CHAPTER 14—PLAIN CONCRETE

CODE

14.1—Scope

14.1.1 This chapter shall apply to the design of plain concrete members, including (a) and (b):

(a) Members in building structures
(b) Members in non-building structures such as arches, underground utility structures, gravity walls, and shielding walls

14.1.2 Plain concrete shall be permitted only in cases (a) through (e):

(a) Members that are continuously supported by soil or supported by other structural members capable of providing continuous vertical support
(b) Members for which arch action provides compression under all conditions of loading
(c) Walls
(d) Pedestals
(e) Cast-in-place concrete deep foundation members designed in accordance with 13.4.4 where the unsupported height of the member does not exceed three times the least horizontal dimension of the member and the member is not required to resist lateral loads

14.1.3 Plain concrete shall be permitted for a structure assigned to Seismic Design Category (SDC) D, E, or F, only in cases (a) and (b):

(a) Footings supporting cast-in-place reinforced concrete or reinforced masonry walls, provided the footings are reinforced longitudinally with at least two continuous reinforcing bars. Bars shall be at least No. 4 and have a total area of not less than 0.002 times the gross cross-sectional area of the footing. Continuity of reinforcement shall be provided at corners and intersections.
(b) Foundation elements (i) through (iii) for detached one- and two-family dwellings not exceeding three stories and constructed with stud bearing walls:
(i) Footings supporting walls
(ii) Isolated footings supporting columns or pedestals
(iii) Foundation or basement walls not less than 7-1/2 in. thick and retaining no more than 4 ft of unbalanced fill.

14.1.4 Plain concrete shall not be permitted for columns and pile caps.

COMMENTARY

R14.1—Scope

R14.1.2 Because strength and structural integrity of structural plain concrete members are based solely on member size, concrete strength, and other concrete properties, use of structural plain concrete should be limited to members:

(a) That are primarily in a state of compression
(b) That can tolerate random cracks without detriment to their structural integrity
(c) For which ductility is not an essential feature of design

The tensile strength of concrete can be used in design of structural plain concrete members. Tensile stresses due to restraint from creep, shrinkage, or temperature effects are to be considered to avoid uncontrolled cracks or structural failure. For residential construction within the scope of ACI CODE-332, refer to 1.4.6.

R14.1.4 Unreinforced columns and pile caps are not permitted because plain concrete lacks the necessary ductility for adequate performance. The Code does allow use of plain concrete for pedestals limited to a ratio of unsupported height to least lateral dimension of 3 or less (refer to 14.1.2(d) and 14.3.3).

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14.2—General

14.2.1 *Materials*

14.2.1.1 Design properties for concrete shall be selected to be in accordance with Chapter 19.

14.2.1.2 Steel reinforcement, if required, shall be selected to be in accordance with Chapter 20.

14.2.1.3 Materials, design, and detailing requirements for embedments in concrete shall be in accordance with 20.6.

14.2.2 *Connection to other members*

14.2.2.1 Tension shall not be transmitted through outside edges, construction joints, contraction joints, or isolation joints of an individual plain concrete element.

14.2.2.2 Walls shall be braced against lateral translation.

14.2.3 *Precast*

14.2.3.1 Design of precast members shall consider all loading conditions from initial fabrication to completion of the structure, including form removal, storage, transportation, and erection.

14.2.3.2 Precast members shall be connected to transfer lateral forces into a structural system capable of resisting such forces.

14.3—Design limits

14.3.1 *Bearing walls*

14.3.1.1 Minimum bearing wall thickness shall be in accordance with Table 14.3.1.1.

Table 14.3.1.1—Minimum thickness of bearing walls

Wall type	Minimum thickness	
General	Greater of:	5.5 in.
		1/24 the lesser of unsupported length and unsupported height
Exterior basement	7.5 in.	
Foundation	7.5 in.	

COMMENTARY

R14.2—General

R14.2.2 *Connection to other members*

R14.2.2.2 Provisions for plain concrete walls are intended only for walls laterally supported in such a manner as to prohibit relative lateral displacement at top and bottom of individual wall elements.

R14.2.3 *Precast*

R14.2.3.1 Precast structural plain concrete members are considered subject to all limitations and provisions for cast-in-place concrete contained in this chapter.

The approach to contraction or isolation joints is expected to be somewhat different than for cast-in-place concrete because the major portion of shrinkage in precast members occurs prior to erection. To ensure stability, precast members should be connected to other members. The connection should transfer no tension.

R14.3—Design limits

R14.3.1 *Bearing walls*

R14.3.1.1 Plain concrete walls are commonly used for basement wall construction for residential and light commercial buildings located in areas of low seismic risk. Although the Code imposes no absolute maximum height limitation on the use of plain concrete walls, experience with use of plain concrete in relatively minor structures should not be extrapolated to using plain concrete walls in multistory construction and other major structures where differential settlement, wind, earthquake, or other unforeseen loading conditions require the walls to possess some ductility and ability to maintain integrity when cracked. For such conditions, the Code encourages the use of walls designed in accordance with Chapter 11.

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14.3.2 *Footings*

14.3.2.1 Footing thickness shall be at least 8 in.

14.3.2.2 Base area of footing shall be determined from unfactored forces and moments transmitted by footing to soil and permissible soil pressure selected through principles of soil mechanics.

14.3.3 *Pedestals*

14.3.3.1 Ratio of unsupported height to average least lateral dimension shall not exceed 3.

14.3.4 *Contraction and isolation joints*

14.3.4.1 Contraction or isolation joints shall be provided to divide structural plain concrete members into flexurally discontinuous elements. The size of each element shall be selected to limit stress caused by restraint to movements from creep, shrinkage, and temperature effects.

14.3.4.2 The number and location of contraction or isolation joints shall be determined considering (a) through (f):

(a) Influence of climatic conditions
(b) Selection and proportioning of materials
(c) Mixing, placing, and curing of concrete
(d) Degree of restraint to movement
(e) Stresses due to loads to which an element is subjected
(f) Construction techniques

COMMENTARY

R14.3.2 *Footings*

R14.3.2.1 Thickness of plain concrete footings of usual proportions will typically be controlled by flexural strength (extreme fiber stress in tension not greater than ($\phi 5\lambda\sqrt{f_c'}$) rather than shear strength. For footings cast against soil, overall thickness h used for strength calculations is specified in 14.5.1.7.

R14.3.3 *Pedestals*

R14.3.3.1 The height-thickness limitation for plain concrete pedestals does not apply for portions of pedestals embedded in soil capable of providing lateral restraint.

R14.3.4 *Contraction and isolation joints*

R14.3.4.1 Joints in plain concrete construction are an important design consideration. In reinforced concrete, reinforcement is provided to resist the stresses due to restraint of creep, shrinkage, and temperature effects. In plain concrete, joints are the only means of controlling, and thereby relieving, the buildup of such tensile stresses. A plain concrete member should be small enough, or divided into smaller elements by joints, to control the buildup of internal stresses. The joint may be a contraction joint or isolation joint. A minimum 25 percent reduction of member thickness is typically sufficient for contraction joints to be effective. The jointing should be such that no axial tension or flexural tension can be developed by reinforcement across a joint after cracking. Where random cracking due to creep, shrinkage, and temperature effects will not affect structural integrity and is otherwise acceptable (such as transverse cracks in a continuous wall footing), transverse contraction or isolation joints are not necessary.

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14.4—Required strength

14.4.1 *General*

14.4.1.1 Required strength shall be calculated in accordance with the factored load combinations defined in Chapter 5.

14.4.1.2 Required strength shall be calculated in accordance with the analysis procedures in Chapter 6.

14.4.1.3 No flexural continuity due to tension shall be assumed between adjacent structural plain concrete elements.

14.4.2 *Walls*

14.4.2.1 Walls shall be designed for an eccentricity corresponding to the maximum moment that can accompany the axial load but not less than $0.10h$, where h is the wall thickness.

14.4.3 *Footings*

14.4.3.1 *General*

14.4.3.1.1 For footings supporting circular or regular polygon-shaped concrete columns or pedestals, it shall be permitted to assume a square section of equivalent area for determining critical sections.

14.4.3.2 *Factored moment*

14.4.3.2.1 The critical section for M_u shall be located in accordance with Table 14.4.3.2.1.

Table 14.4.3.2.1—Location of critical section for M_u

Supported member	Location of critical section
Column or pedestal	Face of column or pedestal
Column with steel base plate	Halfway between face of column and edge of steel base plate
Concrete wall	Face of wall
Masonry wall	Halfway between center and face of masonry wall

14.4.3.3 *Factored one-way shear*

14.4.3.3.1 For one-way shear, critical sections shall be located h from (a) and (b), where h is the footing thickness.

(a) Location defined in Table 14.4.3.2.1

COMMENTARY

R14.4—Required strength

R14.4.1 *General*

R14.4.1.1 Plain concrete members are proportioned for adequate strength using factored loads and forces. When the design strength is exceeded, the cross section should be increased or the specified strength of concrete increased, or both, or the member designed as a reinforced concrete member in accordance with the Code. An increase in concrete section may have a detrimental effect; stress due to load will decrease but stresses due to creep, shrinkage, and temperature effects may increase.

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(b) Face of concentrated loads or reaction areas

14.4.3.3.2 Sections between (a) or (b) of 14.4.3.3.1 and the critical section for shear shall be permitted to be designed for V_u at the critical section for shear.

14.4.3.4 *Factored two-way shear*

14.4.3.4.1 For two-way shear, critical sections shall be located so that the perimeter b_o is a minimum but need not be closer than $h/2$ to (a) through (c):

(a) Location defined in Table 14.4.3.2.1
(b) Face of concentrated loads or reaction areas
(c) Changes in footing thickness

14.4.3.4.2 For square or rectangular columns, concentrated loads, or reaction areas, the critical section for two-way shear shall be permitted to be calculated assuming straight sides.

14.5—Design strength

14.5.1 *General*

14.5.1.1 For each applicable factored load combination, design strength at all sections shall satisfy $\phi S_n \geq U$, including (a) through (d). Interaction between load effects shall be considered.

(a) $\phi M_n \geq M_u$
(b) $\phi P_n \geq P_u$
(c) $\phi V_n \geq V_u$
(d) $\phi B_n \geq B_u$

14.5.1.2 ϕ shall be determined in accordance with 21.2.

14.5.1.3 Tensile strength of concrete shall be permitted to be considered in design.

14.5.1.4 Flexure and axial strength calculations shall be based on a linear stress-strain relationship in both tension and compression.

14.5.1.5 λ for lightweight concrete shall be in accordance with 19.2.4.

14.5.1.6 No strength shall be assigned to steel reinforcement.

COMMENTARY

R14.4.3.4 *Factored two-way shear*

R14.4.3.4.1 The critical section defined in this provision is similar to that defined for reinforced concrete elements in 22.6.4.1, except that for plain concrete, the critical section is based on h rather than d.

R14.5—Design strength

R14.5.1 *General*

R14.5.1.1 Refer to R9.5.1.1.

R14.5.1.2 With no reserve strength or ductility possible due to the absence of reinforcement, equal strength reduction factors for both bending and shear are considered appropriate.

R14.5.1.3 Flexural tension may be considered in design of plain concrete members to resist loads, provided the calculated stress does not exceed the permissible stress, and construction, contraction, or isolation joints are provided to relieve resulting tensile stresses due to restraint of creep, shrinkage, and temperature effects.

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14.5.1.7 When calculating member strength in flexure, combined flexure and axial load, or shear, the entire cross section shall be considered in design, except for concrete cast against soil where overall thickness h shall be taken as 2 in. less than the specified thickness.

14.5.1.8 Unless demonstrated by analysis, horizontal length of wall to be considered effective for resisting each vertical concentrated load shall not exceed center-to-center distance between loads, or bearing width plus four times the wall thickness.

14.5.2 *Flexure*

14.5.2.1 M_n shall be the lesser of Eq. (14.5.2.1a) calculated at the tension face and Eq. (14.5.2.1b) calculated at the compression face:

$$M_n = 5\lambda\sqrt{f_c'}S_m \qquad (14.5.2.1a)$$

$$M_n = 0.85f_c'S_m \qquad (14.5.2.1b)$$

where S_m is the corresponding elastic section modulus.

14.5.3 *Axial compression*

14.5.3.1 P_n shall be calculated by:

$$P_n = 0.60f_c'A_g\left[1-\left(\frac{\ell_c}{32h}\right)^2\right] \qquad (14.5.3.1)$$

14.5.3.2 For cast-in-place deep foundation members embedded in soil capable of providing lateral support, it shall be permitted to use $\ell_c = 0$ in Eq. (14.5.3.1).

14.5.4 *Flexure and axial compression*

14.5.4.1 Unless permitted by 14.5.4.2, member dimensions shall be proportioned to be in accordance with Table 14.5.4.1, where M_n is calculated in accordance with Eq. (14.5.2.1b) and P_n is calculated in accordance with Eq. (14.5.3.1).

Table 14.5.4.1—Combined flexure and axial compression

Location	Interaction equation	
Tension face	$\frac{M_u}{S_m}-\frac{P_u}{A_g} \leq \phi 5\lambda\sqrt{f_c'}$	(a)
Compression face	$\frac{M_u}{\phi M_n}+\frac{P_u}{\phi P_n} \leq 1.0$	(b)

COMMENTARY

R14.5.1.7 The reduced overall thickness h for concrete cast against earth is to allow for unevenness of excavation and for some contamination of the concrete adjacent to the soil.

R14.5.2 *Flexure*

R14.5.2.1 Equation (14.5.2.1b) may control for nonsymmetrical cross sections.

R14.5.3 *Axial compression*

R14.5.3.1 Equation (14.5.3.1) reflects the range of braced and restrained end conditions encountered in plain concrete elements. The effective length factor was omitted as a modifier of ℓ, the vertical distance between supports, because this is conservative for walls with assumed pin supports that are required by 14.2.2.2 to be braced against lateral translation.

R14.5.3.2 Even if the soil is capable of providing lateral support against buckling, it may be necessary to consider combined flexure and axial compression when evaluating P_n. In accordance with 14.1.3, this evaluation is not permitted in SDC D, E, or F.

R14.5.4 *Flexure and axial compression*

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14.5.4.2 For walls of solid rectangular cross section where $M_u \leq P_u(h/6)$, M_u need not be considered in design and P_n is calculated by:

$$P_n = 0.45 f_c' A_g \left[1 - \left(\frac{\ell_c}{32h}\right)^2\right] \qquad (14.5.4.2)$$

14.5.5 *Shear*

14.5.5.1 V_n shall be calculated in accordance with Table 14.5.5.1.

Table 14.5.5.1—Nominal shear strength

Shear action	Nominal shear strength V_n		
One-way	$\frac{4}{3}\lambda\sqrt{f_c'}\,b_w h$		(a)
Two-way	Lesser of:	$\left(1+\frac{2}{\beta}\right)\left(\frac{4}{3}\lambda\sqrt{f_c'}\,b_o h\right)$[1]	(b)
		$2\left(\frac{4}{3}\lambda\sqrt{f_c'}\,b_o h\right)$	(c)

[1]β is the ratio of long side to short side of concentrated load or reaction area.

14.5.6 *Bearing*

14.5.6.1 B_n shall be calculated in accordance with Table 14.5.6.1.

Table 14.5.6.1—Nominal bearing strength

Relative geometric conditions	B_n		
Supporting surface is wider on all sides than the loaded area	Lesser of:	$\sqrt{A_2/A_1}(0.85 f_c' A_1)$	(a)
		$2(0.85 f_c' A_1)$	(b)
Other	$0.85 f_c' A_1$		(c)

14.6—Reinforcement detailing

14.6.1 At least two No. 5 bars shall be provided around window, door, and similarly sized openings. Such bars shall extend at least 24 in. beyond the corners of openings or shall develop f_y in tension at the corners of the openings.

COMMENTARY

R14.5.4.2 If the resultant load falls within the middle third of the wall thickness, plain concrete walls may be designed using the simplified Eq. (14.5.4.2). Eccentric loads and lateral forces are used to determine the total eccentricity of the factored axial force P_u. Equation (14.5.4.2) reflects the range of braced and restrained end conditions encountered in wall design. The limitations of 14.2.2.2, 14.3.1.1, and 14.5.1.8 apply whether the wall is proportioned by 14.5.4.1 or by 14.5.4.2.

R14.5.5 *Shear*

R14.5.5.1 Proportions of plain concrete members usually are controlled by tensile strength rather than shear strength. Shear stress (as a substitute for principal tensile stress) rarely will control. However, because it is difficult to foresee all possible conditions where shear may have to be investigated, such as shear keys, the Code requires the investigation of this basic stress condition.

The shear requirements for plain concrete assume an uncracked section. Shear failure in plain concrete will be a diagonal tension failure, occurring when the principal tensile stress near the centroidal axis becomes equal to the tensile strength of the concrete. Because the major portion of the principal tensile stress results from shear, the Code safeguards against tension failure by limiting the permissible shear at the centroidal axis as calculated for a section of homogeneous material.

Notes