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 21.7.4.1, nominal shear strength $V_n$ of structural walls is not to exceed

$$V_n = A_{cv} \left( 0.265 \alpha_c \sqrt{f'_c} + \rho_n f_y \right)$$  (6.9)

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

- $\alpha_c = 3.0$ for $h_w/l_w \leq 1.5$;
- $\alpha_c = 2.0$ for $h_w/l_w \geq 2.0$;
- $\alpha_c = 2.0$ to 3.0 (linear variation) for $h_w/l_w$ 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 $0.53 A_{cv} \sqrt{f'_c}$, as specified by ACI 21.7.2.2.

Based on ACI 21.7.2.1, the distributed web reinforcement ratios, $\rho_v$ and $\rho_n$ for structural walls shall not be less than 0.0025, except if the design shear force does not exceed
0.265 A_{cv} \sqrt{f_c}, the minimum reinforcement for structural walls shall be permitted to be reduced to that required in 14.3, where ρ_v is ratio of area of distributed reinforcement perpendicular to the plane of A_{cv} to gross concrete area A_{cv}, and ρ_n ratio of area of distributed reinforcement parallel to the plane of A_{cv} to gross concrete area perpendicular to that reinforcement. Reinforcement spacing each way in structural walls shall not exceed 45 cm.

According to ACI 21.7.4.3, walls are to be reinforced with shear reinforcement in two orthogonal dimensions in the plane of the wall.

- For \( h_w/l_w \leq 2.0 \), reinforcement ratio ρ_v shall not be less than reinforcement ratio ρ_n.

**Design for Flexure and Axial Loads:**

Based on ACI 21.7.5.1, structural walls and portions of such walls subject to combined flexural and axial loads shall be designed in accordance with 10.2 and 10.3 except that 10.3.6 and the nonlinear strain requirements of 10.2.2 shall not apply.

In ACI 10.3.2, balanced strain conditions exist at a cross section when the tension reinforcement reaches the strain corresponding to its specified yield strength \( f_y \) just as concrete in compression reaches its assumed ultimate strain of 0.003.

In ACI 10.3.3, sections are compression controlled when the strain in the tension steel = 0.002 (for \( f_y = 4200 \text{ kg/cm}^2 \)).
In ACI 10.3.4, sections are tension-controlled when the net
tensile strain in the extreme tension steel is equal to or
greater than 0.005, just as the concrete in compression
reaches its assumed strain limit of 0.003. Sections with net
tensile strain in the extreme tension steel between the
compression controlled strain limit and 0.005 constitute a
transition region between compression-controlled and
tension-controlled sections.
In ACI 10.3.5, for flexural members with axial loads less
than $0.1 f'_c A_g$, the net tensile strain $\varepsilon_t$ at nominal strength
shall not be less than 0.004.(similar to $\rho_{\text{max}} = 0.75 \rho_b$)

**Horizontal Wall Segments:**

Normal shear strength of horizontal wall segments shall be
assumed not to exceed $2.65 A_{cp} \sqrt{f'_c}$, where $A_{cp}$ is the
cross-sectional area of a horizontal wall segment, as
specified in ACI 21.7.4.5.

**Wall Piers:**

Normal shear strength of all wall piers sharing a common
lateral force shall not be assumed to exceed $2.12 A_{cv} \sqrt{f'_c}$,
where $A_{cv}$ is the total cross-sectional area, and the normal
shear strength of any one of the individual wall pier shall
not be assumed to exceed $2.65 A_{cp} \sqrt{f'_c}$, where $A_{cp}$ is the
cross-sectional area of the pier considered, as specified in
ACI 21.7.4.4.

In ACI 21.7.4.2, the ratio $h_w/l_w$ used for determination of
$V_n$ for segments of a wall shall be the largest of the ratios
for the entire wall and the segment of the wall considered.
Boundary Elements:

Two design approaches for evaluating the need of boundary elements at the edges of structural walls are provided in ACI 21.7.6 and explained below.

A- For walls or wall piers 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 21.7.6.2 requires that compression zones be reinforced with special boundary elements where:

\[
c \geq \frac{l_w}{600(\delta_u / h_w)}
\]  

The quantity \(\delta_u / h_w\) in the previous equation shall not be taken less than 0.007, where \(\delta_u\) is the design displacement. Special boundary element reinforcement shall extend vertically from the critical section a distance not less than the larger of \(l_w\) or \(V_u / M_u \times 4\).

The above design approach uses a displacement-based model. In this method, the wall is displaced an amount equal to 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. Confinement is required over a horizontal length equal to at least the length where the compressive strain exceeds the critical value.

B- Structural walls not designed to the provisions of ACI 21.7.6.2, 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 $0.15 f_c'$.

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

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

(6.11)

**Boundary Element Dimensions:**

As required by ACI 21.7.6.4, boundary elements are to extend horizontally from the extreme compression fiber a distance not less than the larger of $c - 0.1l_w$ and $c/2$. 

![Boundary Element Requirements (ACI 21.7.6.2)](image1)

![Boundary Element Requirements (ACI 21.7.6.3)](image2)
Boundary Element Transverse Reinforcement:

Special boundary element transverse reinforcement shall satisfy the requirements of ACI 21.4.4.1 through 21.4.4.3, except Eq. (21-3) need not be satisfied, as shown below.

- In ACI 21.4.4.1, transverse reinforcement as required below shall be provided.
- The total cross-sectional area of rectangular hoop reinforcement shall not be less than that required by the following Equation.

\[
A_{sh} = \frac{0.09 \cdot S \cdot h_c \cdot f'c}{f_{yh}} \quad (6.12)
\]

Where:
\( S \) = spacing of transverse reinforcement measured along the longitudinal axis of the structural member.
\( h_c \) = cross-sectional dimension of core measured center-to-center of confining reinforcement.
\( f_{yh} \) = specified yield strength of transverse reinforcement.

- 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.
- Transverse reinforcement shall be spaced at a distance not exceeding (a) one-quarter of the minimum member dimension, (b) six times the diameter of the
longitudinal reinforcement, and (c) \( S_x = 22 - 0.085h_x \), where \( h_x \) is maximum horizontal spacing of hoop or crosstie legs on all faces of the boundary element. \( S_x \) shall not exceed 15 cm and need not be taken less than 10 cm.

- Crossties or legs of overlapping hoops shall not be spaced more than 35 cm on center-to-center in the direction perpendicular to the longitudinal axis of a structural member.

In ACI 21.7.6.5, where special boundary elements are not required by 21.7.6.2 or 21.7.6.3, (a) and (b) shall be satisfied.

(a) If the longitudinal reinforcement ratio at the wall boundary is greater than \( 28.12/f_y \), boundary transverse reinforcement shall satisfy 21.4.4.1 (c), 21.4.4.3, and 21.7.6.4 (a). The maximum longitudinal spacing of transverse reinforcement in the boundary shall not exceed 20 cm;

(b) Except when \( V_u \) in the plane of the wall is less than \( 0.265A_{cv} \sqrt{f'c} \), 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 (US system)

\[
A_{sh} = 0.09 f_c y / f_{yh}
\]

Spacing = lesser of:
\[
\frac{\text{min. member dimension}}{4}, \quad \frac{6d_b}{s_x}, \quad 6'' \geq s_x = 4 + \left( \frac{14 - h_x}{3} \right) \geq 4''
\]

Reinforcement ratio \(\geq 0.0025\)

Maximum spacing = 18 in.
Anchorage and Splicing of Reinforcement:

- All continuous reinforcement in structural walls shall be anchored or spliced in accordance with the provisions for reinforcement in tension given in ACI 21.5.4, shown below.

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 Eqn. (6.13), which is applicable to bar diameters ranging from 10 mm to 36 mm.

$$l_{dh} = \frac{0.058 f_y d_b}{\sqrt{f'_c}} \tag{6.13}$$

The 90-degree hook shall be located within the confined core of a column or a boundary element.

For bar diameters 10 mm through 36 mm, the development length $l_d$ for a straight bar shall not be less than (a) and (b):

(a) 2.5 times the length required by Eqn. (6.13) if the depth of the concrete cast in one lift beneath the bar does not exceed 30 cm, and
(b) 3.5 times the length provided by Eqn. (6.13) if the depth of the concrete cast in one lift beneath the bar exceeds 30 cm.

Any portion of the straight embedment length not within the confined area shall be increased by a factor of 1.6.

- Based on ACI 21.7.6.4, specified boundary element transverse reinforcement at the wall base shall extend into the support at least the development length of the largest longitudinal reinforcement in the specified boundary element unless the special boundary element terminates on a footing or mat, where special boundary element transverse reinforcement shall extend at least 30 cm into the footing or mat.

- Based on ACI 21.7.6.4, horizontal reinforcement in the wall web shall be anchored to develop the specified yield strength $f_y$ within the confined core of the boundary element.