How To Determine Critical Section of Timber Piles

By Louis J. Capozzoli, Jr.

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. . . if the stratum does not have sufficient strength or the driving is not hard enough to develop the ultimate strength of the tip, the *critical section* can be at the butt, if the skin friction around the pile is sufficiently high.

. . . the *critical section* for friction piles is always at the butt of the pile or at the top of the bearing stratum.

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Dr. Capozzoli, author of this article as well as the first article in the "Pile Foundations: Know-How" series — "Current Status of Timber Foundation Piles" — has performed consulting engineering on more than 1,000 soils and foundations projects, across the country. While much of this experience has been in Louisiana and the Gulf South areas, the wide variation of soils found there has provided sufficient experience for the successful performance of many projects as far away as 1,000 miles from his home base.

The cases Dr. Capozzoli cites in "How to Determine Critical Section of Timber Piles" are all based upon the above-mentioned experience and knowledge.

DESPITE the use of timber piles before the dawn of recorded history, the location of the critical section in a timber pile still raises some questions. This is because nature, in providing us with timber piles, grows the piles with a taper. This taper, recognized in all specifications, is advantageous from many points but also causes problems. The advantages of the taper are: easier driving due to a smaller tip where most of the driving resistance is generated; a tendency to densify sands by providing lateral pressures thereon; and a large butt to absorb heavy driving energy when getting the pile to final penetration and also to provide support for other construction timbers. Some of the problems produced by the taper are: less cross section area at the deeper depths for primarily point bearing piles; minor difficulties in handling since the tip is not as strong as the butt; and the necessity to consider many variables when determining the location of the critical section.

For any piles of uniform cross section, the critical section is just below the pile cap and the structural analysis and the design of the pile is complete. The problem is not so simple for a tapered pile. Some specifications for allowable loads on timber piles took the critical section at the pile tip and based the total allowable load on the pile tip area and an allowable stress thereat. This was reasonable when one considers that the early development of this country was along rivers and other waterways in the northeastern area. In both cases piles were driven through relatively soft strata down to firm bearing, often to rock or river deposits of sand and gravel. The piles were essentially point bearing, and considering the stresses at the tip to be the critical ones was quite reasonable. As engineering knowledge advanced, it was realized that even soft soils provide some skin friction and the stresses at the tip were not always the most critical. Many codes recognized this and stated that the allowable stresses at the critical section rather than the tip must not exceed a limiting value. Other codes merely allowed a percentage increase in the total pile load over that given by the allowable stresses at the tip. This latter case eliminates the need for calculation of a critical section and is well liked by many designers. However, it is not good engineering procedure from the soils and foundation standpoint.

Before proceeding further, it will be necessary to define the term critical section. For this article, the critical section of a pile is that point along the pile length where the load thereat divided by the cross sectional area produces the maximum stresses. The load at that critical section may be the total load on the pile or it may be only a small portion thereof.

Locating The Critical Section

The location of the critical section will vary with the manner in which the pile distributes the load to the soil, the location where the load begins to go into the soil, and the length of the pile. An ideal situation and one which can prevail under certain circumstances is that where the pile is stressed to approximately the same value for its entire length.

To demonstrate the effect of the variables on the critical section of a timber pile, computations are shown for the stresses in a 60-ft. long Class B timber pile with a 7-in. diameter tip and a 13-in. diameter butt. The cross section of such a pile is shown on Figure 1. The pile was set in 10 different types of soil conditions and the stresses analyzed at 10-ft. centers. These conditions and their results are shown in the accompanying table and are described below. Ultimate loads are considered in all cases to eliminate questions from the magnitude of the factor of safety.

The first case is a friction pile in very soft clay. The skin friction is 200 psf for the entire length of the pile. The maximum stress in the pile is 240 psf at the butt. The ultimate load on this pile is 31 kips.

The next case analyzed is a friction pile in soil where the skin friction is 400 psf. This is typical of the soft clays along the southern coast of Louisiana. Figure 2 shows the load and stress curves on this pile. The maximum stress again is at the butt and is 470 psi. The ultimate load on this pile is 63 kips. With a safety factor of 2, this produces a working load of 15 tons. Many such piles are used in southern Louisiana with working loads of between 10 and 15 tons.

The third case is a friction pile in a stiff clay or similar material which exerts a skin friction of 1500 psf. The maximum stress in this pile is 1780 psi at the butt. The ultimate load is 235 kips or 60 tons.

Summarizing the first three cases, it can be seen that for a friction pile the critical section is at the butt or at the top of the supporting stratum if the upper few feet of the pile were neglected. Stresses at any vertical section will depend upon the skin friction developed along the pile as well as the pile length. The advantage of the taper is quite evident. Conceivably, a skin friction of 2000 psf would produce a stress of approximately 2400 psi at the butt.

Effect of a Tip Load

Let's look at the effect of a tip load. It will be assumed for these computations that the pile is driven to a stratum of sufficient hardness and with a large enough hammer to develop the ultimate strength of the timber at the pile tip. This will be taken as a compressive stress of 2500 psi. This driving situation is likely to occur when piles are driven to dense sands and gravels, hardpan or rock.

The fourth case shows a tip stress of 2500 psi with a skin friction of 200 psf along the length of the pile. This is typical of piles driven through very soft materials to refusal. The maximum stress is at the tip and is 2500 psi. At the butt the stress is less than 1000 psi. If the stress due to skin friction were neglected completely, the stress at the tip would remain unchanged, the stress at the butt would be reduced to approximately 700 psi. The ultimate capacity for such a pile is 126 kips or a working load of 30 tons, a reasonable figure for such conditions. If the skin friction were neglected and the ultimate load taken as the tip area and stress, the ultimate load would be only 95 kips. This is ultraconservative.

The fifth case shows the same pile with a tip stress of 2500 psi and 400 psf skin friction. Load and stress curves on this pile are shown in Figure 3. The maxi-

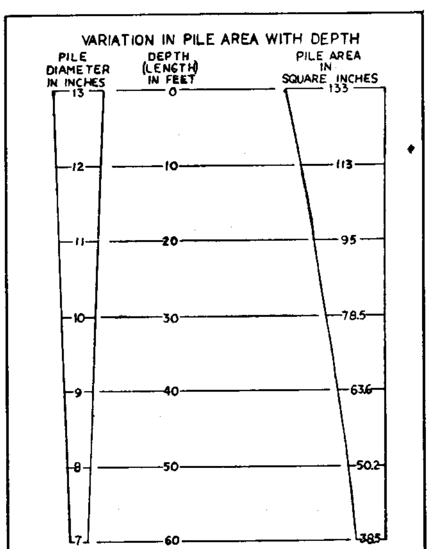

FIGURE 1

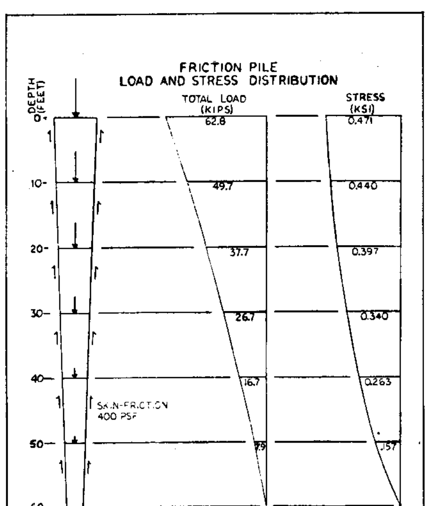

FIGURE 2

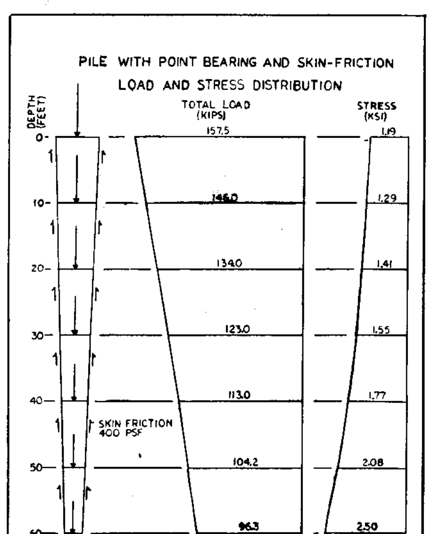

FIGURE 3

"... that point along the pile length where the load divided by the cross sectional area produces the maximum stresses."

mum stress is still at the tip although the butt stress is now 1190 psi. Such a pile has an ultimate load of 158 kips or a safe working load (with a factor safety of 2) of 40 tons. These are the conditions at the First Nitrogen Corporation plant at Donaldsonville, Louisiana described in the first article of this series in November, 1966. These piles tested to between 90 and 95 tons before failure occurred indicating the adequacy of these computations.

The sixth case shows a pile loaded to 2500 psi at the tip in soil with a skin friction of 1500 psf. This is an unusual case where the entire length of the pile is stressed the same amount, 2500 psi. The ultimate strength of such a pile is 332 kips or a working load of slightly in excess of 80 tons. This figure may be questioned but it should be realized that this size pile is no different than some of the patented tapered concrete piles. Such piles have developed these loads in the soil conditions described herein.

The last three cases where the piles are driven to develop their ultimate compressive strength at the tip show that unless the pile is in a stiff clay or other material capable of exerting 1500 psf or more skin friction, the maximum stress will occur at the pile tip. For most cases, the critical section for a timber pile driven to refusal is the tip of the pile. This does not mean that the total load the pile can carry is that at the tip only. The taper of the pile increases the area available to carry additional load developed by skin friction.

Case seven shows a friction pile with the lower half in 1500 psf skin friction soil and the upper half in 400 psf skin friction soil. Here the maximum stress is still at the butt and is 1410 psi. The ultimate load is 187 kips.

Case eight shows the same pile as case seven driven to refusal with 2500 psi stress at the tip. The lower half of the pile is uniformly stressed. The stresses in the upper half are reduced. The ultimate load on this pile is 282 kips or, using factor safety of 2, 70 tons. These last two cases again show that for a friction pile,

TABLE 1

DEPTH BELOW GROUND SURFACE (FT.)	60-FOOT TIMBER PILE 7-INCH TIP DIAMETER – 13-INCH BUTT DIAMETER									
	SKIN FRICTION IN PSF									
	200	400	1500	200	400	1500	400(0'-30') 1500(30'-60')	400(0'-30') 1500(30'-60')	400	1500
	TIP STRESS IN KSI									
	0	0	0	2.50	2.50	2.50	0	2.50	1.50	1.50
	STRESS IN PILE (KSI)									
0	0.24	0.47	1.78	0.95	1.19	2.50	1.41	2.13	0.90	2.21
10	0.22	0.44	1.65	1.07	1.29	2.50	1.38	2.23	0.95	2.16
20	0.20	0.40	1.49	1.21	1.41	2.50	1.34	2.35	1.01	2.10
30	0.17	0.34	1.28	1.38	1.55	2.50	1.28	2.50	1.07	2.01
40	0.13	0.26	0.99	1.64	1.77	2.50	0.99	2.50	1.17	1.90
50	0.08	0.16	0.59	2.00	2.08	2.51	0.59	2.51	1.31	1.74
60	0	0	0	2.50	2.50	2.50	0	2.50	1.50	1.50
	ULTIMATE CAPACITY IN KIPS									
	31	63	235	126	158	332	187	282	120	293

the critical section is at the butt or the top of the supporting stratum. For a pile driven to refusal the critical section is at the tip unless the skin friction on the pile in this case is in excess of 1500 psf.

Case nine shows a pile driven to refusal with the ultimate stress at the tip taken as only 1500 psi and with the pile in soil with skin friction of 400 psf. The maximum stress here occurs at the tip and is 1500 psi. The ultimate capacity of such a pile is 120 kips which produces a working load of 30 tons. This condition is the same as that of case number five except for the allowable stress at the tip. The conservativeness of using only 1500 psi for the tip stress can be seen by the fact that such a pile has been test loaded to 190 kips, considerably more than 120 kips, the ultimate load as shown in this case.

Case ten shows this pile with 1500 psi tip stress and 1500 psf skin friction soil. The skin friction effect here overrides the effect of the tip stress and the critical section is at the butt. The stress is 2210 psi. The ultimate load here is 293 kips or 73 tons (using safety factor of 2).

Effect of Length Variations

Similar computations were performed for a 30-ft. long timber pile to determine the effect of the length variation on the critical section. Rather than using a Class B size pile, a pile with tip and butt diameters of 7 and 13 inches respectively was used to eliminate the size effect. Case results are shown in Table 2.

30-FOOT TIMBER PILE 7-INCH TIP DIAMETER — 13-INCH BUTT DIAMETER					
DEPTH BELOW GROUND SURFACE IN FEET		SKIN FRICTION IN PSF			
	0	400	1500	400	1500
		TIP STRESS IN KSI			
	2.50	0	0	2.50	2.50
	STRESS IN PILE IN KSI				
0	0.72	0.24	0.90	0.96	1.62
10	1.01	0.20	0.75	1.21	1.76
20	1.52	0.13	0.49	1.65	2.01
30	2.50	0	0	2.50	2.50
	ULTIMATE CAPACITY IN KIPS				
	95	32	120	128	215

TABLE 2

In the first case, with a tip stress of 2500 psi and no skin friction, the critical section is at the tip. The pile has an ultimate load of 95 kips or a working load of 25 tons. This is typical of short piles driven to support piers and docks in channels cut in rock.

The second case is a friction pile, 30-ft. long, in 400 psf skin friction soil. This corresponds to the second case for a 60-ft. pile. The critical section is still at the butt but the maximum stress is 240 psi, half of that for the 60-ft. pile. The ultimate load is also half, 32 kips instead of 63 kips.

The next pile is a friction pile in 1500 psf skin friction soil. This corresponds to the third case for the 60-ft. pile and again the critical section is at the butt. The maximum stresses and ultimate load are half of those for the 60-ft. pile, being 900 psi and 120 kips respectively.

In the fourth case, with a tip stress of 2500 psi and a skin friction of 400 psf surrounding the pile, the critical section is at the tip. The ultimate capacity for such a pile is 128 kips.

In the last case where the tip is stressed to 2500 psi with a skin friction of 1500 psf, the stress at the tip is still critical and is 2500 psi. In this case, the pile is not long enough to develop sufficient load to increase the stress at the butt and make the entire pile critical as for the 60-ft. pile. The ultimate load for this 30-ft. pile is 215 kips. This was proven by such a pile having been test loaded to 100 tons with less than ½ inch gross movement at the top.

Conclusions

Reviewing the above data, it can be seen that for any pile driven to a hard stratum with sufficient energy to develop the ultimate strength of the pile at its tip, the critical section will be at the pile tip. If the stratum does not have sufficient strength or the driving is not hard enough to develop the ultimate strength of the tip, the critical section can be at the butt if the skin friction around the pile is sufficiently high. This is evidenced by the last two cases for the 60-ft. pile. For friction piles the critical section is always at the butt of the pile or at the top of the bearing stratum.

The specifications that take the critical section of the pile as being at the pile tip are correct for piles that develop considerable point bearing load. Their continued use is justified provided they take cognizance of the fact that additional load can be developed by friction above the pile tip which, due to the taper of the pile, will keep the stresses below those at the critical section and will still increase the carrying capacity of the pile. For friction piles, the critical section is always at the butt or at the top of the bearing stratum. Generally, the skin friction in such cases is insufficient to develop the full strength of the pile. ■