



# Design of Prestressed Concrete Piles for Seismic Loads Adds a New Dimension

McLeod C. Nigels, P.E. FPCI Senior Associate Davis & Floyd, Inc.

The design of piling in the Charleston, S.C. Area has become more focused on seismic design with the advent of the International Building Code.<sup>1</sup> Regardless of the type of pile selected, design involves a greater awareness of the need for ductility in pile foundations. In years past, the selection and design of piles for use in building foundations has been a simple process in which standard designs were considered for vertical loads. The selection of piles simply meant estimating gravity loads and dividing those loads by allowable axial loads on piles. The piles used were generally 10" square. Lateral loads due to wind or earthquake were taken by providing batter piles. It was general practice to assume that the reactions from lateral loads became axial loads on the batter piles, so piles were not assumed to be subjected to bending moments.

A presentation by Margason<sup>2</sup> in 1977 called attention to the fact that batter piles fared poorly in recent San Francisco earthquakes. If batter piles were not to be used in cases where they had been used in the past, vertical piles were to be called upon to provide enough bending moment capacity to provide lateral resistance. This required piles to be

Table 1: section properties and allowable concentric loads for the three commonly available building foundation piles.						
Size (Inches)	Area (Sq. In.)	Prestress Strands	Effective Prestress	Allowable Axial Load In Tons F'c		
				5000	6000	7000
10	100	4-7/16"	804	71	88	104
12	144	4-1/2"	750	104	128	151
14	196	6-1/2"	819	140	172	204

Figure 1.

stronger and, as a result, piles became larger. Whereas piles were 10" square, they are now generally 12" or 14".

Larger piles are often used in bridge and marine construction but these larger piles require heavier handling and driving equipment than that generally found at building construction sites.

Fig. 1 provides a table showing section properties and allowable concentric loads for the three commonly available building foundation piles. The table also includes a list of the commonly used prestress strand for each pile with the corresponding calculated effective prestress after losses.

Along with greater need for bending capacity, the analysis of piles for

seismic loads indicated the need for greater ductility. Research performed and articles written indicated the need for greater confinement of the "core" of the pile in order to provide greater ductility. The "core" is defined as the central portion of the pile cross section defined by the spiral. Sheppard<sup>3</sup> reported on research done regarding the behavior of prestressed concrete piles subjected to curvatures similar to those to which piles are subjected to during an earthquake. A method to analyze flexural strength and ductility by increasing the spiral reinforcing is presented in a paper by Joen and Park<sup>4</sup>. The results of research conducted in New Zealand are summarized by a later

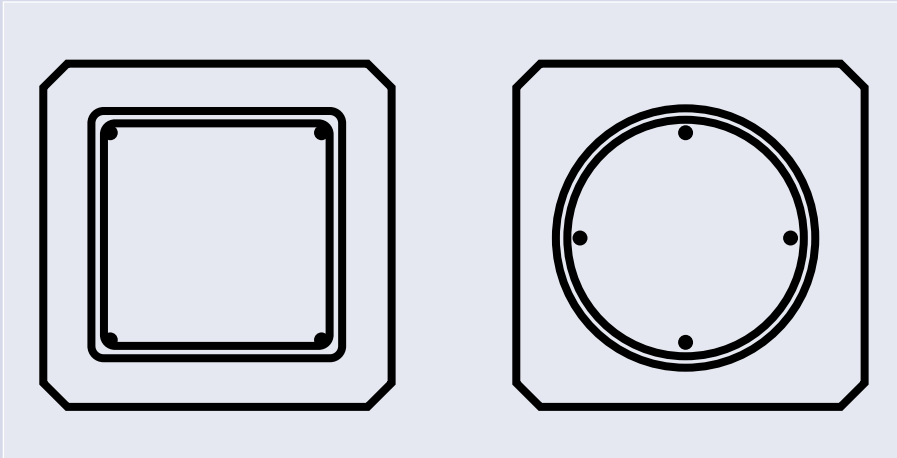


Figure 2.

paper by Joen and Park<sup>5</sup>. Fig. 2 shows typical cross sections of piles, both with square and circular spiral.

### Typical Sections through Piles

Circular spiral wire is generally much larger than the W3.4 wire formerly used as standard spiral. Seismic spiral is circular because of the desire to use the spiral in direct hoop tension to confine the core. (In addition, it becomes impractical to attempt to bend the larger wire in a square).

The upper portion of a pile surrounded by soil and subjected to seismic loads is referred to as the “ductile zone”. The IBC requires that the ductile zone be at least the upper 35 ft. of the pile and that the spiral ratio in this region meet certain criteria. A series of equations is provided and the spiral ratio is required to equal certain minimums. The spiral in the lower portion of the pile, below the ductile region is required to be equal to half that required within the ductile zone. Therefore it is usual practice to provide a spiral pitch throughout the lower portion of the pile twice that provided in the ductile zone.

In 12” square piles it has become the usual practice to provide seismic spiral in the ductile zone consisting of W10 wire at 2” pitch. W10 Wire has a diameter of 0.34-in, close to 3/8”. 14” square piles are usually provided with

W12 Wire at 2” pitch within the ductile region. Such heavy wire is a much more important portion of the cost of a prestressed concrete pile than the W3.4 wire was in days gone by before seismic design was considered. Not only is the cost of the wire a concern, but the congestion caused by the closely spaced wire in the form is of primary concern as well. Whereas a contractor casting concrete in a building column has to cast concrete down both sides of a column spiral, the pre-caster is faced with the task of casting through two layers of confinement reinforcement along the length of the form. Fig. 3 illustrates congestion when 12” square piles are prestressed using 6 strands and reinforced using W10 Wire spiral @ 2” pitch.

### Pile Connections

In the design of pile foundations, piles often are required to be designed for uplift or fixity at the head of the pile. The Code (1808.2.23.1.1) requires reinforcing at the interface between the pile and the pile cap. Reinforcing for this usage can consist of prestressing strand and/or mild steel reinforcing. The four usual options are:

- 1) Cast the pile longer than required, with mild steel added if necessary. Cut the top of the pile off after driving, exposing the strands and/or dowels.



Photo courtesy Palmetto Pile Driving

Figure 3.

- 2) Cast dowels extending from the pile head. Cut holes in the driving helmet or spud so that the helmet or spud can fit over the extending dowels.
- 3) Drill dowel holes in the pile after driving and grout dowels into the holes.
- 4) Cast dowel holes in the pile and grout dowels into the dowel holes after driving.

In this area, the generally accepted practice is to cast dowel holes. This avoids the necessity of cutting off the top of the pile as required under (1), cutting holes in the driving head under (2), or field-drilling dowel holes as required under (3) above.

The dowel hole is generally formed with spiral metal tubing similar to that used in post tensioning sheathing.

The selection of the diameter and length of the dowel hole depends upon the size of the dowel required. The length must accommodate the development length of the dowel and, usually, the development length of the strand. Fig. 4 illustrates design considerations.

The size and number of dowel holes that can be safely provided at the head of a pile must be limited. If

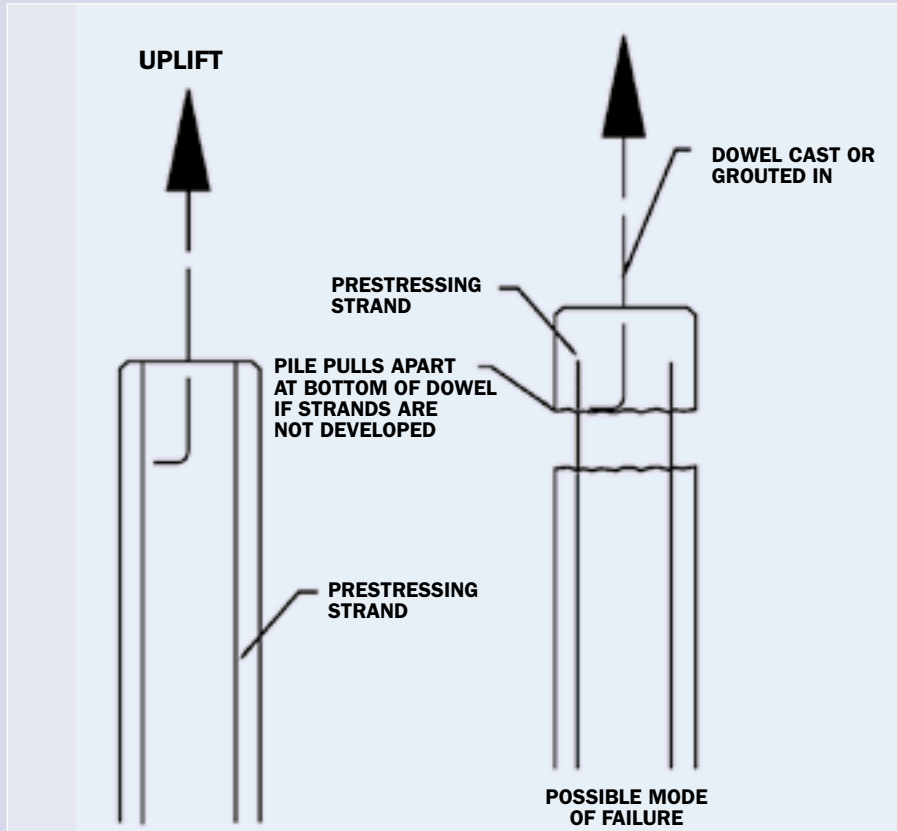


Figure 4.

the cross section of the pile is excessively reduced and hard driving is encountered, the result can be damage to the pile due to driving stresses. In the case of 10" piles, experience has shown that the number of dowel holes must be limited to two. For other piles, as a general rule of thumb, the cross


section should not be reduced more than approximately 6 percent. Most dowel holes are 1¾" dia. for smaller piles and 2" dia. for others. The number of dowel holes provided in 12" and 14" piles is generally limited to four.

A paper<sup>6</sup> by the author discusses the design of dowel connections for uplift.

The design of piles to resist lateral loads due to earthquake has changed the design of pile foundations. However, even with the increased cost due to seismic spiral, prestressed concrete piles remain the piling of choice in the local area as they have been for more than forty years. ▼

### References

- <sup>1</sup> 2003 International Building Code. International Code Council, 5203 Leesburg Pike, Suite 708, Falls Church, VA 22041-3401
- <sup>2</sup> Margason, E., "Earthquake Effects on Embedded Pile Foundations", Associated Pile & Fitting Corp., PILETALK Seminar, San Francisco, California, March 1977.
- <sup>3</sup> Sheppard, D.A., "Seismic Design of Prestressed Concrete Piling," PCI JOURNAL, V.28, No. 2, March-April 1983, pp. 20-49.
- <sup>4</sup> Joen, P.H., and Park, R., "Flexural Strength and Ductility Analysis of Spirally Reinforced Prestressed Concrete Piles," PCI JOURNAL, V.35, No. 4, July-August 1990, pp. 64-83.
- <sup>5</sup> Joen, P.H., and Park, R., "Simulated Seismic Load Tests on Prestressed Concrete Piles and Pile-Pile Cap Connections," PCI JOURNAL, V.35, No. 6, November-December 1990, pp. 42-61.
- <sup>6</sup> Nigels, McLeod C., "Prestressed Concrete Tension Piles and Their Connections", PCI JOURNAL, V.43, No. 4, July-August 1998, pp 138-140.

**SHORELINE  STEEL, INC**

**DOMESTIC STEEL SHEET PILING**

**THOMAS M. WILLEY**

Phone: (800) 522-9550  
 Res: (248) 545-1745  
 Fax: (586) 749-6653  
 Email: tomwilley@shorelinesteel.com  
<http://www.shorelinesteel.com>

(586) 749-9559  
 58201 Main St.  
 New Haven, MI 48048

**Michelle Lusader**  
President

**ALL AMERICAN**  
UNDERPINNING & SHORING, INC.

PH: 630-307-9467  
FAX: 630-213-3927



[www.allamericanunderpinning.com](http://www.allamericanunderpinning.com)

P.O. BOX 72566, ROSELLE, IL 60172

**WBE Certified**

• Underpinning • Earth Retention Systems • Driven Piling • Micropiles  
[aaunderpinning@aol.com](mailto:aaunderpinning@aol.com)