Dynamic load tests of piles in non-cohesive soils

Essais dynamiques de pieux dans des sols non-cohérents

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ABSTRACT
The results of investigations of various types of piles and the analysis of dynamic tests carried out recently in Poland are presented. Particular attention was paid to the quality of installation of the tested piles and factors influencing final results of bearing capacities determined from the tests. It was found that the quality of piles significantly affects the potential difficulties in the interpretation of the results and thus its reliability. The correlations between the results of dynamic and static tests of piles are presented.

RÉSUMÉ
Nous avons présenté des résultats d'essais de pieux en constructions l'analyse des essais dynamiques de la capacité portante des pieux avec différent technologies. Nous avons accordé une attention particulière sur la qualité de la préparation des pieux pour les essais et sur les facteurs concernants les résultats finaux de la capacité portante. Cette préparation a une grande influence sur les difficultés de l'interprétation et sur la crédibilité des résultats des essais. On a présenté également les corrélations des résultats des essais statiques et dynamiques des pieux sur la base des essais en grandeur réelle.

Keywords: dynamic tests of piles, static test of piles, bored piles, CFA piles

1 INTRODUCTION

For the first time, dynamic tests of piles were applied in Poland in 1999. At present, dynamic tests to examine real bearing capacity of piles (PDA, DLT) are used for both driven as well as bored piles (mostly bored and CFA piles, Gwizdała, Brzozowski, Blockus, 2008).

Basic advantages of dynamic tests carried out on piles are: the elimination of anchoring systems and very short time required for execution of the test. The dynamic methods may be also appreciated in the case when technical or site conditions prevent application of static load test method. Additionally, possibility of execution of several tests during a day allows testing the bearing capacity of essentially larger number of piles in comparison to classical static tests (SPLT).

Despite of clear advantages, the majority of national and international codes recommend however execution of, at least, one static load test for verification of few dynamic tests, where static loading is treated as a test referring to the site with similar soil conditions.

Recently, all dynamic tests of piles being carried out in Poland were high strain type tests. The interpretation of the test results adopted by Authors was based on TNODLT method (Middendorp, Van Veele, 1986).

In a majority of cases when dynamic testing was carried out, the stress wave transmitted along the pile was triggered by the impact hammer made of concrete steel pipe of the diameter varying between 0.8 to 1.8 m. The weight was moved along the guide steel pipe (ϕ 100 ÷ ϕ 250 mm) welded on a steel slab anchored into the pile head, Figs. 1 and 2.

For free release of the hammer onto the head of the pile one of two following method is normally used:

– the release by the crane with free fall drilling system, (Fig. 1),
– the use of vibration hammer suspended to the crane (Fig. 2).

Since classical cranes with free fall drilling systems are more and more hardly accessible, the second method is more often used. The weights of hammers applied for bored piles were varying from 20 to 130 kN.

Figure 1. Dynamic load test of bored pile ϕ 1500 mm using hammer weight 50 kN and the crane with free release of the rope.

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Figure 2. Dynamic load test of bored pile ϕ 1500 mm using vibrating hammer and hammer weight 92 kN.

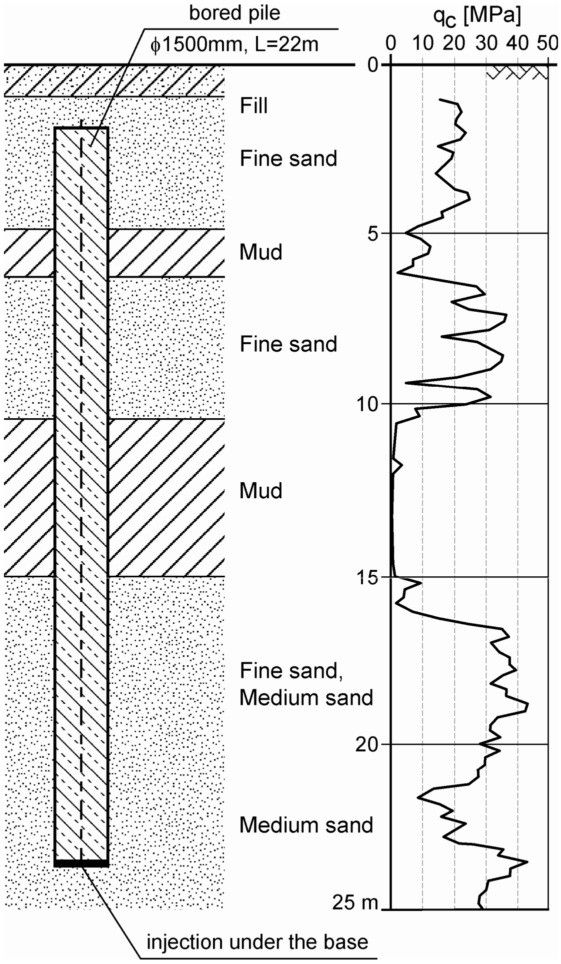

Figure 3. Geotechnical conditions near the area of bored piles.

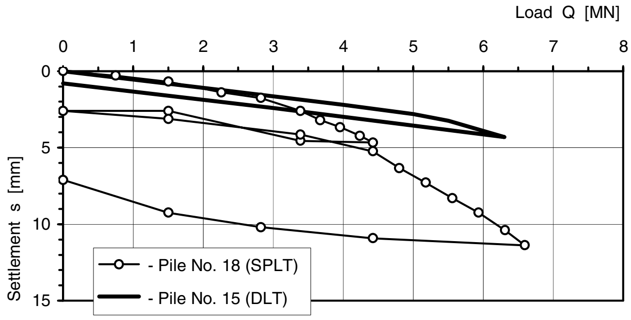

Figure 4. Comparison of static and dynamic test for abutment No. 1.

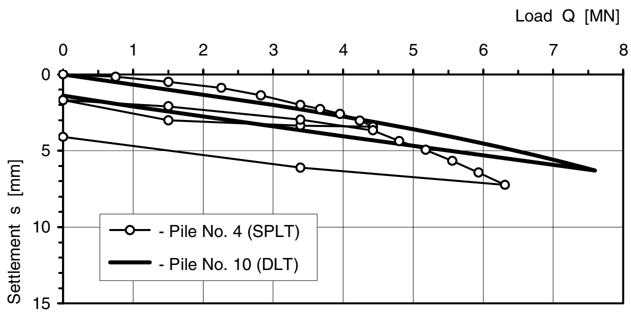

Figure 5. Comparison of static and dynamic test for abutment No. 2.

2 EXAMPLES OF PILE TESTS

In next Subsections, two examples of the tests of piles installed in non-cohesive soils are presented. One example concerns bored piles whereas the second one CFA piles.

2.1 *Example No. 1 – bored piles*

The piles had the diameter of ϕ 1500 mm and were L = 22 m long. They were installed for foundation of abutments under one-span road viaduct over the railway in Gdańsk.

The piles were being installed in casing pipes. In order to increase overall bearing capacity of piles, after setting of the concrete, cement grouting under the bases of the piles was applied, according to the method elaborated in Geotechnical Department of Gdańsk University of Technology, (Tejchman, Gwizdała, 2002, 2003).

Soil conditions in the area of the foundation of the piles are presented in the cross-section shown in Fig. 3. Under the 0.5 m fill there is complex of medium dense and dense sands separated by two layers of highly plastic mud. The floor of the deeper muddy layer is located 15 m below the surface. Under that layer there are again fine and medium sands and gravel, in which the pile bases were founded. The groundwater, which was found at each floor of the muddy layer stabilised 1.0 m under the surface.

For presented construction, totally four bearing capacity tests of piles were performed i.e. two static and two dynamic tests, two pairs under each of two abutments, Figs. 4 and 5

Calculated design load was $Q_r = 4.4$ MN and bearing capacities obtained from static load tests interpreted in terms of Polish Piling Code (PN-83/B-02482) were 4.8 MN and 5.0 MN.

2.2 *Example No. 2 – CFA piles*

CFA piles with ϕ 1100 mm diameter and the length of L = 11 m were installed under the foundation of two-span road viaduct near Kraków.

Generalised soil conditions for this case are presented in Fig. 6. Up to 10.5 m below the surface there are silts and plastic silty clays. Under the layer of cohesive soils dense fine sands were found, where piles bases were installed.

For this construction three bearing capacity tests for piles were performed: one static (support A) and two dynamic tests (supports B and C). The comparison of the results obtained from both test types is shown in Fig. 7.

Design load was $Q_r = 2.3 \div 2.5$ MN and the bearing capacity of the piles based on static load tests interpreted according to Polish Piling Code was 2.8 MN.

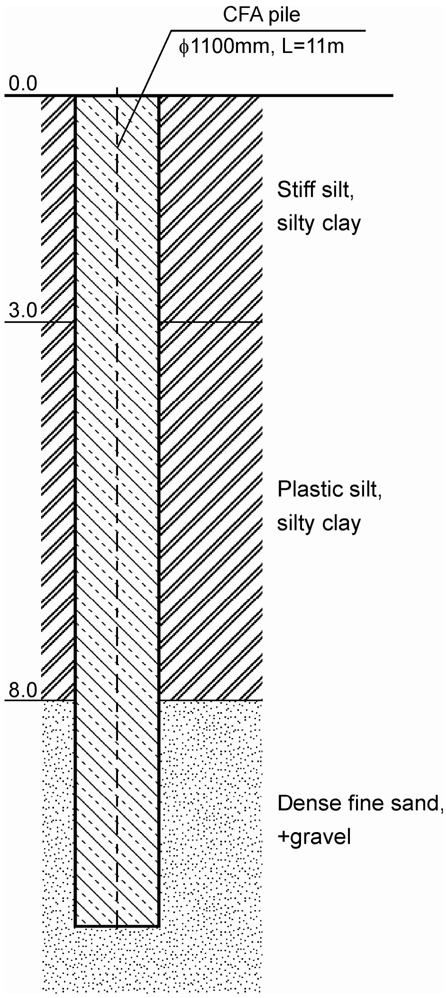

Figure 6. Geotechnical conditions for CFA piles.

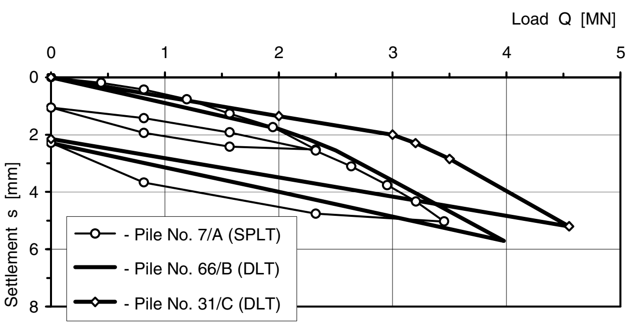

Figure 7. Comparison of static and dynamic tests for viaduct near Krakow.

3 INTERPRETATION OF THE TESTS

All interpretations for the dynamic tests were based on TNODLT indirect method.

In the case of driven piles the test interpretation is not usually too difficult whereas for bored piles the monitored signals are often distorted. The signal distortions are usually caused by the following reasons:

– poorly performed pile head or its contact with the pile causing significant signal dumping,
– cracks inside the pile head or directly under it (in extreme cases preventing recording of the signal),
– inhomogeneities of concrete structure in the pile head or/and the pile (various transmission velocities observed),
– improper location of the gauges (strong signal disturbances),
– eccentric hammering of the weight into the pile head (difficulties in interpretation of the signal).

From several years experience gained during dynamic testing of piles it may be stated that main reasons of the distortion of the signals measured are two first ones from the list presented above. As long as potential eccentricity of hammering and improper location of the gauges can be eliminated during the test, the poorly made pile head and potential cracks within it - not. When the monitored signals are poor one can try to relocate the gauges to another places, however it is not successful too often since majority of cracks can be detected after careful taking the head into the small pieces.

Direct reason of the cracks inside the pile head may be the blow of the hammer, however in the case of large diameter piles made of minimum B25 class concrete, to make the cracks within the pile high eccentricity of the blow would be necessary, what is practically impossible.

The reason of the existence of weak concrete zones in the upper part of the piles may be soil inclusions from the drilling process. In some cases the soil contaminations may come even from the area of pile base. It may happen when the hacking off the head is to short or in the case of the lack of cleaning of the soil from the surface of the concrete mixture.

The quality of the concrete under the pile head can be already assessed during preparation of the pile surface and boring of the holes to house the gauges. Observations regarding the quality of the concrete allowed to correct relations between static and dynamic tests presented in next Section.

4 COMPARISON OF STATIC AND DYNAMIC TEST RESULTS

Comparison of the results obtained form dynamic tests with static load test results was performed for totally 30 dynamic tests, for which correlative static tests were made in the direct vicinity. The piles were tested on several Polish construction sites (mainly bridges and viaducts), the chosen examples of which were presented in Section 2 of this paper. Among 30 piles tested, 23 were bored piles with the diameters ϕ 800, 1000, 1200 and 1500 mm, installed in casing pipes and 7 - CFA piles of the diameter of ϕ 800 1000 and 1100 mm. All the piles tested had its bases in non-cohesive soils.

The difficulty in comparison of load - settlement curves achieved from both static and dynamic tests comes from the fact that the curves should be compared for the full range of loads what makes some problems if we deal with several dozen of piles tested.

The analysis of load – settlement curves was carried out in relation to bearing capacity achieved from dynamic tests assuming that the bearing capacity value taken from Q-s curve based on dynamic tests corresponds to N_{stat}, interpreted in terms of Polish Piling Code PN-83/B-02482, see Fig. 8. N_{stat} bearing capacity is denoted in Polish Piling Code as $k \cdot N_c^0$ and corresponds to ultimate load for partially plastic state of the subsoil, (Tejchman, Gwizdała, Kłos, 1985).

The relationship which follows from the above assumption, for all piles tested, was shown in Fig. 9. Full rhombuses refer to the results presented in Section 2.

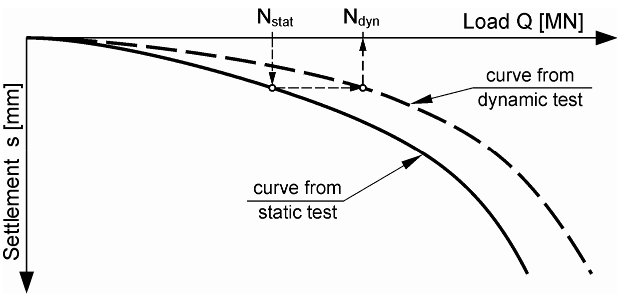

Figure 8. Method of determination of N_{dyn}.

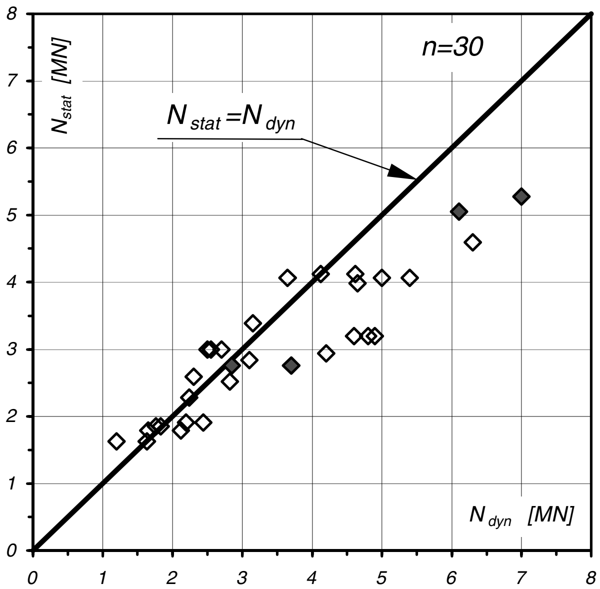

Figure 9. Relationship between static and dynamic test bearing capacity for non-cohesive soils.

In Fig. 11 the result of analysis of load-settlement curves with respect to settlement of the piles according to the assumptions shown in Fig. 10 is presented. In these two figures the settlements from load-settlement curves, corresponding to static load tests bearing capacities (N_{stat}), interpreted from the Polish Piling Code were compared.

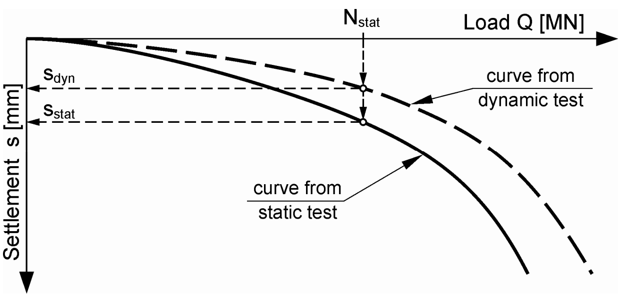

Figure 10. Method of determination of s_{dyn}.

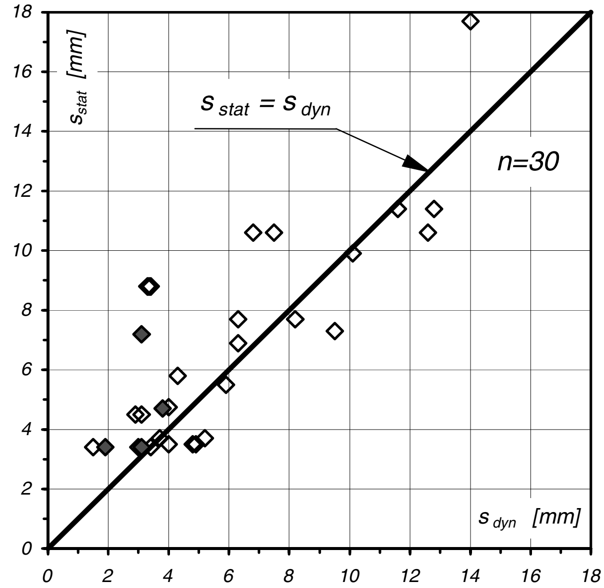

Figure 11. Relationship between settlement for non-cohesive soils.

5 CONCLUSIONS

The correlations can not yet be considered from the quantitative point of view, however the investigations being carried out show that such possibility may be a question of next several years. It is of particular importance with regard to formulation of national appendix to Eurocode, which should include methods allowing the interpretation of dynamic test results as well as the way of its comparison with those obtained by static tests.

In this paper the relations for piles, the bases of which are placed in non-cohesive soils, were presented only. Similar relations for cohesive soils were not presented due to too small number of correlative tests carried out in this type of soils.

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