Guide to Simplified Design for Reinforced Concrete Buildings

(For Buildings of Limited Size and Height, based on ACI 318-14 and ACI IPS-1, "Essential Requirements for Reinforced Concrete Buildings")

Reported by ACI Committee 314

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This document is dedicated to the memory of late subcommittee member W. Gene Corley.

This guide presents simplified methods and design techniques that facilitate and speed the engineering of low-rise buildings within certain limitations. Material is presented in an order that follows typical design process with procedures introduced as the designer will need them in the course of a building design. Much of the information presented in this guide is derived from ACI 318, ASCE 7, and the 2015 International Building Code (IBC) (International Code Council 2015). The quality and testing of materials used in construction are covered by references to the appropriate ASTM standard specifications.

Whereas many of the tables, charts, and values included in this guide originated from the aforementioned reference documents, they have been modified or reorganized to be more conservative, to match design process flow, or better support the holistic and simplified design approach presented.

Although this guide is not written in mandatory language, the information is presented in such a manner that a structure designed following this guide will, in principle, comply with the codes and standards on which it was based. Although this guide is written in nonmandatory language, it is meant to be applied as a whole, because the simplified provisions are interdependent, and it would be unsafe to employ only a portion of this guide and disregard the remainder. This guide is not a code and is not deemed to satisfy ACI 318, ASCE 7, and the International Building Code (International Code Council 2015). This guide is expected to be especially useful in the education and training of engineers in reinforced concrete design of low-rise structures of small to medium floor areas.

There are many options within these standards that are not considered in this guide, such as the use of supplementary cementitious materials in concrete mixtures. As this guide will be used as a design aid, it is the licensed design professional's responsibility to ensure that the structure design satisfies the requirements of ACI 318, ASCE 7, the International Building Code (International Code Council 2015), and the legal requirements of the local jurisdiction. The original draft of the guide, published as ACI IPS-1 (2002), was produced by a Joint Committee of Instituto Colombiano de Normas Técnicas y Certificación (Colombian Institute for Technical Standards and Certification) (ICONTEC) and Asociación Colombiana de Ingeniería Sísmica (Colombian Association for Earthquake Engineering) (AIS).

The initial drafting of ACI IPS-1 (2002) was motivated by frequent worldwide discussions that reinforced concrete codes might be unnecessarily sophisticated for some applications, such as small low-rise buildings. Current knowledge of reinforced concrete behavior obtained through experimentation and experi-

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ence, and its status and dissemination as a structural material used worldwide, made developing a simplified design and construction guide feasible. This guide used ACI IPS-1 (2002) as a basis, with information derived from ACI 318, ASCE 7, and the International Building Code (International Code Council 2015).

This guide presents simplified approaches to assist engineers in designing low-rise buildings within certain limitations, in addition to the following:

(a) Information on the order needed in the course of a design
(b) Explanatory material at appropriate places
(c) Computations only requiring a hand calculator
(d) Graphs and graphical explanations
(e) Design information based on simplified strength models
(f) Other limit states accounted for by minimum dimensions
(g) Conservative loads and simplified analysis guidelines
(h) Simplified geotechnical information to help define soil-bearing capacity
(i) Shear walls as the seismic-force-resisting system
(j) Material and construction guidelines based on commonly available steel grades and medium-strength concrete that can be site mixed.

Keywords: concrete quality; foundation design; frame analysis; inspection; low-rise building construction; low-rise structure; mixing; placing; section analysis; seismic design; simplified design; specifications; structure design; structure layout.

CONTENTS

CHAPTER 1—GENERAL

1.1—Scope

This guide is intended for the planning, design, and construction of reinforced concrete structures in new low-rise buildings of restricted occupancy, number of stories, and area. Although the information presented was developed to produce, when properly used, a reinforced concrete structure with an appropriate margin of safety, this guide is not a replacement for a licensed design professional's experience and working knowledge. For the structure designed by this guide to attain the intended margin of safety, the guide should be used as a whole, and alternative procedures should be used only when explicitly permitted herein. The minimum dimensioning prescribed in the guide replace, in most cases, more detailed procedures prescribed in ACI 318, ASCE 7, and the International Building Code (International Code Council 2015).

1.2—Purpose

This guide provides a licensed design professional with sufficient information to design structural reinforced concrete members that comprise the structural framing of a low-rise building with the limits set in 1.3. Design rules set forth in this guide are simplifications that, when used together, comply with the more detailed requirements of ACI 318, ASCE 7, and the International Building Code (International Code Council 2015).

1.3—Limitations

This guide is only meant for buildings meeting all the limitations set forth in 1.3.1 to 1.3.10. These limits maintain the guide scope in close adherence to the collective experience of the original drafting committee (ICONTEC-AIS). Buildings within this scope are expected to have a normal rectangular footprint with simple standard geometries and member dimensions in both plan and vertical directions. Such buildings also depend primarily on reinforced concrete

Table 1.3.1.1—Permitted uses and occupancies

Occupancy group	Occupancy subgroup		Permitted
Group A—Assembly	A-1	Fixed-seating theaters, television, and radio studios	NO
	A-2 A-3	Building having an assembly room with capacity less than 100 persons and not having a stage	YES
	A-4	Arenas, skating rinks, swimming pools, and tennis courts	NO
	A-5	Amusement parks, bleachers, grandstands, and stadiums	NO
Group B—Business	B	Building for use as offices, or professional services containing eating and drinking establishments with less than 50 occupants	YES
Group E—Educational	E	Educational purposes with less than 500 students and staff	YES
Group F—Factory	F-1	Light industries not using heavy machinery	YES
	F-2	Heavy industries using heavy machinery	NO
Group H—Hazardous	H	Manufacturing, processing, generation, or storage of materials that constitute a physical or health hazard	NO
Group I—Institutional	I-1	Residential board and care facilities	YES
	I-2	Hospitals	NO
	I-3	Prisons, jails, reformatories, and detention centers	YES
	I-4	Daycare facilities	YES
Group M—Mercantile	M	Display and sale of merchandise	YES
Group R—Residential	R-1	Hotels having an assembly room with capacity less than 100 persons and not having a stage	YES
	R-2	Apartment buildings and dormitories	YES
	R-3	Houses	YES
	R-4	Residential care and assisted-living facilities	YES
Group S—Storage	S-1	Storage of heavy or hazardous materials	NO
	S-2	Storage of light materials	YES
Group U—Utility and miscellaneous	U	Utilities, water supply systems, and power-generating plants	NO
	U	Garages for vehicles with carrying capacity up to 4000 lb (1800 kg)	YES
	U	Garages for trucks of more than 4000 lb (1800 kg) carrying capacity	NO

structural walls for lateral load resistance. Observing these limits justifies the simplified analysis and design methods herein without the need for special analyses, including slenderness and second-order effects. Buildings with offsets, reentrant corners, and vertical or horizontal irregularities are outside the scope of this guide.

1.3.1 *Use and occupancy*

1.3.1.1 *Permitted uses and occupancies*—Table 1.3.1.1 lists building occupancy groups and subgroups, indicating for each whether the use of this guide is permitted.

1.3.1.2 *Mixed occupancy*—Recommendations described in this guide apply to cases involving only combinations for which the use of this guide is permitted, as identified in Table 1.3.1.1.

1.3.2 *Maximum number of stories*—Recommendations described in this guide apply to buildings with five or fewer stories above ground and no more than one basement level.

1.3.3 *Maximum area per floor*—The area per floor should not exceed 10,000 ft^2 (1000 m^2).

1.3.4 *Maximum story height*—Story height, measured from floor finish to floor finish, should not exceed 13 ft (4 m).

1.3.5 *Maximum span length*—The span length for girders, beams, and slab-column systems, measured center-to-center of the supports, should not exceed 30 ft (10 m).

1.3.6 *Maximum difference in span length*—Spans should be approximately equal, and the shorter of two adjacent spans should be at least 80 percent of the larger span, except in elevator and stair cores. Refer to 7.9.1 for cores.

1.3.7 *Minimum number of spans*—There should be at least two spans in each of the two principal directions of the building in plan. Single spans may be permitted in one- and two-story buildings if the span length does not exceed 15 ft (5 m).

1.3.8 *Maximum overhang*—For girders, beams, and slabs with overhangs, the length of the overhang should not exceed one-third of the length of the first interior span of the member.

1.3.9 *Maximum slope for slabs, girders, beams, and joists*—When sloping slabs, girders, beams, or joists are used, the slope of the member should not exceed 15 degrees.

1.3.10 *Maximum slope of the terrain*—The slope of the terrain surrounding the building should not exceed 30 degrees (Fig. 1.3.10) or the ratio of the height of the first story to the smaller dimension of the building in plan.

1.4—Supporting codes and standards

For cases within the limits described in 1.3, this guide is intended to be a simplification complying with the following supporting codes and standards:

a) ACI 318

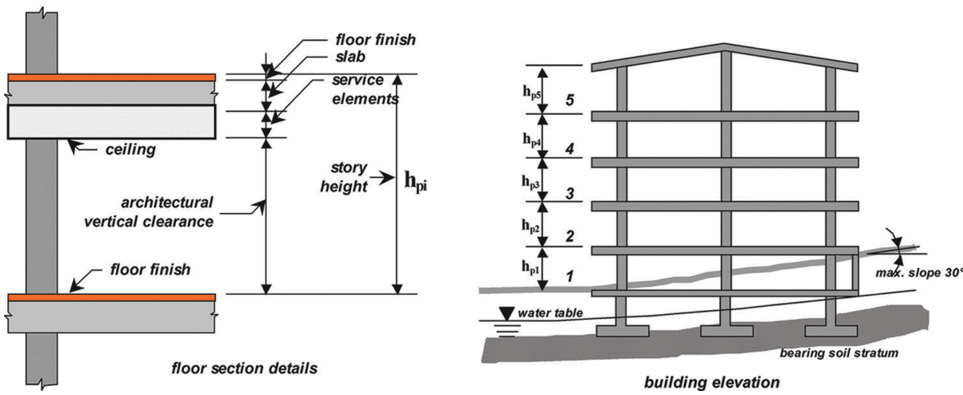

Fig. 1.3.10—General structural layout in elevation.

Table 1.5.1—Design and construction procedure steps

Step	Description	Related chapter(s)
A	Verification that the limitations for using the guide are met. Definition of the layout in plan and height of the structure.	1 and 3
B	Calculation of all gravity loads that act on the structure, excluding the self-weight of the structural members.	4
C	Definition of an appropriate floor system, depending on the span lengths and the magnitude of the gravity loads.	6
D	Selection of trial dimensions for the slab of the floor system. Calculation of the self-weight of the system and design of the members that comprise it, correcting the dimension if needed by the strength and serviceability limit states, complying with the limits for slab systems with beams, or slab-column systems.	6, 7, and 9
E	Trial dimensions for the beams and girders (if needed). Calculation of the self-weight of girders, beams, and joists. Flexural and shear design of the beams and girders, correcting the dimensions if needed by the strength and serviceability limit states.	6 and 8
F	Trial dimensions for the columns. Verification of column slenderness through the use of minimum dimensions. Calculation of the self-weight of the columns. Design of the columns for combination of axial load, moment, and shear. Correcting the dimensions if needed by the strength and serviceability limit states.	10
G	If lateral load, such as earthquake, wind, or lateral earth pressure, is beyond nominal, magnitude and application point are to be established; otherwise the designer may proceed to Step I.	4
H	Preliminary location and trial dimensions for reinforced concrete walls capable of resisting lateral loads. For earthquake loads, the influence of wall self-weight is evaluated. Flexure and shear design of the reinforced concrete walls.	11 and 12
I	Design of the stairways, ramps, small potable water tanks, and retaining walls.	13
J	Loads at the foundation level are determined. Definition of the foundation system is performed. Design of the structural members of the foundation.	14
K	Production of the structural drawings and specifications.	15
L	The structure is built complying with the construction and inspection requirements.	16

b) ASCE 7

c) International Building Code (International Code Council 2015)

Other cases are not covered by this guide. Please refer to Table A.1 in Appendix A for a guide by section to corresponding topics in the supporting codes and standards.

1.5—Design and construction procedure

1.5.1 *Procedure*—The design procedure comprises the steps listed in Table 1.5.1. Refer also to Fig. 1.5.1a and 1.5.1b. Note that by conforming to the dimensional limits and cover of this guide, a 1-hour fire rating is achieved. This rating is usually sufficient for the permitted occupancies in this guide. Other fire ratings are beyond the scope of this guide, and such designs should be performed using ACI 318, ASCE 7, and the International Building Code (International Code Council 2015).

1.5.2 *Design documentation*—The design steps should be recorded as follows.

1.5.2.1 *Calculation record*—The licensed design professional should document all design steps in a calculation record. This record should contain, at a minimum, the following:

(a) General structural program, as defined in Chapter 3

(b) Description of the structural system

(c) Loads

(d) Characteristics, strength, and fabrication standards for all structural materials

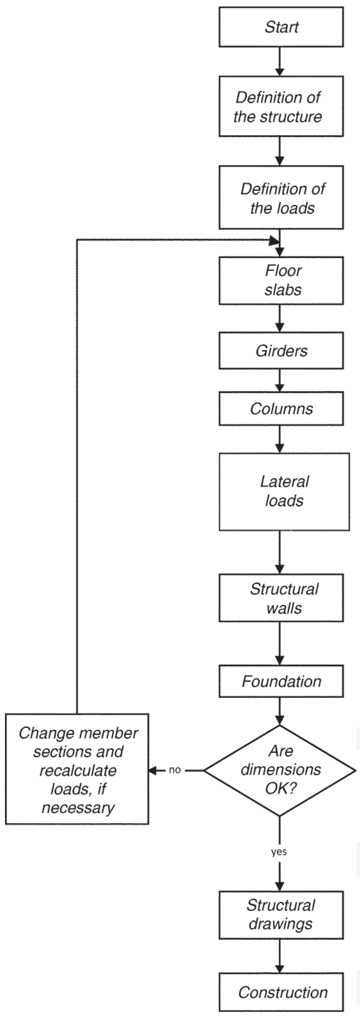

Fig. 1.5.1a—Design and construction procedure.

(e) Justification of all design calculation

(f) Sketches of the reinforcement layout for all structural members

1.5.2.2 *Geotechnical report*—The geotechnical report should record, at a minimum, the soil investigation performed, selected allowable bearing capacity of the soil, soil profile type, lateral soil pressures anticipated for design of any soil-retaining structures, and all other information indicated in Chapters 4 and 14.

1.5.2.3 *Structural drawings*—Structural drawings should include, at a minimum, all the plans indicated by Chapter 15 for construction of the building.

1.5.2.4 *Project specifications*—Project specifications should include, at a minimum, all the construction specifications described in Chapter 15.

1.5.3 *Precast concrete components*—Precast concrete components may be used, including prestressed concrete manufactured in offsite facilities. Such components should be designed by a licensed design professional in accordance with ACI 318, ASCE 7, and the International Building Code (International Code Council 2015). Calculations should be reviewed by the licensed design professional of record (1.2) and included in the calculation record (1.5.2.1). Detailing and placing drawings conforming to 15.2.2 should be

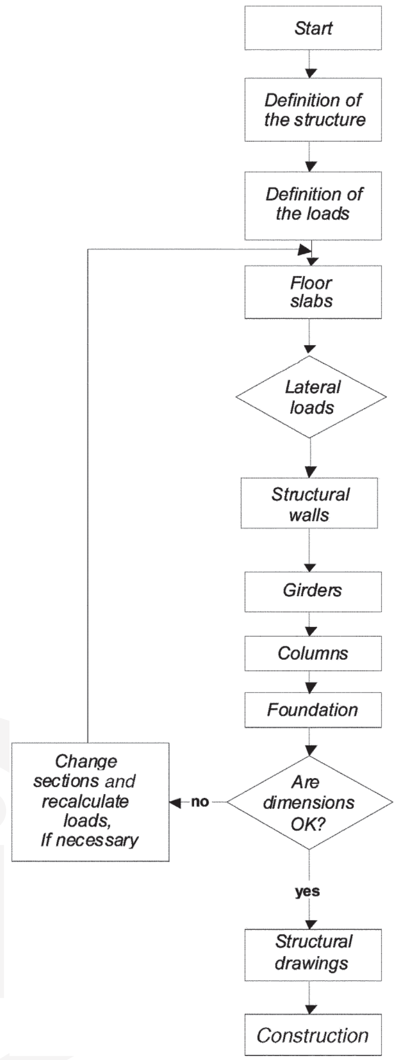

Fig. 1.5.1b—Design and construction procedure for earthquake regions.

furnished and included as part of the structural drawings (1.5.2.3). Manufacture of precast components should be done in a facility with demonstrated capability of producing quality products.

1.6—Limit states

The design approach of this guide is based on limit states, where a limit state is a condition beyond which a structure or member becomes unfit for service and is judged to be unsafe or no longer useful for its intended function. The designer should verify that the strength and serviceability limit states are accounted for in the resulting structure. The following are considered implicitly in the design procedure:

(a) Structural integrity

(b) Lateral load story drift

(c) Durability

(d) Fire resistance

1.7—Strength design

1.7.1 *General*—In strength design, the structure and the structural members are dimensioned to have design strengths at all sections at least equal to the demands calculated for the combinations of factored loads described in Chapter 4.

The basic expression for the strength limit state is

$$\text{resistances} \geq \text{load effects} \quad (1.7.1a)$$

Because resistances may be less than computed and the load effects could be larger than computed, strength reduction factors ϕ less than 1, and load factors γ generally greater than 1, are used

$$\phi R_n \geq \gamma_1 S_1 + \gamma_2 S_2 + \ldots \quad (1.7.1b)$$

where R_n is nominal strength, and S is load effects based on the loads described in Chapter 4. Therefore, the strength design requires that

$$\text{design strength} \geq \text{required strength} \quad (1.7.1c)$$

$$\phi\ (\text{nominal strength}) \geq U \quad (1.7.1d)$$

where the required strength is $U = \gamma_1 S_1 + \gamma_2 S_2 + \ldots$

1.7.2 *Required strength*—The required strength U should be computed for the combinations of factored loads listed in 4.2.

1.7.3 *Design strength*—The design strength provided by a member, its connections to other members, and its cross sections in terms of flexure, axial load, and shear, is the nominal strength multiplied by a strength reduction factor ϕ. Nominal strength should be calculated for each particular force effect in each of the member types at the defined critical sections. The following strength reduction factors ϕ should be used:

a) Flexure, without axial load: $\phi = 0.90$

b) Axial tension and axial tension with flexure: $\phi = 0.90$

c) Axial compression and axial compression with flexure:

i. Columns with ties and reinforced concrete walls: $\phi = 0.65$

ii. Columns with spiral reinforcement: $\phi = 0.75$

d) Shear and torsion: $\phi = 0.75$

e) Bearing of concrete: $\phi = 0.65$

1.8—Serviceability design

To ensure adequate response during service, follow the recommendations in this guide for limiting dimensions, cover, detailing, and construction. These serviceability conditions include effects such as:

(a) Long-term environmental effects, including exposure to aggressive environment or corrosion of the reinforcement

(b) Dimensional changes due to variations in temperature, relative humidity, and other effects

(c) Excessive cracking of the concrete

(d) Excessive vertical deflections

(e) Excessive vibration

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

A_a = effective seismic peak ground horizontal acceleration in rock for short periods of vibration, expressed as a fraction of gravity g

A_b = area of an individual reinforcing bar or wire, in.^{2} (mm^2)

A_{cb} = bearing area of concrete, in.^{2} (mm^2)

A_{cs} = area of core of spirally reinforced compression member measured to outside diameter of spiral, in.^{2} (mm^2)

A_f = contact area of footing with soil, ft^2 (m^2)

A_g = gross area of section, or area of concrete only excluding area of voids, in.^{2} (mm^2)

A_i = area of additional hanger reinforcement where beams are supported by girders or other beams, in.^{2} (mm^2)

A_j = effective cross-sectional shear area within a joint, in.^{2} (mm^2)

A_p = component, or cladding, wind-exposed surface area, ft^2 (m^2)

A_s = area of longitudinal tension reinforcement, in.^{2} (mm^2)

A_s' = area of longitudinal compression reinforcement, in.^{2} (mm^2)

A_{se} = steel area at the extreme face of column or reinforced concrete wall, in.^{2} (mm^2)

$A_{s,min}$ = minimum area of longitudinal tension reinforcement, in.^{2} (mm^2)

A_{ss} = steel area at the side face of column or reinforced concrete wall, in.^{2} (mm^2)

A_{st} = total area of longitudinal reinforcement, in.^{2} (mm^2)

A_{su} = wind-exposed surface area, ft^2 (m^2)

A_v = area of shear reinforcement, in.^{2} (mm^2)

a = depth of equivalent rectangular compressive stress block, in. (mm)

a_w = distance from edge of wall footing to the resultant of soil reaction in wall footing, in. (mm)

B_f = short horizontal dimension of footing, in. (mm)

b = width of compression flange of member, or width of member, in. (mm)

b_c = width of column section, and for punching shear evaluation, the smallest plan dimension of pedestal, column capital, or drop panel, or thickness change in stepped footings, in. (mm)

b_f = width of compression face of member, in. (mm)

b_o = perimeter of critical section for two-way shear (punching shear) in slabs, in. (mm)

b_w = web width of section, or wall width, in. (mm)

C_p = component, or cladding, wind surface pressure coefficient

C_{su} = wind surface pressure coefficient

C_{vx} = coefficient defined in 4.11.4 for design of seismic loads

c_c = least distance from surface of reinforcement to the side face, in. (mm)

D = dead loads or related internal moments and loads

d = effective depth of section, taken as distance from extreme compression fiber to centroid of tension reinforcement, in. (mm)

d' = distance from extreme compression fiber to centroid of compression reinforcement, in. (mm)

d_b = nominal diameter of reinforcing bar or wire, in. (mm)

d_c = distance from extreme tension fiber to centroid of tension reinforcement, in. (mm)

d_s = outside diameter of spiral reinforcement, in. (mm)

E = seismic loads or related internal moments and loads

E_c = modulus of elasticity of concrete, psi (MPa)
e_B = eccentricity of resultant applied to footing in direction parallel to B_f, in. (mm)
e_H = eccentricity of resultant applied to footing in direction parallel to H_f, in. (mm)
e_x = eccentricity, measured in x-direction, between story center of lateral stiffness and application point of story lateral loads acting in y-direction, in. (mm)
e_y = eccentricity, measured in y-direction, between story center of lateral stiffness and application point of story lateral loads acting in x-direction, in. (mm)
F = loads due to weight and pressure of fluids with well-defined densities and controllable maximum heights or related internal moments and loads
F_a = seismic site coefficient for short periods of vibration
F_{ac} = total lateral active soil force, lb (kN)
F_i, F_x = wind or seismic force applied at level i or x, respectively, lb (kN)
F_o = total lateral at-rest soil force, lb (kN)
F_{pw} = equivalent static wind force for components and cladding acting normal to wind-exposed surface, lb (kN)
F_{su} = equivalent static wind force acting normal to wind-exposed surface, lb (kN)
F_{ui}, F_{ux} = factored lateral force applied to wall at level i or x, respectively, lb (kN)
f_c' = specified compressive strength of concrete, psi (MPa)
$\sqrt{f_c'}$ = square root of specified compressive strength of concrete; the result has units of psi (MPa)
f_{cr}' = required average compressive strength of concrete used as the basis for selection of concrete proportions, psi (MPa)
f_{cu} = extreme fiber compressive stress due to factored loads at edges of structural walls, psi (MPa)
f_y = specified yield strength of reinforcement, psi (MPa)
f_{ypr} = probable specified maximum strength of reinforcement, psi (MPa) ($f_{ypr} = 1.25f_y$)
f_{yt} = specified yield strength of transverse or spiral reinforcement, psi (MPa)
g = acceleration due to gravity, 386 in./s^2 (9.8 m/s^2 ≈ 10 m/s^2)
H = loads due to weight and pressure of soil, water in soil, or other materials, or related internal moments and loads
H_f = long horizontal dimension of footing, in. (mm)
h = overall depth or thickness of member, or height of section of member, or outside diameter of circular section, in. or ft (mm or m)
h_b = vertical distance measured from bottom of supporting girder to bottom of supported beam, ft (m)
h_c = depth of column, or dimension of column in direction parallel to girder span; and for punching shear evaluation, the largest plan dimension of capital, drop panel, pedestal, or thickness change in stepped footings, in. (mm)
h_f = flange thickness, in. (mm)
h_g = total depth of supporting girder, in. (mm)
h_i, h_x = height above base to level i or x, respectively, ft (m)
h_n = clear vertical distance between lateral supports of columns and walls, in. (mm)
h_{pi} = story height of floor i measured from floor finish of story to floor finish of story immediately below, ft (m)
h_r = mean roof height for wind design, measured over terrain, ft (m)
h_s = depth of soil against retaining wall, in. (mm)
h_w = height of wall from base to top, in. (mm)
I_c = moment of inertia of column section, in.^{4} (mm^4)
K_a = active soil pressure coefficient
K_o = at-rest soil pressure coefficient
K_p = passive soil pressure coefficient
k_r = story total rotational stiffness
k_x, k_y = wall lateral stiffness in direction x or y, respectively, lb/in. (N/mm) (Eq. (4.14.5a(a)) and Eq. (4.14.5a(b))
L = live loads or related internal moments and loads
L_r = roof live load or related internal moments and loads
ℓ_0 = column confinement length, in. (mm)
ℓ_1 = length of span in direction of moments, measured center-to-center of supports, in. (mm)
ℓ_2 = length of span transverse to ℓ_1, measured center-to-center of supports, in. (mm)
ℓ_a = length of clear span in short direction of two-way slabs or in direction of moments, measured face-to-face of beams or other supports, in. (mm)
ℓ_c = length of clear span in long direction of two-way slabs or systems, measured face-to-face of beams or other supports, in. (mm)
ℓ_d = development length, in. (mm)
ℓ_n = length of clear span, in long direction for two-way systems, measured face-to-face of beams or other supports, in. (mm)
ℓ_{ps} = factor to calculate punching shear strength (9.5.4.3)
ℓ_s = center-to-center span length; shortest distance between adjacent parallel column centerlines, in. (mm)
ℓ_w = horizontal length of wall, in. (mm)
M_a = factored moment in short direction in two-way slabs, lb·in. (N·m) per unit slab width
$M^+_{a \text{ or } b}$ = factored positive moment at section, lb·in. (N·m) per unit slab width
$M^-_{a \text{ or } b}$ = factored negative moment at section, lb·in. (N·m) per unit slab width
M_b = factored moment in long direction in two-way slabs, lb·in. (N·m) per unit slab width
M_{bn} = nominal moment strength at section at balanced conditions, lb·in. (N·m)
M_i, M_x = unfactored overturning moment due to lateral loads for story i or x, respectively, lb·in. (kN·m)
M_{iu}, M_{xu} = factored story moment due to lateral loads at story i or x, respectively, lb·in. (kN·m)
M_n = nominal moment strength at section, lb·in. (N·m)
M_o = total factored moment at section, lb·in. (kN·m)
M_{ot} = unfactored overturning moment due to lateral loads at base of structure, lb·in. (kN·m)
M_{otu} = factored overturning moment due to lateral loads at base of structure, lb·in. (kN·m)
M_{pr} = probable flexural strength of member at joint face, computed using f_{ypr} and ϕ of 1.0, lb·in. (N·m)