CHAPTER 11—WALLS

CODE

11.1—Scope

11.1.1 This chapter shall apply to the design of nonprestressed and prestressed walls including (a) through (c):

(a) Cast-in-place
(b) Precast in-plant
(c) Precast on-site including tilt-up

11.1.2 Design of special structural walls shall be in accordance with Chapter 18.

11.1.3 Design of plain concrete walls shall be in accordance with Chapter 14.

11.1.4 Design of cantilever retaining walls shall be in accordance with Chapter 13.

11.1.5 Design of walls as grade beams shall be in accordance with 13.3.5.

11.1.6 Cast-in-place walls with insulating forms shall be permitted by this Code.

11.2—General

11.2.1 *Materials*

11.2.1.1 Design properties for concrete shall be selected to be in accordance with Chapter 19.

11.2.1.2 Design properties for steel reinforcement shall be selected to be in accordance with Chapter 20.

11.2.1.3 Materials, design, and detailing requirements for embedments in concrete shall be in accordance with 20.6.

11.2.2 *Connection to other members*

11.2.2.1 For precast walls, connections shall be designed in accordance with 16.2.

11.2.2.2 Connections of walls to foundations shall satisfy 16.3.

COMMENTARY

R11.1—Scope

R11.1.1 This chapter applies to walls as vertical and lateral force-resisting members. Provisions for in-plane lateral loads in ordinary structural walls are included in this chapter.

R11.1.2 Requirements for special structural walls are in 18.10. Requirements for intermediate precast structural walls and special structural walls constructed using precast concrete are in 18.5 and 18.11, respectively.

ASCE/SEI 7 defines a structural wall as a wall that meets the definition for a bearing wall or a shear wall. A bearing wall is defined as a wall that supports vertical load beyond a certain threshold value. A shear wall is defined as a wall, bearing or nonbearing, designed to resist lateral forces acting in the plane of the wall.

R11.1.6 Cast-in-place walls with insulating forms should be designed in accordance with the Code. Specific design recommendations can be found in ACI PRC-560.

The licensed design professional should specify requirements to verify consolidation of concrete cast in insulated concrete forms (ICF) as provided in 26.5.2.1.

R11.2—General

11 Walls

CODE

11.2.3 *Load distribution*

11.2.3.1 Unless otherwise demonstrated by an analysis, the horizontal length of wall considered as effective for resisting each concentrated load shall not exceed the lesser of the center-to-center distance between loads, and the bearing width plus four times the wall thickness. Effective horizontal length for bearing shall not extend beyond vertical wall joints unless design provides for transfer of forces across the joints.

11.2.4 *Intersecting elements*

11.2.4.1 Walls shall be anchored to intersecting elements, such as floors and roofs; columns, pilasters, buttresses, or intersecting walls; and to footings.

11.2.4.2 For cast-in-place walls having $P_u > 0.2f_c'A_g$, the portion of the wall within the thickness of the floor system shall have specified compressive strength at least $0.8f_c'$ of the wall.

11.3—Design limits

11.3.1 *Minimum solid wall thickness*

11.3.1.1 Minimum solid wall thicknesses shall be in accordance with Table 11.3.1.1. Thinner walls are permitted if adequate strength and stability can be demonstrated by structural analysis.

Table 11.3.1.1—Minimum solid wall thickness *h*

Wall type	Minimum thickness *h*		
Bearing[1]	Greater of:	4 in.	(a)
		1/25 the lesser of unsupported length and unsupported height	(b)
Nonbearing	Greater of:	4 in.	(c)
		1/30 the lesser of unsupported length and unsupported height	(d)
Exterior basement and foundation[1]	7.5 in.		(e)

[1]Only applies to walls designed in accordance with the simplified design method of 11.5.3.

11.4—Required strength

11.4.1 *General*

11.4.1.1 Required strength shall be calculated in accordance with the factored load combinations in Chapter 5.

COMMENTARY

R11.2.4 *Intersecting elements*

R11.2.4.1 Walls that do not depend on intersecting elements for support, do not have to be connected to those elements. It is not uncommon to separate massive retaining walls from intersecting walls to accommodate differences in deformations.

R11.2.4.2 The 0.8 factor reflects reduced confinement in floor-wall joints compared with floor-column joints under gravity loads.

R11.4—Required strength

R11.4.1 *General*

CODE

11.4.1.2 Required strength shall be calculated in accordance with the analysis procedures in Chapter 6.

11.4.1.3 Slenderness effects shall be calculated in accordance with 6.6.4, 6.7, or 6.8. Alternatively, out-of-plane slenderness analysis shall be permitted using 11.8 for walls meeting the requirements of that section.

11.4.1.4 Walls shall be designed for eccentric axial loads and any lateral or other loads to which they are subjected.

11.4.1.5 Design of basement walls to resist out-of-plane lateral earth pressure shall be in accordance with Section 13.3.7.

11.4.2 *Factored axial force and moment*

11.4.2.1 Walls shall be designed for the maximum factored moment M_u that can accompany the factored axial force for each applicable load combination. The factored axial force P_u at given eccentricity shall not exceed $\phi P_{n,max}$, where $P_{n,max}$ shall be as given in 22.4.2.1 and strength reduction factor ϕ shall be that for compression-controlled sections in 21.2.2. The maximum factored moment M_u shall be magnified for slenderness effects in accordance with 6.6.4, 6.7, or 6.8.

11.4.3 *Factored shear*

11.4.3.1 Walls shall be designed for the maximum in-plane V_u and out-of-plane V_u.

COMMENTARY

R11.4.1.3 The forces typically acting on a wall are illustrated in Fig. R11.4.1.3.

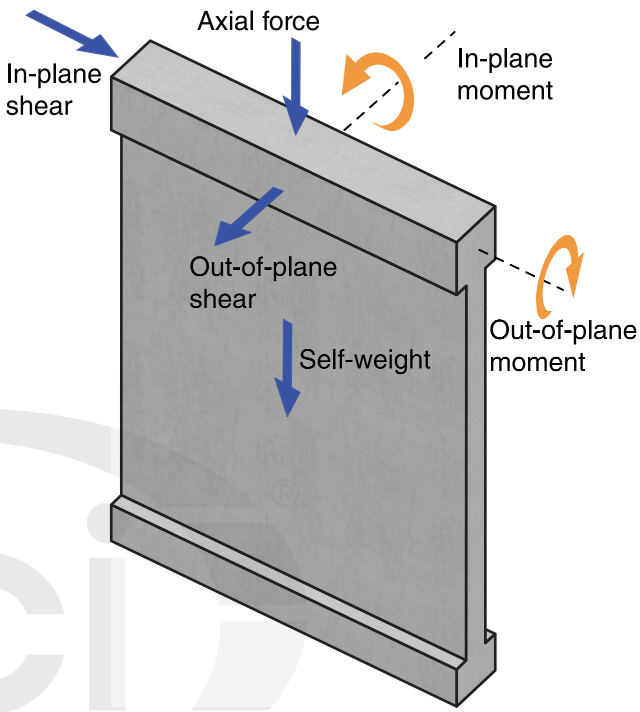

Fig. R11.4.1.3—In-plane and out-of-plane forces.

Walls
11

CODE

11.5—Design strength

11.5.1 *General*

11.5.1.1 For each applicable factored load combination, design strength at all sections shall satisfy $\phi S_n \geq U$, including (a) through (c). Interaction between axial load and moment shall be considered.

(a) $\phi P_n \geq P_u$
(b) $\phi M_n \geq M_u$
(c) $\phi V_n \geq V_u$

11.5.1.2 ϕ shall be determined in accordance with 21.2.

11.5.2 *Axial load and in-plane or out-of-plane flexure*

11.5.2.1 For bearing walls, P_n and M_n (in-plane or out-of-plane) shall be calculated in accordance with 22.4. Alternatively, axial load and out-of-plane flexure shall be permitted to be considered in accordance with 11.5.3.

11.5.2.2 For nonbearing walls, M_n shall be calculated in accordance with 22.3.

11.5.3 *Axial load and out-of-plane flexure – simplified design method*

11.5.3.1 If the resultant of all factored loads is located within the middle third of the thickness of a solid wall with a rectangular cross section, P_n shall be permitted to be calculated by:

$$P_n = 0.55 f_c' A_g \left[1 - \left(\frac{k\ell_c}{32h}\right)^2\right] \qquad (11.5.3.1)$$

COMMENTARY

R11.5—Design strength

R11.5.2 *Axial load and in-plane or out-of-plane flexure*

R11.5.2.2 Nonbearing walls, by definition, are not subject to any significant axial force; therefore, flexural strength is not a function of axial force.

R11.5.3 *Axial load and out-of-plane flexure – simplified design method*

R11.5.3.1 The simplified design method applies only to solid rectangular cross sections; all other shapes should be designed in accordance with 11.5.2.

Eccentric axial loads and moments due to out-of-plane forces are used to determine the maximum total eccentricity of the factored axial force P_u. When the resultant axial force for all applicable load combinations falls within the middle third of the wall thickness (eccentricity not greater than $h/6$) at all sections along the length of the undeformed wall, no tension is induced in the wall and the simplified design method may be used. The design is then carried out considering P_u as a concentric axial force.

Equation (11.5.3.1) results in strengths comparable to those determined in accordance with 11.5.2 for members loaded at the middle third of the thickness with different braced and restrained end conditions. Refer to Fig. R11.5.3.1.

CODE

COMMENTARY

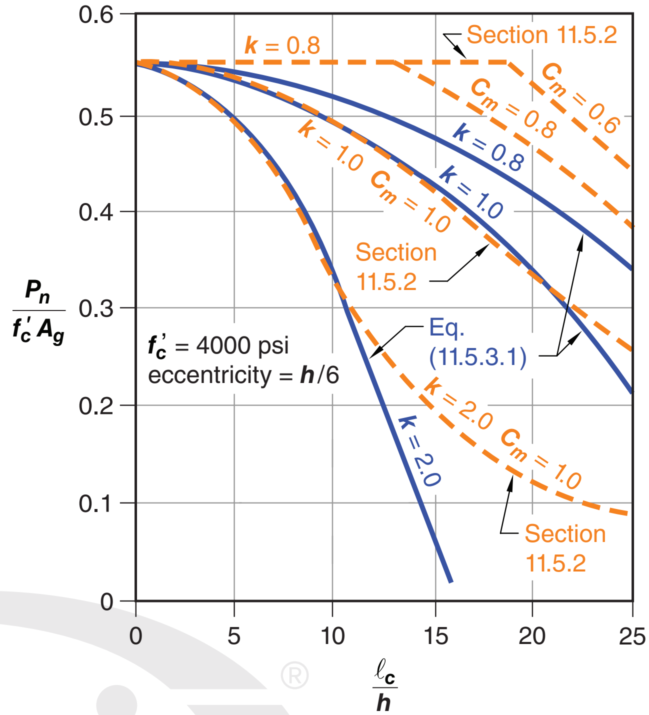

Fig. R11.5.3.1—Simplified design of walls, Eq. (11.5.3.1) versus 11.5.2.

11.5.3.2 Effective length factor k for use with Eq. (11.5.3.1) shall be in accordance with Table 11.5.3.2.

Table 11.5.3.2—Effective length factor *k* for walls

Boundary conditions	k
Walls braced top and bottom against lateral translation and:	
(a) Restrained against rotation at one or both ends (top, bottom, or both)	0.8
(b) Unrestrained against rotation at both ends	1.0
Walls not braced against lateral translation	2.0

11.5.3.3 P_n from Eq. (11.5.3.1) shall be reduced by ϕ for compression-controlled sections in 21.2.2.

11.5.3.4 Wall reinforcement shall be at least that required by 11.6.

11.5.4 *In-plane shear*

11.5.4.1 V_n shall be calculated in accordance with 11.5.4.2 through 11.5.4.4. Alternatively, for walls with $h_w/\ell_w < 2$, it shall be permitted to design for in-plane shear in accordance with the strut-and-tie method of Chapter 23. In all cases, reinforcement shall satisfy the limits of 11.6, 11.7.2, and 11.7.3.

R11.5.4 *In-plane shear*

R11.5.4.1 In-plane shear is primarily of importance for structural walls with a small height-to-length ratio ($h_w/\ell_w < 2$). The design of taller walls, particularly walls with uniformly distributed reinforcement, will likely be controlled by flexural considerations. Possible exceptions may occur in tall structural walls subject to strong earthquake excitation.

Walls
11

11.5.4.2 V_n at any horizontal section shall not exceed $8\sqrt{f_c'}A_{cv}$.

R11.5.4.2 This limit is imposed to guard against diagonal compression failure in structural walls.

11.5.4.3 V_n shall be calculated by:

$$V_n = \left(\alpha_c \lambda \sqrt{f_c'} + \rho_t f_{yt}\right) A_{cv} \qquad (11.5.4.3)$$

where:
$\alpha_c = 3$ for $h_w/\ell_w \leq 1.5$
$\alpha_c = 2$ for $h_w/\ell_w \geq 2.0$
α_c varies linearly between 3 and 2 for $1.5 < h_w/\ell_w < 2.0$

11.5.4.4 For walls subject to a net axial tension, α_c in Eq. (11.5.4.3) shall be taken as:

$$\alpha_c = 2\left(1 + \frac{N_u}{500A_g}\right) \geq 0.0 \qquad (11.5.4.4)$$

where N_u is negative for tension.

R11.5.4.4 For structural walls where a net axial tension force is calculated for the entire wall section, the shear strength contribution attributed to the concrete is reduced and may be negligible. For these members, wall transverse reinforcement must be designed to resist most, if not all, of the factored shear force.

11.5.5 *Out-of-plane shear*

11.5.5.1 V_n shall be calculated in accordance with 22.5.

11.6—Reinforcement limits

11.6.1 If in-plane $V_u \leq 0.5\phi\alpha_c\lambda\sqrt{f_c'}A_{cv}$, minimum ρ_ℓ and minimum ρ_t shall be in accordance with Table 11.6.1. These limits need not be satisfied if adequate strength and stability can be demonstrated by structural analysis.

R11.6—Reinforcement limits

R11.6.1 Both horizontal and vertical shear reinforcement are required for all walls. The distributed reinforcement is identified as being oriented parallel to either the longitudinal or transverse axis of the wall. Therefore, for vertical wall segments, the notation used to describe the horizontal distributed reinforcement ratio is ρ_t, and the notation used to describe the vertical distributed reinforcement ratio is ρ_ℓ.

The reduced minimum reinforcement for precast walls recognizes that precast members have less restraint to shrinkage during curing and are usually not as rigidly connected as monolithic concrete, resulting in reduced restraint stresses due to both shrinkage and temperature change (PCI Committee on Precast Concrete Bearing Wall Buildings 1976; Portland Cement Association 1980). Reduced minimum reinforcement and greater spacings in 11.7.2.2 are allowed because precast wall panels have very little restraint at their edges during early stages of curing and develop less shrinkage stress than comparable cast-in-place walls.

Transverse reinforcement is not required in precast, prestressed walls equal to or less than 12 ft wide because this width is less than that in which shrinkage and temperature stresses can build up to a magnitude requiring transverse reinforcement. In addition, much of the shrinkage occurs before the members are connected into the structure. Once in the final structure, the members are usually not as rigidly connected transversely as monolithic concrete; thus, the transverse restraint stresses due to both shrinkage and temperature change are significantly reduced.

CODE

COMMENTARY

Table 11.6.1—Minimum reinforcement for walls with in-plane $V_u \leq 0.5\phi\alpha_c\lambda\sqrt{f_c'}A_{cv}$

Wall type	Type of nonprestressed reinforcement	Bar/wire size	f_y, psi	Minimum longitudinal[1], ρ_ℓ	Minimum transverse, ρ_t
Cast-in-place	Deformed bars	≤ No. 5	≥ 60,000	0.0012	0.0020
			< 60,000	0.0015	0.0025
		> No. 5	Any	0.0015	0.0025
	Welded-wire reinforcement	≤ W31 or D31	Any	0.0012	0.0020
Precast[2]	Deformed bars or welded-wire reinforcement	Any	Any	0.0010	0.0010

[1]Walls with an average compressive stress, due to effective prestress force only, of at least 225 psi need not meet the requirement for minimum longitudinal reinforcement ρ_ℓ.
[2]In one-way precast, prestressed walls not wider than 12 ft and not mechanically connected to cause restraint in the transverse direction, the minimum reinforcement requirement in the direction normal to the flexural reinforcement need not be satisfied.

11.6.2 If in-plane $V_u > 0.5\phi\alpha_c\lambda\sqrt{f_c'}A_{cv}$, (a) and (b) shall be satisfied:

(a) ρ_ℓ shall be at least the greater of the value calculated by Eq. (11.6.2) and 0.0025, but need not exceed ρ_t required for strength by 11.5.4.3.

$$\rho_\ell \geq 0.0025 + 0.5(2.5 - h_w/\ell_w)(\rho_t - 0.0025) \quad (11.6.2)$$

(b) ρ_t shall be at least 0.0025.

R11.6.2 For monotonically loaded walls with low height-to-length ratios, test data (Barda et al. 1977) indicate that horizontal shear reinforcement becomes less effective for shear resistance than vertical reinforcement. This change in effectiveness of the horizontal versus vertical reinforcement is recognized in Eq. (11.6.2); if h_w/ℓ_w is less than 0.5, the amount of vertical reinforcement is equal to the amount of horizontal reinforcement. If h_w/ℓ_w is greater than 2.5, only a minimum amount of vertical reinforcement is required ($0.0025sh$).

11.7—Reinforcement detailing

11.7.1 *General*

11.7.1.1 Concrete cover for reinforcement shall be in accordance with 20.5.1.

11.7.1.2 Development lengths of deformed and prestressed reinforcement shall be in accordance with 25.4.

11.7.1.3 Splice lengths of deformed reinforcement shall be in accordance with 25.5.

11.7.2 *Spacing of longitudinal reinforcement*

11.7.2.1 Spacing s of longitudinal bars in cast-in-place walls shall not exceed the lesser of $3h$ and 18 in. If shear reinforcement is required for in-plane strength, spacing of longitudinal reinforcement shall not exceed $\ell_w/3$.

11.7.2.2 Spacing s of longitudinal bars in precast walls shall not exceed the lesser of (a) and (b):

(a) $5h$
(b) 18 in. for exterior walls or 30 in. for interior walls

If shear reinforcement is required for in-plane strength, s shall not exceed the smallest of $3h$, 18 in., and $\ell_w/3$.

11.7.2.3 For walls with thickness greater than 10 in., except single story basement walls and cantilever retaining

CODE

walls, distributed reinforcement in each direction shall be placed in at least two curtains, one near each face.

11.7.2.4 Flexural tension reinforcement shall be well distributed and placed as close as practicable to the tension face.

11.7.3 *Spacing of transverse reinforcement*

11.7.3.1 Spacing s of transverse reinforcement in cast-in-place walls shall not exceed the lesser of $3h$ and 18 in. If shear reinforcement is required for in-plane strength, s shall not exceed $\ell_w/5$.

11.7.3.2 Spacing s of transverse bars in precast walls shall not exceed the lesser of (a) and (b):

(a) $5h$
(b) 18 in. for exterior walls or 30 in. for interior walls
If shear reinforcement is required for in-plane strength, s shall not exceed the least of $3h$, 18 in., and $\ell_w/5$.

11.7.4 *Through-thickness shear reinforcement*

11.7.4.1 Shear reinforcement required for out-of-plane strength shall extend as close to the extreme compression and tension surfaces of the wall as practicable, and satisfy the requirements of 25.7.1.3 or 25.7.1.8.

11.7.5 *Lateral support of longitudinal reinforcement*

11.7.5.1 If longitudinal reinforcement is required for compression and if A_{st} exceeds $0.01A_g$, longitudinal reinforcement shall be laterally supported by transverse ties.

11.7.6 *Reinforcement around openings*

11.7.6.1 In addition to the minimum reinforcement required by 11.6, at least two No. 5 bars in walls having two layers of reinforcement in both directions and one No. 5 bar in walls having a single layer of reinforcement in both directions shall be provided around window, door, and similarly sized openings. Such bars shall develop f_y in tension at the corners of the openings.

11.8—Alternative method for out-of-plane slender wall analysis

11.8.1 *General*

11.8.1.1 It shall be permitted to analyze out-of-plane slenderness effects in accordance with this section for walls satisfying (a) through (e):

(a) Cross section is constant over the height of the wall

COMMENTARY

R11.8—Alternative method for out-of-plane slender wall analysis

R11.8.1 *General*

R11.8.1.1 This procedure is presented as an alternative to the requirements of 11.5.2.1 for the out-of-plane design of slender wall panels, where the panels are restrained against overturning at the top.

Panels that have windows or other large openings are not considered to have constant cross section over the height of

CODE

(b) Wall is tension-controlled for out-of-plane moment effect
(c) ϕM_n is at least M_{cr}, where M_{cr} is calculated using f_r as provided in 19.2.3
(d) P_u at the midheight section does not exceed $0.06f_c'A_g$
(e) Calculated out-of-plane deflection due to service loads, Δ_s, including $P\Delta$ effects, does not exceed $\ell_c/150$

11.8.2 *Modeling*

11.8.2.1 The wall shall be analyzed as a simply supported, axially loaded member subject to an out-of-plane uniformly distributed lateral load, with maximum moments and deflections occurring at midheight.

11.8.2.2 Concentrated gravity loads applied to the wall above any section shall be assumed to be distributed over a width equal to the bearing width, plus a width on each side that increases at a slope of 2 vertical to 1 horizontal, but not extending beyond (a) or (b):

(a) The spacing of the concentrated loads
(b) The edges of the wall panel

11.8.3 *Factored moment*

11.8.3.1 M_u at midheight of wall due to combined flexure and axial loads shall include the effects of wall deflection in accordance with (a) or (b):

(a) By iterative calculation using

$$M_u = M_{ua} + P_u\Delta_u \tag{11.8.3.1a}$$

where M_{ua} is the maximum factored moment at midheight of wall due to lateral and eccentric vertical loads, not including $P\Delta$ effects. Δ_u shall be calculated by:

$$\Delta_u = \frac{5M_u\ell_c^2}{(0.75)48E_cI_{cr}} \tag{11.8.3.1b}$$

where I_{cr} shall be calculated by:

$$I_{cr} = \frac{E_s}{E_c}\left(A_s + \frac{P_u}{f_y}\frac{h}{2d}\right)(d-c)^2 + \frac{\ell_w c^3}{3} \tag{11.8.3.1c}$$

and the value of E_s/E_c shall be at least 6.
(b) By direct calculation using:

$$M_u = \frac{M_{ua}}{\left(1 - \frac{5P_u\ell_c^2}{(0.75)48E_cI_{cr}}\right)} \tag{11.8.3.1d}$$

COMMENTARY

the panel. Such walls are to be designed taking into account the effects of openings.

Many aspects of the design of tilt-up walls and buildings are discussed in ACI PRC-551.2, ACI PRC-551.3, and Carter et al. (1993).

R11.8.3 *Factored moment*

R11.8.3.1 The neutral axis depth c in Eq. (11.8.3.1c) corresponds to the following effective area of longitudinal reinforcement.

$$A_{se,w} = A_s + \frac{P_u}{f_y}\left(\frac{h/2}{d}\right)$$

CODE

11.8.4 *Out-of-plane deflection – service loads*

11.8.4.1 Out-of-plane deflection due to service loads, Δ_s, shall be calculated in accordance with Table 11.8.4.1, where M_a is calculated by 11.8.4.2.

Table 11.8.4.1—Calculation of Δ_s

M_a	Δ_s	
$\leq(2/3)M_{cr}$	$\Delta_s = \left(\frac{M_a}{M_{cr}}\right)\Delta_{cr}$	(a)
$>(2/3)M_{cr}$	$\Delta_s = \frac{2}{3}\Delta_{cr} + \frac{\left(M_a - \frac{2}{3}M_{cr}\right)}{\left(M_a - \frac{2}{3}M_{cr}\right)}\left(\Delta_n - \frac{2}{3}\Delta_{cr}\right)$	(b)

11.8.4.2 The maximum moment M_a at midheight of wall due to service lateral and eccentric vertical loads, including $P_s\Delta_s$ effects, shall be calculated by Eq. (11.8.4.2) with iteration of deflections.

$$M_a = M_{sa} + P_s\Delta_s \tag{11.8.4.2}$$

11.8.4.3 Δ_{cr} and Δ_n shall be calculated by (a) and (b):

(a) $$\Delta_{cr} = \frac{5M_{cr}\ell_c^2}{48E_cI_g} \tag{11.8.4.3a}$$

(b) $$\Delta_n = \frac{5M_n\ell_c^2}{48E_cI_{gr}} \tag{11.8.4.3b}$$

11.8.4.4 I_{cr} shall be calculated by Eq. (11.8.3.1c).

COMMENTARY

R11.8.4 *Out-of-plane deflection – service loads*

R11.8.4.1 Test data (Athey 1982) demonstrate that out-of-plane deflections increase rapidly when the service-level moment exceeds $2/3M_{cr}$. A linear interpolation between Δ_u and Δ_u is used to determine Δ_s to simplify the design of slender walls if $M_a > 2/3M_{cr}$.

Service-level load combinations are not defined in Chapter 5 of the Code but are discussed in Appendix C of ASCE/SEI 7. Appendices to ASCE/SEI 7 are not considered mandatory parts of that standard. For calculating service-level lateral deflections of structures, Appendix C of ASCE/SEI 7 recommends using the following load combination:

$$D + 0.5L + W_a$$

in which W_a is wind load based on serviceability wind speeds provided in the commentary to Appendix C of ASCE/SEI 7. If the slender wall is designed to resist earthquake effects E, and E is based on strength-level earthquake effects, the following load combination is considered to be appropriate for evaluating service-level lateral deflections

$$D + 0.5L + 0.7E$$