SCHEME OF VALUATION | TED(15) 5015 |

STRUCTURAL DESIGN - I

Q.No.	PART - A	Marks
I 1.	~~M55~~, M60, M65, M70, M75, M80	2
2.	To avoid the brittle failure (compression failure) of an R.C.C. section, the maximum depth of N.A. is limited. The value of x_{umax} depends upon the grade of steel.	2
3.	Development length for a tension member, $$L_d = \frac{0.87 f_y \cdot \phi}{4\, \tau_{bd}}$$	2
4.	Slenderness ratio $= \frac{\text{Effective length}}{r_{minimum}}$ or $\frac{l_e}{\text{least lateral Dimension}}$	2
5.	Dog legged stairs — no space b/w flights of stairs in plan. Open well stairs — there is space b/w " " "	2

PART - B

II 1.

Working stress method	Limit state method
1. Based on behaviour of working load	1. Based on ultimate load
2. Ensures adequate safety against a satisfactory behaviour under working loads and is assumed to possess adequate safety against collapse	2. Ensures safety of structure against collapse
3. Design of section is based on the linear stress distribution	3. Based on non-linear stress distribution taking in-elastic strain into consideration.
4. Adopted factor of safety F.S. for concrete is 3 and for steel is 1.78	4. Adopted partial safety factors. It 1.5 for concrete and 1.15 for steel.

$4 \times 1\frac{1}{2} =$

II

2\. Partial safety factor for loads (γ_f)

The load to be used for ultimate strength design is termed as factored load. The partial safety factor for load is used to calculate the ultimate load for design.

Factored load = characteristic load x partial safety factor for load. 3

Value of γ_f depends upon the load combination.

Partial safety factor for material strength (γ_m)

In limit state design, the design strength $= \dfrac{\text{characteristic strength}}{\text{Partial safety factor for material strength}}$

As per IS 456 γ_m for concrete is 1.5 and steel 1.15 3

3\. (i) Select basic value of span to depth ratio depending upon the type of beam (K)

(ii) Calculate the modification factor for span above 10m

$$K_1 = \frac{10}{\text{span in metres}}$$

(iii) Select M.F. based on fs and percentage of tension steel from fig (4) of IS 456-2000 (K_2)

(iv) Select M.F based on percentage of compression steel from fig. (5) of IS 456-2000 (K_3)

(v) Calculate the modified value of span to effective depth ratio $= (K_1 \times K_2 \times K_3) K$

(vi) The effective depth required from stiffness consideration $= \dfrac{\text{span}}{(K_1 \times K_2 \times K_3) K}$ (6×1=6)

II 4. (i) When $\tau_v < \tau_c$ minimum shear r/f in the form of vertical stirrups at a spacing of $\dfrac{0.87 f_y \cdot A_{sv}}{0.4 b}$ is provided. Also
In simply supported beams shear force at mid span is zero. Hence at mid span provide minimum shear r/f. 2

(ii)

$b = 300mm$ $\qquad$ $A_{sv} = 2 \times \frac{\pi}{4} \times 8^2 = 100.48 \ mm^2$

$f_y = 250 N/mm^2$ $\qquad$ $d = 400mm$

Spacing of minimum shear reinforcement $\Big\}$ $s_v = \dfrac{0.87 f_y \cdot A_{sv}}{0.4 b}$

$= \dfrac{0.87 \times 250 \times 100.48}{0.4 \times 300} = 182.12mm$ 2

<u>Spacing</u>

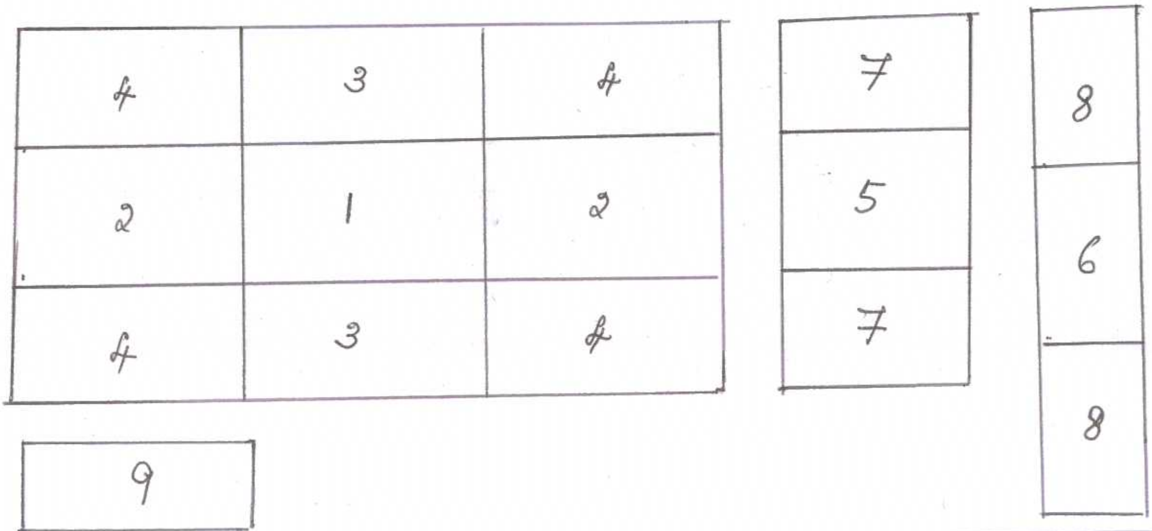
Least of (i) 182mm

(ii) $0.75d = 0.75 \times 400 = 300mm$

(iii) 300mm

Provide 8mm ϕ 2-legged vertical stirrups @ 182mm c/c at mid span. 2

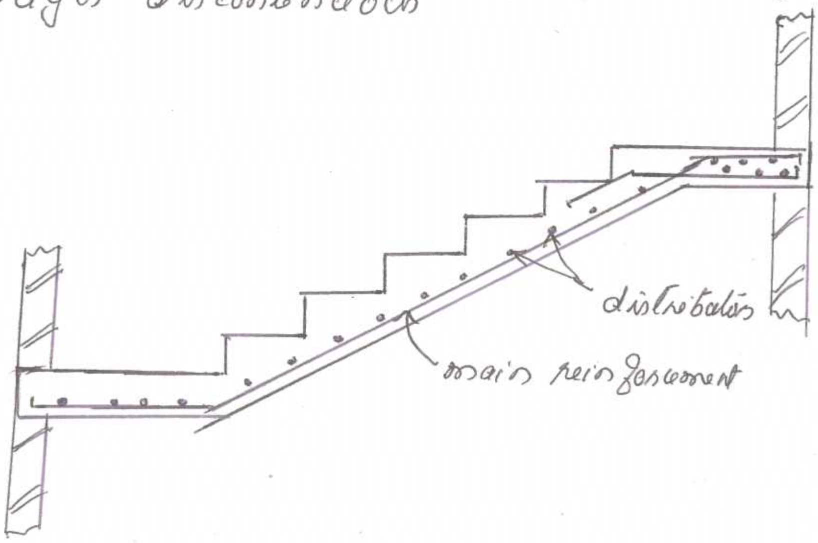
II 5.



4

1. Interior panel
2. One short edge discontinuous
3. One long edge discontinuous
4. Two adjacent edges discontinuous
5. Two short edges discontinuous
6. Two long edges discontinuous
7. Three edges discontinuous (one long edge continuous) 2
8. Three edges discontinuous (One short edge continuous)
9. Four edges discontinuous

II 6.



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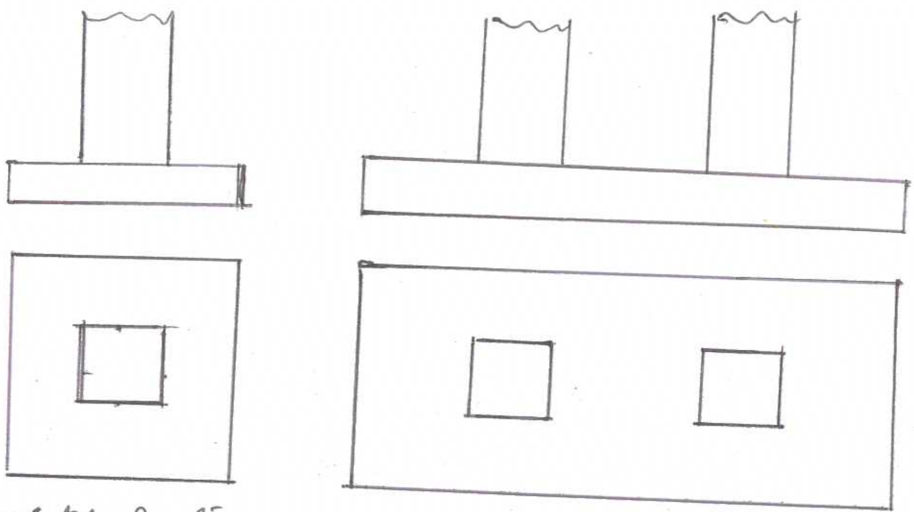
7.



Isolated footing

Combined footing

2×3=6

Isolated footing is constructed to transmit the load of an isolated column

Combined footing transmit the load of two or more column. Combined footing constructed when the individual footings are very near or overlap each other.

III (a)

Underreinforced Section	Overreinforced Section	
(i) Area of steel required is less than that of a balanced section	Area of steel more than that of a balanced section	
(ii) Depth of neutral axis, $x_u < x_{umax}$	$x_u > x_{umax}$	
(iii) Tension failure	Compression failure	
failure - slowly	brittle failure	$3 \times 2 = 6$
(iv) stress in steel controls the resisting moment	stress in concrete controls the resisting moment	

III (b) $b = 250\,mm$ $\quad f_{ck} = 20\,N/mm^2$

$d = 400\,mm$ $\quad f_y = 415\,N/mm^2$

$Ast = 3 \times \frac{\pi}{4} \times 20^2 = 942.5\,mm^2$

Depth of N.A

$$x_u = \frac{0.87 f_y \cdot Ast}{0.36 f_{ck} \cdot b} = \frac{0.87 \times 415 \times 942.5}{0.36 \times 20 \times 250} = \underline{189\,mm} \qquad 3$$

Limiting depth of N.A, $x_{umax} = 0.48d$

$= 0.48 \times 400 = \underline{192\,mm}$ 2

$x_u < x_{umax}$

$\therefore$ the section is underreinforced

the stress in steel controls moment of Resistance

$M.R = 0.87 f_y \cdot Ast\,(d - 0.42\,x_u)$

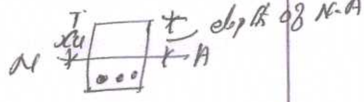
$= 0.87 \times 415 \times 942.5\,(400 - 0.42 \times 189)$ 4

$= 109{,}103{,}560\,Nmm = 109.103560 \times 10^6\,Nmm$

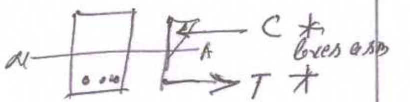
$= \underline{109.103560\,kNm}$

IV.(a) (i) Depth of neutral axis

Neutral axis is a layer along the cross section of a section at which the stress and strain is zero. Depth of N.A. is the depth from the top of compression zone to the neutral axis. (x_u).



(ii) Lever arm



Lever arm is the distance between the line of action of the resultant compression and resultant tension.

(iii) Moment of Resistance

$3 \times 2 = 6$

Moment of resistance is the moment developed by the couple of forces of resultant compression and tension in an R.C. section.

IV (b) span, $l = 5m$ $\qquad f_{ck} = 20\,N/mm^2$

$b = 200\,mm$ $\qquad f_y = 415\,N/mm^2$

$d = 400\,mm$

$d' = 40\,mm$

factored load $= 40 \times 1.5 = 60\,kN/m$

Factored Bending moment $= \frac{wl^2}{8} = \frac{60 \times 5^2}{8} = 187.5\,kNm$

$= \underline{187 \times 10^6\,N\,mm}$ (2)

Limiting Moment of Resistance, M_{ulim}

$M_{ulim} = 0.36\,f_{ck}.b.x_{umax}(d - 0.42\,x_{umax})$

$= 0.138\,f_{ck}\,bd^2$

$= 0.138 \times 20 \times 200 \times 400^2 = 88.32 \times 10^6\,Nmm$ (2)

<u>A_{st1}</u>

$M_{ulim} = 0.87\,f_y.A_{st1}(d - 0.42\,x_{umax})$

$x_{umax} = 0.48d = 0.48 \times 400 = 192\,mm$

$A_{st1} = \frac{88.32 \times 10^6}{0.87 \times 415 \times (400 - 0.42 \times 192)} = \underline{765.97\,mm^2}$ 1½

<u>A_{sc}</u> $\Rightarrow$

$A_{sc} \times f_{sc}(d - d') = \text{Factored BM} - M_{ulim}$

$\frac{d'}{d} = \frac{40}{400} = 0.1 \qquad f_{sc} = 353\,N/mm^2$

$A_{sc} = \frac{187 \times 10^6 - 88.32 \times 10^6}{353\,(400 - 40)} = \frac{98.68 \times 10^6}{127080}$ 1½

$A_{sc} = \underline{776.52\,mm^2}$

Ast₂ ⇒

$$A_{sc} \times f_{sc} = 0.87\, f_y \cdot A_{st_2}$$

$$A_{st_2} = \frac{A_{sc} \cdot f_{sc}}{0.87\, f_y} = \frac{776.52 \times 353}{0.87 \times 415} = \underline{759.2\ mm^2}$$ 1½

Ast

$$A_{st} = A_{st_1} + A_{st_2} = 765.97 + 759.2 = \underline{1525.17\ mm^2}$$ ½

√ (a) For simply supported beam, $\frac{l}{d} = 20$

$$\%\ \text{of tension steel} = \frac{100\, A_{st}}{b_f \cdot d} = \frac{100 \times 1440}{1200 \times 400} = 0.3$$

$$f_s = 0.58\, f_y \cdot \frac{A_{st}\ \text{required}}{A_{st}\ \text{provided}} = 0.58 \times 415 \times \frac{1440}{1440} = 240.7\ N/mm^2$$

modification factor (from fig. 4) = 1.5

$$\frac{b_w}{b_f} = \frac{300}{1200} = 0.25$$

modification factor based on $\frac{b_w}{b_f}$ ⇒ 0.8

modified value of $\frac{l}{d} = 20 \times 1.5 \times 0.8 = 24$

Effective depth required $= \frac{\text{span}}{24} = \frac{6000}{24} = 250\,mm$

d required (250mm) < d provided (400mm)

Hence the beam is safe in deflection. (6)

V (b) Nominal shear stress, $\tau_v = \frac{V_u}{bd} = \frac{40 \times 10^3}{250 \times 360} = 0.44\ N/mm^2$

% of Tension steel, $p_t = \frac{100\ A_{st}}{bd} = \frac{100 \times 700}{250 \times 360} = 0.78$

For M20 concrete & $p_t = 0.78$, $\tau_c = 0.56\ N/mm^2$

$\tau_{c\,max} = 2.8\ N/mm^2$

$\tau_v < \tau_{c\,max}$

$\tau_v < \tau_c$

$\therefore$ Shear reinforcement not necessary

But as per code (IS 456) provide minimum shear reinforcement

Spacing of stirrups, $S_v = \frac{0.87\ f_y \cdot A_{sv}}{0.4\ b}$

Provide 8mm ϕ 2-legged stirrups

$$A_{sv} = 2 \times \frac{\pi}{4} \times 8^2 = 100.53\ mm^2$$

$$S_v = \frac{0.87 \times 415 \times 100.53}{0.4 \times 250} = 363\ mm$$

<u>Spacing</u>

least of (i) 363 mm

(ii) $0.75d = 0.75 \times 360 = 270\ mm$

(iii) 300 mm

Provide 8mm ϕ - 2 legged stirrups @ 270mm c/c

VI

(a) Bond strength

The term bond refers to the adhesion between concrete and steel which resist the slipping of steel bars from the concrete. The stresses transferred from steel to concrete due to this bond. The bond develops due to setting of concrete on drying which results in gripping of the steel bars 3

(b) Curtailment of bars

For curtailment, reinforcement shall extend beyond the point at which it is no longer required to resist bending for a distance equal to the effective depth (d) or 12 times the diameter of bar (12 ϕ) whichever is more except at simple support. 3

VI(b) $b_w = 260\ mm$ $\quad D_f = 120\ mm$

$d = 450\ mm$ $\quad l = 4\ m = 4000\ mm$

$f_y = 500\ N/mm^2$

$A_{st} = 6 \times \frac{\pi}{4} \times 16^2 = 1205.76\ mm^2$ $\quad f_{ck} = 25\ N/mm^2$

Effective width of flange $(b_f) = \frac{l_o}{6} + b_w + 6D_f$

$b_f = \frac{4000}{6} + 260 + (6 \times 120) = \cancel{2847}\ 1647\ mm$

$\underline{b_f}$ least of (i) $1647\ mm$ (2)

(ii) % of span $= 3000\ mm$

$\underline{b_f = 1647\ mm}$

$\underline{x_u}$

Assuming the N.A. lies inside the flange

$$x_u = \frac{0.87 f_y . A_{st}}{0.36 f_{ck} . b_f} = \frac{0.87 \times 500 \times 1205.76}{0.36 \times 25 \times 1647} \quad (2)$$

$x_u = 35.38\ mm$

$x_u < D_f$ $\therefore$ N.A. lies inside the flange

$x_{u\,max} = 0.46d = 0.46 \times 450 = 207\ mm$

$x_u < x_{u\,max}$ $\therefore$ the section is underreinforced (2)

Moment of Resistance $= 0.87 f_y . A_{st} (d - 0.42 x_u)$

$= 0.87 \times 500 \times 1205.76 (450 - 0.42 \times 35.$

$= 228,233,366.78\ Nmm$ (3

$= 228.233 \times 10^6\ Nmm = \underline{228.233\ kNm}$

VII(a) Purpose of distribution steel

(i) To distribute the effect of point loads
(ii) To ~~t~~ resist temperature stresses
(iii) To keep the main reinforcement in position 2

Code provision

~~(i)~~ minimum area of distribution steel
(i) 0.12% of gross area $\left(\frac{0.12}{100} \times bD\right)$ for ~~mild~~ HYSD steel 2
(ii) 0.15% of gross area $\left(\frac{0.15}{100} \times bD\right)$ for mild steel

Maximum spacing of distribution bars 1

5d or 450 mm whichever is less

VII(b) Design of S.S. one way slab

Effective span, $l = 3m$ M_{20} Concrete
Live load $= 3\,kN/m^2$ Fe_{415} steel
Floor Finish $= 1.5\,kN/m^2$

Assume an overall depth of 120 mm (40mm/m of span)
Provide a cover of 20mm
Effective depth, $d = 100$ mm

Loads

Self wt. $= 0.12 \times 25 = 3\,kN/m^2$
Live load $3\,kN/m^2$
Floor finish $1.5\,kN/m^2$
Total load $7.5\,kN/m^2$
Factored load $= 1.5 \times 7.5 = 11.25\,kN/m^2$

Factored BM $= \frac{wl^2}{8} = \frac{11.25 \times 3^2}{8} = 12.656$ kNm
$= 12.656 \times 10^6$ Nmm

Effective depth required

$M_{u\,lim}$ for HYSD bars at (Fe415) $= 0.138 f_{ck} b d^2$

$0.138 f_{ck} \cdot b \cdot d^2$ = Factored BM $= 12.656 \times 10^6$

$$d \text{ required } = \sqrt{\frac{12.656 \times 10^6}{0.138 \times 20 \times 1000}} = 67.71 \text{ mm}$$

d required $= 67.71$ mm < d provided (100 mm) (3)

Hence O.K.

Area of main rft

$$\text{Factored BM} = 0.87 f_y \cdot A_{st} \left(d - \frac{f_y \cdot A_{st}}{f_{ck} \cdot b} \right)$$

$$12.656 \times 10^6 = 0.87 \times 415 \times A_{st} \left(100 - \frac{415 \times A_{st}}{20 \times 1000} \right)$$

$$12.656 \times 10^6 = 36105\, A_{st} - 7.49\, A_{st}^2$$

$$7.49\, A_{st}^2 - 36105\, A_{st} + 12.656 \times 10^6 = 0$$

$$A_{st}^2 - 4820.43\, A_{st} + 1.68972 \times 10^6 = 0$$

$$A_{st} = 381 \text{ mm}^2$$

Min. area of steel required $= \frac{0.12}{100} bD$

$= \frac{0.12}{100} \times 1000 \times 120 = 144 \text{ mm}^2$

< Ast required

Provide 8mm ϕ bars, spacing $= \frac{1000 \times \frac{\pi}{4} \times 8^2}{381} = 131.86$ mm (3)

Max. spacing $= 3d = 3 \times 100 = 300\,mm$

$\therefore$ Provide 8mm ϕ bars @ 130mm c/c along shorter direction

Distributors

Area of distributors $= \frac{0.12}{100} bD = 144\,mm^2$

Provide 6mm ϕ bars, spacing $= \frac{1000 \times \frac{\pi}{4} \times 6^2}{144} = 196.25\,mm$

Max. spacing $= 5d = 5 \times 100 = 500\,mm$ or 450mm whichever is less

$\therefore$ Provide 6mm ϕ bars @ 196mm c/c along longer direction

Bent-up or curtail alternate bars @ 0.1l from support (2)

Check for shear

Factored shear force, $V_u = \frac{wl}{2} = \frac{11.25 \times 3}{2} = 16.875\,kN$
$= 16.875 \times 10^3\,N$

$\tau_v = \frac{V_u}{bd} = \frac{16.875 \times 10^3}{1000 \times 100} = 0.168\,N/mm^2$

At support $A_{st} = \frac{1000}{260} \times \frac{\pi}{4} \times 8^2 = 193\,mm^2$

$p_t = \frac{100 A_{st}}{bd} = \frac{100 \times 193}{1000 \times 100} = 0.193\,\%$

$k = 1.3$

$\tau_v < k \cdot \tau_c$ Hence safe in shear

Check for deflection (2)

Check for development length

VIII (a) Torsion reinforcement is provided at corners where the edges of slab is discontinuous. When the corners are held down torsion reinforcement has to be provided to prevent the cracking of the corners. (3)

(b) $\frac{l}{28} = \frac{4000}{28} = 142\,mm$

Provide an overall depth of 130 mm

Provide a cover of 20 mm

Effective depth = 130 − 20 = 110 mm

Effective span

$l_x = 4 + 0.11 = 4.11\,m$

$l_y = 5 + 0.11 = 5.11\,m$ (1)

Loads

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

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

Floor finish $= 1\ kN/m^2$

Total load $= 7.25\ kN/m^2$

Factored load $= 1.5 \times 7.25 = \underline{10.875\ kN/m^2}$ (1)

$\frac{l_y}{l_x} = \frac{5.11}{4.11} = 1.24$

From Table 26 of IS 456

$\alpha_x = 0.0748 \quad \alpha_y = 0.056$ (1)

Bending Moments

$M_x = \alpha_x \cdot w \cdot l_x^2 = 0.0748 \times 10.875 \times 4.11^2 = 13.74\ kNm$

$M_y = \alpha_y \cdot w \cdot l_x^2 = 0.056 \times 10.875 \times 4.11^2 = 10.29\ kNm$ (2)

Effective depth required

$d = \sqrt{\frac{M_x}{0.138 f_{ck} \cdot b}} = \sqrt{\frac{13.74 \times 10^6}{0.138 \times 20 \times 1000}} = 70.56\ mm < d$ provided

Hence O.K. (1)

Middle strip

$\frac{3}{4} l_x = \frac{3}{4} \times 4.11 = 3.08 m$

$\frac{3}{4} l_y = \frac{3}{4} \times 5.11 = 3.83 m$

Edge strip

$\frac{l_x}{8} = \frac{4.11}{8} = 0.51 m$

$\frac{l_y}{8} = \frac{5.11}{8} = 0.64 m$

(1)

Middle strip reinforcement

Along shorter span

$A_{stx} = \frac{0.36 f_{ck} \cdot b \cdot x_{umax}}{0.87 f_y} = \frac{0.36 \times 20 \times 1000 \times (0.48 \times 70.56)}{0.87 \times 415} = 675\ mm^2$

Provide 8 mm ϕ bars, spacing $= \frac{1000 \times \frac{\pi}{4} \times 8^2}{675} = 74\ mm$

Provide 8 mm ϕ bars @ 74 mm c/c along shorter direction ~~for a length of at mid span~~ middle strip. (3)

Along longer span

$M_y = 0.87 f_y \cdot A_{sty} \left(d' - \frac{f_y \cdot A_{sty}}{f_{ck} \cdot b}\right)$

$10.29 \times 10^6 = 0.87 \times 415 \times A_{sty} \left(102 - \frac{415 \times A_{sty}}{20 \times 1000}\right)$

$A_{sty} = 300\ mm^2$

Using 8 mm ϕ bars, spacing $= \frac{1000 \times \frac{\pi}{4} \times 8^2}{300} = 167\ m$ Say 160 mm

Provide 8ϕ bars @ 160 mm c/c along longer span at middle strip (3)

IX (a)	(i) Effectively held in position and restrained against rotation at both ends	0.65 l	
	(ii) Effectively held in position at both ends, restrained against rotation at one end	0.80 l	
	(iii) Effectively held in position at both ends, but not restrained against rotation	1.0 l	
	(iv) Effectively held in position and restrained against rotation at one end, and at the other restrained against rotation but not held in position	1.20 l	
	(v) Effectively held in position and restrained against rotation at one end but not held in position nor restrained against rotation at the other end.	2.0 l	any 4 × 1½ 6
IX b.	Axial load = 800 kN Factored load, $P_u = 1.5 \times 800 = 1200\ kN$ $= 1200 \times 10^3\ N$ $f_{ck} = 25\ N/mm^2$, $f_y = 500\ kN/mm^2$ A_g = Gross area of column Assuming 1% of steel ∴ Area of steel, $A_{sc} = 0.01 A_g$ $P_u = 0.4 f_{ck} \cdot A_c + 0.67 \cdot f_y \cdot A_{sc}$ $1200 \times 10^3 = [0.4 \times 25 (A_g - 0.01 A_g)] + [0.67 \times 500 \times 0.01 A_g]$ $1200 \times 10^3 = 9.9 A_g + 3.35 A_g$ $A_g = \dfrac{1200 \times 10^3}{13.25} = 90566\ mm^2$		3

Side of column $= \sqrt{90566} = 300.94$ mm

Provide a column of 310×310 mm

$A_g = 310 \times 310 = 96100\ mm^2$

$A_{sc} = 0.01 A_g = 0.01 \times 90566 = 905.66\ mm^2$

Provide 18 mm ϕ bars 4 Nos as main reinforcement 2

Lateral ties

Diameter not less than

(i) $\frac{1}{4} \times$ dia of main bar $= \frac{1}{4} \times 18 = 4.5$

(ii) 6 mm

∴ Provide 6 mm ϕ lateral ties

Spacing

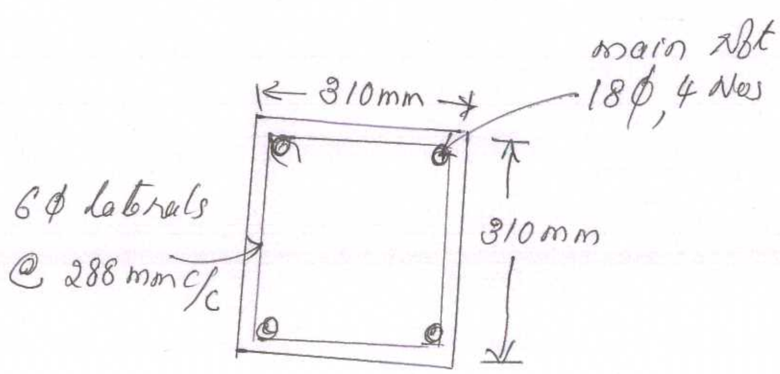
least of

(i) least lateral dimension = 310 mm

(ii) 16 times dia. of main bar $= 16 \times 18 = 288$ mm

(iii) 300 mm 3

Provide 6 mm laterals @ 288 mm c/c



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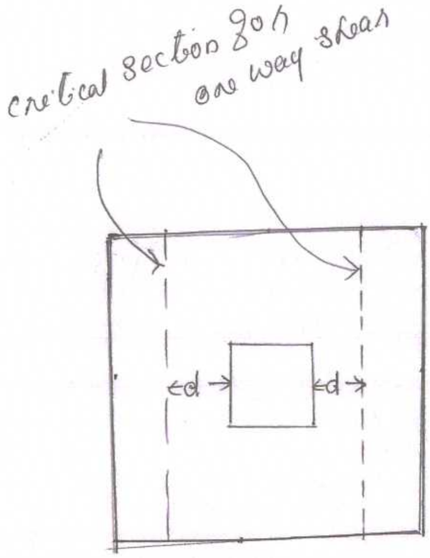
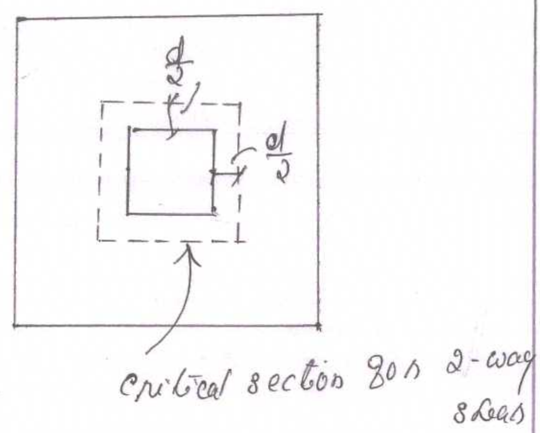
X (a)





2×3=6

d = effective depth

X (b) Dog legged stairs

$l = 4\,m$ $R = 160\,mm$, $T = 270\,mm$ Live load $= 5\,kN/m^2$

$f_{ck} = 20\,N/mm^2$, $f_y = 415\,N/mm^2$

Provide an overall depth of $4 \times 40 = 160\,mm$ for waist slab

Loads

Wt. of slab on horizontal area $= 0.16 \times 25 \times \frac{\sqrt{R^2+T^2}}{T}$

$= 0.16 \times 25 \times \frac{\sqrt{0.16^2+0.27^2}}{0.27} = 4.65\,kN/m^2$

Wt. of steps $= \frac{1000}{270} \times (1/2 \times 0.27 \times 0.16) \times 25 = 2\,kN/m^2$

Live load $= 5\,kN/m^2$

Total load $= 4.65 + 2 + 5 = 11.65\,kN/m^2$

Factored load $= 11.65 \times 1.5 = 17.48\,kN/m^2$ 3

Design of waist slab

Factored Bending moment $= \frac{wl^2}{8} = \frac{17.48 \times 4^2}{8} = 34.96$ kNm

$= 34.96 \times 10^6$ N mm 1

Effective depth required

Factored Bending Moment $= 0.138\, f_{ck} \cdot b \cdot d^2$

$\therefore d = \sqrt{\frac{34.96 \times 10^6}{0.138 \times 20 \times 1000}} = 112.54$ mm 1

Provide an effective depth of 120mm and overall depth of 160mm

Area of main reinforcement

Factored BM $= 0.87\, f_y\, Ast \left(d - \frac{f_y \cdot Ast}{f_{ck} \cdot b}\right)$

$34.96 \times 10^6 = 0.87 \times 415 \times Ast \left(120 - \frac{415 \times Ast}{20 \times 1000}\right)$

$34.96 \times 10^6 = 43326\, Ast - 7.49\, Ast^2$

$Ast^2 - 5784.51\, Ast + \cancel{34}\, 4.668 \times 10^6 = 0$

$Ast = 970\ mm^2$

Provide 8mm Ø bars

spacing $= \frac{1000 \times 50}{970} = 51.54$ mm 3

Provide 8mm Ø bars @ 50mm c/c

Distributors

Area of distributors $= \frac{0.12}{100} bD$

$= \frac{0.12}{100} \times 1000 \times 140 = 168 mm^2$

Provide 6mm ϕ distributors @ 168mm c/c 1