Confinement Reinforcement Requirements for Concrete Piles

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The origins of confinement reinforcement requirements—specifically, circular spiral for square, octagonal, or circular concrete piles—have long been somewhat of a mystery. The outcome has been a myriad of prescriptive rules, which vary widely depending on the code, standard, or specification applicable to a project. The graph below shows the historical variability of some of these prescriptive requirements for 24-in.-octagonal prestressed concrete piles. Inexplicably, the requirements also vary significantly depending on whether the piles are cast-in-place or precast concrete and driven. These provisions affect the size, spacing, and depth below the pile head where varying quantities of spiral reinforcement are required. Clearly, these provisions significantly affect the cost of piles. This article reviews the status of recent research and its applicability to concrete piles.

Background

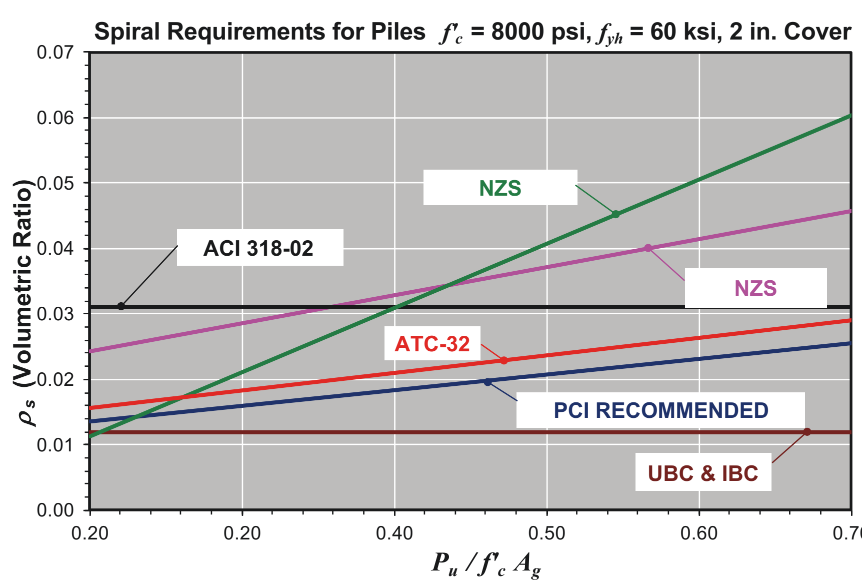
The primary purposes of spiral reinforcement are to provide confinement to the pile concrete core so that it behaves in a ductile manner under combinations of axial and lateral loads, to provide support to restrain bucking of nonprestressed longitudinal reinforcement, and to provide adequate shear strength. The lateral loads imposed by earthquakes are of great concern. Therefore, the spiral reinforcement requirements naturally escalate as the Seismic Design Category (SDC) increases.

Spiral reinforcement in high SDCs, sized in accordance with current requirements, can become very heavy, and, in some cases, may be unconstructable, particularly for smaller pile sizes. For driven piles, the spiral also confines the concrete at the head and tip to mitigate bursting during driving. Mild steel driving rings have also been used for this purpose.

In 1993, the Precast/Prestressed Concrete Institute (PCI) published its "Recommended Practice for Design, Manufacture, and Installation of Prestressed Concrete Piling" (RP).[1] This document provided equations for determining spiral volumetric ratios in moderate and high seismic regions, based primarily on research performed in New Zealand by Joen and Park.[2] However, the equation in the PCI RP for high seismic regions provided roughly half of the spiral volumetric ratio recommended by the New Zealand research shown in the graph. This PCI equation was proposed in the apparent belief that half of the target ductility sought by the New Zealand researchers would be sufficient for high seismic regions in the United States, although the reason for this conclusion is not clear. The PCI RP equation was adopted in the 2000 edition of the International Building Code (IBC); however, IBC 2000 maintained the upper limits on volumetric ratio from previous editions.[3] Chapter 20 of the *PCI Bridge Design Manual*[4] recommends the full volumetric ratio of spiral resulting from the New Zealand research, although this recommendation has not been adopted into American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*.[5]

Iowa State University Research

In light of the uncertainty surrounding prescriptive requirements for spiral reinforcement, PCI funded a research project in 2006 at Iowa State University to develop a rational means of determining spiral volumetric ratios in prestressed concrete piles. The results of this research were detailed in a final report,[6] and a summary was published in the *PCI Journal*.[7] A single equation is proposed to quantify spiral volumetric ratios depending on target curvature ductility. A value of target curvature ductility is suggested for high seismic regions based on a review of literature published on pile testing and a



Variability of spiral reinforcement requirements based on axial load level for 24-in.-octagonal prestressed concrete piles. Note: ATC = Applied Technology Council; NZS = New Zealand Standard. All Figures and Photos: Concrete Technology Corporation.

Driving 24-in.-octagonal prestressed concrete piles at Pier 4, Port of Tacoma, Wash.

"back-end" analysis of piles subjected to actual earthquakes. Lower values of target curvature ductility are also suggested for low and moderate seismic regions. Values of target curvature ductility other than those suggested, such as those derived from a performance-based analysis, can also be used.

The research establishes axial load limits for different sizes and shapes of prestressed concrete piles. The purpose of these limits is to ensure that, under combined axial load and moment, the pile cracks before the concrete cover spalls. When the opposite is true, the decrease in moment capacity due to concrete cover spalling is significant, and the pile does not behave as intended.

The 2018 edition of the IBC adopted these recommendations in place of the previous PCI RP provisions, while maintaining the same upper limits on volumetric ratio provided in previous editions.[8]

The American Concrete Institute (ACI) Committee 318 intends to adopt requirements for deep foundations in the 2019 edition of *Building Code Requirements for Structural Concrete* (*ACI 318-19*). Historically, ACI 318 has not included provisions for piles, unless portions of the pile are not adequately laterally restrained by stiff soil, and for SDCs D, E, and F. Even then, with the exception of provisions related to seismic detailing, no specific provisions existed for piles, which were essentially to be designed under the same rules as columns. Provisions in the AASHTO LRFD specifications for confinement reinforcement in piles are similar to the ACI 318 provisions for columns. ACI Committee 318 is currently balloting provisions for piles similar to those in the 2018 IBC. AASHTO Subcommittee T-10 on Concrete Design should also consider revisions to the AASHTO LRFD specifications to incorporate the most recent research on concrete pile confinement reinforcement.

Precast, Prestressed Concrete Piles versus Cast-in-Place Piles

As mentioned in the opening paragraph of the article, spiral reinforcement requirements vary significantly depending on the type of concrete pile selected. Most of these differences are inexplicable given that different types of concrete piles should be expected to perform similarly under the same conditions. Also, differences that should be considered between the pile types, such as susceptibility to downdrag, cross-sectional tolerances, and tolerances for placement of reinforcement, are generally not considered in prescriptive design provisions for buildings. Such differences should result in higher resistance factors for precast concrete piles than for cast-in-place piles, as is the case for bridge construction. Mays provides an excellent discussion of these aspects of concrete pile design and detailing.[9]

Because time is of the essence for the 2019 release of ACI 318, it is not possible for these differences to be remedied for ACI 318-19. As a member of ACI Committee 318, the author has requested that these discrepancies be taken up as new business in the next code cycle.

Unloading of 24-in.-octagonal prestressed concrete piles on barge at Pier 4, Port of Tacoma, Wash.

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