UNIT-I

1

METHODS OF DESIGN OF CONCRETE STRUCTURES.

Concept of elastic method, ultimate load method and limit state method - Advantages of limit state method over other methods - Design codes and specification - Limit state philosophy as detailed as in IS code - Design of flexural members and slabs by working stress method - Cracked and uncracked sections.

Elastic design method :-

i) It is otherwise known as working stress design.

ii) Elastic behaviour of materials are used in working stress design.

iii) In this method, factor of safety is taken into account only on stress in materials, not on loads.

iv) Permissible / allowable stress is obtained by dividing the ultimate / yield strength of materials by factor of safety.

v) The factors of safety for concrete in bending and steel in tension are 3.0 and 1.8 respectively.

vi) Working stress method of design is used for the designing of retaining walls, water tanks, bridge piers where strength of materials affected due to water / soil conditions.

Modular Ratio :-

It is defined as the ratio of the elastic modulus of steel to that concrete.

$$\text{Modular ratio } (m) = \frac{280}{3\sigma_{cbc}}$$

Permissible comp. stress of concrete

Ultimate Load Method :-

(i) It is otherwise called as the load factor method / ultimate strength method.

(ii) This method is based on the ultimate strength, when the design member would fail.

(iii) In this method factor of safety is taken into account only on loads, is called as load factor.

Load factor = ultimate load / design load.

(iv) Gen. load factors are 1.7 for live load and 1.4 for dead load considered for design.

(v) This method gives more economical designs of beam and columns by comparing working stress method.

(2)

(3)

Limit State Method :-

It is the combination of working stress and ultimate load method.

In this method partial safety factor is considered on both loads and stresses.

This method gives / advances over other two methods since safety is considered on both loads and stresses. Also serviceability is considered.

Advantages of Limit State Method over other methods :-

(i) Ultimate load method only deals with on safety such as strength, overturning, sliding, buckling, fatigue etc.

(ii) Working stress method only deals with serviceability such as deflection, crack, vibration etc.

(iii) LSM advance than over other two methods, hence by considering safety at ultimate loads and serviceability @ working loads.

Design Codes and Specification :-

The design procedures for RC structural members of building in India should be based on the following codes.

Indian codes for RC design, published by the BIS, New Delhi:

The following code books are used for load calculations and design of various RC structural elements

(a) IS 456-2000: Plain and Reinforced concrete - code of practice (Fourth revision).

(b) Code book for loads:-

IS 875-1987, Code of practice for design load (other than earthquake) for buildings and structures (second revision).

Part - 1 – Dead Load.

Part - 2 – Imposed Load.

Part - 3 – Wind Load.

Part - 4 – Snow Load.

Part - 5 – Special Loads such as shrinkage, creep, temperature, soil & fluid pressure and load combinations.

IS 1893-2002 Criteria for earthquake resistant design of structures.

Part - 1 - General provisions & buildings.

Part - 2 - Liquid retaining tanks.

Part - 3 - Bridges and retaining walls.

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Part-4 : Industrial Structures

Part-5 : Dams and Embankments.

Design Hand Books.

SP16 -1980 - Design aids for RC to IS 456-1978.

SP34 - 1987 - Handbook on concrete reinforcement and detailing.

SP 24 - Explanatory Handbook on IS 456-1978.

One way slab :-

Ratio b/n effective long span and short span more than 2 is known as one way slab.

$$\frac{\text{Eff. long span, } l_y}{\text{Eff. short span, } l_x} > 2.$$

Two way slab :-

Ratio b/n effective long span and short span less than or equal to two is known as two way slab.

$$\frac{\text{Eff. long span, } l_y}{\text{Eff. short span, } l_x} \leq 2.$$

Problems on Singly - Reinforced Beam :-

A Reinforced concrete beam of rectangular section has the cross-section of 300 x 500. 4 numbers of 20mm ϕ steel bars is provided as tension reinforcement. Assuming M-20 grade concrete and Fe-415 grade steel are used. Determine the stresses induced in the top compression fibre of the concrete and tension steel when it is subjected to a moment of 65 kNm.

Given :-

Size of beam = 300 x 500 mm.

Width of beam (b) = 300mm.

Overall depth (D) = 500mm.

Moment, (M) = 65 kNm

$= 65 \times 10^3$ N-m.

$= 65 \times 10^6$ N-mm.

Area of tension steel, A_{st} = 4 # 20mm ϕ.

Grade of steel - Fe-415, $\sigma_{st} = 230 N/mm^2$

Grade of concrete - M-20, $\sigma_{cbc} = 7 N/mm^2$.

Solution :-

① Depth of neutral axis, x calculation :-

$$\frac{bx^2}{2} - m \cdot A_{st}(d - x) = 0.$$

(4)

$$m = \frac{280}{3\sigma_{cbc}} = \frac{280}{3 \times 7} = 13.33$$

$$A_{st} = 4 \times \frac{\pi}{4}(20)^2$$

$$= 1256 \, mm^2.$$

Assume clear cover = 25mm.

$$\text{Effective cover} = 25 + \left(\frac{20}{2}\right)$$

$$= 35mm.$$

Effective depth (d) = Overall depth − Eff. cover

$$= 500 - 35$$

$$= 465mm.$$

$$\frac{300 \times x^2}{2} - [13.33 \times 1256 \times (465 - x)] = 0.$$

$$150x^2 + 16742.8x - 7.785 \times 10^6 = 0.$$

$$\div 150, \quad x^2 + 111.62 - 51900 = 0.$$

$$x = +178.74, -290.36$$

$$\therefore x = 178.74 \, mm.$$

(6) Stress calculation :-

Moment of resistance, w.r.t. tension steel,

$$M = (A_{st} \times \sigma'_{st})\left(d - \frac{x}{3}\right).$$

$$65 \times 10^6 = (1256 \times \sigma'_{st})\left(465 - \frac{178.74}{3}\right)$$

Stress in steel,

$$\sigma'_{st} = 127.65 \ N/mm^2$$

$$\frac{\sigma'_{st}}{m} = \frac{127.65}{13.33} = 9.576.$$

Stress in extreme compression fibre of concrete can be calulated from the similar Δ^{le} of stress diagram.

$$\frac{286.26}{9.576} = \frac{178.74}{\sigma'_{cbc}}$$

$$\sigma'_{cbc} = 5.98 \ N/mm^2.$$

Problems on doubly reinforced beam :-

① Design a doubly reinforced beam section subjected to a bending moment of 120 kNm. Consider concrete of grade M20 and steel of grade Fe-415. Consider width of beam as ~~...~~ 300 mm.

Given Data :-

Bending Moment, $M = 120$ kNm

$= 120 \times 10^6$ N-mm.

Width of beam = 300mm.

Grade of concrete, M_{20} ; $\sigma_{cbc} = 7 N/mm^2$.

Grade of steel, Fe-415, $\sigma_{st} = 230 N/mm^2$.

(c) Area of compressive steel, A_{sc} calculation :- (6)

$$A_{sc} = \frac{M - M_{bal}}{\sigma_{st}(d-d')} \text{ (or) } \frac{M - M_{bal}}{(1.5m-1)\sigma_{cbc}'''(d-d')}$$

$$= \frac{(120-80)\times 10^6}{(1.5\times 13.33-1)\times 5.53\times(545-33)}$$

$$\sigma_{cbc}''' = \frac{(x-d')}{x}\cdot\sigma_{cbc}$$

$$x = (0.289\times 545) = 157.51\,mm.$$

$$\sigma_{cbc}''' = 5.53\,N/mm^2.$$

$$A_{sc} = 744\,mm^2.$$

Provide 16mm ϕ @ compression zone,

$$\text{No. of rods} = \frac{744}{201} = 3.71 \simeq 4.$$

Problem on Flanged Beam :-

Analyse a T-beam section of 300mm width and 1000mm width of flange and 500mm eff. depth and 120mm flange thickness. Determine the stresses induced in the top compression fibre of concrete of grade M20 and steel of grade Fe-415. Also calculate moment of resistance of

$$A_{st} = A_{st_1} + A_{st_2}.$$

$$A_{st_1} = \frac{M_{bal}}{\sigma_{st} d\left(1-\frac{k}{3}\right)}$$

$$A_{st_2} = \frac{M - M_{bal}}{\sigma_{st}(d-d')}$$

$$A_{sc} = \frac{M - M_{bal}}{(1.5m-1)\,\sigma_{cbc}^{m}\,(d-d')}$$

$$M_{bal} = \frac{2}{3} \times 120 \times 10^6 = 80 \times 10^6 \text{ N-mm}.$$

$$A_{st_1} = \frac{80 \times 10^6}{230 \times 545\left(1-\frac{0.289}{3}\right)} = 706.25 \text{ mm}^2.$$

$$A_{st_2} = \frac{(120-80) \times 10^6}{230(545-33)}$$

$$= 339.67 \text{ mm}^2.$$

$$d' = 25 + \frac{16}{2} = 33 \text{ mm}.$$

$$A_{st} = A_{st_1} + A_{st_2} = 706.25 + 339.67$$

$$= 1045.92 \text{ mm}^2$$

$$\simeq 1046 \text{ mm}^2.$$

Provide 20mm ϕ @ tension zone,

$$\text{No of rods} = \frac{1046}{314} = 3.33 \simeq 4.$$

(c) Area of compressive steel, Asc calculation :- (6)

$$A_{sc} = \frac{M - M_{bal}}{\sigma_{st}(d-d')} \text{ (or) } \frac{M - M_{bal}}{(1.5m-1)\sigma_{cbc}'''(d-d')}$$

$$= \frac{(120-80) \times 10^6}{(1.5 \times 13.33 - 1) \times 5.53 \times (545-33)}$$

$$\sigma_{cbc}''' = \frac{(x-d')}{x} \cdot \sigma_{cbc}$$

$$x = (0.289 \times 545) = 157.51\,mm.$$

$$\sigma_{cbc}''' = 5.53\,N/mm^2.$$

$$A_{sc} = 744\,mm^2.$$

Provide 16mm ϕ @ compression zone,

$$\text{No. of rods} = \frac{744}{201} = 3.7 \simeq 4.$$

Problem on Flanged Beam :-

Analyse a T-beam section of 300mm width and 1000mm width of flange and 600mm eff. depth and 120mm flange thickness. Determine the stresses induced in the top compression fibre of concrete of grade M20 and steel of grade Fe-415. Also calculate moment of resistance of

Given Data:

Width of beam, b_w = 300 mm.

Thickness of flange, D_f = 120 mm.

Eff. depth of beam, d = 500mm.

Width of flange, b_f = 1000 mm.

Area of tension steel, A_{st} = 4 # 20 mm ϕ

= 1256 mm².

Grade of concrete, M20, $\sigma_{cbc} = 7 N/mm^2$.

Grade of steel, Fe-415, $\sigma_{st} = 230 N/mm^2$.

Solution:

Modular ratio, $m = \dfrac{280}{3\sigma_{cbc}} = 13.33$

Assume $< D_f$, NA lies within the flange portion of a T-beam.

$$\frac{b_f x^2}{2} - m A_{st}(d-x) = 0$$

$$\left(\frac{1000 \times x^2}{2}\right) - 13.33 \times 1256(500-x) = 0.$$

$$500x^2 - 8371240 + 16742.48x = 0$$

$$\div 500, \quad x^2 - 16742.48x + 33.48x = 0.$$

b) Stress Calculation :- (7)

$$k_{bal} = \frac{1}{\left(\frac{\sigma_{st}}{m \cdot \sigma_{cbc}}\right)+1}$$

$$= \frac{1}{\left(\frac{230}{13.33 \times 7}\right)+1}$$

$$k_{bal} = 0.289$$

$$x_{bal} = k_{bal} \times d$$

$$= 0.289 \times 500$$

$$= 144.50 \text{ mm.}$$

Since $x < x_{bal}$, it is an under reinforced section. Steel reaches maximum permissible stress earlier than concrete.

$$\sigma_{st} = 230 \text{ N/mm}^2.$$

$$d - x = 500 - 113.73$$

$$= 386.27 \text{ mm.}$$

From $\parallel^{lr}$ Δ^{le} principle,

$$\frac{386.27}{\left(\frac{230}{13.33}\right)} = \frac{113.73}{\sigma'_{cbc}}$$

$$\sigma'_{cbc} = 5.08 \text{ N/mm}^2.$$

Moment of resistance, $M = A_{st}\,\sigma_{st}\left(d - \frac{x}{3}\right)$

$$= (1256 \times 230)\left(500 - \frac{113.73}{3}\right)$$

$$M = 133.49 \text{ kN·m.}$$

Analyse a doubly reinforced T-beam section of 300mm web width and 1500mm width of flange and 500mm effective depth and 100mm flange thns. Determine the allowable moment of resistance and stresses induced in extreme compression fibre of concrete, centre of compression and tension steel. Tension steel, A_{st} = 4-20mmϕ; and compression steel, A_{sc} = 4-12mmϕ. Consider concrete of grade M-20 and steel of grade Fe-415. Assume $d' = 50mm$.

Given data :-

width of beam, $b_w = 300mm$.

Thickness of flange, $D_f = 100mm$.

Eff. depth of beam, $d = 500mm$.

Eff. cover $d' = 50mm$.

Width of flange, $b_f = 1500mm$.

Area of tension steel, A_{st} = 4-20mmϕ

$= 1256 mm^2$.

Area of compression steel, A_{sc} = 4-12mmϕ

$= 452 mm^2$.

M-20, Fe-415

$\sigma_{cbc} = 7 N/mm^2$, $\sigma_{st} = 230 N/mm^2$.

Solution :-

(a) NA. depth calculation :-

$$m = \frac{280}{3\sigma_{cbc}} = \frac{280}{3\times 7} = 13.33.$$

Assume $x < D_f$, NA lies within the flange. (8)

$$\frac{b_f x^2}{2} + \left\{(1.5m-1)\, A_{sc}\, [x-d']\right\} = m \cdot A_{st}\,(d-x).$$

$$\frac{1500x^2}{2} + \left\{(1.5 \times 13.33 - 1)\, 452\, [x-d']\right\} = m \cdot A_{st}\,(d-x).$$

$$= 13.33 \times 1256\,(500-x).$$

$x = 92.75\text{mm} < D_f$. Assumption is correct.

(6) Moment of resistance calculation :-

$$x_{bal} = k_{bal} \cdot d.$$

$$k_{bal} = \frac{1}{\left(\frac{\sigma_{st}}{m \cdot \sigma_{cbc}}\right)+1} = \frac{1}{\left(\frac{230}{13.33 \times 7}\right)+1}$$

$$k_{bal} = 0.289.$$

$$x_{bal} = k_{bal} \cdot d$$

$$= 0.289 \times 500$$

$$= 144.50 \text{ mm}.$$

Since $x < x_{bal}$. It is an under-reinforced section.

$$\sigma_{st} = \sigma'_{st} = 230 \text{ N/mm}^2.$$

From $\parallel^{lr}$ Δ^{le} principle

$$\frac{500 - 92.75}{\left(\frac{230}{13.33}\right)} = \frac{92.75}{\sigma'_{cbc}}$$

$$\sigma''_{cbc} = 3.93\ N/mm^2.$$

$$\frac{x}{\sigma'_{cbc}} = \frac{x - d'}{\sigma'''_{cbc}}$$

$$\sigma'''_{cbc} = 1.81\ N/mm^2.$$

Moment of resistance,

$$M = 135.23 \times 10^6\ N\text{-}mm.$$

$$= 135.23\ kN.m.$$

Problem on slab :-

Design a simply supported slab supported on masonry walls to the following rqmts.

Clear span b/n supports = 3m.

Live load = $3 kN/m^2$.

M20 and Fe-415 combinations are used.

Given Data :-

Clear span = 3m.

L.L = $3 kN/m^2$.

M20 grade and Fe-415 steel.

$$\sigma_{cbc} = 7 N/mm^2, \ \sigma_{st} = 230\ N/mm^2.$$

Solution :

(a) Load Calulation :-

Assume wall thickness = 230mm

= 0.23m.

Effective span = clear span + bearing width

= 3 + 0.23

= 3.23m.

Consider thns of slab = 40mm / m span.

Thns of slab = 40 × 3.23

= 129.2mm.

Provided 130 mm overall depth,

Self wt. of slab = $0.13 \times 25\ kN/m^3 = 3.25\ kN/m^2$

L.L = $3\ kN/m^2$.

Assume load due to floor finish = $1\ kN/m^2$.

Total load (w) = $7.25\ kN/m^2$

Provide 8mm ϕ bar.

Eff. depth, d = D − Clear cover − $\frac{\text{bar diameter}}{2}$

$d = 130 - 15 - \frac{8}{2}$

= 111 mm = 0.111m.

b) Effective span calculation :-

i) Eff. span = Clear span + d

$= 3.111\ m.$

ii) Eff. span = clear span + bearing width

$= 3 + 0.23 = 3.23m.$

Eff. span, $l_e = 3.111\ m$ [Choose least value].

$$M_{max} = \frac{wl^2}{8} = \frac{7.25 \times (3.111)^2}{8}$$

$$= 8.777\ kN.m.$$

$$M = Qbd^2.$$

$$8.77 \times 10^6 = 0.91 \times 1000 \times d^2$$

$$d_{reqd} = 98.71\ mm.$$

$$d_{prov} = 111\ mm > d_{reqd}.$$

Hence safe.

c) Area of main steel calculation :-

$$A_{st} = \frac{M}{\sigma_{st}\, j\, d}$$

$$A_{st(main)} = 381.69\ mm^2.$$

$$Spacing = \frac{\text{Area of one bar}}{A_{st}} \times 1000$$

10

$$= \frac{50}{381.69} \times 1000$$

$$= 130.99 \text{ mm.}$$

(d) Area of distribution steel calculation :-

$$Ast_{dist} = \frac{0.12}{100} \times bD$$

$$= \frac{0.12}{100} \times 1000 \times 130$$

$$= 156 \text{ mm}^2.$$

$$\text{Spacing} = \frac{50}{156} \times 1000$$

$$= 320.50 \text{ mm.}$$

Provide 8mm diameter bar @ 300mm c/c.