

Role to Be Played by Independent Geotechnical Supervision in the Foundation for Bridge Construction

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Abstract. Some remarks concerning the necessity of employing an independent and over all ethical geotechnical survey were presented in the paper. Starting from the design phase, through the whole construction process, the importance of geotechnical engineer is stated in legal acts. Numerous testing technologies serve for the calibration of geotechnical technologies and allow for confirming the quality and capacity of piles. Special emphasis was paid to the involvement of scientific and research institutions which can not only serve services but also can postprocess and methodize collected data. Such databases enable for new codes, methods and recommendations. Selection of deep foundations for bridge-type structures is most often dependent on complex geotechnical conditions, concentrated loads and constraints for pier displacements. Besides the last ones, prior to more common introduction of the design-construct system, could be a convenient justification for design engineer, who imposed deep foundation because he did not want or was not able to estimate the effect of pier settlement on civil engineering structure. The paper provides some notes about the need to engage a geotechnical supervising service of high competency and ethical quality during engineering and construction stages of foundations for bridge-type structures where legal requirements are of special consideration. Successive stages of projects are reviewed and research methods used for current calibration of geotechnical technologies and verification of geotechnical work quality are analysed. Special attention is given to potential involvement of independent R&D institutions which, apart from rendering specific services, also collect and systemize the research results thus enabling, in the long term, to revise engineering standards, instructions and guidelines.

1. Introduction – documentation of soil subgrade investigations and geotechnical design

Technical conditions affecting selection of the type of foundations result both from the structure designed and from geotechnical conditions at the project location. The latter factor should be analyzed together with geotechnical engineer who has knowledge and experience enabling him to select correct method of foundation and who can forecast the phenomena, which would be encountered during executing specialist geotechnical works and after completing the facility. In Poland, the common ground for cooperation is the “Geotechnical design” as required in the ordinance of 2012. Interestingly, this ordinance imposes obligation to make consultations with “Contractor of geotechnical works”, which - prior introduction of design-construct system was unfeasible in practice.



At present, the pressure to cost-cutting at each stage of construction prefers the “low-cost” technologies, such as deep soil mixing and columns designed solely to reduce settlements. An extreme “swing of pendulum” and departure from rigid foundations are the deep soil replacements, which can be attractive as items in cost estimate, but they generate lots of problem during work execution, which actually are busily concealed from site inspectors (temporary works).

1.1. Geotechnical laboratory – soil samples and trial DSM batches

The Eurocode 7 (PN-EN 1997-1) prefers design procedure based on testing the geotechnical structure. In case of foundation piles, such tests, as they are outlined below, are axial static and dynamic examinations in compression. Some examples from Polish marked were juxtaposed in publication [1]. Similar tests are applied for ground anchors (tension) as described in paper [2]. Just designing these tests requires at least some information about soil subgrade including parameters of this subgrade determined in situ (various penetrometer sampling) or a laboratory analysis of undisturbed soil samples taken during test boring. An extended system of control is necessary to modify the parameters of soil subgrade. This includes from selection of cement type (and additives, if advisable), the volume of injected or mixed binder (e.g. cement slurry) basing on trial batches to as-built survey with measurements of diameters and lengths of the formed columns. It should be stressed that such control procedures at design stage are very time-consuming due to long time (56 days) necessary to get full strength of soil-cement mixtures. Hence, they shall be commissioned in advance to research bodies with extensive experience. An interesting proposal of control system for transport construction was given by Drusa et al. [3].

1.2. Design of foundation on strengthened subgrade or deep foundation

It is a commonly accepted compromise that the procedure to be used for executing foundation on piles or columns should include the following:

- soil subgrade testing to the scope enabling to prepare proper design documentation,
- selecting appropriate technology of piling or subgrade strengthening according to geotechnical conditions,
- preparing piling design together with design of trial loading,
- executing a testing stand for trial loading (possible supplementing tests for soil subgrade, when inconsistencies with design assumptions are found or when pile lengths outreach the identified subgrade),
- testing pile bearing capacity (static and/or dynamic),
- preparing documentation from pile bearing capacity testing or column susceptibility testing (+ possible design correction),
- preparing the as-built documentation.

Unfortunately, the aforementioned correction of design documentation after trial loads is practically used only when the piles didn't demonstrate designed bearing capacity. Design engineer is then obliged to revise the design assumptions basing on the results of testing. Such procedure was described in previous authors' work [4]. When excessive load bearing capacity is revealed and it would be advisable to “limit” the scope of planned piling works (covered by the contract), as a rule neither the contractor, nor the design engineer, or even the construction site inspector, who represents the interest of project owner, are not willing to take responsibility for reducing the scope of works.

In practice, for the pressure to accelerate the works, piles or columns are often tested no earlier than the works are completed. Then, the order of works is as follows:

- testing the soil subgrade,
- selecting the technology,
- preparing the design including the plan of trial loads,

- basic piling works (current analysis of cards) and executing the test stand for trial loads (possible supplementary examination of soil subgrade when incompatibilities with design assumptions are revealed),
- testing the piles for bearing capacity (static and/or dynamic) or the columns for rigidity, and possible testing for continuity,
- preparing documentation of pile testing and working out the as-built documentation.

Such sequence of works makes it impossible to use testing results for optimization (correction) of piling design, and – when the results are negative – considerably makes hard to increase the pile foundation to increase its carrying capacity (the piles constructed could not, as a rule, be made longer). It is only possible to increase the number of piles or columns under the support or to increase bearing capacity of existing piles by injection methods. Examples of “salvaging the situation” by driving in additional piles or by means of some kind of injection are given in previous authors publications [1, 4]. Special responsibility lies on design engineer due to the awareness of the risk. Another factor, which is often neglected, is the drivability (or wider possibility to execute the piling works) described by Sahajda [5]. The load tests in lateral direction (horizontal) usually provides valuable information about pile stiffness which is necessary for numerical modelling [6].

1.3. Forecasting future phenomena

Geotechnical design documentation is required to include evaluation of phenomena which will be found in soil subgrade after the foundation works are completed, the structure is erected, and – what is of importance – after fast forming of high embankments related to construction of approaches at abutments. It should be stressed that this stage of works is often neglected in analysing the foundation of bridge-type structure itself, which leads to numerous minor failures which however are difficult to eliminate (due to the scale of earthworks). What should be stressed, the infrastructure design documentations have many shortcomings as the significance of land drainage system is not fully appreciated. This problem appears both at design stage (e.g. bottoms of excavations broken away by confined ground water from deeper layers of subgrade), and at construction work itself (broken drain tile lines – problems with slightly cohesive or expansive soils) and up to the problems with displacing the structure by water collected in improperly filled in foundation excavations. Many such problems can be prevented by consulting the structural or technological solutions with geotechnical specialist.

2. Execution of geotechnical works – impact monitoring.

The author's experience from vibration monitoring [7] (Figure 1), i.e. a narrow section of measuring work which accompanies execution of specialist geotechnical works, points out enormous psychological importance of these works. Propagation of mechanical vibrations via soil subgrade is much worse tolerated by building site neighbours than, for example, the noise itself. Vibrations are highly irritating factor for surroundings, both due to its impact on people and also impact on building structures and their internal outfit. The cases of building sites closed by Construction Supervision due to buzzing glass in drawers/dressers are of anecdotal value, but the cost of such stopping the works, is reaching a dozen or so zlotys per day, and it is not at all funny. Vibration monitoring which allows to calibrate the geotechnical technology [8] (or to change it, by prior agreement with Project Owner) has one more value. The idea of an additional generator has already been presented in the case of harmonic excitation by Herbut [9]. The efficiency of the proposed solution was verified by different soil conditions and an additional generator's locations. The results were presented for the points located on the ground surface. Finally, it requires the engineer to be at the site all the time to run current analysis and to evaluate dynamic impacts and also, while being outside building site, to act as a “lightning arrester” for claims of annoyed neighbours. Examples of successfully conducted calibration were given in work [10], where the procedure was adopted to highly harmful vibrations caused by Rapid Impulse Compaction. Also in that case the idea of an additional generator has been examined by an impact load, for the points located on the ground surface and deeper below [11].

Experience gained by the staff of Wrocław University of Technology and other Universities points out to one more aspect. An experienced engineer who is not under the pressure of work progress has (if only out of boredom – while watching the vibration recorder) the time to review and to make reflexions over the phenomena taking place around the building site. Many times the contractors of geotechnical works were warned about threats which do not result directly from propagation of vibration in subgrade, but for example, from deep excavations made earlier (often with unsecured slopes) or from demolitions in adjacent buildings (so the rigidity of these structures is reduced). When intervention is necessary, the label with logo of “The University” on the helmet gives dignity to the claims raised. In reverse situation, when unjustified fears need to be disarmed, presence of “Mr Doctor from University of Technology” (and even better “Mrs Doctor”, who is all the time in touch with recorder indications and who expresses a genuine concern for the fate of site neighbours, superbly calms things down.



Figure 1. Monitoring of vibrations

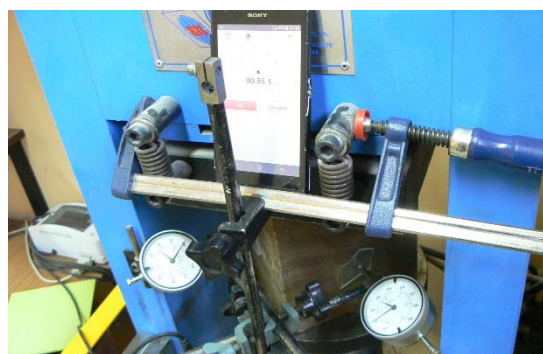


Figure 2. Laboratory testing of cubic samples

3. Checks –DSM materials, concrete columns, piles.

Most of ground improvement and piling technologies are described in specifications and recommendations of PZWFS (Polish Association of Special Foundation Contractors). Appropriate files, for the Polish market, are accessible at the website [12]. However, the problem of current control of pile bearing capacity and quality during work progress deserves a comment. In case of bored piles, the control of spoil and boring resistances provide initial information about consistency of geotechnical conditions with those assumed for the design documentation. Hence, the contractor is able to control the type and, indirectly, the condition of subgrade, and – to the less degree – can also evaluate the pile bearing capacity. In case of driven piles, it is possible to check the sinking resistances (for driving in, screwing) which enable to initial estimation of the pile bearing capacity. However, information on the type and condition of soil is very limited. For the completed elements, various kinds of trial loads and internal strength testing are carried out: soil-cement mixture and concrete on block tests (Figure 2). Some limited scope of identification is also possible for such defects as fractures, inclusions and cross-section changes (diameter reduction) of foundation reinforcing elements. Such defects need not mean lower bearing capacity, but they could affect the durability.

3.1. Core tests for materials of DSM or Jet-Grouting.

Usually, it is the Contractor's responsibility to take the core samples. It should be stressed that the borehole enabling to get the core suitable for testing can be made no earlier than several weeks from column formation. However, this requires for the site infrastructure be brought on long before the start with basic works. For the sake of large costs of downtimes, core tests, in practice, are made exclusively as checks, while data acquiring for designing are from trial batches at laboratories. Obviously, we should be aware of necessity to use safety factors because laboratory results are the “upper estimate” of material strength and rigidity. Possible averaging the parameters of in-situ formed columns related to their large diameter should not be taken into account during designing without confirming them on site.

3.2. Testing concrete columns for integrity.

Slender concrete elements are commonly tested for continuity (and length) with low-strain methods based on analysing propagation of wave in the completed pile or column. Methodology of such testing procedures was widely described in work [13]. The pulse in pile head is generated by a hammer while the receiver is an accelerometer or geophone (depending on the method used). The graph of speed versus time enables, by measuring the time used for reflected wave to return, to estimate the pile length. Any disturbances may point to a change in cross-section (e.g. possible necking or thickening of bored or CFA pile. Signal is recorded after each knock. Testing time for the pile with properly prepared surface of its head is no longer than several minutes. Hence, all piles can be tested in case of especially important project. Testing with the PIT method (Pile Integrity Test) and SIT method (Sonic Integrity Test) has been introduced in Poland in 2005-2006. At present, practically each larger geotechnical firm uses their own equipment for in situ control. Interestingly, experience gained with years greatly reduced the level of firmness of courts referring to evaluation of testing results. In general, a conclusion can be drawn that the “good” signal cannot be received from defective column. However, when “good” signal is not available, it needs not means that the pile/column is made improperly. Close attention shall be paid (like in bearing capacity testing outlined below) to the issue of time elapsed from constructing the column till its testing. This factor needs considering because the modulus of elasticity changes over time so the speed of acoustic wave. Engineering bibliography (the authors also shares in it) [14] includes many items where wave speed is dependent on concrete grade (quality) and the time of column formation.



Figure 3. Testing of integrity by means of PIT method

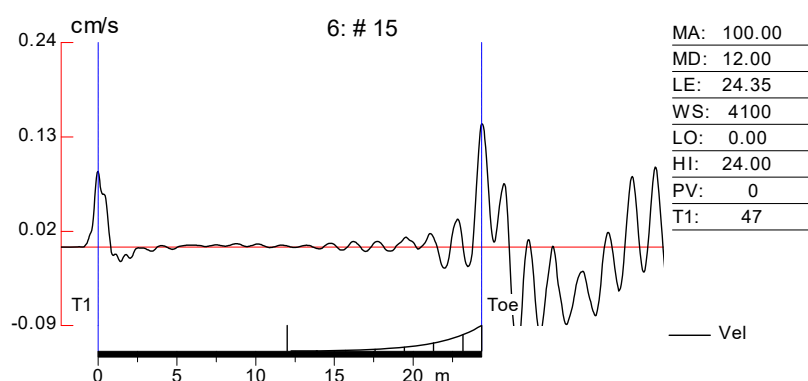


Figure 4. Integrity test graph

3.3. Static and dynamic testing of pile load bearing capacity.

Static test load is more and more frequently used as the reference testing for other control techniques. When the limiting bearing capacity is not attained during trial test and further increase is impossible, e.g. due to insufficient bearing capacity of the loading system or anchoring piles, it is necessary to extrapolate further trajectory basing on data et hand. Usually an assumption is made that prior to the limiting capacity the load-settlement relation is of polynomial or hyperbolic function. Also the authors of this study have elaborated a series of papers on application of extrapolation techniques and methods of resistant estimations to eliminate random errors from analysis [15].

In Poland, dynamic testing has been used since 1996. Since 2004, it is a standard control procedure for prefabricated driven piles. In years 2005-2007, the share of dynamic testing has increased from 57% to 71% of the total number of testing the prefabricated piles. Testing the pile load bearing capacity comes down to measurements of acceleration and strain at pile head level during its dynamic sinking. In case of driven piles, testing technology enables to use the pile driver hammer as a device generating elastic wave in the pile.

Any pile can be tested, also inclined ones. The time for preparing the measurement and execution of dynamic test is comprised (under optimum conditions) within 20-30 minutes, and – what is also important – except the time of signal recording after hammer blow, no “silence” at the building site is required. The equipment for dynamic tests (except the hammering device) fits easily in a suitcase. For other piling technologies than prefabricated piles, when no pile-driver is available on site, it would be necessary to make special stands with falling-down mass. It creates some impediment to transport and to install such stands on the pile.



Figure 5. Static load testing



Figure 6. Dynamic load testing

3.4. Problem with a change (increase) of pile bearing capacity over time.

The aforementioned requirements of optimum procedure to be used during designing and executing piling works are overlapped by the provisions of “the old” pile related standard PN-83/B-02482, item 7.4.2, such as the necessity to make trial test at proper time as started from the date of pile execution. Load bearing capacity of pile is changing following its execution. When the soil relaxation ceases, the pile bearing capacity increases due to decreasing the pore pressure in soil and reconsolidation of soil around side surface of pile. These processes run at various speed for cohesive and non-cohesive soils. Hence, the pile-related standards specify various times which should elapse to make bearing capacity testing. This is to ensure that measurements are made at the moment after which the bearing capacity would change just insignificantly. The standard PN-83/B-02482, item 7.4.2 specifies the times to elapse when the bearing capacity should be tested, Table 1.

Table 1. Time required for pile bearing capacity testing

Pile type	Soil type		
	non-cohesive	fine hydrated, silty and loamy sands, fines and sandy clays	cohesive
Driven	7 days	20 days	30 days
Made in soil	30 days	30 days	30 days

Observing proper order of works and the term of trial load as specified in standard, even for piles driven into non-cohesive soils is a serious impediment as leads to extending the contract time period. In case of prefabricated piles and where technical specification provides no fixed rules, it is possible to accelerate the test loads, so the piling contract time. To this purpose, the dynamic tests, which can be easily repeated, and the phenomenon of pile capacity increase following they are driven into soil as described in [16] are used.

The change of pile bearing capacity over time is given by empirical formula (1) after the study of Skov & Denver (1988) [17].

$$Q/Q_0 - 1 = A \cdot \log_{10}(t/t_0) \quad (1)$$

where: Q – pile bearing capacity after time t
 Q_0 – bearing capacity in the first test (e.g. estimated from driving resistances)
 A – empirical constant (0.60 for dusts and clays, and 0.20 for sands)
 t – time elapsed from driving completion,
 t_0 – time of the first test

In case of large piling contracts or when a large number of columns are made in homogeneous geotechnical conditions when the testing program is to be made over a longer time, attempts can be made to determine local values of the coefficient A .

The aforementioned observations encourage to braver decisions about accelerating the time of static and dynamic testing of pile load bearing capacity for in practice the increases of pile bearing capacity are noticed in all soil types. However, estimation of this increase requires both experience and specialist knowledge. Acceleration of bearing capacity testing leads to shorter construction time. It is of special importance for prefabricated piles which are virtually “ready for all” at the moment of completing the driving operation. If the test result is unsatisfactory as concerns the loads transferred from structure to pile, the test can be repeated, if necessary, after the time specified in the standard. As in practice no erroneous design occurs, but unfortunately it happens that good engineering design takes place with poor data (geotechnical omission – errors in documentations), so fast testing of load bearing capacity gives the designer the opportunity to fast reaction.

Other point which need analysis is the influence of piling works on final bearing capacity of pile foundation. The phenomenon being the basis of volumetric strengthening (CMC, SDC) is in practice neglected in piling contracts, while exemplary, driving a large group of piles causes significant modification to subgrade parameters not pointed out during testing of individual piles. Most often, it is a beneficial phenomenon – like, for instance, additional compaction of non-cohesive soils. It however also leads to disadvantageous phenomena like weakening of water-saturated non-cohesive soils during work using vibrating techniques.

4. Summary and final remarks

It is concluded that modern testing techniques enable full control of quality and bearing capacity of piles and columns, and in wider perspective – the foundations over strengthened subgrade. Starting from recording the process of pile fabrication as automatically-prepared certificates, via cheap and fast testing the continuity and length, up to testing the bearing capacity carried out with static and dynamic methods, the design engineer is able to get information from project progressing. Also information on material strength (concrete, cement-soil mixture) is available at some delay. When cooperation between design engineer, contractor and project owner is satisfactory, safe and well-balanced design process is possible. An important point is the fact that common dynamic testing did not limit the number of static tests at all. However, their function has been changed. Frequently, they are used as reference tests for larger number of dynamic tests. For this sake, static testing should be designed so as they provide limiting bearing capacity of the pile, or at least, they deliver data enabling to get the limiting capacity by extrapolation. If during the trial loads no meaningful increases of settlement are achieved, while the loading arrangement and the testing stand construction enable to continue the loading beyond the trial load range designed in documentation, then the engineer managing the trial loading should decide to continue the testing (to increase the loads in successive steps). Such procedure coincides with the requirements of Eurocode 7 where the pile load bearing capacity is determined on the basis of its limiting capacity.

Testing of columns which are to strengthen the subgrade should be treated quite differently. There is a little point in application of the procedure used for piles due to limited strength of material and confined bearing capacity of the loading structure. However, it is worth to make trial load to the range enabling to confirm the stiffness of support as assumed during design stage.

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