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ADVANCED FIELD INVESTIGATIONS OF SCREW PILES AND COLUMNS

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Field investigations concerning screw piles and columns have been carried out for the "Bearing capacity and work in the soil of screw piles" research project, financed by the Polish Ministry of Science and Higher Education – project No N N506 369234. The tests of three instrumented screw piles were conducted together with CPTU tests and measurements of pile installation parameters (especially torque). The objectives of field investigations and the entire research project include discovering how screw piles work in the soil, locating and describing the correlations between CPTU results and rotation resistance during pile auger installation and next establishing correlations between CPTU results, rotation resistance and the bearing capacity of this kind of piles. The paper describes the investigation procedure and the basic results of tests carried out in the first of a series of sites.

Key words: screw piles, screw columns, CMC columns, displacement piles, bearing capacity of piles, field investigations.

1. Introduction

Screw, cast-in-situ piles, and columns are elements of displacement pile technology. The process of their installation comprises the screwing penetration into the soil of a displacement auger, and next unscrewing the auger whilst simultaneously concreting a pile or column shaft. Concrete is pumped under pressure through an opening in the axis of the auger into the space left in the soil. This kind of pile installation does not excavate and thus increases the density and stress in the soil around the pile. Moreover, this type of pile installation causes neither vibrations nor great noise.

Thanks to their technological advantages, screw piles are very useful in urban areas and the preferred choice for soil conditions of average geotechnical properties, whereas screw columns are a very effective method of soil improvement. Such piles effectively fill the gap between driven and bored piles. The piles are reinforced, whereas the columns are not. Moreover, piles are usually longer than columns.

Screw piles and columns have been applied in civil engineering from about thirty years, mostly with good results. Many varieties of screw pile technology have been

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introduced, for example: Atlas, Omega, CMC, SDP, DeWaal, Olivier and Screwsoil. Nevertheless, there is still a problem in finding an optimal pile and column design method. There is also a problem in selecting the best geometrical parameters (diameter and length) for particular soil conditions and for piling machines.

2. Aim and subject of research project including field tests

As mentioned above, there have been many practical experiences connected with screw piles (e.g. Botiau & Cortvrind [1], Bustamante & Gianeselli [2], De Cock [3], Gwizdala at all [4], Gwizdala & Krasinski [5], Van Impe [6]). Moreover, many screw pile experiments have already been conducted in the real scale (e.g. Martens & Huybrechts [7, 8], Holeyman [9]), and sometimes in model scale (Slatter at all. [10], Krasiński [11]).

The real scale field investigations of screw piles described here are a part of a larger research program entitled "Bearing capacity and work in the soil of screw piles", which also includes model tests, and theoretical analyses.

The general aim of this research project is to identify the work characteristics of screw piles and columns in non-cohesive soils. There are three principle subjects to be investigated:

1) The correlation between q_c resistances of CPT and screwing resistances during pile installation.

2) The correlation between screwing resistances and the bearing capacity of piles.

3) The total load (Q_t) distribution along the shaft (Q_s) and at the base (Q_b) of the piles.

The tests described in this paper concern CMC (Controlled Modulus Columns) installed in a subsoil comprising weak organic mud and peat underlined by medium grain sand.

3. The site and soil conditions

The experiments were carried out in the Polish region of Żuławy on the site of a road under construction, about 20 km from Gdansk. The site was organised in collaboration with the company contracted to improve the ground for the road embankment. The ground improvement was performed using approximately 10 m CMC columns with a nominal diameter of 400 mm. The reaserch was carried out on the actual road embankment columns. These included 3 test columns (piles) and 12 anchoraging columns. Fig. 1 presents the investigation site map.

The site subsoil was of a typical construction for piles or columns, comprising an approximately 6 m layer of organic mud and peat, below which there were medium and fine sands extending to well over 15 m beneath the surface. On the ground surface

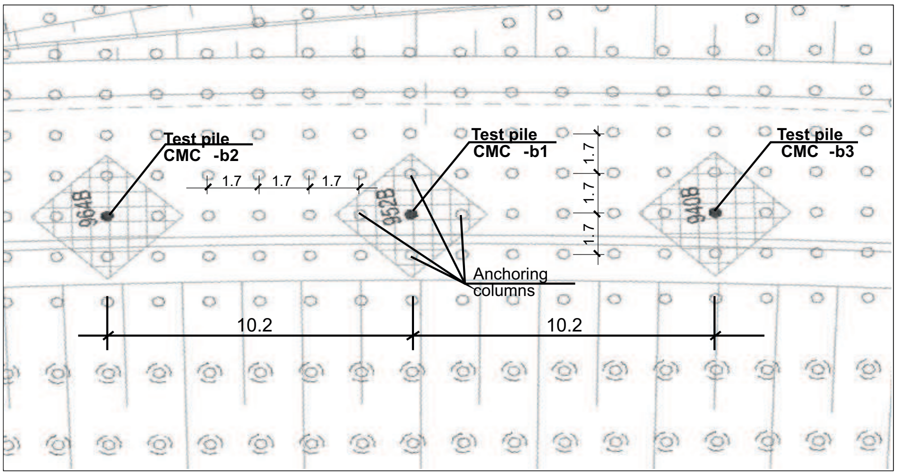

Fig. 1. Investigation site map.
Rys. 1. Plan poletka doświadczalnego

there was also a sand layer of about 2.0 – 2.5 m. The ground water was about 0.8 m below the ground surface. Fig. 3 presents these soil conditions in the form of CPTU tests diagrams. These show that the sands were of high density ($q_c \approx 25$ MPa, which corresponds to $I_D > 0.8$). It should be noted that such soil conditions are not very suitable for screw piles, but very good for screw columns. Screw piles are in turn more suited to sands of medium density ($q_c < 15$ MPa).

4. Investigation procedure

4.1. CPTU Tests

First of all CPTU tests were conducted in the axis of each testing columns, using a penetrometer with electric cone. The soil was tested to approximately 13 ÷ 14 m below the ground surface. Fig. 2 presents diagrams of q_c and f_s resistances, as well as R_f values and water pore pressure u for CMC-b1. (The results for other CMCs were very similar.)

4.2. Installation of piles

The test piles were made following a similar procedure to that of the other soil improvement columns installed on the site. However, in the case of test piles the screwing augers penetrated up to maximum soil resistance, i.e., to maximum piling machine torque. The nominal piling machine torque was 160 kNm. The piling machine and a

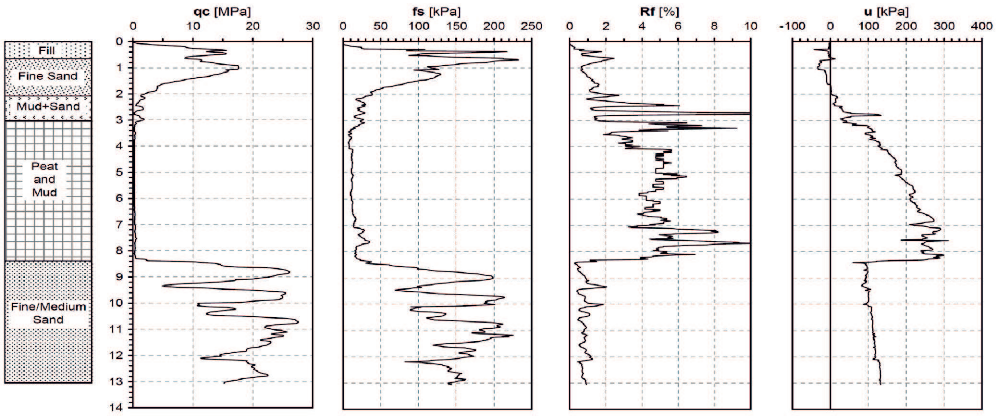

Fig. 2. Sample CPTU test results (other results were very similar – see Fig. 9, 10).
Rys. 2. Przykładowy wynik sondowania CPTU (bardzo podobne wyniki otrzymano w pozostałych punktach – zobacz Rys. 9 i 10)

screwing auger is shown in Fig. 3. During pile installation many technical parameters were measured, e.g. torque, concrete pressure, and concrete consumption. The sample of pile specification is shown in Fig. 4.

Fig. 3. Screwing auger and piling machine used in the experiment.
Rys. 3. Świder i palownica do wykonywania badanych pali i kolumn

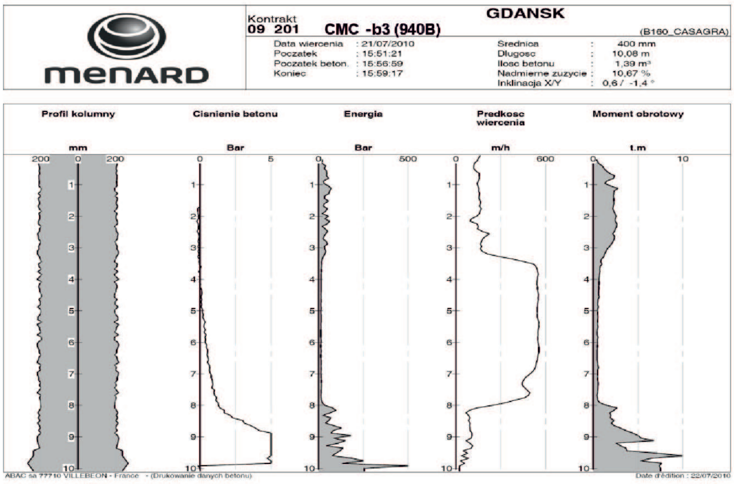

Fig. 4. Sample pile installation reading.
Rys. 4. Przykładowa metryka wykonania pala

Once the test piles were concreted, special steel pipes were inserted along the pile axes right down to the tip. These tubes (Fig. 5) were necessary for the installation of special measuring instruments, which will be described later in this paper.

Fig. 5. Insertion of measuring equipment pipe and fully prepared pile.
Rys. 5. Wprowadzanie rurki pomiarowej do pala oraz w pełni wykonany pal badawczy

The anchoring columns were reinforced with two steel bars in order to connect the loading construction and bear the pulling forces acting on the column.

4.3. Pile loading tests with application of special measurements

The pile bearing capacity tests were performed with a static load some 30 days after pile installation. In addition to standard measurements of the force and settlement on pile heads, measurements of axial force distribution along pile cores were also conducted using a chain of five connected, retrievable extensometers (Fig. 6). The construction and operating principles of the extensometers have already been described in detail, see for example Krasiński & Sieńko [12]. Their construction, using vibrating wires, allows us to measure pile shortening in several sections. Next, if we also know the cross section of the pile and the concrete modulus, we are able to estimate the axial force values in each pile section from top to bottom. In this way it is possible to obtain information on pile shaft Q_s and base Q_b resistances as well as the load carried by friction acting in weak soil.

Fig. 6. Part of extensometer chain and its installation inside the test pile.
Rys. 6. Fragment łańcucha ekstensometrycznego oraz jego instalacja w palu badawczym

The length of particular pile sections and the collocation of extensometers were each time adjusted to the soil configuration. The extensometer chain was inserted into the pile axis pipe, pre-stressed and blocked by special air pressure activated anchors (Fig. 6). To measure the pile core axial stiffness during the loading test, the first measuring pile section was appropriately short (0.85 m) and the surrounding soil was excavated in order to eliminate friction.

Pile tests were carried out applying a static, compressive load with the axial force produced by a hydraulic jack and measured with a load cell (Fig. 7). Pile head settlement and extensometer readings were taken at each stage, during which the load was increased by approximately 80 kN. Up to approximately 600 kN, each loading step lasted until the pile head settlement stabilised, after which the pile was unloaded and reloaded. Beyond the force of 600 kN, the load was increased by the same increments as earlier, but this time each stage lasted approximately 30 minutes regardless of settlement stabilisation. Unfortunately, because of problems with bearing capacity of anchoring columns, it was not possible to achieve the limit values of pile loadings.

Fig. 7. Screw pile at static load test.
Rys. 7. Pal wkręcany w czasie próbnego obciążenia statycznego

5. The results of pile tests

The basic results of pile loading tests in the form of $Q - s$ curves are presented in Fig. 8. These curves are not consistent: pile 1 and 3 head settlements are considerably greater than in the case of pile 2. The measurement obtained from the extensometers has proved that the much more considerable settlements of piles 1 and 3 were actually caused by excessive deformation of the pile core in the area where there was a weak soil. It is possible that these pile sections were weaker (perhaps narrower). This question was not fully answered yet and will be the subject of another analyses.

Figure 9 presents the distributions of axial forces along pile shafts, with the load being increased in stages. These plots are presented together with q_c resistance plots from the CPTU tests and torque M_T plots from measurements taken during pile instal-

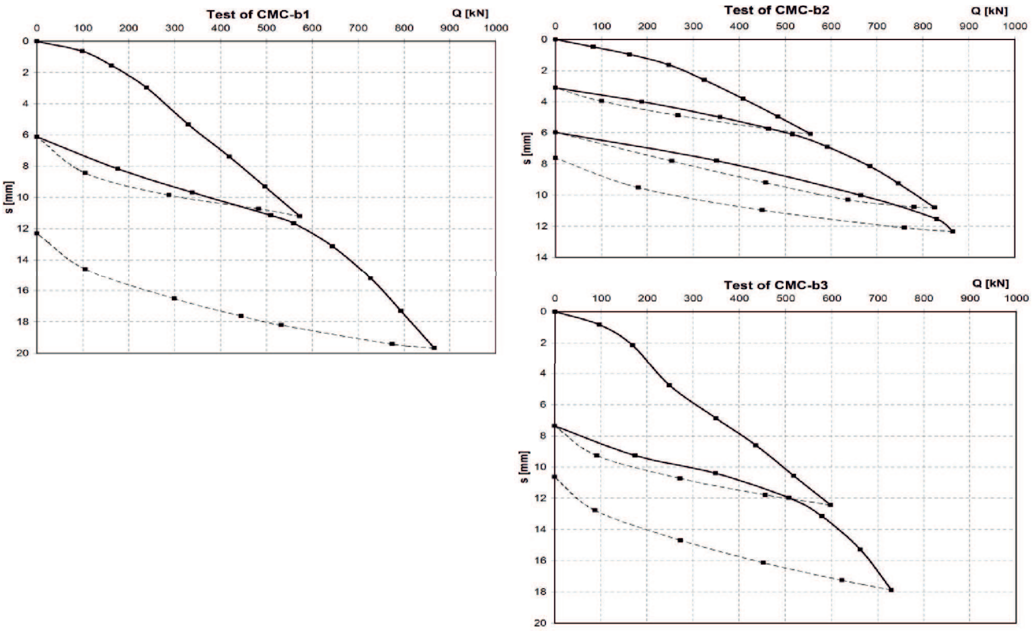

Fig. 8. Basic Q-s curves from pile static load tests.
Rys. 8. Podstawowe wykresy Q-s z próbnych obciążeń pali

lation. By studying these plots together with the $Q-s$ curves presented in Fig. 8, it was possible to separately identify the mobilisation of soil resistance along the pile shafts (Q_s), under the bases (Q_b) and in particular shaft sections in weak soil areas (T_w). The opportunity of obtaining such relations as presented in Fig. 9 and 10 is a major advantage of the application of extensometers during pile loading tests. They provide us with much information about the behaviour and work of piles in the subsoil.

6. Analyses

Following the results presented in Fig. 10, we can observe that generally the shaft resistance of the investigated screw piles carried a greater part of their load. The base resistance of these particular piles was not so high. Soil resistances Q_b and Q_s did not reach their limit values because the loading forces did not reach their limit values. It should be noted that the shaft resistances usually reach their limit values with relatively small pile displacement – c. 5 mm. However, in the case of these particular piles, the shaft resistances increased considerably even after the pile was displaced by more than 5 mm. Base resistance increases, on the other hand, became smaller with each subsequent pile displacement, and gradually approached their limit value.

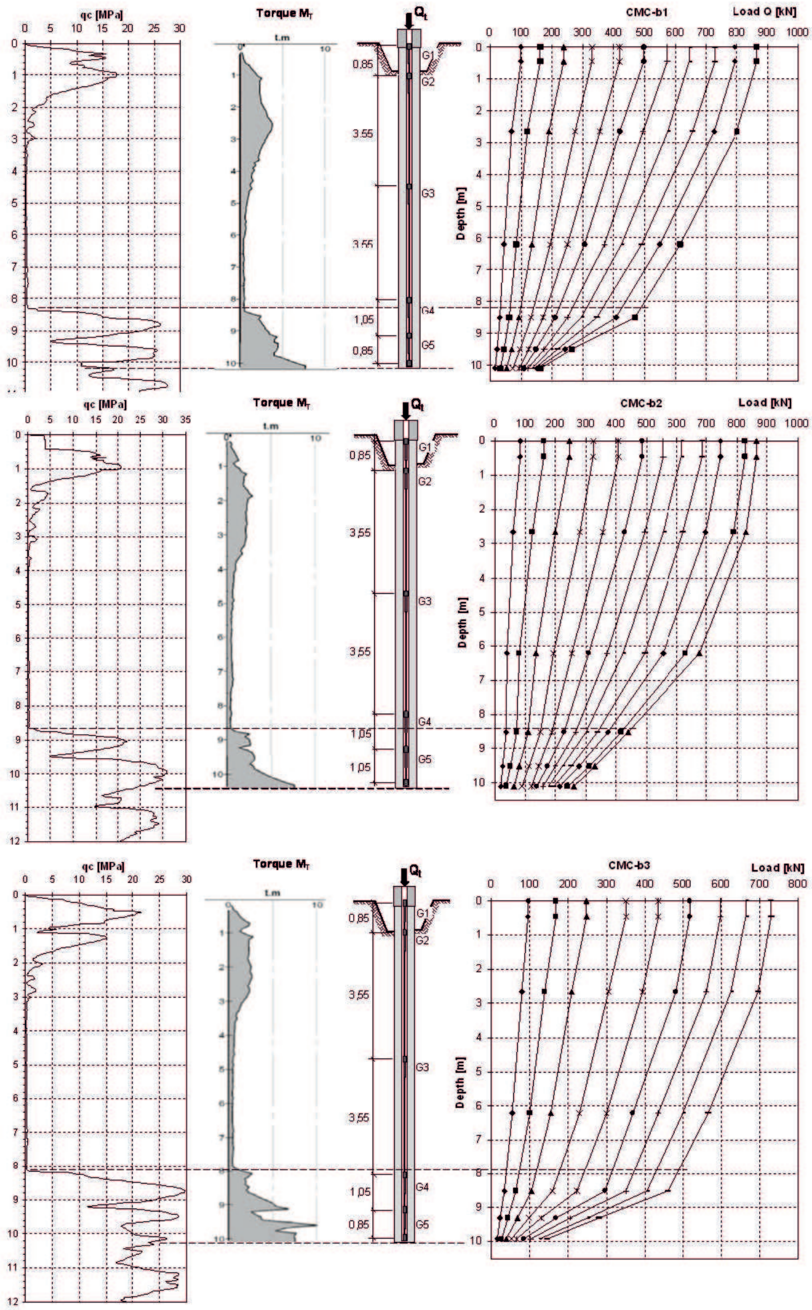

Fig. 9. Vertical distribution of axial force along CMC piles.
Rys. 9. Rozkłady pionowe sił osiowych wzdłuż pali typu CMC

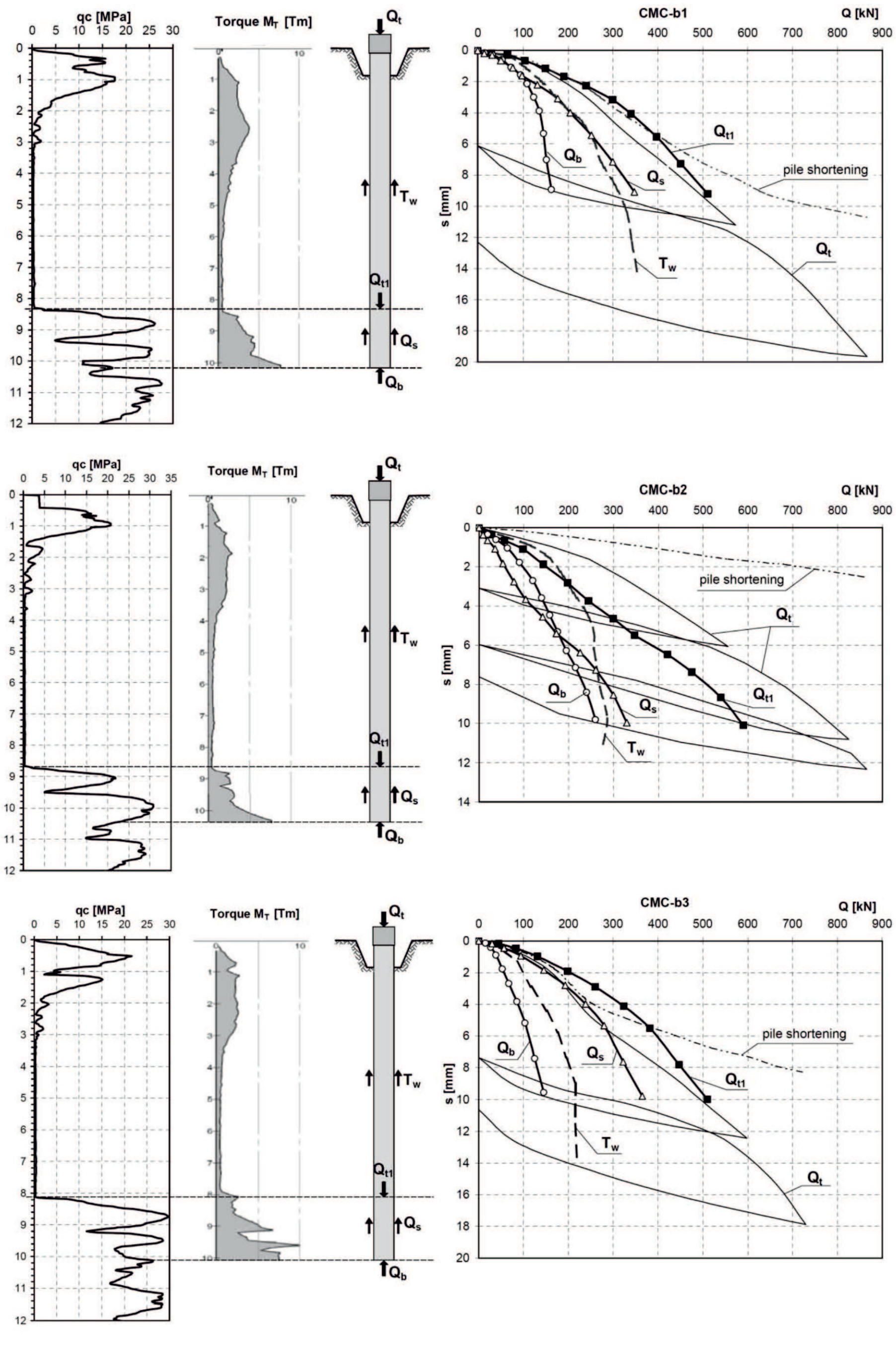

Fig. 10. Mobilization of Q_b, Q_s and T_w resistances in CMC pile tests.
Rys. 10. Mobilizacja oporów Q_b, Q_s i T_w w czasie próbnych obciążeń pali typu CMC

Taking the above observations into account, one may conclude that pile installation by screwing penetration improves soil properties (density and stress state) near the shaft but it does not have such a notable effect under the base. This is due to the auger shape and screwing technique.

Another issue worth noting is that shaft friction in the upper part of a weak soil layer carries a significant part of total pile load. The values representing this friction, T_w, were approximately 200 – 300 kN or more. The relatively high T_w values are probably due to the sand layer directly above the weak soil and/or the high velocity of pile shaft displacements in the weak soil. In the long term, especially when a group of piles or columns are working together, the shaft friction of weak soil is bound to decrease considerably.

More exact analyses and theoretical interpretations of all the project results will be conducted after the experimental part of the project is completed.

7. Conclusions

The results of the experiment obtained so far fully justify the decision to conducting the tests of screw piles, as they have already produced interesting and valuable information.

Even now the test results allow us to make the following conclusions:

• In the cases when there were bearing layers of dense sands with CPT resistances of q_c = 20 – 25 MPa, the screw auger was not able to penetrate them deeper than 2.0 m. This was due to the type of auger used in these particular tests and the machine having 160 kNm torque. This means that such soil conditions are not very suitable for the installation of long screw piles. Better results might possibly be obtained by using CFA piles. Our experiments have shown that such soil conditions are adequate for the application of screw columns, as they required less penetration (1-2 m) into the bearing layer of soil.

• In the cases of thick layers (over about 4 m) of a very weak soil (something that was usually encountered on this particular site) there is a real risk of weaknesses in the pile core occurring. This is a serious problem not only for screw piles, but also for another cast in-situ-pile technologies.

• By using a chain of extensometers as additional measuring equipment in static load tests, we can obtain valuable data concerning pile-soil interaction. This information allows for a much more detailed interpretation of the test results. Bearing in mind that the application of retrievable (i.e. reusable) extensometers is relatively simple and cheap, the author firmly believes that this method will be more widely used not only in research but also in practice.

The experimental site described in this paper was the first one in the author's research project. It is normal that in such situations not everything goes according to plan. The author has already prepared two subsequent experimental sites elsewhere, which have not yet been tested. For this research project similar experiments are planned for a total of 6 to 8 sites in different areas and with different soil conditions. More comprehensive conclusions concerning how screw piles work in the soil will be presented once all the project investigations are completed.

8. Aknowledgements

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ZAAWANSOWANE BADANIA TERENOWE PALI I KOLUMN WKRĘCANYCH

S t r e s z c z e n i e

Dla potrzeb projektu badawczego „Nośność i praca w gruncie pali wkręcanych" finansowanego przez Ministerstwo Nauki i Szkolnictwa Wyższego – projekt nr N N506 369234 rozpoczęto badania terenowe pali i kolumn wkręcanych. W artykule opisano badania na pierwszym zorganizowanym do tego celu poletku doświadczalnym. Przeprowadzono na nim badania trzech pali wkręcanych z użyciem specjalnego systemu pomiarowego oraz w połączeniu z badaniami podłoża gruntowego za pomocą sondowań CPTU oraz z pomiarami parametrów wykonawstwa pali (moment wkręcający i inne). Celem badań terenowych i całego projektu badawczego jest rozpoznanie charakteru pracy pali wkręcanych w gruncie oraz określenie zależności pomiędzy wynikami sondowań CPT a oporami wkręcania i nośnością pali wkręcanych. W artykule zawarto opis przebiegu oraz podstawowe wyniki wykonanych badań.

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