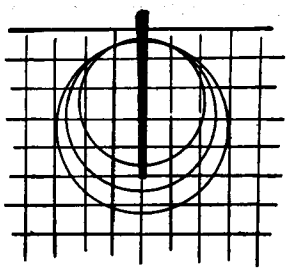

How To Design Pile Caps To Resist Uplift

By Edwin H. Baldwin

THE USE of timber piles in tension has probably been practiced about as long as the use of piling has been known. The application of the extraction value of timber piles has greatly increased in recent years, however, as soil mechanics produced more accurate methods of predicting the behavior of piles in such circumstances. This has been well covered in a previous article in this series. The economic importance of using the pile for two purposes, bearing and anchorage simultaneously, has been heightened by the modern trend to structures of extreme slenderness.

The important relation created between pile and structure leads naturally to the question of how the pile may be adequately secured to the structure in order that the pile strength in tension may be utilized. Other authors have covered the subject, and Chellis[1] has compiled an extensive list of early methods. He includes the use of railroad spikes driven into the sides of the pile, simple bond between pile and concrete, wedging the pile head, notching or tenoning the pile, and the use of timber connectors. Except for the last two these methods share the fault of inconsistency and may not be rationally designed. Tenoning and the use of timber connectors are widely used and will be discussed further.

The use of piles in tension seems to fall in two very broad categories. First, and comprising an ap-

1 Robert D. Chellis, "Pile Foundations," McGraw-Hill, Inc., 1951

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His present duties include consulting work on wharves, bulkheads, mooring structures, and pile foundations.

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TYPE OF ANCHOR	WORKING LOAD Per Unit Illustrated	COST Including Installation	Minimum Concrete Cover
Fig. 1 - Dowels, axial 3-#5 x 24"	10,584 lbs.	$ 5.50	2"
Fig. 2 - Dowels, transverse 2-#8 x 36"	10,060 lbs.	$ 7.00	9½"
Fig. 3 - Bolted hook 1" dia. bolt 2-#5 hooks	5,030 lbs.	$ 8.75	10"
Fig. 4 - Bolted hook 7/8" dia. bolt 4" shear plates 2-#5 hooks	11,100 lbs.	$15.00	11"

TABLE FOR COMPARISON OF VARIOUS TYPES OF ANCHORS

parent large majority of cases, is the application of nominal loads, i.e., in the neighborhood of five tons per pile. Much less common in our experience is the application of extreme loads; those approaching the maximum usable value of the pile. The latter group may amount to 15 to 20 tons safe working load per pile in tension. Both cases will be covered, but the case of extreme loads only briefly.

There are so many variations of schemes for attachment of piles to concrete caps that a comprehensive listing would be purposeless if not impossible. Instead, four basic types of anchors are analyzed: (1) axial dowels, (2) transverse dowels, (3) bolted hook type connectors, and (4) bolted hook type anchors using timber connectors.

Axial dowels, figure 1, present the simplest and lowest cost method that can be devised. The application is much the same as the use of drift pins in wharf building, but there are two important differences: the piles are not prebored, and the dowels used are deformed reinforcing bars. We have made quite a number of extraction tests on such dowels with favorably uniform results. The ⅝" diameter bar is preferred for its ease of handling and driving. Most of our tests have been on this size rod. A ⅝" diameter reinforcing bar driven 24" axially into a sound pile head will require an average force of 10.8 kips to initiate withdrawal and will require a constant force of 7.1 kips to maintain withdrawal once started. The allowable withdrawal load may be calculated by the following formula developed by the U.S. Forest Products Laboratory:

$$P = 138G^{5/2}D$$

where P is the allowable withdrawal load in pounds per inch of penetration, G is the specific gravity of oven dried wood, and D is the fastener diameter. This result, P, applies to the withdrawal of nails and spikes from side grain, and a reduction of one third is made when calculating the withdrawal from end grain.

Calculating the end grain withdrawal of a ⅝" dia. x 24" long bar, allowing .58 as the average specific gravity of Southern pine, the following is obtained:

$P = ⅔ (1380) .58^{5/2}(.625) = 147$ lbs. per inch

Total $P = 24 \times 147 = 3{,}528$ lbs.

Comparison of the calculated allowable with the results of tests reveals a two-to-one safety factor applied to the 7.1 kip load required to maintain withdrawal.

Transverse dowels or reinforcing bars inserted perpendicular to the axis of the pile, figure 2, are effective though less economical than the axial dowels. The allowable load is simply that of a bolt loaded in double shear and may be obtained from tables. Assuming a 1" diameter rod and a 12" diameter pile the allowable load per rod will be 5,030 lbs. The minimum end distance is seven times the bolt diameter, in this case seven inches. The concrete cap will resultingly have to be seven inches deeper than it would otherwise be. Installation is simple. Holes of the same di-

ameter as the rods are drilled through the pile at right angles to its axis, and the rods are driven home. Two rods side by side generally constitute one "layer." Additional excavation may be required around the perimeter of the footing to permit installation.

A third method, figure 3, is too commonly used and offers little to commend it. In this type anchor a flat bar or a fish hook shaped reinforcing bar is bolted to the pile. A variation often consists of a rectangular plate with the hook bar welded to it. A pair of these, whichever, is attached to the pile by transverse bolting. Regardless of how elaborately the attachment is fabricated the maximum strength of the connector is limited to the strength of the attaching bolt in double shear. The illustrated assembly, a 1″ diameter bolt in a 12″ pile loaded at both ends has an allowable load of 5,030 lbs. Minimum end distance is seven bolt diameters with resulting additional footing concrete. Installation cost is about the same as for transverse dowels but depending upon the type of fabricated hook may cost considerably more.

The fourth and most elaborate method of anchorage is the use of a timber shear plate connector in conjunction with a plate and welded hook, figure 4. A pair of 4″ diameter shear plates with a ⅞″ bolt, as illustrated, will develop *approximately* 11,100 lbs. working load. Approximately is what is meant; though an 11 percent increase is permitted for use of metal side plates, an off-setting reduction of 1/9th must be made for bolt threads bearing on the shear plates. In this type construction you cannot consistently avoid this situation. The minimum end distance is again seven inches. This, plus half the ring diameter, totals nine inches of additional footing concrete required. The facing and tooling of the pile to receive this type assembly is an expensive operation.

A summary of the above four types of anchors appears in the accompanying table. It should be noted that the tabulated allowable loads may be increased in some instances for loads of short duration. The reader is referred to the National Design Specification[2] for such allowances.

The number of usable options is narrowed when the application of tension loads in the 15 to 20-ton range is under consideration. This is probably the ultimate practical tension loading for a timber pile. Such cases of high loading not only do exist but are actually found more often than might be expected. Structures of extreme height and slenderness such as transmission towers and petroleum and chemical processing vessels often require such anchorage. Two methods of uplift attachment are suggested as most efficient and economical.

One method enlarges on an already suggested scheme by using multiple shear ring, plate and hook attachments in sufficient numbers to accommodate the loading. An arrangement as shown in figure 5 is an example. The eight 4-inch shear plates will develop about 44 kips safe working load. This translates into a requirement that the hooks be ⅞″ diameter. A lot of extra concrete is required, at least 21″ below pile cut off.

Tenoning the pile as illustrated in figure 6 is the

2 "National Design Specifications for Stress-Grade Lumber and Its Fastenings," National Forest Products Association, 1619 Massachusetts Ave., N.W., Washington, D.C. 20036.

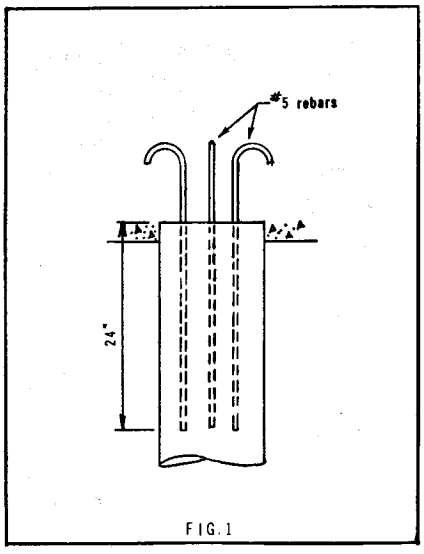

FIG. 1

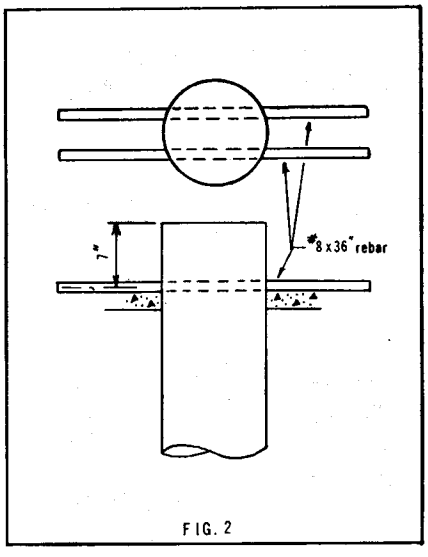

FIG. 2

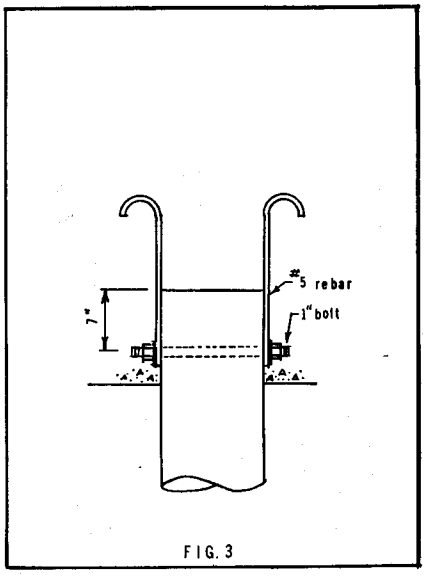

FIG. 3

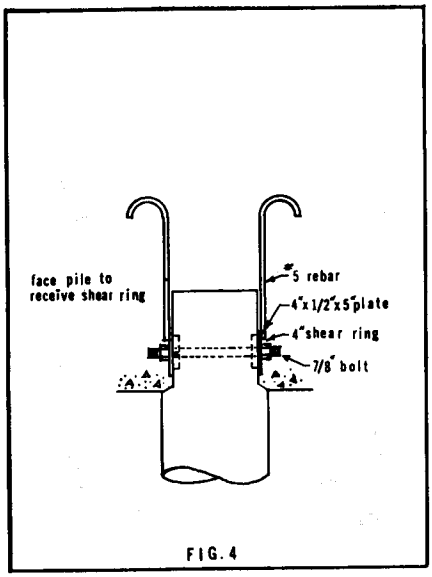

FIG. 4

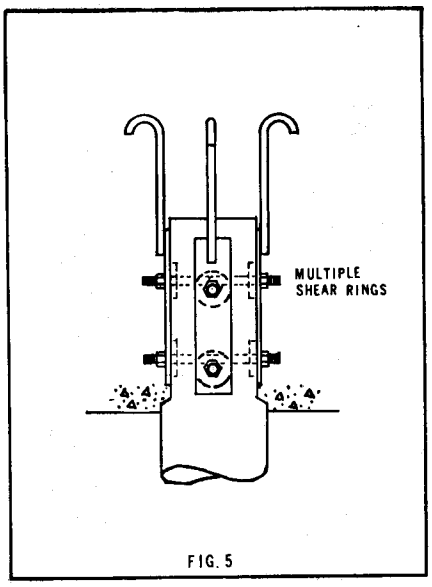

FIG. 5

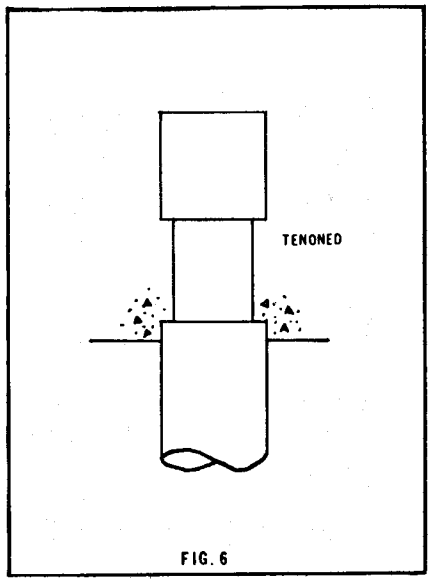

FIG. 6

second suggested method of providing for extreme tension loads. This operation will require more skilled craftsmen than any of the other methods. The work should be done with accuracy and neatness. Two saw cuts, no more than the required depth, are made to form the shoulders of the tenon. The material between the shoulders is then removed with an adze. This must be done without splitting the upper part of the pile. The *illustrated* unit should develop about the same working load as the eight shear plate unit.

The cost of the latter two methods is estimated at $30 and $35 per pile respectively. The cost of additional footing concrete is not included.

Generally the cost of a tension connection is not going to be a major economic factor. However, there are many structures which require such connections in the hundreds, and these are more common than might be suspected. More importantly, the amount of footing concrete may be materially affected, and this should not be overlooked. ■