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Effect of Reaction System on the Test Pile and Test Barrette Response in Vertical Load Tests

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Abstract. The ideal static pile load test which best simulates the applied loads from a structure on the pile foundation, is the one which is subjected to a vertical loading without reaction system. However, in practice this ideal test cannot usually be performed and a reaction system is then needed. The present study deals with the interaction between test pile or barrette and the reaction system using the finite element code Plaxis 3D. The analyses were performed on documented bored pile and barrette load tests carried –out on the construction site of the BECM tower located in Bangkok city, Thailand. The results show that the interaction between the test pile and reaction piles is more important than that between the test barrette and reaction barrettes.

Keywords. Pile load test, barrette load test, Plaxis-3D, reaction system, interaction between test pile and reaction system.

1. Introduction

The reaction systems commonly used in practice for pile test loading include kentledge, tension piles and ground anchors. The interaction between the test pile and the reaction system may affect the pile test results. For the case when tension piles are used as a reaction system, these piles experience tension and uplift during compressive loading of the tested pile, which will tend to reduce the settlement of the test pile. Therefore, the obtained stiffness of the test pile may not reflect the true stiffness of the pile beneath the structure [5].

Many researchers have examined this interaction phenomenon such as [6], [8], [4], [3], etc; and many international codes recommended a minimum distance between the test pile and reaction piles in order to minimize the interaction effect on pile load test results. The commonly used spacing between the test pile and reaction piles in practice varies from 3 to 5 pile diameters. Such spacing is not always enough to avoid the interaction phenomenon and it is not economical to use large spacing. Therefore, it is very important to take into account the interaction phenomenon during the interpretation of the pile load test results.

Kitiyodom et al. [3] carried out a parametric study to investigate the effect of reaction piles on the behavior of the test pile and indicated that the interaction between

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the reaction piles and the test pile and reaction piles led to the increase of the test pile head stiffness. Moreover, it was found that the interaction phenomenon depends mainly on the spacing between the test pile and reaction piles, the pile slenderness and the relative stiffness between the soil and the pile material.

This paper deals with the numerical interpretation of a bored pile load test (57.5m long and 1.5m in diameter) and a rectangular barrette load test with a cross section of 1.5m x 3.0m and a length of 57.5m. Figure1 shows the foundation footprint of the BECM tower project in Bangkok, Thailand and the location of the studied pile and barrette load tests.

The reaction system consisted of four tension piles (or barrettes) having the same dimensions as the test pile (or barrette) (Figure 2). The center to center spacing between each reaction pile and the test pile was set to 5.65m (i.e. 3.77 times the pile diameter) whereas; the center to center spacing between each reaction barrette and the test barrette was set to 5.0m (i.e. 3.33 times the barrette width).

The subsoil profile at the site is characterized by alternating layers of clay and sand deposits. The site investigations carried out comprises unconfined compression tests conducted for the soft clay layer and standard penetration tests (SPT) performed for layers below soft clay layer (Figure 3).

According to Thasnanipan et al. [7], the groundwater condition of the soft Bangkok clay is hydrostatic, starting from 1.0 m below ground level to about 10m depth. Well pumping from deep aquifers has led to the creation of under drainage of the soft clay and stiff clay as well as deeper soil layers. The piezometric level or the phreatic surface of the Bangkok aquifer is, therefore, reduced and quite constant at about 23m below ground surface as shown in Figure 3.

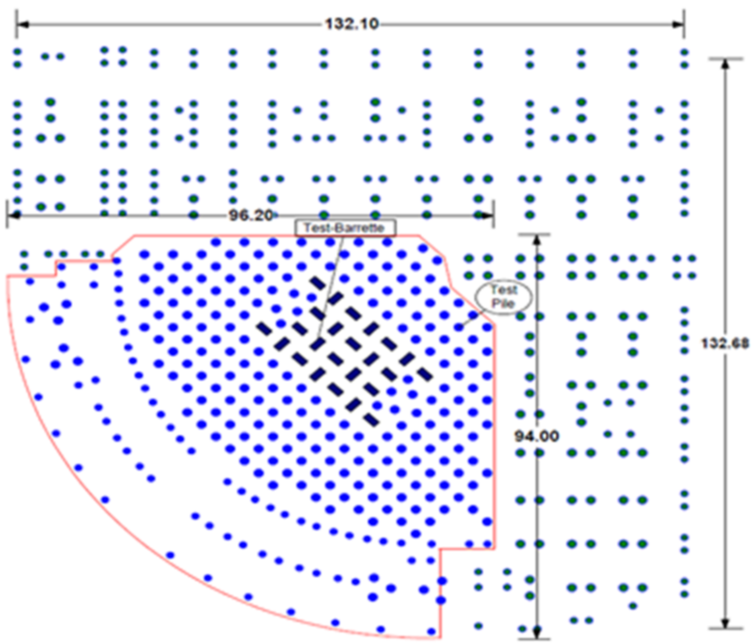

Figure 1. Foundation footprint of BECM tower project, showing the location of test pile and barrette [13].

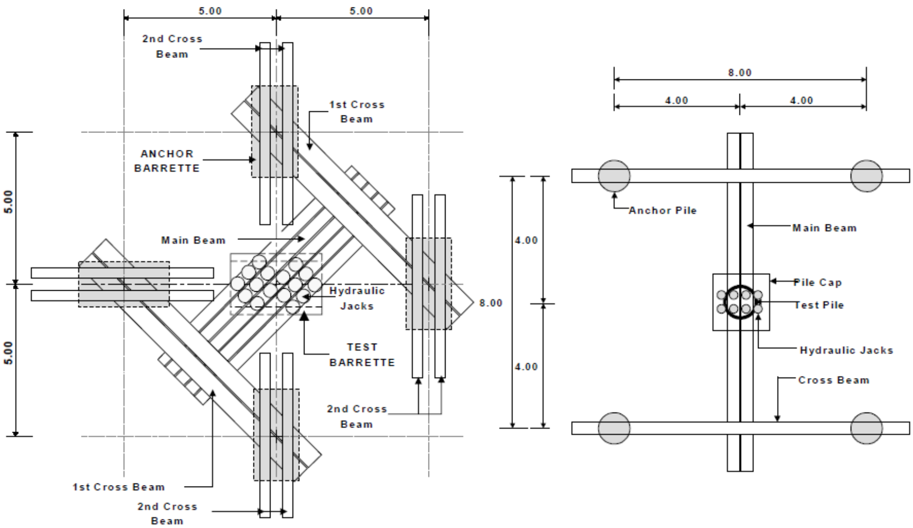

Figure 2. Barrette and pile load tests layout [13].

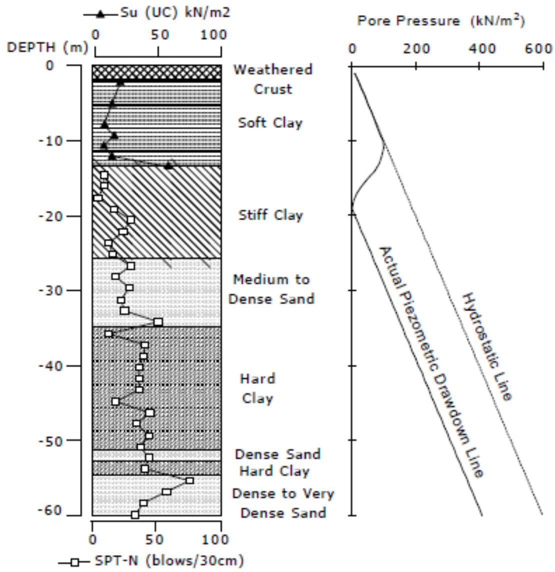

Figure 3. Soil profile at site and the typical ground water condition of Bangkok [13].

2. Numerical analysis

The bored pile and barrette load tests were simulated using the finite element code Plaxis 3D. The pile and barrette were modelled as linear elastic with a unit weight of 25 kN/m^3, Poisson ratio of 0.2 and a Young modulus of 37000 MPa. The soil was modelled using the Hardening Soil model (HS) [1]. Interfaces along the piles and barrettes were taken into account in the numerical simulation by using the interaction factor (R_{inter}) such as:

$$C_{inter} = R_{inter} C_{soil} \tag{1}$$

$$\varphi_{inter} = R_{inter} \varphi_{soil} \tag{2}$$

The soil parameters used in the numerical analysis are summarized in Table 1. Strength parameters are kept the same but stiffness parameters were adjusted through a back analysis of the pile and barrette load test results.

Figure 4 shows the FEM model of the pile (or barrette) load test under 3D condition, composed of ten node volume elements. Considering the symmetry of the pile and barrette load test systems, thus only a quarter of the system was modelled.

Note that for the barrette load test, the center to center spacing between the reaction barrette located on the left side and the test barrette is the same as other reaction barrettes but the clear spacing is different. So, to make the barrette load test layout symmetric about x and y axes with the same clear spacing between the reaction barrettes and test barrette, the reaction barrette located on the left side was rotated to be the same as the one located on right side. The numerical results indicated that the new configuration gives similar results as the original configuration and therefore only a quarter of the barrette load test is modelled.

In order to minimize the effect of the artificial boundaries on the numerical results, mesh of 60m x 60m x 100m has been chosen for the pile and barrette load tests.

The pile load test simulation sequence included an initial phase which corresponds to the initial stress condition, followed by a second phase in which the pile is wished in place. Then, vertical loads were applied on test pile and barrette heads up to 27 MN and 50 MN respectively. Simultaneously, each reaction pile (or barrette) was subjected to tension loads equal to a quarter of the compression load. The applied load was modelled as a distributed load at the pile and barrette heads.

It should be noted that the drilling for the piles and barrettes was carried out under bentonite slurry support and a low base resistance of the pile or barrette was formed due the sedimentation of the bentonite slurry and the cleaning problem of the borehole base [7]. Therefore, in the numerical model a base layer of 0.3m thick was considered under the pile and barrette tips having a unit weight of 11.7 kN/m^3 and a Young modulus of 1000 kPa (Figure 5).

Table 1. Soil parameters.

		Soft Clay	Stiff Clay	1st Sand	Hard Clay	2nd Sand
Depth	[m]	0-13.5	13.5-26	26-36	36-54	54-100
γ_{unsat}	[kN/m^3]	16	17	18.5	19	19
γ_{sat}	[kN/m^3]	16.5	18	19.5	20	20
E^{ref}_{50}	[MPa]	5	60	90	100	100
E^{oed}_{50}	[MPa]	5	60	90	100	100
E^{ref}_{ur}	[MPa]	15	180	270	300	300
m	-	1	1	0.5	1	0.5
C	[kPa]	10	25	0	40	0
φ	[°]	23	26	36	24	36
Ψ	[°]	0	0	6	0	6
R_{inter}	-	0.8	0.8	1	0.5	1

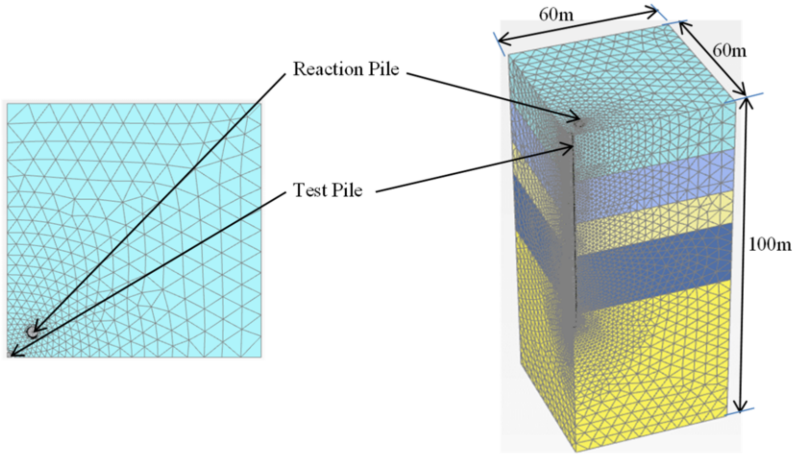

Figure 4. Finite element mesh of the pile load test.

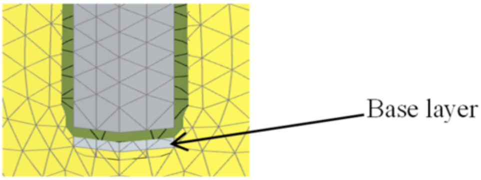

Figure 5. Base layer under the pile tip.

3. Results and discussions

Figures 6 and 7 show the measured and predicted load-settlement curves for the pile and barrette load tests. It can be seen that the numerical results match the pile and barrette load test results quite well.

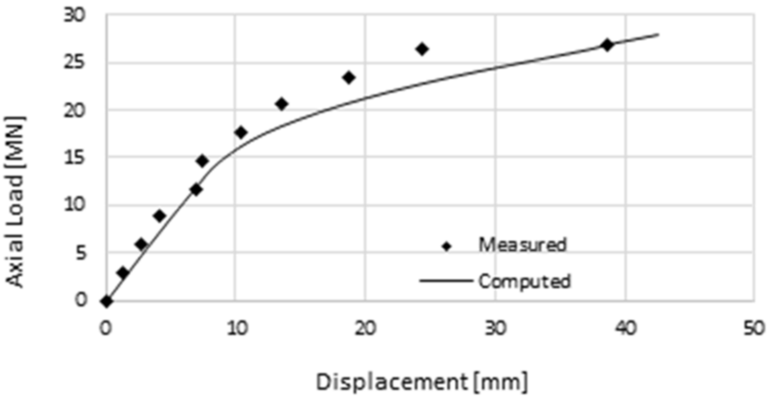

Figure 6. Measured and predicted load - settlement curves for pile load test.

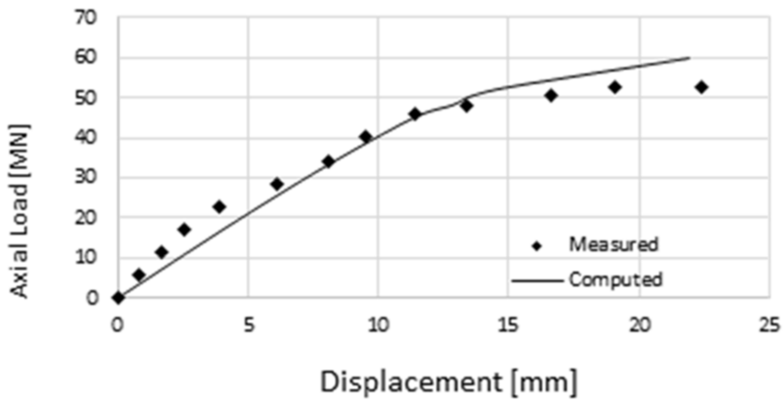

Figure 7. Measured and predicted load - settlement curves for barrette load test.

Figure 8 shows the predicted load-settlement behavior of the test pile and barrette with and without the presence of reaction system. It can be seen that the presence of reaction system reduces the settlement of the test pile or barrette and therefore increases its head stiffness. Note that the initial head stiffness of a pile is defined as the ratio of the load over settlement.

The difference in load-settlement behavior between the test pile or barrette with and without the presence of reaction system is attributed to the interaction effect of reaction system. In fact, when the test pile or barrette is subjected to compression load, the reaction system experience uplift and tends to reduce the settlement of the test pile or barrette. These results agree well with those obtained by [5], [2] and [3].

The results show that the interaction phenomena led to an increase of the test pile head stiffness by about 25% and the test barrette head stiffness by about 39%. The difference in head stiffness may be due to the difference in clear spacing between reaction piles and the test pile (4.15m) and reaction barrettes and the test barrette (1.04m).

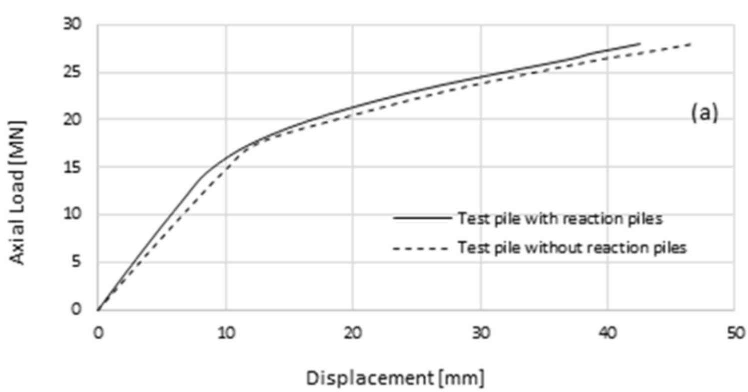

Figure 8. Predicted load-settlement curves of the test pile (a) and barrette (b) with and without the presence of reaction systems.

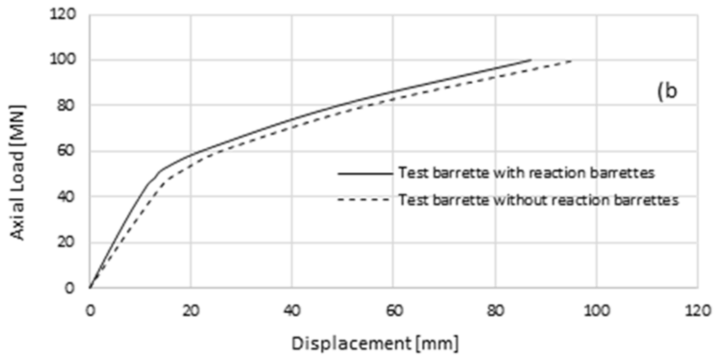

Figure 8. (*continued*) Predicted load-settlement curves of the test pile (a) and barrette (b) with and without the presence of reaction systems.

Figure 9 shows the distribution of the axial load with depth for the pile and barrette load test. It can be seen that the axial load transmitted to the test pile or barrette with reaction system is lower than that without reaction system. This phenomenon can be attributed to the increase of the skin friction caused by the reaction system. From a depth of about 13m (i.e. below the soft clay layer), the difference between the axial loads transmitted to the test pile or barrette with and without reaction systems becomes negligible at higher applied loads i.e. after the plastification of the soil surrounding the pile or barrette.

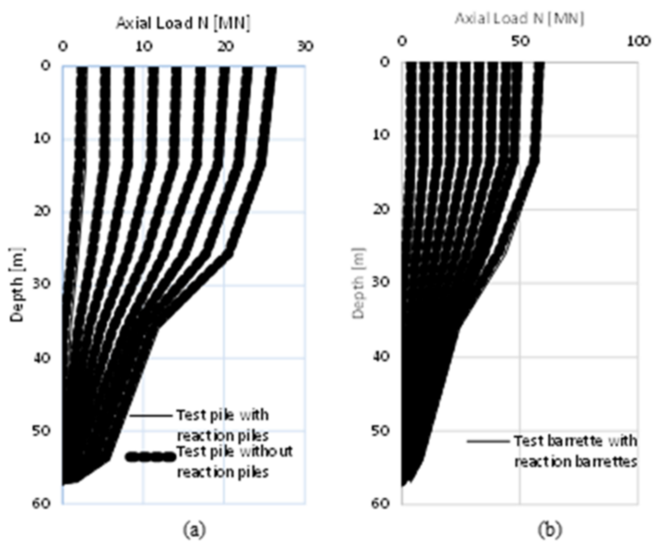

Figure 9. Effect of reaction system on axial load test for the pile load test (a) and the barrette load test (b).

4. Conclusions

The results indicated that the reaction system led to an increase of the test pile head stiffness by about 25% and the test barrette head stiffness by about 39%. This implies that the use of the pile or barrette load test results directly in the design could lead to an overestimation of the stiffness and bearing capacity of the foundation.

This study demonstrates the importance of numerical interpretation of the pile or barrette load tests with reaction system to assess the amount of interaction between the test pile or barrette and reaction system. Therefore, it is possible to use a practical and economical spacing between the test pile or barrette and reaction system, and the test results can be interpreted numerically by taking into consideration the effect of interaction phenomenon, provided that an appropriate material model and parameters are used.

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