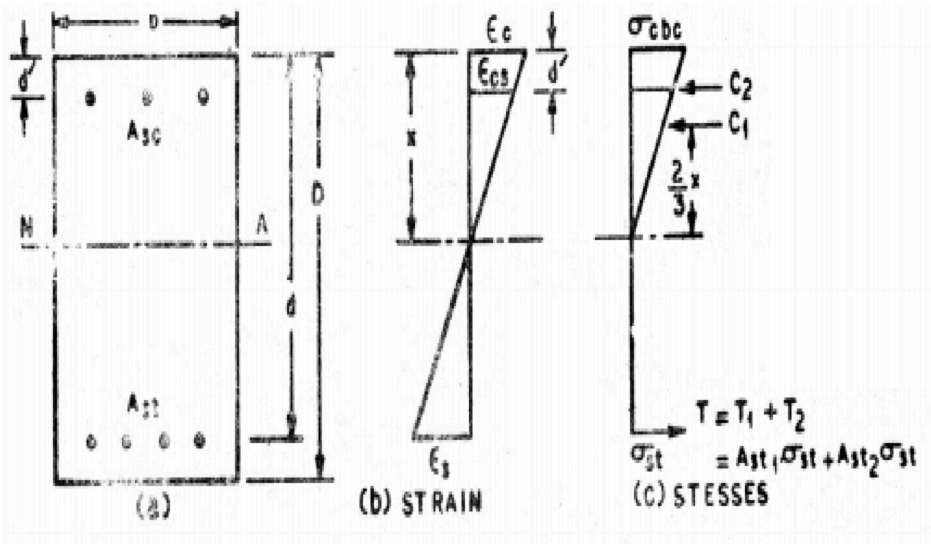


Fig.2.4 (a-c)

Since strains are proportional to the distance from *N.A.*,

$$\frac{Strain\ in\ top\ \ fibre\ \ of\ \ concrete}{Strain\ in\ Compression\ \ Steel} = \frac{x}{x - d'}$$

$$\frac{\sigma_{cbc}/E_C}{\sigma_{sc}/E_s} = \frac{x}{x - d'}$$

$$\frac{\sigma_{cbc}}{\sigma_{sc}} \cdot \frac{E_s}{E_c} = \frac{x}{x - d'}$$

$$\sigma_{sc} = \sigma_{cbc} \cdot \frac{x}{x - d'} .m$$

Since $\sigma_{cbc} . \frac{x-d}{x}$ is the stress in concrete at the level of compression steel, it can be denoted as σ'_{cbc}

$$\therefore \sigma_{sc} = m.\sigma'_{cbc}$$

As per the provisions of IS:456-2000 Code , the permissible compressive stress in bars , in a beam or slab when compressive resistance of the concrete is taken into account, can be taken as 1.5m times the compressive stress in surrounding concrete (1.5m σ'_{cbc}) or permissible stress in steel in compression (σ_{sc}) whichever is less.

$$\sigma_{sc} = 1.5m\ \sigma'_{cbc}$$

Total equivalent concrete area resisting compression

$(x . b-A_{sc}) +1.5m\ A_{sc} = x .b +(1.5m-1)A_{sc}$

Taking moment about centre of tensile steel

Moment of resistance $M = C_1.(d-x/3)+C_2(d-d')$

Where C_1 = total compressive force in concrete,

C_2 = total compressive force in compression steel

$$M = b.x.\frac{\sigma_{cbc}}{2}.(d-\frac{x}{3}) + (1.5m-1)A_{sc}.\sigma_{cbc}.\frac{x-d'}{x}.(d-d') = Q.b.d^2 + (1.5m-1)A_{sc}.\sigma_{cbc}.\frac{x-d'}{x}(d-d')$$

$$= M_1 + M_2$$

$Where\ M_1 = Moment\ of\ resistance\ of\ the\ balanced\ section = M_{bal}$

$M_2 = Moment\ of\ resistance\ of\ the\ compression\ steel$

$$Area\ of\ tension\ steel = A_{st1} = \frac{M_1}{\sigma_{st}.j.d}.$$

$$Area\ of\ tension\ steel\ equivalent\ to\ compression\ steel = A_{st2} = \frac{M_2}{\sigma_{st}(d-d')}$$

Thus the total tensile steel A_{st} shall be:

$$\therefore \quad A_{st} = A_{st1} + A_{st2}$$

The area of compression steel can be obtained as

EXAMPLE: 3.3 Find out the factored moment of resistance of a beam section 300mm wide X 450mm effective depth reinforced with 2 X 20mm diameter bars as compression reinforcement at an effective cover of 50mm and 4 X 25mm diameter bars as tension reinforcement. The materials are M20 grade concrete and Fe 415 HYSD bars.

Solution:

Given;

Width= b =300mm

Effective depth = d = 450mm

Cover to compression reinforcement = d' = 50mm

$\frac{d}{d'} = \frac{50}{450} = 0.11$, next higher value 0.15 may be adopted.

A_{sc} =area compression reinforcement = 2 π 16^2 = 628mm^2

A_{st} = area of reinforcement in tension = 4 x $\pi 25^2$= 1964mm^2

f_{sc} = stress in compression steel=342 N/mm^2

Equating total force

$$0.36 f_{ck}.b.x_u + f_{sc}.\ A_{sc} = 0.87\ f_y.A_{st}$$

$$0.36 \text{ X } 20 \text{ X } 300\ x_u + 628 \text{ X } 342 = 0.87 \text{ X } 415 \text{ X } 1964$$

$x_u = 228.85mm$

But $x_{u,max} = 0.48d$ for Fe415

$x_{u,max} = 0.48 X 450 = 216mm$

So $x_u > x_{u,max}$, $\Rightarrow$ over reinforced

The moment of resistance can be found out by takin moments of compressive forces about centroid of tensile reinforcement.

$$M_u = 2160x_u(450\text{-}0.42x_u) + 214776\ (450\text{-}50)\ X\ 10^{-6}$$

Putting $x_u = 216mm$

$M_u = 253.54$ KN.m

2)Question Set.

Teaching

GROUP-A

1.Establish comparison between WSM & LSM. (2016,2015)

2. Write short notes on limit state of collapse and limit state of serviceability**.**

GROUP-B

1. Write the minimum and maximum tension and compression reinforcement for beams. Also minimum reinforcement and maximum diameter of bars for slab as IS specification. [2015-w]
2. Establish comparison between WSM & LSM. (2016,2015)

GROUP-C

1. Find the depth of neutral axis of a singly reinforced RC beam of 250 mm width and 500 mm effective depth. It is reinforced with 4 bars of 20 mm diameter. Use M20 concrete and Fe 415 bars. Also check for type of section. [2013(S)]

2. A rectangular beam 230 mm wide x 560 mm effective depth is reinforced with 3 no. 16 mm diameter bars. Calculate the stresses in both the materials when bending moment of 50 kNm is applied. The materials are M20 grade concrete and HYSD reinforcement of grade Fe 415

3. Design a short square R.C.C column carrying a factored load of 1800KN. The material are M20 grade concrete and HYSD reinforcement of grade Fe415.use LSM. [2019]

4. A doubly reinforced rectangular beam of size 300 mm x 600mm. Simply supported at both the ends. The effective cover for both tension and compression steel is 35mm. The effective span is 6.0m. The beam carries a service imposed load of 24 kN/m and superimposed dead load of 16kN/m. Use M20 grade of concrete and HYSD steel Fe 415. Determine tension and compression reinforcement (USe LSM) [2013w]

Assignment

GROUP-B

1. Write short notes on limit state of collapse and limit state of serviceability.

2. Derive the stress block parameters for limit state analysis for flexure. (2016,2015,2014,2012W)

GROUP-C

1.Derive the following expression for MOR of a rectangular section without compression reinforcement in LSM of design, Where the terms carry their usual meanings Mu = 0.87 FyAst d (1-AstFy/bdFck)

(2010-W, 2013(S), 2014s,2015]

2. Write down the assumption made for flexure in limit state method of design.

(2017,2016,2015,20142013w,2011-W-O,2019)

3.A doubly reinforced beam section is 250 mm wide and 450mm deep to the centre of the tensile reinforcement. It is reinforced with 2 bars of 16mm. dia as compression reinforcement at an effective cover of 50mm. and 4 bars of 25mm. dia as tensile steel. Using M-15 concrete and Fe250 steel. Calculate the ultimate moment of resistance of the beam(Use LSM). [2013w,2019]

Self practice

GROUP-C

1. A singly reinforced concrete beam 250mm width is reinforced 4 bars of 25 mm diameter at an effective depth of 400 mm. if M20 grade concrete and Fe415 bars are used, compute moment of resistance of the section. Use LSM.
2. A RCC beam 230 mm wide x 500 mm effective width is reinforced with 3 nos 16 mm dia bars in tension. The materials are M20 grade concrete and HYSD reinforcement of grade Fe415. Find the MOR by LSM, Also find out MOR if it is reinforced with 5 nos. 16 mm. dia.

Faculty **HOD** **Principal**