

An ACI Standard

Requirements for Reinforced Concrete Chimneys— Code and Commentary

Reported by ACI Committee 307

ACI CODE-307-23



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Requirements for Reinforced Concrete Chimneys—Code and Commentary

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38800 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

Requirements for Reinforced Concrete Chimneys— Code and Commentary

An ACI Standard

Reported by ACI Committee 307

Denis J. Radecki, Chair

David J. Bird
Victor A. Bochicchio
Shu-Jin Fang
Jon K. Galsworthy
David C. Mattes

Joseph F. Peters
Kelly D. Scott
John C. Sowizal
F. Alan Wiley
John L. Wilson

Consulting Members

John J. Carty

Barry J. Vickery

Note: Special acknowledgments to R. Porthouse (deceased) and S. Richart (deceased) for their contributions to this Code.

This Code provides material, design, and detailing requirements for cast-in-place and precast reinforced concrete chimneys. It sets forth minimum loadings for design and contains methods for determining the concrete and reinforcement required to obtain the strength required by the loadings. The methods of analysis apply primarily to circular chimney walls, but guidance is included for applying the general principles to noncircular chimney walls.

Keywords: across-wind load; construction requirements; earthquake load; flexural strength; load combinations; reinforced concrete; reinforced concrete chimneys; structural design; thermal load; vortex shedding; windload.

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ACI CODE-307-23 supersedes ACI 307-08 and was approved by the ACI Standards Board for publication January 2023, and published September 2023. This Code was first published in 1954 under Committee 505 and revised in 1969, 1988, 1995, 1998, and 2008.

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PREFACE

ACI CODE-307 is based on ACI 318-19 and ASCE/SEI 7-16. Updated requirements in ACI 318 and ASCE/SEI 7, as well as recent studies and research, have resulted in the following revisions of this Code:

- (a) The Code has been reorganized to follow the current ACI 318 format as much as possible.
- (b) Wind loads are based on a strength-level wind speed.
- (c) The damping ratio at the strength-level wind speed for the across-wind load has been decreased from 4% to 2.5%.

(d) Seismic loading and detailing are consistent with ASCE/SEI 7.

(e) Foundation requirements are expanded and revised.

Refer to Appendix F for a more comprehensive list of changes.

This Code was developed by an ANSI-approved consensus process. This Code can supplement a current (ICC) building code, supplement the codes governing new and existing structures of a local jurisdiction authority, or act as a stand-alone code in a locality that has not adopted an existing building code.

CODE

CHAPTER 1—GENERAL

1.1—Scope

1.1.1 ACI 307 includes provisions for the structural design of nonprestressed cast-in-place and nonprestressed precast reinforced concrete chimneys.

1.2—General

1.2.1 ACI 307, “Requirements for Reinforced Concrete Chimneys—Code and Commentary,” is hereafter referred to as “this Code.”

1.2.2 In this Code, the general building code refers to the building code adopted in a jurisdiction. When adopted, this Code forms part of the general building code.

1.2.3 This Code provides minimum requirements for the materials, design, construction, and strength evaluation of cast-in-place or nonprestressed precast reinforced concrete chimneys designed and constructed under the requirements of the general building code.

1.2.4 Modifications to this Code that are adopted by a particular jurisdiction are part of the laws of that jurisdiction but are not a part of this Code.

1.2.5 If no general building code is adopted, this Code provides minimum requirements for the materials, design, construction, and strength evaluation of any reinforced concrete chimney within the scope of this Code.

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, and durability of reinforced concrete chimneys.

1.3.2 This Code does not address all design considerations.

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CHAPTER R1—GENERAL

R1.1—Scope

R1.1.1 The provisions apply to circular and noncircular reinforced concrete chimneys.

A precast reinforced concrete chimney is defined as a chimney constructed from precast reinforced concrete sections (360-degree sections only, which may include openings), assembled one on top of another, to form a self-supporting cantilevered structure. Vertical reinforcement and grout are placed in cores as the precast sections are erected to provide structural continuity and stability during construction and for the completed structure. The design of precast concrete chimneys incorporating post-tensioning of the segments is beyond the scope of this Code.

R1.2—General

R1.2.5 This Code applies to reinforced concrete chimneys having circular or noncircular cross sections.

This Code provides minimum requirements and exceeding these minimum requirements is not a violation of this Code. The licensed design professional is permitted to specify project requirements that exceed the minimum requirements of this Code.

R1.3—Purpose

R1.3.1 This Code provides a means of establishing minimum requirements for the design and construction of reinforced concrete chimneys as well as for acceptance of the design and construction of reinforced concrete chimneys by the building officials or their designated representatives.

R1.3.2 The minimum requirements in this Code do not replace professional judgment or the licensed design professional’s knowledge of the specific factors surrounding a project, including its design, the project site, and other specific or unusual circumstances related to the project.

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1.4—Applicability

1.4.1 This Code applies to circular and noncircular cast-in-place or precast reinforced concrete chimneys designed and constructed under the requirements of the general building code.

1.4.2 If noncircular shapes are used, their design shall be substantiated in accordance with the principles of this Code and, where applicable, in accordance with **ACI 318**.

1.4.3 This Code does not apply to the design and construction of a chimney liner or lining. The effects of the liner or lining shall be considered when determining the loads to be resisted by the concrete chimney structure.

1.5—Interpretation

1.5.1 The official version of this Code is the English language version using inch-pound units published by the American Concrete Institute.

1.5.2 In case of conflict between the official version of this Code and other versions of this Code, the official version governs.

1.5.3 This Code consists of chapters, including text, headings, figures, footnotes to figures, and referenced standards.

1.5.4 The Commentary consists of a preface, commentary text, figures, and cited publications. The Commentary is intended to provide contextual information but is not part of this Code, does not provide binding requirements, and shall not be used to create a conflict with or ambiguity in this Code.

1.5.5 Appendixes are not part of this Code.

1.5.6 This Code shall be interpreted in a manner that harmonizes and avoids conflict between or among its provisions. Specific provisions shall govern over general provisions.

1.5.7 This Code shall be interpreted and applied in accordance with the plain meaning of the words and terms used. Specific definitions of words and terms in this Code shall be used where provided and applicable, regardless of whether

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R1.4—Applicability

R1.4.1 Design equations in this Code have been developed for reinforced concrete chimneys having a circular cross section.

R1.4.2 Due to the many possible configurations of noncircular cross sections, it is not possible to develop specific procedures for every design situation. However, the general principles of this Code and ACI 318 may be applied to the design of reinforced concrete chimneys having a noncircular cross section.

R1.4.3 Vertical (gravity) load will be affected by how the weight of a liner or lining is vertically supported. Wind load and seismic load will be affected by how a liner or lining is laterally and vertically supported by the concrete chimney due to the effects on the chimney's natural frequencies (refer to **7.1.3**). Thermal load will be affected by the insulating properties of a liner or lining. Typically, the chimney is designed considering the wind and seismic loads both with and without the effects of a liner or lining (refer to **R4.3.1** and **R7.2.2**).

R1.5—Interpretation

R1.5.3 Appendixes illustrate acceptable methods for determining some parameters of this Code. The methods illustrated are not necessarily the only acceptable methods.

R1.5.7 This Code addresses numerous requirements that can be implemented fully without modification if other requirements in this Code are determined to be invalid. This severability requirement is intended to preserve the Code if

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other materials, standards, or resources outside of this Code would provide a different definition.

1.5.8 The following words or terms in this Code shall be interpreted in accordance with the following:

- (a) The word “shall” is used to indicate mandatory requirements.
- (b) Words used in the present tense shall also apply to the future.
- (c) The word “and” indicates that all the connected items, conditions, requirements, or events shall apply.
- (d) The word “or” indicates that the connected items, conditions, requirements, or events are alternatives, at least one of which shall be satisfied.

1.5.9 In any case in which one or more provisions of this Code are declared by a court or tribunal to be invalid, that ruling shall not affect the validity of the remaining provisions of this Code, which are severable. The ruling of a court or tribunal shall be effective only in that court’s jurisdiction and shall not affect the content or interpretation of this Code in other jurisdictions.

1.5.10 If conflicts occur between provisions of this Code and those of standards and documents referenced in **Chapter 3**, this Code shall apply.

1.6—Building official

1.6.1 All references in this Code to the building official shall be understood to mean persons who administer and enforce this Code in the legal authority having jurisdiction.

1.6.2 Actions and decisions by the building official affect only the specific jurisdiction and do not change this Code.

1.6.3 The building official 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

1.7.1 All references in this Code to the licensed design professional shall be understood to mean the engineer in either 1.7.1.1 or 1.7.1.2.

1.7.1.1 The licensed design professional responsible for, and in charge of, the structural design work.

1.7.1.2 A specialty engineer to whom a specific portion of the structural design work has been delegated subject to the conditions of (a) and (b):

- (a) The authority of the specialty engineer shall be explicitly limited to the delegated design work.
- (b) The portion of design work delegated shall be well defined such that responsibilities and obligations of the parties are apparent.

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allow it to be implemented to the extent possible following legal decisions affecting one or more of its provisions.

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1.8—Construction documents and design records

1.8.1 The licensed design professional shall provide in the construction documents the information required in Chapter 26 of **ACI 318** and that required by the jurisdiction, as applicable.

1.8.2 Calculations pertinent to design shall be filed with the construction documents if required by the building official. Analyses and designs using computer programs shall be permitted provided design assumptions, user input, and computer-generated output are submitted. Model analyses shall be permitted to supplement calculations.

1.9—Testing and inspection

1.9.1 Concrete shall be tested in accordance with the requirements of Chapters 12 and 26 of **ACI 318**, as applicable.

1.9.2 Concrete construction shall be inspected in accordance with the general building code and in accordance with Chapter 26 of **ACI 318**, as applicable.

1.9.3 Inspection records shall include information required in Chapter 12 of this Code and Chapter 26 of **ACI 318**, as applicable.

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R1.8—Construction documents and design records

R1.8.1 The provisions of Chapter 26 of **ACI 318** for preparing project drawings and specifications are, in general, consistent with those of most general building codes. Additional information may be required by the building official.

R1.8.2 If a computer program is used, sufficient information should be provided to allow the building official to perform a detailed review. This Code permits model analysis to be used to supplement structural analysis and design calculations. Documentation of a model analysis should be provided with the related calculations. Model analysis should be performed by an individual having experience in this technique.

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CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

The terms in this list are used in this Code and as needed in the commentary.

A_g	= gross area of concrete section, in. ²
A_s	= area of reinforcement at top and bottom of the opening, in. ²
B	= band-width parameter
$\bar{b}$	= mean hourly wind speed factor
b_o	= width of the opening in chimney wall, in.
C_b	= coefficient of thermal conductivity of an uninsulated liner or of the insulation around liner or of the lining material applied directly to concrete chimney wall, Btu·in./(h·ft ² ·°F)
C_c	= coefficient of thermal conductivity of concrete, Btu·in./(h·ft ² ·°F)
C_d	= earthquake deflection amplification factor
C_{dr}	= drag coefficient for along-wind load
C_E	= end effect factor
C_L	= root mean square lift coefficient
C_{Lo}	= root mean square lift coefficient modified for local turbulence
C_s	= coefficient of thermal conductivity of insulation filling the space between liner and concrete wall, Btu·in./(h·ft ² ·°F)
c	= ratio of distance from extreme compression fiber to neutral axis to the total thickness for vertical stresses
c'	= ratio of distance from extreme compression fiber to neutral axis to the total thickness for horizontal stresses
D	= dead load
d_b	= mean diameter of uninsulated liner or insulation around steel liner, ft
d_{bi}	= inside diameter of uninsulated liner or insulation around steel liner, ft
d_c	= mean diameter of concrete chimney wall, ft
d_{ci}	= inside diameter of concrete chimney wall, ft
d_{co}	= outside diameter of concrete chimney wall, ft
d_s	= mean diameter of space between liner and concrete chimney wall, ft
$d(h)$	= top outside diameter of chimney, ft
$d(u)$	= mean outside diameter of upper one-third of chimney, ft
$d(z)$	= outside diameter of chimney at height z , ft
$d(z_{cr})$	= outside diameter of chimney at critical height z_{cr} , ft
E	= effect of earthquake-induced forces
E_c	= modulus of elasticity of concrete, psi
E_s	= modulus of elasticity of reinforcement, psi
e_c	= eccentricity of concrete stress resultant, ft
F_a	= short-period site coefficient
F_c	= compressive force in concrete, lb
F'_c	= moment due to compressive force in concrete, lb-ft

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F_v	= long-period site coefficient
F_{1A}	= Strouhal number parameter
F_{1B}	= lift coefficient parameter
f'_c	= specified compressive strength of concrete, psi
$f_c^2(c)$	= f'_c modified for temperature effects, circumferential, psi
$f_c^2(v)$	= f'_c modified for temperature effects, vertical, psi
$f_{ey}'(v)$	= f_y modified for temperature effects, vertical, psi
f_r	= concrete modulus of rupture, psi
f_{STC}	= maximum stress in outside circumferential reinforcement due to temperature, psi
f_{STV}	= maximum stress in outside vertical reinforcement due to temperature, psi
f_y	= specified yield strength of reinforcing steel, psi
$f_y'(c)$	= f_y modified for temperature effects, circumferential, psi
f_{CTC}^2	= maximum circumferential stress in concrete inside chimney wall due to temperature, psi
f_{CTV}^2	= maximum vertical stress in concrete inside chimney wall due to temperature, psi
f_{STV}^2	= maximum stress in inside vertical reinforcement due to temperature, psi
G	= across-wind peaking factor
$G_r(z)$	= gust factor for radial wind pressure at height z
G_w'	= gust factor for along-wind fluctuating load
g	= acceleration of gravity, ft/s ²
h	= chimney height above ground level, ft
I	= local turbulence factor
I_e	= seismic importance factor
K_d	= mean along-wind load directionality factor
K_i	= coefficient of heat transmission from gas to inner surface of liner or to inner surface of lining material applied directly to the chimney wall or to inner surface of chimney wall (when chimney is unlined), Btu/(h·ft ² ·°F)
K_{ic}	= component of K_i due to conduction and convection
K_{ir}	= component of K_i due to radiation
K_o	= coefficient of heat transmission from outside surface of chimney wall to surrounding air, Btu/(h·ft ² ·°F)
K_r	= coefficient of heat transfer by radiation between outside surface of liner and inside surface of chimney wall, Btu/(h·ft ² ·°F)
K_s	= coefficient of heat transfer between outside surface of liner and inside surface of chimney wall for chimneys with ventilated air spaces, Btu/(h·ft ² ·°F)
k	= ratio of wind speed $\bar{V}(z_{cr})$ to critical wind speed V_{cr}
k_a	= aerodynamic damping parameter
k_{ao}	= mass damping parameter of small amplitudes
L	= correlation length parameter
LF_{cw}	= combined along-wind/across-wind load factor
ℓ_w	= wind end effect length, ft
$M_a(b)$	= across-wind base moment, lb-ft
$M_a(z)$	= across-wind moment at height z , lb-ft

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$M_{cr}(z)$	=	cracking moment for a horizontal cross section at height z , lb-ft
$M_{cw}(b)$	=	combined across-wind base moment, lb-ft
$M_{cw}(z)$	=	combined across-wind moment at height z , lb-ft
$M_t(z)$	=	maximum circumferential moment due to radial wind pressure at height z , tension on inside, lb-ft/ft
$M_t(b)$	=	mean along-wind base moment at governing wind speed for across-wind load (lb-ft)
$M_t(z)$	=	mean along-wind moment at height z at governing wind speed for across-wind load, lb-ft
M_n	=	nominal flexural strength at a horizontal cross section, lb-ft
$M_o(z)$	=	maximum circumferential moment due to radial wind pressure at height z , tension on outside, lb-ft/ft
M_u	=	factored moment at a horizontal cross section, lb-ft
$M_w(b)$	=	base moment due to mean wind pressure, lb-ft/ft
$M_w(z)$	=	moment at elevation z due to mean wind pressure, lb-ft/ft
n	=	modular ratio, E_s/E_c
P_n	=	nominal axial strength at a horizontal cross section, lb
P_u	=	factored axial load at a horizontal cross section, lb
$\bar{p}(z)$	=	pressure due to mean hourly wind speed at height z , lb/ft ²
$p_r(z)$	=	radial wind pressure at height z , lb/ft ²
R	=	earthquake response modification factor
r	=	mean radius of a horizontal cross section, ft
r_q	=	ratio of heat transmission through chimney wall to heat transmission through liner for chimneys with a ventilated air space
$r(z)$	=	mean radius of a horizontal cross section at height z , ft
S_a	=	design spectral response acceleration, g
S_c	=	compressive force where steel stress is below the yield strength, lb
S_c'	=	moment about the neutral axis of the compressive force where steel stress is below the yield strength, lb-ft
S_{cy}	=	compressive force where steel stress is at the yield strength, lb
S_{cy}'	=	moment about the neutral axis of the compressive force where steel stress is at the yield strength, lb-ft
S_{DS}	=	design spectral response acceleration at short periods, g
S_{D1}	=	design spectral response acceleration at a period of 1 second, g
S_{M1}	=	maximum considered earthquake, 5% damped, spectral response acceleration at

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	a period of 1 second adjusted for site class effects, g
S_{MS}	= maximum considered earthquake, 5% damped, spectral response acceleration at short periods adjusted for site class effects, g
S_p	= across-wind spectral parameter
S_S	= mapped maximum considered earthquake, 5% damped, spectral response acceleration at short periods, g
S_{sv}	= across-wind mode shape factor
St	= Strouhal number
S_t	= tensile force where steel stress is below the yield strength, lb
S_t'	= moment about the neutral axis of the tensile force where steel stress is below the yield strength, lb-ft
S_{ty}	= tensile force where steel stress is at the yield strength, lb
S_{ty}'	= moment about the neutral axis of the tensile force where steel stress is at the yield strength, lb-ft
S_1	= mapped maximum considered earthquake, 5% damped, spectral response acceleration at a period of 1 second, g
s	= center-to-center spacing of two identical chimneys, ft
T	= temperature effect
T_{amb}	= minimum design ambient air temperature, °F
T_i	= maximum design temperature of flue gas, °F
T_L	= long-period transition period, s
T_n	= n -th mode period of vibration, s
T_S	= earthquake response spectrum parameter
T_x	= temperature gradient across the chimney wall, °F
T_0	= earthquake response spectrum parameter
t_b	= thickness of uninsulated liner or thickness of insulation around liner or thickness of lining material applied directly to concrete chimney wall, in.
t_c	= thickness of concrete wall, in.
t_s	= thickness of insulation filling the space between liner and chimney wall, in.
V_{cr}	= critical wind speed for across-wind load, ft/s
V_{ELF}	= base shear using the equivalent lateral force procedure, lb
V_s	= serviceability wind speed, mph
V_t	= total earthquake design base shear, lb
V_u	= basic wind speed, mph
$\bar{V}_u(33)$	= mean hourly basic wind speed at height of 33 ft, ft/s
$\bar{V}(z_{cr})$	= variable mean hourly wind speed at height z_{cr} , ft/s
$\bar{V}_s(z)$	= mean hourly serviceability wind speed at height z , ft/s
$\bar{V}_u(z)$	= mean hourly design wind speed at height z , ft/s

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$\bar{V}_u(z_{cr})$	= mean hourly design wind speed at height z_{cr} , ft/s
W	= wind load due to radial wind pressure
W_{along}	= wind load due to along-wind loading
W_{comb}	= wind load due to across-wind loading combined with along-wind loading at the same wind speed
W_e	= effective seismic weight, lb
$w(z)$	= total along-wind load per unit length at height z , lb/ft
$\bar{w}(z)$	= mean along-wind load per unit length at height z , lb/ft
$w'(z)$	= fluctuating along-wind load per unit length at height z , lb/ft
$wt(u)$	= average weight per unit height for top one-third of chimney, lb/ft
$y_{cw,s}(h)$	= deflection due to combined wind serviceability load at top of chimney, ft
$y_{cw,s}(z)$	= deflection due to combined wind serviceability load at height z , ft
$y_{cw,u}(z)$	= deflection due to combined wind load at height z , ft
$y_{w,s}(h)$	= deflection due to along-wind serviceability load at top of chimney, ft
$y_{w,s}(z)$	= deflection due to along-wind serviceability load at height z , ft
$y_{w,u}(z)$	= deflection due to along-wind load $w(z)$ at height z , ft
Z_c	= exposure length, ft
z	= height above ground level, ft
z_{cr}	= critical height for across-wind load = 5/6 x height of chimney above top of foundation, ft
α	= for a horizontal cross section, one-half the angle subtended by neutral axis, rad
α_{te}	= thermal coefficient of expansion of reinforced concrete, 1/°F
$\bar{\alpha}$	= mean hourly wind speed power law exponent
β	= one-half of the central angle subtended by an opening on the chimney cross section, rad
β_a	= aerodynamic damping factor for across-wind load
β_s	= structural damping factor for across-wind load
β_1	= factor relating depth of equivalent rectangular compressive stress block to neutral axis depth
ϵ_c	= concrete compressive strain
ϕ	= strength reduction factor
γ_1	= ratio of inside face vertical reinforcement area to outside face vertical reinforcement area
γ_1'	= ratio of inside face circumferential reinforcement area to outside face circumferential reinforcement area
γ_{2i}	= ratio of distance between outer surface of chimney wall and inside face vertical reinforcement to total wall thickness

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γ_{2i}'	=	ratio of distance between outer surface of chimney wall and inside face circumferential reinforcement to total wall thickness
γ_{2o}	=	ratio of distance between inner surface of chimney wall and outside face vertical reinforcement to total wall thickness
γ_{2o}'	=	ratio of distance between inner surface of chimney wall and outside face circumferential reinforcement to total wall thickness
ρ_a	=	specific weight of air, lb/ft ³
ρ_o	=	ratio of area of vertical outside face reinforcement to total area of chimney wall
ρ_o'	=	ratio of area of circumferential outside face reinforcement per unit height to total area of concrete wall per unit height
ρ_t	=	ratio of total area of vertical reinforcement to total area of concrete cross section
Ω_0	=	overstrength factor

2.2—Definitions

The following terms used in this Code supplement the terms defined in [ACI 318](#).

buttress—exterior or interior support projecting from the chimney wall.

jamb area—concrete wall area on either side of an opening containing additional vertical reinforcing bars.

liner/lining—material employed to prevent conveyed gases from direct contact with the structural concrete; liner is used for cases where there is a resultant air space between the liner and the concrete wall; lining is used when lining materials are applied directly to the concrete wall.

lintel area—concrete wall area above an opening containing additional horizontal reinforcing bars.

mean recurrence interval—estimate of the average time between a specified severity of earthquake motion, a specified wind speed, or a specified value of some other randomly occurring event.

sill area—concrete wall area below an opening containing additional horizontal reinforcing bars.



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CHAPTER 3—REFERENCED STANDARDS

ACI 318-19—Building Code Requirements for Structural Concrete

ACI 117-10(15)—Specification for Tolerances for Concrete Construction and Materials

American Society of Civil Engineers

ASCE/SEI 7-16—Minimum Design Loads and Associated Criteria for Buildings and Other Structures

ASTM International

ASTM A615/A615M-20—Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement

ASTM A706/A706M-16—Standard Specification for Deformed and Plain Low-Alloy Steel Bars for Concrete Reinforcement

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

ASTM C150/C150M-20—Standard Specification for Portland Cement

ASTM C260/C260M-10a(2016)—Standard Specification for Air-Entraining Admixtures for Concrete

ASTM C309-19—Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete

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

ASTM C595/C595M-20—Standard Specification for Blended Hydraulic Cements

ASTM C618-19—Standard Specification for Coal Fly Ash and Raw or Calcinated Natural Pozzolan for Use in Concrete

ASTM C989/C989M-18a—Standard Specification for Slag Cement for Use in Concrete and Mortars

ASTM C1017/C1017M-13e1—Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete (withdrawn 2022)

ASTM C1240-20—Standard Specification for Silica Fume Used in Cementitious Mixtures

ASTM C1582/C1582M-11(2017)e1—Standard Specification for Admixtures to Inhibit Chloride-Induced Corrosion of Reinforcing Steel in Concrete

ASTM C1602/C1602M-18—Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete

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CHAPTER 4—STRUCTURAL SYSTEM REQUIREMENTS

4.1—Materials

4.1.1 Properties of concrete shall be in accordance with Chapter 5.

4.1.2 Properties of reinforcement shall be in accordance with Chapter 6.

4.2—Design loads

4.2.1 Loads and load combinations considered in design shall be in accordance with Chapter 7.

4.3—Structural system

4.3.1 The structural system shall include the following, as applicable:

- (a) Chimney wall
- (b) Foundation
- (b) Connections, anchors, and grout as required to transmit forces through the structure to the foundation

4.3.2 Design strength of horizontal chimney cross sections shall be determined in accordance with Chapter 8.

4.3.3 Design strength of vertical chimney cross sections for circumferential ring moments shall be determined in accordance with Chapter 9.

4.3.4 Detailing near openings shall be determined in accordance with Chapter 10.

4.3.5 Foundations shall be designed in accordance with Chapter 11.

4.3.6 Anchors in concrete used to transmit loads by means of tension, shear, or a combination of tension and shear shall be designed in accordance with Chapter 17 of ACI 318.

4.3.7 Compressive forces transferred through bearing shall be designed in accordance with Section 22.8 of ACI 318 using the strength reduction factor $\phi = 0.65$ and the factored load combinations of Table 5.3.1 in ACI 318.

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CHAPTER R4—STRUCTURAL SYSTEM REQUIREMENTS

R4.3—Structural system

R4.3.1 The stiffness of liners (or linings) is often negligible compared to the stiffness of the concrete chimney wall; in such cases, liner (or lining) stiffness may be neglected in the structural system. However, the weight of the liners (or linings) is usually not negligible when considering gravity loads and lateral inertia effects. For this reason, the liner weight (or lining weight) must be distributed in the structural model to account for the additional gravity load and inertia effect. If the concrete wall is completely constructed before the liner (or lining) is installed, it may be necessary to consider a structural system without the liners (or linings) as well as a structural system with the liners (or linings).

R4.3.2 Chapter 8 presents methods used to determine the vertical reinforcing steel required to meet the bending moment demand at horizontal cross sections.

R4.3.3 Chapter 9 presents methods used to determine the horizontal reinforcing steel required to meet the ring bending moment demand at vertical cross sections.

R4.3.4 Because openings are a significant consideration for the design of reinforced concrete chimneys, a separate chapter is dedicated to detailing near openings.

R4.3.6 Chapter 17 of ACI 318 applies to cast-in anchors and to post-installed expansion (torque-controlled and displacement-controlled), undercut, and adhesive anchors.

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CHAPTER 5—CONCRETE: MATERIALS, DESIGN,
AND DURABILITY REQUIREMENTS

5.1—General

5.1.1 Concrete materials, design properties, and durability requirements not addressed in this chapter shall be in accordance with **ACI 318**.

5.2—Materials

5.2.1 *Cementitious materials*

5.2.1.1 A single type of cement shall be specified for the construction of the chimney wall above ground level.

5.2.1.2 Portland cement shall conform to **ASTM C150/C150M**.

5.2.1.3 Blended hydraulic cements shall conform to **ASTM C595/C595M**.

5.2.1.4 Fly ash and natural pozzolan shall conform to **ASTM C618**.

5.2.1.5 Slag cement shall conform to **ASTM C989/C989M**.

5.2.1.6 Silica fume shall conform to **ASTM C1240**.

5.2.1.7 All cementitious materials specified in this chapter and the combinations of these materials shall be included in calculating the water-cement ratio (w/c) of the concrete mixture.

5.2.2 *Aggregates*

5.2.2.1 Aggregates shall conform to **ASTM C33/C33M**.

5.2.2.2 The maximum size of coarse aggregate shall not exceed one-eighth of the narrowest dimension between inside and outside forms.

5.2.2.3 The maximum size of coarse aggregate shall not exceed one-half the minimum clear distance between reinforcing bars.

5.2.3 *Water*

5.2.3.1 Mixing water shall conform to **ASTM C1602/C1602M**.

5.2.4 *Admixtures*

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CHAPTER R5—CONCRETE: MATERIALS, DESIGN,
AND DURABILITY REQUIREMENTS

R5.1—General

R5.1.1 Materials listed in the following are the ones most commonly used for chimney construction.

R5.2—Materials

R5.2.1 *Cementitious materials*

R5.2.1.1 Chimneys are highly visible. Typically, a single brand should be specified to minimize color variations. For chimneys constructed such that a section of the chimney wall is below ground level, a different type of cement may be used for that section if required due to exposure to the soil conditions.

R5.2.1.2 Type IV (low-heat-of-hydration) cement is seldom used for chimney walls because they are relatively thin. Type IV may be advantageous for chimney foundations.

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5.2.4.1 Water-reducing admixtures and setting time modification admixtures shall conform to **ASTM C494/C494M**.

5.2.4.2 Admixtures used to produce flowing concrete shall conform to **ASTM C1017/C1017M**.

5.2.4.3 Air-entraining admixtures shall conform to **ASTM C260/C260M**.

5.2.4.4 Admixtures used to inhibit chloride-induced corrosion of reinforcing steel shall conform to **ASTM C1582/C1582M**.

5.2.5 *Concrete mixture requirements*

5.2.5.1 Based on the exposure classes assigned in Section 5.4, concrete mixtures shall conform to the most restrictive requirements of Table 19.3.2.1 of **ACI 318**.

5.3—Concrete properties for design

5.3.1 *General*

5.3.1.1 The concrete properties of this section shall apply when the mean in-service temperature of the concrete wall does not exceed 150°F. When the mean concrete wall in-service temperature exceeds 150°F, the concrete design properties shall be adjusted to account for temperature dependence.

5.3.2 *Compressive strength*

5.3.2.1 The value of f'_c shall be specified in the construction documents.

5.3.2.2 The specified value of f'_c shall be in accordance with:

- (a) Structural strength requirements
- (b) Durability requirements of Section 5.4

5.3.2.3 The specified compressive strength shall be used for proportioning of concrete mixtures in accordance with Section 26.4.3 of ACI 318.

5.3.2.4 Compliance with f'_c shall be based on cylinder tests in accordance with Section 26.12 of ACI 318. Test age, if other than 28 days, shall be indicated in the contract documents.

5.3.3 *Modulus of elasticity*

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R5.3—Concrete properties for design

R5.3.1 *General*

R5.3.1.1 The in-service temperature for the evaluation of concrete properties is generally taken as the mean concrete temperature calculated at the normal operating temperature, or the maximum expected operating temperature that may exist for an extended period of time, if higher. It is not intended to use the maximum expected excursion or upset temperature that may exist for longer than approximately 1 day.

Values of concrete design properties at temperatures exceeding 150°F should be obtained from tests or sources providing data based on tests of concrete with similar composition.

R5.3.2 *Compressive strength*

R5.3.2.2 Table 19.3.2.1 of ACI 318 lists strength and durability requirements for concrete by exposure class.

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5.3.3.1 The modulus of elasticity for concrete, E_c , shall be in accordance with **ACI 318**, Section 19.2.2.

5.3.4 *Modulus of rupture*

5.3.4.1 The modulus of rupture for concrete, f_r , shall be in accordance with ACI 318, Section 19.2.3.

5.3.5 *Thermal coefficient of expansion*

5.3.5.1 The thermal coefficient of expansion of reinforced concrete, α_{te} , is permitted to be taken as 5.5×10^{-6} per °F.

5.4—Durability requirements

5.4.1 Concrete durability requirements shall be in accordance with Section 19.3 of ACI 318 except that f'_c shall not be less than 3000 psi. The licensed design professional shall assign exposure classes in accordance with the severity of the anticipated exposure of the chimney for each exposure category in Table 19.3.1.1 of ACI 318.

R5.3.5 *Thermal coefficient of expansion*

R5.3.5.1 Per **ACI 209R**, the value specified is a reasonable average value for the coefficient of thermal expansion.

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CHAPTER 6—REINFORCING STEEL: MATERIALS, DESIGN, AND DURABILITY REQUIREMENTS

6.1—General

6.1.1 Reinforcing steel materials, design properties, and durability requirements not addressed in this chapter shall be in accordance with **ACI 318**.

6.2—Materials

6.2.1 Reinforcement shall be deformed bars conforming to **ASTM A615/A615M**, Grades 40, 60, and 80, or conforming to **ASTM A706/A706M**, Grades 60 and 80.

6.2.2 Other deformed steel reinforcements are permitted provided that the material has an ultimate tensile strain equal to or exceeding 0.06.

6.3—Steel properties for design

6.3.1 *Yield strength*

6.3.1.1 Yield strength for reinforcing bars shall be based on the specified grade of reinforcement but shall not exceed 80,000 psi.

6.3.2 *Modulus of elasticity*

6.3.2.1 Modulus of elasticity, E_s , for reinforcing bars is permitted to be taken as 29,000,000 psi.

6.4—Durability requirements

6.4.1 The specified concrete cover shall be at least 2 in. for cast-in-place chimneys.

6.4.2 The specified concrete cover shall be at least 1.5 in. for plant-cast precast units.

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CHAPTER R6—REINFORCING STEEL: MATERIALS, DESIGN, AND DURABILITY REQUIREMENTS

R6.2—Materials

R6.2.2 The ultimate tensile strain requirement has been changed from 0.07 to 0.06 so that ASTM A615/A615M Grade 80 is permitted.



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CHAPTER 7—LOADS

7.1—General

7.1.1 Chimney loads shall include:

- (a) Dead load
- (b) Temperature gradient load
- (c) Wind load
- (d) Earthquake load

7.1.2 Every chimney shall be assigned a risk category as defined in Section 1.5 of **ASCE/SEI 7**. The risk category shall be either Category III or Category IV, as applicable.

7.1.3 For wind and earthquake loads, natural frequencies or periods shall be computed by a dynamic analysis that takes into account the mass and stiffness distribution of the chimney; the effect of any significant nonstructural weights such as access platforms and slabs; and the effect of liner(s) supported, braced, or both, by the chimney.

7.2—Dead load

7.2.1 For calculation of self-weight, the unit weight for normalweight reinforced concrete is permitted to be taken as 150 lb/ft³.

7.2.2 Permanent loads, such as the weight of liners, roofs, and platforms supported by the chimney wall shall be included in the dead load.

7.3—Temperature gradient load

7.3.1 *General*

7.3.1.1 Reinforced concrete chimneys shall be designed to resist vertical and circumferential stress due to a temperature gradient across the chimney wall.

7.3.1.2 For circular chimneys, the temperature gradient across the chimney wall shall be determined according to 7.3.2 or by a rational heat-balance study.

7.3.1.3 For noncircular chimneys, the temperature gradient across the chimney wall shall be determined by a rational heat-balance study.

7.3.2 *Temperature gradient for circular chimneys*

7.3.2.1 Equations (7.3.2.2), (7.3.2.3), (7.3.2.4), (7.3.2.5), and (7.3.2.6) are permitted to be used to obtain the temperature gradient across the chimney wall of a circular chimney. For circular chimneys with multiple liners, the equations are permitted to be used by setting the liner diameter equal to an

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CHAPTER R7—LOADS

R7.1—General

R7.1.2 Previous versions of this Code stated that every chimney should be designated as an essential facility classified as a Risk Category IV structure. The revised code provides for the designation of a chimney as a Risk Category III structure, if appropriate.

R7.2—Dead load

R7.2.2 When there is a time delay between completion of the chimney wall construction and installation of any permanent load, the design should be checked with and without that permanent load. **ASCE/SEI 37** provides guidance for design loads for structures during construction.

R7.3—Temperature gradient load

R7.3.2 *Temperature gradient for circular chimneys*

R7.3.2.1 For chimneys with multiple liners, a rational heat-balance study would be needed to accurately determine the temperature gradient across the chimney wall; however, Eq. (7.3.2.4) and (7.3.2.5) are permitted to be used with an equivalent liner diameter to represent the multiple liners. The normal practice is to use a liner diameter equal to the

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equivalent diameter that approximates the thermodynamic conditions.

7.3.2.2 For unlined circular chimneys

$$T_x = \frac{t_c d_{ci}}{C_c d_c} \left(\frac{T_i - T_{amb}}{\frac{1}{K_i} + \frac{t_c d_{ci}}{C_c d_c} + \frac{d_{ci}}{K_o d_{co}}} \right) \quad (7.3.2.2)$$

7.3.2.3 For circular chimneys with lining material applied directly to the inside surface of the chimney wall

$$T_x = \frac{t_c d_{bi}}{C_c d_c} \left(\frac{T_i - T_{amb}}{\frac{1}{K_i} + \frac{t_b d_{bi}}{C_b d_b} + \frac{t_c d_{bi}}{C_c d_c} + \frac{d_{bi}}{K_o d_{co}}} \right) \quad (7.3.2.3)$$

7.3.2.4 For circular chimneys with insulation completely filling the space between the liner and the chimney wall (no annular air space)

$$T_x = \frac{t_c d_{bi}}{C_c d_c} \left(\frac{T_i - T_{amb}}{\frac{1}{K_i} + \frac{t_b d_{bi}}{C_b d_b} + \frac{t_s d_{bi}}{C_s d_s} + \frac{t_c d_{bi}}{C_c d_c} + \frac{d_{bi}}{K_o d_{co}}} \right) \quad (7.3.2.4)$$

7.3.2.5 For circular chimneys with an unventilated air space between the liner and the chimney wall

$$T_x = \frac{t_c d_{bi}}{C_c d_c} \left(\frac{T_i - T_{amb}}{\frac{1}{K_i} + \frac{t_b d_{bi}}{C_b d_b} + \frac{d_{bi}}{K_r d_s} + \frac{t_c d_{bi}}{C_c d_c} + \frac{d_{bi}}{K_o d_{co}}} \right) \quad (7.3.2.5)$$

7.3.2.6 For circular chimneys with a ventilated air space between the liner and the chimney wall

$$T_x = \frac{t_c d_{bi}}{C_c d_c} \left(\frac{T_i - T_{amb}}{\frac{1}{r_q K_i} + \frac{t_b d_{bi}}{r_q C_b d_b} + \frac{d_{bi}}{K_s d_s} + \frac{t_c d_{bi}}{C_c d_c} + \frac{d_{bi}}{K_o d_{co}}} \right) \quad (7.3.2.6)$$

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sum of the individual liner diameters; however, in certain cases, the sum of the individual diameters may be greater than the inside diameter of the chimney wall, in which case a smaller diameter should be used providing a nominal airspace. It may also be necessary to check the gradient using several different equivalent diameters to represent the thermodynamic conditions from variations in gas flow and temperature among the multiple liners.

R7.3.2.3 This case is added to explicitly address glass block or shotcrete applied to the chimney wall.

R7.3.2.5 The equation suggests that the liner is not insulated. For an insulated liner, it is permissible to still use this equation, but let the terms with subscript “b” refer to the insulation material instead of the liner material. The assumption is that the thermal resistance of the liner material is negligible compared to the thermal resistance of the insulation material.

R7.3.2.6 Refer to R7.3.2.5 for use of the equation with an insulated liner.

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7.3.2.7 When multiple layers of material are to be considered, additional terms can be added to the equations.

7.3.2.8 Unless complete heat balance studies are made for the particular chimney, it is permissible to use the following approximate values: $r_q = 0.5$ (refer to 7.3.2.9); C_c is to be obtained from the manufacturer of the materials used—for normalweight concrete, 12 is permitted to be used; C_s is to be obtained from the manufacturer of the materials used; C_b is to be obtained from the manufacturer of the materials used; $K_i = K_{ic} + K_{ir}$ film coefficient to be determined from curves in Fig. 7.3.2.8; $K_o = 12$; $K_r = T_i/120$; and $K_s = T_i/150$.

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R7.3.2.7 For example, Eq. (7.3.2.5) and (7.3.2.6) can be modified to include a term for the liner material and a term for the insulation material. Refer to [Appendix C](#).

R7.3.2.8 The research data available to establish the coefficients of heat transfer through the liner(s) and the chimney wall, especially as they concern the heat transfer from gases to the surfaces and through the ventilated air space between the liner(s) and the chimney wall, are limited. Unless complete heat-balance studies are made for the particular chimney, it is permissible to use the coefficients as determined or stated in this Code.

These coefficients, when entered into equations for temperature differential through the chimney wall, T_x , will give a value having accuracy in keeping with the basic design assumptions for the structural design of the concrete. More refined values, a more refined method, or both, may be needed for other purposes, such as accurately calculating the temperature in the annular air space between the liner and the chimney wall.

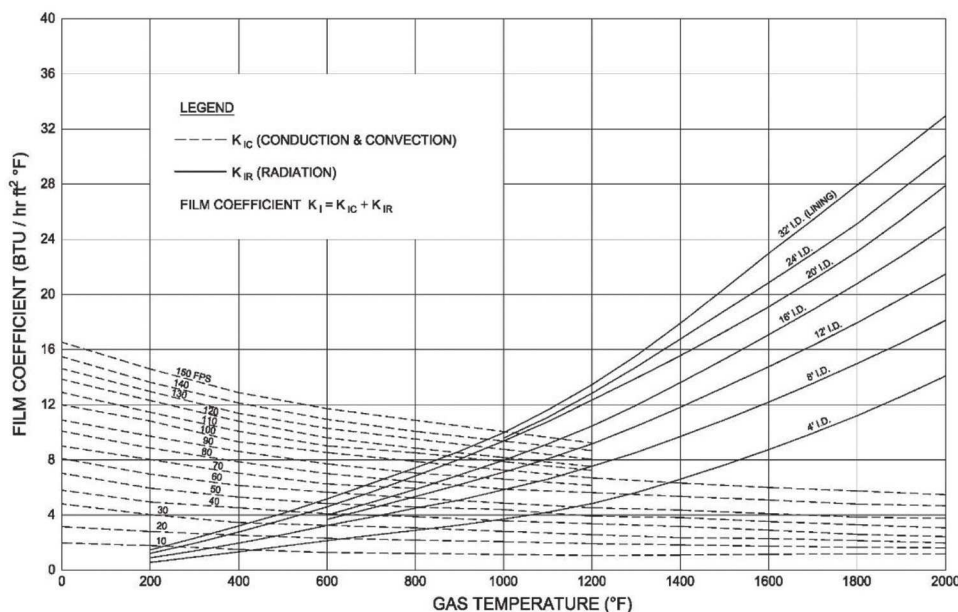


Fig. 7.3.2.8—Flue gas film coefficients.

7.3.2.9 The value of $r_q = 0.5$ shall apply only where:

- The distance between the liner and the chimney wall is not less than 4 in. throughout the entire height of the liner and ventilation air inlet and outlet openings are provided at the bottom and top of the chimney wall, respectively
- The free area of inlet and outlet openings, in square feet, are each numerically equal to or greater than two-thirds of the top inside diameter of the chimney wall, in feet
- Local obstructions in the air space between the liner and the chimney wall do not restrict the free area of the air space at any horizontal section to less than the free area specified for the inlet and outlet openings