Combined load testing of piles

L’étude des pieux sous charges combinées

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ABSTRACT

Although, in practice, piles are often subjected to a combination of both vertical and lateral loads, only few experimental studies have been conducted to investigate the behavior of piles under this combined case of loading. A rare case combined load testing is presented and compared with a three-dimensional numerical model to prove the importance of studying the combined effect of loading in the analysis of piles, and the need for specificastions and reference codes to judge their combined behavior.

RÉSUMÉ

Bien que, les fondations en pieux soient souvent soumises à une combinaison de chargement vertical et latéral, seule une minorité d’études expérimentales a étudié le comportement des pieux sous cette combinaison de chargement. Un cas exceptionnel d’un essai ou le chargement est vertical et latéral est présenté et comparé à un modèle numérique tridimensionnel, pour prouver l'importance d'étudier l'effet de cette combinaison de chargement dans l'analyse des pieux, et le besoin des spécifications et des normes de référence de juger leur comportement combiné.

Keywords : Piles, combined loading, full scale model, numerical model.

1 INTRODUCTION

Experimental, full-scale and model, measurements are still the most essential reference for comparing and validating any design approach. In any important project, at least one, full scale pile should be tested regardless of the method used in the design. Also, in any numerical analysis, full-scale and/or model tests are conducted to compare the results.

For vertically loaded piles lots of full scale and model tests were conducted. They cover almost all types of piles in a variety of soil conditions.

For laterally loaded piles the number of tests that were conducted is relatively small compared to vertically loaded piles, due to the special requirements of this type of testing. But still, they cover a wide range of pile types in a variety of soil conditions.

Combined load testing is very rare due to the following reasons:

1) It is a very complicated test, where the vertical load should be applied in a very special way so as not to induce any frictional resistance for the horizontal deflection resulting from the horizontal load. This may be achieved using plate and roller assembly or anti-friction plate assembly, as given in Figure (1).

2) Even if the test is conducted, there is no code or specification to judge the obtained results.

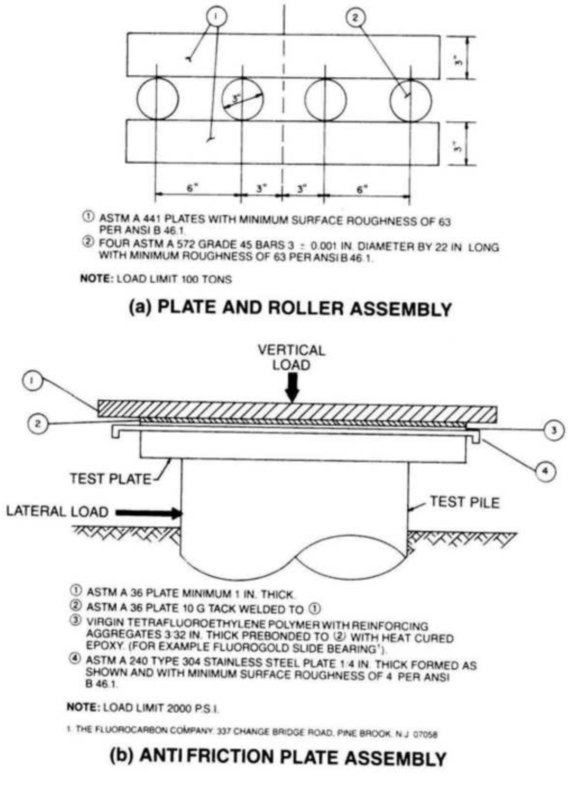

Figure 1: Typical antifriction devices for combined load test.

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For the previous reasons the number of conducted tests is very small. Lee (2008) performed combined load tests on instrumented model piles in sand. Experiments on model H-piles in dry silca sand were performed by Amade, et al. (1997) to determine the influence of lateral displacements on the vertical load-carrying capacity of the piles. In fact, the number of combined load tests on model piles is limited and that on full scale tests is extremely rare.

The aim of this paper is to define the problem and point out its related deficiencies.

2 CASE STUDY

In this paper a full-scale combined axial/lateral load test is presented in details. Test results are also compared with that of three-dimensional finite element analysis (El-Geneidy 1995; El-Geneidy 1997).

As mentioned before, it is very difficult to find a published case study for a combined load test due to the complications associated with this kind of tests and the lack of guidance in interpreting its results. All codes and standards have ignored this kind of tests and did not put any limit for analyzing or interpreting their results. ASTM (2007) is the only specification, so far, that has given a testing procedure for combined loading (as a sub-section in specification number D 3966 dedicated for lateral load testing). But still, it is just some guidelines for testing procedures and does not cover the interpretation or analysis of test results nor the application of test results to foundation design.

2.1 *Site Description*

The test was conducted during the geotechnical investigations for the upgrading of the east treatment plant, as a part of the Alexandria sewage project. The east treatment plant is about 2 km east of El-Nozha Airport and north of the Hydrodrome in Alexandria. The test was conducted under the new proposed headwork, which is located at the middle top (north) part of the site.

The soil profile at the test location is as shown in Figure (2). It consists of the following layers starting from ground surface.

- A discontinuous layer of fill consisting of brown sandy clay, calcareous, and miscellaneous materials up to (1) meter of depth.
- A continuos layer of gray very soft clay that begins below the topsoil layer and extends to a depth of (7) meters.
- A relatively thin layer of very stiff clay that extends from the soft clay to a depth of (8) meters.
- A discontinuous layer of brown medium sand with pockets of clay up to a depth of (20) meters.
- A continuous layer of gray hard clay reaching a depth of (24) meters.
- Then yellow medium dense sand to the end of the borehole.

Beside the description of each layer, results of the static penetrometer (Dutch cone) are also given for the top (20) meters of the soil. These results give an indication of the overall (macro) behavior of each layer in bearing and skin friction, regardless of the individual (micro) behavior of each constituent of soil. The overall behavior of each layer is what, really, matters in the analysis of any soil-structure interaction problem. Results of the static penerometer are given in Figure (3).

2.2 *Test Procedure*

The combined axial/lateral load test was conducted on December 21, 1987 in the Headwork area of the east treatment plant of Alexandria, on a 35 cm diameter concrete bored pile of length 24 m. The test was executed in general conformance with the previously mentioned ASTM D 3966 testing procedures.

DEPTH (m)	DESCRIPTION	SAMPLE	SPT (per 15 cm)	RECOVERY (cm)	LOG
1.00	Sandy clay, calc. & misc.	SS	3,2,2	25	
7.00	Gr. very soft CLAY	SS	—	60	
8.00	Very stiff CLAY	SS	7,12,12	25	
	Br. med. SAND pockets of clay	SS	10,18,25	60	
		ST	—	20	
20.00		SS	15,23,21	60	
24.00	Gr. hard CLAY	SS	20,29,20	60	
	Yel. med. dense SAND	SS	17,25,35	35	

LEGEND :
SS : Disturbed split spoon sample
ST : Undisturbed shelby tube sample

Figure 2: Soil profile at the location of the test.

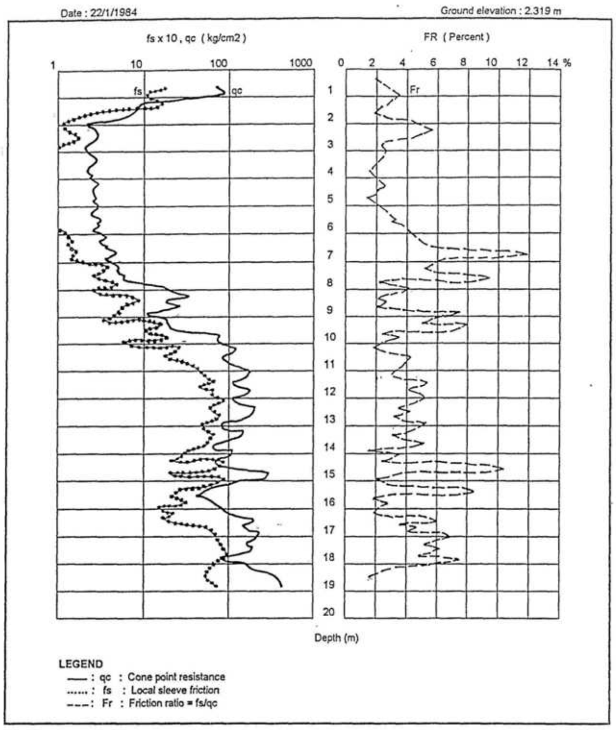

Figure 3: Results of static penetrometer test.

Figure (4) shows the general arrangement of the testing equipment and monitoring devices. The antifriction slide plates used under the main hydraulic jack (compression test) were manufactured according to ASTM specifications. Testing procedures were as follows:

1) A 190 ton compression load was applied in four increments and maintained for approximately two hours before applying a lateral force.
2) The lateral force was applied initially by smooth pumping on the horizontal hydraulic jack. As the pile began to move, pumping was continued at a rate sufficient to maintain a constant rate of lateral movement (0.1 inch per minute) for 2.5 inches.
3) At this point the pumping ceased, and the pile was monitored for thirty minutes.
4) The lateral load was reduced to 8 ton over 30 minutes.
5) The compression test was then reduced to zero in four decrements.
6) The remaining lateral force was removed over a three minutes period.
7) Zero load reading was taken for 30 minutes.

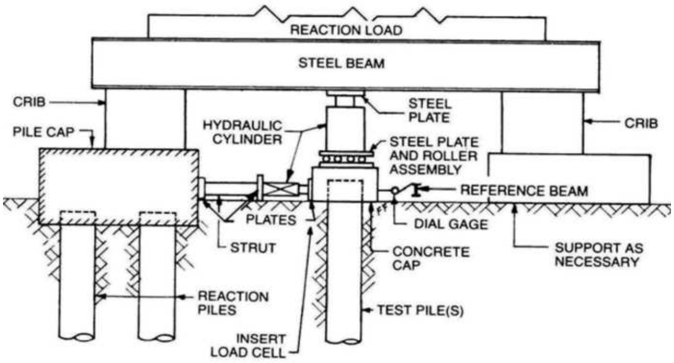

Figure-4 Testing arrangement of combined load test.

2.3 *Test Results*

Figure (5) presents the rate of change of horizontal and vertical deflection of the pile with load. Though the test was conducted in accordance with ASTM, the consulting engineer did not know what to do with the results.

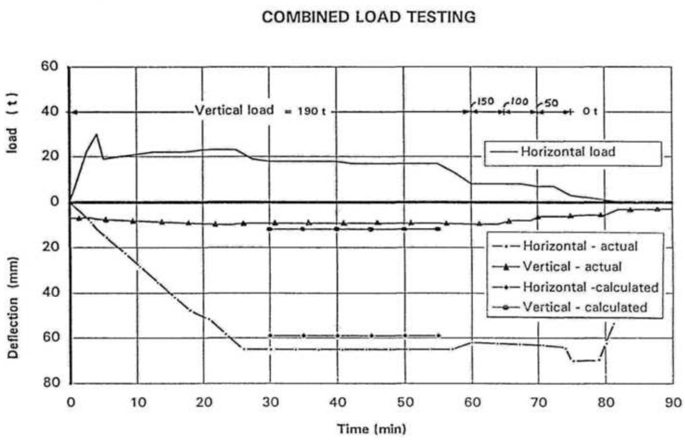

Figure 5: Results of the case study

The test indicates that the pile can sustain the imposed loads, but what about the superstructure? Does the behavior of the pile during this test prove that the superstructure will be safe during its life span? How can the results of the test be interpreted for the design? Lots of questions had no answers.

3 ANALYSIS USING FINITE ELEMENT METHOD

Soil may be approximated into two main layers: an upper very weak layer underlain by a stronger layer. A rate dependent soil model that takes the effect of time can simulate this test. The only part that can be simulated with rate independent soil models is the interval from 30 minute to 55 minute, where a state of equilibrium was reached between the applied loads and the reacting pile-soil system.

Elastic, no-tension, analysis is conducted using ANSYS finite element program. As shown in Figure (6), the continuum is divided into a finite number of three-dimensional, brick elements. Only one half of the model is shown due to the symmetry along the vertical plane including the centerline of the pile and that of the loading.

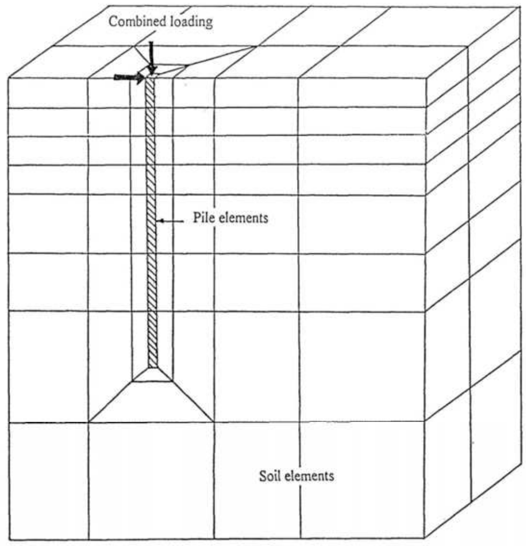

Figure 6: The three-dimensional pile-soil model.

The distances from the boundaries to the centerline of the pile are chosen, such that elements near the boundary are nearly unaffected by the movement of the pile. Elements at the vertical boundaries are restrained from outward movement and those at the base from vertical movement. are applied at nodes, and due to symmetry one half of the applied load is distributed over the topmost four pile nodes. The parameters used in the analysis are given as follows:

Vertical Force = 190 t	Horizontal Force = 22 t
Pile Length = 24 m	Pile width = 0.356 m
Soil's Poisson's ratio = 0.3	Pile's Poisson's ratio = 0.45
E soil (bottom) = 10000 t/m^2	E pile = 2100000 t/m^2
E soil (top) = 250 t/m^2	

Results of the analysis compared to actual test results are presented in Figure (5). It is clear that results are close to real behavior. This is because for this case the upper layer was very soft. So the expected difference in behavior before and after failure is not remarkable.

4 CONCLUSIONS

- Adopted testing procedures do not simulate actual behavior of most piles. It is very rare to find a pile that is actually subject to single type of loading.

- Combined load testing of piles is still an uncovered area by all specifications. Personal experience is the only judge for test results.
- For the time being, three-dimensional analysis seems to be the only accurate way for the analysis of piles subjected to combined loading.
- With the introduction of user-friendly three-dimensional methods of analysis, accurate analysis of combined loading became possible. Thus the need for codes and specifications to cover this issue is now very important.

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