

## Chapter 11

### SEISMIC DESIGN CRITERIA

#### 11.1 GENERAL

**11.1.1 Purpose.** Chapter 11 presents criteria for the design and construction of buildings and other structures subject to earthquake ground motions. The specified earthquake loads are based upon post-elastic energy dissipation in the structure, and because of this fact, the requirements for design, detailing, and construction shall be satisfied even for structures and members for which load combinations that do not contain earthquake loads indicate larger demands than combinations that include earthquake loads. Minimum requirements for quality assurance for seismic force-resisting systems are set forth in Appendix 11A.

**11.1.2 Scope.** Every structure, and portion thereof, including nonstructural components, shall be designed and constructed to resist the effects of earthquake motions as prescribed by the seismic requirements of this standard. Certain nonbuilding structures, as described in Chapter 15, are also within the scope and shall be designed and constructed in accordance with the requirements of Chapter 15. Requirements concerning alterations, additions, and change of use are set forth in Appendix 11B. Existing structures and alterations to existing structures need only comply with the seismic requirements of this standard where required by Appendix 11B. The following structures are exempt from the seismic requirements of this standard:

1. Detached one- and two-family dwellings that are located where the mapped, short period, spectral response acceleration parameter,  $S_S$ , is less than 0.4 or where the Seismic Design Category determined in accordance with Section 11.6 is A, B, or C.
2. Detached one- and two-family wood-frame dwellings not included in Exception 1 with not more than two stories, satisfying the limitations of and constructed in accordance with the IRC.
3. Agricultural storage structures that are intended only for incidental human occupancy.
4. Structures that require special consideration of their response characteristics and environment that are not addressed in Chapter 15 and for which other regulations provide seismic criteria, such as vehicular bridges, electrical transmission towers, hydraulic structures, buried utility lines and their appurtenances, and nuclear reactors.

**11.1.3 Applicability.** Structures and their nonstructural components shall be designed and constructed in accordance with the requirement of the following sections based on the type of structure or component:

- a. Buildings: Chapter 12
- b. Nonbuilding Structures: Chapter 15
- c. Nonstructural Components: Chapter 13
- d. Seismically Isolated Structures: Chapter 17
- e. Structures with Damping Systems: Chapter 18

#### 11.1.4 Alternate Materials and Methods of Construction.

Alternate materials and methods of construction to those prescribed in the seismic requirements of this standard shall not be used unless approved by the authority having jurisdiction. Substantiating evidence shall be submitted demonstrating that the proposed alternate, for the purpose intended, will be at least equal in strength, durability, and seismic resistance.

#### 11.2 DEFINITIONS

The following definitions apply only to the seismic requirements of this standard.

**ACTIVE FAULT:** A fault determined to be active by the authority having jurisdiction from properly substantiated data (e.g., most recent mapping of active faults by the United States Geological Survey).

**ADDITION:** An increase in building area, aggregate floor area, height, or number of stories of a structure.

**ALTERATION:** Any construction or renovation to an existing structure other than an addition.

**APPENDAGE:** An architectural component such as a canopy, marquee, ornamental balcony, or statuary.

**APPROVAL:** The written acceptance by the authority having jurisdiction of documentation that establishes the qualification of a material, system, component, procedure, or person to fulfill the requirements of this standard for the intended use.

**ATTACHMENTS:** Means by which components and their supports are secured or connected to the seismic force-resisting system of the structure. Such attachments include anchor bolts, welded connections, and mechanical fasteners.

**BASE:** The level at which the horizontal seismic ground motions are considered to be imparted to the structure.

**BASEMENT:** A basement is any story below the lowest story above grade.

**BASE SHEAR:** Total design lateral force or shear at the base.

**BOUNDARY ELEMENTS:** Diaphragm and shear wall boundary members to which the diaphragm transfers forces. Boundary members include chords and drag struts at diaphragm and shear wall perimeters, interior openings, discontinuities, and reentrant corners.

**BOUNDARY MEMBERS:** Portions along wall and diaphragm edges strengthened by longitudinal and transverse reinforcement. Boundary members include chords and drag struts at diaphragm and shear wall perimeters, interior openings, discontinuities, and reentrant corners.

**BUILDING:** Any structure whose intended use includes shelter of human occupants.

**CANTILEVERED COLUMN SYSTEM:** A seismic force-resisting system in which lateral forces are resisted entirely by columns acting as cantilevers from the base.

**CHARACTERISTIC EARTHQUAKE:** An earthquake assessed for an active fault having a magnitude equal to the best estimate of the maximum magnitude capable of occurring on the fault, but not less than the largest magnitude that has occurred historically on the fault.

**COMPONENT:** A part or element of an architectural, electrical, mechanical, or structural system.

**Component, Equipment:** A mechanical or electrical component or element that is part of a mechanical and/or electrical system within or without a building system.

**Component, Flexible:** Component, including its attachments, having a fundamental period greater than 0.06 s.

**Component, Rigid:** Component, including its attachments, having a fundamental period less than or equal to 0.06 s.

**COMPONENT SUPPORT:** Those structural members or assemblies of members, including braces, frames, struts, and attachments that transmit all loads and forces between systems, components, or elements and the structure.

**CONCRETE, PLAIN:** Concrete that is either unreinforced or contains less reinforcement than the minimum amount specified in ACI 318 for reinforced concrete

**CONCRETE, REINFORCED:** Concrete reinforced with no less reinforcement than the minimum amount required by ACI 318 prestressed or nonprestressed, and designed on the assumption that the two materials act together in resisting forces.

**CONSTRUCTION DOCUMENTS:** The written, graphic, electronic, and pictorial documents describing the design, locations, and physical characteristics of the project required to verify compliance with this standard.

**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.

**DEFORMABILITY:** The ratio of the ultimate deformation to the limit deformation.

**High-Deformability Element:** An element whose deformability is not less than 3.5 where subjected to four fully reversed cycles at the limit deformation.

**Limited-Deformability Element:** An element that is neither a low-deformability or a high-deformability element.

**Low-Deformability Element:** An element whose deformability is 1.5 or less.

#### **DEFORMATION:**

**Limit Deformation:** Two times the initial deformation that occurs at a load equal to 40 percent of the maximum strength.

**Ultimate Deformation:** The deformation at which failure occurs and that shall be deemed to occur if the sustainable load reduces to 80 percent or less of the maximum strength.

**DESIGNATED SEISMIC SYSTEMS:** The seismic force-resisting system and those architectural, electrical, and mechanical systems or their components that require design in accordance with Chapter 13 and for which the component importance factor,  $I_p$ , is greater than 1.0.

**DESIGN EARTHQUAKE:** The earthquake effects that are two-thirds of the corresponding Maximum Considered Earthquake (MCE) effects.

**DESIGN EARTHQUAKE GROUND MOTION:** The earthquake ground motions that are two-thirds of the corresponding MCE ground motions.

**DIAPHRAGM:** Roof, floor, or other membrane or bracing system acting to transfer the lateral forces to the vertical resisting elements.

**DIAPHRAGM BOUNDARY:** A location where shear is transferred into or out of the diaphragm element. Transfer is either to a boundary element or to another force-resisting element.

**DIAPHRAGM CHORD:** A diaphragm boundary element perpendicular to the applied load that is assumed to take axial stresses due to the diaphragm moment.

**DRAG STRUT (COLLECTOR, TIE, DIAPHRAGM STRUT):** A diaphragm or shear wall boundary element parallel to the applied load that collects and transfers diaphragm shear forces to the vertical force-resisting elements or distributes forces within the diaphragm or shear wall.

**ENCLOSURE:** An interior space surrounded by walls.

**EQUIPMENT SUPPORT:** Those structural members or assemblies of members or manufactured elements, including braces, frames, legs, lugs, snuggers, hangers, or saddles that transmit gravity loads and operating loads between the equipment and the structure.

**FLEXIBLE EQUIPMENT CONNECTIONS:** Those connections between equipment components that permit rotational and/or translational movement without degradation of performance. Examples include universal joints, bellows expansion joints, and flexible metal hose.

#### **FRAME:**

**Braced Frame:** An essentially vertical truss, or its equivalent, of the concentric or eccentric type that is provided in a building frame system or dual system to resist seismic forces.

**Concentrically Braced Frame (CBF):** A braced frame in which the members are subjected primarily to axial forces. CBFs are categorized as ordinary concentrically braced frames (OCBF) or special concentrically braced frames (SCBF).

**Eccentrically Braced Frame (EBF):** A diagonally braced frame in which at least one end of each brace frames into a beam a short distance from a beam-column or from another diagonal brace.

**Moment Frame:** A frame in which members and joints resist lateral forces by flexure as well as along the axis of the members. Moment frames are categorized as intermediate moment frames (IMF), ordinary moment frames (OMF), and special moment frames (SMF).

#### **Structural System:**

**Building Frame System:** A structural system with an essentially complete space frame providing support for vertical loads. Seismic force resistance is provided by shear walls or braced frames.

**Dual System:** A structural system with an essentially complete space frame providing support for vertical loads. Seismic force resistance is provided by moment-resisting frames and shear walls or braced frames as prescribed in Section 12.2.5.1.

**Shear Wall-Frame Interactive System:** A structural system that uses combinations of ordinary reinforced concrete shear walls and ordinary reinforced concrete moment frames

designed to resist lateral forces in proportion to their rigidities considering interaction between shear walls and frames on all levels.

**Space Frame System:** A 3-D structural system composed of interconnected members, other than bearing walls, that is capable of supporting vertical loads and, where designed for such an application, is capable of providing resistance to seismic forces.

**GLAZED CURTAIN WALL:** A nonbearing wall that extends beyond the edges of building floor slabs, and includes a glazing material installed in the curtain wall framing.

**GLAZED STOREFRONT:** A nonbearing wall that is installed between floor slabs, typically including entrances, and includes a glazing material installed in the storefront framing.

**GRADE PLANE:** A reference plane representing the average of finished ground level adjoining the structure at all exterior walls. Where the finished ground level slopes away from the exterior walls, the reference plane shall be established by the lowest points within the area between the buildings and the lot line or, where the lot line is more than 6 ft (1,829 mm) from the structure, between the structure and a point 6 ft (1,829 mm) from the structure.

**HAZARDOUS CONTENTS:** A material that is highly toxic or potentially explosive and in sufficient quantity to pose a significant life-safety threat to the general public if an uncontrolled release were to occur.

**IMPORTANCE FACTOR:** A factor assigned to each structure according to its Occupancy Category as prescribed in Section 11.5.1.

**INSPECTION, SPECIAL:** The observation of the work by a special inspector to determine compliance with the approved construction documents and these standards in accordance with the quality assurance plan.

**Continuous Special Inspection:** The full-time observation of the work by a special inspector who is present in the area where work is being performed.

**Periodic Special Inspection:** The part-time or intermittent observation of the work by a special inspector who is present in the area where work has been or is being performed.

**INSPECTOR, SPECIAL (who shall be identified as the owner's inspector):** A person approved by the authority having jurisdiction to perform special inspection.

**INVERTED PENDULUM-TYPE STRUCTURES:** Structures in which more than 50 percent of the structure's mass is concentrated at the top of a slender, cantilevered structure and in which stability of the mass at the top of the structure relies on rotational restraint to the top of the cantilevered element.

**JOINT:** The geometric volume common to intersecting members.

**LIGHT-FRAME CONSTRUCTION:** A method of construction where the structural assemblies (e.g., walls, floors, ceilings, and roofs) are primarily formed by a system of repetitive wood or cold-formed steel framing members or subassemblies of these members (e.g., trusses).

**LONGITUDINAL REINFORCEMENT RATIO:** Area of longitudinal reinforcement divided by the cross-sectional area of the concrete.

**MAXIMUM CONSIDERED EARTHQUAKE (MCE) GROUND MOTION:** The most severe earthquake effects considered by this standard as defined in Section 11.4.

**MECHANICALLY ANCHORED TANKS OR VESSELS:** Tanks or vessels provided with mechanical anchors to resist overturning moments.

**NONBUILDING STRUCTURE:** A structure, other than a building, constructed of a type included in Chapter 15 and within the limits of Section 15.1.1.

**NONBUILDING STRUCTURE SIMILAR TO A BUILDING:** A nonbuilding structure that is designed and constructed in a manner similar to buildings, will respond to strong ground motion in a fashion similar to buildings, and have basic lateral and vertical seismic-force-resisting-system conforming to one of the types indicated in Tables 12.2-1 or 15.4-1.

**ORTHOGONAL:** To be in two horizontal directions, at 90° to each other.

**OWNER:** Any person, agent, firm, or corporation having a legal or equitable interest in the property.

**PARTITION:** A nonstructural interior wall that spans horizontally or vertically from support to support. The supports may be the basic building frame, subsidiary structural members, or other portions of the partition system.

**P-DELTA EFFECT:** The secondary effect on shears and moments of structural members due to the action of the vertical loads induced by horizontal displacement of the structure resulting from various loading conditions.

**PILE:** Deep foundation components including piers, caissons, and piles.

**PILE CAP:** Foundation elements to which piles are connected including grade beams and mats.

**REGISTERED DESIGN PROFESSIONAL:** An architect or engineer, registered or licensed to practice professional architecture or engineering, as defined by the statutory requirements of the professional registrations laws of the state in which the project is to be constructed.

**SEISMIC DESIGN CATEGORY:** A classification assigned to a structure based on its Occupancy Category and the severity of the design earthquake ground motion at the site as defined in Section 11.4.

**SEISMIC FORCE-RESISTING SYSTEM:** That part of the structural system that has been considered in the design to provide the required resistance to the seismic forces prescribed herein.

**SEISMIC FORCES:** The assumed forces prescribed herein, related to the response of the structure to earthquake motions, to be used in the design of the structure and its components.

**SELF-ANCHORED TANKS OR VESSELS:** Tanks or vessels that are stable under design overturning moment without the need for mechanical anchors to resist uplift.

**SHEAR PANEL:** A floor, roof, or wall component sheathed to act as a shear wall or diaphragm.

**SITE CLASS:** A classification assigned to a site based on the types of soils present and their engineering properties as defined in Chapter 20.

**STORAGE RACKS:** Include industrial pallet racks, moveable shelf racks, and stacker racks made of cold-formed or hot-rolled structural members. Does not include other types of racks such as

drive-in and drive-through racks, cantilever racks, portable racks, or racks made of materials other than steel.

**STORY:** The portion of a structure between the tops of two successive finished floor surfaces and, for the topmost story, from the top of the floor finish to the top of the roof structural element.

**STORY ABOVE GRADE:** Any story having its finished floor surface entirely above grade, except that a story shall be considered as a story above grade where the finished floor surface of the story immediately above is more than 6 ft (1,829 mm) above the grade plane, more than 6 ft (1,829 mm) above the finished ground level for more than 40 percent of the total structure perimeter, or more than 12 ft (3,658 mm) above the finished ground level at any point.

**STORY DRIFT:** The horizontal deflection at the top of the story relative to the bottom of the story as determined in Section 12.8.6.

**STORY DRIFT RATIO:** The story drift, as determined in Section 12.8.6, divided by the story height.

**STORY SHEAR:** The summation of design lateral seismic forces at levels above the story under consideration.

#### STRENGTH:

**Design Strength:** Nominal strength multiplied by a strength reduction factor,  $\phi$ .

**Nominal Strength:** Strength of a member or cross-section calculated in accordance with the requirements and assumptions of the strength design methods of this standard (or the reference documents) before application of any strength-reduction factors.

**Required Strength:** Strength of a member, cross-section, or connection required to resist factored loads or related internal moments and forces in such combinations as stipulated by this standard.

**STRUCTURAL OBSERVATIONS:** The visual observations to determine that the seismic force-resisting system is constructed in general conformance with the construction documents.

**STRUCTURE:** That which is built or constructed and limited to buildings and nonbuilding structures as defined herein.

**SUBDIAPHRAGM:** A portion of a diaphragm used to transfer wall anchorage forces to diaphragm cross ties.

**SUPPORTS:** Those structural members, assemblies of members, or manufactured elements, including braces, frames, legs, lugs, snubbers, hangers, saddles, or struts, which transmit loads between the nonstructural components and the structure.

**TESTING AGENCY:** A company or corporation that provides testing and/or inspection services.

**VERNEERS:** Facings or ornamentation of brick, concrete, stone, tile, or similar materials attached to a backing.

**WALL:** A component that has a slope of 60° or greater with the horizontal plane used to enclose or divide space.

**Bearing Wall:** Any wall meeting either of the following classifications:

1. Any metal or wood stud wall that supports more than 100 lb/linear ft (1,459 N/m) of vertical load in addition to its own weight.

2. Any concrete or masonry wall that supports more than 200 lb/linear ft (2,919 N/m) of vertical load in addition to its own weight.

**Light-Framed Wall:** A wall with wood or steel studs.

**Light-Framed Wood Shear Wall:** A wall constructed with wood studs and sheathed with material rated for shear resistance.

**Nonbearing Wall:** Any wall that is not a bearing wall.

**Nonstructural Wall:** All walls other than bearing walls or shear walls.

**Shear Wall (Vertical Diaphragm):** A wall, bearing or non-bearing, designed to resist lateral forces acting in the plane of the wall (sometimes referred to as a “vertical diaphragm”).

**Structural Wall:** Walls that meet the definition for bearing walls or shear walls.

**WALL SYSTEM, BEARING:** A structural system with bearing walls providing support for all or major portions of the vertical loads. Shear walls or braced frames provide seismic force resistance.

**WOOD STRUCTURAL PANEL:** A wood-based panel product that meets the requirements of DOC PS1 or DOC PS2 and is bonded with a waterproof adhesive. Included under this designation are plywood, oriented strand board, and composite panels.

## 11.3 NOTATION

The unit dimensions used with the items covered by the symbols shall be consistent throughout except where specifically noted. Notation presented in this section applies only to the seismic requirements in this standard as indicated.

$A_{ch}$  = cross-sectional area (in.<sup>2</sup> or mm<sup>2</sup>) of a structural member measured out-to-out of transverse reinforcement

$A_0$  = area of the load-carrying foundation (ft<sup>2</sup> or m<sup>2</sup>)

$A_{sh}$  = total cross-sectional area of hoop reinforcement (in.<sup>2</sup> or mm<sup>2</sup>), including supplementary cross-ties, having a spacing of  $s_h$  and crossing a section with a core dimension of  $h_c$

$A_{vd}$  = required area of leg (in.<sup>2</sup> or mm<sup>2</sup>) of diagonal reinforcement

$A_x$  = torsional amplification factor (Section 12.8.4.3)

$a_i$  = the acceleration at level  $i$  obtained from a modal analysis (Section 13.3.1)

$a_p$  = the amplification factor related to the response of a system or component as affected by the type of seismic attachment, determined in Section 13.3.1

$b_p$  = the width of the rectangular glass panel

$C_d$  = deflection amplification factor as given in Tables 12.2-1, 15.4-1, or 15.4-2

$C_s$  = seismic response coefficient determined in Section 12.8.1.1 and 19.3.1 (dimensionless)

$C_T$  = building period coefficient in Section 12.8.2.1

$C_{vx}$  = vertical distribution factor as determined in Section 12.8.3

$c$  = distance from the neutral axis of a flexural member to the fiber of maximum compressive strain (in. or mm)

$D$  = the effect of dead load

- $D_{clear}$  = relative horizontal (drift) displacement, measured over the height of the glass panel under consideration, which causes initial glass-to-frame contact. For rectangular glass panels within a rectangular wall frame,  $D_{clear}$  is set forth in Section 13.5.9.1
- $D_p$  = relative seismic displacement that a component must be designed to accommodate as defined in Section 13.3.2
- $D_s$  = the total depth of stratum in Eq. 19.2-12 (ft or m)
- $d_C$  = The total thickness of cohesive soil layers in the top 100 ft (30 m); see Section 20.4.3 (ft or m)
- $d_i$  = The thickness of any soil or rock layer  $i$  (between 0 and 100 ft [30 m]); see Section 20.4.1 (ft or m)
- $d_S$  = The total thickness of cohesionless soil layers in the top 100 ft (30 m); see Section 20.4.2 (ft or m)
- $E$  = effect of horizontal and vertical earthquake-induced forces (Section 12.4)
- $F_a$  = short-period site coefficient (at 0.2 s-period); see Section 11.4.3
- $F_i, F_n, F_x$  = portion of the seismic base shear,  $V$ , induced at Level  $i, n$ , or  $x$ , respectively, as determined in Section 12.8.3
- $F_p$  = the seismic force acting on a component of a structure as determined in Section 13.3.1
- $F_v$  = long-period site coefficient (at 1.0 s-period); see Section 11.4.3
- $f'_c$  = specified compressive strength of concrete used in design
- $f'_s$  = ultimate tensile strength (psi or MPa) of the bolt, stud, or insert leg wires. For A307 bolts or A108 studs, it is permitted to be assumed to be 60,000 psi (415 MPa).
- $f_y$  = specified yield strength of reinforcement (psi or MPa)
- $f_{yh}$  = specified yield strength of the special lateral reinforcement (psi or kPa)
- $G = \gamma v_s^2 / g$   
= the average shear modulus for the soils beneath the foundation at large strain levels (psf or Pa)
- $G_0 = \gamma v_{s0}^2 / g$   
= the average shear modulus for the soils beneath the foundation at small strain levels (psf or Pa)
- $g$  = acceleration due to gravity
- $H$  = thickness of soil
- $h$  = height of a shear wall measured as the maximum clear height from top of foundation to bottom of diaphragm framing above, or the maximum clear height from top of diaphragm to bottom of diaphragm framing above
- $h$  = average roof height of structure with respect to the base; see Chapter 13
- $\bar{h}$  = effective height of the building as determined in Section 19.2.1.1 or 19.3.1 (ft or m)
- $h_c$  = core dimension of a component measured to the outside of the special lateral reinforcement (in. or mm)
- $h_i, h_n, h_x$  = the height above the base to Level  $i, n$ , or  $x$ , respectively
- $h_p$  = the height of the rectangular glass panel
- $h_{sx}$  = the story height below Level  $x = (h_x - h_{x-1})$
- $I$  = the importance factor in Section 11.5.1
- $I_0$  = the static moment of inertia of the load-carrying foundation; see Section 19.2.1.1 (in.<sup>4</sup> or mm<sup>4</sup>)
- $I_p$  = the component importance factor as prescribed in Section 13.3.1
- $i$  = the building level referred to by the subscript  $i$ ;  $i = 1$  designates the first level above the base
- $K_p$  = the stiffness of the component or attachment, Section 13.6.2
- $K_y$  = the lateral stiffness of the foundation as defined in Section 19.2.1.1 (lb/in. or N/m)
- $K_\theta$  = the rocking stiffness of the foundation as defined in Section 19.2.1.1 (ft-lb/degree or N-m/rad)
- $KL/r$  = the lateral slenderness ratio of a compression member measured in terms of its effective length,  $KL$ , and the least radius of gyration of the member cross section,  $r$
- $k$  = distribution exponent given in Section 12.8.3
- $\bar{k}$  = stiffness of the building as determined in Section 19.2.1.1 (lb/ft or N/m)
- $L$  = overall length of the building (ft or m) at the base in the direction being analyzed
- $L_0$  = overall length of the side of the foundation in the direction being analyzed, Section 19.2.1.2 (ft or m)
- $M_0, M_{01}$  = the overturning moment at the foundation-soil interface as determined in Sections 19.2.3 and 19.3.2 (ft-lb or N-m)
- $M_t$  = torsional moment resulting from eccentricity between the locations of center of mass and the center of rigidity (Section 12.8.4.1)
- $M_{ta}$  = accidental torsional moment as determined in Section 12.8.4.2
- $m$  = a subscript denoting the mode of vibration under consideration; that is,  $m = 1$  for the fundamental mode
- $N$  = standard penetration resistance, ASTM 1586
- $N$  = number of stories (Section 12.8.2.1)
- $\bar{N}$  = Average field standard penetration resistance for the top 100 ft (30 m); see Sections 20.3.3 and 20.4.2
- $\bar{N}_{ch}$  = average standard penetration resistance for cohesionless soil layers for the top 100 ft (30 m); see Sections 20.3.3 and 20.4.2
- $N_i$  = Standard penetration resistance of any soil or rock layer  $i$  (between 0 and 100 ft [30 m]); see Section 20.4.2
- $n$  = designation for the level that is uppermost in the main portion of the building
- $P_x$  = total unfactored vertical design load at and above Level  $x$ , for use in Section 12.8.7
- $PI$  = plasticity index, ASTM D4318
- $Q_E$  = effect of horizontal seismic (earthquake-induced) forces
- $R$  = response modification coefficient as given in Tables 12.2-1, 12.14-1, 15.4-1, or 15.4-2

- $R_p$  = component response modification factor as defined in Section 13.3.1
- $r$  = a characteristic length of the foundation as defined in Section 19.2.1.2.
- $r_a$  = characteristic foundation length as defined by Eq. 19.2-7 (ft or m)
- $r_m$  = characteristic foundation length as defined by Eq. 19.2-8 (ft or m)
- $S_S$  = mapped MCE, 5 percent damped, spectral response acceleration parameter at short periods as defined in Section 11.4.1
- $S_1$  = mapped MCE, 5 percent damped, spectral response acceleration parameter at a period of 1 s as defined in Section 11.4.1
- $S_{aM}$  = the site-specific MCE spectral response acceleration at any period
- $S_{DS}$  = design, 5 percent damped, spectral response acceleration parameter at short periods as defined in Section 11.4.4
- $S_{D1}$  = design, 5 percent damped, spectral response acceleration parameter at a period of 1 s as defined in Section 11.4.4
- $S_{MS}$  = the MCE, 5 percent damped, spectral response acceleration at short periods adjusted for site class effects as defined in Section 11.4.3
- $S_{M1}$  = the MCE, 5 percent damped, spectral response acceleration at a period of 1 s adjusted for site class effects as defined in Section 11.4.3
- $s_u$  = undrained shear strength; see Section 20.4.3
- $\bar{s}_u$  = average undrained shear strength in top 100 ft (30 m); see Sections 20.3.3 and 20.4.3, ASTM D2166 or ASTM D2850
- $s_{ui}$  = undrained shear strength of any cohesive soil layer  $i$  (between 0 and 100 ft [30 m]); see Section 20.4.3
- $s_h$  = spacing of special lateral reinforcement (in. or mm)
- $T$  = the fundamental period of the building
- $\tilde{T}, \tilde{T}_1$  = the effective fundamental period (s) of the building as determined in Sections 19.2.1.1 and 19.3.1
- $T_a$  = approximate fundamental period of the building as determined in Section 12.8.2
- $T_L$  = long-period transition period as defined in Section 11.4.5
- $T_p$  = fundamental period of the component and its attachment, Section 13.6.2
- $T_0 = 0.2S_{D1}/S_{DS}$
- $T_S = S_{D1}/S_{DS}$
- $T_4$  = net tension in steel cable due to dead load, prestress, live load, and seismic load (Section 14.1.7)
- $V$  = total design lateral force or shear at the base
- $V_i$  = design value of the seismic base shear as determined in Section 12.9.4
- $V_x$  = seismic design shear in story  $x$  as determined in Section 12.8.4 or 12.9.4
- $\tilde{V}$  = reduced base shear accounting for the effects of soil structure interaction as determined in Section 19.3.1
- $\tilde{V}_1$  = portion of the reduced base shear,  $\tilde{V}$ , contributed by the fundamental mode, Section 19.3 (kip or kN)
- $\Delta V$  = reduction in  $V$  as determined in Section 19.3.1 (kip or kN)
- $\Delta V_1$  = reduction in  $V_1$  as determined in Section 19.3.1 (kip or kN)
- $v_s$  = shear wave velocity at small shear strains (equal to  $10^{-3}$  percent strain or less); see Section 20.4.1 (ft/s or m/s)
- $\bar{v}_s$  = average shear wave velocity at small shear strains in top 100 ft (30 m); see Sections 20.3.3 and 20.4.1
- $v_{si}$  = the shear wave velocity of any soil or rock layer  $i$  (between 0 and 100 ft [30 m]); see Section 20.4.1
- $v_{so}$  = average shear wave velocity for the soils beneath the foundation at small strain levels, Section 19.2.1.1 (ft/s or m/s)
- $W$  = effective seismic weight of the building as defined in Section 12.7.2. For calculation of seismic-isolated building period,  $W$  is the total effective seismic weight of the building as defined in Sections 19.2 and 19.3 (kip or kN)
- $\bar{W}$  = effective seismic weight of the building as defined in Sections 19.2 and 19.3 (kip or kN)
- $W_c$  = gravity load of a component of the building
- $W_p$  = component operating weight (lb or N)
- $w$  = moisture content (in percent), ASTM D2216
- $w_i, w_n, w_x$  = portion of  $W$  that is located at or assigned to Level  $i, n,$  or  $x,$  respectively
- $x$  = level under consideration, 1 designates the first level above the base
- $z$  = height in structure of point of attachment of component with respect to the base; see Section 13.3.1
- $\beta$  = ratio of shear demand to shear capacity for the story between Level  $x$  and  $x - 1$
- $\bar{\beta}$  = fraction of critical damping for the coupled structure-foundation system, determined in Section 19.2.1
- $\beta_0$  = foundation damping factor as specified in Section 19.2.1.2
- $\gamma$  = average unit weight of soil (lb/ft<sup>3</sup> or N/m<sup>3</sup>)
- $\Delta$  = design story drift as determined in Section 12.8.6
- $\Delta_{fallout}$  = the relative seismic displacement (drift) at which glass fallout from the curtain wall, storefront, or partition occurs
- $\Delta_a$  = allowable story drift as specified in Section 12.12.1
- $\delta_{max}$  = maximum displacement at Level  $x,$  considering torsion, Section 12.8.4.3
- $\delta_{avg}$  = the average of the displacements at the extreme points of the structure at Level  $x,$  Section 12.8.4.3
- $\delta_x$  = deflection of Level  $x$  at the center of the mass at and above Level  $x,$  Eq. 12.8-15

$\delta_{xe}$  = deflection of Level  $x$  at the center of the mass at and above Level  $x$  determined by an elastic analysis, Section 12.8-6

$\delta_{xm}$  = modal deflection of Level  $x$  at the center of the mass at and above Level  $x$  as determined by Section 19.3.2

$\bar{\delta}_x, \bar{\delta}_{x1}$  = deflection of Level  $x$  at the center of the mass at and above Level  $x$ , Eqs. 19.2-13 and 19.3-3 (in. or mm)

$\theta$  = stability coefficient for  $P$ -delta effects as determined in Section 12.8.7

$\rho$  = a redundancy factor based on the extent of structural redundancy present in a building as defined in Section 12.3.4

$\rho_s$  = spiral reinforcement ratio for precast, prestressed piles in Sections 14.2.7.1.6 and 14.2.7.2.6

$\lambda$  = time effect factor

$\Omega_0$  = overstrength factor as defined in Tables 12.2-1, 5.4-1, and 15.3-1

## 11.4 SEISMIC GROUND MOTION VALUES

**11.4.1 Mapped Acceleration Parameters.** The parameters  $S_S$  and  $S_1$  shall be determined from the 0.2 and 1.0 s spectral response accelerations shown on Figs. 22-1 through 22-14, respectively. Where  $S_1$  is less than or equal to 0.04 and  $S_S$  is less than or equal to 0.15, the structure is permitted to be assigned to Seismic Design Category A and is only required to comply with Section 11.7.

**11.4.2 Site Class.** Based on the site soil properties, the site shall be classified as Site Class A, B, C, D, E, or F in accordance with Chapter 20. Where the soil properties are not known in sufficient detail to determine the site class, Site Class D shall be used unless the authority having jurisdiction or geotechnical data determines Site Class E or F soils are present at the site.

**11.4.3 Site Coefficients and Adjusted Maximum Considered Earthquake (MCE) Spectral Response Acceleration Parameters.** The MCE spectral response acceleration for short periods ( $S_{MS}$ ) and at 1 s ( $S_{M1}$ ), adjusted for Site Class effects, shall be determined by Eqs. 11.4-1 and 11.4-2, respectively.

$$S_{MS} = F_a S_S \quad (11.4-1)$$

$$S_{M1} = F_v S_1 \quad (11.4-2)$$

where

$S_S$  = the mapped MCE spectral response acceleration at short periods as determined in accordance with Section 11.4.1, and

$S_1$  = the mapped MCE spectral response acceleration at a period of 1 s as determined in accordance with Section 11.4.1

where site coefficients  $F_a$  and  $F_v$  are defined in Tables 11.4-1 and 11.4-2, respectively. Where the simplified design procedure

**TABLE 11.4-1 SITE COEFFICIENT,  $F_a$**

Site Class	Mapped Maximum Considered Earthquake Spectral Response Acceleration Parameter at Short Period				
	$S_S \leq 0.25$	$S_S = 0.5$	$S_S = 0.75$	$S_S = 1.0$	$S_S \geq 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	See Section 11.4.7				

NOTE: Use straight-line interpolation for intermediate values of  $S_S$ .

**TABLE 11.4-2 SITE COEFFICIENT,  $F_v$**

Site Class	Mapped Maximum Considered Earthquake Spectral Response Acceleration Parameter at 1-s Period				
	$S_1 \leq 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \geq 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	See Section 11.4.7				

NOTE: Use straight-line interpolation for intermediate values of  $S_1$ .

of Section 12.14 is used, the value of  $F_a$  shall be determined in accordance with Section 12.14.8.1, and the values for  $F_v$ ,  $S_{MS}$ , and  $S_{M1}$  need not be determined.

**11.4.4 Design Spectral Acceleration Parameters.** Design earthquake spectral response acceleration parameter at short period,  $S_{DS}$ , and at 1 s period,  $S_{D1}$ , shall be determined from Eqs. 11.4-3 and 11.4-4, respectively. Where the alternate simplified design procedure of Section 12.14 is used, the value of  $S_{DS}$  shall be determined in accordance with Section 12.14.8.1, and the value for  $S_{D1}$  need not be determined.

$$S_{DS} = \frac{2}{3} S_{MS} \quad (11.4-3)$$

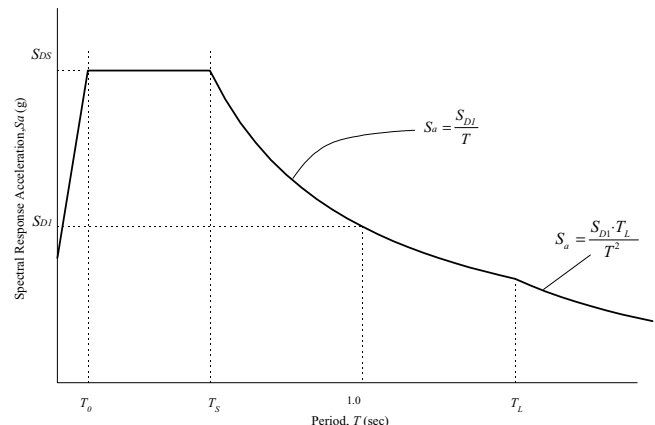
$$S_{D1} = \frac{2}{3} S_{M1} \quad (11.4-4)$$

**11.4.5 Design Response Spectrum.** Where a design response spectrum is required by this standard and site-specific ground motion procedures are not used, the design response spectrum curve shall be developed as indicated in Fig. 11.4-1 and as follows:

1. For periods less than  $T_0$ , the design spectral response acceleration,  $S_a$ , shall be taken as given by Eq. 11.4-5:

$$S_a = S_{DS} \left( 0.4 + 0.6 \frac{T}{T_0} \right) \quad (11.4-5)$$

2. For periods greater than or equal to  $T_0$  and less than or equal to  $T_S$ , the design spectral response acceleration,  $S_a$ , shall be taken equal to  $S_{DS}$ .



**FIGURE 11.4-1 DESIGN RESPONSE SPECTRUM**

3. For periods greater than  $T_S$ , and less than or equal to  $T_L$ , the design spectral response acceleration,  $S_a$ , shall be taken as given by Eq. 11.4-6:

$$S_a = \frac{S_{D1}}{T} \quad (11.4-6)$$

4. For periods greater than  $T_L$ ,  $S_a$  shall be taken as given by Eq. 11.4-7:

$$S_a = \frac{S_{D1} T_L}{T^2} \quad (11.4-7)$$

where

$S_{DS}$  = the design spectral response acceleration parameter at short periods

$S_{D1}$  = the design spectral response acceleration parameter at 1-s period

$T$  = the fundamental period of the structure, s

$$T_0 = 0.2 \frac{S_{D1}}{S_{DS}}$$

$$T_S = \frac{S_{D1}}{S_{DS}} \text{ and}$$

$T_L$  = long-period transition period (s) shown in Fig. 22-15 (Conterminous United States), Fig. 22-16 (Region 1), Fig. 22-17 (Alaska), Fig. 22-18 (Hawaii), Fig. 22-19 (Puerto Rico, Culebra, Vieques, St. Thomas, St. John, and St. Croix), and Fig. 22-20 (Guam and Tutuila).

**11.4.6 MCE Response Spectrum.** Where a MCE response spectrum is required, it shall be determined by multiplying the design response spectrum by 1.5.

**11.4.7 Site-Specific Ground Motion Procedures.** The site-specific ground motion procedures set forth in Chapter 21 are permitted to be used to determine ground motions for any structure. A site response analysis shall be performed in accordance with Section 21.1 for structures on Site Class F sites, unless the exception to Section 20.3.1 is applicable. For seismically isolated structures and for structures with damping systems on sites with  $S_1$  greater than or equal to 0.6, a ground motion hazard analysis shall be performed in accordance with Section 21.2.

## 11.5 IMPORTANCE FACTOR AND OCCUPANCY CATEGORY

**11.5.1 Importance Factor.** An importance factor,  $I$ , shall be assigned to each structure in accordance with Table 11.5-1 based on the Occupancy Category from Table 1-1.

**11.5.2 Protected Access for Occupancy Category IV.** Where operational access to an Occupancy Category IV structure is required through an adjacent structure, the adjacent structure shall conform to the requirements for Occupancy Category IV structures. Where operational access is less than 10 ft from an interior lot line or another structure on the same lot, protection from potential falling debris from adjacent structures shall be provided by the owner of the Occupancy Category IV structure.

**TABLE 11.5-1 IMPORTANCE FACTORS**

Occupancy Category	$I$
I or II	1.0
III	1.25
IV	1.5

**TABLE 11.6-1 SEISMIC DESIGN CATEGORY BASED ON SHORT PERIOD RESPONSE ACCELERATION PARAMETER**

Value of $S_{DS}$	Occupancy Category		
	I or II	III	IV
$S_{DS} < 0.167$	A	A	A
$0.167 \leq S_{DS} < 0.33$	B	B	C
$0.33 \leq S_{DS} < 0.50$	C	C	D
$0.50 \leq S_{DS}$	D	D	D

## 11.6 SEISMIC DESIGN CATEGORY

Structures shall be assigned a Seismic Design Category in accordance with Section 11.6.1.1.

Occupancy Category I, II, or III structures located where the mapped spectral response acceleration parameter at 1-s period,  $S_1$ , is greater than or equal to 0.75 shall be assigned to Seismic Design Category E. Occupancy Category IV structures located where the mapped spectral response acceleration parameter at 1-s period,  $S_1$ , is greater than or equal to 0.75 shall be assigned to Seismic Design Category F. All other structures shall be assigned to a Seismic Design Category based on their Occupancy Category and the design spectral response acceleration parameters,  $S_{DS}$  and  $S_{D1}$ , determined in accordance with Section 11.4.4. Each building and structure shall be assigned to the more severe Seismic Design Category in accordance with Table 11.6-1 or 11.6-2, irrespective of the fundamental period of vibration of the structure,  $T$ .

Where  $S_1$  is less than 0.75, the Seismic Design Category is permitted to be determined from Table 11.6-1 alone where all of the following apply:

1. In each of the two orthogonal directions, the approximate fundamental period of the structure,  $T_a$ , determined in accordance with Section 12.8.2.1 is less than  $0.8T_s$ , where  $T_s$  is determined in accordance with Section 11.4.5.
2. In each of two orthogonal directions, the fundamental period of the structure used to calculate the story drift is less than  $T_s$ .
3. Eq. 12.8-2 is used to determine the seismic response coefficient  $C_s$ .
4. The diaphragms are rigid as defined in Section 12.3.1 or for diaphragms that are flexible, the distance between vertical elements of the seismic force-resisting system does not exceed 40 ft.

Where the alternate simplified design procedure of Section 12.14 is used, the Seismic Design Category is permitted to be determined from Table 11.6-1 alone, using the value of  $S_{DS}$  determined in Section 12.14.8.1.

## 11.7 DESIGN REQUIREMENTS FOR SEISMIC DESIGN CATEGORY A

**11.7.1 Applicability of Seismic Requirements for Seismic Design Category A Structures.** Structures assigned to Seismic Design Category A need only comply with the requirements of

**TABLE 11.6-2 SEISMIC DESIGN CATEGORY BASED ON 1-S PERIOD RESPONSE ACCELERATION PARAMETER**

Value of $S_{D1}$	OCCUPANCY CATEGORY		
	I or II	III	IV
$S_{D1} < 0.067$	A	A	A
$0.067 \leq S_{D1} < 0.133$	B	B	C
$0.133 \leq S_{D1} < 0.20$	C	C	D
$0.20 \leq S_{D1}$	D	D	D



Section 11.7. The effects on the structure and its components due to the forces prescribed in this section shall be taken as E and combined with the effects of other loads in accordance with the load combinations of Section 2.3 or 2.4. For structures with damping systems, see Section 18.2.1.

**11.7.2 Lateral Forces.** Each structure shall be analyzed for the effects of static lateral forces applied independently in each of two orthogonal directions. In each direction, the static lateral forces at all levels shall be applied simultaneously. For purposes of analysis, the force at each level shall be determined using Eq. 11.7-1 as follows:

$$F_x = 0.01w_x \quad (11.7-1)$$

where

$F_x$  = the design lateral force applied at story  $x$ , and  
 $w_x$  = the portion of the total dead load of the structure,  $D$ , located or assigned to Level  $x$

**11.7.3 Load Path Connections.** All parts of the structure between separation joints shall be interconnected to form a continuous path to the lateral force-resisting system, and the connections shall be capable of transmitting the lateral forces induced by the parts being connected. Any smaller portion of the structure shall be tied to the remainder of the structure with elements having design strength of not less than 5 percent of the portion's weight. This connection force does not apply to the overall design of the lateral force-resisting system. Connection design forces need not exceed the maximum forces that the structural system can deliver to the connection.

**11.7.4 Connection to Supports.** A positive connection for resisting a horizontal force acting parallel to the member shall be provided for each beam, girder, or truss either directly to its supporting elements, or to slabs designed to act as diaphragms. Where the connection is through a diaphragm, then the member's supporting element must also be connected to the diaphragm. The connection shall have a minimum design strength of 5 percent of the dead plus live load reaction.

**11.7.5 Anchorage of Concrete or Masonry Walls.** Concrete and masonry walls shall be anchored to the roof and all floors and members that provide lateral support for the wall or that are supported by the wall. The anchorage shall provide a direct connection between the walls and the roof or floor construction. The connections shall be capable of resisting the horizontal forces specified in Section 11.7.3, but not less than a minimum strength level horizontal force of 280 lb/ linear ft (4.09 kN/m) of wall substituted for E in the load combinations of Section 2.3 or 2.4.

## 11.8 GEOLOGIC HAZARDS AND GEOTECHNICAL INVESTIGATION

**11.8.1 Site Limitation for Seismic Design Categories E and F.** A structure assigned to Seismic Design Category E or F shall not

be located where there is a known potential for an active fault to cause rupture of the ground surface at the structure.

**11.8.2 Geotechnical Investigation Report for Seismic Design Categories C through F.** A geotechnical investigation report shall be provided for a structure assigned to Seismic Design Category C, D, E, or F in accordance with this section. An investigation shall be conducted and a report shall be submitted that shall include an evaluation of the following potential geologic and seismic hazards:

- a. Slope instability.
- b. Liquefaction.
- c. Differential settlement.
- d. Surface displacement due to faulting or lateral spreading.

The report shall contain recommendations for appropriate foundation designs or other measures to mitigate the effects of the previously mentioned hazards. Where deemed appropriate by the authority having jurisdiction, a site-specific geotechnical report is not required where prior evaluations of nearby sites with similar soil conditions provide sufficient direction relative to the proposed construction.

**11.8.3 Additional Geotechnical Investigation Report Requirements for Seismic Design Categories D through F.** The geotechnical investigation report for a structure assigned to Seismic Design Category D, E, or F shall include:

1. The determination of lateral pressures on basement and retaining walls due to earthquake motions.
2. The potential for liquefaction and soil strength loss evaluated for site peak ground accelerations, magnitudes, and source characteristics consistent with the design earthquake ground motions. Peak ground acceleration is permitted to be determined based on a site-specific study taking into account soil amplification effects or, in the absence of such a study, peak ground accelerations shall be assumed equal to  $S_S/2.5$ .
3. Assessment of potential consequences of liquefaction and soil strength loss, including estimation of differential settlement, lateral movement, lateral loads on foundations, reduction in foundation soil-bearing capacity, increases in lateral pressures on retaining walls, and flotation of buried structures.
4. Discussion of mitigation measures such as, but not limited to, ground stabilization, selection of appropriate foundation type and depths, selection of appropriate structural systems to accommodate anticipated displacements and forces, or any combination of these measures and how they shall be considered in the design of the structure.

