Proceedings of the 20th International Conference on Soil Mechanics and Geotechnical Engineering– Rahman and Jaksa (Eds)

Model tests of cast-in-place piles formed by using different types of auger

Essais sur modèle de pieux coulés en place formés à l'aide de différents types de tarière

Adam Krasiński, Paweł Więcławski, Mateusz Wiszniewski & Tomasz Kusio
Faculty of Civil and Environmental Engineering, Gdansk University of Technology, Poland, adam.krasinski@pg.edu.pl

ABSTRACT: Model tests are still a popular research tool used to observe and determine the mechanisms of pile-soil interaction. Due to the significant scale effect, the results of model tests performed in the 1g system can only be analysed from the qualitative side. This article describes and presents the results of 1g pile model tests carried out for comparative purposes. There were tested the effectiveness and efficiency of various types of drilling augers forming cast-in-place piles in non-cohesive soil. The SDP and prototype DPDT augers were mainly tested. The tests were performed in fine, moist and fully saturated sand. The screwing resistance of individual drills and *Q-s* characteristics of pile models were analysed, with its division into the shaft and base resistances. Pile test results were correlated with CPT results. Comparative analyses have shown some advantages and disadvantages of the DPDT auger versus the SDP drill in relation to the screwing torque, load-bearing capacity and settlement characteristic of piles formed by both augers.

RÉSUMÉ: Les tests sur modèles sont toujours un outil de recherche utilisé pour analyser et déterminer les mécanismes d'interaction pile-sol. En raison de l'effet d'échelle important, les résultats des tests sur modèles réduits effectués à 1g ne peuvent être analysés que qualitativement. Cet article décrit et présente les résultats d'essais sur modèles de pieux 1g effectués à titre comparative. On a testé l'efficacité et l'efficience de différents types de tarières de forage formant des pieux coulés en place dans un sol non cohérent. Les tarières SDP et prototypes DPDT ont été principalement testées. Les essais ont été réalisés dans du sable fin, humide et totalement saturé. La résistance au vissage des forêts individuels et les caractéristiques *Q-s* des modèles de pieux ont été analysés, avec la répartition entre résistances de fût et de base. Les résultats des tests de pieux étaient corrélés aux résultats du CPT. Des analyses comparatives ont montré certains avantages et inconvénients de la tarière DPDT par rapport au forêt SDP en ce qui concerne le couple de vissage, la capacité de charge et la caractéristique de tassement des pieux formés par les deux tarières.

KEYWORDS: pile model test, cast-in-situ piles, screw displacement piles, pile auger, pile load test.

1 INTRODUCTION.

Screw displacement piles (SDP) are currently one of the most popular pile installation technology. Its popularity and attractiveness come from its numerous advantages. For over 30 years this technology has been intensively researched in many countries. The results of these studies and the problems characteristics were discussed in publications like: Bustamante &Gianeselli (1993), Bottiau&Cortvrindt (1994), De Cock (2001), Maertens&Huybrechts (2003), Van Impe (2003), Prezzi&Basu (2005). For more than 10 years, authors of this paper have also dealt with the issue of screw displacement piles in their research, their work have been published in e.g. Gwizdała et al. (2006), Krasinski (2010, 2012, 2014), Krasinski&Kusio (2014, 2015, 2017).

Disadvantage of the technology is the high soil resistance during pile forming by augers, especially in sandy soils. This resistance generates difficulties in passing through intermediate sand layers and limits the pile lengths. There is no such limitation in CFA pile technology for example, however, SDP piles are still more readily used. The problem of screwing resistance of displacement augers has been presented and analyzed by NeSmith (2003), Baxter (2006), Krasinski (2014), among the others.

A method for solving high screwing resistance problems may be to select an auger with a right shape. Many varieties and models of displacement pile augers can be found in the contractor market, such as "Atlas", "Omega", SDP, CMC, FDP, "De Waal". New auger designs continue to be developed. The searched for auger would give lower screwing resistance, but at the same time would not cause significant degradation of pile bearing capacity and pile-soil interaction parameters.

The discussed topic was also addressed by the authors. The research project "DPDT-Auger" carried out in cooperation with the Polish geotechnical contractor Budokop was launched at the Gdansk University of Technology. The main subject of the project is to test a prototype, original version of the auger with the DPDT (Displacement Pile Drilling Tool) symbol - Figure 1, which was patented in Poland in 2020 (patent no. PL 235442 B1). Model tests were the first stage of the project.

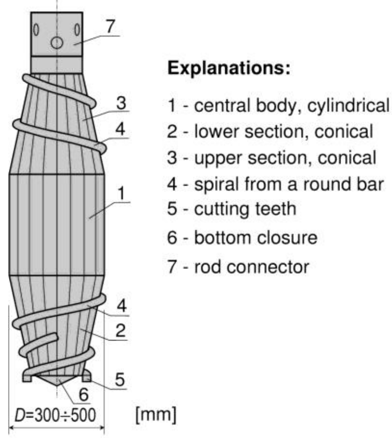

Figure 1. Scheme of the prototype DPDT auger (Displacement Pile Drilling Tool).

2 DESCRIPTION OF THE MODEL TESTS

A number of pile model studies have been already carried out in the past in Geotechnical Laboratory of GUT. Authors have acquired significant experience and developed proven research methods, which, together with the results, were published in several of papers listed above.

The aim of model tests described in this paper was to directly compare technological processes of constructing displacement piles formed by various augers types, as well as characteristics and parameters of their interaction with soil during load transfer. The research covered SDP, DPDT, DPDT-S, "DeWaal" and CFA auger models (Fig. 2).

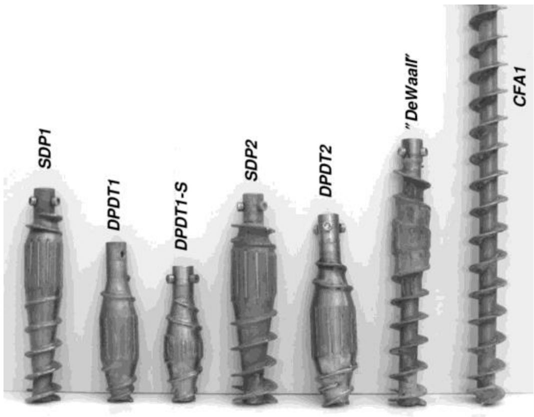

Figure 2. Models of tested augers

Models shown in Figure 2 are scaled-down (1:7,5) copies of the real augers. The augers SDP1, DPDT1, DPDT1-S, DeWall1 and CFA1, with a diameter of 55 mm, correspond to real piles with a diameter of $D = 400$ mm. The SDP2 and DPDT2 models, with a diameter of 65 mm correspond to real augers with a diameter of $D = 460$mm. The tests were carried out in the Geotechnical Laboratory of Gdansk University of Technology at a test stand shown in Figure 3. The station allows testing of piles and other geotechnical structures in fine sand, either dry, moist and fully saturated.

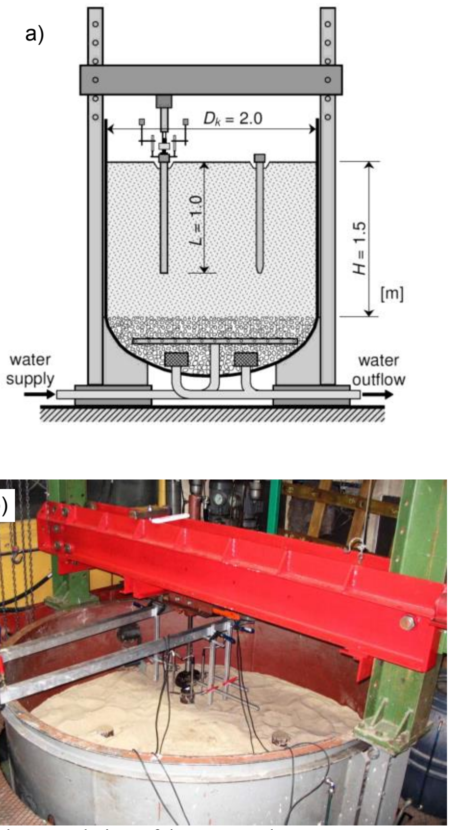

Figure 3. Scheme and view of the test stand.

The model piles were tested in moist and fully saturated fine sand with compaction of $I_D \approx 0{,}33$ and internal friction angle $\phi' \approx 33{,}5°$. A total of 15 test series were completed, testing 4 pile models in each series.

This paper is limited to comparative analyses of the SDP1 and DPDT1 pile models The sand in each test series was prepared first by liquefaction, then sedimentation, and finally compaction using a hand-held deep vibrator (Fig. 4a). Different compaction states were obtained by selecting the appropriate time and number of vibration cycles. With a single vibration cycle a compaction of $I_D \approx 0{,}30 \div 0{,}35$ was obtained and with a double cycle $I_D \approx 0{,}40 \div 0{,}45$ was obtained. Depending on whether the tests were to be carried out in saturated or in moist sand, the water was left in or drained from the reservoir in the next stage.

Next was CPT probing performed at four points A, B, C, and D (Fig. 4b), using a probe of individual design (Fig. 5) but meeting the parameters of a standard CPT probe - cone angle and diameter (60°and 36,7 mm) and insertion speed (2 cm/sec). The probe only allowed to measure the cone resistance q_c.

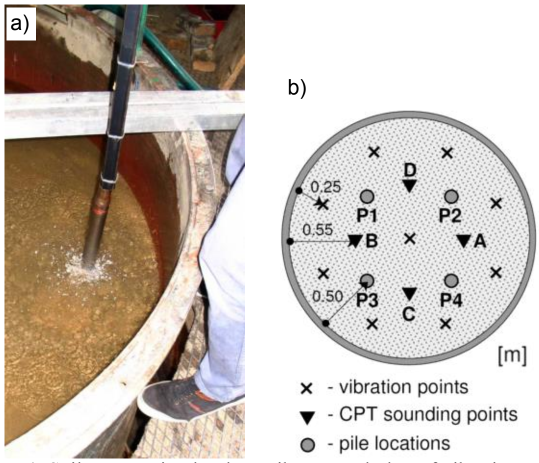

Figure 4. Soil compaction by deep vibrator and plan of vibration points, CPT probing and pile locations.

Figure 5. CPT probe design.

The next research stage was screwing-in the augers and forming the pile models in the soil. This was done with a manual system using special tools. While screwing-in a given auger, the number of rotations n_R needed to penetrate the auger for each 10 cm and the torque M_T were measured. The pile models, of $L = 1.0$ m length, were concreted using fastperforming cement mortar, that gained full strength after 5 days. Piles were equipped with test heads and with *T1* and *T2* electrofusion strain gauges of the author's design (Fig. 6b), embedded in the shafts center axes at the levels shown in Fig. 6c. Sensors were used to determine force values in pile shafts at selected depths (levels). For the analysis considered in this paper only the measurements from *T1* sensors were used. The applied measurement system proved itself in the authors' previous modeling studies, described in the works: Krasiński (2010), Krasiński&Kusio (2014, 2015)

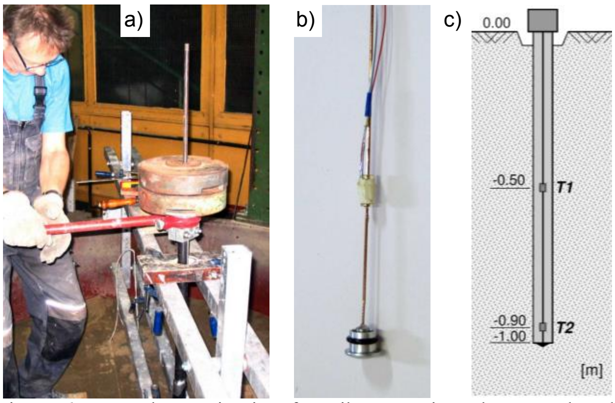

Figure 6. Manual screwing-in of a pile auger into the ground and measuring instrumentation of the pile model with electrofusion strain gauges.

The main stage of the research consisted of static load tests on pile models, which were applied in steps by hydraulic cylinder until the limit load capacity of the pile was reached. The force value was determined by electronic dynamometer, and the displacement (settlement) of pile was determined by electronic displacement sensors (Fig. 7a). Readings (signals) from sensors *T1* and *T2* were recorded simultaneously.

Immediately after the load test, pile models were extracted from the soil in order to precisely measure their geometry and to perform *T1* and *T2* sensor characterization by compressing pile shafts axially in the testing machine and to record the compression force and the signals from sensors.

A view of the SDP1 and DPDT1 pile models excavated from the ground is shown in Figure 7b.

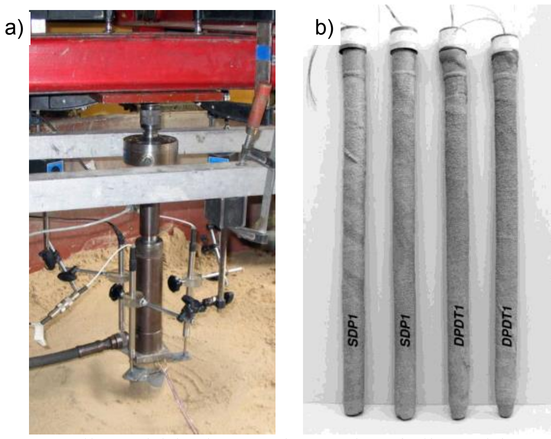

Figure 7. Pile model load test and examples of pile models extracted from the soil.

3 RESEARCH RESULTS

This chapter presents example results of the No. 6 series of DPDT1 pile models installed in moist sand. Fig. 8 shows plots of auger screwing resistance during formation of successive piles, juxtaposed with CPT sounding plots. Because of the differences in the soundings results in a given series, as well as between individual series, the values of torques are additionally presented in normalized version (M_T/q_{cs} - Fig. 8d), where q_{cs} is a representative value of the cone resistance, averaged over the pile length. Fig. 9 shows the diagrams of *Q-s* settlements of all four piles of the 6th series, while Fig. 10 shows the *Q-s* characteristic of one of the piles divided into the shaft resistance Q_s and the base resistance Q_b (possible to obtain thanks to *T1* sensor measurements).

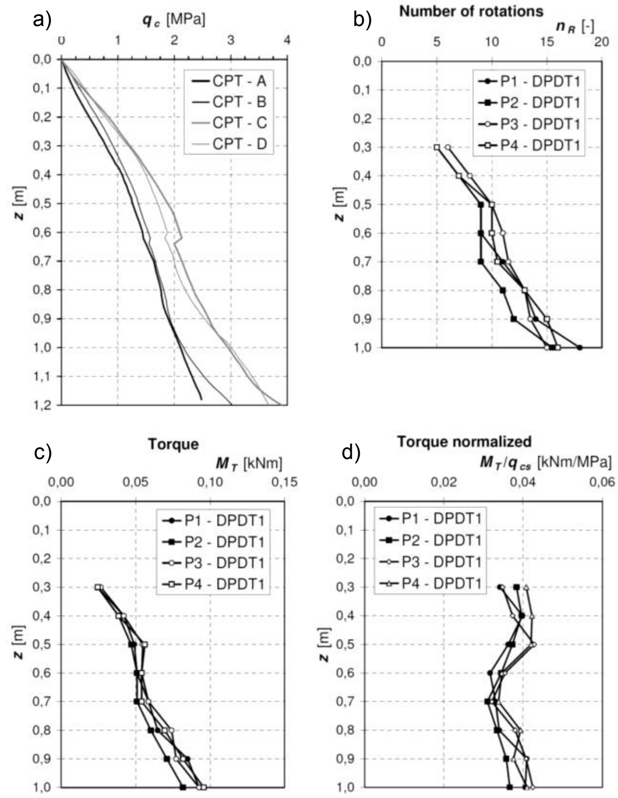

Figure 8. Example CPT sounding charts and auger penetration resistance charts (Test Series No. 6)

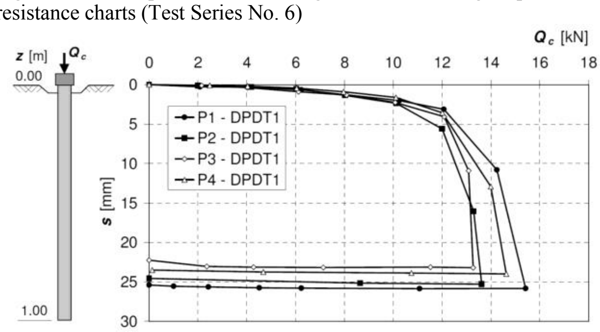

Figure 9. Example *Q-s* curves from load tests on pile models (Test Series No. 6).

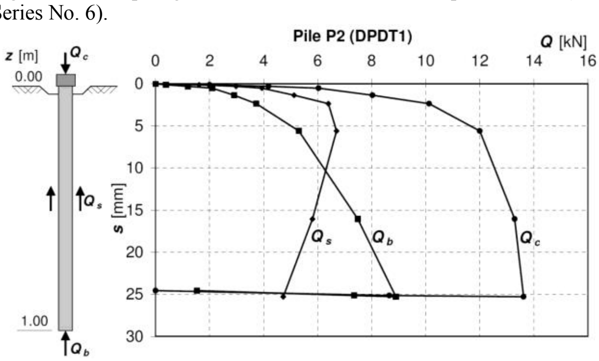

Figure 10. Example *Q-s* curve of one of the pile models separated into shaft and base resistance (Test Series No. 6).

Fig. 11 shows mobilisation plots of unit soil resistances q_s and q_b around the pile as a displacements function (pile settlements). Plots of resistance q_s and q_b normalized by representative values of cone resistance q_{cs} and q_{cb} respectively were also prepared (q_{cb} - averaged cone resistance over the depth interval $-2D \div +2D$ from the level of the pile base).

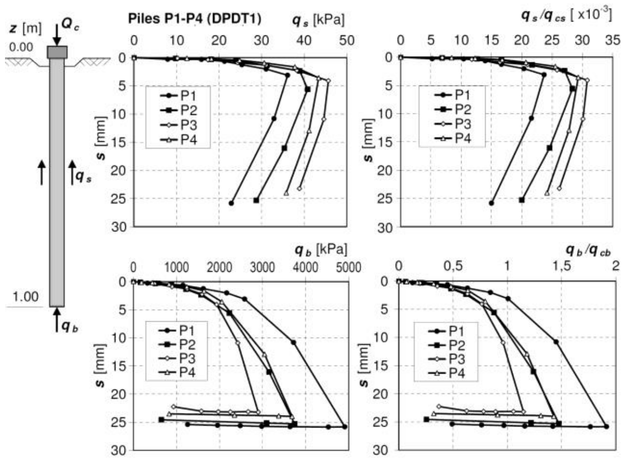

Figure 11. Graphs of soil unit resistances q_s and q_b mobilization with their normalisation by cone resistance q_c (Test Series No. 6).

4 COMPARATIVE ANALYSES OF RESEARCH RESULTS

This work subject is an efficiency comparison of the SDP and DPDT augers. For this purpose, the most relevant tests results of the series 3 and 4 - performed in saturated sand, and the 5 and 6 - performed in moist sand have been compared. Fig. 12 summarises the CPT sounding plots from series 3 and 4, and Fig. 13 from series 5 and 6. Due to the mainly manual preparation of the soil backfill, the sounding curves show some heterogeneity.

Fig. 14 shows plots of auger screwing resistance from tests in saturated sand (series 3 and 4), and Fig. 15 shows a similar plot from tests in moist sand (series 5 and 6). Both comparisons show that screwing the DPDT auger required from 1.5 to almost 3 times more rotations than the SDP auger, but from 1.5 to 2 times less M_T torque (especially at depths above 0.5 m).

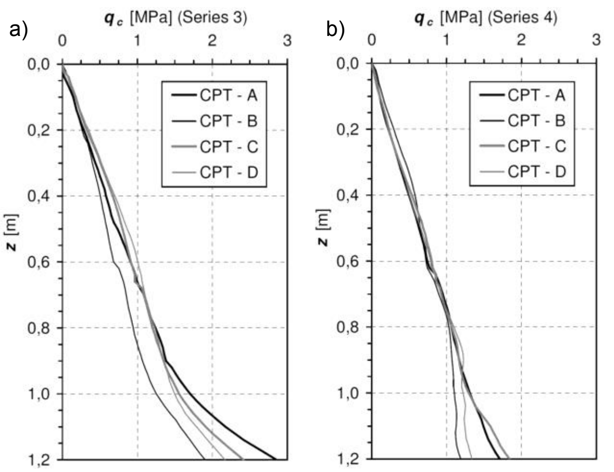

Figure 12. Comparison of CPT sounding graphs in saturated fine sand: a) Series No. 3 - SDP1 pile tests, b) Series No. 4 - DPDT1 pile tests.

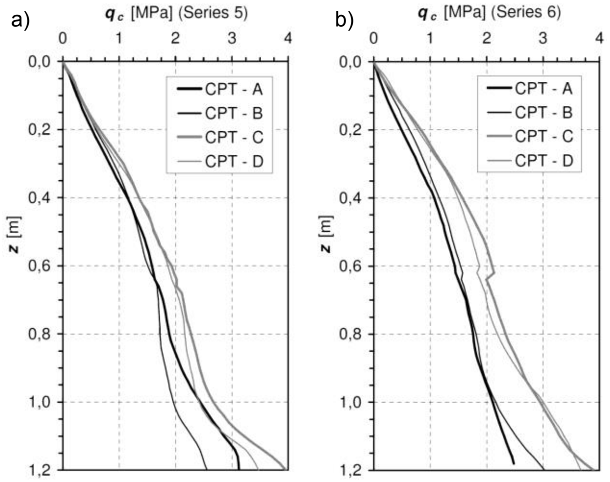

Figure 13. Comparison of CPT sounding graphs in moist fine sand: a) Series No. 5 - SDP1 pile tests, b) Series No. 6 - DPDT1 pile tests.

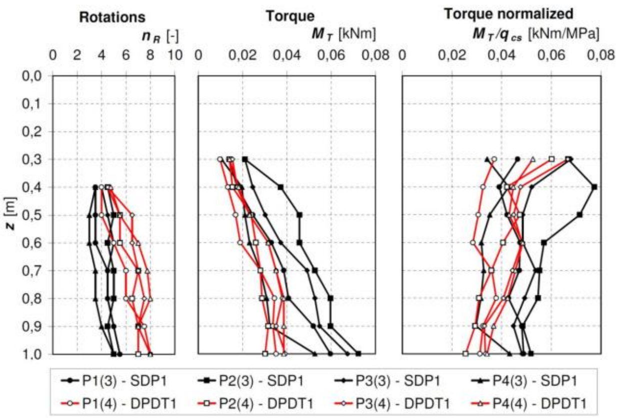

Figure 14. Comparison of SDP1 and DPDT1 augers screwing resistance in saturated fine sand (Series No. 3 and 4).

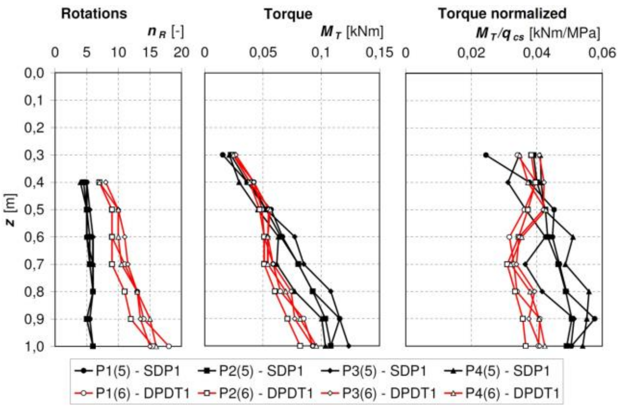

Figure 15. Comparison of SDP1 and DPDT1 augers screwing resistance in moist fine sand (Series No. 5 and 6).

The comparison of *Q-s* characteristics in Figs. 16 and 17 shows that pile models made with DPDT auger generally reach lower ultimate bearing capacities than SDP piles by about 5% to 15%, while in the initial phases of loading (in the design load range), the *Q-s* diagrams of both pile types are similar to each other.

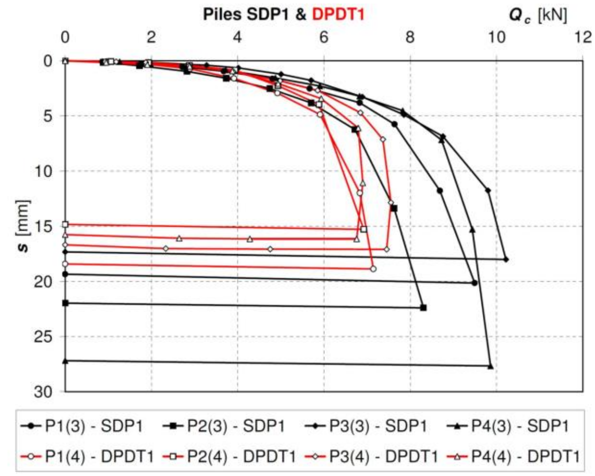

Figure 16. Comparison of load test curves of SDP1 and DPDT1 pile models in saturated fine sand (Series No. 3 and 4).

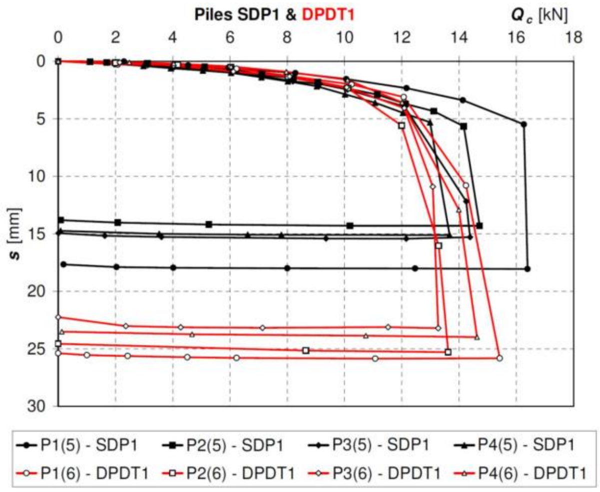

Figure 17. Comparison of load test curves of SDP1 and DPDT1 pile models in moist fine sand (Series No. 5 and 6).

A summary of the unit soil resistances in Fig. 18 shows that in saturated sand (series 3 and 4), piles made with the DPDT auger perform better than those made with the SDP auger with regard to the q_s resistance of the soil along the shaft and worse with regard to the q_b resistance of the soil under the pile base.

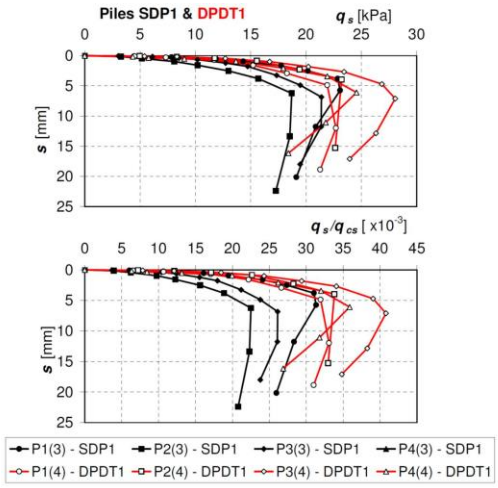

Figure 18a. Comparison of soil resistance mobilization graphs q_s (absolute and normalized) from load tests of pile models SDP1 and DPDT1 in saturated fine sand (Series No. 3 and 4).

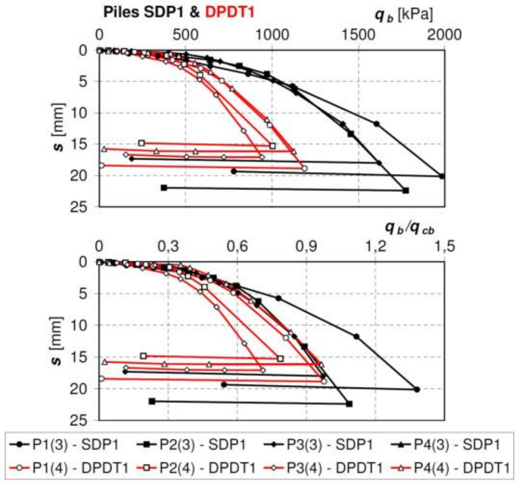

Figure 18b. Comparison of soil resistance mobilization graphs q_b (absolute and normalized) from load tests of pile models SDP1 and DPDT1 in saturated fine sand (Series No. 3 and 4).

The situation is slightly different in Figure 19, which compares the results of pile tests in moist sand (series 5 and 6). Piles made with the DPDT auger perform worse than those made with the SDP auger with regard to the q_s resistance of the soil, while the graphs of the q_b resistance of the soil are similar for both types of piles.

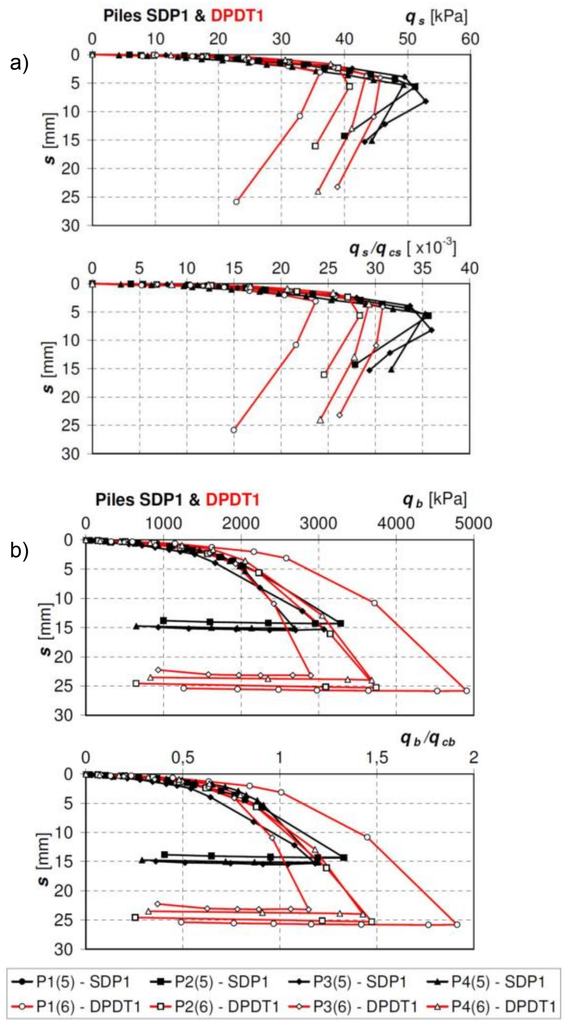

Figure 19. Comparison of soil resistance mobilization graphs q_s (a) and q_b (b) (absolute and normalized) from load tests of pile models SDP1 and DPDT1 in moist fine sand (Series No. 5 and 6).

5 CONCLUSIONS

The prototype pile auger DPDT generally performs well when screwing into a sandy, non-cohesive soil and forming screw displacement pile models.

Screwing a DPDT auger into a non-cohesive soil generates less torque M_T (red graphs in the figures) than a similar (same diameter) SDP auger (black graphs in the figures). The reduction in M_T torque values ranges from 20% to over 40% and is slightly greater in saturated fine sand than in moist fine sand.

However, the reduction in M_T torque comes with a cost in the number of n_R rotations required to penetrate the auger. Screwing a DPDT auger to a depth of 1.0 m requires 1.5 to 2.5 times more rotations than an SDP auger.

From a practical point of view, the reduction of the torque M_T in case of the DPDT auger is an advantage, as it makes it possible to use a less powerful piling machine or to achieve a greater auger penetration depth (and thus a greater pile length). On the other hand, the higher number of rotations is not a major technical problem as it is only important in the final stage of screwing (when entering sandy bearing layers) and only slightly increases the time of the auger penetration.

Load tests showed that piles made with the prototype DPDT auger (red graphs in the figures) reach slightly lower ultimate bearing capacities than similar piles made with the SDP auger. But, it is important that the initial sections of *Q-s* settlement curves (in the design load range) are similar for both types of piles.

The reason for lower ultimate bearing capacity of DPDT piles in the saturated sand is the lower soil resistance q_b under the pile base than those of SDP piles. The soil resistance q_s along DPDT pile shafts are slightly higher than those of SDP piles in this case. In the case of moist sand the reason is oposite – the lower soil resistance q_s along DPDT pile shafts than those of SDP piles. The values of soil unit resistance q_b under the base of SDP and DPDT piles are close to each other in this case, despite the different (partly conical) shape of the DPDT pile base.

The research project is currently in the phase of field tests of analogous augers and piles at full natural scale (1:1). Preliminary results of these tests generally confirm the outcomes of the model tests. They are slightly better with the respect to bearing capacity and *Q-s* characteristics of DPDT piles. The results of field tests will be published shortly.

6 ACKNOWLEDGEMENTS

The described model tests of augers and piles were conducted as a part of "DPDT Auger" project, financially supported by the Polish National Centre for Research and Development (project No. POIR 4.1.4. 0124/18) carried out in consortium with a Polish geotechnical company Budokop Wojciech Sukow Sp. z o.o.

7 REFERENCES

Baxter D. 2006. Design and installation of bored displacement piles and their effects on the soil. *6th Int. PhD Symposium in Civil Engineering*, Zurich, August 23-26.

Bottiau M., Cortvrindt G. 1994. Recent experience with the Omega-Pile. *Proc. of the Fifth International Conference on Piling and Deep Foundations*, 13-15 June, Bruges.

Bustamante M., Gianeselli L. 1993. Design of auger displacement piles from in-situ tests. *Proc. of the 2nd International Geotechnical Seminar on Deep Foundations on Bored and Auger Piles*, Ghent.

De Cock F. A. 2001. A database approach to overview pile loading tests on displacement screw piling in Western Europe – 1970-2000. *Proc. of the symposium on Screw piles – Installation and Design in stiff clay*, Holeyman (ed.), 15 March, Brussels.

Gwizdała K., Krasiński A., Brzozowski T. 2006. Experience gained at the application of Atlas piles in Poland. *Proc. of 10th International Conference on Piling and Deep Foundations*, Amsterdam, 31st May - 2nd June.

Huybrechts N., Maertens J., Holeyman A. 2003. Ground displacement screw piles project in Belgium – 72 pile load testing at two different sites. *Proc. of the 13th European Conference on Soil Mechanics and Geotechnical Engineering*, Praha, August 25-28.

Krasiński A. 2010. Model tests of screwed piles, *Proc. of the XIV Danube-European Conf. on Geotechnical Engineering „From Research to Design in European Practice"*, Bratislava, (on CD).

Krasiński A. 2012. Proposal for calculating the bearing capacity of screw displacement piles in non-cohesive soils based on CPT results. *Studia Geotechnica et Mechanica*, Vol. XXXIV, No. 4, pp. 41-51.

Krasiński A. 2012. Shaft and base resistances of screw piles in non-cohesive soil, *Proc. of the 12th Baltic Sea Geotechnical Conference*, Rostock, (on CD).

Krasiński A. 2014. The analysis of soil resistance during screw displacement pile installation, *Studia Geotechnica et Mechanica*, Vol. XXXVI, No. 3, pp. 49-56.

Krasiński A., Kusio T. 2014. Comparative model test of SDP and CFA pile groups in non-cohesive soil, *Studia Geotechnica et Mechanica*, Vol. XXXVI, No. 4, pp. 7-11.

Krasiński A., Kusio T. 2015. Pile Model Tests Using Strain Gauge Technology, *Studia Geotechnica et Mechanica*, Vol. XXXVII, No. 3, pp. 49-52.

Krasiński A., Kusio T. 2017. Load-settlement characteristics of piles working in a group. *Proc. of the 19th International Conference on Soil Mechanics and Geotechnical Engineering*, Seoul, 17-22 September, pp. 2797 - 2800.

Maertens J. &Huybrechts N. 2003. Results of Static Pile Load Tests at the Limelette test site. *Proc. of the symposium on Belgium Screw pile technology – Design and recent developments*, Maertens and Huybrechts (ed.), Brussels.

Maertens J. &Huybrechts N. 2003. *Belgian screw pile technology. Design and recent developments*, Swets&Zeitlinger B.V., Lisse, The Netherlands.

NeSmith W.M. 2003. Installation effort as an indicator of displacement screw pile capacity. *Deep Foundation on Bored and Auger Piles, BAP IV*, Van Impe (ed.), Millpress, Rotterdam, pp. 177-181.

Prezzi M., Basu P. 2005. Overview of construction and design of auger cast-in-place and drilled displacement piles. *Proc. of DFI's 30th Annual Conference on Deep Foundation*, Chicago, USA, pp. 497-512.

Van Impe W.F. 2003. Screw piling: still a challenging discussion topic? *Proc. of International Geotechnical Seminar on Deep Foundations on Bored and Auger piles*, Ghent.