

Nuclear Safety-Related Concrete Structures— Code Requirements and Commentary

Reported by ACI Committee 349

ACI CODE-349-23



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Nuclear Safety-Related Concrete Structures—Code Requirements and Commentary

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Nuclear Safety-Related Concrete Structures— Code Requirements and Commentary

An ACI Standard

Reported by ACI Committee 349

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Note: ACI Committee 349 would like to thank O. Gurbuz and N. Orbovic for their many years of membership to ACI Committee 349 and their hard work and dedication to this Code. Special acknowledgment is given G. Leon Flores, K. McBride, and J. Draper to for their contributions to this Code.

This Code covers the design and construction of concrete structures that form part of a nuclear facility and that have nuclear safety-related functions but does not cover concrete reactor vessels and concrete containment structures, as defined by ASME BPVC Section III Division 2:2019, or steel-plate composite walls and steel-plate composite slabs, as defined by ANSI/AISC N690.

The structures covered by this Code include concrete structures inside and outside the containment system.

This Code may be referenced and applied subject to agreement between the owner and the Regulatory Authority.

The format of this Code is such that it depends on the “Building Code Requirements for Structural Concrete (ACI CODE-318-14)” and should be used in conjunction with that Code. Unless otherwise stated, all instances of ACI 318 are referring to ACI CODE-318-14. When searching for subsections, tables, and figures in this Code, first refer to the main section of this Code to see if it is included and to find potential exceptions to the corresponding subsection, table or figure in ACI-318.

The Commentary, which is presented after the Code, discusses some of the considerations of ACI Committee 349 in developing “Code Requirements for Nuclear Safety-Related Concrete Structures (ACI 349).” This information is provided in the Commentary because the Code is written as a legal document and therefore cannot present background details or suggestions for carrying out its requirements.

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CODE

CHAPTER 1—GENERAL

1.1—Scope

1.1.1 This chapter addresses (a) through (h):

- (a) General requirements of this Code
- (b) Purpose of this Code
- (c) Applicability of this Code
- (d) Interpretation of this Code
- (e) Definition and role of the authority having jurisdiction (AHJ) and the licensed design professional (LDP)
- (f) Construction documents
- (g) Testing and inspection
- (h) Approval of special systems of design, construction, or alternative construction materials

Nuclear safety-related structures and structural members subject to this Code are those concrete structures that support, house, or protect nuclear safety class systems or component parts of nuclear safety class systems.

Specifically excluded from this Code are those structures covered by **ASME BPVC Section III Division 2:2019**.

This Code includes design and loading conditions that are unique to nuclear facilities, including shear design under biaxial tension conditions, consideration of thermal and seismic effects, and impact and impulsive loads.

1.2—General

1.2.1 ACI 349, “Code Requirements for Nuclear Safety-Related Concrete Structures,” is hereafter referred to as “this Code.”

1.2.2 If provisions in a given section of this Code differ from provisions in the same section of **ACI 318**, the ACI 349 provision governs. In cases where a section of this Code is deemed “Same as ACI 318,” the user must check all embedded references within the given Section for applicable changes to ACI 318 provisions given in this Code. If the provision in the embedded section reference differs, the provisions of ACI 349 govern.

1.2.3 Same as ACI 318.

1.2.4 Same as ACI 318.

1.2.5 This Code provides minimum requirements for the materials, design, construction, and strength evaluation of nuclear safety-related concrete structures and structural members for nuclear facilities.

1.2.6 This Code shall govern in all matters pertaining to design and construction of reinforced concrete structures, as defined in Section 1.1.1, except wherever this Code is in conflict with the specific provisions of the AHJ.

COMMENTARY

CHAPTER R1—GENERAL

R1.1—Scope

R1.1.1 This Code includes provisions for the design of concrete used for structural purposes, including concrete containing nonprestressed reinforcement, prestressed reinforcement, or both; and anchorage to concrete.

This chapter includes numerous provisions that explain where this Code applies and how it is to be interpreted.

In general, the code requirements are based on concrete having a compressive strength of between 3000 and 6000 psi. Although no maximum compressive strength is specified, the applicability of various requirements and formulation should be verified when concrete compressive strengths are higher than 6000 psi.

Minimum concrete compressive strength has been established as 3000 psi to be consistent with the seismic provisions of **Chapter 18**.

R1.2—General

R1.2.1 The American Concrete Institute recommends that this Code be adopted in its entirety.

R1.2.2 As a dependent code, ACI 349 states in many places “Same as ACI 318.” These sections sometimes have embedded references. The embedded reference may not always be the same in ACI 318 and this Code.

R1.2.3 ACI Committee 349 developed this Code in English, using inch-pound units. Based on that version, ACI Committee 349 approved a version that is in English using SI units. Jurisdictions may adopt this Code.

R1.2.5 Same as ACI 318.

CODE

1.2.7 Intentionally left blank.

1.3—Purpose

1.3.1 The purpose of this Code is to provide for public health and safety by establishing minimum requirements for strength, stability, serviceability, durability, and integrity of nuclear safety-related concrete structures.

1.3.2 Same as **ACI 318**.

1.3.3 Same as ACI 318.

1.4—Applicability

1.4.1 This Code shall apply to nuclear safety-related concrete structures.

1.4.2 Intentionally left blank.

1.4.3 Intentionally left blank.

1.4.4 Same as ACI 318.

1.4.5 Intentionally left blank.

1.4.6 The following provisions (a) or (b) apply to concrete piles, drilled piers, and caissons:

- (a) Portions in air or water, or in soil incapable of providing adequate lateral restraint to prevent buckling throughout their length, shall be designed in accordance with the applicable provisions of **Chapter 13** and **Chapter 18**.
- (b) Portions fully embedded in ground shall be designed in accordance with the applicable provisions of Chapter 18. This Code does not include all necessary design and installation provisions for portions fully embedded in ground.

COMMENTARY

R1.2.7 Section 1.2.7 has been intentionally left blank because this Code is not intended to be adopted as a general building code.

R1.3—Purpose

R1.3.1 This Code provides a means of establishing minimum requirements for the design and construction of structural concrete, as well as for acceptance of design and construction of nuclear safety-related concrete structures by the AHJ.

This Code does not provide a comprehensive statement of all duties of all parties to a contract or all requirements of a contract for a project constructed under this Code.

R1.3.2 Same as ACI 318.

R1.4—Applicability

R1.4.1 Concrete structures that are not nuclear safety-related are not specifically addressed by this Code.

R1.4.2 Section 1.4.2 has been intentionally left blank because the Code is not intended to be adopted as a general building code.

R1.4.3 Section 1.4.3 has been intentionally left blank because the scope of the Code does not include the design of thin shells and folded plate concrete structures.

R1.4.4 In its most basic application, the noncomposite steel deck serves as a form, and the concrete slab is designed to resist all loads whereas, in other applications, the concrete slab may be designed to resist only the superimposed loads. The design of a steel deck in a load-resisting application is given in **ANSI/SDI NC**.

R1.4.5 Section 1.4.5 has been intentionally left blank because the scope of this Code does not include the design of one- and two-family dwellings, multiple single-family dwellings, townhouses, and accessory structures.

R1.4.6 The design and installation of concrete piles fully embedded in the ground is regulated by the AHJ. Recommendations for concrete piles are given in **ACI PRC-543**. Recommendations for drilled piers are given in **ACI PRC-336.3**.

Recommendations for precast prestressed concrete piles are given in **Precast/Prestressed Concrete Institute (1993)**. Refer to **Section 18.13.4** for supplemental requirements for concrete piles, drilled piers, and caissons in nuclear safety-related concrete structures.

CODE

1.4.7 The provisions of this Code apply to slabs-on-ground.

1.4.8 This Code, along with relevant sections of **ACI CODE-350**, govern design and construction of tanks and reservoirs (nonlined) associated with nuclear safety-related structures.

1.4.9 Same as **ACI 318**.

1.5—Interpretation

Same as ACI 318.

1.6—Authority having jurisdiction

1.6.1 All references in this Code to the AHJ shall be understood to mean agencies who enforce this Code as governed by the licensing basis of the nuclear safety-related structure.

1.6.2 Actions and decisions by the AHJ affect only the specific nuclear safety-related structure and do not change this Code.

1.6.3 The owner shall have the right to order testing of any materials used in concrete construction to determine if materials are of the quality specified.

1.7—Licensed design professional

Same as ACI 318.

1.8—Construction documents and design records

1.8.1 Same as ACI 318.

1.8.2 Calculations pertinent to design shall be filed with the construction documents if required by the AHJ. Analyses and designs using computer programs shall be permitted, provided design assumptions, user input, and computer-generated output are submitted. Documentation of verification and validation for each computer program used shall be provided. Model analysis shall be permitted to supplement calculations.

COMMENTARY

R1.4.7 In addition to the requirements of this Code, the LDP should consider other issues, as outlined in **ACI PRC-360** and **PTI DC10.1**.

R1.4.8 This Code is applied to the spent fuel pool pit and refueling canal as well as other nuclear safety-related tanks. In addition, detailed recommendations given in ACI CODE-350 should be followed for nonlined tanks and reservoirs associated with safety-related nuclear structures. In case of a conflict, the more restrictive provision of this Code or ACI CODE-350 should be followed.

R1.4.9 In this type of construction, the steel deck serves as the positive moment reinforcement. **ANSI/AISC N690:2018**, Chapter NI, contains design provisions for composite steel members by reference to **ANSI/AISC 360**. Also refer to **ANSI/SDI C**. This standard refers to the appropriate portions of ACI 318 for the design and construction of the concrete portion of the composite assembly. ANSI/SDI C also provides guidance for design of composite concrete-steel deck slabs. The design of negative moment reinforcement to create continuity at supports is a common example where a portion of the slab is designed in conformance with this Code.

R1.5—Interpretation

Same as ACI 318.

R1.6—Authority having jurisdiction

R1.6.1 AHJ is defined in **Chapter 2**.

R1.6.2 Same as ACI 318.

R1.6.3 Section 1.6.3 has been intentionally left blank because the scope of the Code does not include the responsibilities of the building official.

R1.7—Licensed design professional

Same as ACI 318.

R1.8—Construction documents and design records

R1.8.1 Additional information may be required by the AHJ.

R1.8.2 Documented computer output is acceptable instead of manual calculations. The extent of input and output information required will vary according to the specific requirements of the AHJ. This should consist of sufficient input and output data and other information to allow the AHJ to perform a detailed review and make comparisons using another program or manual calculations. Input data should be identified as to member design or member class, and span lengths. The related output data should include member

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COMMENTARY

1.9—Testing and inspection

1.9.1 Same as **ACI 318**.

1.9.2 Concrete construction shall be inspected in accordance with **Chapters 17** and **26**.

1.9.3 Same as ACI 318.

1.10—Approval of special systems of design, construction, or alternative construction materials

1.10.1 Sponsors of any system of design, construction, or alternative construction products or materials within the scope of this Code, the adequacy of which has been shown by successful use or by analysis or test, but which does not conform to or is not covered by this Code, shall have the right to present the data on which their design is based to the AHJ.

designation and the shears, moments, and reactions at key points in the span. For column design, it is desirable to include moment magnification factors in the output where applicable.

This Code permits model analysis to be used to supplement structural analysis and design calculations. Documentation of the model analysis should be provided with the related calculations. Model analysis should be performed by an individual having experience in this technique.

R1.10—Approval of special systems of design, construction, or alternative construction materials

R1.10.1 New methods of design, new materials, and new uses of materials should undergo a period of development before being covered in a code. Hence, good systems or components might be excluded from use by implication if means are not available to obtain acceptance.

For special systems considered under this section, specific tests, load factors, deflection limits, and other pertinent requirements should be established by the LDP, subject to the review and approval of the AHJ, and should be consistent with the intent of this Code.

The provisions of this Section do not apply to model tests used to supplement calculations under Section 1.8.2 or to strength evaluation of existing structures under **Chapter 27**.

CODE

COMMENTARY

CHAPTER 2—NOTATION AND TERMINOLOGY

CHAPTER R2—NOTATION AND TERMINOLOGY

Units are defined only for those variables that are used in equations with the same units consistently throughout this Code. For variables that are used in equations that may require different units, units are not defined.

2.1—Scope

2.1.1 For sections in this Code and Commentary that are labeled “Same as ACI 318,” the notations and definitions given in ACI 318 are applicable and are not repeated in this chapter. All notations and definitions that are cited explicitly in this Code and Commentary are included in this chapter.

2.2—Notation

The terms in this list are used in this Code and as needed in the commentary and differ from ACI 318.

- A = effective tensile area of concrete surrounding the reinforcing bars and having the same centroid as that reinforcement, divided by the number of bars, in.² When the reinforcement consists of several bar sizes, the number of bars shall be computed as the total steel area divided by the area of the largest bar use.
- A_b = area of an individual bar or wire, in.²
- A_{bp} = area of the attachment base plate in contact with the concrete or grout when loaded in compression, in.²
- A_{brg} = net bearing area of the head of stud, anchor bolt, or headed deformed bar, in.²
- A_c = area of concrete section resisting shear transfer, in.²
- A_{ch} = cross-sectional area of a member measured to the outside edges of transverse reinforcement, in.²
- A_{cp} = area enclosed by outside perimeter of concrete cross section, in.²
- A_{cv} = gross area of concrete section bounded by web thickness and length of section in the direction of shear force considered in the case of walls, and gross area of concrete section in the case of diaphragms, not to exceed the thickness times the width of the diaphragm, in.²
- A_{cw} = area of concrete section of an individual pier, horizontal wall segment, or coupling beam resisting shear, in.²
- A_d = area of diagonal bars, in.²
- $A_{ef,st}$ = effective bearing area of shear lug, in.²
- A_g = gross area of concrete section, in.² For a hollow section, A_g is the area of the concrete only and does not include the area of the void(s)
- A_{hs} = total cross-sectional area of hooked or headed bars being developed at a critical section, in.²
- A_j = effective cross-sectional area within a joint in a plane parallel to plane of beam reinforcement generating shear in the joint, in.²

R2.2—Notation

The terms in this list are used in the commentary, but not in the Code.

CODE

COMMENTARY

A_{Na}	=	projected influence area of a single bonded anchor or group of bonded anchors, for calculation of bond strength in tension, in. ²
A_{Nao}	=	projected influence area of a single bonded anchor, for calculation of bond strength in tension if not limited by edge distance or spacing, in. ²
A_{Nc}	=	projected concrete failure area of a single anchor or group of anchors, for calculation of strength in tension, in. ²
A_{Nco}	=	projected concrete failure area of a single anchor, for calculation of strength in tension if not limited by edge distance or spacing, in. ²
A_{ps}	=	area of prestressing steel in flexural tension zone, in. ²
A_s	=	area of nonprestressed longitudinal tension reinforcement, in. ² or area of steel
A'_s	=	area of compression reinforcement, in. ²
$A_{s,min}'$	=	minimum reinforcement for concrete section having a thickness of 48 in. or more
$A_{se,N}$	=	effective cross-sectional area of anchor in tension, in. ²
$A_{se,V}$	=	effective cross-sectional area of anchor in shear, in. ²
A_{sh}	=	total cross-sectional area of transverse reinforcement, including crossties, within spacing s and perpendicular to dimension b_c , in. ² or area of hoop reinforcement in Appendix F, in. ²
A_{st}	=	total area of nonprestressed longitudinal reinforcement including bars or steel shapes, and excluding prestressing reinforcement, in. ²
A_{th}	=	total cross-sectional area of ties or stirrups confining hooked bars, in. ²
A_{tt}	=	area of nonprestressed reinforcement in a tie, in. ²
A_v	=	area of shear reinforcement within spacing s , in. ²
A_{vd}	=	total area of reinforcement in each group of diagonal bars in a diagonally reinforced coupling beam, in. ²
A_{vf}	=	area of shear-friction reinforcement, in. ²
$A_{v,min}$	=	minimum area of shear reinforcement within spacing s , in. ²
A_{Vc}	=	projected concrete failure area of a single anchor or group of anchors, for calculation of strength in shear, in. ²
A_{Vco}	=	projected concrete failure area of a single anchor, for calculation of strength in shear, if not limited by corner influences, spacing, or member thickness, in. ²
a	=	depth of equivalent rectangular stress block, in.
a_g	=	aggregate size of concrete
b	=	width of compression face of member, in.
b_c	=	cross-sectional dimension of member core measured to the outside edges of the transverse reinforcement composing area A_{sh} , in.

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COMMENTARY

b_{sl}	=	width of shear lug, in.		
C	=	compressive force acting on a nodal zone, lb		
C_{cr}	=	rated capacity of crane including the maximum wheel loads of the crane and the vertical, lateral, and longitudinal forces induced by the moving crane, including impact factor, where appropriate		
C_F	=	net compression force on the baseplate		
C_{Na}	=	projected distance from center of an anchor shaft on one side of the anchor required to develop the full bond strength of a single bonded anchor, in.		
c	=	distance from extreme compression fiber to neutral axis, in.		
c_1	=	dimension of rectangular or equivalent rectangular column, capital, or bracket measured in the direction of the span for which moments are being determined, in.		
c_2	=	dimension of rectangular or equivalent rectangular column, capital, or bracket measured in the direction perpendicular to c_1 , in.		
c_{ac}	=	critical edge distance required to develop the basic strength as controlled by concrete breakout or bond of a post-installed anchor in tension in uncracked concrete without supplementary reinforcement to control splitting, in.		
$c_{a,max}$	=	maximum distance from center of an anchor shaft to the edge of concrete, in.		
$c_{a,min}$	=	minimum distance from center of an anchor shaft to the edge of concrete, in.		
c_{a1}	=	distance from the center of an anchor shaft to the edge of concrete in one direction, in. If shear is applied to anchor, c_{a1} is taken in the direction of the applied shear. If tension is applied to the anchor, c_{a1} is the minimum edge distance. Where anchors subject to shear are located in narrow sections of limited thickness.		
			c'_{a1}	= limiting value of c_{a1} where anchors are located less than $1.5c_{a1}$ from three or more edges, in.
c_{a2}	=	distance from center of an anchor shaft to the edge of concrete in the direction perpendicular to c_{a1} , in.		
c_b	=	lesser of: (a) the distance from center of a bar or wire to nearest concrete surface; and (b) one-half the center-to-center spacing of bars or wires being developed, in.		
c_r	=	reinforcing bar spacing		
c_{sl}	=	distance from the centerline of the row of anchors in tension nearest the shear lug to the centerline of the shear lug measured in the direction of shear, in.		
D	=	effect of service dead load	D	= effective missile diameter (Appendix F, Table 2.2.1)
d	=	distance from extreme compression fiber to centroid of longitudinal tension reinforcement, in.	d	= effective diameter or the diameter of the hard/rigid part if the missile contains flexible part, in.



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COMMENTARY

d_a = outside diameter of anchor or shaft diameter of headed stud, headed bolt, or hooked bolt, in.
 d_a' = value substituted for d_a if an oversized anchor is used, in.
 d_b = nominal diameter of bar, wire, or prestressing strand, in.

d_e = distance between the front face and reinforcement, m
 d_{load} = diameter of loaded area, m
 d_p = distance from extreme compression fiber to centroid of prestressing reinforcement, in.
 E = effect of horizontal and vertical earthquake-induced forces
 E_c = modulus of elasticity of concrete, psi
 E_o = load effects of operating basis earthquake (OBE) or related internal moments and forces, including OBE-induced piping and equipment reactions
 E_{ss} = load effects of safe shutdown earthquake (SSE) or related internal moments and forces, including SSE-induced piping and equipment reactions

e_N' = distance between resultant tension load on a group of anchors loaded in tension and the centroid of the group of anchors loaded in tension, in.; e_N' is always positive

e_V' = distance between resultant shear load on a group of anchors loaded in shear in the same direction, and the centroid of the group of anchors loaded in shear in the same direction, in.; e_V' is always positive

F = effect of service lateral load due to fluids with well-defined pressures and maximum heights

$\bar{F}$ = impact force demand for high-mass, low-velocity impact of object ([Section F.6.3](#))

F_1 = maximum value of impulse loading

F_2 = approximately constant value of impulse loading during Δt

F_p = equivalent static punching capacity of a concrete slab/wall under low velocity soft missile impact

F_t = resultant force ([Appendix F](#))

F_μ = inelastic energy absorption factor

f_c' = specified compressive strength of concrete, psi

$\sqrt{f_c'}$ = square root of specified compressive strength of concrete, psi

f_{dc} = dynamic concrete stress, psi, or dynamic compressive strength ([Appendix F](#))

f_{ds} = dynamic reinforcement stress, psi, or dynamic stress capacity of steel reinforcement ([Appendix F](#))

d_{burst} = distance from the anchorage device to the centroid of the bursting force T_{bursts} , in.

e_{anc} = eccentricity of the anchorage device or group of devices with respect to the centroid of the cross section, in.

$\bar{F}$ = average value of the time-dependent force resultant of the missile

F_e = effective load for a single-degree-of-freedom model, lb ([Section RF.6.1](#))

CODE

COMMENTARY

f_{m1}	=	concrete membrane stress acting along length b_1' , to be taken as positive for compression and negative for tension, psi
f_{m2}	=	concrete membrane stress acting along length b_2' , to be taken as positive for compression and negative for tension, psi
f_{pc}	=	compressive stress in concrete, after allowance for all prestress losses, at centroid of cross section resisting externally applied loads or at junction of web and flange where the centroid lies within the flange, psi. In a composite member, f_{pc} is the resultant compressive stress at centroid of composite section, or at junction of web and flange where the centroid lies within the flange, due to both prestress and moments resisted by precast member acting alone.
f_{pe}	=	compressive stress in concrete due only to effective prestress forces, after allowance for all prestress losses, at extreme fiber of section if tensile stress is caused by externally applied loads, psi
f_{ps}	=	stress in prestressing reinforcement at nominal flexural strength, psi
f_r	=	modulus of rupture of concrete, psi
f_s'	=	compressive stress in reinforcement under factored loads, excluding prestressing reinforcement, psi
f_s'	=	stress in reinforcing steel, psi
f_t'	=	specified tensile strength of concrete, psi
f_u	=	ultimate tensile yield strength, psi
f_{uta}	=	specified tensile strength of anchor steel, psi
f_y	=	specified yield strength for nonprestressed reinforcement, psi
f_{ya}	=	specified yield strength of anchor steel, psi
f_{yt}	=	specified yield strength of transverse reinforcement, psi
H	=	effect of service load due to lateral earth pressure, ground water pressure, or pressure of bulk materials, lb
H_0	=	target thickness (Appendix F)
h	=	overall thickness, height, or depth of member, in.
h_{ef}	=	effective embedment depth of anchor, in.
$h_{ef,sl}$	=	effective embedment depth of shear lug, in.
h_{sl}	=	embedment depth of shear lug, in.

f_{si} = stress in the i -th layer of surface reinforcement, psi

G = factor used to compute penetration into concrete (Appendix F, Table 2.2.1)

h_{anc} = dimension of anchorage device or single group of closely spaced devices in the direction of bursting being considered, in.

h_{ef}' = limiting value of h_{ef} where anchors are located less than $1.5h_{ef}$ from three or more edges, in.

CODE

COMMENTARY

h_w	=	height of entire wall from base to top, or clear height of wall segment or wall pier considered, in.		
h_x	=	maximum center-to-center spacing of longitudinal bars laterally supported by corners of crossties or hoop legs around the perimeter of the column, in.		
I	=	total impulse		
I_{cr}	=	moment of inertia of cracked section transformed to concrete, in. ⁴		
I_e	=	effective moment of inertia for calculation of deflection, in. ⁴		
I_g	=	moment of inertia of gross concrete section about centroidal axis, neglecting reinforcement, in. ⁴		
K_e	=	elastic stiffness, psi	K	= value of F_t to cause unit deflection at point of application of resultant force (Section RF.6.1); concrete penetrability factor (Section RF.7.2.1)
K_{tr}	=	transverse reinforcement index, in.	K_t	= torsional stiffness of member; moment per unit rotation
k	=	stiffness of the impactor, kip/in. (Section F.6.3)	K_{05}	= coefficient associated with the 5% fractile
k_c	=	coefficient for basic concrete breakout strength in tension		
k_{cp}	=	coefficient for pryout strength		
k_f	=	concrete strength factor		
k_n	=	confinement effectiveness factor		
L	=	effect of live load		
L_r	=	effect of roof live load		
ℓ	=	span length of beam or one-way slab; clear projection of cantilever, in.	ℓ_{anc}	= length along which anchorage of a tie must occur, in.
ℓ_b	=	embedded length of the bar, in.	ℓ_b	= width of bearing, in.
ℓ_d	=	development length in tension of deformed bar, deformed wire, plain and deformed welded wire reinforcement, or pretensioned strand, in.	ℓ_{dc}	= development length of deformed bars and deformed wire in confined volume of concrete
ℓ_{dc}	=	development length in compression of deformed bars and deformed wire, in.		
ℓ_{dh}	=	development length in tension of deformed bar or deformed wire with a standard hook, measured from outside end of hook, point of tangency, toward critical section, in.	ℓ_{dm}	= required increase of straight embedment length of deformed bar or deformed wire that extends beyond the confined volume of concrete
ℓ_{dt}	=	development length in tension of headed deformed bar, measured from the bearing face of the head toward the critical section, in.		
ℓ_e	=	load-bearing length of anchor for shear, in.		
ℓ_h	=	unsupported length, in.		
ℓ_n	=	length of clear span measured face-to-face of supports, in.		

CODE

COMMENTARY

ℓ_o	=	length, measured from joint face along axis of member, over which special transverse reinforcement must be provided, in.
ℓ_{st}	=	tension lap splice length, in.
ℓ_t	=	span of member under load test, taken as the shorter span for two-way slab systems, in. Span is the lesser of: (a) distance between centers of supports, and (b) clear distance between supports plus thickness h of member. Span for a cantilever shall be taken as twice the distance from face of support to cantilever end.
ℓ_u	=	unsupported length of column or wall, in.
ℓ_w	=	length of entire wall, or length of wall segment or wall pier considered in direction of shear force, in.
M	=	mass of missile
M_a	=	maximum moment in member due to service loads at stage deflection is calculated, in.-lb
M_{cr}	=	cracking moment, in.-lb
M_e	=	equivalent mass
M_{nb}	=	nominal flexural strength of beam including slab where in tension, framing into joint, in.-lb
M_{nc}	=	nominal flexural strength of column framing into joint, calculated for factored axial force, consistent with the direction of lateral forces considered, resulting in lowest flexural strength, in.-lb
M_{pr}	=	probable flexural strength of members, with or without axial load, determined using the properties of the member at joint faces assuming a tensile stress in the longitudinal bars of at least $1.25f_y$ and a strength reduction factor ϕ of 1.0, in.-lb
M_u	=	factored moment at section, in.-lb
m	=	mass per unit area (Section RF.6.1); mass of the impactor (Section F.6.3)
N	=	missile nose shape factor
N_a	=	nominal bond strength in tension of a single bonded anchor, lb
N_{ag}	=	nominal bond strength in tension of a group of bonded anchors, lb
N_b	=	basic concrete breakout strength in tension of a single anchor in cracked concrete, lb
N_{ba}	=	basic bond strength in tension of a single bonded anchor, lb
N_{cb}	=	nominal concrete breakout strength in tension of a single anchor, lb
N_{cbg}	=	nominal concrete breakout strength in tension of a group of anchors, lb
N_{cp}	=	basic concrete pryout strength of a single anchor, lb
N_{cpg}	=	basic concrete pryout strength of a group of anchors, lb
N_n	=	nominal strength in tension, lb

M = moment acting on anchor or anchor group, in.-lb

N = tension force acting on anchor or anchor group, lb



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COMMENTARY

N_p	=	pullout strength in tension of a single anchor in cracked concrete, lb
N_{pn}	=	nominal pullout strength in tension of a single anchor, lb
N_{sa}	=	nominal strength of a single anchor or individual anchor in a group of anchors in tension as governed by the steel strength, lb
N_{sb}	=	side-face blowout strength of a single anchor, lb
N_{sbg}	=	side-face blowout strength of a group of anchors, lb
N_{ua}	=	factored tensile force applied to anchor or individual anchor in a group of anchors, lb
$N_{ua,g}$	=	total factored tensile force applied to anchor group, lb
$N_{ua,i}$	=	factored tensile force applied to most highly stressed anchor in a group of anchors, lb
$N_{ua,s}$	=	factored sustained tension load, lb
n	=	number of items, such as, bars, wires, anchorage devices, or anchors
n_t	=	number of threads per inch
P_a	=	differential pressure load, or related internal moments and forces, generated by a postulated pipe break accident
P_b	=	nominal axial strength at balanced strain conditions, lb
P_n	=	nominal axial compressive strength of member, lb
P_u	=	factored axial force; to be taken as positive for compression and negative for tension, lb
R	=	cumulative load effect of service rain load
R_a	=	piping and equipment reactions, or related internal moments and forces, under thermal conditions generated by a postulated pipe break and including R_o
R_m	=	resistance (Appendix F)
R_{m1}	=	resistance required by the impulsive loading with peak value F_1 that acts before the time interval Δt
R_{m2}	=	resistance required at F_2 (Appendix F)
R_o	=	piping and equipment reactions, or related internal moments and forces, that occur under normal operating and shutdown conditions, excluding dead load and earthquake reactions
R_s	=	static force to be combined with impactive or impulsive loads
S	=	effect of snow load

n_t = number of threads per inch

$P\delta$ = secondary moment due to individual member slenderness, in.-lb

p = pressure ([Section RF.6.1](#)); perimeter of missile cross section ([Section RF.7.2.1](#))

R = reaction, lb

R_{avail} = available resistance

R_{DL} = dead load resistance

$r_{\theta'}$ = effective support rotation ([Appendix F, Table 2.2.1](#))

r_s = static support rotation [Appendix F, Table 2.2.1](#)

CODE

COMMENTARY

S_n	=	nominal moment, shear, axial, torsional, or bearing strength
SR	=	strain rate, in./in./s
s	=	center-to-center spacing of items, such as longitudinal reinforcement, transverse reinforcement, tendons, or anchors, in.
s_{cr}	=	critical spacing for bond, in.
s_h	=	hoop spacing, in.
s_i	=	center-to-center spacing of reinforcement in the i -th direction adjacent to the surface of the member, in.
s_o	=	center-to-center spacing of transverse reinforcement within the length ℓ_o , in.
T	=	cumulative effects of service temperature, creep, shrinkage, differential settlement, and shrinkage-compensating concrete
T_a	=	internal moments and forces caused by temperature distributions within the concrete structure occurring as a result of accident conditions generated by a postulated pipe break and including T_o
T_b	=	base temperature, °F
T_m	=	mean temperature distribution
T_{NL}	=	temperature distribution
T_o	=	internal moments and forces caused by temperature distributions within the concrete structure and other temperature-induced loads occurring as a result of normal operating or shutdown conditions
TF	=	triaxiality factor
t	=	total section thickness, ft
$t_{0.9I}$	=	time when 90% of the total impulse ($0.9I$) is reached during the dynamic loading transient (Appendix F and Table 2.2.1)
t_d	=	impulse duration for elastic impact, s
t_p	=	perforation thickness
t_s	=	scabbing thickness
t_{sl}	=	thickness of shear lug, in.
U	=	strength of a member or cross section required to resist factored loads or related internal moments and forces in such combinations as stipulated in this Code
u	=	reference velocity, ft/s (Appendix F and Table 2.2.1)
u_{max}	=	impact velocity, ft/s

T = tension force acting on a nodal zone in a strut-and-tie model, lb (T is also used to define the cumulative effects of service temperature, creep, shrinkage, differential settlement, and shrinkage-compensating concrete in the load combinations defined in Section 5.3.6.)

T_{burst} = tensile force in general zone acting ahead of the anchorage device caused by spreading of the anchorage force, in.

V = shear force acting on anchor or anchor group, lb
 $V_{\parallel}$ = maximum shear force that can be applied parallel to the edge, lb
 $V_{\perp}$ = maximum shear force that can be applied perpendicular to the edge, lb

CODE

COMMENTARY

V_b	= basic concrete breakout strength in shear of a single anchor in cracked concrete, lb
$V_{brg,sl}$	= nominal bearing strength of a shear lug in direction of shear force, lb
V_c	= nominal shear strength provided by concrete, lb
V_{cb}	= nominal concrete breakout strength in shear of a single anchor, lb
$V_{cb,sl}$	= nominal concrete breakout strength in shear of attachment with shear lugs, lb
V_{cbg}	= nominal concrete breakout strength in shear of a group of anchors, lb
V_{cp}	= nominal concrete pryout strength of a single anchor, lb
V_{cpg}	= nominal concrete pryout strength of a group of anchors, lb
V_d	= shear force at section due to unfactored dead load, lb
V_d	= direct shear capacity (Appendix F and Table 2.2.1)
V_e	= design shear force for load combinations including earthquake effects, lb
V_n	= nominal shear strength, lb
V_p	= perforation velocity of reinforced concrete
V_{sa}	= nominal shear strength of a single anchor or individual anchor in a group of anchors as governed by the steel strength, lb
V_u	= factored shear force at section, lb
V_{ua}	= factored shear force applied to a single anchor or group of anchors, lb
$V_{ua,g}$	= total factored shear force applied to anchor group, lb
$V_{ua,l}$	= factored shear force applied to most highly stressed anchor in a group of anchors, lb
v	= missile impact velocity (Appendix F and Table 2.2.1)
v_o	= missile impact velocity (Appendix F and Table 2.2.1)
W	= effect of operating basis wind load
W_t	= loads generated by the design basis tornado or related internal moments and forces. These include loads due to tornado wind pressure, tornado-created differential pressures, and tornado-generated missiles
w_c	= density, unit weight, of normalweight concrete, lb/ft ³ ; lightweight concrete is not permitted in nuclear safety-related structures

X_m = maximum acceptable displacement, in.

V_a = missile velocity computed from RF.7.2.1.3

W = weight of missile (Appendix F, Table 2.2.1)

W_a = service-level wind load, lb

w_s = width of a strut perpendicular to the axis of the strut, in.

w_t = effective height of concrete concentric with a tie, used to dimension nodal zone, in.

$w_{t,max}$ = maximum effective height of concrete concentric with a tie, in.

X_s = displacement due to static loads

CODE

COMMENTARY

X_y	=	effective yield point of the structural member, in.
x	=	shorter overall dimension of rectangular part of cross section, in., or penetration depth of missile, in. (Appendix F and Table 2.2.1)
x_s	=	displacement due to static loads
Y_j	=	jet impingement load, or related internal moments and forces, on the structure generated by a postulated pipe break
Y_m	=	missile impact load, or related internal moments and forces, on the structure generated by a postulated pipe break, such as pipe whip
Y_r	=	loads, or related internal moments and forces, on the structure generated by the reaction of the broken pipe during a postulated break
y_t	=	distance from centroidal axis of gross section, neglecting reinforcement, to tension face, in.
α	=	angle defining the orientation of reinforcement, degrees
α_c	=	coefficient defining the relative contribution of concrete strength to nominal wall shear strength
α_f	=	ratio of flexural stiffness of beam section to flexural stiffness of a width of slab bounded laterally by centerlines of adjacent panels, if any, on each side of the beam
α_{fm}	=	average value of α_f for all beams on edges of a panel
β	=	ratio of long to short dimensions: clear spans for two-way slabs, sides of column, concentrated load, or reaction area; or sides of a footing
β_e	=	ratio of length of continuous edges to total perimeter of a slab panel
γ	=	ratio of bending moments of factored loads to unfactored loads
δ_u	=	design displacement, in.

Δf_{pt} = difference between the stress that can be developed in the strand at the section under consideration and the stress required to resist factored bending moment at section, M_u/ϕ , psi

Δ_r	=	residual deflection measured 24 hours after removal of the test load. For the first load test, residual deflection is measured relative to the position of the structure at the beginning of the first load test. For the second load test, residual deflection is measured relative to the position of the structure at the beginning of the second load test, in.
Δt	=	time interval
Δ_u	=	calculated out-of-plane deflection at midheight of wall due to factored loads, in.
Δ_1	=	maximum deflection, during first load test, measured 24 hours after application of the full test load, in.

ϵ_{cu} = maximum usable strain at extreme concrete compression fiber



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COMMENTARY

λ	= modification factor to reflect the reduced mechanical properties of lightweight concrete relative to normalweight concrete of the same compressive strength	ζ	= exponent symbol in tensile/shear force interaction equation
λ_a	= modification factor to reflect the reduced mechanical properties of lightweight concrete in certain concrete anchorage applications	λ	= lightweight concrete is not permitted for nuclear safety-related structures
λ_Δ	= multiplier used for additional deflection due to long-term effects		
μ	= coefficient of friction; ductility ratio (Appendix F and Table 2.2.1)		
μ_d	= permissible ductility ratio		
ξ	= time-dependent factor for sustained load		
ρ	= ratio of A_s to bd	ρ	= concrete density
ρ'	= ratio of A_s' to bd		
ρ_ℓ	= ratio of area of distributed longitudinal reinforcement to gross concrete area perpendicular to that reinforcement		
ρ_p	= average percentage of reinforcement on the tensioned face		
ρ_s	= ratio of volume of spiral reinforcement to total volume of core confined by the spiral, measured out-to-out of spirals		
ρ_t	= ratio of area of distributed transverse reinforcement to gross concrete area perpendicular to that reinforcement		
ϕ	= strength reduction factor	$\phi(x,y)$	= deformed shape function (Appendix F)
$\phi(x,y)$	= function can generally be taken either as the fundamental mode shape or as the deformed shape had the load been applied statically.	ϕ_K	= stiffness reduction factor
		σ	= wall boundary extreme fiber concrete nominal compressive stress, psi
σ_1	= principal stress 1		
σ_2	= principal stress 2		
σ_3	= principal stress 3		
σ_e	= effective or equivalent stress	σ_t	= concrete factor in calculating penetration into concrete (Appendix F)
τ	= bond strength, psi		
τ_{cr}	= characteristic bond stress in cracked concrete, psi		
τ_{uncr}	= characteristic bond stress in uncracked concrete, psi		
$\psi_{brg,sl}$	= shear lug bearing factor used to modify bearing strength of shear lugs based on the influence of axial load		
ψ_c	= factor used to modify development length based on cover		
$\psi_{c,N}$	= factor used to modify tensile strength of anchors based on presence or absence of cracks in concrete		

CODE

COMMENTARY

$\psi_{c,P}$	= factor used to modify pullout strength of anchors based on presence or absence of cracks in concrete
$\psi_{c,V}$	= factor used to modify shear strength of anchors based on presence or absence of cracks in concrete and presence or absence of supplementary reinforcement
$\psi_{cp,N}$	= factor used to modify tensile strength of post-installed anchors intended for use in uncracked concrete without supplementary reinforcement to account for the splitting tensile stresses due to installation
$\psi_{cp,Na}$	= bond splitting factor used to modify tensile strength of bonded anchors intended for use in uncracked concrete without supplementary reinforcement to account for the splitting tensile stresses due to installation
ψ_e	= factor used to modify development length based on reinforcement coating
$\psi_{ec,N}$	= factor used to modify tensile strength of anchors based on eccentricity of applied loads
$\psi_{ec,Na}$	= breakout eccentricity factor used to modify tensile strength of bonded anchors based on eccentricity of applied loads
$\psi_{ec,V}$	= factor used to modify shear strength of anchors based on eccentricity of applied loads
$\psi_{ed,N}$	= factor used to modify tensile strength of anchors based on proximity to edges of concrete member
$\psi_{ed,Na}$	= breakout edge effect factor used to modify tensile strength of bonded anchors based on proximity to edges of concrete member
$\psi_{ed,V}$	= factor used to modify shear strength of anchors based on proximity to edges of concrete member
ψ_g	= factor used to modify development length based on grade of reinforcement
$\psi_{h,V}$	= factor used to modify shear strength of anchors located in concrete members with $h_a < 1.5c_{a1}$
ψ_o	= factor used to modify development length of hooked and headed bars based on side cover and confinement
ψ_p	= factor used to modify development length for headed reinforcement based on parallel tie reinforcement
ψ_r	= factor used to modify development length based on confining reinforcement
ψ_s	= factor used to modify development length based on reinforcement size
ψ_t	= factor used to modify development length for casting location in tension
ω_p	= prestressing steel index

2.2.1 Appendix F units

Refer to Table 2.2.1 for consistent unit for **Appendix F** variables.

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Table 2.2.1—Consistent units for Appendix F variables

Consistent units	in.-lb				
Forcing function	lbf	lbf	psi	psi	lbf/in
Time	s	s	s	ms	s
Impulse	lbf-s	lbf-s	psi-s	psi-ms	lbf/in.-s
Deflection	in.	ft	in.	in	in.
Stiffness	lbf/in.	lbf/ft	psi/in.	psi/in.	lbf/in. ²
Mass	lbf-s ² /in.	slug (lbf-s ² /ft)	psi-s ² /in.	psi-ms ² /in.	lbf-s ² /in. ²

2.3—Terminology

The following terms are defined for general use in this Code and differ from **ACI 318**.

accident or abnormal temperatures—short-duration or transient temperatures that usually produce nonlinear temperature distributions across structural sections.

abnormal, extreme environmental, abnormal and extreme environmental load categories—structural members designed to resist impactive and impulsive loads and dynamic effects in the abnormal, extreme environmental, and abnormal and extreme environmental categories can have permanent, plastic deformations.

admixture—material other than water, aggregate, or hydraulic cement used as an ingredient of concrete and added to concrete before or during its mixing to modify its properties.

aggregate—granular material, such as sand, gravel, crushed stone, and iron blast-furnace slag, used with a cementing medium to form concrete or mortar.

aggregate, lightweight—aggregate meeting the requirements of **ASTM C330/C330M** and having a loose bulk density of 70 lb/ft³ or less, determined in accordance with **ASTM C29/C29M**.

ambient temperatures—outdoor atmospheric temperatures that depend on the location of the nuclear safety-related structure and vary with meteorological changes.

anchor—steel element either cast into concrete or post-installed into a hardened concrete member and used to transmit applied loads to the concrete.

anchor, bonded—post-installed anchor, inserted into hardened concrete, that transfers loads to the concrete by bond.

R2.3—Terminology

For consistent application of this Code, it is necessary that terms be defined where they have particular meanings. The definitions given are for use in application of this Code only and do not always correspond to ordinary usage. A glossary of most-used terms relating to cement manufacturing, concrete design and construction, and research in concrete is contained in “ACI Concrete Terminology” available on the ACI website.

aggregate, lightweight—In some standards, the term “lightweight aggregate” is being replaced by the term “low-density aggregate.”

anchor—Cast-in anchors include headed bolts, hooked bolts (J- or L-bolt), and headed studs. Post-installed anchors include expansion anchors, undercut anchors, screw anchors, and bonded anchors; steel elements for bonded anchors include threaded rods, deformed reinforcing bars, or internally threaded steel sleeves with external deformations. Anchor types are shown in Fig. R2.2a.

anchor, bonded—To limit shrinkage and reduce displacement under load, most bonded anchor systems require the annular gap to be as narrow as practical while still maintaining sufficient clearance for insertion of the anchor element in the filled hole and ensuring complete wetting of the bonded area over the embedded length. The annular

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anchor, cast-in—headed bolt, headed stud, or hooked bolt installed before placing concrete.

anchor, expansion—post-installed anchor, inserted into hardened concrete, that transfers loads to or from the concrete by direct bearing, or friction, or both.

anchor, horizontal or upwardly inclined—anchor installed in a hole drilled horizontally or in a hole drilled at any orientation above horizontal.

anchor, post-installed—anchor installed in hardened concrete; bonded, expansion, screw, and undercut anchors are examples of post-installed anchors

anchor, screw—post-installed threaded, mechanical anchor inserted into hardened concrete that transfers loads to the concrete by engagement of the hardened threads of the screw with the grooves that the threads cut into the sidewall of a predrilled hole during anchor installation.

anchor, undercut—post-installed anchor that develops its tensile strength from the mechanical interlock provided by undercutting of the concrete at the embedded end of the anchor. Undercutting is achieved with a special drill before installing the anchor or alternatively by the anchor itself during its installation.

anchor group—number of similar anchors having approximately equal effective embedment depths with spacing s between adjacent anchors such that the projected areas overlap.

anchor pullout strength—strength corresponding to the anchoring device or a major component of the device sliding out from the concrete without breaking out a substantial portion of the surrounding concrete.

anchorage device—in post-tensioned members, the hardware used to transfer force from prestressed reinforcement to the concrete.

anchorage device, basic monostrand—anchorage device used with any single strand or a single 5/8 in. or smaller diameter bar that is in accordance with 25.8.1, 25.8.2, and 25.9.3.1(a).

anchorage device, basic multistrand—anchorage device used with multiple strands, bars, or wires, or with single bars larger than 5/8 in. diameter that satisfies 25.8.1, 25.8.2, and 25.9.3.1(b).

anchorage device, special—anchorage device that satisfies tests required in 25.9.3.1(c).

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gap for reinforcing bars is generally greater than that for threaded rods. The required hole size is provided in the manufacturer's printed installation instructions (MPII).

anchor, expansion—Expansion anchors may be torque-controlled, where the expansion is achieved by a torque acting on the screw or bolt; or displacement controlled, where the expansion is achieved by impact forces acting on a sleeve or plug and the expansion is controlled by the length of travel of the sleeve or plug.

anchor, horizontal or upwardly inclined—Figure R2.2b illustrates the potential hole orientations for horizontal or upwardly inclined anchors.

anchor, screw—The required predrilled hole size for a screw anchor is provided by the anchor manufacturer.

anchor group—For all potential failure modes (steel, concrete breakout, pullout, side-face blowout, and pryout), only those anchors susceptible to a particular failure mode should be considered when evaluating the strength associated with that failure mode.

anchorage device—Most anchorage devices for post-tensioning are standard manufactured devices available from commercial sources. In some cases, nonstandard details or assemblages are developed that combine various wedges and wedge plates for anchoring prestressed reinforcement. Both standard and nonstandard anchorage devices may be classified as basic anchorage devices or special anchorage devices as defined in this Code and [AASHTO LRFDUS](#).

anchorage device, basic—Devices that are so proportioned that they can be checked analytically for compliance with bearing stress and stiffness requirements without having to undergo the acceptance-testing program required of special anchorage devices.

anchorage device, special—Special anchorage devices are any devices (monostrand or multistrand) that meet the relevant PTI or AASHTO LRFDUS bearing stress and

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anchorage zone—in post-tensioned members, portion of the member through which the concentrated prestressing force is transferred to concrete and distributed more uniformly across the section; its extent is equal to the largest dimension of the cross section; for anchorage devices located away from the end of a member, the anchorage zone includes the disturbed regions ahead of and behind the anchorage device.

attachment—structural assembly, external to the surface of the concrete, that transmits loads to or receives loads from the anchor.

authority having jurisdiction—federal government agency (or agencies), such as the Nuclear Regulatory Commission or the Department of Energy, that is empowered to enforce regulations affecting the design, construction, and operation of nuclear facilities.

base of structure—level at which horizontal earthquake ground motions are assumed to be imparted to a building. This level does not necessarily coincide with the ground level.

base temperature—the temperature at which a concrete member is cured.

beam—member subjected primarily to flexure and shear, with or without axial force or torsion; beams in a moment frame that forms part of the lateral-force-resisting system are predominantly horizontal members; a girder is a beam.

beyond design basis earthquake—rare, but possible, earthquake excitation exceeding the design hazard approved by the authority having jurisdiction.

boundary element—portion along wall and diaphragm edge, including edges of openings, strengthened by longitudinal and transverse reinforcement.

breakout strength, concrete—strength corresponding to a volume of concrete surrounding the anchor or group of anchors separating from the member.

cementitious materials—materials that have cementing value if used in concrete either by themselves, such as portland cement, blended hydraulic cements, and expansive cement; or such materials in combination with fly ash, other raw or calcined natural pozzolans, silica fume, and slag cement.

collector—element that acts in axial tension or compression to transmit forces between a diaphragm and a vertical element of the lateral-force-resisting system.

column—member, usually vertical or predominantly vertical, used primarily to support axial compressive load,

where applicable, stiffness requirements. Most commercially marketed multi-bearing surface anchorage devices are special anchorage devices. As provided in [Section 25.9.3](#), such devices can be used only if they have been shown experimentally to be in compliance with the AASHTO requirements. This demonstration of compliance will ordinarily be furnished by the device manufacturer.

anchorage zone—Refer to [ACI 318 Fig. R25.9.1.1b](#).

base temperature—This is the temperature at which it is assumed the material is free of thermal stresses. Seventy degrees Fahrenheit can be used as a base temperature for most calculations.

beta factor—Reliability factor that represents the probability that an item will survive to a particular time.

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but that can also resist moment, shear, or torsion. Columns used as part of a lateral-force-resisting system resist combined axial load, moment, and shear. See also **moment frame**.

compliance requirements—construction-related code requirements directed to the contractor to be incorporated into construction documents by the licensed design professional, as applicable.

concrete—mixture of portland cement or any other cementitious material, fine aggregate, coarse aggregate, and water, with or without admixtures.

concrete, lightweight—concrete containing lightweight aggregate and having an equilibrium density, as determined by **ASTM C567/C567M**, between 90 and 115 lb/ft³. Due to radiation shielding requirements in nuclear safety-related facilities, lightweight concrete is not permitted.

concrete, nonprestressed—reinforced concrete with at least the minimum amount of nonprestressed reinforcement and no prestressed reinforcement; or for two-way slabs, with less than the minimum amount of prestressed reinforcement.

concrete, normalweight—concrete containing only coarse and fine aggregates that conform to **ASTM C33/C33M**.

concrete, plain—concrete with no reinforcement or with reinforcement less than the minimum amount specified for reinforced concrete.

concrete, precast—concrete element cast elsewhere than its final position in the structure.

concrete, prestressed—concrete in which internal stresses have been introduced to reduce potential tensile stresses in concrete resulting from service loads.

concrete, reinforced—concrete reinforced with at least the minimum amounts of nonprestressed or prestressed reinforcement required by this Code.

concrete, steel fiber-reinforced—concrete containing a prescribed amount of dispersed, randomly oriented, discontinuous deformed steel fibers.

concrete strength, specified compressive—compressive strength of concrete used in design and evaluated in accordance with provisions of this Code, psi; wherever the quan-

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compliance requirements—Although primarily directed to the contractor, the compliance requirements are also commonly used by others involved with the project.

concrete, lightweight—Lightweight concrete is not permitted in nuclear safety-related structures.

concrete, normalweight—Normalweight concrete typically has a density (unit weight) between 135 and 160 lb/ft³ and is normally taken as 145 to 150 lb/ft³.

concrete, plain—Plain concrete is not permitted in nuclear safety-related structures.

concrete, prestressed—The term “prestressed concrete” includes members with unbonded tendons or bonded prestressing reinforcement. Although the behavior of a prestressed member with unbonded tendons may vary from that of members with bonded prestressed reinforcement, bonded and unbonded prestressed concrete are combined with conventionally reinforced concrete under the generic term “reinforced concrete.” Provisions common to both prestressed and conventionally reinforced concrete are integrated to avoid overlapping and conflicting provisions.

concrete, reinforced—Includes members satisfying the requirements for nonprestressed and prestressed concrete.

concrete, sand-lightweight—By Code terminology, sand-lightweight concrete is lightweight concrete with all of the fine aggregate replaced by sand. This definition may not be in agreement with usage by some material suppliers or contractors where the majority, but not all, of the lightweight fines are replaced by sand. For proper application of the Code provisions, the replacement limits should be stated, with interpolation if partial sand replacement is used.

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tity f_c' is under a radical sign, the square root of numerical value only is intended, and the result has units of psi.

connection—region of a structure that joins two or more members; a connection also refers to a region that joins members of which one or more is precast.

construction documents—written and graphic documents and specifications prepared or assembled for describing the location, design, materials, and physical characteristics of the elements of a project necessary for obtaining a building permit and construction of the project.

cover, specified concrete—distance between the outermost surface of embedded reinforcement and the closest outer surface of the concrete.

crosstie—continuous reinforcing bar having a seismic hook at one end and a hook not less than 90 degrees with at least a $6d_b$ extension at the other end. The hooks shall engage peripheral longitudinal bars. The 90-degree hooks of two successive crossties engaging the same longitudinal bars shall be alternated end for end.

design basis—established licensing commitment for the safety-related concrete structure in question, composed of original design calculations, drawings, codes and standards, technical specification and safety analysis report requirements, and as-built construction documents.

design basis accident—postulated accident that a nuclear facility must be designed and built to withstand without loss to the systems, structures, and components necessary to ensure public health and safety.

design basis earthquake—earthquake excitation consistent with the design hazard approved by the authority having jurisdiction.

design basis tornado—the combinations of translational speed, rotational speed, and prescribed pressure drop related to the effects of tornadoes on structures; shall be as defined by authority having jurisdiction at the site.

design displacement—total calculated lateral displacement expected for the design basis earthquake.

design information—project-specific information to be incorporated into construction documents by the licensed design professional, as applicable.

design load combination—combination of factored loads and forces.

development length—length of embedded reinforcement, including pretensioned strand, required to develop the design strength of reinforcement at a critical section.

discontinuity—abrupt change in geometry or loading.

design displacement—The design displacement is an index of the maximum lateral displacement expected in design for the design-basis earthquake. In documents such as [ASCE/SEI 7](#) and the International Building Code ([ICC IBC](#)), the design displacement is calculated using static or dynamic linear elastic analysis under code-specified actions considering effects of cracked sections, effects of torsion, effects of vertical forces acting through lateral displacements, and modification factors to account for expected inelastic response. The design displacement generally is greater than the displacement calculated from design-level forces applied to a linear-elastic model of the building.

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distance sleeve—sleeve that encases the center part of an undercut anchor, a torque-controlled expansion anchor, or a displacement-controlled expansion anchor, but does not expand.

durability—ability of a structure or member to resist deterioration that impairs performance or limits service life of the structure in the relevant environment considered in design.

dynamic increase factor—ratio of dynamic to static yield strengths for steel or dynamic compressive strength to static compressive strength for concrete and are direct functions of the strain rates involved.

edge distance—distance from the edge of the concrete surface to the center of the nearest anchor.

effective depth of section—distance measured from extreme compression fiber to centroid of longitudinal tension reinforcement.

effective embedment depth—overall depth through which the anchor transfers force to or from the surrounding concrete; effective embedment depth will normally be the depth of the concrete failure surface in tension applications; for cast-in headed anchor bolts and headed studs, the effective embedment depth is measured from the bearing contact surface of the head.

effective embedment depth—Effective embedment depths for a variety of anchor types are shown in Fig. R2.2a.

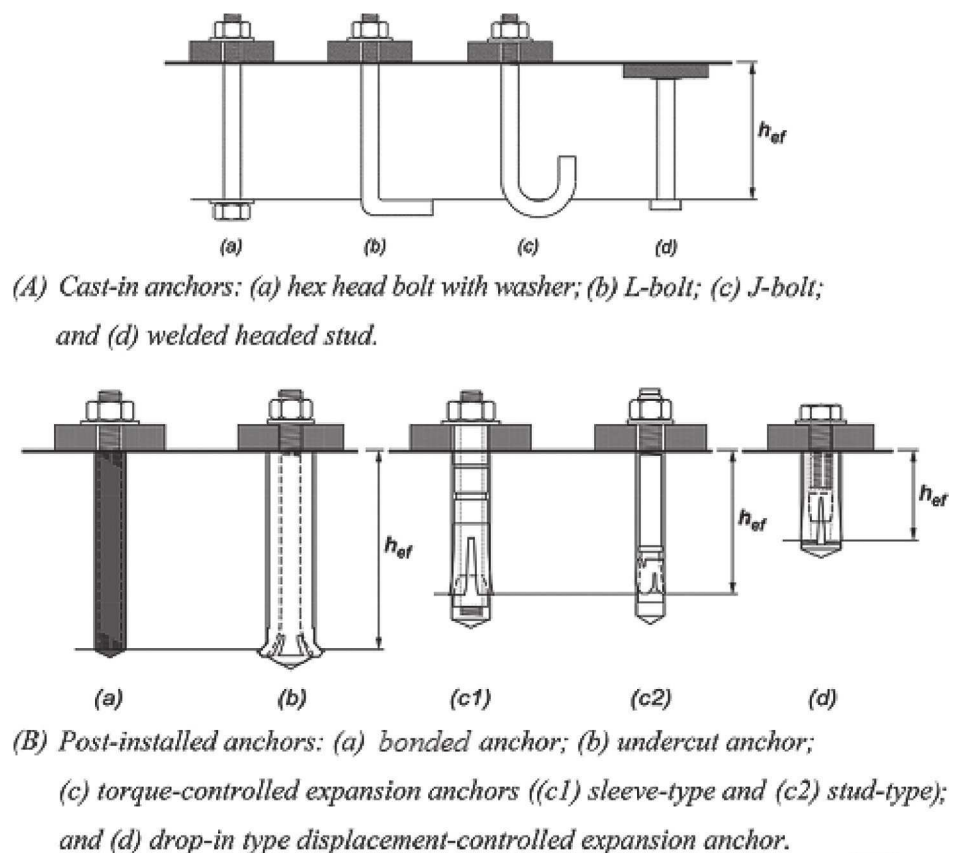


Fig. R2.2a—Types of anchors.

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effective prestress—stress remaining in prestressed reinforcement after losses in 20.3.2.6 have occurred.

elevated or differential temperature—refers to the temperatures that are different than the construction temperatures, which are assumed to be stress-free.

embedments—items embedded in concrete, excluding reinforcement as defined in Chapter 20 and anchors as defined in Chapter 17; reinforcement or anchors welded, bolted, or otherwise connected to the embedded item to develop the strength of the assembly, are considered part of the embedment.

embedment length—length of embedded reinforcement provided beyond a critical section.

embedments, pipe—embedded pipes, conduits, and sleeves.

engineering evaluation—calculation using a numerical model or empirical equations.

essentially elastic—state of response of structural members that may be past cracking but with no permanent, plastic deformation. Such members are deemed to unload along an idealized linearly elastic resistance displacement curve depicted in Fig. F.3.1

expansion sleeve—outer part of an expansion anchor that is forced outward by the center part, either by applied torque or impact, to bear against the sides of the predrilled hole. See also **anchor, expansion**.

extreme tension reinforcement—layer of prestressed or nonprestressed reinforcement that is the farthest from the extreme compression fiber.

five percent fractile—statistical term indicating 90 percent confidence that there is a 95 percent probability of the actual strength exceeding the nominal strength.

finite element analysis—numerical modeling technique in which a structure is divided into numerous discrete elements for analysis.

full body impulse—uniform pressure with duration applied on the entire concrete member from face of support to face of support.

gradient temperature distribution—temperature distribution minus the mean temperature distribution across a section at a point in time.

hard impact—impact resulting from a hard missile also known as a nondeformable missile colliding with a target; response of the target is often governed by local damage such as penetration, perforation, or scabbing, which can be assessed by empirical formulas.

headed bolt—cast-in-steel anchor that develops its tensile strength from the mechanical interlock provided by either a head or nut at the embedded end of the anchor.

headed deformed bars—deformed bars with heads attached at one or both ends.

five percent fractile—The determination of the coefficient K_{05} associated with the 5% fractile, $\bar{x} - K_{05}s_s$, depends on the number of tests, n , used to calculate the sample mean, $\bar{x}$, and sample standard deviation, s_s . Values of K_{05} range, for example, from 1.645 for $n = \infty$, to 2.010 for $n = 40$, and 2.568 for $n = 10$. With this definition of the 5% fractile, the nominal strength in Chapter 17 is the same as the characteristic strength in ACI CODE-355.2 and ACI CODE-355.4.

headed deformed bars—The bearing area of the headed deformed bar is, for the most part, perpendicular to the bar

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headed stud—steel anchor conforming to the requirements of [AWS D1.1](#) and affixed to a plate or similar steel attachment by the stud arc welding process before casting; also referred to as a welded headed stud.

headed shear stud reinforcement—reinforcement consisting of individual headed studs or groups of studs, with anchorage provided by a head at each end, or by a head at one end and a common base rail consisting of a steel plate or shape at the other end.

hooked bolt—cast-in anchor anchored mainly by bearing of the 90-degree bend (L-bolt) or 180-degree bend (J-bolt) against the concrete, at its embedded end, and having a minimum e_h equal to $3d_a$.

hoop—closed tie or continuously wound tie, made up of one or several reinforcement elements, each having seismic hooks at both ends. A closed tie shall not be made up of interlocking headed deformed bars. Refer to 25.7.4.

impactive loads—time-dependent loads due to collision of finite, solid masses (that is, hard missiles) that are associated with finite amounts of kinetic energy upon a localized loading area. Refer to [F.1.4](#) for examples.

impulsive loads—time-dependent loads that are expressed in terms of time-dependent force or time dependent pressure over a specified area. Refer to [F.1.5](#) for example.

inspection—observation, verification, and required documentation of the materials, installation, fabrication, erection, or placement of components and connections to determine compliance with construction documents and referenced standards.

inspection, continuous—full-time observation, verification, and required documentation of work in the area where the work is being performed.

inspection, periodic—part-time or intermittent observation, verification, and required documentation of work in the area where the work is being performed.

isolation joint—separation between adjoining parts of a concrete structure, usually a vertical plane at a designed location such as to interfere least with performance of the structure, yet such as to allow relative movement in three directions and avoid formation of cracks elsewhere in the concrete, and through which all or part of the bonded reinforcement is interrupted.

joint—portion of structure common to intersecting members.

axis. In contrast, the bearing area of the head of headed stud reinforcement is a nonplanar spatial surface of revolution. The two types of reinforcement differ in other ways. The shanks of headed studs are smooth, not deformed as with headed deformed bars. The minimum net bearing area of the head of a headed deformed bar is permitted to be as small as four times the bar area. In contrast, the minimum stud head area is not specified in terms of the bearing area, but by the total head area which must be at least 10 times the area of the shank.

joint—The effective cross-sectional area of a joint of a moment frame, A_j , for shear strength computations is given in [Section 18.8.4.3](#).



Documents

Document Sharing Hub



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licensed design professional—individual who is licensed to practice structural design as defined by the statutory requirements of the professional licensing laws of the state or jurisdiction in which the project is to be constructed, and who is in responsible charge of the structural design.

load—forces or other actions that result from the weight of all building materials, occupants, and their possessions, environmental effects, differential movement, and restrained dimensional changes; permanent loads are those loads in which variations over time are rare or of small magnitude; all other loads are variable loads.

load, dead—(a) the weights of the members, supported structure, and permanent attachments or accessories that are likely to be present on a structure in service; or (b) loads meeting specific criteria found in the general building code; without load factors.

load, factored—load, multiplied by appropriate load factors.

load, live—(a) load that is not permanently applied to a structure but is likely to occur during the service life of the structure (excluding environmental loads); or (b) load meeting specific criteria found in this Code without load factors.

load, roof live—load on a roof produced: (a) during maintenance by workers, equipment, and materials, and (b) during the life of the structure by movable objects, such as planters or other similar small decorative appurtenances that are not occupancy related; or loads meeting specific criteria found in the general building code without load factors.

load, service—all loads, static or transitory, imposed on a structure or element thereof, during the operation of a facility, without load factors.

loads, abnormal—loads generated by a postulated high-energy pipe break accident, including P_a , T_a , R_a , Y_r , Y_j , and Y_m .

loads, normal—those loads that are encountered during normal plant operation and shutdown, including C_{cr} , D , L , F , H , L_r , S , R , T_o , and R_o .

loads, extreme environmental—loads that are credible but are highly improbable, including E_{ss} and W_t .

loads, severe environmental—loads that could infrequently be encountered during the plant life, including E_o and W .

local area—region of structure exposed to elevated temperature that may affect concrete performance and stress distribution in the immediate area, without changing the overall component or member behavior (for example, areas around hot piping penetrating transversely through the component).

localized impulse—a uniform pressure with duration applied on a partial area of the concrete member less than that defined for full body as postulated by the accident scenario.

loss of coolant accident—postulated accidents that result in a loss of reactor coolant at a rate in excess of the capability of the reactor makeup system from breaks in the reactor

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licensed design professional (LDP)—May also be referred to as “registered design professional” in other documents.

loads—A number of definitions for loads are given as this Code contains requirements that are to be met at various load levels. The terms “dead load” and “live load” refer to the unfactored, sometimes called “service” loads specified or defined by the general building code. Service loads (loads without load factors) are to be used where specified in this Code to proportion or investigate members for adequate serviceability. Loads used to proportion a member for adequate strength are defined as factored loads. Factored loads are service loads multiplied by the appropriate load factors for required strength except wind and earthquake loads, which are already specified as strength loads in [ASCE/SEI 7](#). The factored load terminology clarifies where the load factors are applied to a particular load, moment, or shear value as used in the Code provisions.

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coolant pressure boundary, up to and including a break equivalent in size to the double-ended rupture of the largest pipe of the reactor coolant system.

manufacturer's printed installation instructions—published instructions for the correct installation of a bonded anchor under all covered installation conditions as supplied in the product packaging.

mean temperature distribution—average temperature distribution across a section at a point in time.

modulus of elasticity—ratio of normal stress to corresponding strain for tensile or compressive stresses below proportional limit of material.

moment frame—frame in which beams, slabs, columns, and joints resist forces predominantly through flexure, shear, and axial force; beams or slabs are predominantly horizontal or nearly horizontal; columns are predominantly vertical or nearly vertical.

nodal zone—volume of concrete around a node that is assumed to transfer strut-and-tie forces among each other.

node—point in a strut-and-tie model where the axes of the struts, ties, and concentrated forces acting on the joint intersect.

normal and severe environmental load category—structural members designed to resist loads in the normal and severe environmental load categories and required to remain essentially elastic.

one-way construction—members designed to be capable of supporting all loads through bending in a single direction; see also **two-way construction**.

operating basis earthquake—Operating basis earthquake ground motion (OBE) is the vibratory ground motion for which those features of the nuclear power plant necessary for continued operation without undue risk to the health and safety of the public will remain functional. The operating basis earthquake ground motion is only associated with plant shutdown and inspection unless specifically selected by the applicant as a design input. The OBE is only associated with plant shutdown and inspection unless selected by the owner as a design input. Refer to Appendix S of [USNRC 10CFR50:2015](#) of the Federal Regulation.

operating basis wind—wind velocities and forces required for the design of a structure in accordance with [ASCE/SEI 7](#).

operating temperatures—temperatures obtained in various locations inside the nuclear power facility under normal operating conditions; under steady state normal operating conditions, these temperatures usually produce linear temperature distributions across structural sections.

pedestal—member with a ratio of height-to-least lateral dimension less than or equal to 3 used primarily to support axial compressive load; for a tapered member, the least lateral dimension is the average of the top and bottom dimensions of the smaller side.

penetration—displacement of a missile into an impacted structural member (that is, target); a measure of the depth of the crater formed at the zone of impact.

one-way construction—Joists, beams, girders, and some slabs and foundations are considered one-way construction.

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perforation—passing of a missile completely through the impacted structural member with or without exit velocity (that is, full penetration).

plastic hinge region—length of frame element over which flexural yielding is intended to occur due to earthquake design displacements, extending not less than a distance h from the critical section where flexural yielding initiates.

post-tensioning—method of prestressing in which prestressing reinforcement is tensioned after concrete has hardened.

projected area—area on the free surface of the concrete member that is used to represent the greater base of the assumed rectilinear failure surface.

projected influence area—rectilinear area on the free surface of the concrete member that is used to calculate the bond strength of bonded anchors.

pryout strength, concrete—strength corresponding to formation of a concrete spall behind short, stiff anchors displaced in the direction opposite to the applied shear force.

punching shear—local shear failure occurring in the immediate vicinity of the impacted zone. A punching shear failure occurs as part of perforation.

realistic assessment—validating numerical model or empirical equations by using real service life data or representative experimental data; only applicable to determination of service load effects.

reinforcement—steel element or elements embedded in concrete and conforming to Sections 20.2 through 20.5; prestressed reinforcement in external tendons is also considered reinforcement.

reinforcement, anchor—reinforcement used to transfer the design load from the anchors into the structural member.

reinforcement, deformed—deformed bars, welded bar mats, deformed wire, and welded wire reinforcement conforming to 20.2.1.3, 20.2.1.5, or 20.2.1.7, excluding plain wire.

reinforcement, nonprestressed—bonded reinforcement that is not prestressed.

reinforcement, prestressed—prestressing reinforcement that has been tensioned to impart forces to concrete.

reinforcement, prestressing—high-strength reinforcement such as strand, wire, or bar conforming to 20.3.1.

reinforcement, supplementary—reinforcement that acts to restrain the potential concrete breakout but is not designed to transfer the design load from the anchors into the structural member.

reinforcement, anchor—Anchor reinforcement is designed and detailed specifically for the purpose of transferring anchor loads from the anchors into the member. Hairpins are generally used for this purpose (refer to Sections 17.4.2.9 and 17.5.2.9); however, other configurations that can be shown to effectively transfer the anchor load are acceptable.

reinforcement, deformed—Deformed reinforcement is defined as that meeting the reinforcement specifications in this Code. No other reinforcement qualifies. This definition permits accurate statement of development lengths. Bars or wire not meeting the deformation requirements or welded wire reinforcement not meeting the spacing requirements are “plain reinforcement,” for code purposes, and may be used only for spirals.

reinforcement, supplementary—Supplementary reinforcement has a configuration and placement similar to anchor reinforcement but is not specifically designed to transfer loads from the anchors into the structural member. As used for shear reinforcement, it may fall into this category.

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reinforcement, welded deformed steel bar mat—mat conforming to 20.2.1.5 consisting of two layers of deformed bars at right angles to each other welded at the intersections.

reinforcement, welded wire—plain or deformed wire fabricated into sheets or rolls conforming to 20.2.1.7.

safe shutdown earthquake—vibratory ground motion for which certain structures, systems, and components (SSCs) in nuclear power plants must be designed to remain functional. For the definition of these SSCs and for more information, refer to Appendix S of USNRC 10CFR50:2015 of the Federal Regulation. In the DOE nuclear facilities and older nuclear plants, the term “design basis earthquake” (DBE) is used, conveying the same meaning as SSE for design purposes.

scabbing—ejection of material from the back face of the impacted structural member opposite to the face of impact.

seismic-force-resisting system—portion of the structure designed to resist earthquake effects using the applicable provisions and load combinations.

seismic hook—hook on a stirrup, hoop, or crosstie having a bend not less than 135 degrees, except that circular hoops shall have a bend not less than 90 degrees; hooks shall have an extension of at least $6d_b$, but not less than 3 in. Hooks shall engage the longitudinal reinforcement and the extension shall project into the interior of the stirrup or hoop.

severe damage—damage to the extent where the component (that is, beam, slab, or panel) has not failed, but it has significant permanent deflections causing it to be unrepairable.

shear lug—steel element connected to an attachment base plate for transferring shear forces from the base plate to the concrete.

shear wall—structural wall designed to resist lateral forces acting in the plane of the wall.

short term—period before stabilization of the temperature distribution across the concrete section. (Short term for the purposes of Section E.3.2 is considered up to 30 days.)

shrinkage—time-temperature-humidity-dependent volume reduction of concrete as a result of hydration, moisture migration, and drying process.

side-face blowout strength, concrete—strength of anchors with deep embedment and thin side-face cover such that spalling occurs on the side face around the embedded head without breakout occurring at the top concrete surface.

soft story—story in which the lateral stiffness is less than 70% of that in the story above or less than 80% of the average stiffness of the three stories above.

spacing—center-to-center distance between adjacent items, such as longitudinal reinforcement, transverse reinforcement, prestressing reinforcement, or anchors.

spacing, clear—least dimension between the outermost surfaces of adjacent items.

sheathing—Typically, sheathing is a continuous, seamless, high-density polyethylene material extruded directly on the coated prestressing reinforcement.

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spalling—ejection of material from the front face of the impacted structural member. Front face is the side that the missile impacts.

span length—clear distance between supports.

specialty insert—predesigned and prefabricated cast-in anchors specifically designed for attachment of bolted or slotted connections.

spiral reinforcement—continuously wound reinforcement in the form of a cylindrical helix.

steel element, brittle—element with a tensile test elongation of less than 14%, or reduction in area of less than 30% at failure.

steel element, ductile—element with a tensile test elongation of at least 14% and reduction in area of at least 30%; steel element meeting the requirements of **ASTM A307** shall be considered ductile; except as modified by for earthquake effects, deformed reinforcing bars meeting the requirements of **ASTM A615/A615M**, **ASTM A706/A706M**, or **ASTM A955/A955M** shall be considered ductile steel elements.

stirrup—reinforcement used to resist shear and torsion forces in a member; typically deformed bars, deformed wires, or welded wire reinforcement either single leg or bent into L, U, or rectangular shapes and located perpendicular to, or at an angle to, longitudinal reinforcement. See also **tie**.

strength, design—nominal strength multiplied by a strength reduction factor ϕ .

strength, nominal—strength of a member or cross section calculated in accordance with provisions and assumptions of the strength design method of this Code before application of any strength reduction factors.

strength, required—strength of a member or cross section required to resist factored loads or related internal moments and forces in such combinations as stipulated in this Code.

stretch length—length of anchor, extending beyond concrete in which it is anchored, subject to full tensile load applied to anchor, and for which cross-sectional area is minimum and constant.

structural concrete—concrete used for structural purposes, including plain and reinforced concrete.

structural diaphragm—member, such as a floor or roof slab, that transmits forces acting in the plane of the member to vertical elements of the lateral-force-resisting system. A structural diaphragm may include chords and collectors as part of the diaphragm.

specialty insert—Specialty inserts are devices often used for handling, transportation, erection, and anchoring elements; specialty inserts are not within the scope of this Code.

steel element, brittle—The 14% elongation should be measured over the gauge length specified in the appropriate ASTM standard for the steel.

steel element, ductile—The 14% elongation should be measured over the gauge length specified in the appropriate ASTM standard for steel. Due to concerns over fracture in cut threads, it should be verified that threaded deformed reinforcing bars satisfy the strength requirements of **Section 25.5.7.1**.

stirrup—The term “stirrup” is usually applied to transverse reinforcement in beams or slabs and the term “ties” or “hoops” to transverse reinforcement in compression members.

strength, nominal—Nominal or specified values of material strengths and dimensions are used in the calculation of nominal strength. The subscript n is used to denote the nominal strengths; for example, nominal axial load strength P_n , nominal moment strength M_n , and nominal shear strength V_n . For additional discussion on the concepts and nomenclature for strength design, refer to the Commentary of **Chapter 22**.

strength, required—The subscript u is used only to denote the required strengths; for example, required axial load strength P_u , required moment strength M_u , and required shear strength V_u , calculated from the applied factored loads and forces. The basic requirement for strength design may be expressed as follows: design strength $\geq$ required strength; for example, $\phi P_n \geq P_u$; $\phi M_n \geq M_u$; $\phi V_n \geq V_u$. For additional discussion on the concepts and nomenclature for strength design, refer to the Commentary of Chapter 22.

stretch length—Length of an anchor over which inelastic elongations are designed to occur under earthquake loadings. Examples illustrating stretch length are shown in Fig. R17.2.3.4.3.

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structural integrity—ability of a structure through strength, redundancy, ductility, and detailing of reinforcement to redistribute stresses and maintain overall stability if localized damage or significant overstress occurs.

structural system—interconnected members designed to meet performance requirements.

structural truss—assemblage of reinforced concrete members subjected primarily to axial forces.

structural wall—wall proportioned to resist combinations of shears, moments, and axial forces in the plane of the wall.

strut—compression member in a strut-and-tie model representing the resultant of a parallel or a fan-shaped compression field.

strut, bottle-shaped—strut that is wider at midlength than at its ends.

strut-and-tie model—truss model of a member or of a D-region in such a member, made up of struts and ties connected at nodes and capable of transferring the factored loads to the supports or to adjacent B-regions.

temperature distribution—variation of the temperature across a section at a point in time.

tendon—in post-tensioned members, a complete assembly consisting of anchorages, prestressing reinforcement, and sheathing with coating for unbonded applications or ducts filled with grout for bonded applications.

tendon, bonded—tendon in which prestressed reinforcement is continuously bonded to the concrete through grouting of ducts embedded within the concrete cross section.

tendon, unbonded—tendon in which prestressed reinforcement is prevented from bonding to the concrete; prestressing force is permanently transferred to the concrete at the tendon ends by the anchorages only.

thermal strain—strain produced by thermal expansion or contraction due to thermal loads, including the effects of thermal restraint.

thermal stress—stress produced by restraint of thermal strain.

tie—(a) loop of reinforcing bar or wire enclosing longitudinal reinforcement; a continuously wound transverse bar

structural wall, intermediate precast—Requirements of Section 18.5 are intended to result in an intermediate precast structural wall having minimum strength and toughness equivalent to that for an ordinary reinforced concrete structural wall of cast-in-place concrete. A precast concrete wall not satisfying the requirements of Section 18.5 is considered to have ductility and structural integrity less than that for an intermediate precast structural wall.

temperature distribution—The temperature distribution across a section can vary with time as well as varying along the length of the member. For such variations, the engineer should evaluate the effects of temperature distribution at numerous sections and for numerous time durations.

tendon, external—In new or existing post-tensioned applications, a tendon totally or partially external to the member concrete cross section, or inside a box section, and attached at the anchor device and deviation points.

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or wire in the form of a circle, rectangle, or other polygonal shape without reentrant corners enclosing longitudinal reinforcement; see also **stirrup**, **hoop**; (b) tension element in a strut-and-tie model.

time dependent—transient temperature distribution and the final steady state condition.

transfer—act of transferring stress in prestressing reinforcement from jacks or pretensioning bed to concrete member.

two-way construction—members designed to be capable of supporting loads through bending in two directions; some slabs and foundations are considered two-way construction. See also **one-way construction**.

wall—vertical element designed to resist axial load, lateral load, or both, with a horizontal length-to-thickness ratio greater than 3, used to enclose or separate spaces.

wall segment—portion of wall bounded by vertical or horizontal openings or edges.

wall segment, horizontal—segment of a structural wall, bounded vertically by two openings or by an opening and an edge.

wall segment, vertical—segment of a structural wall, bounded horizontally by two openings or by an opening and an edge; wall piers are vertical wall segments.

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

water-cementitious materials ratio—ratio of mass of water, excluding that absorbed by the aggregate, to the mass of cementitious materials in a mixture, stated as a decimal.

work—entire construction or separately identifiable parts thereof that are required to be furnished under the construction documents.

yield strength—specified minimum yield strength or yield point of reinforcement; yield strength or yield point shall be determined in tension according to applicable ASTM standards as modified by this Code.

wall segment, horizontal—A horizontal wall segment is shown in Fig. R18.10.4.5.

wall pier—Wall piers are vertical wall segments with dimensions and reinforcement intended to result in shear demand being limited by flexural yielding of the vertical reinforcement in the pier.

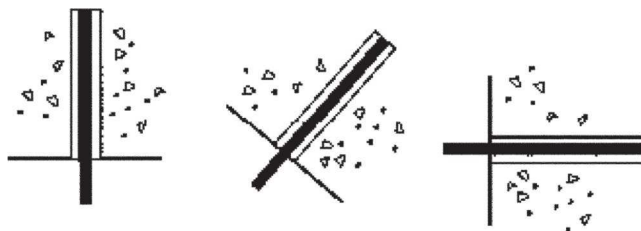


Fig. R2.2b—Possible orientations of overhead, upwardly inclined, or horizontal anchors.

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COMMENTARY

CHAPTER 3—REFERENCED STANDARDS

CHAPTER R3—REFERENCED STANDARDS

3.1—Scope

3.1.1 For sections in this Code and Commentary that are labeled “Same as **ACI 318**,” the referenced standards given in ACI 318 are applicable and are not repeated in this chapter. All referenced standards that are cited explicitly in this Code and Commentary are included in this chapter.

3.2—Referenced standards

3.2.1 *American Association of State Highway and Transportation Officials (AASHTO)*

AASHTO LRFDCONS 2017—LRFD Bridge Construction Specification

AASHTO LRFDUS 2017—LRFD Bridge Design Specifications

3.2.2 *American Concrete Institute (ACI)*

ACI CODE-318-14—Building Code Requirements for Structural Concrete and Commentary

ACI CODE-355.2-19—Qualifications of Post-Installed Mechanical Anchors in Concrete and Commentary

ACI CODE-355.4-19—Qualification of Post-Installed Adhesive Anchors in Concrete and Commentary

3.2.3 *American Society of Civil Engineers (ASCE)*

ASCE/SEI 7-10—Minimum Design Loads and Associated Criteria for Buildings and Other Structures

ASCE/SEI 59-11—Blast Protection of Buildings

3.2.4 *American Society of Mechanical Engineers (ASME)*

ASME BPVC Section III Division 2:2019—Code for Concrete Containments, ASME Boiler and Pressure Vessel Code Section III, Division 2

ASME B31.3-2018—Process Piping, ASME Code for Pressure Piping, B31, 2018

3.2.5 *ASTM International*

ASTM A184/A184M-06(2011)—Standard Specification for Welded Deformed Steel Bar Mats for Concrete Reinforcement

ASTM A307-21—Standard Specification for Carbon Steel Bolts, Studs, and Threaded Rod 60 000 PSI Tensile Strength

ASTM A416/A416M-12a—Standard Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete

ASTM A421/A421M-10—Standard Specification for Stress-Relieved Steel Wire for Prestressed Concrete, including Supplementary Requirement SI, Low-Relaxation Wire and Relaxation Testing

ASTM A615/A615M-14—Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement

ASTM A706/A706M-14—Standard Specification for Deformed and Plain Low-Alloy Steel Bars for Concrete Reinforcement

R3.1—Scope

R3.1.1 In this Code, references to standard specifications or other material are to a specific edition of the cited document. This is done by using the complete serial designation for the referenced standard including the title that indicates the subject and year of adoption.

R3.2—Referenced standards

R3.2.1 Same as ACI 318.

R3.2.2 Same as ACI 318.

R3.2.3 Same as ACI 318.

R3.2.4 Same as ACI 318 except as noted:

Use of zinc-coated (galvanized) steel reinforcing bars (**ASTM A767/A767M**) is excluded for use in nuclear structures. Use of rail- and axle-steel reinforcing bars (**ASTM A996/A996M**) is excluded because of inadequate traceability.

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ASTM A722/A722M-12—Standard Specification for Uncoated High-Strength Steel Bars for Prestressing Concrete

ASTM A775/A775M-07b (2014)—Standard Specification for Epoxy-Coated Steel Reinforcing Bars

ASTM A820/A820M-11—Standard Specification for Steel Fibers for Fiber-Reinforced Concrete

ASTM A884/A884M-14—Standard Specification for Epoxy-Coated Steel Wire and Welded Wire Reinforcement

ASTM A934/A934M-13—Standard Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars

ASTM A955/A955M-14—Standard Specification for Deformed and Plain Stainless-Steel Bars for Concrete Reinforcement

ASTM A1022/A1022M-14—Standard Specification for Deformed and Plain Stainless Steel Wire and Welded Wire for Concrete Reinforcement

ASTM A1035/A1035M-14—Standard Specification for Deformed and Plain, Low-Carbon, Chromium, Steel Bars for Concrete Reinforcement

ASTM A1064/A1064M-13—Standard Specification for Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete

ASTM C29/C29M-23—Standard Test Method for Bulk Density (“Unit Weight”) and Voids in Aggregate

ASTM C31/C31M-12—Standard Practice for Making and Curing Concrete Test Specimens in the Field

ASTM C33/C33M-18—Standard Specification for Concrete Aggregates

ASTM C39/C39M-14a—Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

ASTM C42/C42M-20—Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

ASTM C88/C88M-18—Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or 31 Magnesium Sulfate

ASTM C109/C109M-20—Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)

ASTM C131/C131M-20—Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

ASTM C150/C150M-12—Standard Specification for Portland Cement

ASTM C295/C295M-19—Standard Guide for Petrographic Examination of Aggregates for Concrete

ASTM C330/C330-23—Standard Specification for Lightweight Aggregates for Structural Concrete

ASTM C567/C567M-14—Standard Test Method for Determining Density of Structural Lightweight Concrete

ASTM C595/C595M-14—Standard Specification for Blended Hydraulic Cements

ASTM C637/C637M-20—Standard Specification for Aggregates for Radiation-Shielding Concrete

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ASTM C1012/C1012M-18—Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution

ASTM C1157/C1157M-11—Standard Performance Specification for Hydraulic Cement

ASTM C1218/C1218M-99(2008)—Standard Test Method for Water-Soluble Chloride in Mortar and Concrete

ASTM C1260-21—Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)

ASTM C1293-20a—Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction

ASTM C1567-21—Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)

ASTM C494/C494M-19—Standard Specification for Chemical Admixtures for Concrete

3.2.6 *American Welding Society (AWS)*

Same as **ACI 318**.

3.2.7 *National Energy Institute*

NEI-07-13—Methodology for Performing Aircraft Impact Assessments for New Plant Designs

3.2.9 *United States Nuclear Regulatory Commission (USNRC)*

USNRC 10CFR50:2015—Code of Federal Regulations, Title 10, Part 50, Domestic Licensing of Production and Utilization Facilities

CODE

CHAPTER 4—STRUCTURAL SYSTEM
REQUIREMENTS**4.1—Scope**

4.1.1 This chapter shall apply to design of nuclear safety-related concrete structures or portions of structures defined in **Chapter 1**.

4.2—Materials

Same as **ACI 318**.

4.3—Design loads

Same as ACI 318.

4.4—Structural system and load paths

4.4.1 Same as ACI 318.

4.4.2 Same as ACI 318.

4.4.3 Same as ACI 318.

4.4.4 Same as ACI 318.

4.4.5 Same as ACI 318.

4.4.6 *Seismic-force-resisting system*

4.4.6.1 In a nuclear facility, all nuclear safety-related structures shall be assigned to a seismic classification as defined by the owner, licensed design professional (LDP), or both.

COMMENTARY

CHAPTER R4—STRUCTURAL SYSTEM
REQUIREMENTS**R4.1—Scope**

This chapter was added to this Code to introduce structural system requirements. Requirements more stringent than provisions in this Code may be desirable for unusual construction or construction where enhanced performance is appropriate. This Code and Commentary must be supplemented with sound engineering knowledge, experience, and judgment.

R4.2—Materials

Same as ACI 318.

R4.3—Design loads

R4.3.1 The provisions in **Chapter 5** are the requirements for loads and load combinations applicable to nuclear safety-related structures. The design loads include, but are not limited to, dead loads, live loads, snow loads, wind loads, earthquake effects, prestressing effects, crane loads, vibration, impact, shrinkage, temperature changes, creep, expansion of shrinkage compensating concrete, and predicted unequal settlement of supports. Other project-specific loads may be specified by the licensed design professional (LDP) in accordance with the requirements set by the authority having jurisdiction (AHJ).

R4.4—Structural system and load paths

R4.4.1 Same as ACI 318.

R4.4.2 Same as ACI 318.

R4.4.3 Same as ACI 318.

R4.4.4 Same as ACI 318.

R4.4.5 The effects of column and wall creep and shrinkage, restraint of creep and shrinkage in long roof and floor systems, creep caused by prestress forces, volume changes caused by temperature variation, as well as potential damage to supporting members caused by these volume changes should be considered in design. Reinforcement, closure strips, or expansion joints are common ways of accommodating these effects. Minimum reinforcement controls cracking to an acceptable level in all exposed concrete surfaces of nuclear safety-related concrete structures. Differential settlement or heave may be an important consideration in design.

R4.4.6 *Seismic-force-resisting system*

R4.4.6.1 Intentionally left blank.

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4.4.6.2 Structural systems designated as part of the seismic-force-resisting system shall be restricted to those systems defined in **Chapter 18**.

4.4.6.3 Intentionally left blank.

4.4.6.4 Nuclear safety-related structural systems shall satisfy the requirements of Chapter 18 in addition to applicable requirements of other chapters of this Code.

4.4.6.5 Same as ACI 318.

4.4.6.5.1 All structural and nonstructural members, including foundation members that materially affect the response of the structure to earthquake motions, shall be considered explicitly in the design and analysis of the structure.

4.4.6.5.2 Intentionally left blank.

4.4.6.5.3 In nuclear safety-related structures, structural members not considered part of the seismic-force-resisting system shall meet the applicable requirements of Chapter 18.

4.4.6.6 Same as ACI 318.

4.4.7 *Diaphragms*

4.4.7.1 Same as ACI 318.

4.4.7.2 Same as ACI 318.

4.4.7.3 Same as ACI 318.

4.4.7.4 Same as ACI 318.

4.4.7.5 Same as ACI 318.

4.4.7.6 Diaphragms that are part of the seismic-force-resisting system shall be designed for the applied forces. In

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R4.4.6.2 Intentionally left blank.

R4.4.6.3 Section 4.4.6.3 has been intentionally left blank because seismic design categories (SDCs), as defined in **ACI 318**, are not used in this Code.

R4.4.6.4 Intentionally left blank.

R4.4.6.5 In nuclear safety-related structures, structural members not considered part of the seismic-force-resisting system are required to be designed to accommodate drifts and forces that occur as the structures respond to an earthquake.

R4.4.6.5.2 Section 4.4.6.5.2 has been intentionally left blank because SDCs, as defined in ACI 318, are not used in this Code.

R4.4.6.6 Although the design of nonstructural elements for earthquake effects is not included in the scope of this Code, the potential negative effects of nonstructural elements on the structural behavior need to be considered in nuclear safety-related structures. Interaction of nonstructural elements with the structural system—for example, the short-column effect—have led to failure of structural members and collapse of some structures in nonnuclear facilities during earthquakes in the past.

R4.4.7 *Diaphragms*—Floor and roof slabs play a dual role by simultaneously supporting gravity loads and transmitting lateral forces in their own plane as a diaphragm. General requirements for diaphragms are provided in **Chapter 12** and roles of the diaphragm are described in the Commentary to that Chapter. Additional requirements for design of diaphragms in nonnuclear facilities are prescribed in Chapter 18.

R4.4.7.5 Same as ACI 318.

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nuclear safety-related structures, the diaphragm design shall be in accordance with **Chapter 18**.

4.5—Structural analysis

Same as **ACI 318**.

4.6—Strength

4.6.1 Same as ACI 318.

4.6.2 Structures and structural members shall have design strength at all sections, ϕS_n , greater than or equal to the required strength U calculated for the factored loads and forces in such combinations as required by this Code.

COMMENTARY

R4.5—Structural analysis

Same as ACI 318.

R4.6—Strength

The basic requirement for strength design may be expressed as follows:

$$\text{design strength} \geq \text{required strength} \\ \phi S_n \geq U$$

In the strength design procedure, the level of safety is provided by a combination of factors applied to the loads and strength reduction factors ϕ applied to the nominal strengths.

The strength of a member or cross section, calculated using standard assumptions and strength equations, along with nominal values of material strengths and dimensions, is referred to as nominal strength and is generally designated S_n . Design strength or usable strength of a member or cross section is the nominal strength reduced by the applicable strength reduction factor ϕ . The purpose of the strength reduction factor is to account for the probability of under-strength due to variations of in-place material strengths and dimensions, the effect of simplifying assumptions in the design equations, the degree of ductility, potential failure mode of the member, the required reliability, and significance of failure and existence of alternative load paths for the member in the structure.

This Code prescribes design load combinations, also known as factored load combinations, which define the way different types of loads are multiplied (factored) by individual load factors and then combined to obtain a factored load U . The individual load factors and additive combination reflect the variability in magnitude of the individual load effect, the probability of simultaneous occurrence of various load effects, and the assumptions and approximations made in the structural analysis when determining required design strengths.

A typical design approach, when linear analysis is applicable, is to analyze the structure for individual unfactored load cases, and then combine the individual unfactored load cases in a factored load combination to determine the design load effects. Where effects of loads are nonlinear—for example, in foundation uplift—the factored loads are applied simultaneously to determine the nonlinear factored load effect. The load effect includes moments, shears, axial forces, torsions, and bearing forces. Required strength or strengths are the maximum absolute values of negative and positive factored load effects, as applicable.

Sometimes, design displacements are determined for factored load effects.

In the course of applying these principles, the LDP should be aware that providing more strength than is required does not necessarily lead to a safer structure because doing so may

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4.7—Serviceability

Same as **ACI 318**.

4.8—Durability

Same as ACI 318.

4.9—Sustainability

Same as ACI 318.

4.10—Structural integrity

Same as ACI 318.

4.11—Fire resistance

Same as ACI 318.

4.11.1 Structural concrete members shall satisfy the fire protection requirements of the nuclear facility design specification.

4.11.2 Where the nuclear facility design specification requires a thickness of concrete cover for fire protection greater than the concrete cover specified in **Section 20.6.1**, the greater thickness shall govern.

4.12—Requirements for specific types of construction

Same as ACI 318.

4.12.1 *Precast concrete systems*

Same as ACI 318.

4.12.2 *Prestressed concrete systems*

Same as ACI 318.

change the potential failure mode. For example, increasing longitudinal reinforcement area beyond that required for moment strength as derived from analysis without increasing transverse reinforcement could increase the probability of a shear failure occurring prior to a flexural failure.

R4.7—Serviceability

Serviceability refers to the ability of the structural system or structural member to provide appropriate behavior and functionality under the actions affecting the system. Serviceability requirements address issues such as deflections and cracking, among others.

Chapter 24 provides requirements for serviceability including control of deflection.

R4.8—Durability

The environment where the structure will be located will dictate the exposure category for materials selection, design details, and construction requirements to minimize potential for premature deterioration of the structure caused by environmental effects.

Durability of a structure is also impacted by the level of preventative maintenance, which is not addressed in this Code. Refer to **ACI PRC-349.3** for discussion on maintenance requirements of nuclear safety-related structures.

Chapter 19 provides requirements for protecting concrete against major environmental causes of deterioration.

R4.9—Sustainability

Same as ACI 318.

R4.10—Structural integrity

Same as ACI 318.

R4.11—Fire resistance

Additional guidance on fire resistance of structural concrete is provided by **ACI CODE-216.1** and applicable National Fire Protection Association (NFPA) codes.

R4.12—Requirements for specific types of construction

Same as ACI 318. Additionally, 4.12.5 has been intentionally left blank, as structural plain concrete provisions are not permitted in nuclear safety-related structures.

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COMMENTARY

4.12.3 *Composite concrete flexural members*

Same as **ACI 318**.

4.12.4 *Composite steel and concrete construction*

Same as ACI 318.

4.12.5 Intentionally left blank.**4.13—Construction and inspection****4.13.1** Same as ACI 318.

4.13.2 Inspection during construction shall be in accordance with **Chapter 26** and the project specification including the requirements from the authority having jurisdiction (AHJ).

4.14—Strength evaluation of existing structures

Same as ACI 318.

R4.13—Construction and inspection

Same as ACI 318.

R4.14—Strength evaluation of existing structures

Same as ACI 318.

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COMMENTARY

CHAPTER 5—LOADS

CHAPTER R5—LOADS

5.1—Scope

Same as ACI 318.

5.2—General

5.2.1 Structures and structural members shall be designed to have design strengths at all sections at least equal to the required strengths calculated for the factored loads and forces in such combinations as are stipulated for the following loads combined in accordance with the provisions specified in Section 5.3.

R5.2—General

Chapter 5 parallels the requirements for strength presented in Chapter 5 of ACI 318. The general requirements and the section on required strength have been completely revised to reflect the requirements regarding loads and load combinations applicable to nuclear safety-related concrete structures. Chapter 5 of the commentary on ACI 318 should be referenced for nuclear safety-related concrete structures, except as noted herein.

The changes to this Code are explained as follows:

Crane load-rated capacity (C_{cr}) is added as a separate load. This addition will help treat the crane hook load according to its variability and its probability of occurrence. The crane component dead loads should be considered in dead load (D) estimation. The live load (L) definition has been accordingly modified.

The definition of temperature load (T_o) has been modified to include other temperature-induced loads. These loads could be caused by the restraint of concrete members on the attached metallic components, or by the prolonged cyclic temperature changes in the concrete members. In the first scenario, the thermal loads will depend on the restraint of the concrete member. In the second scenario, the induced thermal loads will continuously reduce as the deformation of the concrete members increases in response to the thermal load. Eventually, the concrete members will arrive at a deformed state when the internal forces equilibrate the thermal load. In general, this load will not necessitate additional reinforcement, but will cause additional deformation. This additional deformation may require further investigation. The provisions of Appendix E should be useful in investigating the effects of these loads.

To be consistent with the expanded definitions in Chapter 2, E_o and E_{ss} definitions have been modified.

In the notation for D , E_o , E_{ss} , R_o , and R_e , “equipment” is to include all items that are permanently attached to the concrete structure, such as cable trays and conduits.

R5.2.1 In this Code, the loads appropriate for nuclear safety-related structures are defined in Section 2.3 and categorized in Section 5.2 as normal loads, severe environmental loads, extreme environmental loads, and abnormal loads.

Piping and equipment reactions to be included as R_o are those reactions produced by normal operating temperatures acting on the piping system or equipment, piping reactions generated by normal operation flow transients, and any other reactions occurring during normal operation or shutdown. In this Code, R_o is considered to have lower variability in its estimation than that for the live load. This is based on the existing practice of estimating T_o based on the possible operating temperature, and conservatively estimated flow

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COMMENTARY

5.2.1.1 Normal loads—Those loads that are encountered during normal plant operation and shutdown, including C_{cr} , D , L , F , H , L_r , S , R , T_o , and R_o .

5.2.1.2 Severe environmental loads—Those loads that could infrequently be encountered during the plant life, including E_o and W .

5.2.1.3 Extreme environmental loads—Those loads that are credible but are highly improbable, including E_{ss} and W_t .

transients. However, if it is recognized that there could be a larger uncertainty (that is, greater than that inherent in live loads) in estimating these parameters, the designer should consider the use of larger load factors for T_o and R_o . Note that dead load and earthquake reactions are not included in R_o .

When considering impactive and impulsive loads such as those associated with postulated rupture of high-energy pipes or missiles, the strength of local sections may be exceeded. Under these concentrated loads, elastoplastic behavior may be assumed with appropriate ductility ratios per Appendix F, provided resulting deformation will not result in loss of function of any safety-related system.

Live loads associated with elevators and machinery should be increased to allow for impact in accordance with the recommendations of [ASCE/SEI 7](#).

The discharge of safety relief valves into a suppression pool generates loads that are unique to boiling water reactor power plant structures. Specific classification of these loads is not given by this Code.

R5.2.1.1 Dead and live loads form a generic category of normal loads. During initial design, most of the piping loads and suspended system loads (HVAC and cable trays) are not available, and the load allowance for these items is included in L as an area-averaged load. Once the final attachment loads are determined, the initial load assumptions should be confirmed. When designing for weights or pressures from fluids, either existing in the structure or due to hydrostatic heads, both cases (with fluid present or absent) should be evaluated to establish the governing load condition. When a detailed dynamic analysis is performed for crane systems, elevators, or other moving machinery, the resulting load with dynamic amplification may be used instead of the load increases (dynamic impact factors) specified in [ASCE/SEI 7](#).

R5.2.1.2 These loads include wind or earthquake loads. For the safety-related concrete structures in nuclear facilities, wind load W , if not specified by the plant-specific documents, may be defined as the wind load calculated in accordance with [ASCE/SEI 7](#), considering them as Category IV structures. The operating basis earthquake (OBE) load E_o should be in accordance with the requirements set by the authority having jurisdiction (AHJ). In the case of nuclear power plants, E_o should be in accordance with Appendix S of [USNRC 10CFR50:2015](#).

R5.2.1.3 These loads include loads generated by the design basis tornado (DBT) W_t and safe shutdown earthquake (SSE) E_{ss} . For nuclear facilities, they are defined by the AHJ at the site (for example, U.S. Nuclear Regulatory Commission). For older nuclear power plants and Department of Energy facilities, E_{ss} is defined as the design basis earthquake (DBE). These are low-probability natural phenomena hazards. These loads are excluded from the documents controlling the facility design.

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5.2.1.4 Abnormal loads—Those loads generated by a postulated high-energy pipe break accident, including P_a , T_a , R_a , Y_r , Y_j , and Y_m .

5.2.2 Members shall meet all other requirements of this Code to ensure adequate performance at normal load levels.

5.2.3 In the design for normal loads, consideration shall be given to the forces due to such effects as prestressing, vibration, impact, shrinkage, creep, unequal settlement of supports, construction, and testing.

5.2.4 In the determination of earthquake loads, consideration shall be given to the dynamic response characteristics of the concrete structure and its foundation and surrounding soil.

5.2.5 The determination of impulsive and impactive loads, such as the loads associated with missile impact, whipping pipes, jet impingement, and compartment pressurization, shall be consistent with the provisions of **Appendix F**.

5.2.6 Design of structures and structural members using the load factor combinations and strength-reduction factors of **Appendix C** shall be permitted. The use of load factor combinations from this chapter in conjunction with strength reduction factors of **Appendix C** shall not be permitted.

5.3—Load factors and combinations

5.3.1 Required strength U shall be at least equal to the effects of factored loads in Eq. (5.3.1a) through (5.3.1i). The effect of one or more loads not acting simultaneously shall be investigated. If the operating basis earthquake (OBE) (E_o) ground motion in Eq. (5.3.1d) is set equal to one-third or less of the safe shutdown earthquake (SSE) (E_{ss}) and if the structure being designed is not a buried structure, then load combinations including E_o need not be considered.

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R5.2.1.4 In nuclear power plants, these loads are from a design basis accident (DBA) and are postulated to result from (**USNRC SRP 3.6.2**):

- (a) A break in any of the high-energy piping existing in the plant. This can create compartment pressurization, short-term high temperatures, and dynamic loads of reaction and/or impingement associated with the postulated pipe rupture (**USNRC SRP 3.6.2**).
- (b) A break in a small pipeline containing high-temperature fluids or steam. This would result in a long-term high temperature and associated pressure loading.
- (c) Other extreme load phenomena, which have a probability of occurrence larger than 10^{-7} events per year, the consequence of which could lead to release of radiation in excess of **USNRC 10CFR100** limits.

In addition to the pressure P_a , temperature T_a , and reaction loads R_a associated with a DBA, the loads could include the consequences of a rupture of a high-energy pipe that would give rise to loads Y_r , Y_j , and Y_m . Other nuclear facilities could have other abnormal loads depending upon the type of accidents postulated for those facilities.

R5.3—Load factors and combinations

R5.3.1 The load combinations with (L_r or S or R) from Section 5.3.1 may be altered to include ice loads as per Items 1 and 2 of Section 2.3.4 of **ASCE/SEI 7-10**. Thickness of the ice and the concurrent wind gust speed should be site specific.

The basic concept of **ACI 318** has been adopted for this Code for nuclear safety-related concrete structures. The load combinations and load factors of the equipment and consideration of the likelihood of individual and combined event

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$$U = 1.4(D + F + R_o) + T_o \quad (5.3.1a)$$

$$U = 1.2(D + F + T_o + R_o) + 1.6(L + H) + 1.4C_{cr} + 0.5(L_r \text{ or } S \text{ or } R) \quad (5.3.1b)$$

$$U = 1.2(D + F + T_o + R_o) + 0.8(L + H) + 1.4C_{cr} + 1.6(L_r \text{ or } S \text{ or } R) \quad (5.3.1c)$$

$$U = 1.2(D + F + R_o) + C_{cr} + T_o + L + 1.6(H + E_o) \quad (5.3.1d)$$

$$U = 1.2(D + F + R_o) + 1.6H + L + W + T_o \quad (5.3.1e)$$

$$U = D + F + 0.8L + C_{cr} + H + T_o + R_o + E_{ss} \quad (5.3.1f)$$

$$U = D + F + 0.8L + H + T_o + R_o + W_t \quad (5.3.1g)$$

$$U = D + F + 0.8L + C_{cr} + H + T_a + R_a + 1.2P_a \quad (5.3.1h)$$

$$U = D + F + 0.8L + H + T_a + R_a + P_a + Y_r + Y_j + Y_m + E_{ss} \quad (5.3.1i)$$

5.3.1.1 If wind load W is based on service-level loads, $1.6W$ shall be used in place of $1.0W$ in Eq. (5.3.1e).

5.3.1.2 The effect of dynamic soil pressure and hydrodynamic fluid pressure due to earthquake shall be considered in Eq. (5.3.1d) and (5.3.1f).

5.3.1.3 The seismic component of crane load C_{cr} shall be considered in Eq. (5.3.1d) and (5.3.1f).

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occurrences as well as possible excess load effects such as variations in loads, assumptions in the structural analysis, and simplifications in the calculations.

The basic criterion used in arriving at the load combinations (Eq. (5.3.1a) to (5.3.1e)) (normal and severe environmental loads) follows the same logic as in ACI 318, which is based on ASCE/SEI 7-10 Section 2.3. For consideration of extreme environmental and abnormal loads, the criterion is based on the philosophy developed in Ellingwood et al. (1982), Galambos et al. (1982), Hwang et al. (1987), and, to some extent, on Hwang et al. (1983). The overall approach used, however, is the same as that explained in the commentary of Section 2.5 of ASCE/SEI 7-10.

Equations (5.3.1a) to (5.3.1e) involve normal loads and normal loads in combination with severe environmental loads. Similar to ACI 318, this standard uses load factors of 1.4, 1.2, 1.6, and fractional load factors (that is, 0.5) for roof loads, and loads due to snow and rain. The load factor on L has been kept as 0.8. This is based on the consensus estimate made in Hwang et al. (1983), where the mean value of L is estimated as $0.8L$.

While considering the load combinations (5.3.1d), (5.3.1f), and (5.3.1i) for the local design of floors and beams, a fraction of the live load L or roof load L_r , which is most likely to be existing on the members, should be considered as an input into seismic analysis, instead of the factors associated with L and L_r . A common practice in the design of concrete structures in nuclear power plants would be to use 25% of L or 75% of L_r . The gravity load effects of these loads should be in accordance with the factors established in the load combinations. For the global seismic analysis, L and L_r should be based on the mean value associated with these loads, that is, $0.8L$ or $0.5L_r$, as applicable. ASCE/SEI 7 has converted wind loads to strength level and reduced the wind load factor to 1.0. This Code requires use of the previous load factor for wind loads, 1.6, when service-level wind loads are used. Self-relieving effects of temperature distribution occurring as a result of normal operating or shutdown conditions (T_o), and accident conditions (T_a) given in Load Combinations (5.3.1a) through (5.3.1i) should be considered.

Unit load factors are used in Load Combinations (5.3.1f) and (5.3.1g) involving extreme environmental loads, except that a factor of 0.8 is used for live load as it is a companion load in these load combinations. This recognizes that the loads caused by the SSE or the DBT are extreme and are of low probability.

The structural components of overhead and gantry cranes in a nuclear facility are designed for OBE and SSE loads as required by ASME NOG-1. In this Code, crane load C_{cr} with a load factor of 1.0 has been added to Eq. (5.3.1d) to maintain consistency with Eq. (5.3.1f).

Load Combination (5.3.1h) is associated with the basic loads generated as a result of a postulated accident, and Load Combination (5.3.1i) is associated with the combined effects of a postulated accident and E_{ss} . The following documents will be useful in designing for such low-probability events.