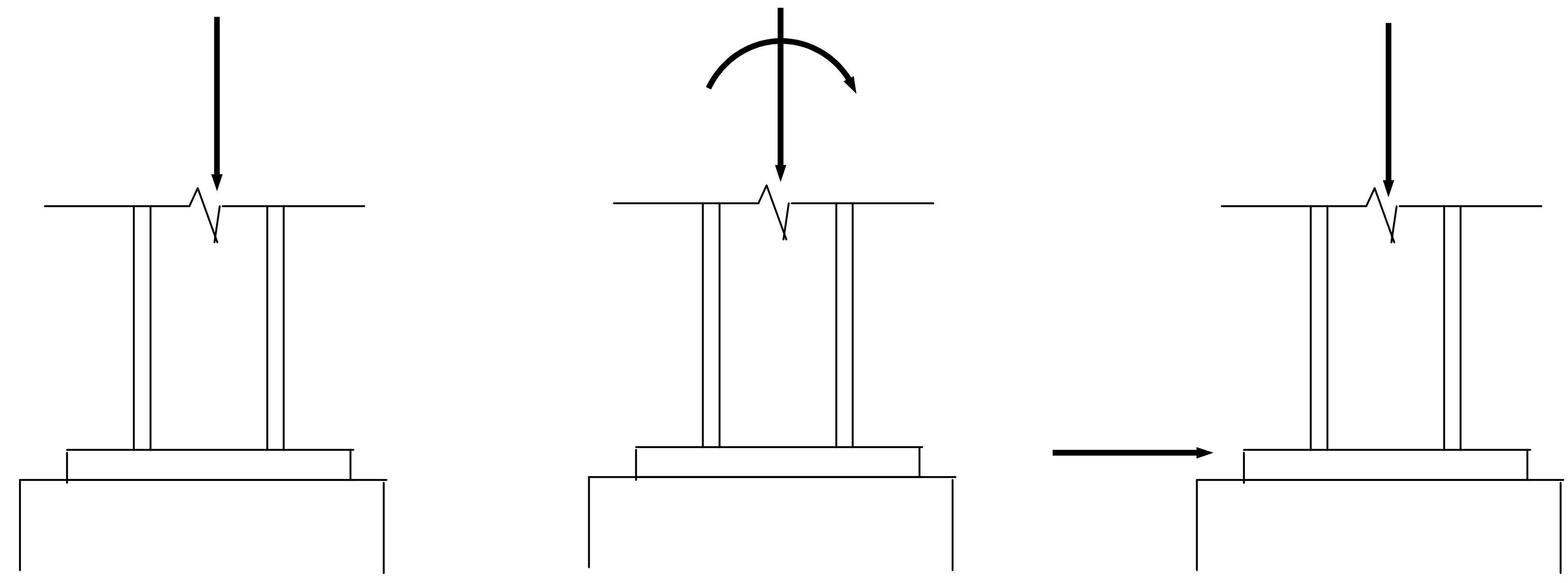
COLUMN BASES

- The function of a column base is to safely transfer column forces to the reinforced column footing underneath.
- The same concept may also be used to design bearing plates for the beams resting on reinforced concrete or masonry.
- The column base may be subjected to only axial load, axial load plus moment or axial load plus shear as shown in Figure 10.6.



a) Axial Load b) Axial Load Plus Moment c) Axial Load Plus Shear

Figure 10.13. Basic Types of Column Bases.

- In the first case, the load is applied through the centroid of the column at the centroid of the base plate.
- The column end in this case is considered as a hinge for the analysis.
- In the second case, either the load acts at some eccentricity from the column centroid or moment is also transferred to the foundation making the column end either a fixed or a partially fixed end.

- Anchor bolts are needed to resist the developed tension in case of heavy moments.
- Although some shear force is also present in this second type, a separate design for this shear force is not generally required.
- The third type is usually more important when the bracing is connected at the base.
- The shear is resisted through the friction between the column and the base plate due to heavy axial loads or bearing in the horizontal direction by the provision of bolts or shear lugs.

In case of bearing plates with moments, three different combined bearing stress distributions are possible depending upon the magnitude of the eccentricity.

Case I: $e \leq N/6$

- This case, as in Figure 10.14, represents the application of load in the kern of the section (middle one-third dimension) and the bearing stresses will be compressive throughout with no anchor bolts required for the moment. However, minimum anchor bolts may be used for shear and for extra safety in the horizontal direction.

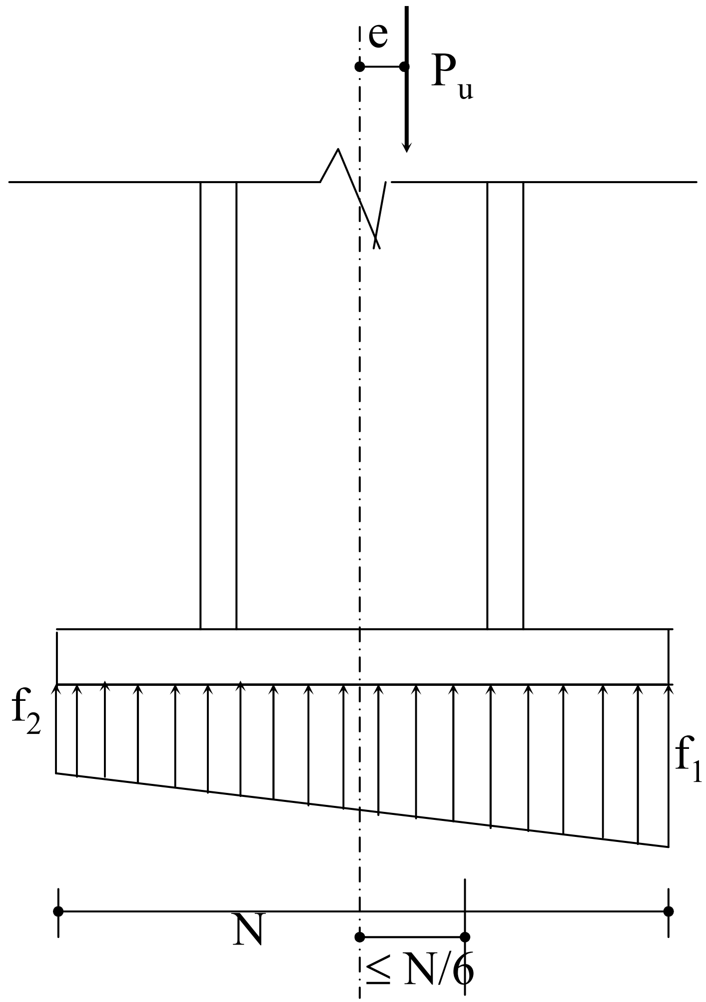


Figure 10.14.Base Plates with Low Eccentricity of Load.

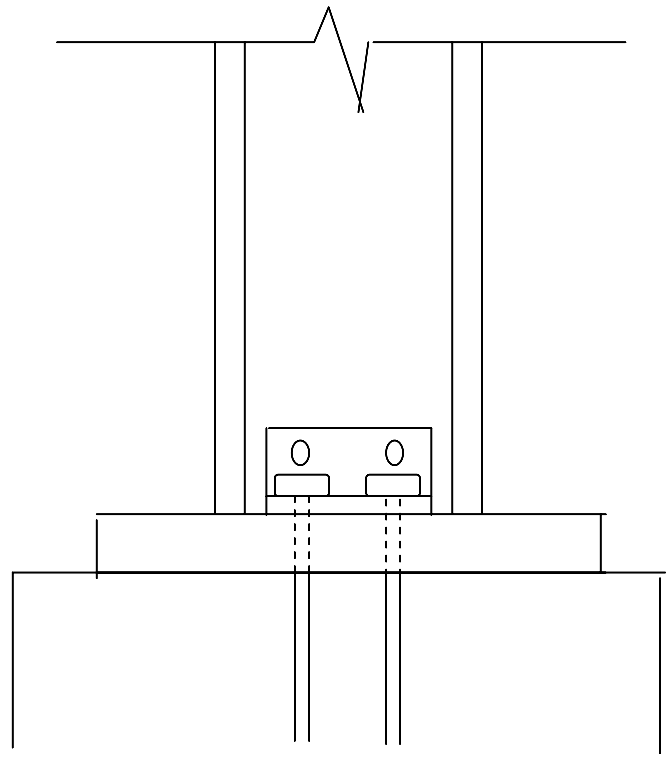


Figure 10.19.A Common Hinged Column Base.

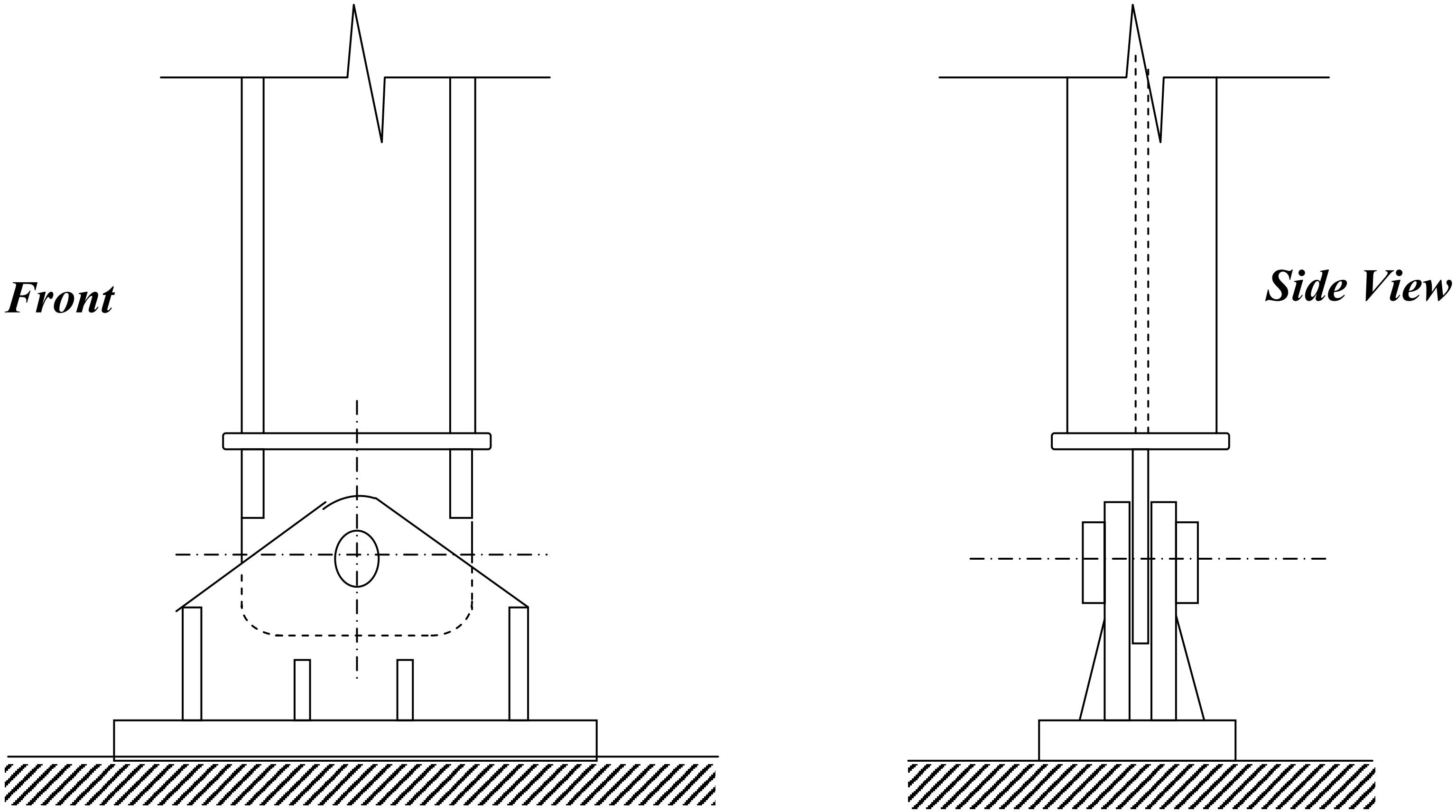


Figure 10.20. A True Hinged Column Base.

Case II: $N/6 < e \leq N/2$ Without Anchor Bolts

- For this moderate eccentricity without anchor bolts (Figure 10.15), bearing occurs over a portion of the plate denoted by $A = 3\,(N/2 - e)$, for equilibrium of applied and resistive forces and moments.

Greater is the value of e, smaller is A and the bearing pressure increases quickly.

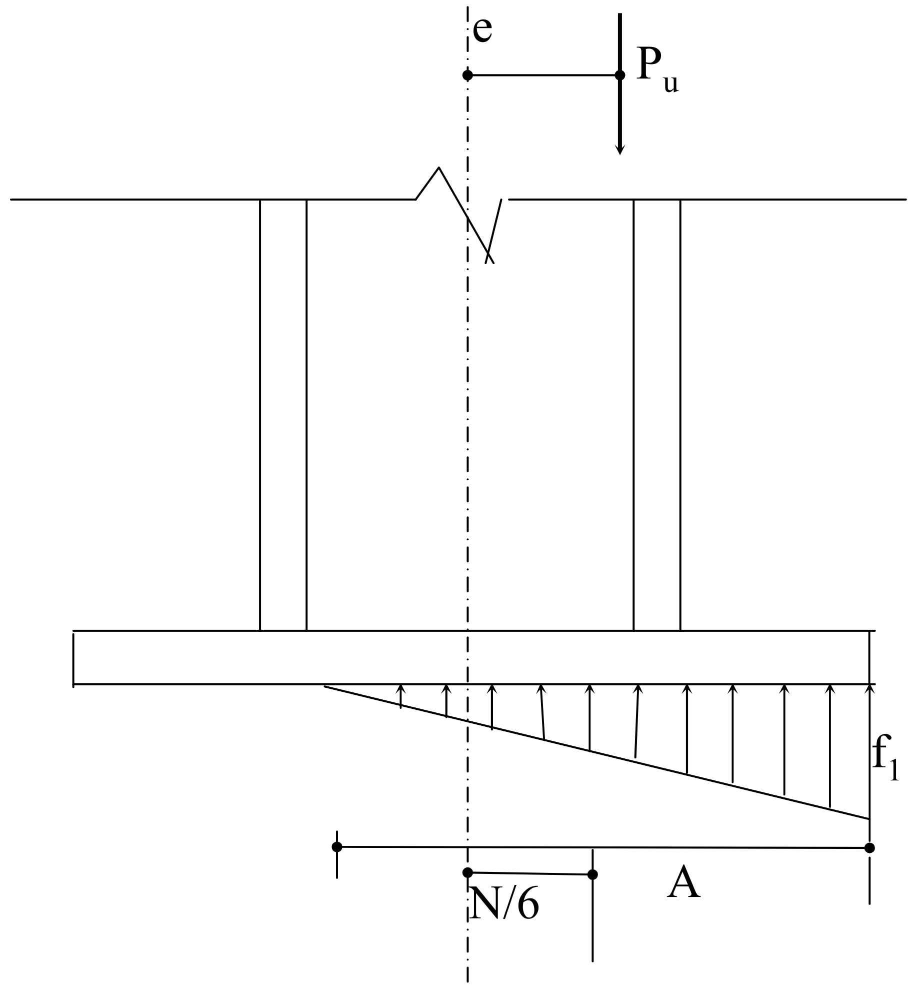
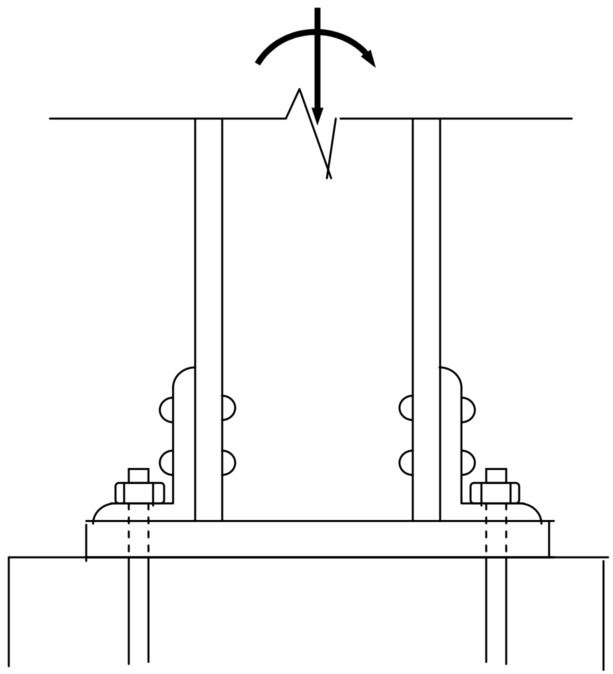


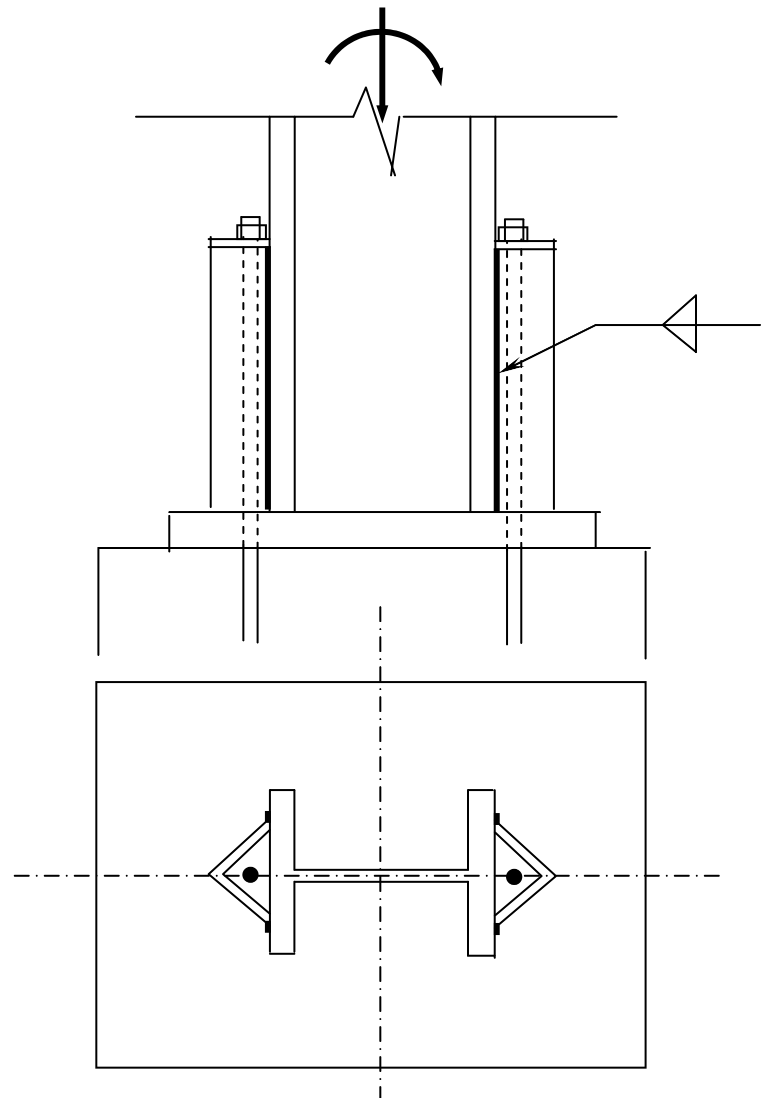
Figure 10.15.Base Plates Having Moderate Eccentricity Without Anchor Bolts.

Case III: Large Eccentricity With Anchor Bolts

- Figure 10.16 shows the case of base plate with large eccentricity, in which anchor bolts are to be used providing the developed tensile resistive forces.
- Linear distribution of pressure is still assumed even at the ultimate stages as an approximation.



(a) Base With Moderate Moment



(a) Base With High Moment

Figure 10.18.Column Bases With Moments.

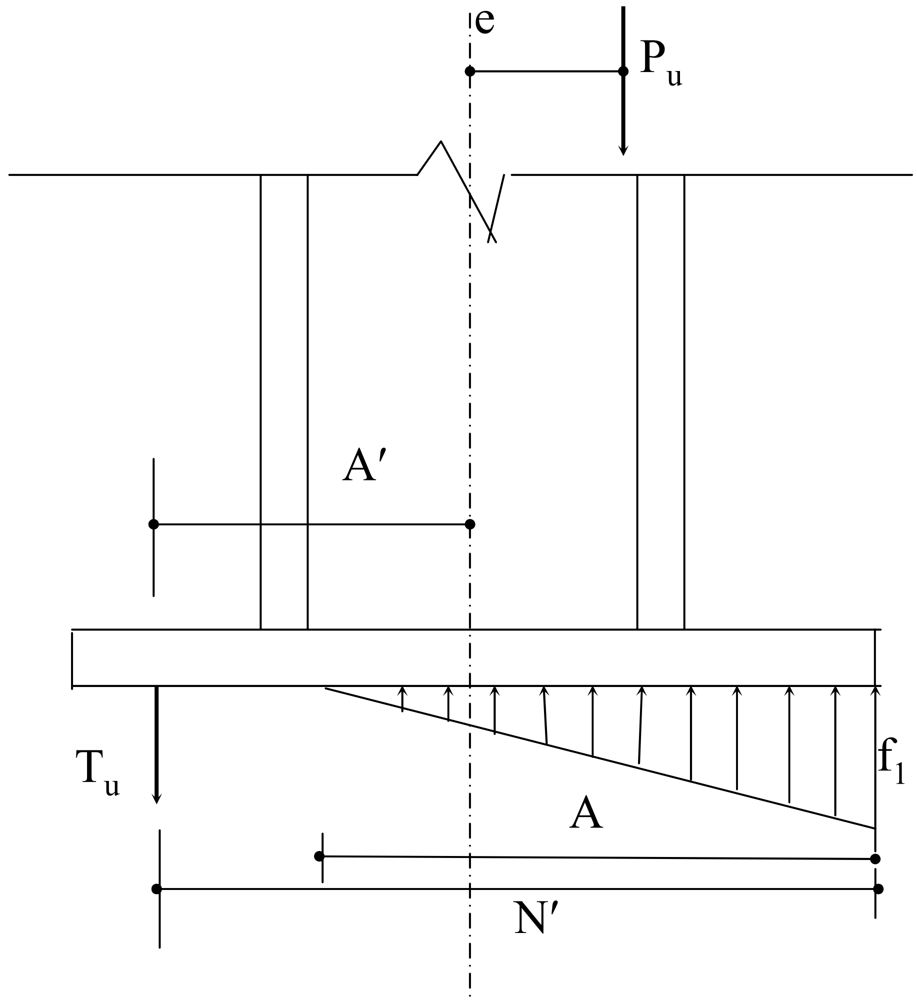


Figure 10.16.Base Plates Having Large Eccentricity With Anchor Bolts.

Axially Loaded Base Plates

- W-section columns are considered here that are centered over the base plate and the reinforced concrete footing.
- The following nomenclature will be used for the design:

t_p = base plate thickness,

f_p = bearing stresses under the base plate,

B = base plate size parallel to flange of the W section,

N = base plate size parallel to web of the W section,

$0.80\ b_f$ = supported base plate dimension parallel to the flange,

$0.95\ d$ = supported base plate dimension parallel to the depth of the section,

n = overhang of base plate parallel to the flange,

= $(B - 0.80\ b_f) / 2$,

m	=	overhang of base plate parallel to the column depth,
	=	$(N - 0.95\,d) / 2$,
f_c'	=	concrete compressive strength, MPa,
A_1	=	area of the base plate, $B \times N$,
A_2	=	area of the supporting concrete foundation that is geometrically similar to the base plate,
ϕ_c	=	resistance factor for bearing on concrete,
	=	0.60,

P_p = ultimate capacity of the concrete in bearing,

$$= 0.85 f_c' A_1 \sqrt{\frac{A_2}{A_1}} \le 1.7 f_c' A_1$$

when the concrete area is greater than the plate area, bearing stress is increased due to confinement provided by the extra concrete,

and P_u = factored axial load from the column.

- The base plate is assumed to bend about the critical sections (perimeter of central $0.85\ b_f \times 0.95\ d$ portion of the base plate) as a cantilever beam subjected to uniformly distributed bearing stress.
- The critical cantilever span is the greater of m and n.
- The most economical base plate may be designed when the cantilever lengths in the two directions are equal and the concrete area is equal to or greater than four times the plate area.

- If m or n is lesser than either $b_f/2$ or $d/2$, the area between the column flanges is to be checked for bending.
- This approximate method to make this check assumes a maximum permitted bearing pressure over an H-shaped contact area under the column cross-section between the plate and the concrete.
- The second method assumes a uniform bearing stress distribution and results in a conservative but easy design.

The procedure of this method involves calculation of equivalent cantilever length, ℓ, for bending within the flanges as follows:

$$n' = \frac{1}{4}\sqrt{d\,b_f}$$

The critical section used to calculate bending moment is at 0.95 times the outside column dimension for rectangular tubes and at 0.80 times the outside dimension for round pipes.

Procedure For Design of Axially Loaded Base Plate

- The procedure is started with the known values of the concrete pad size A_2, factored column load P_u, depth of the section d and the flange width of the section b_f.
- If the concrete area is not known in the start, it is reasonably assumed and then is revised later if required.

- The required area of the plate is calculated as follows:

A_1 = larger of

1. $$\frac{1}{A_2}\left[\frac{P_u}{0.60 \times 0.85 f_c'}\right]^2 \quad or \quad \frac{1}{\sqrt{A_2 / A_1}}\left[\frac{P_u}{0.60 \times 0.85 f_c'}\right]$$

2. $$\frac{P_u}{0.60 \times 1.7 f_c'}$$

3. Minimum size, which may be (d + 18) x (b_f + 18) mm.

- The plate size $B \times N$ is determined such that m and n are approximately equal.
- One way to achieve above objective is to calculate x and then B and N as follows:

$$x = 0.5x(0.95d - 0.80b_f)$$

$$N = SQRT(A_1) + x \quad >= \quad d + 18$$

$$B = A_1 / N \quad >= \quad b_f + 18$$

- The sizes are rounded to the nearest 10 mm multiples.
- The area of the base plate A_1 is then evaluated.

- The exact values of the cantilever lengths in the two directions and the equivalent cantilever length for bending within the flanges are determined.
- The greatest value out of the three is chosen as the design cantilever length.

$$n = (B - 0.80\, b_f) / 2$$

$$m = (N - 0.95\, d) / 2$$

$$n' = \frac{1}{4}\sqrt{d\, b_f}$$

$$\ell = \max(m, n, n')$$

- The required plate thickness is calculated and is rounded to upper whole number millimeters up to 10 mm and then in the sequence 12, 15, 18, 20, etc.
- Required plate thickness is then evaluated as follows:

$$t_p = \ell \sqrt{\frac{2\,P_u}{0.90\,F_y\,B\,N}}$$

Example 10.3

- Design a hinged base plate for a W360×314 column having a total factored load of 5000 kN. Use A36 steel and concrete of 17 MPa compressive strength.

Solution:

$P_u = 5000$ kN

$d = 399$ mm

$b_f = 401$ mm

$= 17$ MPa

Using $A_2 \approx 2.0\, A_1$

$A_1 \quad = \quad$ larger of

$$\frac{1}{\sqrt{2}}\left[\frac{5{,}000{,}000}{0.60 \times 0.85 \times 17}\right] = 407{,}790\, mm^2$$

$$\frac{5{,}000{,}000}{0.60 \times 1.7 \times 17} = 288{,}351\, mm^2$$

$(d + 18)$ x $(b_f + 18)$ $= 174{,}723$ mm^2

$= 407{,}790$ mm^2

(say 640×640mm $= 409{,}600$ mm^2)

$$A_2 \quad = \quad 2 \times 407{,}790 \;=\; 815{,}580 \text{ mm}^2$$

$$(\text{say } 910 \times 910 \text{ mm} \;=\; 828{,}100 \;\text{ mm}^2)$$

$$n \quad = \quad (640 - 0.80 \times 401) \,/\, 2 = \; 160 \text{ mm}$$

$$n' \quad = \quad \frac{1}{4}\sqrt{399 \times 401} \;=\; 100 \text{ mm}$$

$$m \quad = \quad (640 - 0.95 \times 399) \,/\, 2 = \; 131 \text{ mm}$$

$$\ell \;=\; \max\,(m, n, n') \;=\; 160 \text{ mm}$$

$$t_p = 160\sqrt{\frac{2 \times 5{,}000{,}000}{0.90 \times 250 \times 409{,}600}}$$

$$= 52.7 \text{ mm}$$

(say 55 mm thick plate of size 640×640 mm)

Base Plates With Moments

Case I: $e \leq N/6$

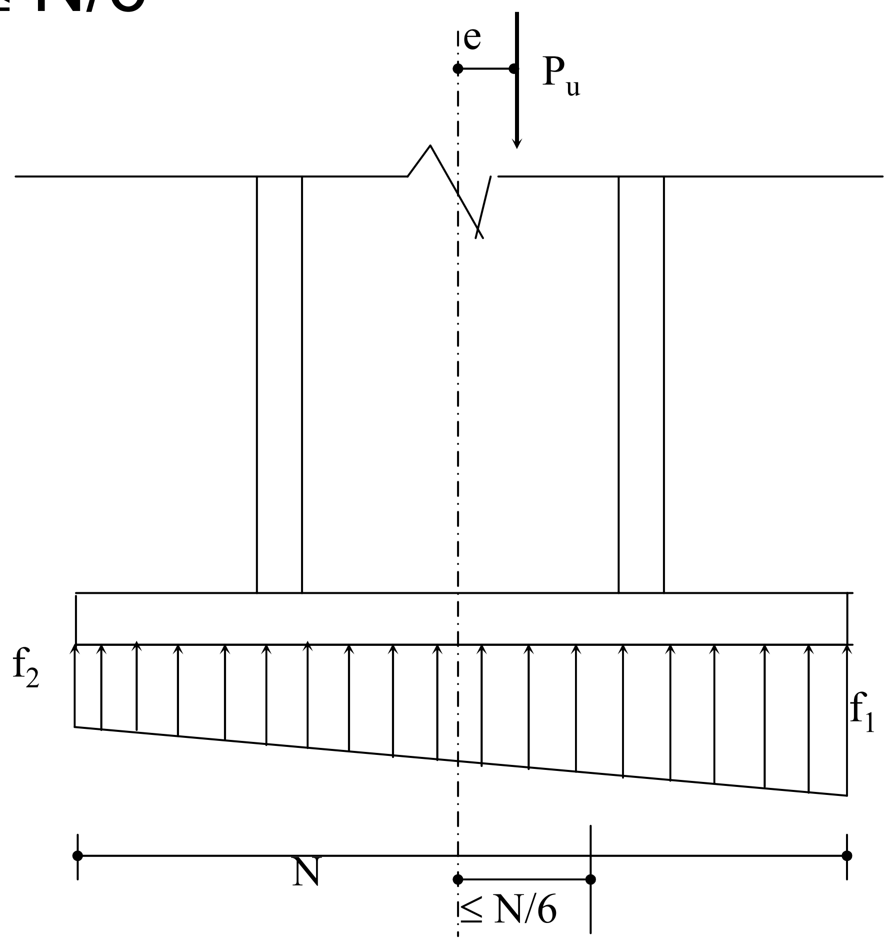


Figure 10.14. Base Plates with Low Eccentricity of Load.

This case, as in Figure 10.14, represents the application of load in the kern of the section (middle one-third dimension) and the bearing stresses will be compressive throughout with no anchor bolts required for the moment.

However, minimum anchor bolts may be used for shear and for extra safety in the horizontal direction.

The bearing stresses may be calculated by considering the plate area as cross-section of a beam subjected to eccentric loads.

$$f_1 \text{ and } f_2 = \frac{P_u}{B\,N} \pm \frac{M_u(N/2)}{B\,N^3/12}$$

$$= \frac{P_u}{B\,N} \pm \frac{6M_u}{B\,N^2}$$

Case II: $N/6 < e \leq N/2$ Without Anchor Bolts

For this moderate eccentricity without anchor bolts (Figure 10.15), bearing occurs over a portion of the plate denoted by $A = 3\,(N/2 - e)$, for equilibrium of applied and resistive forces and moments.

This expression is derived based on the fact that A must be equal to N when $e = N / 6$ and A must be zero when $e = N / 2$.

Greater is the value of *e*, smaller is *A* and the bearing pressure increases quickly.

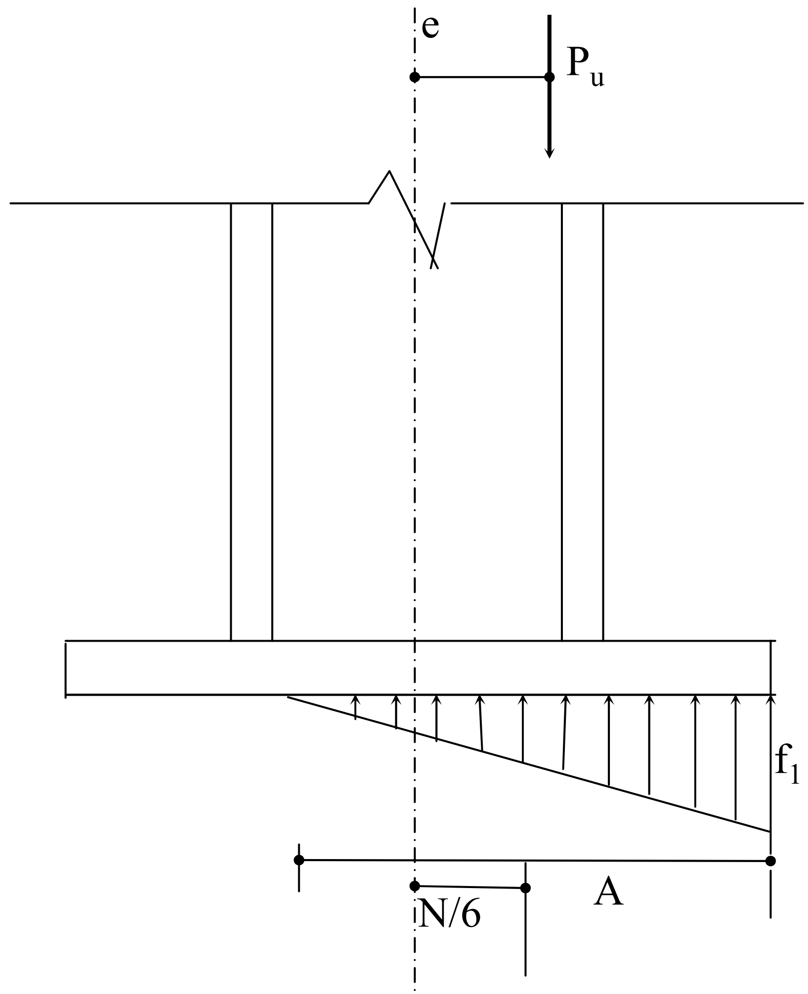


Figure 10.15. Base Plates Having Moderate Eccentricity Without Anchor Bolts.

For equilibrium,

$$\frac{1}{2} f_1 A\, B = P_u \qquad f_1 = \frac{2P_u}{A\, B}$$

Case III: Large Eccentricity With Anchor Bolts

Figure 10.16 shows the case of base plate with large eccentricity, in which anchor bolts are to be used providing the developed tensile resistive forces.

Linear distribution of pressure is still assumed even at the ultimate stages as an approximation.

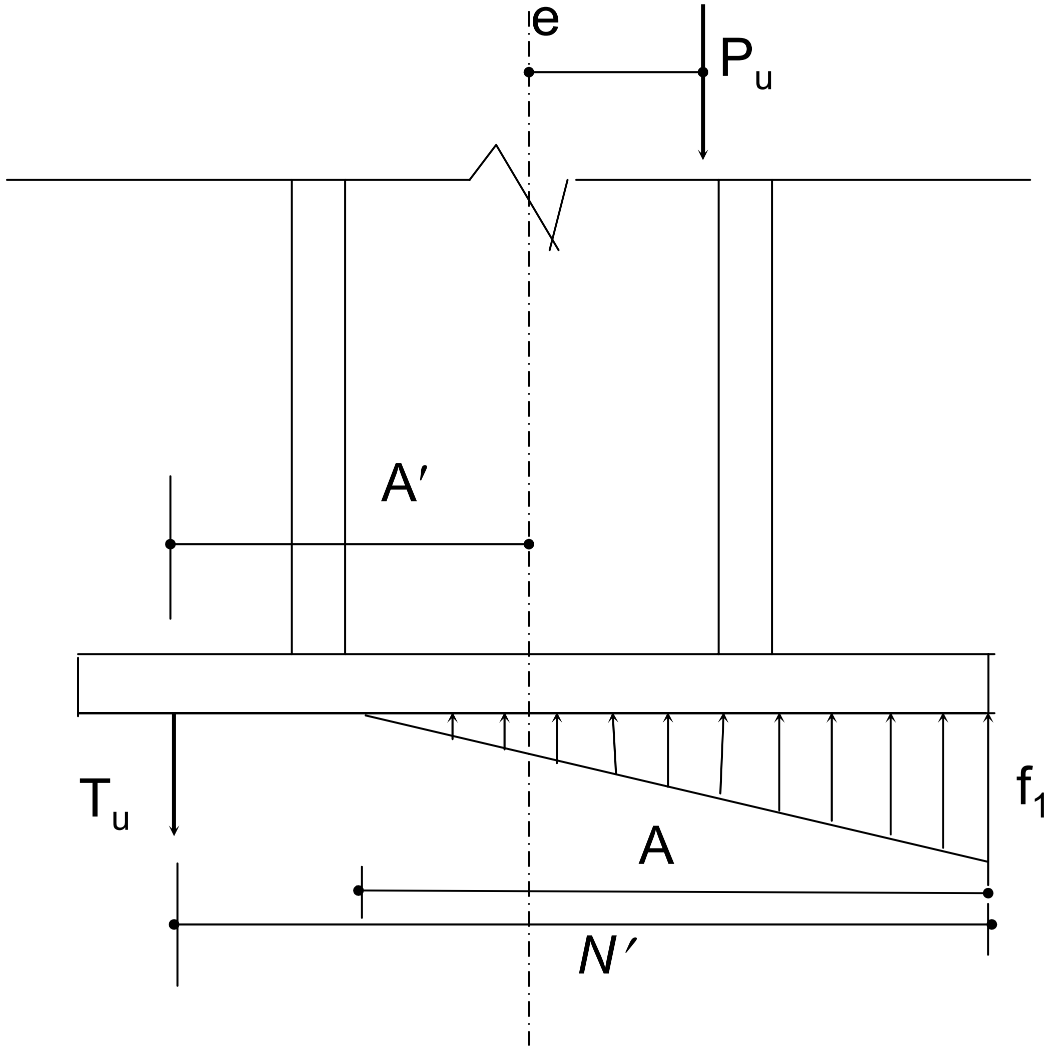


Figure 10.16. Base Plates Having Large Eccentricity With Anchor Bolts.

T_u = tensile force developed in the anchor bolts,

A' = distance of anchor bolt from the column center,

A = dimension of the portion in compression,

and

N' = centroidal distance of the anchor bolt in tension from the compression face.

For equilibrium of forces,

$$T_u + P_u = f_1 A B / 2$$

For equilibrium of moments at the location of anchor bolts:

$$P_u A' + M_u = f_1 \frac{AB}{2}\left(N' - \frac{A}{3}\right) \qquad M_u = P_u \times e$$

$$f_1 \frac{B}{6} A^2 - f_1 \frac{BN'}{2} A + (P_u A' + M_u) = 0$$

$$\therefore \quad A = \frac{F \pm \sqrt{F^2 - 4\left(\frac{f_1 B}{6}\right)\left(P_u A' + M\right)}}{f_1 B / 3}$$

where $F = f_1 (B N') / 2$

After knowing the value of A as above, the equation for equilibrium of forces presented earlier gives

$$T_u = f_1\, A\, B\, /\, 2 - P_u.$$

For evaluating this equation, the value of f_1 may be taken equal to the maximum allowable bearing stress.

The step-by-step procedure for the design of column base plate subjected to moment may be summarized as follows:

1. Calculate the eccentricity e from the known values of P_u and M_u.

2. Determine the allowable bearing stress by selecting some reasonable A_2/A_1 ratio.

$$F_p = 0.85\phi_c f_c' \sqrt{A_2 / A_1} \leq 1.7\phi_c f_c'$$

where $A_1 = A \times B$ and $\phi_c = 0.60$

3. Calculate minimum area of the plate required, A_1, by assuming zero eccentricity as before.

4. Assume a plate size, $N \times B$, reasonably bigger than A_1 depending upon the amount of eccentricity of the load.

Usually N is taken closer to two times the eccentricity.

5. If $e \leq N / 6$, design by steps 6 and 7, otherwise move to step 8.

6. Calculate f_1, and if $f_1 > F_p$, increase the plate size and revise the calculations.

7. Calculate the cantilever length m and calculate bending moment acting on 1-mm strip of the plate (M_{plu}) due to the bearing pressure.

Bearing stress at the critical section,

$$f_c = f_1 - \frac{(f_1 - f_2)}{N} \times m$$

$$M_{plu} = \frac{f_c \times m^2}{2} + \frac{(f_1 - f_c) \times m^2}{3} \quad \text{N–mm / mm}$$

$$t_p = \sqrt{\frac{4M_{plu}}{0.90\,F_y}}$$

8. Calculate ℓ (equal to lesser of n and n') just like an axially loaded base plate with pressure f_1 and find t_p as under:

$$t_p = \ell \sqrt{\frac{2f_1}{0.90\,F_y}}$$

9. If $e > N / 2$, anchor bolts are a must.

However, for $e > N / 6$ and $e < N / 2$, anchor bolts may or may not be used.

The distance A is then determined using the applicable equation, using f_1 equal to F_p.

If its value is closer to N', revise plate size such that the anchor bolt may develop tension.

$$F = \frac{f_1 BN'}{2}$$

$$A = \frac{F \pm \sqrt{F^2 - 4\left(\frac{f_1 B}{6}\right)\left(P_u A' + M_u\right)}}{f_1 B / 3}$$

10. Calculate the value of $A_1 = A \times B$ and $A_2 =$ (A + extra dimension on one side) $\times$ width of pedestal and check for the assumption of A_2 / A_1 in step 2.

11. Determine the total force in the anchor bolts. If the values are unreasonable, revise the plate size.

12. Calculate m, M_{plu} and t_p as follows:

$$m = (N - 0.95\, d) / 2$$

Moment From Plate Bearing Side

Case I: $A \geq m$

$$f_c = f_1 - \frac{f_1}{A} \times m$$

$$M_{plu} = \frac{f_c \times m^2}{2} + \frac{\left(f_1 - f_c\right) \times m^2}{3} \qquad \text{N–mm / mm}$$

Case II: $A < m$

$$M_{plu} = \frac{f_1 \times A}{2}\left(m - \frac{A}{3}\right) \qquad \text{N–mm / mm}$$

Moment From Anchor Bolt Side

The plate width over which the anchor bolt force is spread is assumed based on the load spreading out at 45^o angle towards the critical plane (Figure 10.17).

This width is equal to the distance from the bolt to the critical section for each bolt (ℓ_1) plus smaller of this distance and the bolt edge distance (*w*).

Total effective width for the anchor bolts:

$W_e = \ell_1$ + smaller of ℓ_1 and w

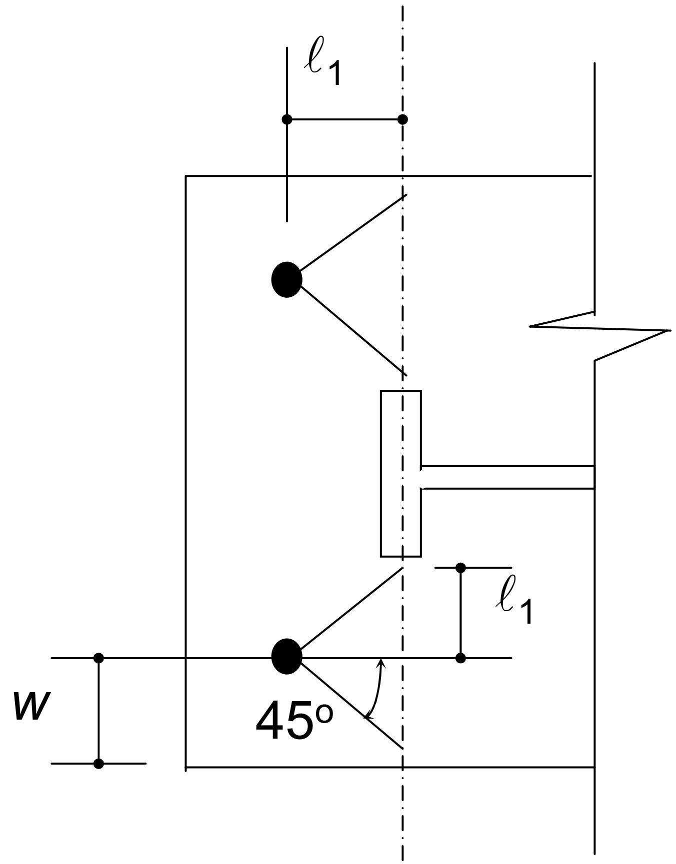


Figure 10.17. Spreading of Anchor Bolt Force on the Bearing Plate.

$$M_{plu} = (T_u \times \ell_1) / W_e$$

The maximum M_{plu} value out of the above two values is used to calculate the required plate thickness.

$$t_p = \sqrt{\frac{4M_{plu}}{0.90\,F_y}}$$

13. The plate thickness is taken as the larger value out of the calculated values.

Design Of Hooked Anchor Bolts

For the design of anchor bolts, AISC Specification refer to the Appendix-D of ACI – 318 (2005) Code.

Anchor bolts are required for all base plates to prevent accidental column overturning and to resist moments and uplift.

The tensile load is resisted by bond between anchor bolts and concrete and the hook at the bottom.

The lower hook may also consist of a welded nut but its design procedure will become different.

a) Select the diameter of the anchor bolt arbitrarily, or as follows ignoring the shear in the anchor bolts. If shear is also significant, F_u is reduced accordingly.

$$\pi/4\, d^2 = \frac{T_u}{0.75\,\phi_t\, F_u\, N_{bt}}$$

where N_{bt} = number of bolts on the tension side

and ϕ_t = 0.75

$$\therefore \quad d = \sqrt{\frac{T_u}{0.44\, F_u\, N_{bt}}}$$

b) Determine the bolt tensile capacity,

$$T_{bu} = 0.75\ \phi_t\ F_u\ A_g \text{ where } \phi_t = 0.75.$$

c) Check that sufficient tensile capacity is provided for the moment.

d) Calculate the required hook length according to the ACI Code provisions.

__Example 10.4__**:** A W 200 × 26.6 column is assumed fixed at the bottom for the analysis and design. The service axial dead and live loads are 100 and 165 kN, respectively. The bending is about the strong axis and the service dead and live load moments at the bottom of the column are 20 and 35 kN-m, respectively. The ratio of the concrete column to base plate area (A_2 / A_1) is to be kept closer to a value of 2.0. Design the base plate for the column using A36 steel for both the base plate and the anchor bolts and concrete having f_c' equal to 20 MPa.

Solution:

P_u = 1.2 (100) + 1.6 (165) = 384 kN

M_u = 1.2 (20) + 1.6 (35) = 80 kN-m

e = Mu / Pu = (80 / 384) $\times$ 1000 = 208 mm

$F_p = 0.85 \times 0.60 \times 20 \times \sqrt{2}$

$\leq 1.7 \times 0.60 \times 20$

= 14.42 MPa

$A_{1,min} = P_u / F_p = 483 \times 1000 / 14.42$

= 26,630 mm^2

Assuming a base plate size of 350 $\times$ 350 mm:

N / 6 = 58.3 mm : N / 2 = 175 mm

e = 208 mm

Because $e > N / 2$, anchor bolts are definitely required. Assume that the anchor bolts are placed at an edge distance of 40 mm.

$$N' = 350 - 40 = 310\ mm$$

$$A' = 350/2 - 40 = 416\ mm$$

$$Let\quad f_1 = F_p = 14.42\ MPa$$

$$F = f_1 (B N')/2$$

$$= 14.42 \times 350 \times 310 / 2$$

$$= 782{,}285\ N$$

$$A = \frac{782{,}285 \pm \sqrt{782{,}285^2 - 4\left(\dfrac{14.42 \times 350}{6}\right)\left(384{,}000 \times 135 + 80 \times 10^6\right)}}{14.42 \times 350 / 3}$$

$= 221$ mm (sufficiently lesser than N')

$T_u = f_1 \, A \, B / 2 - P_u$

$= 14.42 \times 221 \times 350 / 2 - 384{,}000$

$= 173{,}694$ *N* (*or 173.7 kN*)

[*reasonable for the bolt sizes available*]

For the column section, d = 207 mm and b_f = 133 mm.

Calculate ℓ (equal to lesser of n and n') just like an axially loaded base plate with pressure f_1 and find t_p as under:

$$t_p \quad = \quad \ell\sqrt{\frac{2f_1}{0.90\,F_y}}$$

$$n \quad = \quad (350 - 0.80 \times 133) / 2 \quad = \quad 121.8 \text{ mm}$$

$$n' \quad = \quad \frac{1}{4}\sqrt{207 \times 133} \quad = \quad 41.5 \text{ mm}$$

$$\ell \quad = \quad \max(n, n') \quad = \quad 121.8 \text{ mm}$$

$$t_p \quad = \quad 121.8\sqrt{\frac{2 \times 14.42}{0.90 \times 250}}$$

$$= \quad 43.61 \text{ mm}$$

Moment From Plate Bearing Side

$m \quad = \quad (N - 0.95\,d) / 2$

$\quad\quad = \quad (350 - 0.95 \times 207) /2 \quad\quad = \quad 76.7 \text{ mm}$

$A > m \quad\quad \Rightarrow$

$f_c \quad = \quad 14.42 - (14.42 / 221) \times 76.7 \quad\quad = \quad 9.42 \text{ MPa}$

$M_{plu} \quad = \quad 9.42 \times 76.72 / 2 + (14.42 - 9.42) \times 76.72 / 3$

$\quad\quad = \quad 37{,}513 \text{ N-mm/mm}$

Moment From Anchor Bolts Side

Distance of the anchor bolt from critical section,

$$\ell_1 = m - 40$$
$$= 36.7 \text{ mm}$$

Width on which anchor bolt force of one side is spread $= (36.7 + 36.7)$
$$= 73.4 \text{ mm}$$

M_{plu} = total moment / total width, for two anchor bolts on tension side

$$= (173{,}694 \times 36.7) / (2 \times 73.4)$$
$$= 43{,}424 \text{ N-mm/mm}$$

$\therefore \quad M_{plu}$ = larger of the above two values
= 43,424 N-mm/mm

$$t_p = \sqrt{\frac{4M_{plu}}{0.90\,F_y}}$$

$$= \sqrt{\frac{4 \times 43{,}424}{0.90 \times 250}}$$

$= 27.8$ *mm*

<u>say 45 mm</u>

(larger of all of above calculated values)

Use a 350 × 350 × 45 mm base plate

$$d = \sqrt{\frac{T_u}{0.44\, F_u\, N_{bt}}}$$

$$= \sqrt{\frac{173{,}694}{0.44 \times 400 \times 2}}$$

$$= 22.2 \text{ mm} \qquad \underline{\text{say } 25 \text{ mm}}$$

$$\phi_t\, T_n = 0.75 \times 0.75 \times 400 \times (\pi / 4) \times 25^2$$

$$= 110{,}447\ N$$