Chapter 7

FOUNDATION DESIGN REQUIREMENTS

7.1 GENERAL: This chapter includes only those foundation requirements that are specifically related to seismic resistant construction. It assumes compliance with all other basic requirements. These requirements include, but are not limited to, requirements for the extent of the foundation investigation, fills to be present or to be placed in the area of the *structure*, slope stability, subsurface drainage, and settlement control. Also included are pile requirements and capacities and bearing and lateral soil pressure recommendations. Except as specifically noted, where the term "pile" is used in Sec. 7.4.4 and 7.5.4, it shall include all foundation piers, caissons, and piles. The term "pile cap" shall include all elements to which piles are connected, including grade beams and mats.

7.2 STRENGTH OF COMPONENTS AND FOUNDATIONS: The resisting capacities of the foundations, subjected to the prescribed *seismic forces* of Chapters 1, 4 and 5, shall meet the requirements of this chapter.

7.2.1 Structural Materials: The *strength* of foundation *components* subjected to *seismic forces* alone or in combination with other prescribed loads and their detailing requirements shall conform to the requirements of Chapter 8, 9, 10, 11, or 12. The *strength* of foundation *components* shall not be less than that required for forces acting without *seismic forces*.

7.2.2 Soil Capacities: The capacity of the foundation soil in bearing or the capacity of the soil interface between pile, pier, or caisson and the soil shall be sufficient to support the *structure* with all prescribed loads, without *seismic forces*, taking due account of the settlement that the *structure* can withstand. For the load combination including earthquake as specified in Sec. 5.2.7, the soil capacities must be sufficient to resist loads at acceptable strains considering both the short duration of loading and the dynamic properties of the soil.

7.3 SEISMIC DESIGN CATEGORIES A AND B: Any construction meeting the requirements of Sec. 7.1 and 7.2 is permitted to be be used for *structures* assigned to *Seismic Design Category* A or B.

7.4 SEISMIC DESIGN CATEGORY C: Foundations for *structures* assigned to *Seismic Design Category* C shall conform to all of the requirements for *Seismic Design Categories* A and B and to the additional requirements of this section.

7.4.1 Investigation: The authority having jurisdiction may require the submission of a written report that shall include, in addition to the requirements of Sec. 7.1 and the evaluations required in Sec. 7.2.2, the results of an investigation to determine the potential hazards due to slope instability, liquefaction, and surface rupture due to faulting or lateral spreading, all as a result of earthquake motions.

7.4.2 Pole-Type Structures: Construction employing posts or poles as columns embedded in earth or embedded in concrete footings in the earth are permitted to be used to resist both axial and lateral loads. The depth of embedment required for posts or poles to resist *seismic forces* shall be determined by means of the design criteria established in the foundation investigation report.

7.4.3 Foundation Ties: Individual pile caps, drilled piers, or caissons shall be interconnected by ties. All ties shall be capable of carrying, in tension or compression, a force equal to the product of the larger pile cap or column load times S_{DS} divided by 10 unless it can be demonstrated that equivalent restraint can be provided by *reinforced concrete* beams within slabs on grade or *reinforced concrete* slabs on grade or confinement by competent rock, hard cohesive soils, very dense granular soils, or other approved means.

7.4.4 Special Pile Requirements: The following special requirements for piles, piers, or caissons are in addition to all other requirements in the code administered by the authority having jurisdiction.

All concrete piles and concrete filled pipe piles shall be connected to the pile cap by embedding the pile reinforcement in the pile cap for a distance equal to the development length as specified in ACI 318 as modified by Chapter 9 of the *Provisions*. The pile cap connection can be made by the use of field-placed dowel(s) anchored in the concrete pile. For deformed bars, the development length is the full development length for compression or tension, in the case of uplift, without reduction in length for excess area.

Ends of rectangular hoops, spirals, and ties in piles shall be terminated with seismic hooks as defined in Sec. 21.1 of ACI 318 turned into the confined concrete core. The ends of circular spirals and hoops shall be terminated with 90-degree hooks turned into the confined concrete core.

For resistance to uplift forces, anchorage of steel pipe (round HSS sections), concrete filled steel pipe or H piles to the pile cap shall be made by means other than concrete bond to the bare steel section.

> **Exception:** Anchorage of concrete filled steel pipe piles is permitted to be accomplished using deformed bars developed into the concrete portion of the pile.

Where a minimum length for reinforcement or the extent of closely spaced confinement reinforcement is specified at the top of the pile, provisions shall be made so that those specified lengths or extents are maintained after pile cut-off.

7.4.4.1 Uncased Concrete Piles: A minimum reinforcement ratio of 0.0025 shall be provided for uncased cast-in-place concrete drilled or augured piles, piers, or caissons in the top one-third of the pile length, a minimum length of 10 ft (3 m) below the ground, or throughout the flexural length of the pile, whichever length is greatest. There shall be a minimum of four bars with closed ties (or equivalent spirals) of a minimum of a 3/8 in. (9 mm) diameter provided at 16 longitudinal-bar-diameter maximum spacing. A maximum spacing of 6 in. (152mm) or eight longitudinal-bar-diameters, whichever is less, shall be provided in the pile within three pile diameters of the bottom of the pile cap.

7.4.4.2 Metal-Cased Concrete Piles: Reinforcement requirements are the same as for uncased concrete piles.

> **Exception:** Spiral welded metal-casing of a thickness not less than No. 14 gauge can be considered as providing concrete confinement equivalent to the closed ties or equivalent spirals required in an uncased concrete pile, provided that the metal casing is adequately protected against possible deleterious action due to soil constituents, changing water levels, or other factors indicated by boring records of site conditions.

7.4.4.3 Concrete-Filled Pipe: Minimum reinforcement 0.01 times the cross-sectional area of the pile concrete shall be provided in the top of the pile with a length equal to two times the required cap embedment anchorage into the pile cap.

7.4.4.4 Precast (non-prestressed) Concrete Piles: Longitudinal reinforcement shall be provided for precast concrete piles with a minimum steel ratio of 0.01. The longitudinal reinforcing shall be confined with closed ties or equivalent spirals of a minimum 3/8 in. (10mm) diameter. Transverse confinement reinforcing shall be provided at a maximum spacing of eight times the diameter of the smallest longitudinal bar, but not to exceed 6 inches (152 mm), within three pile diameters of the bottom of the pile cap. Outside of the confinement region, closed ties or equivalent spirals shall be provided at a 16 longitudinal-bar-diameter maximum spacing, but not greater than 8 in. (200 mm). Longitudinal reinforcement shall be full length.

7.4.4.5 Precast-Prestressed Piles: The minimum volumetric ratio of spiral reinforcement shall not be less than 0.007 or the amount required by the following formula for the upper 20 ft (6 m)of the pile:

$$\rho_s = \frac{0.12 f'_c}{f_{yh}} \qquad (7.4.4.5\text{-}1)$$

where:

ρ_s = spiral reinforcement index (vol. spiral/ vol. core)

f_c' = specified compressive strength of concrete, psi (Mpa), and

f_{yh} = yield strength of spiral reinforcement, which shall not be taken greater than 85,000 psi (586 MPa).

Below the 20 ft (6 m) length, provide at least one-half the volumetric ratio provided by Eq, 7.4.4.5-1.

7.5 SEISMIC DESIGN CATEGORIES D, E, AND F: Foundations for *structures* assigned to *Seismic Design Categories* D, E, and F shall conform to all of the requirements for *Seismic Design Category* C construction and to the additional requirements of this section. Design and construction of concrete foundation *component*s shall conform with the requirements of ACI 318, Sec. 21.8, except as modified by the requirements of this section.

Exception: Detached one and two family dwellings of light frame construction not exceeding two stories in height above grade need only comply with the requirements of Sec.7.4 and Sec. 7.5.3.

7.5.1 Investigation: The *owner* shall submit to the authority having jurisdiction a written report that includes an evaluation of potential site hazards such as slope instability, liquefaction, and surface rupture due to faulting or lateral spreading and the determination of lateral pressures on *basement* and retaining *walls* due to earthquake motions.

7.5.2 Foundation Ties: Individual spread footings founded on soil defined in Sec. 4.1.2 as *Site Class* E or F shall be interconnected by ties. Ties shall conform to Sec. 7.4.3.

7.5.3 Liquefaction Potential and Soil Strength Loss: The geotechnical report shall assess potential consequences of any liquefaction and soil *strength* loss, including estimation of differential settlement, lateral movement or reduction in foundation soil-bearing capacity, and shall discuss mitigation measures. Such measures shall be given consideration in the design of the *structure* and can include, but are not limited to, ground stabilization, selection of appropriate foundation type and depths, selection of appropriate structural systems to accommodate anticipated displacements, or any combination of these measures.

The potential for liquefaction and soil *strength* loss shall be evaluated for site peak ground accelerations, magnitudes, and source characteristics consistent with the *design earthquake* ground motions. Peak ground acceleration is permitted to be determined based on a site-specific study taking into account soil amplification effects or, in the absence of such a study, peak ground accelerations shall be assumed equal to $S_{DS}/2.5$.

7.5.4 Special Pile and Grade Beam Requirements: Piling shall be designed and constructed to withstand maximum imposed curvatures from earthquake ground motions and *structure* response. Curvatures shall include free-field soil strains (without the *structure*) modified for soil-pile interaction coupled with pile deformations induced by lateral pile resistance to *structure seismic forces*. Concrete piles in *Site Class* E or F shall be designed and detailed in accordance with Sec. 21.4.4.1, 21.4.4.2, and 21.4.4.3 of ACI 318 within seven pile diameters of the pile cap and the interfaces of soft to medium stiff clay or liquefiable strata. For precast prestressed concrete piles, detailing provisions as given in Sec. 7.5.4.4 shall apply.

Section 21.8.3.3 of ACI 318 need not apply when grade beams have the required strength to resist the forces from the load combinations of Section 5.2.7.1. Section 21.8.4.4(a) of ACI 318 need not apply to concrete piles. Section 21.8.4.4(b) of ACI 318 need not apply to precast prestressed concrete piles.

Design of anchorage of piles into the pile cap shall consider the combined effect of axial forces due to uplift and bending moments due to fixity to the pile cap. For piles required to resist uplift forces or provide rotational restraint, anchorage into the pile cap shall be capable of developing the following:

1. In the case of uplift, the lesser of the nominal tensile strength of the longitudinal reinforcement in a concrete pile, or the nominal tensile strength of a steel pile, or the pile uplift soil nominal strength factored by 1.3, or the axial tension force resulting from the load combinations of Sec. 5.2.7.1.

2. In the case of rotational restraint, the lesser of the axial and shear forces, and moments resulting from the load combinations of Section 5.2.7.1 or development of the full axial, bending, and shear nominal strength of the pile.

Splices of pile segments shall develop the nominal strength of the pile section, but the splice need not develop the nominal strength of the pile in tension, shear, and bending when it has been designed to resist axial and shear forces, and moments from the load combinations of Sec. 5.2.7.1.

Pile moments, shears, and lateral deflections used for design shall be established considering the interaction of the shaft and soil. Where the ratio of the depth of embedment of the pile-to-the-pile diameter or width is less than or equal to 6, the pile may be assumed to be rigid with respect to the soil.

Pile group effects from soil on lateral pile nominal strength shall be included where pile center-to-center spacing in the direction of the lateral force is less than eight pile diameters. Pile group effects on vertical nominal strength shall be included where pile center-to-center spacing is less than three pile diameters. The pile uplift soil nominal strength shall be taken as the pile uplift strength as limited by the frictional force developed between the soil and the pile.

The connection between batter piles and grade beams or pile caps shall be designed to resist the full strength of the pile acting as a short column. Batter piles shall be capable of resisting forces and moments from the load combinations of Sec. 5.2.7.1.

7.5.4.1 Uncased Concrete Piles: A minimum longitudinal reinforcement ratio of 0.005 shall be provided for uncased cast-in-place drilled or augured concrete piles, piers, or caissons in the top one-half of the pile length, a minimum length of 10 ft (3 m) below ground, or throughout the flexural length of the pile, whichever length is greatest. The flexural length shall be taken as the length of pile to a point where the concrete section cracking moment multiplied by the resistance factor 0.4 exceeds the required factored moment at that point. There shall be a minimum of four longitudinal bars with transverse confinement reinforcing provided in the pile in accordance with Sec. 21.4.4.1, 21.4.4.2, and 21.4.4.3 of ACI 318 within three pile diameters of the bottom of the pile cap.

It shall be permitted to use a transverse spiral reinforcing ratio of not less than one-half of that required in Sec. 21.4.4.1(a) of ACI 318 for other than Class E, F, or liquefiable sites. Tie spacing of longitudinal bars throughout the remainder of the pile length shall not exceed 12 longitudinal bar diameters, one-half the diameter of the section, or 12 inches (305 mm). Ties shall be a minimum of No. 3 bars for up to 20-in.-diameter (500 mm) piles and No. 4 bars for piles of larger diameter.

7.5.4.2 Metal-Cased Concrete Piles: Reinforcement requirements are the same as for uncased concrete piles.

> **Exception:** Spiral welded metal-casing of a thickness not less than No. 14 gauge can be considered as providing concrete confinement equivalent to the closed ties or equivalent spirals required in an uncased concrete pile, provided that the metal casing is adequately protected against possible deleterious action due to soil constituents, changing water levels, or other factors indicated by boring records of site conditions.

7.5.4.3 Precast (non-prestressed) Concrete Piles: Transverse confinement reinforcing of closed ties or equivalent spirals shall be provided in accordance with Sec. 21.4.4.1, 21.4.4.2, and 21.4.4.3 of ACI 318 within three pile diameters of the bottom of the pile cap. It shall be permitted to use a transverse spiral reinforcing ratio of not less than one-half of that required in Sec. 21.4.4.1(a) of ACI 318 for other than Class E, F, or liquefiable sites.

7.5.4.4 Precast-Prestressed Piles: The requirements of ACI 318 need not apply unless specifically referenced.

Where the total pile length in the soil is 35 ft (10.7 m) or less, transverse confinement reinforcement shall be provided throughout the length of the pile. Where the pile length exceeds 35 ft (10.7 m), transverse confinement reinforcement shall be provided for the greater of 35 ft (10.7 m) or the distance from the underside of the pile cap to the point of zero curvature plus three times the least pile dimension.

The transverse confinement reinforcement shall be spiral or hoop reinforcement with a center-to-center spacing not greater than one-fifth of the least pile dimension, six times the diameter of the longitudinal tendons, or 8 in. (203mm), whichever is smaller.

Circular spiral reinforcement shall be spliced by lapping one full turn and bending the end of the spiral to a 90-degree hook or by use of a mechanical or welded splice complying with Sec. 12.14.3 of ACI 318. Where the transverse confinement reinforcement consists of circular spirals, the volumetric ratio of spiral transverse reinforcement shall comply with:

$$\rho_s = 0.25\left(\frac{f_c'}{f_{yh}}\right)\left(\frac{A_g}{A_{ch}} - 1.0\right)\left(0.5 + \frac{1.4P}{f_c' A_g}\right) \qquad (7.5.4.4\text{-}1)$$

but not less than

$$\rho_s = 0.12\left(\frac{f_c'}{f_{yh}}\right)\left(0.5 + \frac{1.4P}{f_c' A_g}\right) \qquad (7.5.4.4\text{-}2)$$

and need not exceed $\rho_s = 0.021$ where:

ρ_s = spiral reinforcement index (vol. spiral/ vol. core),

f_c' = specified compressive strength of concrete, psi (MPa),

f_{yh} = yield strength of spiral reinforcement, which shall not be taken as greater than 85,000 psi (586 MPa),

A_g = pile cross-sectional area,

A_{ch} = core area defined by spiral outside diameter, and

P = axial load on pile resulting from the load combinations of Sec. 5.2.7

The required amount of spiral reinforcement shall be permitted to be obtained by providing an inner and outer spiral.

When transverse confinement reinforcement consists of rectangular hoops and cross ties, the total cross-sectional area of lateral transverse reinforcement in the ductile region with spacing s and perpendicular to dimension h_c shall conform to:

$$A_{sh} = 0.12\, sh_c \left(\frac{f'_c}{f_{yh}} \right) \left(\frac{A_g}{A_{ch}} - 1 \right) \left(0.5 + \frac{1.4P}{f'_c A_g} \right) \qquad (7.5.4.4\text{-}3)$$

but not less than

$$A_{sh} = 0.12\, sh_c \left(\frac{f'_c}{f_{yh}} \right) \left(0.5 + \frac{1.4P}{f'_c A_g} \right) \qquad (7.5.4.4\text{-}4)$$

where

s = spacing of transverse reinforcement measured along length of pile,

h_c = cross-sectional dimension of pile core measured center to center of hoop reinforcement,

f_c' = specified compressive strength of concrete, psi (Mpa), and

f_{yh} = yield strength of transverse confinement reinforcement which shall not be taken as greater than 70,000 psi (483 MPa).

The hoops and cross ties shall be equivalent to deformed bars not less than No.3 in size. Rectangular hoop ends shall terminate at a corner with seismic hooks.

Outside of the length of the pile requiring transverse confinement reinforcing, the spiral or hoop reinforcing with a volumetric ratio not less than one-half of that required for transverse confinement reinforcing shall be provided.

7.5.4.5 Steel Piles: The connection between the pile cap and steel piles or unfilled steel pipe piles shall be designed for a tensile force no less than 10 percent of the pile compression capacity.

> **Exception:** The pile connection need not meet this requirement where it can be demonstrated that the pile connection has the strength to resist the axial forces and moments resulting from the load combinations of Sec. 5.2.7.1.