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**Failure mechanism of long bored piles  
in layered soils of Bangkok**

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## **FAILURE MECHANISM OF LONG BORED PILES IN LAYERED SOILS OF BANGKOK**

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### **ABSTRACT**

Simple superposition principle for the estimation of ultimate shaft friction capacity of bored piles sometimes found to be not directly applicable for the piles embedded in the multilayered soils of Bangkok. Because of the early yielding of the stiff clay layers, a localized plunging of the load-settlement curve is often observed. For these layers, although the maximum mobilized skin friction corresponds to the adhesion factor  $\alpha$  equal to around 0.35, suggested by different researchers. But due to the movement softening behavior of these layers, residual friction values near the ultimate failure of the piles drops to a corresponding  $\alpha$  values of the order of 0.15 or even smaller. It is recommended that due to the progressive nature of failure, lower  $\alpha$  values for stiff to hard clay layers should be considered for the estimation of ultimate skin friction capacity under such conditions.

### **INTRODUCTION**

Ultimate shaft friction capacity of piles embedded in the layered soils is calculated as summation of the ultimate shear resistances offered by different soil horizons present along the pile shaft. Load movement curves obtained from instrumented pile load tests have revealed that the very stiff to hard clay layers present within the Bangkok aquifer sands frequently exhibit a well defined movement softening behavior. Peak friction values in these layers have been found to be mobilized at very low pile head movements and well before the ultimate friction values of other layers present along the pile shaft. When rest of the layers reach their ultimate values these layers have already reached their residual friction values, which are as low as 50 percent of the peak friction values. So the simple superposition of ultimate friction values give rise to overestimation of the total shaft friction capacity under these conditions.

### **SOIL PROFILE**

Typical soil profile of plain of Bangkok is shown in Figure 1. Thickness of Bangkok Soft Clay (BSC) at the top varies generally between 15 to 18m. BSC changes to medium stiff consistency before the first stiff clay, which is generally present at 20 to 25 m depth. First sand layer is usually 5 to 10 m thick and found at 25 m to 30 m depth, below is a series of stiff to hard clay and medium to very dense silty sand layers.

### **PILES EMBEDMENT CONDITIONS**

Pile embedment conditions are designed depending upon the actual soil profiles encountered at the sites, as depicted by three locations P-1, P-2 and P-3 in Figure 1. Thasnanipan et al. (1998), presented the instrumented pile load test results of wet process bored piles tested in Bangkok subsoils. The authors have revealed that in case of pile

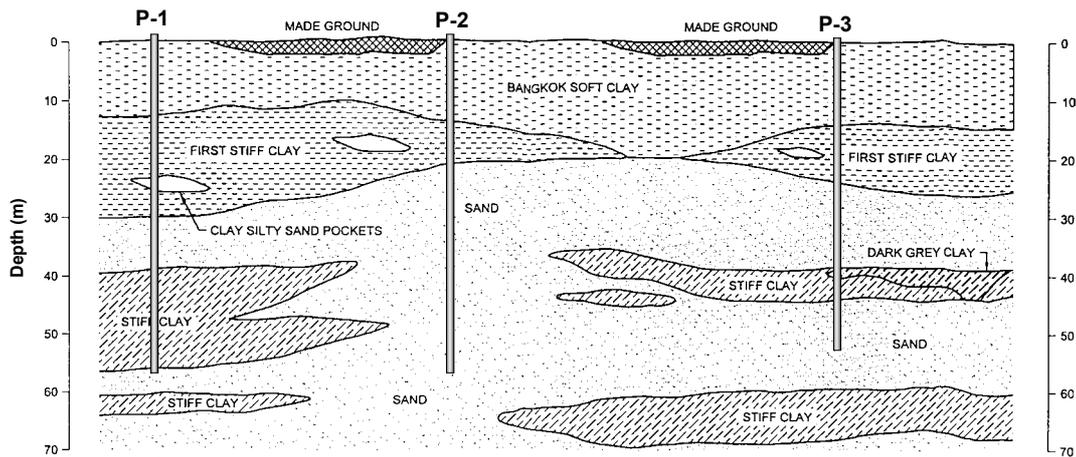


Figure 1: Typical soil profile along a 4.5 km long stretch of an expressway in the plain of Bangkok, with different pile embedment conditions.

embedment conditions like P-1 and P-3, 2<sup>nd</sup> stiff clay often exhibit a brittle type of failure and peak skin friction values are mobilized well before the sand layers.

A family of t-z curves obtained from the instrumented pile load tests showing this type of failure is presented in Figure 2. The peak friction values in these layers are mobilized at very low pile head movements (10 – 15 mm depending upon the depth of stiff clay layer) and well before the ultimate friction values of other soil layers present along the pile shaft. When rest of the soil layers reach their peak friction values stiff clay layers have reached the residual friction values.

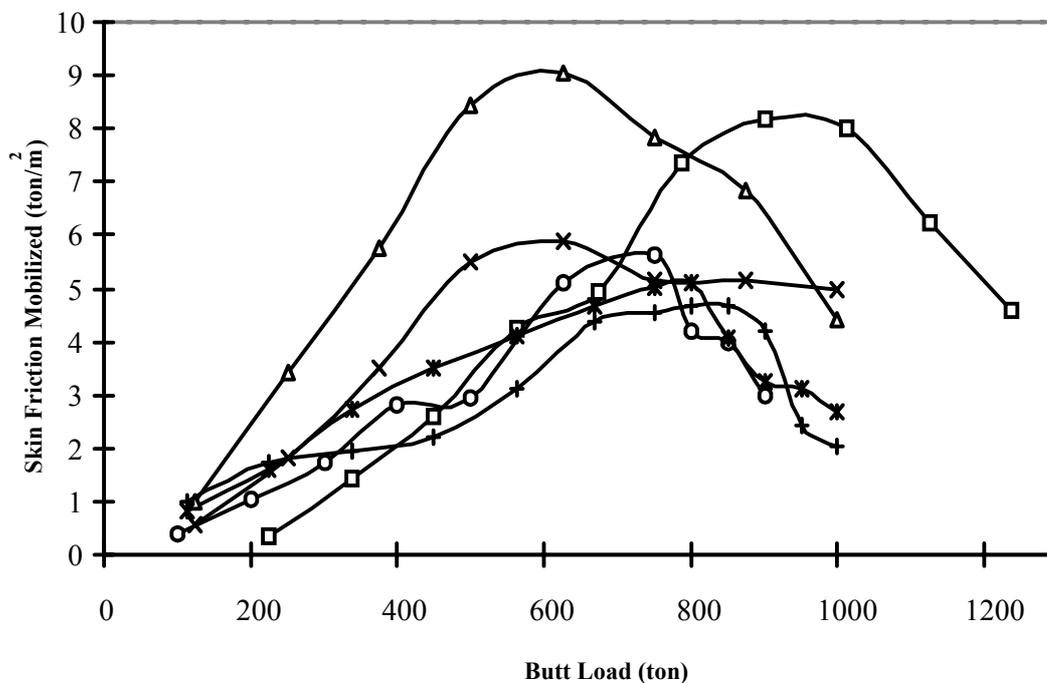


Figure 2: Family of curves obtained from instrumented pile load tests showing typical brittle failure in stiff clay layers.

A typical load test showing this type of behavior is shown in Figure 3. It can be seen that the stiff clay layers reach their ultimate friction values well before the sand layers and at the maximum test load stiff clay layers reach their residual friction values. Design parameters like  $\alpha$  and  $\beta$  suggested by different researchers like Suchada (1995) for the estimation of ultimate skin friction in Bangkok subsoils give a reasonable estimate for the embedment conditions like at P-2 in Figure 1 or where the thickness of 2<sup>nd</sup> stiff clay layer is relatively low. Exceptions have been observed in case of embedment conditions especially like P-1, where a thick 2<sup>nd</sup> stiff clay layer is present. Owing to the difference in shaft friction development with pile head movement in the stiff clay layers as shown in Figure 3, direct summation of (simple superposition) ultimate shaft friction capacities in different soil horizons leads to over estimation of shaft capacity of these piles. Due to the brittle nature of failure mechanism in very stiff to hard clay layers peak friction resistance is mobilized at comparatively very little movement at the pile/soil interface. Residual values of friction resistance in these layers drop to 50 percent or even smaller of the peak friction values mobilized.

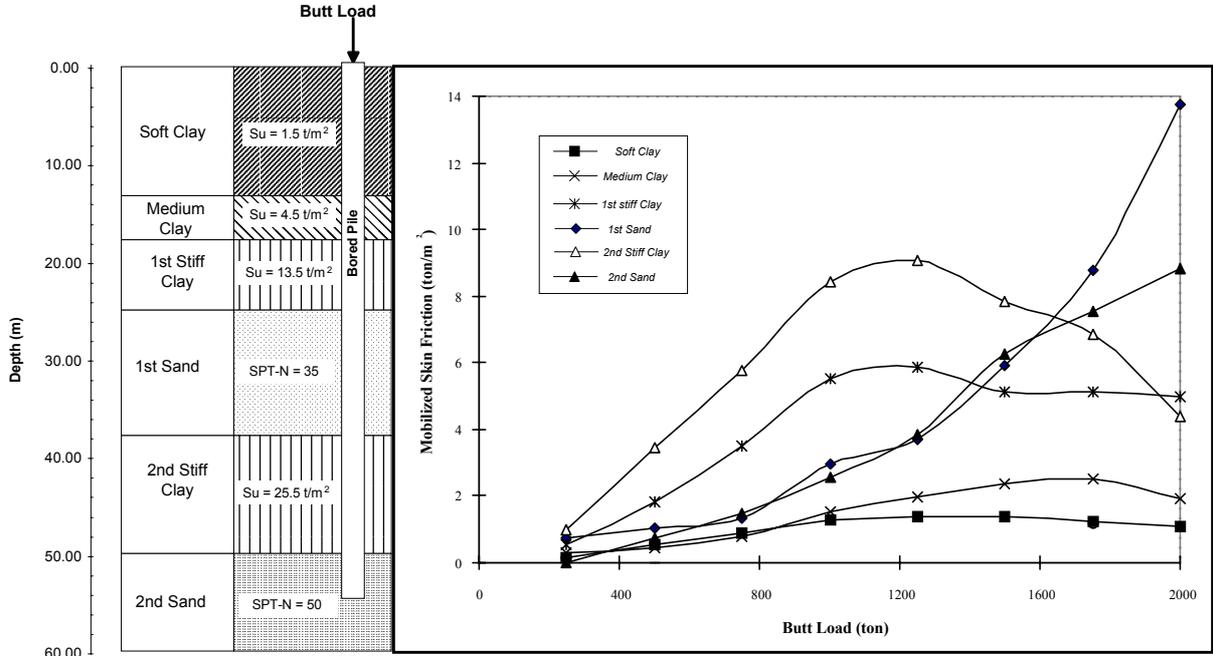


Figure 3: Skin friction development with the increase in butt load which clearly shows a typical early yielding of stiff clay layers.

On the extreme, from some instrumented pile load test results it has been observed that stiff clay layers reach their peak friction values near the design service loads. Rest of the soil layers need further pile/soil interface movement for the full mobilization of skin friction, and at this stage, stiff clay layers have already arrived at their residual friction values. Now depending upon the relative thickness of stiff clay layers, overall shaft friction capacity mobilization is affected differently. If the thickness of very stiff to hard clay layers is such that their contribution in the total shaft friction capacity is proportionally high, when stiff clay layer yields, load settlement curve shows a localized plunging behavior. The movement of such plunging consists of few millimeters and when the other soil layers shares the deficit in

Table 1: Comparison of maximum skin friction values mobilized and the values at maximum test load.

Clay Layer	Undrained Shear Strength $S_u$ (ton/m <sup>2</sup> )	Mobilized Unit Skin Friction Values (ton/m <sup>2</sup> )			
		Max. Mobilized		At Max. Test Load	
		$f_s$	$\alpha$	$f_s$	$\alpha$
Soft Clay	1.5	1.7	1.13	1.6	1.07
Medium Clay	4.5	2.2	0.49	1.9	0.42
1 <sup>st</sup> Stiff Clay	13.5	5.8	0.42	5.1	0.38
2 <sup>nd</sup> Stiff Clay	25.5	8.8	0.34	4.2	0.16

peak and residual friction capacity of these layers, once again pile starts taking load followed by this local plunging, as shown in figure 4, till the final plunge exhibiting the failure of all soil layers along the pile shaft reaches. It must be noted that this localized plunging was earlier conjectured to be because of the soft toe of the piles. On the other hand if the contribution of skin friction derived from very stiff to hard clay layers is proportionally low, localized plunging due to earlier failure of very stiff to hard clay layer is not visible. Normal practice to estimate the contribution of skin friction from clay layers is by using  $\alpha$ -method, with a value of  $\alpha$  equal to around 0.3 for very stiff to hard clay layers. Instrumented pile load test results have shown that skin friction values calculated using  $\alpha$  value equal to 0.3 corresponds to the peak skin friction in these layers. Owing to the brittle type of failure mechanism in these layers,  $\alpha$  values at full mobilization of total shaft friction capacities drop to as low as 0.15 in some cases and the ultimate shaft capacity calculated gives over estimates as compared to the actually mobilized capacities. Skin friction values mobilized in the pile load test shown in Figure 3 are given in Table 1.

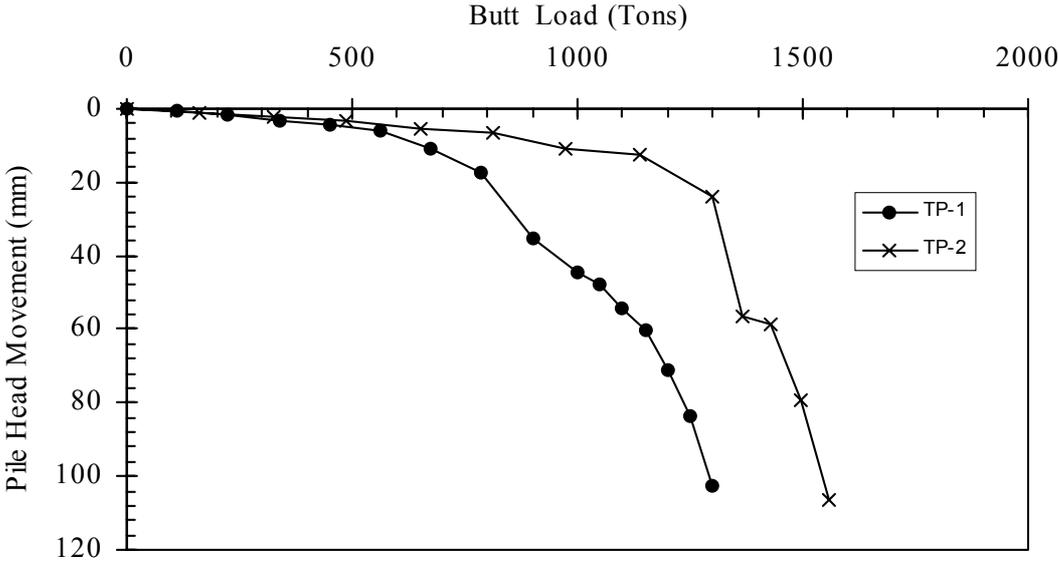


Figure 4: Typical load-settlement curves showing localized plunging before the overall failure of the pile.

Peak and residual  $\alpha$  values mobilized in the stiff clay layers from Table 1 are plotted in figure 5 along with the suggested curves by different researchers. It can be noted that the peak  $\alpha$  value mobilized in 2<sup>nd</sup> stiff clay layer corresponds well to the value suggested by Stas & Kulhawy (1984). But the residual  $\alpha$  value at the maximum test load drops below the curve suggested by Suchada (1989). So the  $\alpha$  values proposed in figure 5 for the stiff to hard clay layers gives overestimate of the ultimate shaft friction under these conditions.

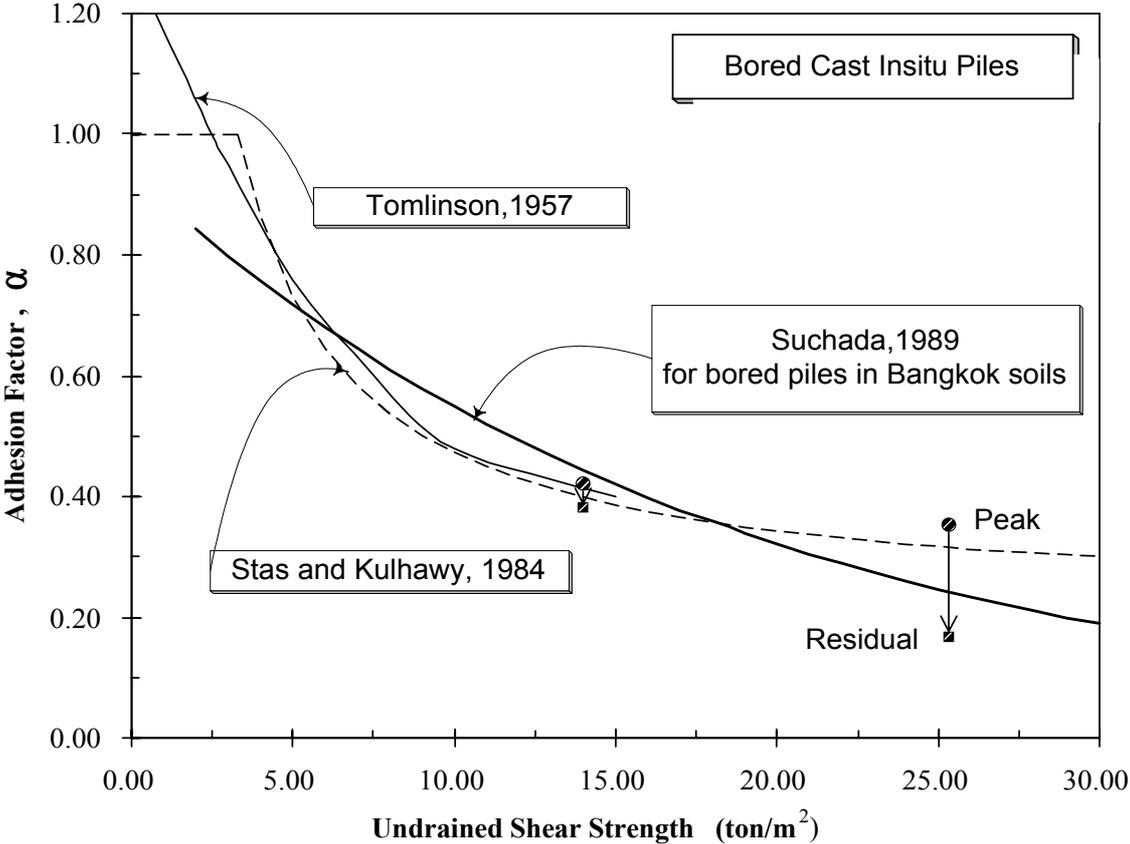


Figure 5: Comparison of adhesion factor  $\alpha$  , suggested by different researchers with the actual mobilized in the stiff clay layers.

EFFECT OF LOWER END BEARING VALUES ON SKIN FRICTION

Meibner & Van Impe (1993) firstly reported the influence of lower end bearing values on the shaft friction capacity of piles. Laboratory model tests as well as finite element analysis performed by the authors showed that the presence of soft soil within a depth of two to four times pile diameter below the pile tip, not only decrease the end bearing but also the skin friction capacity. Thasnani et al. (1998) also revealed that the end bearing capacity of bored pile where toe is embedded in to the clay layer would be reduced and this end bearing capacity reduction might influence the shaft resistance capacity too. This conclusion was reinforced by the pilot pile load test result in the project located on Rama III road in Bangkok where bore pile having diameter 1500 mm, toe founded at 60m in clay layer, failed at only about 1750 tons with total settlement of over 90 mm. While the designed maximum test load was 2500 tons. An other contract pile of same diameter and founded in sand layer at depth 55

m and base grouted was successfully tested up to 2500 tons with total settlement of only 29.26 mm and elastic recovery was 17.52 mm recorded. Even though the second pile was shorter in length than the first, more skin friction was mobilized due to the improved end bearing conditions. A similar decrease in the shaft friction capacity in the sand layers has been observed from the instrumented pile load tests at another project in Bangkok.

## CONCLUSIONS

For the piles embedded in the multi layered soils of Bangkok, estimation of ultimate shaft friction capacity needs to consider the brittle type of failure mechanism of stiff to hard clay layers and the  $\alpha$  values selected need to be adjusted accordingly. Where the pile tips are embedded in the clay layer, effect of lower values of end bearing on shaft capacity should also be considered.

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