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COMPARATIVE MODEL TESTS OF SDP AND CFA PILE GROUPS IN NON-COHESIVE SOIL

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Abstract: The research topic relates to the subject of deep foundations supported on continuous flight auger (CFA) piles and screw displacement piles (SDP). The authors have decided to conduct model tests of foundations supported on the group of piles mentioned above and also the tests of the same piles working as a single. The tests are ongoing in Geotechnical Laboratory of Gdańsk University of Technology. The description of test procedure, interpretation and analysis of the preliminary testing series results are presented in the paper.

Key words: *CFA piles, screw displacement piles, deep foundation, model tests, group of piles*

1. INTRODUCTION

The technology of CFA and SDP piles is widely developed in practice due to its efficiency. In literature there is a lot of information and research results concerning this pile technology. Several design methods for these piles have also been proposed. The information and data refer mainly to piles working as a single. There are rather scarce data about the characteristics of these piles working in group. Some model tests of pile groups concerning precast driven and bored piles were performed, for example, by Tejchman [3], [4], Knabe [1] or Słabek [3].

Due to the differences in installation technique, there is a belief that the work of CFA and SDP piles in group differs from each other significantly. Additionally, there is a need for explanation of some technical issues related to the installation process of SDP piles in group. This concerns, for example, the influence of current pile installation on neighboring piles made before, the effect of pile installation sequence in group on the whole foundation bearing capacity and other effects. The issues mentioned are of big interest to contractors and designers.

Since about 2005, one of the subjects of research in the Department of Geotechnics, Geology and Maritime Engineering in GUT has been analysis of screw displacement piles technology. As a natural consequence of the study concerning single pile behavior in the subsoil is to take into consideration and analysis also a group of piles.

Practical experiences related to SDP piles working as a single allow us to establish a thesis that a group of such piles will work better than a similar group of bored piles.

To confirm this thesis the authors have decided to investigate the model scale foundations supported on SDP and CFA piles.

The test results and their comparison will allow us to find out how piles of both technologies work in the group and also to calibrate the existing design methods of such foundations.

2. RESEARCH METHODOLOGY

Model tests were carried out using the existing research device in the Geotechnical Laboratory of GUT. The device consists of a steel container (2.0 m in diameter and 2.0 m in height) for soil and a steel frame for applying load on foundation models.

The process of soil preparation, model piles installation, construction of foundations, performance of tests and measurement technique are described in the following sections.

2.1. SOIL PREPARATION AND SOIL PROPERTIES

Pile model tests were carried out in fine sand. First, the soil was loosed by liquefaction with water flowing in upward direction. Next, after lowering the water table to the level of ground surface, a vibratory compaction of soil was carried out. Next, the top soil part of 0.5 m thickness was mechanically loosed to create a weak layer. At the end, the water was gravitationally removed from the ground.

In order to identify the soil density and its strength properties, static penetration tests were performed at four points. The diagrams of cone resistance q_c related to soil preparation for SDP and CFA pile foundations tests are shown in Fig. 1. These tests were performed in two separate series of soil preparation.

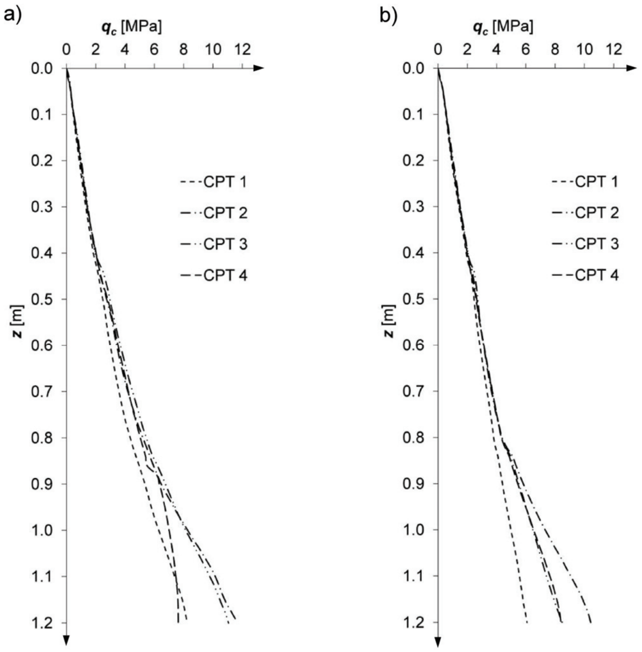

Fig. 1. Soil conditions, expressed in the form of cone resistances: (a) for test of SDP piles, (b) for test of CFA piles

It can be seen that the soil conditions for both tests were prepared in a similar way and soil strength properties (related with cone resistances q_c) were close to each other.

2.2. CONSTRUCTION OF FOUNDATION MODELS

To install SDP and CFA pile models there was applied the same equipment (pile augers and rotary drive) as developed for earlier research project concerning model tests of single piles [2].

Pile models were made to 1:7.5 scale. In both tests, the foundation was supported by nine piles in a three by three arrangement (Fig. 2). One meter long piles with a diameter of 60 mm were installed at intervals of 275 mm between their axes.

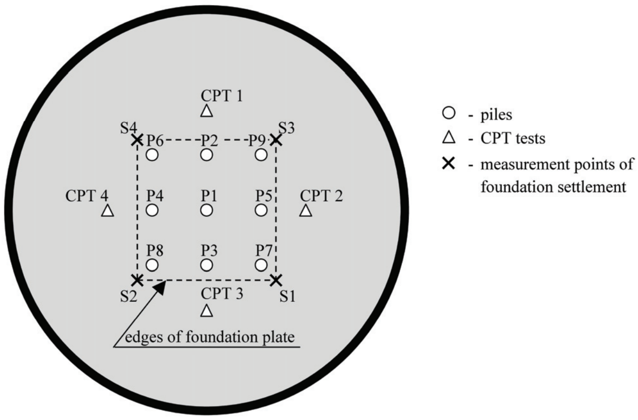

Fig. 2. The geometry and order of piles in model tests

To protect the previously made piles against destruction, the appropriate sequence of pile installation

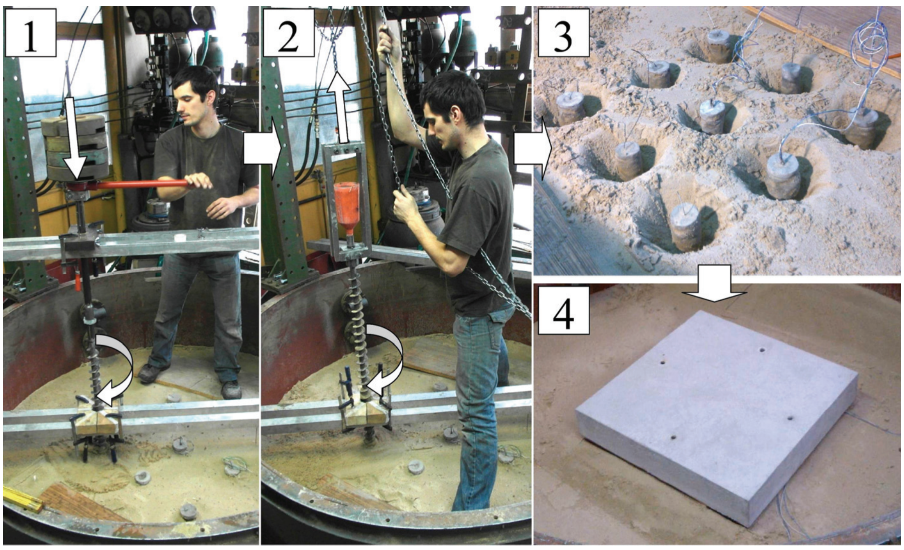

Fig. 3. Several stages of test preparation for CFA piles: (1) pile auger penetration into the soil; (2) pile concreting, (3) completed piles without plate; (4) foundation plate lying on the piles

was applied (Fig. 2). In the case of SDP piles there were also applied an adequate time intervals between the installation of each individual pile. After the installation of pile No. P1 – one day break was made. Next piles Nos. P2 and P3 were made on the same day. After the next daily break piles Nos. P4 and P5 were installed. Finally, after the last daily interval corner piles Nos. P6, P7, P8 and P9 were installed.

One week after the last pile had been installed, the reinforced concrete slab of dimensions: 0.70 m × 0.70 m × 0.12 m was put on the group of piles and connected with their heads. The plate had no contact with the ground.

Several stages of piles and foundation slab installation are shown in Fig. 3.

2.3. TESTING AND MEASUREMENT TECHNIQUE

Both foundations supported on SDP and on CFA piles were tested by using similar loading and measurement procedures.

Figure 4 presents a view of the pile foundation under the testing. We can also see parts of loading and measuring systems.

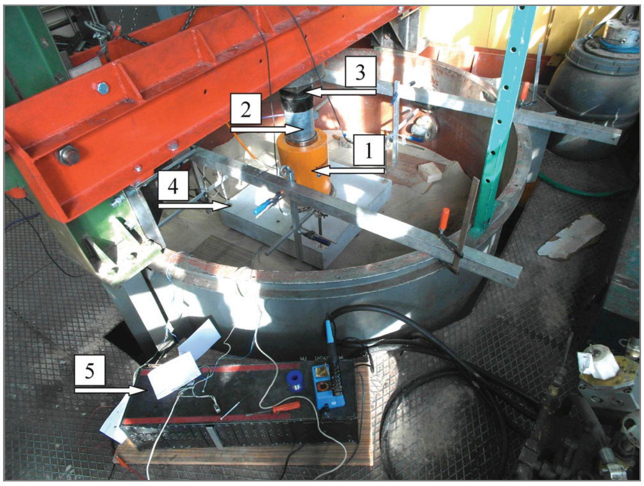

Fig. 4. A view of loading and measurement equipment during the pile foundation test: (1) hydraulic cylinder; (2) force cell; (3) joint; (4) displacement sensors; (5) strain gauge signal amplifier with multimeter

The load of the foundation was increased in steps by using a hydraulic cylinder. During each step of load the following values were measured and recorded:

- global force transmitted on the foundation,
- settlement of the foundation plate (in each corner),
- electric signals from sensors installed in heads of selected piles.

The electric sensors were installed in pile heads in order to measure axial forces transmitted from the plate to the piles. Unfortunately, measurements showed that these sensors were very sensitive to the bending of piles. In the tests planned in future, this problem will be solved by the use of:

(a) joints between the piles and foundation plate,

(b) construction of strain gauge-sensors allowing only the vertical load to be measured.

Each step of loading was kept up to the settlement stabilization. Load increasing was continued up to the ultimate state.

Figure 5 presents the basic results of loading tests in the form of load-settlement curves for both SDP and CFA pile foundations. In the diagrams there were taken the average values of settlements measured in all corners of the plate, but one must note a small inclination of the foundation slab during the tests. It means that the stiffness of piles was not uniform.

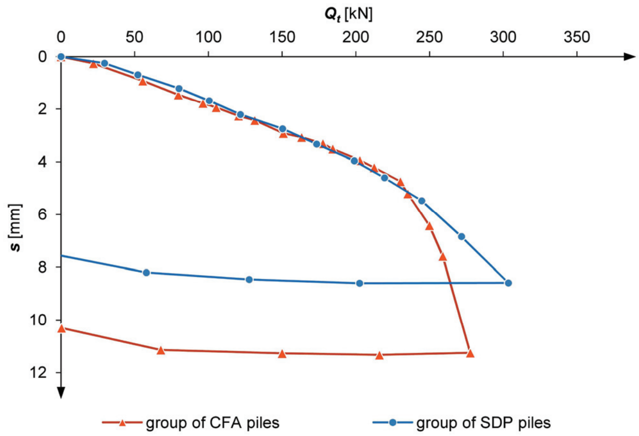

Fig. 5. Load-settlement curves of foundations supported on groups of SDP and CFA piles

2.4. TESTS OF SINGLE PILES

Apart from the tests of pile groups also the tests of single piles were carried out. Two SDP and two CFA piles were installed for tests. Single piles were prepared of the same geometrical characteristics as piles in groups. Also the soil conditions were prepared in the same manner and tested by CPT. Figure 6 presents the plan of soil container with the localization of piles and points of CPTs as well as the picture of a single pile being under the loading test.

Figure 7 presents the q_c diagrams of CPT tests carried out in soil prepared for single pile tests and the Q-s curves as a results of pile load tests.

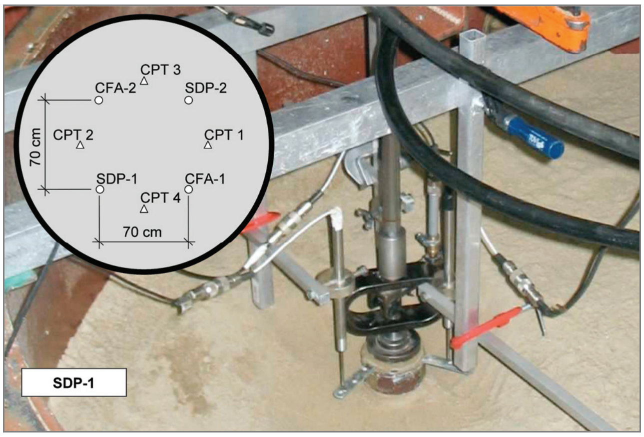

Fig. 6. Localization of single piles and CPTs in the container plan and view of a single pile under the loading test

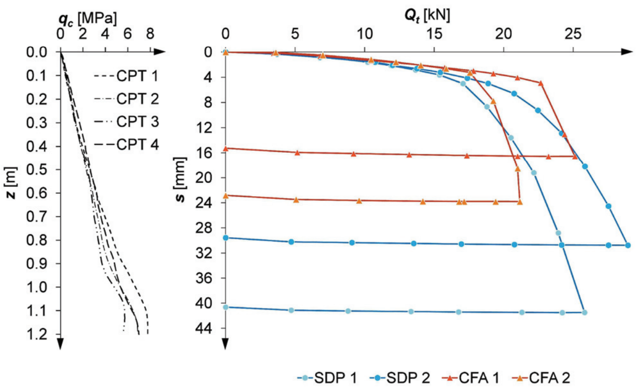

Fig. 7. Diagrams of q_c from CPT tests and *Q*-*s* curves from single pile load tests

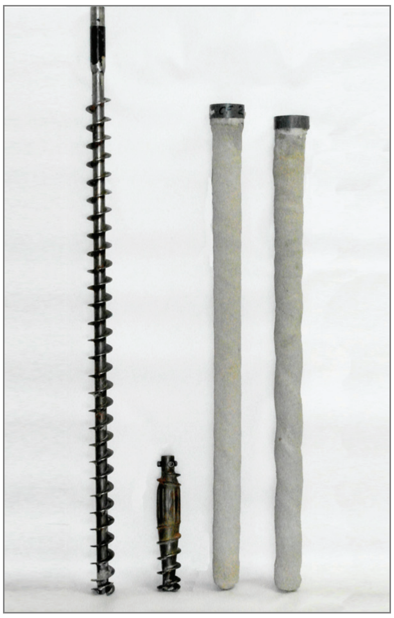

Fig. 8. Pictures of auger models which were used for pile installation and pile models after removal from the soil (starting from left: CFA auger; SDP auger; CFA pile model; SDP pile model)

3. ANALYSIS OF PILE LOAD TEST RESULTS

Analysing the *Q*-*s* curves of pile groups presented in Fig. 5, one can notice that in the initial parts both loading curves are very similar to each other. The difference appears in the final phase of loading. The ultimate load for foundation supported on SDP piles is about 20% bigger than for foundation on CFA piles (the curve of SDP pile foundation required extrapolation). One should conclude that there is not any big difference in loading characteristic between foundations supported on SDP and CFA piles, especially in the range before the limit state. However, the foundation supported on SDP piles is safer than that supported on CFA piles. Similar behavior of both foundations can result from the high value of sand density prepared for the tests (q_c = 6–8 MPa at a 1.0 m depth). Maybe the next series of tests, which will be prepared in sand of less density, with allow us to explain this phenomenon.

A very similar situation we can observe also in the case of single pile test results, presented in Fig. 7. The differences in *Q*-*s* curves of single piles result to a greater extent from pile localization rather than from pile technology.

To find out the relation between piles working in groups and piles working as a single, the results of single pile tests were multiplied by 9 and curves obtained in such a way were compared with the curves obtained from the tests of pile groups. These curves are presented in Fig. 9 and in Table 1 there are presented the ultimate values of total loads Q_{ult} of the foundation. The value of ultimate load was determined by using criterion as presented in Fig. 9. Because the load-settlement characteristics for each pair of single piles differ among themselves, the average characteristics were taken into account as a representative.

The analysis of test results showed that:

- the total ultimate bearing capacity of SDP pile groups is 22% bigger than the total ultimate bearing capacity of CFA piles;
- in the case of SDP piles, the total ultimate bearing capacity of pile groups is 37% bigger than the ultimate bearing capacity of the sum of nine single piles;
- in the case of CFA piles, the total ultimate bearing capacity of pile groups is 26% bigger than the ultimate bearing capacity of the sum of nine single piles.

Bigger bearing capacity of pile groups in comparison with the sum of bearing capacity of single piles

Table 1. Ultimate loads of piles

Foundation type	Cone resistance q_c [MPa]			Ultimate load Q_{ult} [kN]
	z = 0.5 m	z = 0.75 m	z = 1.0 m	
Group of CFA piles	2.60	3.95	6.32	256
Group of SDP piles	2.75	4.63	7.43	330
Group of CFA piles taken as a sum of single piles (Q_{ult} of single pile × 9)	2.46	3.79	5.55	189
Group of SDP piles taken as a sum of single piles (Q_{ult} of single pile × 9)				208
Single CFA pile				20.95
Single SDP pile				23.16

can partly result from different sand density. As can be seen in Table 1, in the case of single pile tests the cone resistances q_c were about 20% smaller than in the cases of pile group tests.

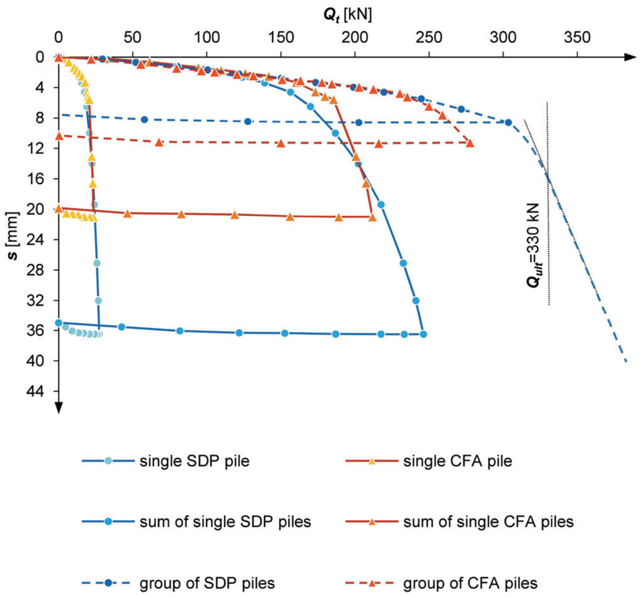

Fig. 9. Q-s curves of pile groups and sums of single piles

4. CONCLUSIONS

The research described in this paper was the preliminary one and it will be developed in future and supplemented with additional series of tests.

The results of model tests showed that in soil conditions, applied in these particular cases, the load-settlement characteristics of SDP and CFA pile groups do not differ from each other very much. It is probably the matter of a relatively high density of sand, in which the behaviors of displacement and bored piles are close.

The total ultimate bearing capacity of a group of piles is higher than the sum of single piles bearing capacity by about 37% in the case of SDP piles and of about 26% in the case of CFA piles.

The settlement of SDP and CFA pile groups is smaller than settlements of a single pile under the equivalent load.

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