DOI 10.1007/s11204-016-9394-4
Soil Mechanics and Foundation Engineering, Vol. 53, No. 4, September, 2016 (Russian Original No. 4, July-August, 2016)

EXPERIMENTAL INVESTIGATIONS

EXPERIENCE IN APPLYING PILE STATIC TESTING METHODS AT THE EXPO 2017 CONSTRUCTION SITE

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UDC 624.154:624.131.152

Results of static pile tests using the static cycling quick-load test (SCQLT) and Osterberg (O-Cell) methods are presented.

Introduction

Static tests were carried out on three bored piles to test deep foundations at the EXPO 2017 construction site at Astana (Kazakhstan). One of the piles (No. 166) was tested using the SCQLT method; the other two (RTR-1 and RTR-2), using the O-Cell method.

A package of laboratory and field studies of the soil bed was carried out first at the construction site.

From the field description of the soil, which was confirmed by the results of static penetration and laboratory testing, the geological engineering elements making up the survey area were identified (Table 1). The construction site is distinguished by the uniform occurrence of soil layers, and consequently, the geological engineering conditions at the site for testing experiential piles are identical.

Per the results of geological engineering surveys and studies of soil properties, bored piles 31.5 m long, 1000 mm in diameter, and resting on crushed stone soil (EGE-6) were chosen as a foundation. Field static tests were carried out to verify and assess the pile's soil load-bearing capacity with respect to design loads.

Pile static testing using the SCQLT method

Testing with a static load (cyclic) was carried out in accordance with ASTM D 1143 [1].

Vertical static loading of piles using the SCQLT method is one of the most widely used field test methods for soil used to analyze pile bearing capacity (Fig. 1). In SCQLT testing, the test load on the pile is specified for two cycles (6000 kN and 12000 kN, respectively). Test were carried out after the pile concrete strength had attained more than 80% of the design value. Loading and unloading was carried out in the following sequence: 25, 50, 75, 100, 50, 0, 25, 50, 75, 100, 125, 150, 175, 200, 150, 100, 50, and 0% of design. In the first cycle, the experimental pile was loaded to 100% of the design value (6000 kN); during the second cycle, to 200% (12000 kN). The hold time while loading was 30 min; while unloading – 20 min. It took 120 min and 240 min, respectively, to attain peak load.

Translated from Osnovaniya, Fundamenty i Mekhanika Gruntov, No. 4, pp. 19-22, July-August, 2016.
0038-0741/16/5304-0251

TABLE 1

EGE	Soils	Depth of occurrence, m	Soil description						
			ρ, g/cm^3	c, kPa	φ, deg	E, MPa	e	$I_{L\max}$	S_r
EGE-2	Clay loam	0-11.25	1.97	21	31	13	0.6	0.71	0.6
EGE-3	Medium-grain sand	11.25-13.75	1.62	2	35	17.0	–	–	–
EGE-4	Gravel soil	13.75-18.3	2.00	–	–	23.0	–	–	–
EGE-5	Clay loam	18.3-30.9	2.00	35	33	16.0	0.66	0.04	0.83
EGE-6	Crushed stone soil	>30.9	2.40	–	–	32.0	–	–	–

Fig. 1. Vertical static pile tests using the SCQLT method.

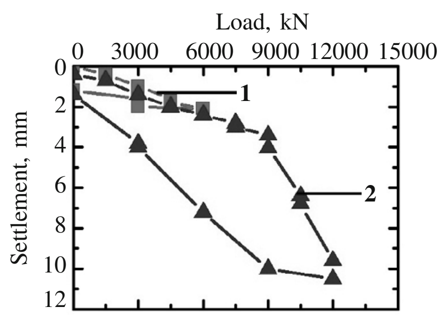

Fig. 2. "Load-settlement" plot for the SCQLT method for pile No. 166: 1) 6000 kN load; 2) 12000 kN load.

Figure 2 shows the results of SCQLT testing. The total settlement of the pile during the first cycle was 2.09 mm (curve 1 on Fig. 2). During the second cycle, the total settlement was 10.51 mm up to the 12000 kN load (curve 2 on Fig. 2).

It should be noted that even at the maximum test load of 12000 kN, the pile is operating only elastically in the soil, which is indicated by the insignificant residual soil settlement after unloading, which amounts to 1.4 mm.

The O-Cell method or static testing of a pile with a bidirectional load

Soil testing with piles using the Osterberg method allows tests to be carried out to determine the bearing capacity of piles both along the lateral surface and under the heel (Fig. 3).

A feature of the O-Cell method is that the load is not applied to the pile cap, but acts on the pile body, where a jack (O-Cell) has been installed, exerting force in two directions. This cell divides the pile being tested into two parts, an upper (UTE) and lower (LTE) tested element (see Fig. 3) and corresponds to a system of calibrated hydraulic jacks combined into a single module. It is connected, via

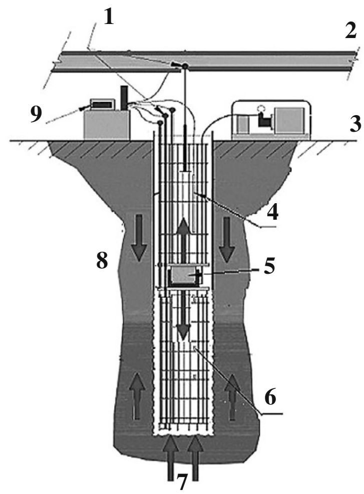

Fig. 3. Diagram for testing piles using the O-Cell method: 1) displacement sensors; 2) reference beam; 3) hydraulic system controls; 4) upper tested element (UTE); 5) O-Cell; 6) lower tested element (LTE); 7) resistance under the center; 8) resistance along the lateral side; 9) PC + data recorder.

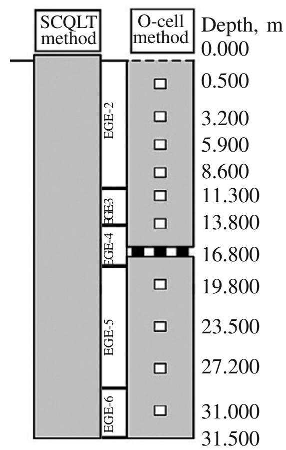

Fig. 4. Diagram of strain-gauge sensor mounting locations on bored piles: □) strain gauges; ■) hydraulic jacks (500 mt).

hydraulic hoses, to a hydraulic pump that is located on the surface of the ground [2]. The hydraulic jack is mounted at a depth of 1/2 the pile length, or 16.8 m.

When testing using the O-Cell method, particular attention is devoted to the study of the geological engineering composition of the soil mass at the construction site, since a differentiated determination of bearing capacity components (along the lateral surface and under the bottom end) reduces to the correct selection of the ratio of the pressure along the upper element and the resistance under the bottom end of the bottom element of the experimental pile.

It is also necessary to consider that pile material strength must be greater than the maximum assumed bearing capacity of the pile soil element [3].

Before testing, ten strain gauge sensors were mounted on the body of the experimental pile, and these were connected to the data recorder (datalogger). A diagram of their location at depths of 0.5-31.0 m and associated soil conditions is shown in Fig. 4.

Devices for measurement of displacements will be mounted at the jack installation level. The data from these devices are transmitted to the surface and undergo computer processing.

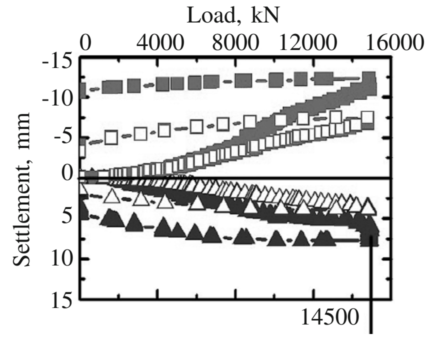

Fig. 5. Displacement results for piles RTR-1 and RTR-2 during O-Cell tests: ▲ and △) LTE of piles RTR-1 and RTR-2; □ and ■) UTE of piles RTR-1 and RTR-2.

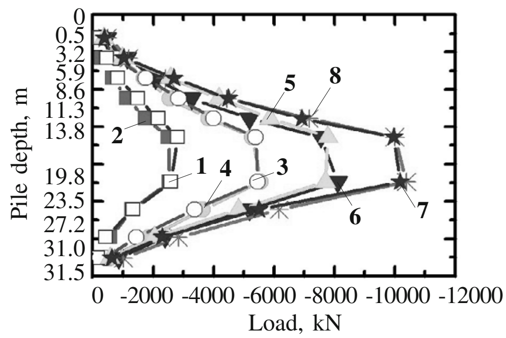

Fig. 6. Load distribution over the lateral surfaces of RTR-1 and RTR-2 (O-Cell method): 1, 2) 50% load; 3, 4) 100% load; 5, 6) 150% load; 7, 8) 200% load.

O-Cell testing, in distinction from SCQLT tests, allow two "load-settlement" dependences to be obtained. One describes pile resistance under the bottom end and the lateral surface (LTE); the second, only along its lateral surface (UTE) (Fig. 5).

Using the data from the two curves, we may obtain an equivalent "load-settlement" curve that is an analogue of the curve obtained using the SCQLT method. The standard principle for constructing an equivalent curve consists in summing the loads exerted on the UTE and LTE for fixed displacements [4].

Figure 6 shows the results obtained by the strain gauge sensors mounted in pile elements.

From the plot of the load distribution along the lateral surface, it is clear that at maximum load, the pile is being held by lateral soil resistance and only an insignificant part of it is exerted at the bottom end of the pile. Numerical values for pile lateral resistance by depth are shown in Table 2.

The minimum stress in experimental pile RTR-1 due to lateral soil compression is observed at a depth of 0.5 m and corresponds to 76 kN/m^2 at a maximum test load of 29000 kN (200% of the working load); for pile RTR-2, the minimum value was recorded at a depth of 0.5 m and equaled 83 kN/m^2 for the same test load [5].

It is known that soil receives load from the pile shaft in the case where the pile is displaced relative to the soil. Critical displacement determines the maximum load that the soil can accept from the pile shaft, and its value depends on the properties and condition of the soil. Tested pile foundations rest on crushed stone soil, and along the side, the greater portion of the load is borne by clay loam, the characteristics of which are shown in Table 1.

TABLE 2

Strain gauge sensor depth, m	Pile lateral surface resistance, kN/m^2, for a test load of, kN			
	7250	14500	21750	29000
0.500	24/21	57/63	73/79	76/83
3.200	43/43	116/96	187/110	196/143
5.900	77/55	129/100	188/142	212/240
8.600	80/72	135/151	199/225	286/321
11.300	83/97	179/184	245/301	388/362
13.800	86/118	197/208	245/353	481/477
19.800	110/114	189/180	335/293	458/437
23.500	107/107	180/165	248/252	402/363
27.200	78/63	165/153	239/240	276/286
31.000	30/45	116/145	167/175	190/207

Note: The number before the forward slash is the value for RTR-1; after the forward slash, for RTR-2.

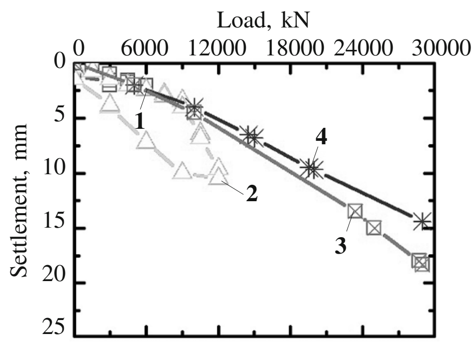

Fig. 7. Comparison of the test results: 1, 2) SCQLT method, pile No. 166 (6000 and 12000 kN, respectively); 3, 4) O-Cell method, piles Nos. RTR-1 and RTR-2 (29000 kN).

Curves of the "load-settlement" dependence, obtained using the SCQLT and O-Cell methods [6], are shown in Fig. 7.

The convergence of the plots is observed only during the initial stages of loading, after which changes are observed in the path of the SCQLT curve, which is typical for the creep phase of soil resistance, at a time when, at loads of 0-12000 kN, the O-Cell curve more closely corresponds to soil elastic resistance. Based on the results of unloading using the SCQLT method, we can still see that the residual part of the settlement is insignificant, i.e., elastic soil operation is discernible. The reason for the sharp changes in the path of the curve using the SCQLT method, which is not typical for elastic soil behavior, may be the load hold time (which is smaller as compared to the O-Cell test method).

Conclusions

1. O-Cell tests offer a new tool for evaluating the operation of piles in soil. In distinction from the SCQLT method, the O-Cell method allows a great deal of information to be obtained regarding the pile bearing capacity, and soil resistances under the bottom end and the lateral surface.

2. It is advisable to carry out O-Cell tests for large pile bearing capacities and large test loads. This test method does not require the setup of additional anchor piles or the presence of a ballast stand. The anchor system is the pile itself, and specifically, its upper tested element. Consequently, this method should be used even in confined environments.

3. When testing using the O-Cell method, it is important to correctly assess the ratio of resistance along the lateral surface and under the heel of the pile, and on this basis, to select the correct pile element length and maximum jack power.

4. O-Cell tests allow not only the overall bearing capacity to be obtained for piles with previously specified dimensions, but also the work of its separate components to be assessed, depending on soil characteristics.

5. It should be noted that even at the maximum test load for "top down" testing of piles using the SCQLT method, the pile is operating only elastically in the soil, which is indicated by the insignificant residual soil settlement after unloading.

6. For pile tests using the O-Cell method, at the 29000 kN maximum test load, both elastic as well as plastic soil deformation were observed, conditioned by the large-as compared to the SCQLT method-pile test load.

7. The results of static testing of experimental bored piles using the O-Cell method showed that the overall load on the pile is distributed nonuniformly between the lateral surface and under the bottom of the pile.

8. A comparison of "load-settlement" curves for the SCQLT and O-Cell test methods shows convergence of curves during the initial stages of experimental pile loading. The reason for divergence of test results during later stages of loading, in all probability, is the hold time while applying load to the pile.

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