Combined Footings

Design and Detailing of steel in Combined Footings

Learning Outcomes:

- After this students will be able design and detail combined footings through drawing and bar bending schedule. This is for Part B and is one full question for about 70 marks.

Footings

The function of a footing or a foundation is to transmit the load form the structure to the underlying soil.

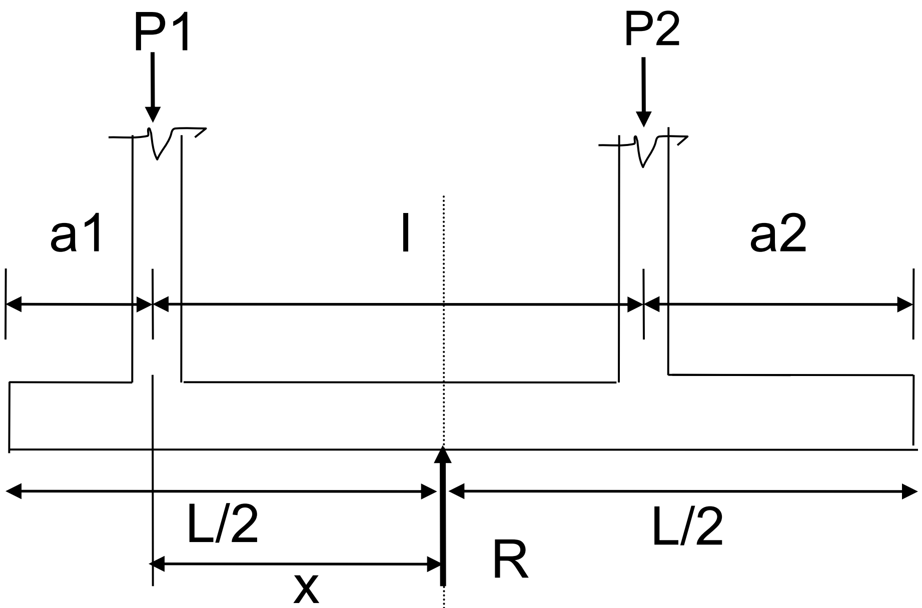
The choice of suitable type of footing depends on the depth at which the bearing strata lies, the soil condition and the type of superstructure.

Combined footing

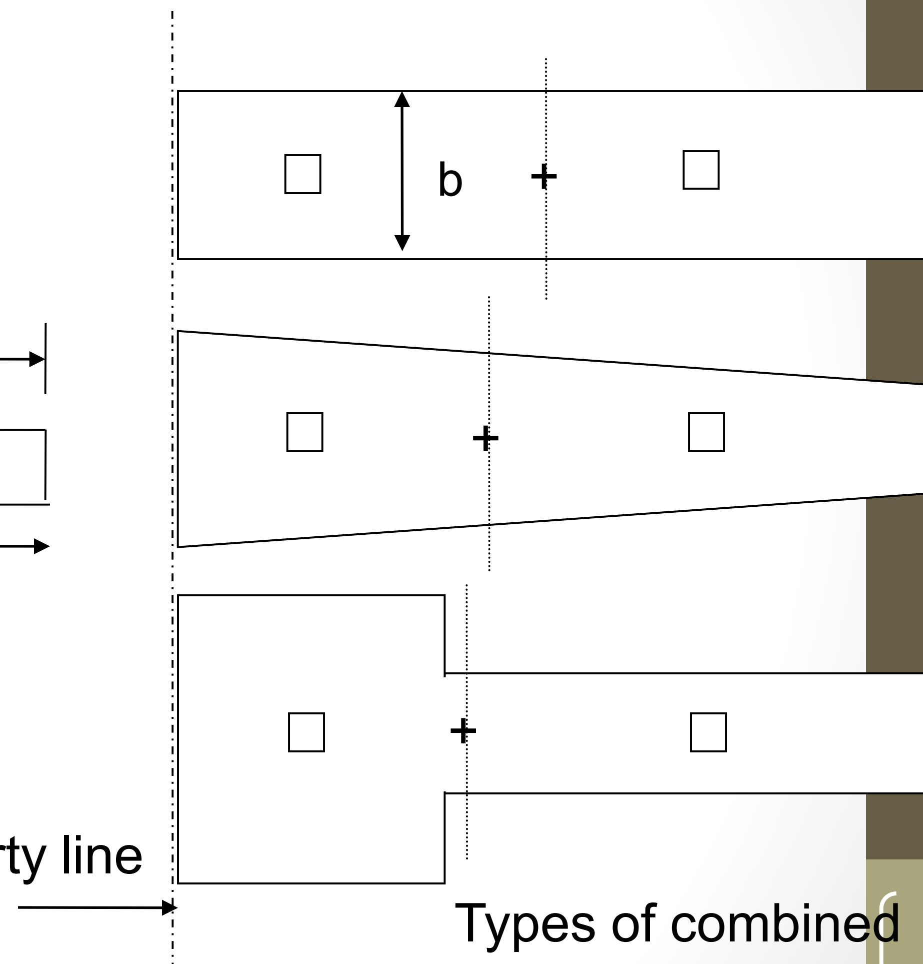
- Whenever two or more columns in a straight line are carried on a single spread footing, it is called a combined footing. Isolated footings for each column are generally the economical.

- Combined footings are provided only when it is absolutely necessary, as

1. When two columns are close together, causing overlap of adjacent isolated footings
2. Where soil bearing capacity is low, causing overlap of adjacent isolated footings
3. Proximity of building line or existing building or sewer, adjacent to a building column.

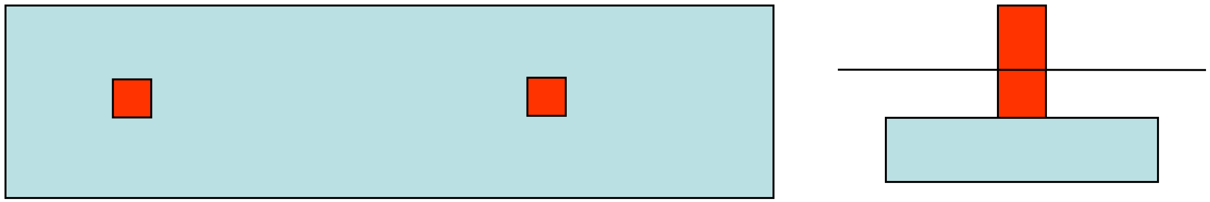


Combined footing with loads

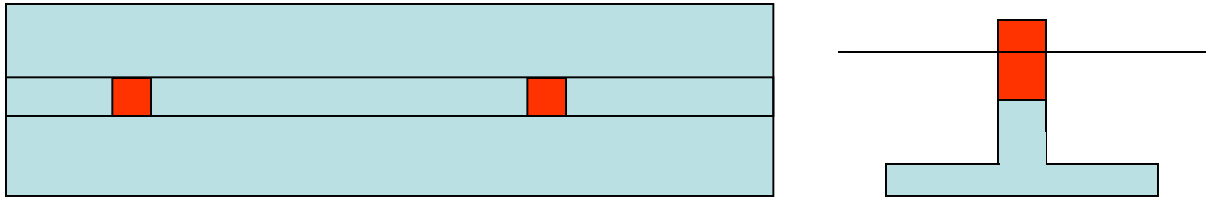


Types of combined footings

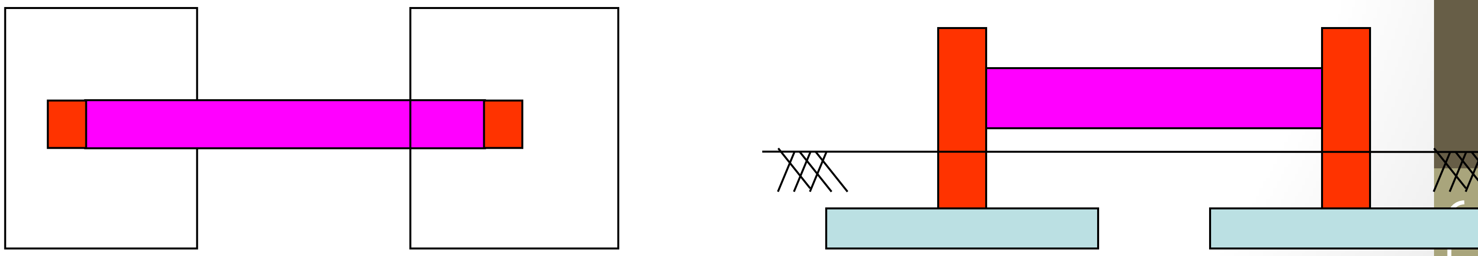
Types of combined footing



1. Slab type



2. Slab and beam type



3. Strap type

- The combined footing may be rectangular,
  trapezoidal or Tee-shaped in plan.
  The geometric proportions and shape are so fixed that the centeroid of the footing area coincides with the resultant of the column loads. This results in uniform pressure below the entire area of footing.

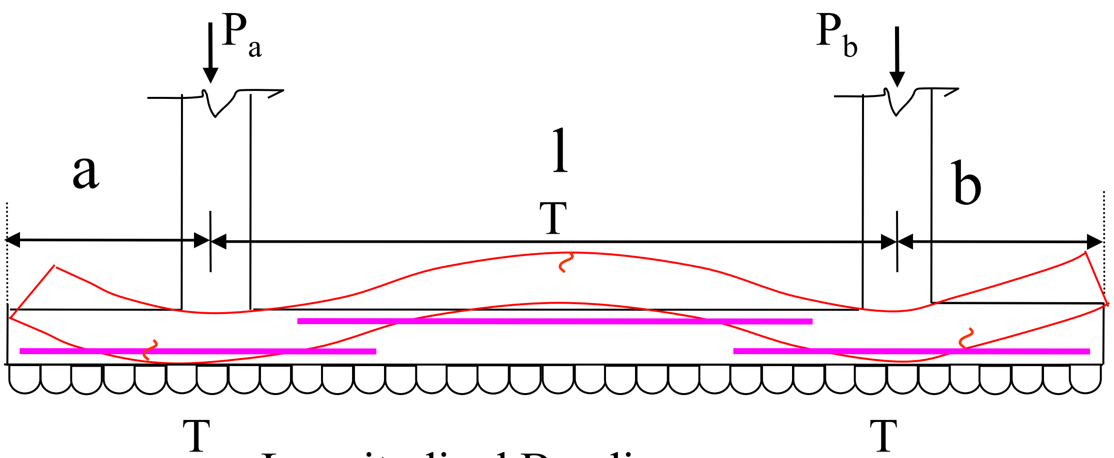
- Trapezoidal footing is provided when one column load is much more than the other. As a result, the both projections of footing beyond the faces of the columns will be restricted.

- Rectangular footing is provided when one of the projections of the footing is restricted or the width of the footing is restricted.

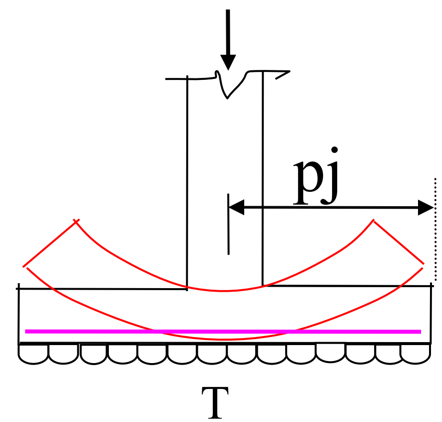
Rectangular combined footing

- Longitudinally, the footing acts as an upward loaded beam spanning between columns and cantilevering beyond. Using statics, the shear force and bending moment diagrams in the longitudinal direction are drawn. Moment is checked at the faces of the column. Shear force is critical at distance ‘d’ from the faces of columns or at the point of contra flexure. Two-way shear is checked under the heavier column.

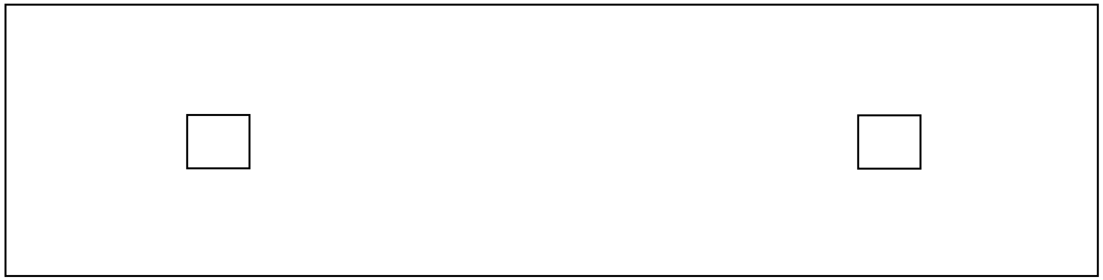
- The footing is also subjected to transverse bending and this bending is spread over a transverse strip near the column.



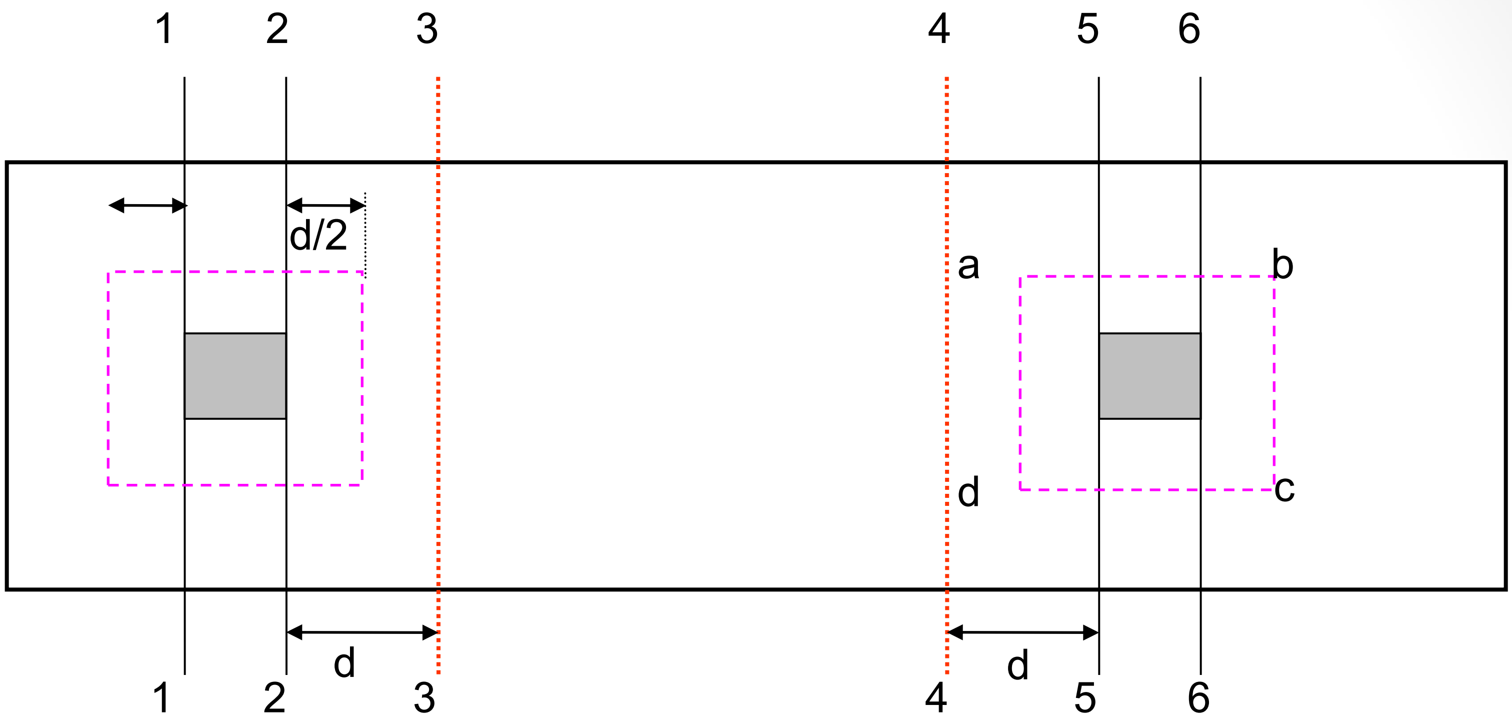
Longitudinal Bending



Transverse Bending

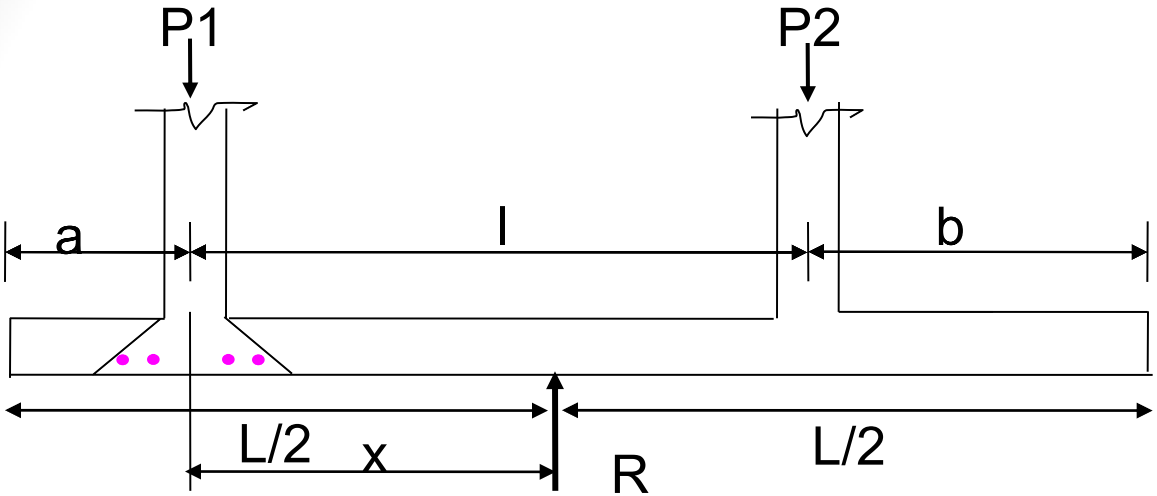


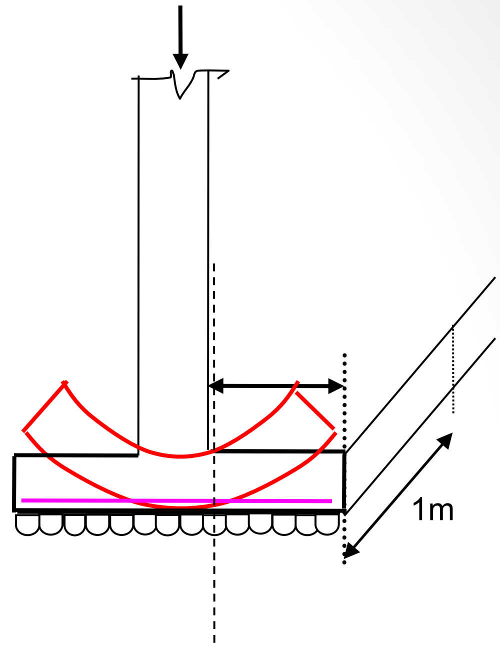
SLAB TYPE COMBINED FOOTING

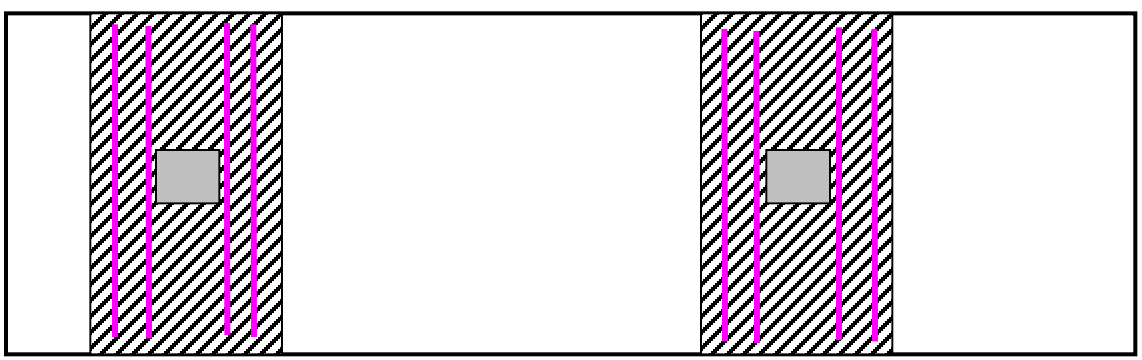


Section 1-1, 2-2, 5-5, and 6-6 are sections for critical moments
Section 3-3, 4-4 are sections for critical shear (one way)
Section for critical two way shear is abcd

CRITICAL SECTIONS FOR MOMENTS AND SHEAR







TRANSVERSE BEAM
BELOW COLUMS

Design Steps

- Locate the point of application of the column loads on the footing.
- Proportion the footing such that the resultant of loads passes through the center of footing.
- Compute the area of footing such that the allowable soil pressure is not exceeded.
- Calculate the shear forces and bending moments at the salient points and hence draw SFD and BMD.
- Fix the depth of footing from the maximum bending moment.
- Calculate the transverse bending moment and design the transverse section for depth and reinforcement. Check for anchorage and shear.

Design Steps -Contd.,

- Check the footing for longitudinal shear and hence design the longitudinal steel
- Design the reinforcement for the longitudinal moment and place them in the appropriate positions.
- Check the development length for longitudinal steel
- Curtail the longitudinal bars for economy
- Draw and detail the reinforcement
- Prepare the bar bending schedule

Detailing

Detailing of steel (both longitudinal and transverse) in a combined footing is similar to that of conventional beam-SP-34

Detailing requirements of beams and slabs should be followed as appropriate-SP-34

Design of combined footing – Slab and Beam type

1. Two interior columns A and B carry 700 kN and 1000 kN loads respectively. Column A is 350 mm x 350 mm and column B is 400 mm X 400 mm in section. The centre to centre spacing between columns is 4.6 m. The soil on which the footing rests is capable of providing resistance of 130 kN/m^2. Design a combined footing by providing a central beam joining the two columns. Use concrete grade M25 and mild steel reinforcement.

- Draw to a suitable scale the following

1. The longitudinal sectional elevation
2. Transverse section at the left face of the heavier column
3. Plan of the footing

Marks 60

- Solution: Data
- f_{ck} = 25 Nlmm^2,
- f_y= 250 N/mm^2,
- f_b = l30 kN/m^2 (SBC),
- Column A = 350 mm x 350 mm,
- Column B = 400 mm x 400 mm,
- c/c spacing of columns = 4.6 m,
- P_A = 700 kN and P_B = 1000 kN
- Required: To design combined footing with central beam joining the two columns.
- Ultimate loads
- P_{uA}= 1.5 x 700 = 1050 kN, P_{uB} = 1.5 x 1000 = 1500 kN

Proportioning of base size

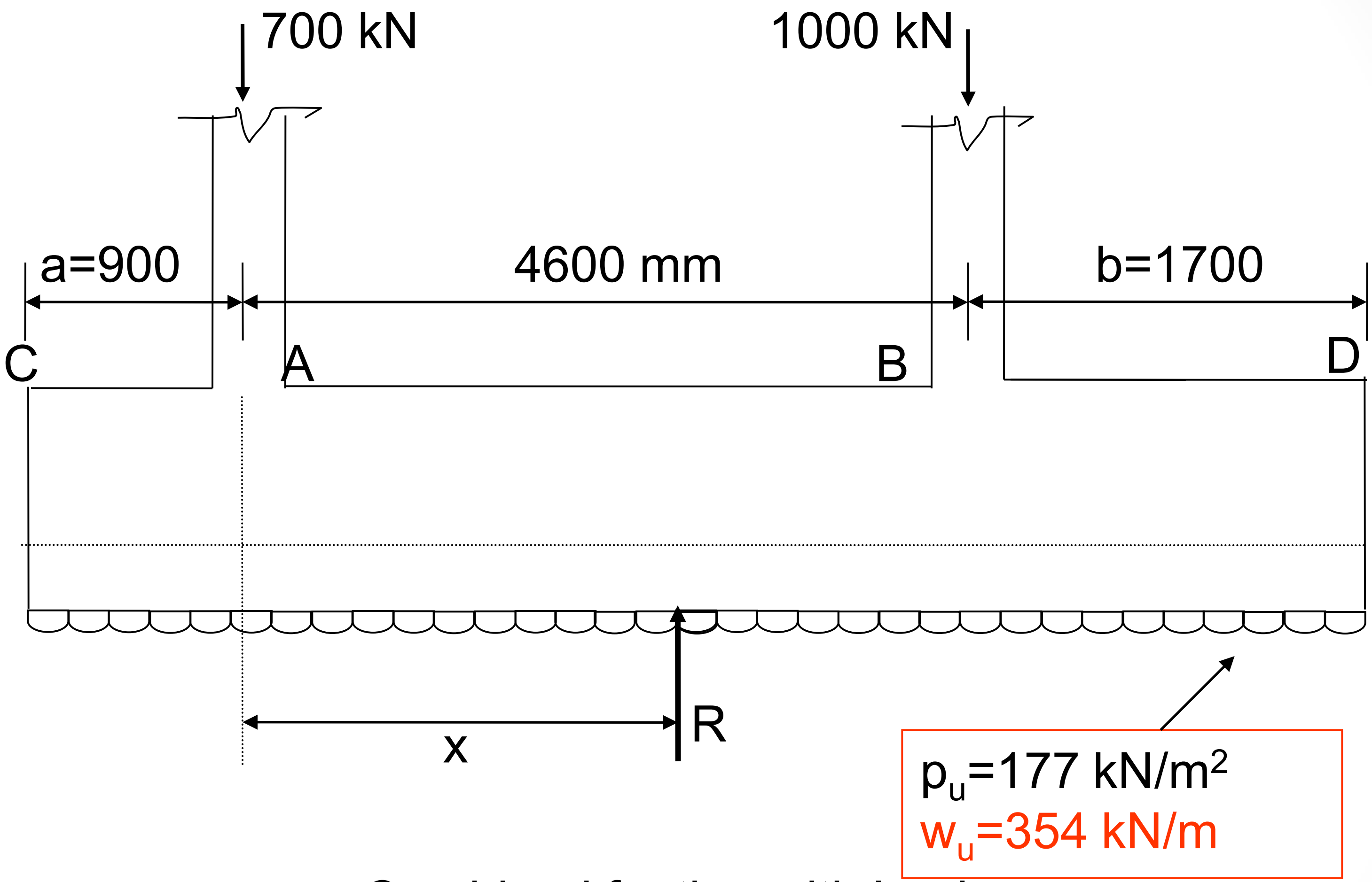
Working load carried by column A = P_A = 700 kN
Working load carried by column B = P_B = 1000 kN
Self weight of footing 10 % x (P_A + P_B) = 170 kN
Total working load = 1870 kN
Required area of footing = A_f = Total load /SBC
=1870/130 = 14.38 m^2
Let the width of the footing = B_f = 2m
Required length of footing = L_f = A_f /B_f = 14.38/2 = 7.19m
Provide footing of size 7.2m X 2m,A_f = 7.2 x 2 = 14.4 m^2

For uniform pressure distribution the C.G. of the footing should coincide with the C.G. of column loads. Let x be the distance of C.G. from the centre line of column A

Then $x = (P_B \times 4.6)/(P_A + P_B) = (1000 \times 4.6)/(1000 + 700)$
= 2.7 m from column A.
If the cantilever projection of footing beyond column A is 'a'
then, $a + 2.7 = L_f/2 = 7.2/2$, Therefore $a = 0.9$ m

Similarly if the cantilever projection of footing beyond B is 'b'
then, $b + (4.6-2.7) = L_f/2 = 3.6$ m,

Therefore $b = 3.6 - 1.9 = 1.7$ m
The details are shown in Figure



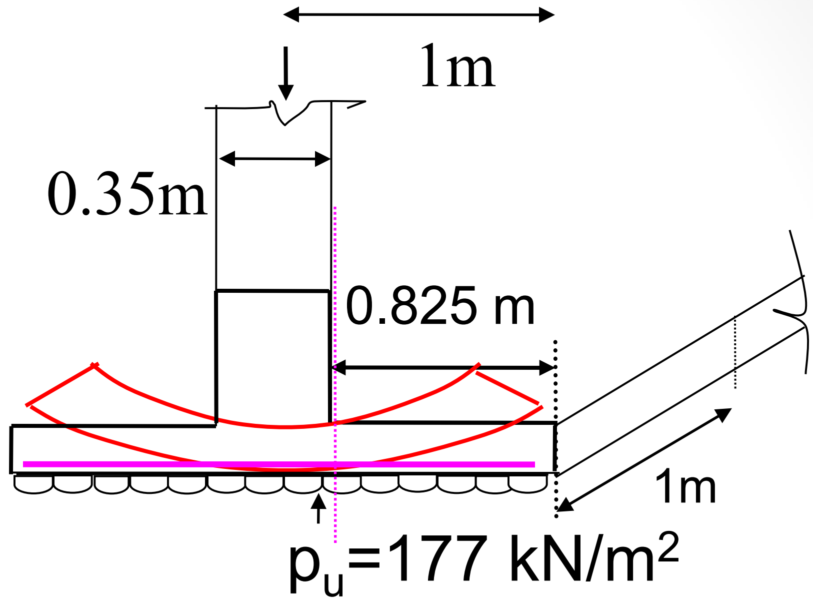
Combined footing with loads

Rectangular Footing with Central Beam:-Design of Bottom slab.

- Total ultimate load from columns = P_u= 1.5(700 + 1000) = 2550 kN.
- Upward intensity of soil pressure w_u= P/A_f= 2550/14.4 = 177 kN/m^2

- **Design of slab**
- Intensity of Upward pressure = w_u =177 kN/m^2
- Consider one meter width of the slab (b=1m)
- Load per m run of slab at ultimate = 177 x 1 = 177 kN/m
- Cantilever projection of the slab (For smaller column)
- =1000 - 350/2 = 825 mm
- Maximum ultimate moment = 177 x $0.825^2/2$ = 60.2 kN-m.

Slab design-Contd.,



For M25 and Fe 250, $Q_{u\,max}$ = 3.71 N/mm²

Required effective depth = $\sqrt{(60.2 \times 10^6/(3.71 \times 1000))}$ = 128 mm

Since the slab is in contact with the soil clear cover of 50 mm is assumed.

Using 20 mm diameter bars

Required total depth = 128 + 20/2 + 50 =188 mm say 200 mm

Provided effective depth = d = 200-50-20/2 = 140 mm

To find steel

$M_u/bd^2 = 3.07 < 3.73$, URS

$M_u = 0.87\, f_y\, A_{st}[d - f_y A_{st}/(f_{ck} b)]$

$p_t = 1.7\%$
$A_{st} = 2380\ mm^2$

Use Φ20 mm diameter bar at spacing
= 1000 x 314 / 2380 = 131.93 say 130 mm c/c
Area provided =1000 x 314 / 130 = 2415 mm^2

Check the depth for one - way shear considerations- At ‘d’ from face

Design shear force=V_u=177x(0.825-0.140)=121kN

<u>Nominal shear</u>

stress=τ_v=V_u/bd=121000/(1000x140)=0.866MPa

<u>Permissible shear stress</u>

P_t = 100 x 2415 /(1000 x 140) = 1.7 %, τ_{uc} = 0.772 N/mm^2

Value of k for 200 mm thick slab =1.2

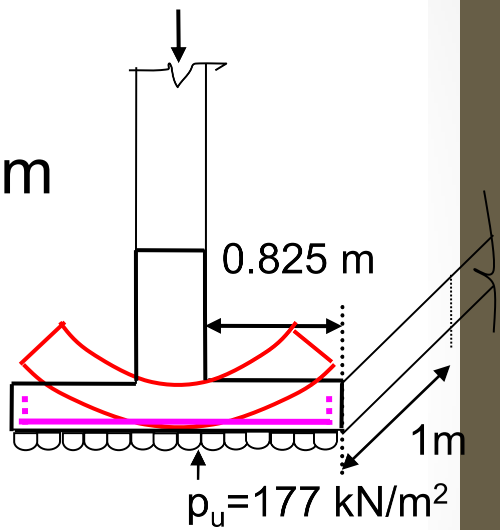
Permissible shear stress = 1.2 x 0.772 = 0.926 N/mm^2

$\tau_{uc} > \tau_v$ and hence safe

The depth may be reduced uniformly to 150 mm at the edges.

Check for development length

L_{dt}= [0.87 x 250 / (4 x 1.4)]Φ =39 Φ
= 39 x 20 = 780 mm
Available length of bar=825 - 25 = 800mm
> 780 mm and hence safe.



Transverse reinforcement

Required A_{st}=0.15bD/100
=0.15x1000 x 200/100 = 300mm^2
Using Φ8 mm bars, Spacing=1000x50/300
= 160 mm
Provide distribution steel of Φ8 mm at 160 mm c/c,<300, <5d

Design of Longitudinal Beam

Load from the slab will be transferred to the beam.
As the width of the footing is 2 m, the net upward soil pressure per meter length of the beam

$= w_u = 177 \times 2 = 354$ kN/m

Shear Force and Bending Moment

$V_{AC} = 354 \times 0.9 = 318.6$ kN, $V_{AB} = 1050 - 318.6 = 731.4$ kN

$V_{BD} = 354 \times 1.7 = 601.8$ kN, $V_{BA} = 1500 - 601.8 = 898.2$ kN

Point of zero shear from left end C

$X_1 = 1050/354 = 2.97$m from C or

$X_2 = 7.2 - 2.97 = 4.23$ m from D

Maximum B.M. occurs at a distance of 4.23 m from D

$M_{uE} = 354 \times 4.23^2 / 2 - 1500 (4.23 - 1.7) = -628$ kN.m

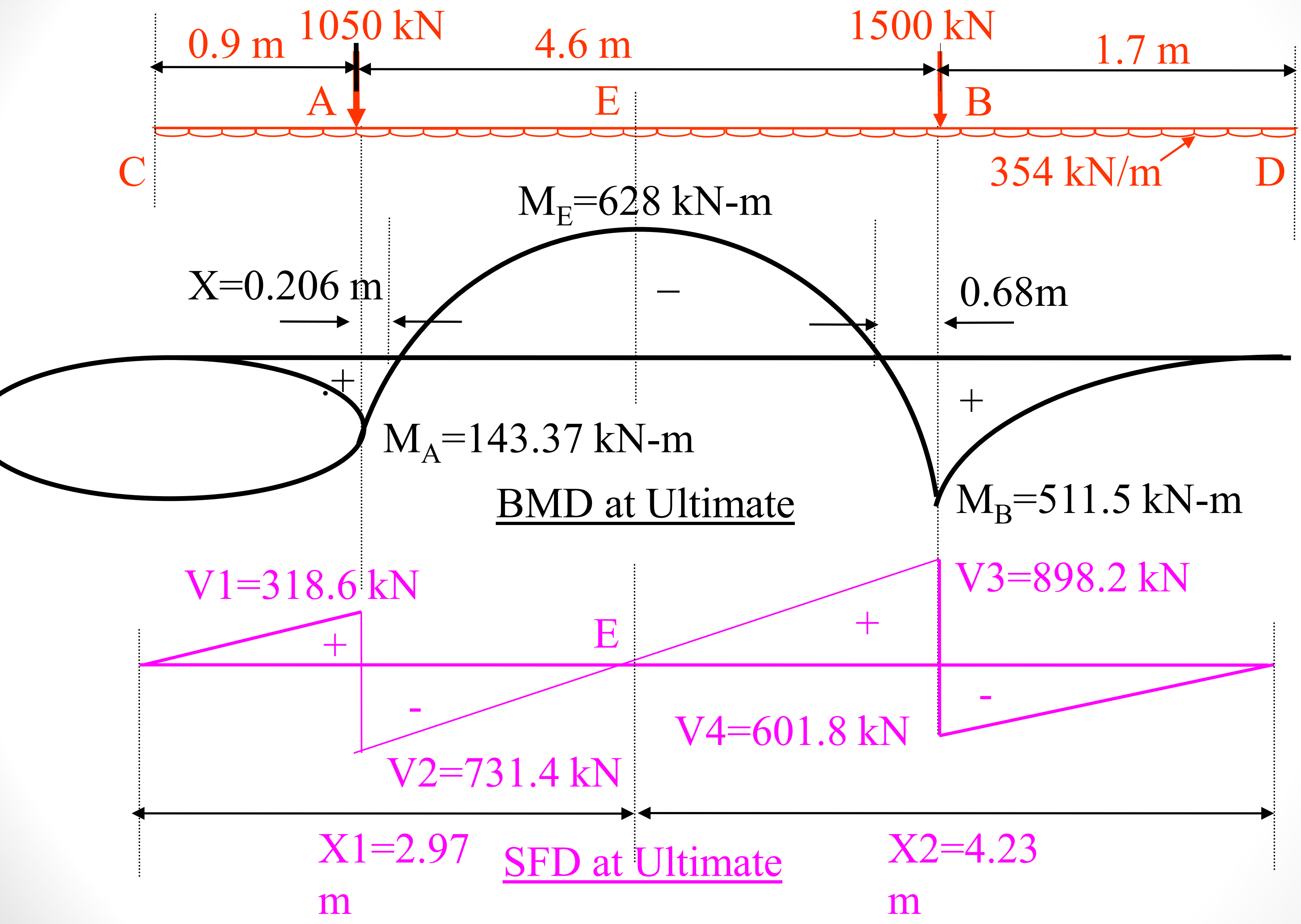
Bending moment under column A= $M_{uA}=354 x 0.9^2 /2$ = 143.37 kN.m

Bending moment under column B = $M_{uB} = 354 \times 1.7^2$ = 511.5 kN-m

Let the point of contra flexure be at a distance x from the centre of column A

Then, M_x= I050x - 354 (x + 0.9)²/ 2 = 0

Therefore x = 0.206 m and 3.92 m from column A i.e. 0.68 m from B.


0.9 m
1050 kN
4.6 m
1500 kN
1.7 m
A
E
B
C
354 kN/m
D
ME=628 kN-m
X=0.206 m
0.68m
MA=143.37 kN-m
BMD at Ultimate
MB=511.5 kN-m
V1=318.6 kN
V3=898.2 kN
E
V4=601.8 kN
V2=731.4 kN
X1=2.97 m
SFD at Ultimate
X2=4.23 m

Depth of beam from B.M.

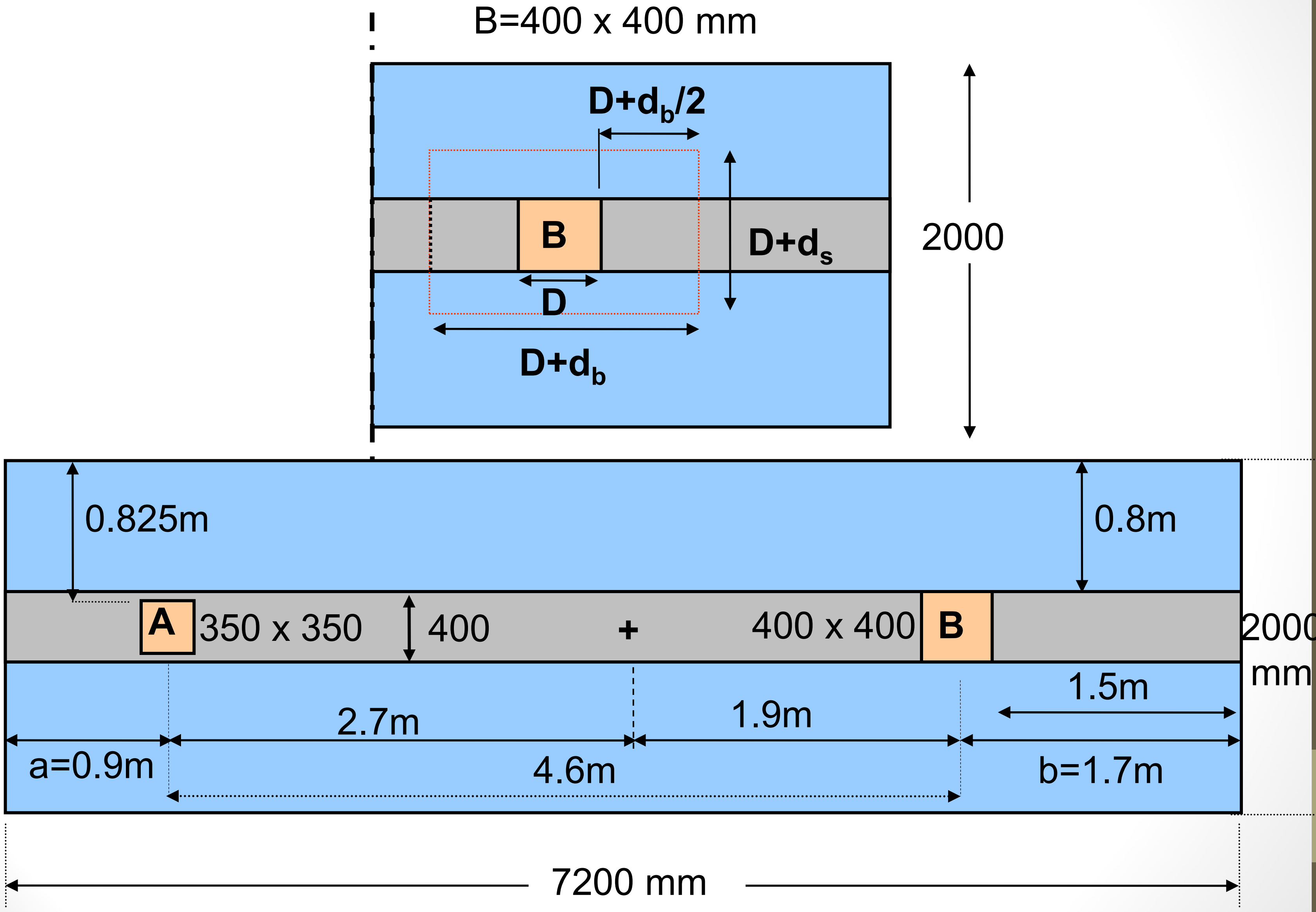
The width of beam is kept equal to the maximum width of the column i.e. 400 mm. Determine the depth of the beam where T- beam action is not available. The beam acts as a rectangular section in the cantilever portion, where the maximum positive moment = 511.5 kN/m.

$d \;= \sqrt{(511.5 \times 10^6 / (3.73 \times 400))} = 586$ mm

Provide total depth of 750 mm. Assuming two rows of bars with effective cover of 70 mm.
Effective depth provided = d= 750-70 = 680 mm (Less than 750mm and hence no side face steel is needed.

Check the depth for Two-way Shear

The heaver column B can punch through the footing only if it shears against the depth of the beam along its two opposite edges, and along the depth of the slab on the remaining two edges. The critical section for two-way shear is taken at distance d/2 (i.e. 680/2 mm) from the face of the column. Therefore, the critical section will be taken at a distance half the effective depth of the slab (ds/2) on the other side as shown in Fig.


B=400 x 400 mm
D+d_b/2
B
D+d_s
2000
D
D+d_b
0.825m
0.8m
A
350 x 350
400
+
400 x 400
B
2000 mm
1.5m
2.7m
1.9m
a=0.9m
4.6m
b=1.7m
7200 mm

In this case b=D=400 mm, d_b=680 mm, d_s=140 mm

Area resisting two - way shear

$= 2(b \times d_b + d_s \times d_s) + 2 (D + d_b)ds$

$= 2 (400 \times 680 + 140 \times 140) + 2(400+680)\ 140 = 885600\ mm^2$

Design shear=P_{ud}= column load – W_u x area at critical section

$= 1500 - 177 \times (b + d_s) \times (D + d_b)$

$=1500-177 \times (0.400+0.140) \times (0.400+ 0.680)$

=1377.65kN

$\tau_v=P_{ud}/b_o d$= 1377.65x1000/885600=1.56 MPa

Shear stress resisted by concrete = $\tau_{uc} = \tau_{uc} \times K_s$

where, $\tau_{uc} = 0.25 \sqrt{f_{ck}} = 0.25\sqrt{25} = 1.25\ N/mm^2$

$K_s = 0.5 + d / D = 0.5 + 400/400 = 1.5 \leq 1$ Hence $K_s = 1$

$\tau_{uc} =$ 1 x 1.25 = 1.25 N/mm^2. Therefore Unsafe

Area of Steel: Cantilever portion BD

Length of cantilever from the face of column
=1.7- 0.4/2 = 1.5 m.
Ultimate moment at the face of column
$=354 x 1.5^2/2=398.25$ kN-m

$M_{umax} = 3.71 \times 400 \times 680^2 \times 10^{-6} = 686$ kN-m > 398.25 kN-m
Therefore Section is singly reinforced.
$M_u/bd^2 = 398.25 \times 10^6/(400 \times 680^2) = 2.15 < 3.73$, URS
$P_t = 1.114\%$
$A_{st} = 3030$ mm^2, Provide 3-Φ32 mm + 4-Φ16 mm at bottom face,
Area provided = 3217 mm^2
$L_{dt} = 39 \times 32 = 1248$ mm

Curtailment

All bottom bars will be continued up to the end of cantilever. The bottom bars of 3 - Φ 32 will be curtailed at a distance d (= 680 mm) from the point of contra flexure (λ = 680 mm) in the portion BE with its distance from the centre of support equal to 1360 mm from B.

Cantilever portion AC

Length of cantilever from the face of column =900-350/2 = 725 mm

Ultimate moment = 354 x 0.7252 /2 = 93 kN-m

M_u/bd^2 =93x10^6/(400x6802) =0.52 $<$3.73, URS

P_t=0.245% (Greater than minimum steel)

A_{st} =660 mm^2

Provide 4 - Φ 16 mm at bottom face, Area provided = 804 mm^2

Continue all 4 bars of 16 mm diameter through out at bottom.

Region AB between points of contra flexures

The beam acts as an isolated T- beam.

$b_f = [L_o/(L_o / b + 4)] + b_w$, where,

$L_o = 4.6 - 0.206 - 0.68 = 3.714$ m = 3714 mm

b= actual width of flange = 2000 mm, $b_w = 400$ mm

$b_f = [3714/(3714/2000+4) + 400] = 1034$mm < 2000mm

$D_f = 200$ mm, $M_u = 628$ kN-m

Moment of resistance M_{uf} of a beam for $x_u = D_f$ is :

$M_{uf} = [0.36 \times 25 \times 1034 \times 200(680 - 0.42 \times 200)] \times 10^{-6}$

$= 1109$ kN.m > M_u (= 628 kN-m)

Therefore $X_u < D_f$

$M_u = 0.87 f_y A_{st}(d - f_y A_{st}/f_{ck} b_f)$

$A_{st} = 4542\ mm^2$

Provide 5 bars of Φ 32 mm and 3 bars of Φ 16 mm,

Area provided = 4021 + 603 = 4624 mm^2 >4542 mm^2

p_t = 100 x 4624/(400x680) = 1.7 %

Curtailment:

Consider that 2 - Φ 32 mm are to be curtailed

No. of bars to be continued = 3 - Φ16 + 3 - Φ 32

giving area = A_{st} =3016 mm^2

Moment of resistance of continuing bars

M_{ur}= (0.87 x 250 x 3016 (680 – ((250 x 3016) / (25 x 400)) x 10^{-6}

= 396.6 kN-m

Let the theoretical point of curtailment be at a distance x from the free end C,

Then, M_{uc}= M_{ur} Therefore -354 x^2 / 2 + 1050 (x- 0.9) = 396.6

x^2-5.93x + 7.58 =0, Therefore x = 4.06m or 1.86m from C

Actual point of curtailment = 4.06 + 0.68 = 4.74 m from C or 1.86 - 0.68 = 1.18 m from C

Terminate 2 - Φ 32 mm bars at a distance of 280 mm (= 1180 - 900) from the column A and 760mm (= 5500 - 4740) from column B. Remaining bars 3 - Φ 32 shall be continued beyond the point of inflection for a distance of 680 mm i.e. 460 mm from column A and up to the outer face of column B. Remaining bars of 3 - Φ 16 continued in the cantilever portion.

Design of shear reinforcement Portion between column i.e. AB

In this case the crack due to diagonal tension will occur at the point of contra flexure because the distance of the point of contra flexure from the column is less than the effective depth d(= 680mm)

(i) Maximum shear force at B = V_{umax} = 898.2 kN

Shear at the point of contra flexure

= V_{uD} - 898.2-354 x 0.68 = 657.48 kN

τ_v=657000/(400x680) =2.42 MPa < $\tau_{c,max.}$

Area of steel available 3 - Φ 16 + 3 - Φ 32 ,

A_{st} = 3016 mm^2

p_t = 100 x 3016 / (400 x 680) = 1.1%

τ_c=0.664MPa

$\tau_v > \tau_c$

Design shear reinforcement is required.

Using 12 mm diameter 4 - legged stirrups,

Spacing= [0.87 x 250x(4x113)] /(2.42-0.664)x400 =139 mm

say 120 mm c/c

Zone of shear reinforcements between τ_v to τ_c

= m from support B towards A

(ii) Maximum shear force at A
= $V_{u\,max}$= 731.4 kN.

Shear at the point contra flexure = V_{uD} = 731.4 - 0.206 x 354 = 658.5 kN

τ_v=658500/(400x680) =2.42MPa $< \tau_{c,max.}$

Area of steel available = 4624 mm^2, p_t= 100 x 4624 / (400 * 680) = 1.7 %
τ_{uc} = 0.772 N/ mm^2,

$\tau_v > \tau_c$

Design shear reinforcement is required.

Using 12 mm diameter 4 - legged stirrups,
Spacing = 0.87 x 250 x (4 x 113) /(2.42-0.774)x400
=149 mm say 140 mm c/c

Zone of shear reinforcement.
From A to B for a distance as shown in figure

For the remaining central portion of 1.88 m provide minimum shear reinforcement using 12 mm diameter 2 - legged stirrups at
Spacing , s = 0.87 x 250 x (2 x 113)/(0.4 x 400)=307.2 mm, Say 300 mm c/c< 0.75d

Cantilever portion BD

V_{umax} = 601.8kN,
V_{uD}=601.8-354(0.400/2 + 0.680) = 290.28kN.

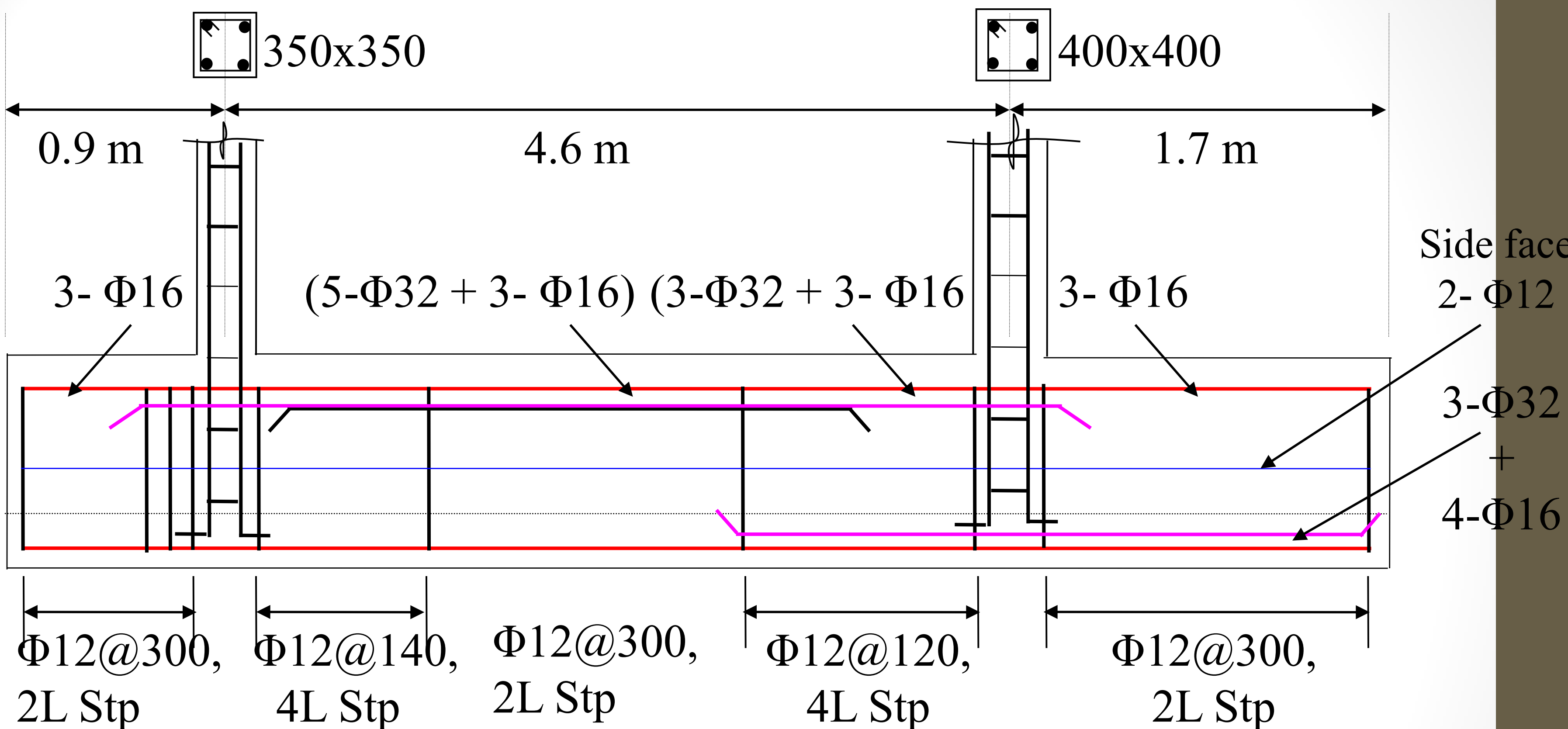
τ_v=290280/(400x680) =1.067MPa $< \tau_{c,max.}$

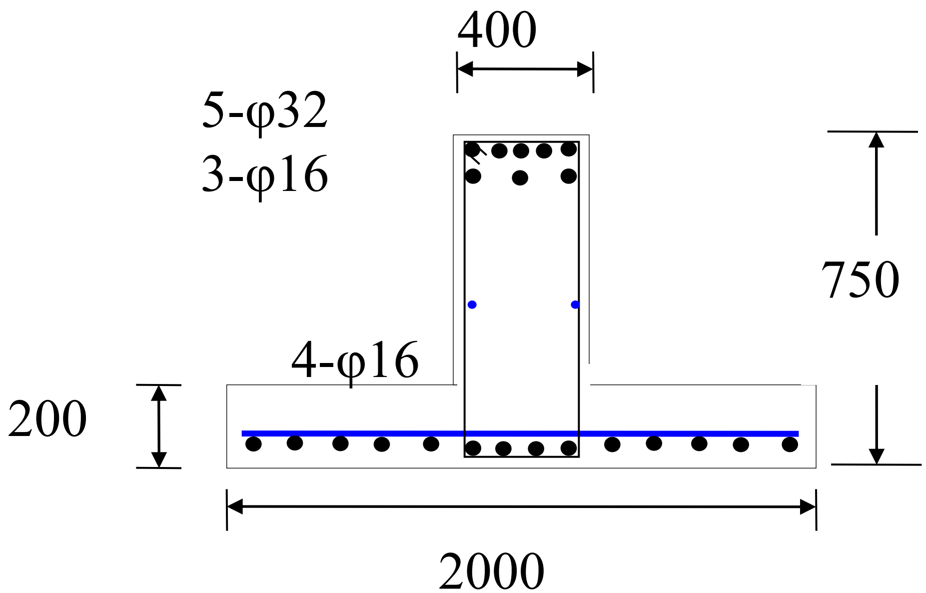
A_{st} = 3217 mm^2 and p_t = 100 x 3217/(400 x 680) = 1.18%
τ_c =0.683N/mm^2 (Table IS:456-2000)
$\tau_v > \tau_c$ and $\tau_v - \tau_c < 0.4$. Provide minimum steel.

Using 12 mm diameter 2- legged stirrups,
Spacing = 0.87 x 250 x (2 x 113) /(0.4x400) =307.2 mm say 300 mm c/c

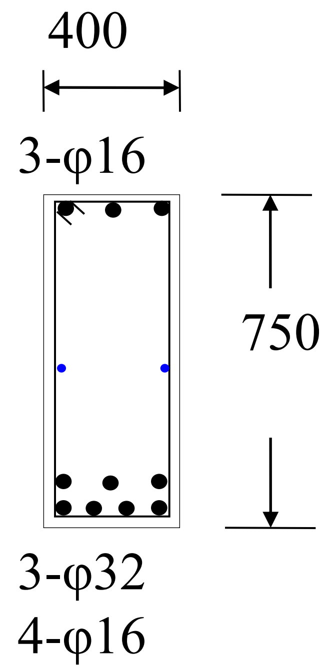
Cantilever portion AC

Minimum shear reinforcement of Φ 12 mm diameters 2 - legged stirrups at 300mm c/c will be sufficient in the cantilever portions of the beam as the shear is very less.

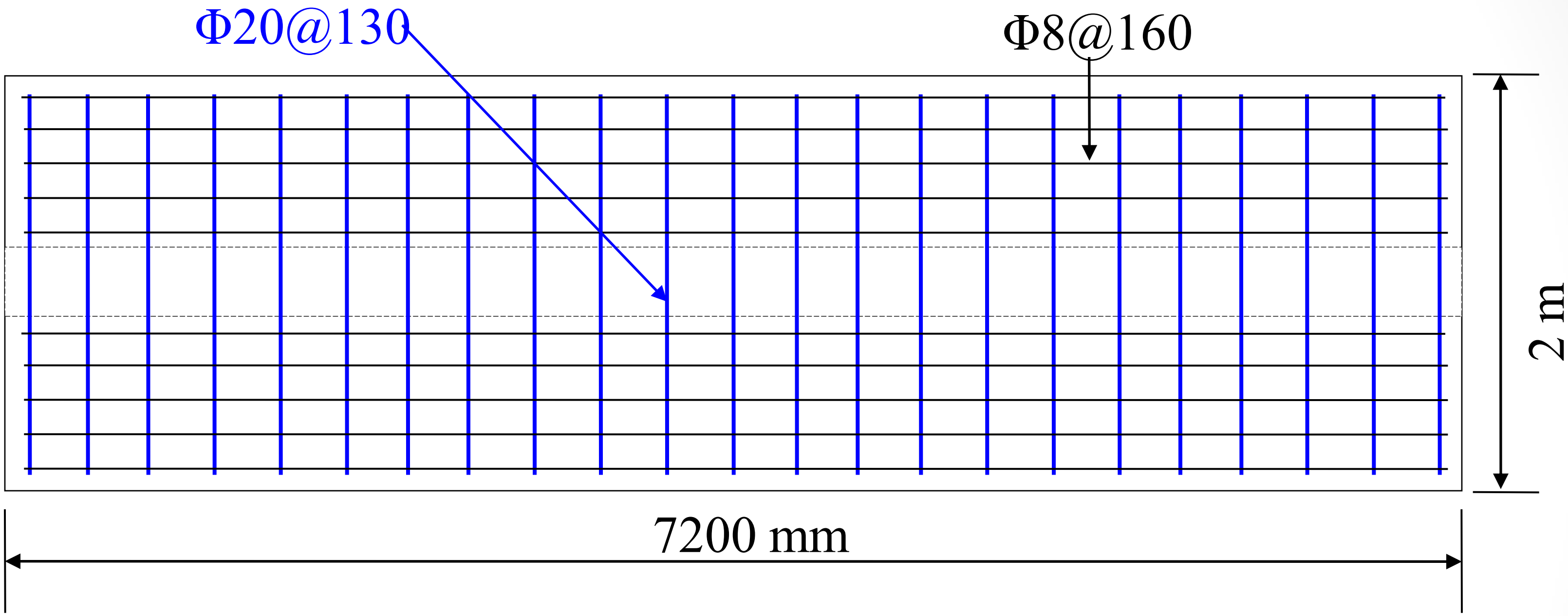

350x350
400x400
0.9 m
4.6 m
1.7 m
3- Φ16
(5-Φ32 + 3- Φ16)
(3-Φ32 + 3- Φ16
3- Φ16
Side face
2- Φ12
3-Φ32
+
4-Φ16
Φ12@300,
2L Stp
Φ12@140,
4L Stp
Φ12@300,
2L Stp
Φ12@120,
4L Stp
Φ12@300,
2L Stp



C/S at Centre



C/S at the junction
(Right of B)



Plan of footing slab