Some Remarks on Foundation Pile Testing Procedures

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Abstract. This work presents the review of pile capacity testing techniques. In an overview, the key points in pile designing are: determination of the appropriate computational schemes, reliable data on loads and the properties of structural materials (in particular, of the soil mass, which is marked by the greatest variability). The procedure of constructing a pile foundation should include: carrying out soil tests in the scope that ensures safe designing, selecting a piling technology that is relevant both to geotechnical conditions and expected loads, drafting a piling design together with the design of load tests, setting up a testing station for further load tests, static and/or dynamic tests of pile load capacity, preceded by supplementary soil tests when the conditions of test pile installation fail to comply with the design assumptions or when the pile length exceeds the depth of the previously investigated soil, making documentation of load capacity tests (with an additional correction of the piling design), the actual piling (ongoing analysis of pile driving logs and, if necessary, testing the piles' integrity), drawing up the as-built documentation. Unfortunately, the design is corrected after the load test have been conducted only if the piles fail to show the designed bearing capacity. The designer is then obliged to revise the design assumptions on the basis of tests results. If the test results account for the a greater bearing capacity than necessary and it would be recommendable to limit the extent of the planned (i.e. set out in the contract) piling works, usually neither the contractor nor the designer, nor even the Construction Site Supervisor, acting for the benefit of the Investor, are willing to take on the responsibility for reducing the scope of the piling works. The necessity of conducting additional control tests before and during the implementation of the construction project is often treated by the investors as an attempt at extorting extra financial resources or at delaying the project implementation. The designer, however, has no other possibility (and often – he/she does not have required qualifications) to verify the obtained test results.

1. Introduction - pile testing methods

As the construction market is experiencing a dynamic growth, while more and more difficult is to find attractive lands for development, new projects are located on degraded lands which were earlier considered as unfit for development. This generates a significant increase on the market of geotechnical works which allow developing such plots. In practice, all modern geotechnical technologies are now present in our country, like: pile and subbase strengthening methods and also deep excavation shoring. A separate problem pertains to compatibility of valid standards on design engineering, constructing and inspecting geotechnical works with methods and technologies actually used in practice. The methods of inspecting the bearing capacity of foundation piles and their quality are here the good examples. A static load test is the fundamental verification of the load bearing capacity [1]. According to polish Code of Practice PN-83/B-02482, two tests are made for the first 100
piles and one test for each 100 started piles. Hence, in practice less than 2% of piles made within the contract are examined. These tests, independently of their questionable “randomness” (as the piling works contractor usually knows which piles will subject to test load), are highly susceptible to transgressions of procedures and not always provide results enabling for proper interpretation. Application of dynamic tests of bearing capacity is the solution which ensures higher reliability of pile bearing capacity and quality. Such testing requires however appropriate number and scope of prior static tests so as to be a basis for formulating the rules of calibrating the dynamic examinations.

The construction of piles underneath the erected objects is preceded by the obligatory testing determined by the code of practice, and thus leads to the prolonging of the works execution. As it is in the whole EU, static testing constitutes the basic bearing capacity testing due to local regulations (Polish code of practice) and, as follows, contract specifications. Vibration testing [2] and high-strain dynamic testing (CASE, CAPWAP, DLT, PDA) [3] and integrity testing (PIT, SIT) are typically carried out as the additional control procedures, which provides the quality, and not quantity, assessment. Kinetic bearing capacity testing (STATNAMIC, DYNA TEST) are not typically carried out “in-situ”: counting and the analysis of blows in course of pre-cast concrete pile driving-in process, the measurement of energy (power) necessary for driving-in the continuous flight auger (CFA), or driving-in the full displacement piles (FDP, SDC, ATLAS). Such analyses are of course carried out and are especially helpful for the contractor and the supervisor on the building site. Those methods provide fast and reliable information about the conformity of actual geotechnical conditions with the previously assumed data.

2. Static load tests
Static load tests are usually run with the reversed beam method using neighbouring piles and the anchoring piles (Figures 1 through 10) and the following ballast:

- road plates or concrete blocks,
- prefabricated piles to be driven-in later on (Figure 7), or
- containers filled in with water (Figure. 2 and Figure. 9).

The method of interpreting the static load tests for foundation piles is detailed in PN-83/B-02482. The standard requires preparing “Load test design” which should be an integral part of the pile foundation design. The key requirement of correct testing is to get stable settlements in successive stages of loading made with hydraulic cylinders (or, rarely – using precision ballast). Another factor which significantly affects the quality of testing is the appropriate construction of reference system used to measure settlement values. For the sake of the dimensions of testing stands and usually large loads used, special attention shall be paid to maintain the distances from anchoring piles to that with test load and also to clamping points of reference system for settlement recording [4] (Figure 4).

2.1. Measurement procedure and interpretation of testing results according to Polish Standard
The analysis is based on: (i) the loading versus settlement relationship found during field tests, i.e. \( s(Q) \), (ii) the \( dQ/ds \) curve drawn from aforementioned tests, and (iii) characteristic points to be found on this curve enabling to determine the designed bearing capacity of the pile, \( k \cdot N^c_n \). An important matter is that in static testing, its range is presupposed; the maximum field load during test is fixed as about \( 1.5(N_e + T^n) \), where \( N_e \) is the pile bearing capacity determined from static formulae, and \( T^n \) is estimated (calculated) value of negative friction which could sometimes occur at the side surface of the pile. Such procedure of testing verifies design assumptions and static calculations for correctness for the pile in question, however it generally provides no precise information about the limiting load capacity understood as the load for which no stabilization of increasing settlements is reached. Extrapolating the results of such testing to the remaining piles, at complex geotechnical conditions (which usually occur at sites where deep foundations is applied) is also highly questionable. A separate drawback of static load bearing testing is the time necessary during testing allowing to get
required stabilization of settlement [5]. For piles driven in cohesive soils, the time to wait for successive steps of load may be over one hour and the period of the whole testing – a dozen or so hours. Anyway, a proper testing provides valuable data for further design [6]. Another important issue is related to appropriate loading procedure for various piling technologies. Author remarks for driven piles and CMC columns were juxtaposed in papers [7][8].

2.2. Exemplary stands for testing the pile bearing capacity are illustrated in Figures 1 through 10.

![Figure 1 and Figure 2. Testing stands for large diameter bored piles (INKOM)](image1)

![Figure 3 and Figure 4. Testing stands for bored piles (PILETEST) and Fundex (ENERGOPOL)](image2)

![Figure 5 and Figure 6. Stands for testing jet-grouting piles (GEOSERVICE, PPI CHROBOK)](image3)
Figure 7 and Figure 8. Testing of driven piles (AARSLEFF) – ballast out of piles or anchoring to slanted piles

Figure 9. Testing of concrete columns (KELLER)  Figure 10. Micropile testing (GEOSERVICE)

2.3. Static load test as reference examination.

For the dynamic testing be admitted as the bearing capacity examination, a reliable correlation between determined limiting capacity and the designed capacity need to be established, which can be used as a reference for design pile capacity. Polish Standard PN-EN 12699, “Special geotechnical works. Driven piles” introduced in 2005, admits a dynamic test as the bearing capacity examination, however provides no these necessary correlations which allow to determine the design bearing capacity of a pile. Hence, the correlation must be each time determined at site on the basis of reference test represented by the static test load. In Poland, the coefficient allowing to transform the limiting capacity to design value is generally in the range of 1.6 to 2.5. However, it should be noted that in case of prefabricated piles in non-cohesive soils, the value of this coefficient may reach 1.3. Ultimately, such correlations should be included in the national appendix to Eurocode 7.

Numerical modelling of the test requires proper calibration data, granted by the static test [9]. When during static load test the limiting bearing capacity is not reached and further increase of load is impossible, for instance due to insufficient capacity of the loading arrangement or the anchoring piles, it would be necessary to extrapolate further run of examination on the basis of data at hand. Usually, it is assumed that the load-settlement relationship, prior reaching the limiting capacity, is of a polynomial or hyperbolic function [10]. A series of methods for interpreting the load bearing capacity can be found in bibliography, however just some of them allow to estimate the limiting capacity. What is confusing is a reported risk of over- and underestimation of extrapolated bearing capacity. The risk is proportional to the relation between the capacity and the maximum load reached in test.
Other problems are related to abiding by the time specified in the standard which must elapse from making the pile to its loading. It is important as concerns both the attaining appropriate strength of pile material (not to lead to essential overloading) and the bringing on full strength at the pile-soil contact. These questions are detailed in numerous papers [5].

3. Dynamic test load

In Poland, dynamic tests have been made since 1996. They are especially frequent for prefabricated driven piles, and starting on 2004 they are, in practice, made for each piling work contract in this technology [3]. The percentage share of dynamic testing in total tests made for prefabricated piles has risen from 57% to 71% in years 2005-2007. The prevailing percentage share of dynamic test in total examinations of prefabricated piles attains now 80%. For other technologies, this share is essentially lower due to no clear-cut authorization by regulations and more difficult testing procedure.

![Figure 11. a) Equipment for dynamic testing the piles    b) Dynamic testing for bearing capacity](image)

In case of driven piles, the technology enables to use the pile driver hammer as a device which generates elastic wave in the pile. An example of prefabricated pile testing is shown in Figure 5b. In case of other piling technologies, it is necessary to make special frames with falling down weight, which transport and installation on a pile constitute additional impediment.

The equipment for dynamic tests (except the hammering device) fits easily in a suitcase (Figure 14a). Installation of sensors and the testing itself (Figure 14b) last about half an hour and, what is also important, except the moment of recording, no “silence” at the site is required. The most important advantages of dynamic tests are: free selection of piles to be tested at each stage of piling works and opportunity to re-load the piles which were tested earlier, which allows, for instance, to evaluate the time-dependent increment of pile bearing capacity.

4. Other methods of testing the pile bearing capacity - Statnamic and Rapid Load Test

Concurrently to static and dynamic testing of pile axial capacity, other examination techniques are being developed. A searched compromise between static examinations commonly recognized as standard and more and more popular dynamic testing, are the trials to exert load in a fast way, however not the pulse one. A common method is so called Statnamic. The method was originally developed by Berminghammer and Profound. It consists in application of the ballast with mass about 10 times lower than design load and an explosion chamber between the pile and the ballast. Decompression from gas explosion causes that the ballast is given a momentary acceleration of about 9g, thus allowing for “momentary” loading the pile with designed force. Pile displacement at load moment is measured remotely using geodesic methods.

The result of examination is the interpreted load-settlement curve as in the static testing; the curve is used to estimate the limiting bearing capacity of the pile. Such examination requires usually a calibration with the static test, however relocation of testing stand is much easier, especially when the area around pile head is inaccessible (e.g. flooded with water).
5. Examining the side (lateral) bearing capacity

Side test load is carried out relatively rarely, though the stand construction is simply, at least for low diameter piles – it is sufficient to stretch aside (or attract together) two non-distant piles using an actuator. Measurements taken simultaneously for side displacements allow to estimate the side bearing capacity of both piles [11]. Interesting results are reached while testing simultaneously the piles in the middle and at the edge of pile group. It allows, apart from assessment their side capacity, to estimate the changes in soil condition within the pile group after its completion (e.g. a change of compaction caused by driving operations). An example of examining the side bearing capacity of prefabricated driven piles is shown in Figure 15. The graph in Figure 16 shows the load-side displacement relationships for both stretched aside piles. Observations confirmed intuition that the pile pushed outward the group (series 1) will displace more than that in the middle of the pile group (series 2). Other important issue is the durability of piles exposed to heavy driving [11] or corrosion [12]. Examinations of side bearing capacity are especially developed for very slender piles (usually those with low diameters), e.g. injection micro-piles (Figs. 17 and 18). According to the need (and technical capabilities) simulations are made for partial or full restraining a micro-pile in the pile capping beam (Figure 17) or load is applied directly to steel pipe being pile reinforcement (Figure 18). When the distance between piles under testing is significant, so safe stretching aside is impossible, loading arrangement with strings may be applied (Figure 19). Such solution has however a risk of overlapping the zones of passive earth pressure in front of the piles and demonstrating overstated

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**Figure 12.** Scheme of Statnamic examinations – distance of displacement recorder

**Figure 13.** Statnamic examination

**Figure 14.** Hybridnamic Load Test® examination

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bearing capacity. In practice it would be difficult to apply a test load to pile group in one direction (which is typical situation in the structure). The conformity between “test conditions” and the real stiffness of soil layers is mostly emphasized in reliability based computations [13,14], especially in the case of very sophisticated models like HDMR (High Density Model Representation), [15].

6. Summary – basic recommendations on the way and scope of pile examinations

It should be mentioned that introducing the dynamic test loads considerably increased the reliability of piling works. For instance: In 2005-2007, the average number of tests made for prefabricated piles exceeds 2.5 per each 1,000 of driven piles. For comparison, the requirements of standards command to test somewhat over 1 pile per each 100 piles (so at an average length over 10 m means the coefficient of about 1.0 per each 1,000 of linear meters). An important observation is that common use of dynamic test for prefabricated piles did not reduce the number of static test performed. Their function was however changed. They are no longer basic test for bearing capacity to verify the design, but they are rather reference tests for larger number of dynamic tests. For this reason, static tests shall be designed so as they will give limiting bearing capacity of the pile, or at least provide data enabling to determine the limiting capacity by extrapolation. If no significant increments of settlement are reached during the test load while the loading system an testing stand construction allow to continue the load beyond the range designed for the test load, the engineer carrying out the test load examination should decide to continue the testing (rising the load in successive steps).

As it is necessary to eliminate dynamic effects on the subbase and loading system, basically all construction works (especially piling works) should be excluded in the immediate vicinity of the testing stand. Hence, the tests should be run in night hours, which additionally allows excluding thermal effects from solar radiation on loading system and on the reference system for settlement measurements.
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