ANNAMALAI UNIVERSITY

Department: Civil and Structural Engineering
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Course: Structural concrete design-III
Course Code: 01PE604
Course Teacher:
Dr.G.SRINIVASAN
Associate professor
Dept. of Civil & Strl Engg.
E-mail: drgs72@gmail.com
Phone: 9443223458

Unit–IV

Syllabus:

Design of Flat Slabs using Direct Design Method - Equivalent Frame Method - Reinforcement detailing as per SP 34: 1987.

Definitions of Flat slab and its components:

1. **Flat slab** :
   A flat slab is a typical type of construction in which a reinforced slab is built monolithically with the supporting columns and is reinforced in two or more directions, without any provision of beams.
2. **Drop of flat slab**:
   Drop is that part of the slab around the column, which is of greater thickness than the rest of the slab.
3. **Capital or column head**:
   Sometimes the diameter of a supporting column is increased below the slab. This part of column with increased diameter is called column head.
4. **Panel**:
   It is the area enclosed between the centre lines connecting adjacent columns in two directions and the outline of the column heads.

Types of Flat slabs:

1. Slabs without drops and column heads
2. Slabs without drops

3. Slab with drops and column with column head

Methods of analysis of flat slab:

1. The direct design method
2. The equivalent frame method

<u>The direct design method</u>

Assumptions made in direct design method:

1. There shall be minimum of three continuous spans in each direction.
2. The panel shall be rectangular, and the ratio of the longer span to the shorter span within a panel shall not be greater than 2.0.

<u>The equivalent frame method</u>

Assumptions made in equivalent frame method:

1. The structure is considered to be made of equivalent frames longitudinally and transversely.
2. Each frame is analysed by any established method like moment distribution method.
3. The relative stiffness is computed by assuming gross cross section of the concrete alone in the calculation of the moment of inertia.
4. Any variation of moment of inertia along the axis of the slab on account of provision of drops should be considered.

Limitations of direct design method:

- There must be at least three continuous spans in each direction.
- The panels should be rectangular and the ratio of longer span to shorter span within a panel
  shall not be greater than 2.0.
- The successive span length in each direction shall not differ by more than one third of the
  longer span.
- The end spans may be shorter but not longer than the interior spans.
- The design live load should not exceed three times the design dead load.

SLAB REINFORCEMENT

Spacing:

The spacing of bars in a flat slab, shall not exceed 2 times the slab thickness.

Area of reinforcement:

When the drop panels are used, the thickness of drop panel for determining area of reinforcement
shall be the lesser of the following:

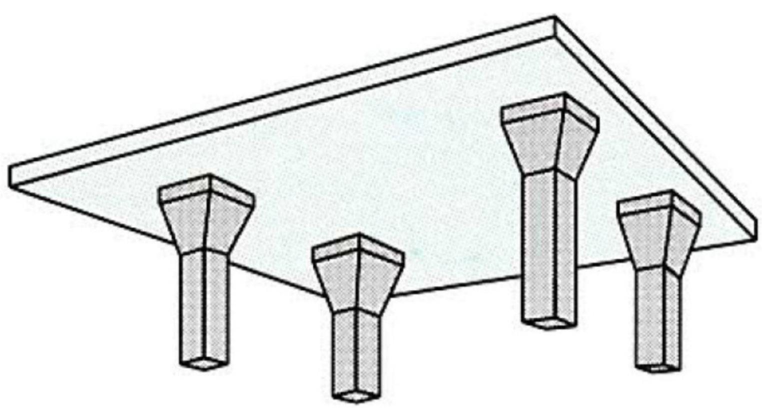
(*a*) Thickness of drop, and

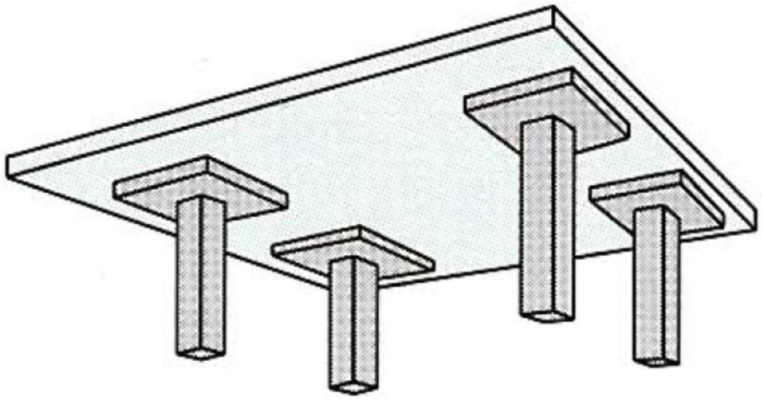
(*b*) Thickness of slab plus one quarter the distance between edge of drop and edge of capital.

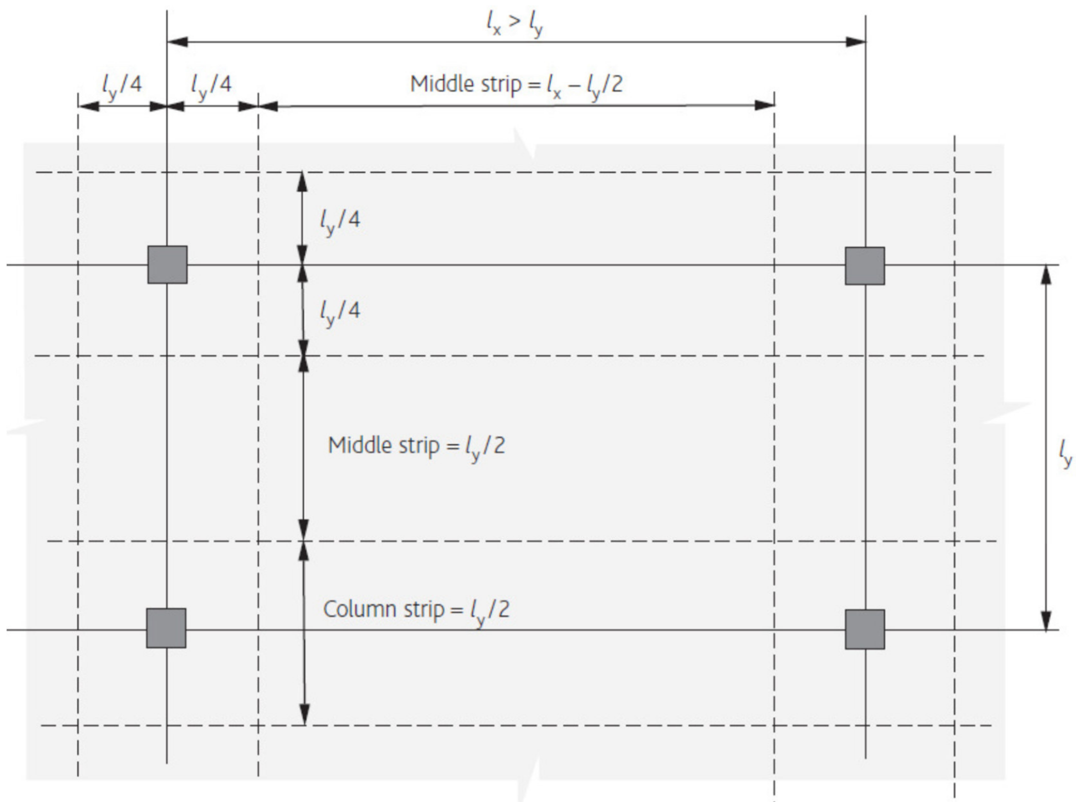
The minimum percentage of the reinforcement is same as that in solid slab *i.e.*, 0.12 percent if HYSD bars used and 0.15 percent, if mild steel is used.

***Minimum length of reinforcement*:**

At least 50 percent of bottom bars should be from support to support. The rest may be bent up. The minimum length of different reinforcement in flat slabs should be as shown in Fig. 16 in IS 456–2000. If adjacent spans are not equal, the extension of the –ve reinforcement beyond each face shall be based on the longer span. All slab reinforcement should be anchored property at discontinuous edges.







$l_x > l_y$
$l_y/4$
$l_y/4$
Middle strip = $l_x - l_y/2$
$l_y/4$
$l_y/4$
Middle strip = $l_y/2$
Column strip = $l_y/2$
l_y

DESIGN COMPONENTS OF FLAT SLAB

a) *Column strip :*

Column strip means a design strip having a width of 0.25 I,, but not greater than 0.25 1, on each side of the column centre-line, where I, is the span in the direction moments are being etermined, measured centre to centre of supports and 1, is the -span transverse to 1,, measured centre to centre of supports.

b) *Middle strip :*

Middle strip means a design strip bounded on each of its opposite sides by the column strip.

c) *Panel:*

Panel means that part of a slab bounde d on-each of its four sides by the centre -line of a Column or centre-lines of adjacent-spans.

Division into column and middle strip along:

Longer span:

L =6.6 m , $_2L$ =5.6 m
(i) column strip
= 0.25 $_2L$ = 1.4 m
But not greater than 0.25 $_1L$ = 1.65 m
(ii) Middle strip
= 5.6 – (1.4+1.4) = 2.8 m

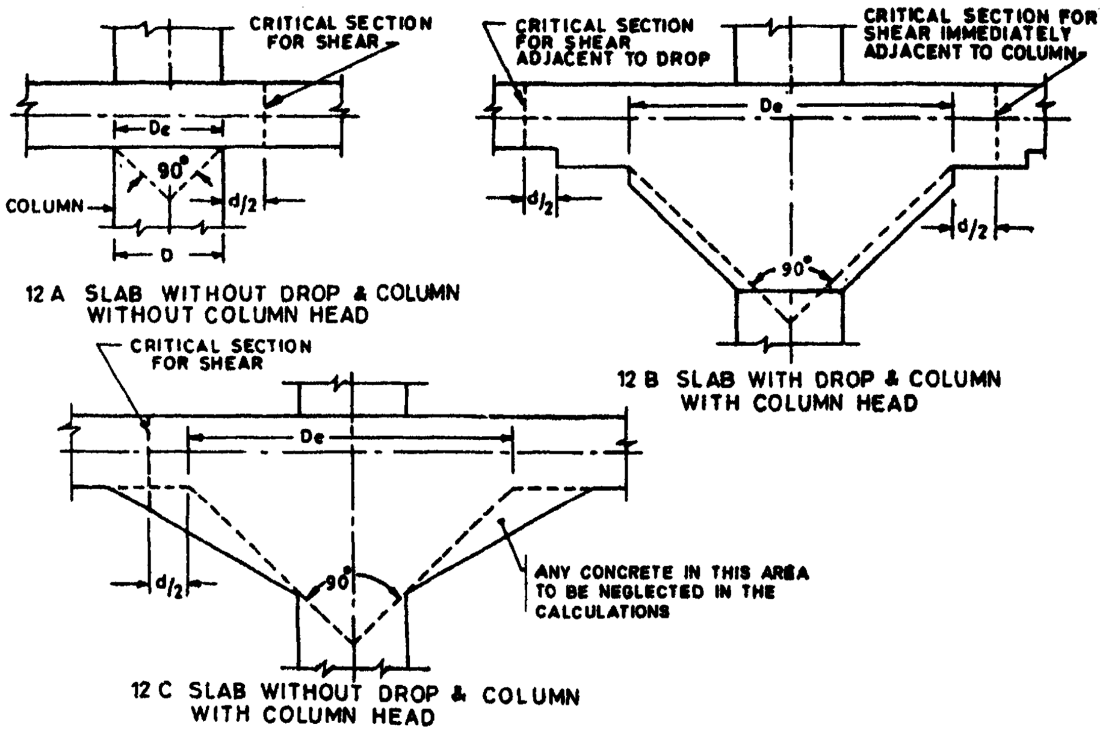
Shorter span:
L =5.6 m , $_2L$ =6.6 m
(i) column strip
= 0.25 $_2L$ = 1.65 m
But not greater than 0.25 $_1L$ = 1.4 m
(ii) Middle strip
= 6.6 – (1.4+1.4) = 3.8 m

The drops when provided shall be rectangular in plan, and have a length in each direction not less than one- third of the panel length in that direction. For exterior panels, the width of drops at right angles to the non- continuous edge and measured from the centre -line of the columns shall be equal to one –half the width of drop for interior panels.Since the span is large it is desirable to provide drop.

Drop dimensions along:
Longer span
L =6.6 m , $_2L$ =5.6 m
Not less than $_1L$ /3 = 2.2 m
Shorter span
L =5.6 m , $_2L$ =6.6 m
Not less than $_1L$ /3 = 1.866 m
Hence provide a drop of size 2.2 x 2.2 m i.e. in column strip width.

Column head :

Where column heads are provided, that portion of a column head which lies with in the largest right circular cone or pyramid that has a vertex angle of 90”and can be included entirely within the outlines of the column and the column head, shall be considered for design purposes



NOTE- *D.* is the diameter of column or column head to be considered for design.. and *d* is effective depth of slab or drop

CRITICAL SECTIONS FOR SHEAR IN FLAT SLABS:

Column head dimension along:
Longer span
L =6.6 m , L_2 =5.6 m
Not greater than $L_1/4$ = 1.65 m
Shorter span
L =5.6 m , L_2 =6.6 m
Not greater than $L_1/4$ = 1.4 m
Adopting the diameter of column head = 1.30 m =1300 mm
f) Depth of flat slab:

The thickness of the flat slab up to spans of 10 m shall be generally controlled by considerations of span
(L) to effective depth (d) ratios given as below:
Cantilever 7; simply supported 20; Continuous 26
For slabs with drops, span to effective depth ratios gi ven above shall be applied directly; otherwise the span to effective depth ratios in accordance with above shall be multiplied by 0.9. For this purpose, the longer span of the panel shall be considered. The minimum thickness of slab shall be 125 mm
Depth of flat slab:
Considering the flat slab as a continuous slab over a span not exceeding 10 m

L/d=26
then
d=L/26
Depth considering along:
Longer span

L_1 =6.6 m, L_2 =5.6 m

$$d = \frac{L}{26} = \frac{6000}{26} = 253.8mm \ \approx 260mm$$

Shorter span:
L_1 =5.6 m , L_2=6.6 m

$$d = \frac{L}{26} = \frac{5600}{26} = 215.3mm \approx 220mm$$

Taking effective depth of 25mm
Overall depth D = 260 +25 = 285 mm > 125 mm (minimum slab thickness as per IS: 456)
∴ It is safe to provide depth of 285 mm.

Estimation of load acting on the slab:

Dead load acting on the slab = 0.285 x 25 = 6.25 $KN/m^2 = w_{d1}$

Floor finishes etc. load on slab = 1.45 $KN/m^2 = w_{d2}$

Live load on slab = 7.75 $KN/m^2 = w_l$

Total dead load = $w_{d1} + w_{d2}$ =7.7 $KN/m^2 = w_d$

The design live load shall not exceed three times the design dead load.

Total design load = $w_l + w_d =$ 15.45 KN/m ^{2}

Total Design Moment for a Span
The absolute sum of the positive and average and is given by negative bending moments in each direction shall be taken as:
$Mo = Wln/8$
M = total moment.
W = design load on an area l_1 l_2
l_n = clear span extending from face to face of columns, capitals, brackets or walls, but not less than
0.65 l_1

l_1 = length of span in the direction of M_0 .
l_2 = length of span transverse to l_1 .
Circular supports shall be treated as square supports having the same area.

$$a = \frac{\pi}{4} d2 \ = 1.152m$$

Clear span along long span= l_n = $6.6 - \frac{1}{2}(1.152) - \frac{1}{2}(1.152)$ 5.448 4.29=5.448>4.29
Should not be less than 0.65 l_1
Hence ok

Clear span along long span = l_n = $5.6 - \frac{1}{2}(1.152) - \frac{1}{2}(1.152)$ 4.44m > 3.64m
Should not be less than 0.65 l_1
Hence ok
Total design load along:
Longer span:
l_n =5.448 m , l_2=5.6 m
$W = w\, l_2\, l_n$
$W = 15.45 \times 5.6 \times 5.448 = 471.36 KN$

Shorter span:
l_n=4.44 m , l_2=6.6 m
$_{2\,n}$ $W = w\, l_2\, l_n$
$W = 15.45 \times 6.6 \times 4.44 = 452.74 KN$
The absolute sum of –ve and +ve moment in a panel along:
Longer span :
l_n =5.448 m , l_2 =5.6 m
$M_o = \frac{Wl_n}{8} = 320.99 KNm$
Shorter span:
l_n =4.44 m , l_2 =6.6 m
$M_o = \frac{Wl_n}{8} = 251.2 KNm$

Negative and Positive Design Moments :

The negative design moment shall be at the fac e of rectangular supports, circular supports being treated as square supports having the same 31.4.5.1 Columns built integrally with the slab system area. Shall be designed to-resist moments arising from loads .

In an interior span, the total design moment M_0 shall be distributed in the following proportions:

Negative design moment 0.65

Positive design moment 0.35

In an end span, the total design moment M_0 shall be distributed in the following proportions:

Interior negative design moment: $\frac{0.10}{1+1/\propto C}$ 0.75

Positive design moment: $\frac{0.28}{1+1/\propto C}0.63$

Exterior negative design moment: $\frac{0.65}{1+1/\propto C}$

$\propto C$ Is the ratio of flexural stiffness of the exterior columns to the flexural stiffness of the slab at a $\propto c = \sum \frac{Kc}{Ks}$ joint taken in the direction moments are being determined and is given by:

Kc = sum of the flexural stiffness of the columns meeting at the joint.

Ks= flexural stiffness of the slab, expres sed as moment per unit rotation

It shall be permissible to modify these design moments by up to 10 percent, so lon g as the total design moment $_0M$ for the panel in the direction considered is not less than that required by:

$M_o = \frac{Wl\,n}{8}$

The negative moment section shall be designed to resist the larger of the two interior negative design moments determined for the spans framing into a common support unless an analysis is made to distribute the unbalanced moment in accordance with the stiffness of the adjoining parts.

Column strip :

Negative moment at an interior support:

At an interior support, the column strip shall be designed to resist 75 percent of the total negative moment in the panel at that support.

Negative moment at an exterior support:

a) At an exterior support, the column strip shall be designed to resist the t otal negative moment in the panel at that support.

b) Where the exterior support consists of a column or a wall extending for a distance equal to or greater than three-quarters of the value of l_2 . The length of span transverse t o the direction moments are being determined, the exterior negative moment shall be considered to be uniformly distributed across the length l_2 .

Positive moment for each span: For each span, the column strip shall be designed to resist 60 percent of the total positive moment in the panel.

Moments in the middle strip:

a) That portion of-the design moment not resisted by the column strip shall be assigned to the adjacent middle strips.

b) Each middle strip shall be proportioned d to resist the sum of the moments assigned to its two half middle strips.

c) The middle strip adjacent and parallel to an edge supported by a wall shall be proportioned, to resist twice the moment assigned to half the middle strip corresponding to the first row of interior columns.

Distribution of bending moment across the panel width:

It is an exterior panel.

Longer span

column strip [$\propto C = 1.39$]

-ve B.M at exterior support = $\left[\frac{-0.65\ \ Mo}{1+1/\propto C}\right]$ X1= -121.34 KNm

+ve span BM = $\left[0.63 - \frac{0.28}{1+1/\propto C}\right]$X MoX0.60=90KNm

-ve span BM at interior support = - $\left[0.75 - \frac{0.10}{1+1/\propto C}\right]$X MoX0.75= - 165.50KNm

Middle strip:

-ve BM at exterior support = $\left[\frac{-0.65\ \ Mo}{1+1/\propto C}\right]$ x 0.0 =0 KNm

+ve span BM= $\left[0.63 - \frac{0.28}{1+1/\propto C}\right]$X MoX0.40= 59.96 KNm

-ve BM at interior support = - $\left[0.75 - \frac{0.10}{1+1/\propto C}\right]$X MoX0.25= - 55.50KNm

Short span

column strip [$\propto C = 2.79$]

-ve moment at exterior support = $\left[\frac{-0.65\ \ Mo}{1+1/\propto C}\right]$ X 1.0 = -120.19 KNm

+ve moment = $\left[0.63 - \frac{0.28}{1+1/\propto C}\right]$X MoX0.60= 63.88 KNm

-ve moment at interior support = - $\left[0.75 - \frac{0.10}{1+1/\propto C}\right]$X MoX0.75= - 127.43 KNm

Middle strip

-ve moment at exterior support = = $\left[\frac{-0.65\ \ Mo}{1+1/\propto C}\right]$ x 0.0=0.0 KNm

+ve mid-span moment= $\left[0.63 - \frac{0.28}{1+1/\propto C}\right]$X MoX0.40= 42.59 KNm

-ve moment at interior span= - $\left[0.75 - \frac{0.10}{1+1/\propto C}\right]$X MoX0.25= - 42.44KNm

Effective depth of the slab:

Thickness of the slab, from consideration of maximum positive moment any where in the slab.
Maximum +ve BM occurs in the column strip (long span) = 90.91 KNm
∴factored moment = 1.50 x 90.91 = 136.36 KNm

$M_{o}= 0.138\, fck\, bd^2$ $[b=2800mm]$

$$d = \sqrt{\frac{136.36X106}{0.138X20X2800}}$$

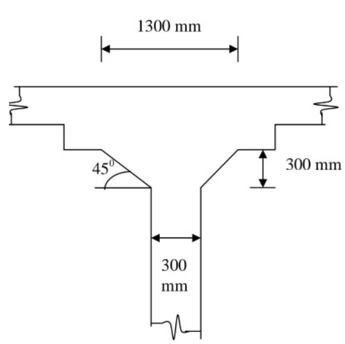
d=132.83 mm ≈ 140 mm
Using 12 mm ∅ (diameter) main bars.
Overall thickness of slab =140+15+12/2=161mm ≈170mm
∴Depth (along longitudinal direction) =170-15-12/2=150mm

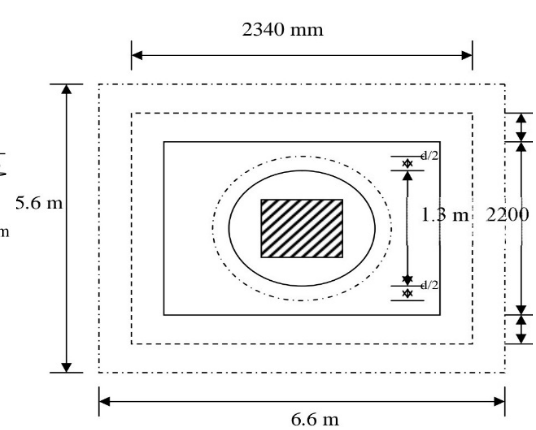
∴Depth (along longitudinal direction) = 150 –12 =138 mm
Thickness of drop from consideration of maximum –ve moment any where in the panel.
Max –ve BM occurs in the column strip = 166.6 KNm

$M_U = 0.138\, fck\, bd^2$

$1.5\ X166.6\ X10^6 = 0.138\ X20\ X1400X\ d^2$

Keeping d =254.3
Say d=260mm
Use 12 mm ∅ bars
Over all thickness of flat slab:D=260+15+12/2=281





Shear in Flat Slab:

The critical section for shear shall be at a distance d/2 from the periphery of the column/capital/ drop panel, perpendicular to the plane of the slab where d is the effective depth of the section The shape in plan is geometrically similar to the support immediately below the slab.

Check for shear stress developed in slab:

The critical section for shear for the slab will be at a distance d/2 from the face of drop.

Perimeter of critical section = 4 x 2340 = 9340 mm

V_O = 1.5X15.45X [L_1XL_2 –(2.34) (2.34)]

Total factored shear force: V_O = 729.78 KN

Nominal shear stress = $\tau_V = \frac{Vu}{bd}$ = 0.55 N/mm^2

shear strength of concrete =

if $\tau_V < \tau_C$ the design is safe

if $\tau_V > 1.5\ \tau_C$ then the slab should be re-designed

check for shear in drop:

b_O = (D+d_O) π

b_O = 4.89 m

V = 812.27 KN

Nominal shear stress = $\tau_V = \frac{Vu}{bd}$ = 0.683 N/mm^2

τ_C = 1.11 N/mm^2

$\tau_V < \tau_C$

the design is safe

Reinforcement details:

Longer span:

-ve exterior reinforcement:

$Mu= 0.87 f_y A_{st} [\ d-0.42x_u]$

A_{st} = 4209mm^2

Use 12 mm Ø bars

Number of bars = 38 No.

12mm dia. Bars @ 35mmc/c

+ve steel:-

A_{st} = 3122mm^2

Using 12mm dia. bars 28 Nos. are used @ spacing of 135 mm c/c

Along shorter span:

Column strip:

$Mu= 0.87 f_y A_{st} [\ d-0.42x_u]$

A_{st} = 3768 mm^2
Using 12mm dia. bars 33 Nos. are used @ spacing of 40 mm c/c
Middle strip:
$$Mu= 0.87f_yA_{st}\ [d-0.42x_u]$$
A_{st} = 1182 mm^2
Using 12mm dia. bars 10 Nos. are used @ spacing of 280 mm c/c

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