number and arrangement of piles. When lateral loads due to wind or earthquake are included in the governing load combination for footings, advantage may be taken of the 25 percent reduction in required strength in accordance with Section A.2.2.

16.3—Footings supporting circular or regular polygon-shaped columns or pedestals

For location of critical sections for moment, shear, and development of reinforcement in footings, it shall be permitted to treat circular or regular polygon-shaped concrete columns or pedestals as square members with the same area.

16.4—Moment in footings

16.4.1 External moment on any section of a footing shall be determined by passing a vertical plane through the footing, and computing the moment of the forces acting over entire area of footing on one side of that vertical plane.

16.4.2 Maximum factored moment M_u for an isolated footing shall be computed as prescribed in 16.4.1 at critical sections located as follows:

(a) At face of column, pedestal, or wall, for footings supporting a concrete column, pedestal, or wall

(b) Halfway between middle and edge of wall, for footings supporting a masonry wall

(c) Halfway between face of column and edge of steel base plate, for footings supporting a column with steel base plate

16.4.3 In one-way footings, and two-way square footings, reinforcement shall be distributed uniformly across entire width of footing.

16.4.4 In two-way rectangular footings, reinforcement shall be distributed in accordance with 16.4.4.1 and 16.4.4.2.

16.4.4.1 Reinforcement in long direction shall be distributed uniformly across entire width of footing.

16.4.4.2 For reinforcement in short direction, a portion of the total reinforcement given by Eq. (16-1) shall be distributed uniformly over a band width (centered on centerline of column or pedestal) equal to the length of short side of footing. Remainder of reinforcement required in short direction, $(1 - \gamma_s)A_s$, shall be distributed uniformly outside center band width of footing.

$$\gamma_s = \frac{2}{(\beta + 1)} \qquad (16\text{-}1)$$

R16.4—Moment in footings

R16.4.4 In previous codes, the reinforcement in the short direction of rectangular footings should be distributed so that an area of steel given by Eq. (16-1) is provided in a band width equal to the length of the short side of the footing. The band width is centered about the column centerline.

The remaining reinforcement required in the short direction is to be distributed equally over the two segments outside the band width, one-half to each segment.

16.5—Shear in footings

16.5.1 Shear strength of footings shall be in accordance with 11.11.

R16.5—Shear in footings

R16.5.1 and R16.5.2 The shear strength of footings is determined for the more severe condition of 11.11.1.1 or 11.11.1.2. The critical section for shear is measured from

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16.5.2 Location of critical section for shear in accordance with Chapter 11 shall be measured from face of column, pedestal, or wall, for footings supporting a column, pedestal, or wall. For footings supporting a column or pedestal with steel base plates, the critical section shall be measured from location defined in 16.4.2(c).

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the face of supported member (column, pedestal, or wall), except for supported members on steel base plates.

Computation of shear requires that the soil reaction q_s be obtained from the factored loads and the design be in accordance with the appropriate equations of Chapter 11.

Where necessary, shear around individual piles may be investigated in accordance with 11.11.1.2. If shear perimeters overlap, the modified critical perimeter b_o should be taken as that portion of the smallest envelope of individual shear perimeter that will resist the critical shear for the group under consideration. One such situation is illustrated in Fig. R16.5.

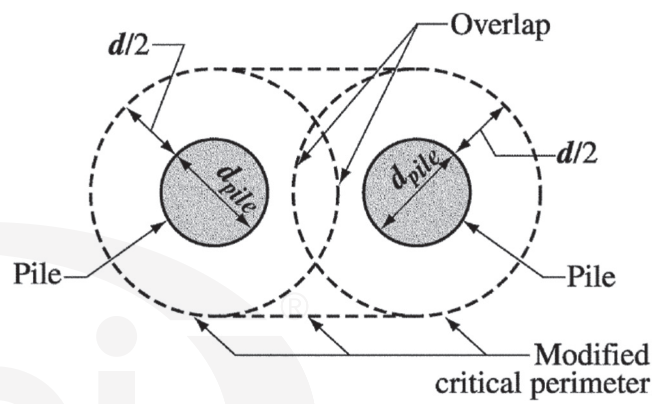

Fig. R16.5—Modified critical perimeter for shear with overlapping critical perimeters.

16.5.3 Where the distance between the axis of any pile to the axis of the column is more than two times the distance between the top of the pile cap and the top of the pile, the pile cap shall satisfy 11.11 and 16.5.4. Other pile caps shall satisfy 11.11 or 16.5.4.

R16.5.3 When piles are located inside the critical sections d or $d/2$ from face of column, for one-way or two-way shear, respectively, an upper limit on the shear strength at a section adjacent to the face of the column should be considered. The *CRSI Handbook* (CRSI 2008) offers guidance for this situation.

16.5.4 Computation of shear on any section through a footing supported on piles shall be in accordance with 16.5.4.1, 16.5.4.2, and 16.5.4.3.

16.5.4.1 Entire reaction from any pile whose center is located $d_p/2$ or more outside the section shall be considered as producing shear on that section.

16.5.4.2 Reaction from any pile whose center is located $d_p/2$ or more inside the section shall be considered as producing no shear on that section.

16.5.4.3 For intermediate positions of pile center, the portion of the pile reaction to be considered as producing shear on the section shall be based on straight-line interpolation between full value at $d_p/2$ outside the section and zero value at $d_p/2$ inside the section.

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COMMENTARY

16.6—Development of reinforcement in footings

16.6.1 Development of reinforcement in footings shall be in accordance with Chapter 12.

16.6.2 Calculated tension or compression in reinforcement at each section shall be developed on each side of that section by embedment length, hook (tension only) or mechanical device, or a combination thereof.

16.6.3 Critical sections for development of reinforcement shall be assumed at the same locations as defined in 16.4.2 for maximum factored moment, and at all other vertical planes where changes of section or reinforcement occur. Refer also to 12.8.10.6.

16.7—Minimum footing depth

Depth of footing above bottom reinforcement shall not be less than 6 in. for footings on soil, nor less than 12 in. for footings on piles.

16.8—Transfer of force at base of column, wall, or reinforced pedestal

16.8.1 Forces and moments at base of column, wall, or pedestal shall be transferred to supporting pedestal or footing by bearing on concrete and by reinforcement, dowels, and mechanical connectors.

R16.8—Transfer of force at base of column, wall, or reinforced pedestal

Section 16.8 provides the specific requirements for force transfer from a column, wall, or pedestal (supported member) to a pedestal or footing (supporting member). Force transfer should be by bearing on concrete (compressive force only) and by reinforcement (tensile or compressive force). Reinforcement may consist of extended longitudinal bars, dowels, anchor bolts, or suitable mechanical connectors.

The requirements of 16.8.1 apply to both cast-in-place construction and precast construction. Additional requirements for cast-in-place construction are given in 16.8.2. Section 16.8.3 gives additional requirements for precast construction.

16.8.1.1 Bearing on concrete at contact surface between supported and supporting member shall not exceed concrete bearing strength for either surface as given by 10.14.

R16.8.1.1 Compressive force may be transmitted to a supporting pedestal or footing by bearing on concrete. For strength design, allowable bearing stress on the loaded area is equal to $0.85\phi f_c'$ if the loaded area is equal to the area on which it is supported.

In the common case of a column bearing on a footing larger than the column, bearing strength should be checked at the base of the column and the top of the footing. Strength in the lower part of the column should be checked because the column reinforcement cannot be considered effective near the column base because the force in the reinforcement is not developed for some distance above the base, unless dowels are provided, or the column reinforcement is extended into the footing. The unit bearing stress on the column will normally be $0.85\phi f_c'$. The permissible bearing strength on the footing may be increased in accordance with 10.14 and will usually be two times $0.85\phi f_c'$. The compressive force that exceeds that developed by the permissible bearing strength at the base of the column or at the top of the footing should be carried by dowels or extended longitudinal bars.

CODE

16.8.1.2 Reinforcement, dowels, or mechanical connectors between supported and supporting members shall be adequate to transfer:

(a) All compressive force that exceeds concrete bearing strength of either member

(b) Any computed tensile force across interface

In addition, reinforcement, dowels, or mechanical connectors shall satisfy 16.8.2 or 16.8.3.

16.8.1.3 If calculated moments are transferred to supporting pedestal or footing, then reinforcement, dowels, or mechanical connectors shall be adequate to satisfy 12.9.4.

16.8.1.4 Lateral forces shall be transferred to supporting pedestal or footing in accordance with shear-friction provisions of 11.6, or by other appropriate means.

16.8.2 In cast-in-place construction, reinforcement required to satisfy 16.8.1 shall be provided either by extending longitudinal bars into supporting pedestal or footing, or by dowels.

16.8.2.1 For cast-in-place columns and pedestals, area of reinforcement across interface shall be not less than 0.005 times gross area of supported member.

16.8.2.2 For cast-in-place walls, area of reinforcement across interface shall be not less than minimum vertical reinforcement given in 15.4.

16.8.2.3 At footings, it shall be permitted to lap splice No. 14 and No. 18 longitudinal bars, in compression only, with dowels to provide reinforcement required to satisfy 16.8.1. Dowels shall not be larger than No. 11 bar and shall extend into supported member a distance not less than the larger of ℓ_{dc} of No. 14 or No. 18 bars and compression lap-splice length of the dowels, whichever is greater, and into the footing a distance not less than ℓ_{dc} of the dowels.

COMMENTARY

For the alternate design method of Appendix A, permissible bearing stresses are limited to 50 percent of the values in 10.14.

R16.8.1.2 All tensile forces, whether created by uplift, moment, or other means, should be transferred to supporting pedestal or footing entirely by reinforcement or suitable mechanical connectors. Generally, mechanical connectors would be used only in precast construction.

R16.8.1.3 If computed moments are transferred from the column to the footing, the concrete in the compression zone of the column will generally be stressed to $0.85\phi f_c'$ under factored load conditions and, as a result, all the reinforcement will generally have to be doweled into the footing.

R16.8.1.4 The shear-friction method given in 11.6 may be used to check for transfer of lateral forces to supporting pedestal or footing. Shear keys may be used, provided that the reinforcement crossing the joint satisfies 16.8.2.1, 16.8.3.1, and the shear-friction requirements of 11.6. In precast construction, resistance to lateral forces may be provided by shear-friction, shear keys, or mechanical devices.

R16.8.2.1 and R16.8.2.2 A minimum amount of reinforcement is required between all supported and supporting members to ensure ductile behavior. The Code does not require that all bars in a column be extended through and be anchored into a footing. Reinforcement with an area of 0.005 times the column area or an equal area of properly spliced dowels, however, is required to extend into the footing with proper anchorage. This reinforcement is required to provide a degree of structural integrity during the construction stage and during the life of the structure.

R16.8.2.3 Lap splices of No. 14 and No. 18 longitudinal bars in compression only to dowels from a footing are specifically permitted in 16.8.2.3. The dowel bars should be No. 11 or smaller in size. The dowel lap splice length should meet the larger of the two criteria: 1) be able to transfer the stress in the No. 14 and No. 18 bars; and 2) fully develop the stress in the dowels as a splice.

This provision is an exception to 12.9.1.2.1, which prohibits lap splicing of No. 14 and No. 18 bars. This exception results from many years of successful experience with the lap splicing of these large column bars with footing dowels of the smaller size. The reason for the restriction on dowel bar size is recognition of the anchorage length problem of the large bars, and to allow use of the smaller size dowels. A similar exception is allowed for compression splices between different size bars in 12.9.3.2.

16.8.2.4 If a pinned or rocker connection is provided in cast-in-place construction, connection shall conform to 16.8.1 and 16.8.3.

16.8.3 In precast construction, anchor bolts or suitable mechanical connectors shall be permitted for satisfying 16.8.1. Anchor bolts shall be designed in accordance with Appendix E.

16.8.3.1 Connection between precast columns or pedestals and supporting members shall meet the requirements of 17.5.1.3(a).

16.8.3.2 Connection between precast walls and supporting members shall meet the requirements of 17.5.1.3(b) and (c).

R16.8.3.1 and R16.8.3.2 For cast-in-place columns, 16.8.2.1 requires a minimum area of reinforcement equal to $\mathbf{0.005}A_g$ across the column-footing interface to provide some degree of structural integrity. For precast columns, this requirement is expressed in terms of an equivalent tensile force that should be transferred. Thus, across the joint, $A_sf_y = \mathbf{200}A_g$ (refer to 17.5.1.3(a)). The minimum tensile strength required for precast wall-to-footing connection (refer to 17.5.1.3(b)) is somewhat less than that required for columns because an overload would be distributed laterally and a sudden failure would be less likely. Because the tensile strength values of 17.5.1.3 have been arbitrarily chosen, it is not necessary to include a strength reduction factor ϕ for these calculations.

16.8.3.3 Anchor bolts and mechanical connectors shall be designed to reach their design strength before anchorage failure or failure of surrounding concrete. Anchor bolts shall be designed in accordance with Appendix E.

16.9—Sloped or stepped footings

16.9.1 In sloped or stepped footings, angle of slope or depth and location of steps shall be such that design requirements are satisfied at every section. (Refer also to 12.8.10.6.)

16.9.2 Sloped or stepped footings designed as a unit shall be constructed to assure action as a unit.

16.10—Combined footings and mats

16.10.1 Footings supporting more than one column, pedestal, or wall (combined footings or mats) shall be proportioned to resist the factored loads and induced reactions, in accordance with appropriate design requirements of this Code.

R16.10—Combined footings and mats

R16.10.1 Any reasonable assumption with respect to the distribution of soil pressure or pile reactions can be used as long as it is consistent with the type of structure and the properties of the soil, and conforms with established principles of soil mechanics (refer to 16.1). Similarly, as prescribed in 16.2.2 for isolated footings, the base area or pile arrangement of combined footings and mats should be determined using the unfactored forces, moments, or both, transmitted by the footing to the soil, considering permissible soil pressures and pile reactions.

Design methods using factored loads and strength reduction factors ϕ can be applied to combined footings or mats, regardless of the soil pressure distribution.

CODE

16.10.2 The Direct Design Method of Chapter 14 shall not be used for design of combined footings and mats.

16.10.3 Distribution of soil pressure under combined footings and mats shall be consistent with properties of the soil and the structure and with established principles of soil mechanics.

16.10.4 Minimum reinforcing steel in nonprestressed mat foundations shall meet the requirements of 12.13.1 in each principal direction. Maximum spacing shall not exceed 12 in.

COMMENTARY

Detailed recommendations for design of combined footings and mats are reported in 336.2R. Refer also to Kramrisch and Rogers (1961).

R16.10.2 Minimum reinforcing steel may be distributed near the top or bottom of the section, or may be allocated between the two faces of the section as deemed appropriate for specific conditions, such that the total area of continuous reinforcing steel satisfies 12.13.1.

Notes

CODE

CHAPTER 17—PRECAST CONCRETE

17.1—Scope

17.1.1 All provisions of this Code, not specifically excluded and not in conflict with the provisions of Chapter 17, shall apply to structures incorporating precast concrete structural members.

17.2—General

17.2.1 Design of precast members and connections shall include loading and restraint conditions from initial fabrication to end use in the structure, including form removal, storage, transportation, and erection.

17.2.2 When precast members are incorporated into a structural system, the forces and deformations occurring in and adjacent to connections shall be included in the design.

17.2.3 Tolerances for both precast members and interfacing members shall meet the requirements of ACI ITG-7

COMMENTARY

CHAPTER R17—PRECAST CONCRETE

R17.1—Scope

R17.1.1 Refer to 2.2 for definition of precast concrete.

Design and construction requirements for precast concrete structural members differ in some respects from those for cast-in-place concrete structural members, and these differences are addressed in this chapter. Where provisions for cast-in-place concrete apply to precast concrete, they have not been repeated. Similarly, items related to composite concrete in Chapter 18 and to prestressed concrete in Chapter 19 that apply to precast concrete are not restated.

More detailed recommendations concerning precast concrete are given in ACI SP-48 (*Industrialization in Concrete Building Construction* 1975), Waddell (1974), PCI (1988, 1992), ATC (1981), PCI Committee on Building Code and PCI Technical Activities Committee (1986), and ACI 550R. Tilt-up concrete construction is a form of precast concrete. It is recommended that ACI 551R be reviewed for tilt-up structures.

The provisions of this chapter are based on precast concrete members produced under plant-controlled conditions. Environmental structural elements precast at the job site will also qualify under this section if the control of form dimensions, placing of reinforcement, quality control of concrete, and curing procedures are equal to those specified in PCI's *Manual for Quality Control for Plants and Production of Precast and Prestressed Concrete Products, Fourth Edition, MNL-116-99* (PCI 1999).

R17.2—General

R17.2.1 Stresses developed in precast members during the period from casting to final connection may be greater than the service load stresses. Handling procedures may cause undesirable deformations. Care should be given to the methods of storing, transporting, and erecting precast members so that performance at service loads and strength under factored loads meet Code requirements.

R17.2.2 The structural behavior of precast members may differ substantially from that of similar members that are cast-in-place. Design of connections to minimize or transmit forces due to shrinkage, creep, temperature change, elastic deformation, differential settlement, wind, and earthquake require special consideration in precast construction. Where precast members are part of a liquid-containing structure, connections should be designed and detailed to maintain liquid tightness and should be protected from the corrosive effects of the liquid contents. In building structures that house environmental processes, the atmosphere may be wet, humid, and corrosive and the connections should be detailed and protected from the corrosive environment.

R17.2.3 Design of precast members and connections is particularly sensitive to tolerances on the dimensions of individual members and on their location in the structure.

CODE

and Chapter 15. Design of precast members and connections shall include the effects of these tolerances.

17.2.4 In addition to the requirements for contract documents in 1.2, the following shall be included in either the contract documents or shop drawings:

(a) Details of reinforcement, inserts and lifting devices required to resist temporary loads from handling, storage, transportation, and erection

(b) Required concrete strength at stated ages or stages of construction.

17.2.5 Embedded items, such as inserts or lifting devices, shall be permanently protected against corrosion.

17.3—Distribution of forces among members

17.3.1 Distribution of forces that are perpendicular to the plane of members shall be established by analysis or by test.

17.3.2 Where the system behavior requires in-plane forces to be transferred between the members of a precast floor or wall system, 17.3.2.1 and 17.3.2.2 shall apply.

17.3.2.1 In-plane force paths shall be continuous through both connections and members.

17.3.2.2 Where tension forces occur, a continuous path of steel or steel reinforcement shall be provided.

COMMENTARY

To prevent misunderstanding, the tolerances used in design should be specified in the contract documents. Instead of specifying individual tolerances, the tolerance standard assumed in design may be specified. It is important to specify any deviations from accepted standards.

The tolerances required by 12.5 are considered a minimum acceptable standard for reinforcement in precast concrete. The tolerances required by ACI ITG-7 are considered a minimum acceptable standard for product and erection tolerances in precast concrete.

R17.2.4 The additional requirements may be included in either contract documents or shop drawings, depending on the assignment of responsibility for design.

R17.2.5 Embedded items, including inserts and lifting devices, are commonly used in precast construction, and should not be left exposed to the liquid contents unless they are made from a corrosion-resistant metal suitable for the intended exposure. They are typically recessed a minimum of 1/2 in. from the face of the precast element (due to commercially available hardware), the surface is prepared, and a non-shrink, cementitious grout is used to fill the void around the embedded item. Where reduced cover exists compared to that required for reinforcement, additional corrosion-protection measures such as corrosion inhibitors, barrier coatings, or mounding of the grout should be used.

R17.3—Distribution of forces among members

R17.3.1 Concentrated point and line loads can be distributed among members, provided they have sufficient torsional stiffness and that shear can be transferred across joints. Torsionally stiff members such as hollow-core or solid slabs have more favorable load distribution properties than do torsionally flexible members such as double tees with thin flanges. The actual distribution of the load depends on many factors discussed in detail in LaGue (1971), Johnson and Ghadiali (1972), Pfeifer and Nelson (1983), Stanton (1987, 1992), PCI (1985b), and Aswad and Jacques (1992). Large openings can cause significant changes in distribution of forces.

R17.3.2 In-plane forces result primarily from diaphragm action in floors and roofs, causing tension or compression in the chords and shear in the body of the diaphragm. A continuous path of steel, steel reinforcement, or both, using lap splices, mechanical or welded splices, or mechanical connectors, should be provided to carry the tension, whereas the shear and compression may be carried by the net concrete section. A continuous path of steel through a connection includes bolts, weld plates, headed studs, or other steel devices. Tension forces in the connections are to be transferred to the primary reinforcement in the members.

In-plane forces in precast wall systems result primarily from diaphragm reactions and external lateral loads.

Connection details should provide for the forces and deformations due to shrinkage, creep, and thermal effects. Connection details may be selected to accommodate volume changes and rotations caused by temperature gradients and long-term deflections. When these effects are restrained, connections and members should be designed to provide adequate strength and ductility.

17.4—Member design

17.4.1 In one-way precast floor and roof slabs and in one-way precast, prestressed wall panels, all not wider than 12 ft, and where members are not mechanically connected to cause restraint in the transverse direction, the shrinkage and temperature reinforcement requirements of 12.13 in the direction normal to the flexural reinforcement shall be permitted to be waived. This waiver shall not apply to members that require reinforcement to resist transverse flexural stresses.

R17.4—Member design

R17.4.1 For prestressed concrete members not wider than 12 ft, such as hollow-core slabs, solid slabs, or slabs with closely spaced ribs, there is usually no need to provide transverse reinforcement to withstand shrinkage and temperature stresses in the short direction. This is generally true also for nonprestressed floor and roof slabs. The 12 ft width is less than that in which shrinkage and temperature stresses can build up to a magnitude requiring transverse reinforcement. In addition, much of the shrinkage occurs before the members are tied into the structure. Once in the final structure, the members are usually not as rigidly connected transversely as monolithic concrete; thus, the transverse restraint stresses due to both shrinkage and temperature change are significantly reduced.

The waiver does not apply to members such as single and double tees with thin, wide flanges.

For prestressed concrete members or slabs tied together with a grout or concrete topping, shrinkage and temperature nonprestressed reinforcement in the topping should be provided in accordance with the requirements of cast-in-place concrete.

17.4.2 For precast, nonprestressed walls, the reinforcement shall be designed in accordance with the provisions of Chapters 10 or 15, except that the area of horizontal and vertical reinforcement each shall not be less than $\mathbf{0.001}\boldsymbol{A_g}$, where $\boldsymbol{A_g}$ is the gross cross-sectional area of the wall panel, instead of the minimum reinforcement areas for walls stated in 15.3. Spacing of reinforcement shall not exceed 12 in.

R17.4.2 This minimum area of wall reinforcement, instead of the minimum values in 15.3, has been used for many years and is recommended by the PCI (1992), CSA A23.3, and CSA A23.4. The provisions for reduced minimum reinforcement and greater spacing recognize that precast wall panels have very little restraint at their edges during early stages of curing and develop less shrinkage stress than comparable cast-in-place walls.

17.5—Structural integrity

17.5.1 Except where the provisions of 17.5.2 govern, the minimum provisions of 17.5.1.1 through 17.5.1.4 for structural integrity shall apply to all precast concrete structures.

R17.5—Structural integrity

R17.5.1 The provisions of 12.14.3 apply to all precast concrete structures. Sections 17.5.1 and 17.5.2 give minimum requirements to satisfy 12.14.3. It is not intended that these minimum requirements override other applicable provisions of the Code for design of precast concrete structures.

The overall integrity of a structure can be substantially enhanced by minor changes in the amount, location, and detailing of member reinforcement and in the detailing of connection hardware.