

Chapter 9

CONCRETE STRUCTURE DESIGN REQUIREMENTS

9.1 GENERAL

9.1.1 Scope. The quality and testing of concrete and steel (reinforcing and anchoring) materials and the design and construction of concrete components that resist seismic forces shall comply with the requirements of ACI 318 except as modified in this chapter.

9.1.2 References. The following documents shall be used as specified in this chapter.

ACI 318	<i>Building Code Requirements for Structural Concrete</i> , American Concrete Institute, 2002.
ACI T1.1	<i>Acceptance Criteria for Moment Frames Based on Structural Testing</i> , American Concrete Institute, 2001.
ATC-24	<i>Guidelines for Seismic Testing of Components of Steel Structures</i> , Applied Technology Council, 1992.

9.1.3 General definitions

Base: See Sec. 4.1.3. Base is defined as “base of structure” in Sec. 21.1 of ACI 318.

Basement: See Sec. 7.1.3.

Boundary elements: See Sec. 2.1.3 and Sec. 21.1 of ACI 318.

Confined region: The portion of a reinforced concrete component in which the concrete is confined by closely spaced special transverse reinforcement restraining the concrete in directions perpendicular to the applied stress.

Coupling beam: A beam that is used to connect adjacent concrete wall elements to make them act together as a unit to resist lateral loads.

Design strength: See Sec. 4.1.3.

Diaphragm: See Sec. 4.1.3. Diaphragm is defined as “structural diaphragm” in Sec. 21.1 of ACI 318.

Intermediate moment frame: See Sec. 4.1.3 and Sec. 21.1 of ACI 318.

Joint: See Sec. 21.1 of ACI 318.

Moment frame: See Sec. 4.1.3 and Sec. 21.1 of ACI 318.

Nominal strength: See Sec. 4.1.3.

Ordinary moment frame: See Sec. 4.1.3 and Sec. 21.1 of ACI 318.

Plain concrete: See Sec. 2.1 of ACI 318.

Reinforced concrete: See Sec. 2.1 of ACI 318.

Required strength: See Sec. 4.1.3.

Seismic Design Category: See Sec. 1.1.4.

Seismic-force-resisting system: See Sec. 1.1.4. Seismic-force-resisting system is defined as “lateral-force-resisting system” in Sec. 21.1 of ACI 318.

Seismic forces: See Sec. 1.1.4. Seismic forces are defined as “specified lateral forces” in Sec. 21.1 of ACI 318.

Shear wall: See Sec. 4.1.3. Shear walls are defined as “structural walls” in Sec. 21.1 of ACI 318.

Special moment frame: See Sec. 4.1.3 and Sec. 21.1 of ACI 318.

Special transverse reinforcement: Reinforcement composed of spirals, closed stirrups, or hoops and supplementary cross-ties provided to restrain the concrete and qualify the portion of the component, where used, as a confined region.

Story: See Sec. 4.1.3.

Structure: See Sec. 1.1.4.

Wall: See Sec. 4.1.3.

9.2 GENERAL DESIGN REQUIREMENTS

9.2.1 Classification of shear walls. Structural concrete shear walls that resist seismic forces shall be classified in accordance with this section.

9.2.1.1 Ordinary plain concrete shear walls. Ordinary plain concrete shear walls shall satisfy the requirements of Sec. 21.1 of ACI 318 for ordinary structural plain concrete walls.

9.2.1.2 Detailed plain concrete shear walls. Detailed plain concrete shear walls above the base shall satisfy the requirements of Sec. 21.1 of ACI 318 for ordinary structural plain concrete walls and contain reinforcement as follows:

Vertical reinforcement of at least 0.20 in.^2 (129 mm^2) in cross-sectional area shall be provided continuously from support to support at each corner, at each side of each opening, and at the ends of walls. The reinforcement required by Sec. 22.6.6.5 of ACI 318 shall be provided.

Horizontal reinforcement of at least 0.20 in.^2 (129 mm^2) in cross-sectional area shall be provided:

1. Continuously at structurally connected roof and floor levels and at the top of walls,
2. At the bottom of load-bearing walls or in the top of foundations where doweled to the wall, and
3. At a maximum spacing of 120 in. (3050 mm).

Reinforcement at the top and bottom of openings, where used in determining the maximum spacing specified in Item 3 above, shall be continuous in the wall.

Basement, foundation, or other walls below the base shall be reinforced as required by Sec. 22.6.6.5 of ACI 318.

9.2.1.3 Ordinary precast shear walls. Ordinary precast shear walls shall satisfy the requirements of Sec. 21.1 of ACI 318 for ordinary precast structural walls. See Sec. 9.2.2.1.1.

9.2.1.4 Ordinary reinforced concrete shear walls. Ordinary reinforced concrete shear walls shall satisfy the requirements of Sec. 21.1 of ACI 318 for ordinary reinforced concrete structural walls. See Sec. 9.2.2.1.1.

9.2.1.5 Intermediate precast shear walls. Intermediate precast shear walls shall satisfy the requirements of both Sec. 21.1 of ACI 318 and Sec. 9.2.2.5 for intermediate precast structural walls.

9.2.1.6 Special reinforced concrete shear walls. Special reinforced concrete shear walls shall satisfy the requirements of Sec. 21.1 of ACI 318 for special reinforced concrete structural walls or for special precast structural walls.

9.2.2 Modifications to ACI 318

9.2.2.1 General

9.2.2.1.1 Additional or modified definitions. Add or modify the following definitions in Sec. 21.1 of ACI 318:

Design displacement: Design story drift as specified in Sec. 5.2.6.1 of the 2003 *NEHRP Recommended Provisions*.

Design load combinations: Combinations of factored loads and forces specified in Sec. 9.2 or C.2 where seismic load E is specified in Sec. 4.2.2 of the 2003 *NEHRP Recommended Provisions*.

Ordinary precast structural wall: A wall incorporating precast concrete elements and complying with the requirements of Chapters 1 through 18 with the requirements of Chapter 16 superseding those of Chapter 14.

Ordinary reinforced concrete structural wall: A cast-in-place wall complying with the requirements of Chapters 1 through 18.

Wall pier: A wall segment with a horizontal length-to-thickness ratio of at least 2.5, but not exceeding 6, whose clear height is at least two times its horizontal length.

9.2.2.1.2 Additional notation. Add or modify the following notation in Sec. 21.0 of ACI 318:

Δ_m = $C_d \Delta_s$. Also equal to δ_u of ACI 318.

Δ_s = design level response displacement, which is the total drift or total story drift that occurs when the structure is subjected to the design seismic forces.

9.2.2.1.3 Scope: Delete Sec. 21.2.1.2, 21.2.1.3, and 21.2.1.4 of ACI 318 and replace with the following:

“21.2.1.2 For structures assigned to Seismic Design Category A or B, provisions of Chapters 1 through 18 and 22 shall apply except as modified by the requirements of Chapter 9 of the 2003 *NEHRP Recommended Provisions*. Where the design seismic loads are computed using provisions for intermediate or special concrete systems, the requirements of Chapter 21 for intermediate or special systems, as applicable, shall be satisfied.

“21.2.1.3 For structures assigned to Seismic Design Category C, intermediate or special moment frames, ordinary or special reinforced concrete structural walls, or intermediate or special precast structural walls shall be used to resist seismic forces induced by earthquake motions. Where the design seismic loads are computed using the provisions for intermediate or special concrete systems, the requirements of Chapter 21 for special systems, as applicable, shall be satisfied.

“21.2.1.4 For structures assigned to Seismic Design Category D, E or F, special moment frames, special structural walls, diaphragms, trusses and foundations complying with Sec. 21.2 through 21.10, or intermediate precast structural walls complying with 21.13, shall be used to resist earthquake motions. Frame members not proportioned to resist earthquake forces shall comply with Sec. 21.11.”

9.2.2.1.4. Delete Sec. 21.2 of ACI 318 and replace with following:

“21.2.5 Reinforcement in members resisting earthquake-induced forces.

“21.2.5.1 Deformed reinforcement resisting earthquake-induced flexural and axial forces in the frame members and in structural wall boundary elements shall comply with ASTM A 706. ASTM A 615 Grades 40 and 60 reinforcement shall be permitted in these members if:

“(a) The actual yield strength based on mill tests does not exceed the specified yield strength by more than 18,000 psi (retests shall not exceed this value by more than an additional 3000 psi); and

“(b) The ratio of the actual ultimate tensile strength to the actual tensile yield strength is not less than 1.25.

“**21.2.5.2** Prestressing steel resisting earthquake-induced flexural and axial loads in frame members shall comply with ASTM A 421 or ASTM A 722. The average prestress, f_{pc} , calculated for an area equal to the member’s shortest cross-sectional dimension multiplied by the perpendicular dimension shall not exceed the lesser of 700 psi or $f'_c/6$ at plastic hinge regions.

“ **21.2.9 –Anchorages for post-tensioning tendons.**

“**21.2.9** Anchorages for unbonded post-tensioning tendons resisting earthquake induced forces in structures in regions of moderate or high seismic risk, or assigned to intermediate or high seismic performance or design categories shall withstand, without failure, 50 cycles of loading between 40 and 85 percent of the specified tensile strength of the prestressing steel.”

9.2.2.2 Special moment frames. Add the following new Sec. 21.3.2.5 to ACI 318:

“**21.3.2.5** – Unless the special moment frame is qualified for use through structural testing as required by 21.6.3, for flexural members, prestressing steel shall not provide more than one quarter of the strength for either positive or negative moment at the critical section in a plastic hinge location and shall be anchored at or beyond the exterior face of a joint.”

9.2.2.3 Special reinforced concrete shear walls

9.2.2.3.1. In Sec. 21.7.3 of ACI 318, change “factored load combinations” to “design load combinations.”

9.2.2.3.2. Add a new Sec. 21.7.10 to ACI 318 which reads as follows:

“ **21.7.10 Wall piers and wall segments**

“ **21.7.10.1:** Wall piers not designed as part of a special moment frame shall have transverse reinforcement designed to satisfy the requirements of Sec. 21.7.10.2.

“**Exceptions:** This requirement need not be applied in the following conditions:

“1. Wall piers that satisfy Sec. 21.11, and

“2. Wall piers along a wall line within a story where other shear wall segments provide lateral support to the wall piers and such segments have a total stiffness of at least six times the sum of the stiffness of all the wall piers.

“ **21.7.10.2:** Transverse reinforcement with seismic hooks at both ends shall be designed to resist the shear forces determined from Sec. 21.4.5.1. Spacing of transverse reinforcement shall not exceed 6 in. (152 mm). Transverse reinforcement shall be extended beyond the pier clear height for at least 12 in. (304mm).

“**21.7.10.3** Wall segments with a horizontal length-to-thickness ratio less than 2.5 shall be designed as columns.”

9.2.2.4 Special structural walls constructed using precast concrete . Add a new Sec. 21.8.2 to ACI 318 as follows:

“**21.8.2** Wall systems not meeting the requirements of 21.8.1 shall be permitted if substantiating experimental evidence and analysis meets the requirements of Sec. 9. 6 of the 2003 NEHRP Recommended *Provisions*.”

9.2.2.5 Intermediate precast structural walls. Delete existing Sec. 21.13.3 of ACI 318 and replace with following:

“**21.13.3** Connections that are designed to yield shall be capable of maintaining 80 percent of their design strength at the deformation induced by design displacement, or shall use type 2 mechanical splices.

“**21.13.4** Elements of the connection that are not designed to yield shall develop at least $1.5 S_y$.”

“**21.13.5** Wall piers not designed as part of a moment frame shall have transverse reinforcement designed to resist the shear forces determined from Sec. 21.12.3. Spacing of transverse reinforcement shall not exceed 8 in., and (b) six times the diameter of the longitudinal reinforcement. Transverse reinforcement shall be extended beyond the pier clear height for at least 12 in.

Exception: The above requirement need not apply in the following situations:

1. Wall piers that satisfy Sec. 21.11, and
2. Wall piers along a wall line within a story where other shear wall segments provide lateral support to the wall piers and such segments have a total stiffness of at least six times the sum of the stiffnesses of all the wall piers.

“Wall segments with a horizontal length-to-thickness ratio less than 2.5 shall be designed as columns.”

9.2.2.6 Foundations. Delete Sec. 21.10.1.1 of ACI 318 and replace with following:

“ **21.10.1.1** Foundations resisting earthquake-induced forces or transferring earthquake-induced forces between a structure and the ground shall comply with requirements of 21.10 and other applicable provisions except as modified by Chapter 7 of the 2003 *NEHRP Recommended Provisions*.”

9.2.2.7 Frame members that are not part of the seismic-force-resisting system. Delete Sec.21.11.2.2 of ACI 318 and replace with following:

“ **21.11.2.2** . Members with factored gravity axial forces exceeding $A_g f'_c / 10$ shall satisfy 21.4.3, 21.4.4.1(c), 21.4.4.3, and 21.4.5. The maximum longitudinal spacing of ties shall be s_o for the full column height. The spacing, s_o , shall not be more than six diameters of the smallest longitudinal bar enclosed or 6 in. (152 mm), whichever is smaller. Lap splices of longitudinal reinforcement in such members need not satisfy 21.4.3.2 in structures where the seismic-force-resisting system does not include special moment frames.”

9.2.2.8 Anchoring to Concrete

9.2.2.8.1. Delete Sec. D.3.3.2 of ACI 318 and replace with following:

“**D.3.3.2** – In structures assigned to Seismic Design Category C, D, E or F, post-installed structural anchors for use under D.2.3 shall have passed the Simulated Seismic Tests of ACI 355.2.”

9.2.2.8.2. Delete Sec. D.3.3.3 of ACI 318 and replace with following:

“**D.3.3.3** – In structures assigned to Seismic Design Category C, D, E or F, the design strength of anchors shall be taken as $0.75 \phi N_n$ and $0.75 \phi V_n$, where ϕ is given in D 4.4 when the load combinations of Sec. 9.2 are used and in D 4.5 when the load combinations of Appendix C are used, and N_n and V_n are determined in accordance with D.4.1.”

9.2.2.8.3. Delete Sec. D.3.3.4 of ACI 318 and replace with following:

“**D 3.3.4** – In structures assigned to Seismic Design Category C, D, E or F, anchors shall be designed to be governed by tensile or shear strength of a ductile steel element, unless D.3.3.5 is satisfied.”

9.2.2.8.4. Delete Sec. D 3.3.5 of ACI 318 and replace with following:

“**D 3.3.5** – Instead of D 3.3.4, the attachment that the anchor is connecting to the structure shall be designed so that the attachment undergoes ductile yielding at a load level corresponding to anchor forces no greater than the design strength of anchors specified in D.3.3.3, or the minimum design strength of the anchors shall be at least 2.5 times the factored forces transmitted by the attachment.

9.3 SEISMIC DESIGN CATEGORY B

Structures assigned to Seismic Design Category B shall satisfy the requirements of Sec.21.2.1.2 of ACI 318 and this section.

9.3.1 Ordinary moment frames. Flexural members of all ordinary moment frames forming part of the seismic-force-resisting system shall be designed in accordance with Sec. 7.13.2 of ACI 318. For such elements, at least two main flexural reinforcing bars shall be provided continuously, top and bottom, throughout the beams and shall extend through or be developed within exterior columns or boundary elements.

Columns of ordinary moment frames having a clear-height-to-maximum-plan-dimension ratio of 5 or less shall be designed for shear in accordance with Sec. 21.12.3 of ACI 318.

9.4 SEISMIC DESIGN CATEGORY C

Structures assigned to Seismic Design Category C shall satisfy the requirements for Seismic Design Category B, Sec. 21.2.1.3 of ACI 318 and the additional requirements of this section.

9.4.1 Discontinuous members. Columns supporting reactions from discontinuous stiff members such as walls shall be designed for the seismic load effects defined in Sec. 4.2.2.2 and shall be provided with transverse reinforcement at the spacing s_o as defined in Sec. 2.12.5.2 of ACI 318 over their full height beneath the level at which the discontinuity occurs. This transverse reinforcement shall be extended above and below the column as required in Sec. 21.4.4.5 of ACI 318.

9.4.2 Plain concrete. Plain concrete members shall comply with the requirements of ACI 318 and the additional requirements and limitations of this section.

9.4.2.1 Walls. Ordinary and detailed plain concrete walls are not permitted.

Exception: In detached one- and two-family dwellings three stories or less in height constructed with stud bearing walls, plain concrete basement, foundation, or other walls below the base are permitted. Such walls shall have reinforcement in accordance with Sec. 22.6.6.5 of ACI 318.

9.4.2.2 Footings. Isolated footings of plain concrete supporting pedestals or columns are permitted provided the projection of the footing beyond the face of the supported member does not exceed the footing thickness.

Exception: In detached one- and two-family dwellings three stories or less in height constructed with stud bearing walls, the projection of the footing beyond the face of the supported member shall be permitted to exceed the footing thickness.

Plain concrete footings supporting walls shall be provided with no less than two continuous longitudinal reinforcing bars. Bars shall not be smaller than No. 4 (13 mm) and shall have a total area of not less than 0.002 times the gross cross-sectional area of the footing. For footings that exceed 8 in. in thickness, a minimum of one bar shall be provided at the top and bottom of the footing. For foundation systems consisting of plain concrete footing and plain concrete stemwall, a minimum of one bar shall be provided at the top of the stemwall and at the bottom the footing. Continuity of reinforcement shall be provided at corners and intersections.

Exceptions:

1. In detached one- and two-family dwellings three stories or less in height and constructed with stud bearing walls, plain concrete footings supporting walls shall be permitted without longitudinal reinforcement.
2. Where a slab-on-ground is cast monolithically with the footing, one No. 5 (16 mm) bar is permitted to be located at either the top or bottom of the footing.

9.4.2.3 Pedestals. Plain concrete pedestals shall not be used to resist lateral seismic forces.

9.5 SEISMIC DESIGN CATEGORIES D, E, AND F

Structures assigned to Seismic Design Category D, E, or F shall satisfy the requirements for Seismic Design Category C and Sec. 21.2.1.4 of ACI 318.

9.6 ACCEPTANCE CRITERIA FOR SPECIAL PRECAST STRUCTURAL WALLS BASED ON VALIDATION TESTING**9.6.1 Notation**

Symbols additional to those in Chapter 21 of ACI 318 are defined.

E_{max} = maximum lateral resistance of test module determined from test results (forces or moments).

E_n = nominal lateral resistance of test module calculated using specified geometric properties of test members, specified yield strength of reinforcement, specified compressive strength of concrete, a strain compatibility analysis or deformation compatibility analysis for flexural strength and a strength reduction factor ϕ of 1.0.

E_{nt} = Calculated lateral resistance of test module using the actual geometric properties of test members, the actual strengths of reinforcement, concrete, and coupling devices, obtained by testing per 9.6.7.7, 9.6.7.8, and 9.6.7.9; and a strength reduction factor ϕ of 1.0.

θ = drift ratio.

β = relative energy dissipation ratio.

9.6.2 Definitions

Definitions additional to those in Chapter 21 of ACI 318 are defined.

9.6.2.1 Coupling Elements. Devices or beams connecting adjacent vertical boundaries of structural walls and used to provide stiffness and energy dissipation for the connected assembly greater than the sum of those provided by the connected walls acting as separate units.

9.6.2.2 Drift ratio. Total lateral deformation of the test module divided by the height of the test module.

9.6.2.3 Global toughness. The ability of the entire lateral force resisting system of the prototype structure to maintain structural integrity and continue to carry the required gravity load at the maximum lateral displacements anticipated for the ground motions of the maximum considered earthquake.

9.6.2.4 Prototype structure. The concrete wall structure for which acceptance is sought.

9.6.2.5 Relative energy dissipation ratio. Ratio of actual to ideal energy dissipated by test module during reversed cyclic response between given drift ratio limits, expressed as the ratio of the area of the hysteresis loop for that cycle to the area of the circumscribing parallelograms defined by the initial stiffnesses during the first cycle and the peak resistances during the cycle for which the relative energy dissipation ratio is calculated Sec. 9.6.9.1.3.

9.6.2.5 Test module. Laboratory specimen representing the critical walls of the prototype structure. See 9.6.5.

9.6.3 Scope and general requirements

9.6.3.1 These provisions define minimum acceptance criteria for new precast structural walls, including coupled precast structural walls, designed for regions of high seismic risk or for structures assigned to high seismic performance or design categories, where acceptance is based on experimental evidence and mathematical analysis.

9.6.3.2. These provisions are applicable to precast structural walls, coupled or uncoupled, with height to length, h_w/l_w , ratios equal to or greater than 0.5. These provisions are applicable for either prequalifying precast structural walls for a specific structure or prequalifying a new precast wall type for construction in general.

9.6.3.3. Precast structural walls shall be deemed to have a response that is at least equivalent to the response of monolithic structural walls designed in accordance with Sec.21.2 and 21.7 of ACI 318, and the corresponding structural walls of the prototype structure shall be deemed acceptable, when all of the conditions in Sec. 9.6.3.3.1 through 9.6.3.3.5 are satisfied.

9.6.3.3.1. The prototype structure satisfies all applicable requirements of these provisions and of ACI 318 except Sec.21.7.

9.6.3.3.2. Tests on wall modules satisfy the conditions in Sec. 9.6.4 and 9.6.9.

9.6.3.3.3. The prototype structure is designed using the design procedure substantiated by the testing program.

9.6.3.3.4. The prototype structure is designed and analyzed using effective initial properties consistent with those determined in accordance with Sec. 9.6.7.11, and the prototype structure meets the drift limits of these provisions.

9.6.3.3.5. The structure as a whole, based on the results of the tests of Sec. 9.6.3.3.2 and analysis, is demonstrated to have adequate global toughness (the ability to retain its structural integrity and support its specified gravity loads) through peak displacements equal to or exceeding the story-drift ratios specified in Sec.9.6.7.4, 9.6.7.5 or 9.6.7.6, as appropriate.

9.6.4 Design procedure

9.6.4.1. Prior to testing, a design procedure shall be developed for the prototype structure and its walls. That procedure shall account for effects of material non-linearity, including cracking, deformations of members and connections, and reversed cyclic loading. The design procedure shall include the procedures specified in Sec. 9.6.4.1.1 through 9.6.4.1.4 and shall be applicable to all precast structural walls, coupled and uncoupled, of the prototype structure.

9.6.4.1.1. Procedures shall be specified for calculating the effective initial stiffness of the precast structural walls, and of coupled structural walls, that are applicable to all the walls of the prototype structure.

9.6.4.1.2. Procedures shall be specified for calculating the lateral strength of the precast structural walls, and of coupled structural walls, applicable to all precast walls of the prototype structure.

9.6.4.1.3. Procedures shall be specified for designing and detailing the precast structural walls so that they have adequate ductility capacity. These procedures shall cover wall shear strength, sliding shear strength, boundary tie spacing to prevent bar buckling, concrete confinement, reinforcement strain, and any other actions or elements of the wall system that can affect ductility capacity.

9.6.4.1.4. Procedures shall be specified for determining that an undesirable mechanism of nonlinear response, such as a story mechanism due to local buckling of the reinforcement or splice failure, or overall instability of the wall, does not occur.

9.6.4.2. The design procedure shall be used to design the test modules and shall be documented in the test report.

9.6.4.3. The design procedure used to proportion the test specimens shall define the mechanism by which the system resists gravity and earthquake effects and shall establish acceptance values for sustaining that mechanism. Portions of the mechanism that deviate from code requirements shall be contained in the test specimens and shall be tested to determine acceptance values.

9.6.5 Test Modules

9.6.5.1. At least two modules shall be tested. At least one module shall be tested for each limiting engineering design criteria (shear, axial load and flexure) for each characteristic configuration of precast structural walls, including intersecting structural walls or coupled structural walls. If all the precast walls of the structure have the same configuration and the same limiting engineering design criterion, then two modules shall be tested. Where intersecting precast wall systems are to be used, the response for the two orthogonal directions shall be tested.

9.6.5.2. Where the design requires the use of coupling elements, those elements shall be included as part of the test module.

9.6.5.3. Modules shall have a scale large enough to represent the complexities and behavior of the real materials and of the load transfer mechanisms in the prototype walls and their coupling elements, if any. Modules shall have a scale not less than one half and shall be full-scale if the validation testing has not been preceded by an extensive analytical and experimental development program in which critical details of connections are tested at full scale.

9.6.5.4. The geometry, reinforcing details, and materials properties of the walls, connections, and coupling elements shall be representative of those to be used in the prototype structure.

9.6.5.5. Walls shall be at least two panels high unless the prototype structure is one for which a single panel is to be used for the full height of the wall.

9.6.5.6. Where precast walls are to be used for bearing wall structures, as defined in SEI/ASCE 7-02, the test modules shall be subject during lateral loading to an axial load stress representative of that anticipated at the base of the wall in the prototype structure.

9.6.5.7. The geometry, reinforcing, and details used to connect the precast walls to the foundation shall replicate those to be used in the prototype structure.

9.6.5.8. Foundations used to support the test modules shall have geometric characteristics, and shall be reinforced and supported, so that their deformations and cracking do not affect the performance of the modules in a way that would be different than in the prototype structure.

9.6.6 Testing Agency. Testing shall be carried out by an independent testing agency approved by the Authority Having Jurisdiction. The testing agency shall perform its work under the supervision of a registered design professional experienced in seismic structural design.

9.6.7 Test Method

9.6.7.1 Test modules shall be subjected to a sequence of displacement-controlled cycles representative of the drifts expected under earthquake motions for the prototype structure. If the module consists of coupled walls, approximately equal drifts (within 5 percent of each other) shall be applied to the top of each wall and at each floor level. Cycles shall be to predetermined drift ratios as defined in Sec. 9.6.7.2 through 9.6.7.6.

9.6.7.2 Three fully reversed cycles shall be applied at each drift ratio.

9.6.7.3 The initial drift ratio shall be within the essentially linear elastic response range for the module. See 9.6.7.11. Subsequent drift ratios shall be to values not less than 5/4 times, and not more than 3/2 times, the previous drift ratio.

9.6.7.4 For uncoupled walls, testing shall continue with gradually increasing drift ratios until the drift ratio in percent equals or exceeds the larger of : (a) 1.5 times the drift ratio corresponding to the design

displacement or (b) the following value:

$$0.80 \leq 0.67 \left[h_w / l_w \right] + 0.5 \leq 2.5 \quad (9.6-1)$$

where:

h_w = height of entire wall for prototype structure, in.

l_w = length of entire wall in direction of shear force, in.

9.6.7.5 For coupled walls, h_w/l_w in Eq. 9.6.1 shall be taken as the smallest value of h_w/l_w for any individual wall of the prototype structure.

9.6.7.6 Validation by testing to limiting drift ratios less than those given by Eq. 9.6.1 shall be acceptable provided testing is conducted in accordance with this document to drift ratios equal or exceeding of those determined for the response to a suite of nonlinear time history analyses conducted in accordance with Sec. 9.5.8 of SEI/ASCE 7-02 for maximum considered ground motions.

9.6.7.7 Actual yield strength of steel reinforcement shall be obtained by testing coupons taken from the same reinforcement batch as used in the test module. Two tests, conforming to the ASTM specifications cited in Sec. 3.5 of ACI 318, shall be made for each reinforcement type and size.

9.6.7.8 Actual compressive strength of concrete shall be determined by testing of concrete cylinders cured under the same conditions as the test module and tested at the time of testing the module. Testing shall conform to the applicable requirements of Sec.5.6.1 through 5.6.4 of ACI 318.

9.6.7.9 Where strength and deformation capacity of coupling devices does not depend on reinforcement tested as required in Sec. 9.6.7.7, the effective yield strength and deformation capacity of coupling devices shall be obtained by testing independent of the module testing.

9.6.7.10 Data shall be recorded from all tests such that a quantitative interpretation can be made of the performance of the modules. A continuous record shall be made of test module drift ratio versus applied lateral force, and photographs shall be taken that show the condition of the test module at the peak displacement and after each key testing cycle.

9.6.7.11 The effective initial stiffness of the test module shall be calculated based on test cycles to a force between $0.6E_{nt}$ and $0.9E_{nt}$, and using the deformation at the strength of $0.75E_{nt}$ to establish the stiffness.

9.6.8. Test Report

9.6.8.1 The test report shall contain sufficient evidence for an independent evaluation of all test procedures, design assumptions, and the performance of the test modules. As a minimum, all of the information required by Sec. 9.6.8.1.1 through 9.6.8.1.11 shall be provided.

9.6.8.1.1 A description shall be provided of the design procedure and theory used to predict test module strength, specifically the test module nominal lateral resistance, E_n , and the test module actual lateral resistance E_{nt} .

9.6.8.1.2 Details shall be provided of test module design and construction, including fully dimensioned engineering drawings that show all components of the test specimen.

9.6.8.1.3 Details shall be provided of specified material properties used for design, and actual material properties obtained by testing in accordance with Sec. 9.6.7.7.

9.6.8.1.4 A description shall be provided of test setup, including fully dimensioned diagrams and photographs.

9.6.8.1.5 A description shall be provided of instrumentation, its locations, and its purpose.

9.6.8.1.6 A description and graphical presentation shall be provided of applied drift ratio sequence.

9.6.8.1.7 A description shall be provided of observed performance, including photographic documentation, of the condition of each test module at key drift ratios including, (as applicable), the ratios corresponding to first flexural cracking or joint opening, first shear cracking, and first crushing of the concrete for both positive and negative loading directions, and any other significant damage events that occur. Photos shall be taken at peak drifts and after the release of load.

9.6.8.1.8 A graphical presentation shall be provided of lateral force versus drift ratio response.

9.6.8.1.9 A graphical presentation shall be provided of relative energy dissipation ratio versus drift ratio.

9.6.8.1.10 A calculation shall be provided of effective initial stiffness for each test module as observed in the test and as determined in accordance with Sec. 9.6.7.11 and a comparison made as to how accurately the design procedure has been able to predict the measured stiffness. The design procedure shall be used to predict the overall structural response and a comparison made as to how accurately that procedure has been able to predict the measured response.

9.6.8.1.11 The test date, report date, name of testing agency, report author(s), supervising registered design professional, and test sponsor shall be provided.

9.6.9 Test module acceptance criteria

9.6.9.1 The test module shall be deemed to have performed satisfactorily when all of the criteria Sec. 9.6.9.1.1 through 9.6.9.1.3 are met for both directions of in-plane response. If any test module fails to pass the validation testing required by these provisions for any test direction, then the wall system has failed the validation testing.

9.6.9.1.1 Peak lateral strength obtained shall be at least $0.9E_{nt}$ and not greater than $1.2 E_{nt}$.

9.6.9.1.2 In cycling up to the drift level given by Sec. 9.6.7.4 through 9.6.7.6, fracture of reinforcement or coupling elements, or other significant strength degradation, shall not occur. For a given direction, peak lateral strength during any cycle of testing to increasing displacement shall not be less than 0.8 times E_{max} for that direction.

9.6.9.1.3 For cycling at the given drift level for which acceptance is sought in accordance with Sec. 9.6.7.4, 9.6.7.5 or 9.6.7.6, as applicable, the parameters describing the third complete cycle shall have satisfied the following:

1. The relative energy dissipation ratio shall have been not less than 1/8; and
2. The secant stiffness between drift ratios of -1/10 and +1/10 of the maximum applied drift shall have been not less than 0.10 times the stiffness for the initial drift ratio specified in Sec. 9.6.7.3.

9.6.10. Reference

Minimum Design Loads on Buildings and Other Structures Standards Committee, "Minimum Design Loads for Buildings and Other Structures (SEI/ASCE 7-02) - Earthquake Loads," Structural Engineering Institute, American Society of Civil Engineers, Reston, VA, 2002.

This page is intentionally left blank.