Prestressed Concrete Tension Piles and Their Connections

by

McLeod C. Nigels, P.E.
Senior Associate
Davis & Floyd, Inc.
Charleston, South Carolina

Prestressed concrete piles are vital elements in many structures. Generally, the prime purpose of piles is to carry compression loads. It is not unusual, however, to encounter projects that require tension piles. Lateral loads from wind and earthquakes often create overturning, resulting in uplift on piles supporting the structure. When piles are subjected to uplift, connections are required between the pile and pile cap that must be properly designed to resist tensile forces.

Proper connection details transfer the axial tension from the structure to the prestressed section of the pile. Mild steel dowels are the most often used means of connecting pile caps to prestressed concrete piling, although connections are sometimes made to the prestressing strands.

The method by which connections are made via mild steel dowels is a very important consideration in the design of the foundation. Dowels can be cast into the pile head to protrude for embedment in the pile cap. However, dowels that protrude from the pile head are an obstruction to the pile hammer.

Dowels can also be totally cast in and exposed after pile driving by breaking off the top of the pile. This practice requires increased pile lengths to account for the part that is to be cut off. The practice of field-cutting is time consuming and expensive. Because it is generally possible to cast in only straight bars, field bending is sometimes required to develop bars in relatively shallow pile caps. The field bending of bars as large as a No. 11 size can be an obvious problem for the contractor.

Another method of connecting a pile to a pile cap is to remove the concrete at the head of the pile, thus exposing the prestressing strands for connection to the pile cap. Again, this method is sometimes objectionable because it requires field-cutting of the pile head.

A method for grouting dowels into holes cast in the piling is given in the following example. This is the preferred method for providing mild steel dowels and is best used when pile lengths can be predetermined. A similar connection can be used in other instances where piles are driven to refusal (impenetrable foundation). In these instances, dowel holes are field-drilled and dowels are grouted in just as they are in formed holes.

If dowel holes are drilled in, special care must be taken to ensure that the holes are thoroughly cleaned prior to grouting in the dowels. Any concrete dust or soft paste resulting from drilling must be removed in order to ensure a good bonding surface. The presence of a good bonding surface for the grout is an implicit assumption in the design of grouted dowels.

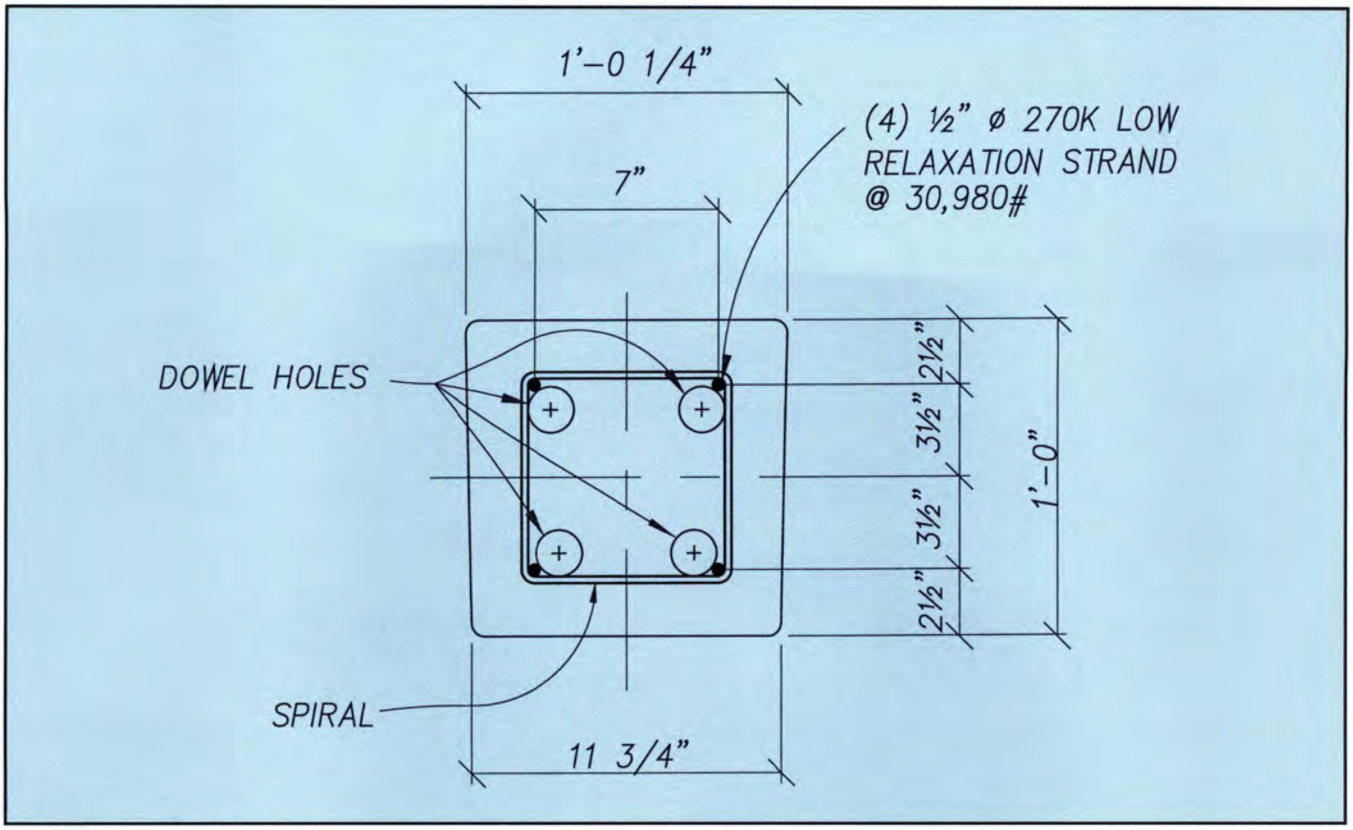

Fig. 1. Cross section of pile.

PROBLEM

12 x 12 in. (305 x 305 mm) square prestressed concrete piles are being designed for a building foundation. Seismic analysis indicates that resistance to overturning subjects piles to an axial tensile working load of 50 kips (222.4 kN) per pile.

Design the connection between the pile and the pile cap and check the design of the pile for an uplift of 50 kips (222.4 kN). Using ACI 318-95, Section 9.2.3,[1] the required load factor is 1.7(1.1*E*) or 1.87*E*.

The piles are to be prestressed using four ½ in. (12.7 mm) diameter low relaxation strands, 270 ksi, tensioned to 75 percent ultimate [A_{ps} per strand = 0.153 sq in. (98.7 mm^2)].

$f_c' = 6000$ psi (41MPa)

The method chosen to provide a connection at the top of the piles is to provide dowel holes cast in at the head of the piles and, after the piles have been driven to grade, grout dowels into the holes using non-shrink grout. The dowels will extend above the head of the piles to be embedded into the pile cap when the pile cap is cast.

SOLUTION

Certain criteria must be satisfied in order to provide a proper connection and ensure against failure of the pile in tension.

- The dowel holes must be fully developed in the pile. In this example, tubing will consist of spiral metal tubing similar to that commonly used for post-tensioning sheathing. This type of tubing conforms to ASTM A525 requirements. Smooth tubing should not be used to form dowel holes unless special means are taken to ensure against bond failure between the tube and the surrounding concrete.
- The dowel must be fully developed in the grouted dowel hole. Refer to ACI 318-95, Chapter 12.[1]
- The strands must be developed sufficiently, at a distance equal to the embedment depth of the dowel, to prevent tensile failure of the pile at a plane at the bottom of the dowel. Refer to the PCI Design Handbook, Fifth Edition, Fig. 4.12.4.[2]

A section through the 12 in. (305 mm) pile is shown in Fig. 1. Dowel holes will be formed with a 1¾ in. (45 mm) diameter spiral metal tube in each corner of the pile.

1. Dowel Size Required

$T_u = 1.87\ (50) = 93.5$ kips (415.9 kN)

Dowel area required :

$$A_s = \frac{T_u}{\phi f_y} = \frac{93.5}{0.9 \times 60}$$

$$= 1.73 \text{ sq in. } (1116 \text{ mm}^2)$$

Provide four #6 dowels = 1.76 sq in. (1136 mm^2).

2. Dowel Embedment

Embedment length required = l_d.

From ACI 318, Chapter 12, Eq. (12-1), l_d is calculated as 17.43 in. (443 mm).

The PCI Design Handbook, Fifth Edition, Table 6.5.1,[2] indicates a development length of 18.25 in. (464 mm).

Try an embedment length of 20 in. (508 mm).

3. Check Pile Capacity at 20 in. (508 mm) From Head

Prior calculations show that the ef-

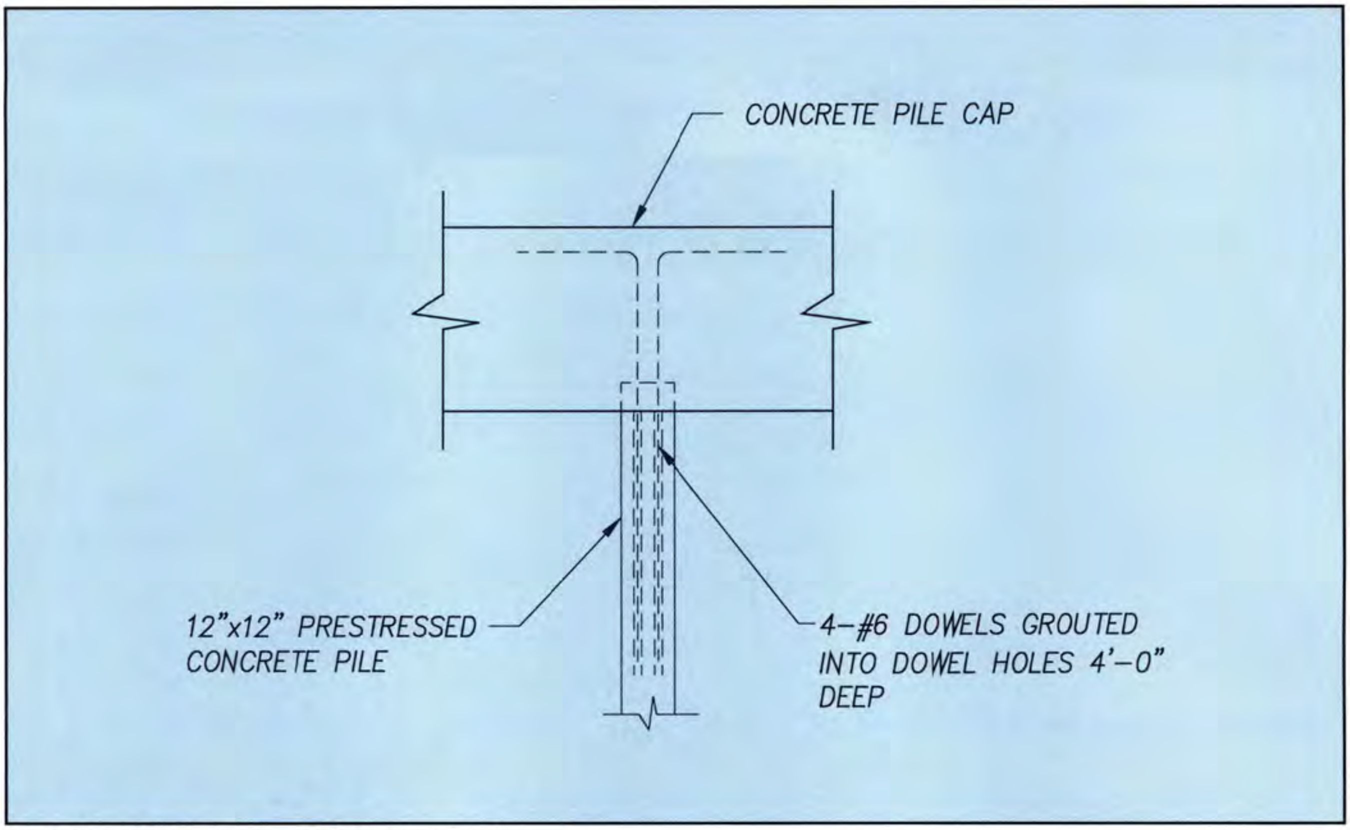

Fig. 2. Pile section showing reinforcement details.

fective prestress in the pile is 749 psi (5 MPa) and that the effective stress f_{se} in the strand is approximately 170 ksi (1172 MPa).

Using the PCI Design Handbook, Fifth Edition, Design Aid 11.2.6, with f_{se} = 170 ksi (1172 MPa) and f_{ps} = 270 ksi (1862 MPa), the development length for 1/2 in. (12.7 mm) strand = 78.3 in. (1990 mm). The available development length at the bottom end of the dowels = 24 in. (610 mm). Therefore, the tensile capacity of the strands will be less than the ultimate strength.

Using the PCI Design Handbook, Fig 4.12.4, with l_d = 24 in. (610 mm), f_{ps} = 150 ksi (1034 kN).

Ultimate tensile capacity:

$$T_n = \phi f_{ps} A_{ps} = 0.9 \times 150 \times 4 \times 0.153$$
$$= 82.6 \text{ kips} < 93.5 \text{ kips}$$
$$(367526 \text{ N} < 415.9 \text{ kN})$$

The calculated tensile capacity, as governed by the strength of the strands at the lower end of the dowels, will be less than required.

Dowel holes must extend farther into the pile in order to achieve a greater percentage of the full development length for the strands.

Extend the dowels 48 in. (1219 mm) below the head of the pile.

Using Fig. 4.12.4 of the Design Handbook, with l_d = 48 in. (1219 mm), f_{ps} = 195 ksi (1345 MPa):

$$T_n = 0.9 \times 195 \times 4 \times 0.153$$
$$= 107 \text{ kips} > 93.5 \text{ kips}$$
$$(475936 \text{ N} > 415.9 \text{ kN}) \text{ (ok)}$$

4. Check Stresses in Piles

Stress due to prestress = 749 psi (5 MPa)

Stress due to 50 kip uplift = T/A = 50,000/144 = 347 psi (2.4 MPa)

Total stress 749 – 347 = 402 psi (2.8 MPa) compression (ok)

The net area at the head of a pile is reduced when dowel holes are cast in and driving stresses are therefore increased. Past practice has shown that, as a general rule, the total cross-sectional area of the dowel holes should not exceed 6 percent of the gross cross-sectional area of the pile.

The practice of providing dowel holes cast into the heads of piles works very well when pile lengths can be predetermined. If a pile with cast-in holes reaches refusal prior to being driven to grade, it must be cut off. In this instance, when dowel holes no longer exist, they must be field-drilled. Dowels are then grouted into the drilled holes as they would have been had the cast-in holes been available.

The completed detail is shown in Fig. 2.

REFERENCES

1. ACI Committee 318, "ACI Building Code for Structural Concrete (ACI 318-95)," American Concrete Institute, Farmington Hills, MI, 1995.
2. *PCI Design Handbook,* Fifth Edition, Precast/Prestressed Concrete Institute, Chicago, IL, 1998.