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Bearing capacity testing of pre-cast driven-in piles

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1. Introduction

After the foundation piles have been installed in the ground, the increase of their load capacity may be observed, due to the dissipation of ground water pore pressures and the reconsolidation of the soil around the pile (set-up effect). Hence, the norms and regulations recommend that the pile load capacity tests should be carried out from several to dozens days after the piles have been constructed. That requirement of preserving such a long time span between the pile installation and their testing (as well as the continuation of the whole pile construction work) may cause, for one thing, many problems from the point of view of organisation; secondly, delay and additional costs.

The installation of pre-cast driven-in piles enables one to estimate their load capacity on the basis of dynamic formulae, systematically, as the installation work progresses. The examining of the load capacity increase in time permits to determine that increase in terms of its quantity. On the basis of those data it is possible to accelerate the pile load capacity testing, and thus reduce the time of the entire foundation construction works.

The article presents the test results for piles installed before the norm-conditioned time limit, with reference to their length and the soil types (the subject has been exemplified on the basis of foundation works in course of the construction of several road projects in Poland since 2004).

2. Current conditions

The current possibility of obtaining financial resources from the European Union funds results in the increase of road investments in Poland. Development of motorway and land road network, connected with simultaneous construction of ring roads for many towns, brings about the necessity of erecting a large amount of engineering objects – bridges and viaducts. The majority of those objects are founded on foundation piles, for the following reasons:

- severe restrictions for construction support settlement and horizontal movement
- the necessity to transfer large loads, in which horizontal forces may play a significant role,
- unfavourable geotechnical conditions under the structure (especially in the case of bridges)
- the necessity to protect the bridge abutments and pillars, located near to the river main stream, from the possible jetting.

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 (see fig 1.).

Fig. 1. Static load testing stand.

High-strain dynamic testing (CASE, CAPWAP, DLT, PDA) 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, DYNATEST) are not frequently used (unfortunately).

Neither is the pile bearing capacity assessment admitted on the basis of the following practices 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,
- the measurement of the energy of driving-in the full displacement piles (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. It must be mentioned here, that the binding Polish codes of practice, regulating the pile and pile foundation designing and the execution of works, date back to the early '80s of the previous century. That is a blessing as much as a curse. On the one hand, the whole generations of building engineers "speak the same language". On the other hand, however, a wide range of new piling technologies is neither described nor defined in the code of practice, which results in the impossibility of referring to Polish standards. The works leading to updating the codes and the implementation of EU standards (Eurocode 7 and execution guidelines) to local conditions are still being carried out.

Time pressure in the execution of pile foundations, combined with high reliability requirements, causes the situation in which some piling technologies are favoured over the others. In Polish conditions last decades stood for the period of the definite domination of "large diameter pile monoculture", when large diameter piles were designed even to support the smallest footbridge. Nowadays, we deal with the renaissance of the pre-cast concrete piles, which did not appear until the mid-eighties of the 20th century.

Pre-cast concrete piles become more and more present in civil engineering. Pile drivers have relatively small dimensions and weight, and, as such, enable piling on hardly accessible sites. The application of pre-cast concrete piles allows for eliminating the use heavy piling rigs, the transport of which may be expensive and technically complicated. In the case of prefabricated piles, only a small amount of equipment is necessary on site. Basically, only the pile driver is indispensable, after the piles have been unloaded with the help of travelling crane.

It is not insignificant that the piling process may be carried out very fast. Depending on the soil conditions it is possible to drive in 200-350 running metres of piles per day, using a single pile driver. It is commonly objected that the pile driving process may have a severe dynamic influence on the surrounding area and structures. The dynamic influence may be generally neglected in the case of the investments outside built-up areas. Even in the urban areas, the measurements carried out during pile driving prove that the noise and vibration levels caused by that process have no vital influence on the neighbouring objects. The pile driver mast may be inclined in the wide range of angles. However, for the sake of the machine stability, if the pile length exceeds 12 meters, the possible inclination of the mast is limited to 30 deg. The designing of inclined piles allows to reduce the dimensions of pile capping beam, as well as to transfer significant part of horizontal forces (fig.2).

Fig. 2. Driving in of the 15-meter long pile, inclined by 27 deg.

Most commonly used pile driver masts are up to 22 meters long. That permits to drive in a single 18-meter long pile. When it is necessary to drive in longer piles, they must be assembled from sections joined with steel joints. Essentially, thanks to the steel joint use(see fig. 3), the depth of penetration is not limited (may be as deep as 40m).

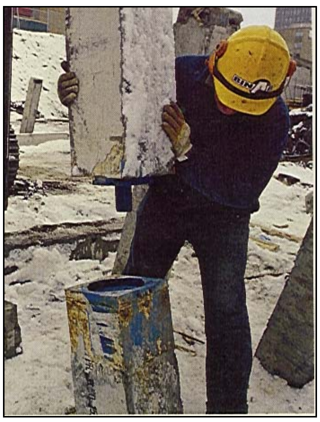

Fig. 3. Steel joints used to join the piles with 40×40cm section.

The common use of pre-cast concrete piles in bridge engineering is also conditioned by:

- the possibility to load prefabricated piles in a very short time (immediately after driving in), which allows to gain time needed for the hardening of the concrete,
- very high pile durability resulting from the use of high homogeneity and quality of concrete, as well as its resistance against aggressive factors.

In course of the pile driving it is possible to verify constantly the pile bearing capacity assumed in the original design. The basis for the bearing capacity control is the counting of the blows required for each 20-centimeter penetration of the pile. Such measurement makes it possible to test pile bearing capacity right away on the building site.

Fig. 4. Dynamic load capacity testing equipment.

The piles may, therefore, undergo dynamic testing shortly after they have been driven in. Fig. 4 provides a relevant example of the necessary equipment.

3. The subject of study

Because of the above mentioned advantages, the use of prefabricated piles leads to the shortening of pile work time. The time span, which should be preserved between the driving in of a pile and its static bearing capacity testing, is also noteworthy. Those time intervals are presented in Chart 14 in the code PN-83/B-02482.

Piling technology	Ground conditions		
	non-cohesive		cohesive
driven-in	7 days	20 days	30 days
bored	30 days	30 days	30 days

Therefore, it is troublesome to postpone the decision about the continuation of pile work until the static load test results. Another organisational difficulty arises from the necessity to adjust the building site only in order to install the piles in the testing site (the transport of pile driver). That disadvantage is crucial especially when the number of piles is small and the cost of re-adjustment of the building site or the standstill in the works caused by the testing methodology are irrelevantly expensive in comparison with the contract value.

4. Test results

The conditions presented above form the basis for the undertaken attempt at the analysis of the influence of the time - elapsing between the pile installation and the static load test – on the test results. The analysis comprised prefabricated pile bearing capacity tests, carried out by the Institute of Geotechnics and Hydrotechnics at Wroclaw University of Technology. Numerous (over 100) static load test results have been gathered for the last two years. The research has been done for the 33 foundation piles constructed as the elements of bridge foundation.

The chart juxtaposes:

- the dates of pile driving
- the dates of static load tests
- geotechnical conditions
- load testing results compared with the pile bearing capacity computations.

piling project	pile	pile instalation	test	pile length	ground	number of days	result*
Highway A2 WD-184 40×40cm	1/18	------	2005-01-19	16,0	clay	------	51%
	2/21	------	2005-01-20	14,0		------	51%
	3/17	2005-01-21	2005-01-27	6,7		6	58%
Highway A2 MA-194 40×40cm	1L/17	2004-11-23	2005-01-07	11,0	sand	14	-3%
	2L/31	2004-11-22	2005-01-11	8,0		19	15%
	3L/17	2004-11-24	2004-12-15	8,0		21	27%
	4L/73	2004-11-24	2004-12-12	8,0		18	56%
Highway A2 WD-196 40×40cm	31/1	2005-01-30	2005-02-06	16,0	sand & clay	7	16%
	16/2	2005-01-29	2005-02-05	16,0		7	38%
	11/3	2005-01-28	2005-02-04	16,0		7	20%
Highway A2 WD-201 40×40cm	23/1	2005-01-26	2005-02-10	12,0	sand & clay	14	66%
	12/2	2005-01-25	2005-02-01	13,8		6	11%
	11/3	2005-01-24	2005-01-31	11,0		6	65%
Highway A2 WD-202 40×40cm	25/1	2005-01-27	2005-02-03	11,6	sand	7	65%
	11/2	2005-01-26	2005-02-11	11,3		15	54%
	11/3	2005-01-27	2005-02-14	8,3		17	61%
Highway A2 WDp-206 40×40cm	1/08	2005-01-29	2005-02-16	20,0	clay	18	47%
	2/05‘	2005-01-31	2005-02-19	17,4		19	53%
	3/23	2005-01-31	2005-02-17	20,0		17	56%
Kwidzyn ring 30×30cm	P1.13	2005-05-01	2005-05-09	15,0	sand	8	55%
	P2.16	2005-04-28	2005-05-10	15,0		12	51%
Elblag ring 40×40cm	nr12/P3	2005-04-07	2005-04-11	12,0	sand	4	21%
	nr12/P4	2005-03-31	2005-04-12	11,0		12	32%
Szubin ring C1 40×40cm	T1/48	2005-04-04	2005-04-16	11,0	sand	12	40%
	T2/111	2005-04-04	2005-04-12	11,0		8	58%
Szubin ring C2 40×40cm	T1/98p	2005-03-19	2005-04-15	14,0	clay	26	76%
	T2/45p	2005-03-10	2005-04-13	14,0		33	-30%
Szubin ring C3 40×40cm	T1/93p	2005-03-08	2005-04-11	14,0	clay	33	75%
	T2/59p	2005-03-04	2005-04-05	14,0		31	20%
	T3/32p	2005-03-06	2005-04-13	14,0		37	30%
Szubin ring C4 40×40cm	T1/005	2005-04-06	2005-04-27	14,0	clay	21	60%
	T2/010	2005-04-28	2005-05-11	14,0		14	60%
	T3/118p	2005-04-06	2005-05-09	14,0		33	45%

* additional bearing capacity (above the required safety margin)

5. Conclusions

After the analysis of the static load tests it seems that the time which elapses between the pile installation and its testing is of secondary importance from the point of view of the test running and its result. It is inadvisable to underestimate the influence of the pore pressure dissipation in the pile surroundings after the pile has been driven in.

It has been stated that the decisive factors for the pile bearing capacity obtained in the test are:

- the conformity of geotechnical conditions with those assumed in the pile design,
- the adequacy of computation model (design quality).

Bearing in mind that the bearing capacity of a pile driven into cohesive subsoil increases in time, it is the contractor who takes the risk of the acceleration of the testing procedure. If the static load test result is negative, the testing procedure may be repeated after the time required by the codes of practice. The obtaining of a positive result makes the further examination unnecessary.

In the presented juxtaposition of many static load tests there was no single case in which the acceleration of the testing procedure affected the appraisal of its suitability in the object foundation. According to the authors' intention, the carried out tests, after they are supplemented with the results of the subsequent bearing capacity tests, are supposed to form the basis for contract specifications. Such specifications determine general conditions for static load testing and help to split responsibility between the contractor, the client and engineering design office.

It is necessary to remark that in some of the analysed cases the test results were negative and pointed to an insufficient pile bearing capacity. As a rule, that resulted from the lack of conformity between the actual geotechnical conditions and the data assumed for the need of pile bearing capacity computations. At the same time, for the same reason in many cases the pile bearing capacity obtained from the test confirmed the pile suitability, despite the fact that they haven't been driven in to the penetration depth required in the project.

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