Special Reinforced Concrete Structural Walls

The requirements of this section apply to special reinforced concrete structural walls serving as part of the earthquake force-resisting system.

Shear Strength:

Based on ACI 18.10.4.1, nominal shear strength $V_n$ of structural walls is not to exceed

$$V_n = A_{cv} \left( \alpha_c \cdot \sqrt{f'_c} + \rho_t \cdot f_y \right)$$

Where $\alpha_c$ is a coefficient defining the relative contribution of concrete strength to wall strength, given as follows.

- $\alpha_c = 0.80$ for $h_u/l_w \leq 1.5$;
- $\alpha_c = 0.53$ for $h_u/l_w \geq 2.0$;
- $\alpha_c = 0.53$ to 0.80 (linear variation) for $h_u/l_w$ between 1.5 and 2.0.

$A_{cv}$ = gross area of concrete section bounded by web thickness and length of section in the direction of shear force considered, cm$^2$.

Shear Reinforcement:

At least two curtains of reinforcement shall be used in a wall if the in-plane factored shear force assigned to the wall exceeds $0.53A_{cv} \cdot \sqrt{f'_c}$ or $h_u/l_w \geq 2.0$, as specified by ACI 18.10.2.2. Based on ACI 18.10.2.1, the distributed web reinforcement ratios, $\rho_t$ and $\rho_t$, for structural walls shall not be less than 0.0025, except if $V_u$ does not exceed $0.27A_{cv} \cdot \sqrt{f'_c}$, $\rho_i$ and $\rho_t$ shall be permitted to be reduced to the values required in ACI 11.6. Reinforcement spacing each way in structural walls shall not exceed 45 cm. reinforcement contributing to $V_u$ shall be continuous and shall be distributed across the shear plane.

According to ACI 18.10.4.3, walls are to be reinforced with shear reinforcement in two orthogonal directions in the plane of the wall.

If $h_u/l_w \leq 2.0$, reinforcement ratio $\rho_i$ shall be at least the reinforcement ratio $\rho_I$. 

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Design for Flexure and Axial Loads:

Based on ACI 18.10.5.1, structural walls and portions of such walls subject to combined flexural and axial loads shall be designed in accordance with ACI 22.4.

Horizontal Wall Segments:

ACI 2.3 defines a horizontal wall segment, shown in the Figure R18.10.4.5, as a segment of structural wall, bounded vertically by two openings or by an opening and an edge. A vertical wall segment is a segment of a structural wall bounded horizontally by two openings, or by an opening and an edge; wall piers are vertical wall segments. A vertical wall segment is referred to as a coupling beam when openings are aligned vertically over the building height.

Normal shear strength of horizontal wall segments shall be assumed not to exceed $2.65 A_{cw} \sqrt{f'_c}$, where $A_{cw}$ is the cross-sectional area of a horizontal wall segment or coupling beam, as specified in ACI 18.10.4.5.

Wall Piers:

ACI 2.3 defines a wall pier as a vertical wall segment within a structural wall, bounded horizontally by two openings or by an opening and an edge, with ratio of horizontal length to wall thickness ($l_w/b_w$) less than or equal to 6.0, and ratio of clear height to horizontal length ($h_w/l_w$) greater than or equal to 2.0

ACI 18.10.4.4 states that normal shear strength of all wall segments sharing a common lateral force, $V_n$, shall not be taken larger than $2.12 A_{cv} \sqrt{f'_c}$, where
$A_{cv}$ is the total cross-sectional area of concrete bounded by web thickness and length of section. The normal shear strength of any one of the individual wall pier, $V_n$, shall not be taken larger than $2.65 A_{cw} \sqrt{f'_c}$, where $A_{cw}$ is the cross-sectional area of the individual vertical wall segment considered.

In ACI 18.10.4.2, the value of ratio $h_w/l_w$ used for determination of $V_n$ for segments of a wall shall be the larger of the ratios for the entire wall and the segment of wall considered.

**Boundary Elements:**

ACI 2.3 defines a boundary element as a portion along wall and diaphragm edge, including edges of openings, strengthened by longitudinal and transverse reinforcement.

Two design approaches for evaluating the need of boundary elements at the edges of structural walls are provided in ACI 18.10.6.2 and explained below.

A- For walls or wall piers with $h_w/l_w \geq 2.0$ that are effectively continuous from the base of the structure to top of wall and designed to have a single critical section for flexure and axial loads, ACI 18.10.6.2 requires that compression zones be reinforced with special boundary elements where:

$$c \geq \frac{l_w}{600(1.5\delta_u/h_u)}$$

and $c$ corresponds to the largest neutral axis depth calculated for the factored axial force and nominal moment strength consistent with the direction of design displacement $\delta_u$. The ratio $\delta_u/h_u$ in the previous equation shall not be taken less than 0.005.

Special boundary element reinforcement shall extend vertically above and below the critical section at least the greater of $l_w$ and $M_u/4V_u$, except when the critical section occurs at wall base, the boundary element transverse reinforcement at the wall base shall extend into the support at least $l_e$ of the largest longitudinal reinforcement in the special boundary element. Where the special boundary element terminates on a footing, mat, or pile cap, special boundary element transverse reinforcement shall extend at least 30 cm into the footing, mat, or pile cap, unless a greater extension is required by ACI 18.13.2.3.
The above design approach uses a displacement-based model. In this method, the wall is displaced an amount equal to 1.5 the expected design displacement, and boundary elements are required to confine the concrete when the strain at the extreme compression fiber of the wall exceeds a critical value.

**Boundary Element Requirements (ACI 18.10.6.2)**

B- Structural walls not designed to the provisions of ACI 18.10.6.2, shall have special boundary elements at boundaries and edges around openings of structural walls where the maximum extreme fiber compressive stress, corresponding to factored forces including earthquake effect, exceeds 0.2$f'_c$. The special boundary element shall be permitted to be discontinued where the calculated compressive stress is less than 0.15$f'_c$, as stated in ACI 18.10.6.3.

Stresses are calculated for the factored forces using a linearly elastic model and gross section properties, as given here

$$f = \frac{P_u}{A_s} \pm \frac{M_u(l_u/2)}{I_s}$$
Boundary Element Requirements (ACI 18.10.6.3)

Boundary Element Dimensions:

As required by ACI 18.10.6.4, boundary elements are to extend horizontally from the extreme compression fiber a distance not less than the larger of \( c - 0.1 l_w \) and \( c/2 \).

Width of the flexural compression zone, \( b \), over the horizontal distance calculated above, including flange if present, shall be at least \( h_u/16 \), where \( h_u \) is equivalent to \( l_u \). For walls or wall piers with \( h_w/l_w \geq 2.0 \) and with \( c/l_w \geq 3/8 \), width of flexural compression zone shall be greater than or equal to 30 cm.

Boundary Element Transverse Reinforcement:

The boundary element transverse reinforcement shall satisfy the requirements of ACI 18.7.5.2(a) through (e) and 18.7.5.3, except the value of \( h_i \) in 18.7.5.2 shall not exceed the lesser of 35 cm and two-thirds of the boundary element thickness, and the transverse reinforcement spacing limit of 18.7.5.3(a) shall be one-third of the least dimension of the boundary element.

The amount of transverse reinforcement shall be in accordance with Table 18.10.6.4(f).

The above requirements are summarized below:
Transverse reinforcement shall be provided by either single or overlapping hoops. Crossties of the same bar size and spacing as the hoops shall be permitted. Each end of the crossties shall engage a peripheral long reinforcing bar. Consecutive crossties shall be alternated end for end and along the longitudinal reinforcement. Spacing of crossties or legs of rectangular hoops, \( h_x \) within a cross section of the member shall not exceed 35 cm on center.

**Table 18.10.6.4(f)—Transverse reinforcement for special boundary elements**

<table>
<thead>
<tr>
<th>Transverse reinforcement</th>
<th>Applicable expressions</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A_{sh}/sb_x ) for rectilinear hoop</td>
<td>Greater of ( 0.3 \left( \frac{A_x}{A_{yb}} - 1 \right) \frac{f'<em>c}{f</em>{ytr}} ) (a)</td>
</tr>
<tr>
<td>( \rho_s ) for spiral or circular hoop</td>
<td>Greater of ( 0.45 \frac{A_x}{A_{yb}} - 1 \frac{f'<em>c}{f</em>{ytr}} ) (c)</td>
</tr>
</tbody>
</table>

where:
- \( A_{sh} \) = total cross-sectional area of transverse reinforcement, including crossties, within spacing \( S \) and perpendicular to dimension \( b_x \), cm\(^2\).
- \( A_g \) = gross area of concrete section, cm\(^2\).
- \( A_{ch} \) = cross-sectional area of a member measured to the outside edges of transverse reinforcement, cm\(^2\).
- \( S \) = spacing of transverse reinforcement measured along the longitudinal axis of the structural member, center-to-center.
- \( b_x \) = cross-sectional dimension of member core measured to the outside edges of the transverse reinforcement composing area \( A_{sh} \), cm.
- \( s_x \) = maximum center-to-center spacing of longitudinal bars supported by corners of crossties or hoop legs around the perimeter of the boundary element.
- \( f_{ytr} \) = specified yield strength of transverse reinforcement.
- \( f'_c \) = specified compressive strength of concrete.
Based on ACI 18.7.5.3, spacing of transverse reinforcement shall not exceed the smallest of (a) through (c):
(a) one-third of the minimum member dimension (as modified by ACI 18.10.6.4(e)),
(b) six times the diameter of the smallest longitudinal bar
(c) \( s_s \) as calculated by:
\[
s_s = 10 + \left( \frac{35 - h_s}{3} \right)
\]
The value of \( s_s \) shall not exceed 15 cm and need not be taken less than 10 cm.

In ACI 18.10.6.5, where special boundary elements are not required by ACI 18.10.6.2 or 18.10.6.3, (a) and (b) shall be satisfied.

(a) If the longitudinal reinforcement ratio at the wall boundary is greater than \( 28/y_f \), boundary transverse reinforcement shall satisfy 18.7.5.2(a) through (e) over the distance calculated in accordance with 18.10.6.4(a). The maximum longitudinal spacing of transverse reinforcement in the boundary shall not exceed the lesser of 20 cm and \( 8d_b \);

(b) Except when \( V_u \) in the plane of the wall is less than \( 0.265 A_{cv} \lambda \sqrt{f'_c} \), horizontal reinforcement terminating at the edges of structural walls without boundary elements shall have a standard hook engaging the edge reinforcement or the edge reinforcement shall be enclosed in U-stirrups having the same size and spacing as and spliced to the horizontal displacement.
Reinforcement Details for Boundary Elements

Anchorage and Splicing of Reinforcement:

In ACI 18.8.5.1, the development length \( l_{dh} \) for a bar with a standard 90 degree hook shall not be less than the largest of \( 8d_b \), 15 cm, and the length required by the following equation, which is applicable to bar diameters ranging from 10 mm to 36 mm.

\[
l_{dh} = \frac{d_b f_y}{17 \lambda \sqrt{f''_c}}
\]

The 90-degree hook shall be located within the confined core of a boundary element.
In ACI 18.8.5.3, for bar diameters 10 mm through 36 mm, the development length $l_d$ in tension, for a straight bar shall not be less than (a) and (b):

(a) 2.5 times the length required by the above-mentioned equation if the depth of the concrete cast in one lift beneath the bar does not exceed 30 cm, and

(b) 3.25 times the length provided by the same equation if the depth of the concrete cast in one lift beneath the bar exceeds 30 cm.

In ACI 18.8.5.4, straight bars terminated at a joint shall pass through the confined core of a boundary element. Any portion of $l_d$ not within the confined core shall be increased by a factor of 1.6.

The next figures show boundary element requirements for special shear walls.

---

**Fig. R18.10.6.4.1**—Development of wall horizontal reinforcement in confined boundary element.
(a) Wall with $h_w^2 / l_w \geq 2.0$ and a single critical section controlled by flexure and axial load designed using 18.10.6.2, 18.10.6.4, and 18.10.6.5

(b) Wall and wall pier designed using 18.10.6.3, 18.10.6.4, and 18.10.6.5

Fig. R18.10.6.4.2—Summary of boundary element requirements for special walls.
Example (7):

Redesign shear wall 'A' in example (6) as a special shear wall using ACI 318-14 for reinforced concrete design. Use $f'_c = 300 \text{ kg/cm}^2$ and $f_y = 4200 \text{ kg/cm}^2$.

Solution:

1- Design for shear:

At least two curtains of reinforcement shall be used in a wall if the in-plane factored shear force exceeds $0.53 A_{cv} \sqrt{f'_c}$ or $h_w / l_w \geq 2.0$.

$V_n = 0.53 A_{cv} \sqrt{f'_c} = 0.53(20)(300) \sqrt{300}/1000 = 55.08 \text{ tons}$

$\frac{V_n}{\phi} = \frac{15.16}{0.75} = 20.21 < 55.08 \text{ tons}$

Since $h_w / l_w = \frac{24}{3} = 8$ , two curtains of reinforcement are required.

1-1 Horizontal shear reinforcement:

$\rho_t = 0.0025$

$S_{2,\text{max}} = 45 \text{ cm}$

$\frac{A_t}{S_2} = \frac{0.0025 h = 0.0025(20)}{S_2} \text{ and } \frac{A_t}{S_2} = 0.05 \text{ cm}^2 / \text{cm}$

For two curtains of reinforcement and trying $\phi 10 \text{ mm bars}$

$\frac{2(0.785)}{S_2} = 0.05 , S_2 = 31.4 \text{ cm} < S_{2,\text{max}}$. Use $\phi 10 \text{ mm bars} @ 30 \text{ cm}$.

$0.27 A_{cv} \sqrt{f'_c} = 0.27(20)(300) \sqrt{300}/1000 = 28.06 \text{ tons} > 17.374 \text{ tons}$

Thus $\rho_t$ and $\rho_f$ may be reduced based according to ACI 11.6. Nevertheless, it will not be reduced in this example.
1-2 Vertical shear reinforcement:

\[ S_{I,\text{max}} = 45 \text{ cm} \]

For two curtains of reinforcement, and trying \( \phi 10 \text{ mm bars} \)

\[ \frac{A_l}{S_I} = 0.0025 \quad h = 0.0025(20) = \frac{2(0.785)}{S_I} \]

and \( S_I = 31.40 \text{ cm} < S_{I,\text{max}} \). Use \( \phi 10 \text{ mm bars} @ 30 \text{ cm} \).

Check for shear reinforcement capacity

\[ V_n = 15.16/0.75 = 20.21 \text{ tons} \]

\[ V_n = A_{cy} \left( \alpha_c \sqrt{f'_{c}} + \rho_t f_y \right) \]

\[ h_w/l_w = \frac{24}{3} = 8 \text{, i.e. } \alpha_c = 0.53 \]

\[ V_{n,\text{max}} = A_c \lambda \left( \alpha_c \sqrt{f'_{c}} + \rho_t f_y \right) = \]

\[ \left( 20 \right) \left( 300 \right) \left( 0.53 \sqrt{300} + 0.0025(4200) \right)/1000 = 118.08 \text{ tons} > 20.21 \text{ tons O.K} \]

2- Design for flexure and axial loads:

Boundary elements are required where the maximum fiber compression stress \( > 0.2 f'_{c} \), calculated from the following equation:

\[ f = \frac{P_u}{A_g} \pm \frac{M_u (l_w/2)}{I_g} \]

The boundary elements may be disconnected where the compressive stress \( < 0.15 f'_{c} \)

\[ M_u = \phi \left[ 0.5 A_s f_y l_w \left( 1 + \frac{P_u}{A_s f_y} \right) \left( 1 - \frac{c}{l_w} \right) \right] \]

where:

\[ \frac{c}{l_w} = \frac{\omega + \alpha}{2\omega + 0.85 \beta_1} \]

\[ \omega = \frac{A_s f_y}{l_w h f'_{c}} \text{ and } \alpha = \frac{p_u}{l_w h f'_{c}} \]

For the vertical shear reinforcement of \( \phi 10 \text{ mm} \)

@30cm, \( A_s = 17.28 \text{ cm}^2 \) \( \beta = 0.85 - \frac{0.05}{70} \left( 300 - 280 \right) = 0.836 \),

\[ \omega = \frac{A_s f_y}{l_w h f'_{c}} = \frac{17.28(4200)}{300(20)(300)} = 0.04032 \]
Load combinations are
\[(1.2 + 0.2 S_{DS})D + \rho Q_E\]
\[(0.9 - 0.2 S_{DS})D + \rho Q_E\]

For first storey:

\[P_u = 1.22(0.2)(3)(24)(2.5) = 43.92 \text{ tons}\]
\[f = \frac{43.92(1000)}{20(300)} \pm \frac{265.47(100000)(300/2)}{20(300)^2/12} = 95.81 \text{ kg/cm}^2 > 0.2(300)\]

i.e., special boundary elements are required at wall ends.

Flexural capacity at section of maximum moment:

\[c = \frac{0.04032 + 0.00055(43.92)}{0.79124} = 0.08094\]
\[c = 0.08094(300) = 24.28 \text{ cm}, \text{ and length of boundary element is not less than the larger of} \ c - 0.1 l_w \text{ and} \ c/2 = 12.14 \text{ cm}\]
\[M_u = 144.54 \text{ t.m}\]
and
\[M'_u = 265.47 - 144.54 = 120.93 \text{ t.m}\]

For a boundary element 35 cm in length, additional reinforcement in each of the two boundaries is given as follows

\[A_{x, \text{additional}} = \frac{120.93(100000)}{0.9(4200)(261)} + 4(0.785) = 15.40 \text{ cm}^2\]

Use 8 $\phi$ 16 mm bars in each of the two boundary elements.

Boundary element transverse reinforcement:

The larger of:

\[A_{u, t} = \frac{0.09 f'_c s b_t}{f_{y,t}}\]
\[A_{u, t} = 0.30 \left( \frac{A_x}{A_{ch}} - 1 \right) \frac{f'_c}{f_{y,t}}\]
\[
S_{\text{max}} \leq \text{the smallest of} \\
\begin{align*}
20/3 &= 6.67\text{cm} \\
6(1.6) &= 9.6\text{cm} \\
\end{align*}
\]

where \( h_x \) is the lesser of 35 cm and \((20\times2/3)\)
and
\( S_{\text{max}} \) is taken as 5 cm.

For the longer direction of boundary,
\( b_{c1} = 20 - 2(4) = 12 \text{ cm} \)

For the shorter direction of boundary,
\( b_{c2} = 35 - (4) = 31 \text{ cm} \)

\[
A_{sh} = \frac{0.09(5)(12)(300)}{4200} = 0.39 \text{ cm}^2
\]

\[
A_{sh} = 0.30(12)(5)\left[\frac{(35)(20)}{(12)(31)} - 1\right] \frac{300}{4200} = 1.13 \text{ cm}^2
\]

Use 2-legged \( \phi10\text{mm} \) ties \( @ 5 \text{ cm} \)

**Anchorage of horizontal shear reinforcement:**

For 10 mm bars hooked at 180 degree,

\[
A_{sh} = \frac{f_y d_p}{17\sqrt{f'_c}} = \frac{4200(1)}{17\sqrt{300}} = 14.26 \text{ cm}
\]

For straight bars

\( l_d = (3.5)14.26 = 49.91 \text{ cm}, \) taken as 50 cm, N.O.K

**For second storey:**

\[
P_u = 1.22(0.2)(3)(21)(2.5) = 38.43 \text{ tons}
\]
\[ f = \frac{38.43(1000)}{20(300)} \pm \frac{219.99(100000)(300/2)}{20(300)^3/12} = 79.74 \text{kg/cm}^2 > 0.2(300) \]

i.e., special boundary elements are required at wall ends.

Flexural capacity at section of maximum moment:

\[ \frac{c}{l_w} = \frac{0.04032 + 0.00055(38.43)}{0.79124} = 0.0771 \]

\[ c = 0.0771(300) = 23.13 \text{ cm}, \] and length of boundary element is not less than the larger of \[ c - 0.1 l_w \] and \[ c/2 = 11.57 \text{ cm} \]

\[ M_u = 138.3 \text{ t.m} \]

and

\[ M'_u = 219.99 - 138.30 = 81.69 \text{ t.m} \]

For a boundary element 35 cm in length, additional reinforcement in each of the two boundaries is given as follows

\[ A_{x,\text{additional}} = \frac{81.69(100000)}{0.9(4200)(261)} + 4(0.785) = 11.42 \text{ cm}^2 \]

Use 8 \( \phi \) 14 mm bars in each of the two boundary elements.

Boundary element transverse reinforcement:

The larger of:

\[ A_{s,h} = \frac{0.09 f' c b_c}{f_y} \]

\[ A_{s,h} = 0.30 \left( \frac{A_s}{A_{ch}} - 1 \right) \frac{f'_c}{f_y} \]

\[ S_{\text{max}} \leq \text{the smallest of} \]

\[ \begin{bmatrix} 
20/3 = 6.67 \text{ cm} \\
6(1.6) = 9.6 \text{ cm} \\
s_s = 10 + \left( \frac{35 - 13.33}{3} \right) = 17.22 \text{ cm} 
\end{bmatrix} \]

where \( h_s \) is the lesser of 35 cm and \( (20 \times 2/3) \)

and

\( S_{\text{max}} \) is taken as 5 cm.

For the longer direction of boundary, \( b_{s,i} = 20 - 2(4) = 12 \text{ cm} \)
For the shorter direction of boundary, 
\[ b_{c2} = 35 - 4 = 31 \text{ cm} \]

\[ A_{sh} = \frac{0.09(5)(12)(300)}{4200} = 0.39 \text{ cm}^2 \]

\[ A_{sh} = 0.30(12)(5)\left[ \frac{35(20)}{(12)(31)} - 1 \right] \frac{300}{4200} = 1.13 \text{ cm}^2 \]

Use 2-legged \( \phi_{10 \text{mm}} \) ties @ 5 cm

**Anchorage of horizontal shear reinforcement:**

For 10 mm bars hooked at 180 degree,

\[ A_{sh} = \frac{f_y d_p}{17\sqrt{f'_c}} \left( \frac{4200(1)}{17\sqrt{300}} \right) = 14.26 \text{ cm} \]

For straight bars

\[ l_d = (3.5)(14.26) = 49.91 \text{ cm} \], taken as 50 cm, N.O.K

For third storey:

\[ P_u = 1.22(0.2)(3)(18)(2.5) = 32.94 \text{ tons} \]

\[ f = \frac{32.94(1000)}{20(300)} \pm \frac{175.41(10000)(300/2)}{20(300)^2/12} = 63.96 \text{ kg/cm}^2 > 0.2(300) \]

i.e., special boundary elements are required at wall ends.

Flexural capacity at section of maximum moment:

\[ \frac{c}{l_w} = \frac{0.04032 + 0.00055(32.94)}{0.79124} = 0.0733 \]

\[ c = 0.0733(300) = 22 \text{ cm} \], and length of boundary element is not less than the larger of \( c - 0.1 \ l_w \) and \( c/2 = 11 \text{ cm} \)

\[ M_u = 132.0 \text{ t.m} \]

and

\[ M'_u = 175.41 - 132.0 = 43.41 \text{ t.m} \]

For a boundary element 35 cm in length, additional reinforcement in each of the two boundaries is given as follows
\[ A_{x, \text{additional}} = \frac{43.41(100000)}{0.9(4200)(261)} + 4(0.785) = 7.54 \text{ cm}^2 \]

Use 6\( \phi \) 14 mm bars in each of the two boundary elements.

Boundary element transverse reinforcement:

The larger of:

The larger of:

\[ A_{sh} = \frac{0.09 f' c b y}{f_{yt}} \]

\[ A_{sh} = 0.30 \left( \frac{A_x}{A_{ch}} - 1 \right) \frac{f' c}{f_{yt}} \]

\[ S_{\text{max}} \leq \text{the smallest of} \]

\[ 20/3 = 6.67 \text{ cm} \]

\[ 6(1.6) = 9.6 \text{ cm} \]

\[ s_x = 10 + \left( \frac{35 - 13.33}{3} \right) = 17.22 \text{ cm} \]

where \( h_x \) is the lesser of 35 cm and \((20 \times 2)/3\) and \( s_{\text{max}} \) is taken as 5 cm.

For the longer direction of boundary,

\( b_{c1} = 20 - 2(4) = 12 \text{ cm} \)

For the shorter direction of boundary,

\( b_{c2} = 35 - (4) = 31 \text{ cm} \)

\[ A_{sh} = \frac{0.09(5)(12)(300)}{4200} = 0.39 \text{ cm}^2 \]

\[ A_{sh} = 0.30(12)(5) \left[ \frac{(35)(20)}{(12)(31)} - 1 \right] \frac{300}{4200} = 1.13 \text{ cm}^2 \]

Use 2-legged \( \phi 10 \text{ mm} \) ties @ 5 cm

**Anchorage of horizontal shear reinforcement:**

For 10 mm bars hooked at 180 degree,

\[ A_{sh} = \frac{f' c d_y}{17 \sqrt{f' c}} = \frac{4200(1)}{17 \sqrt{300}} = 14.26 \text{ cm} \]
For straight bars
\[ l_d = (3.5)14.26 = 49.91 \text{ cm}, \text{ taken as 50 cm, N.O.K} \]

For fourth storey:
\[ P_u = 1.22(0.2)(3)(15)(2.5) = 27.45 \text{ tons} \]
\[ f = \frac{27.45(1000)}{20(300)} \pm \frac{132.90(100000)(300/2)}{20(300)^2/12} = 48.88 \text{ kg/cm}^2 < 0.2(300) \]
i.e., special boundary elements are required at wall ends, and will be discontinued when \( f < 0.15(300) \). Nevertheless, the boundary will be used throughout the entire fourth floor.

Flexural capacity at section of maximum moment:
\[ \frac{c}{l_w} = \frac{0.04032 + 0.00055(27.45)}{0.79124} = 0.06950 \]
\[ c = 0.0695(300) = 20.85 \text{ cm}, \text{ and length of boundary element is not less than the larger of } c - 0.1 l_w \text{ and } c/2 = 10.43 \text{ cm} \]
\[ M_u = 125.65 \text{ t.m} \]
and
\[ M'_u = 132.90 - 125.65 = 7.25 \text{ t.m} \]
For a boundary element 35 cm in length, additional reinforcement in each of the two boundaries is given as follows
\[ A_{x, \text{additional}} = \frac{7.25(100000)}{0.9(4200)(261)} + 4(0.785) = 3.87 \text{ cm}^2 \]
Use 6\( \phi \) 10 mm bars in each of the two boundary elements.
Boundary element transverse reinforcement:
The larger of:
\[ A_{sh} = \frac{0.09 f'_s s b_t}{f_{yt}} \]
\[ A_{sh} = 0.30 \left( \frac{A_x}{A_{ch}} - 1 \right) f'_s \]

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\[
S_{\text{max}} \leq \text{the smallest of } \begin{cases} 
20/3 = 6.67 \text{cm} \\
6(1.6) = 9.6 \text{cm} \\
s_s = 10 + \left( \frac{35 - 13.33}{3} \right) = 17.22 \text{cm} 
\end{cases}
\]

where \( h_x \) is the lesser of 35 cm and (20x2/3) and \( S_{\text{max}} \) is taken as 5 cm.

For the longer direction of boundary, 
\[ b_{x1} = 20 - 2(4) = 12 \text{ cm} \]

For the shorter direction of boundary, 
\[ b_{x2} = 35 - (4) = 31 \text{ cm} \]

\[
A_{sh} = \frac{0.09(5)(12)(300)}{4200} = 0.39 \text{ cm}^2 \\
A_{sh} = 0.30(12)(5) \left[ \frac{35(20)}{(12)(31)} - 1 \right] \frac{300}{4200} = 1.13 \text{ cm}^2
\]

Use 2-legged \( \phi 10 \text{mm} \) ties @ 5 cm

**Anchorage of horizontal shear reinforcement:**

For 10 mm bars hooked at 180 degree, 
\[
A_{sh} = \frac{f_y d_y}{17 \sqrt{f'_c}} = \frac{4200(1)}{17 \sqrt{300}} = 14.26 \text{ cm}
\]

For straight bars 
\[ l_d = (3.5)14.26 = 49.91 \text{ cm}, \text{ taken as 50 cm, N.O.K} \]

**For fifth storey:**

\[ P_u = 1.22(0.2)(3)(12)(2.5) = 21.96 \text{ tons} \]

\[
f = \frac{21.96(1000)}{20(300)} \pm \frac{93.78(100000)(300/2)}{20(300)^{3/2} / 12} = 34.92 \text{ kg/cm}^2 < 0.2(300)
\]
and < 0.15 (300)
i.e., special boundary elements are no longer required at wall ends.

Flexural capacity at section of maximum moment:

\[
\frac{c}{l_w} = \frac{0.04032 + 0.00055(21.96)}{0.79124} = 0.0657
\]

\[M_u = 119.24 \text{ t.m} > 93.78 \text{ t.m}\]

Thus, no additional reinforcement is required at wall ends.

**For sixth, seventh and eighth storeys**

No additional reinforcement is required.