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APPLICATION OF THE ABSA-PPL SURVEY-DIAGNOSTIC SYSTEM IN EXPERIMENTAL RESEARCH

***Safa Abbas*[1], *Bogdan Wolski*[2]**
[1]Architecture and Environmental Engineering
Technical University of Lodz, Faculty of Civil Engineering,
[2]Division of Engineering Surveying
Cracow University of Technology, Faculty of Environmental Engineering

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Abstract

According to the authors, survey systems can be classified into three categories: geodetic, survey-diagnostic and specialist. The ABSA-PPL system presented in the paper, developed for geotechnical research purposes, integrates two survey techniques: the geodetic one and the one using linear transducers. Developed for continuous monitoring of displacements, as well as periodical measurements, it is composed of linear displacement transducers, a control-processing unit and a mechanical base which is used as a reference system for vertical displacements. A special computer program set enables to carry out advanced data analysis of experiment results of foundation pile test loads. An analysis of the geometrical parameters of a rheological model of the deformation process is performed in the first stage. The results of this analysis with accuracy parameters are used to determine variables in relation to the deformation-load capacity of a structure element. Advanced computer procedures can also be used to optimize the program of field experiments. The algorithm of control procedures is based on a learning model and covers the number of observations, time of experiment and number of load stages. The assumed criterion takes into consideration the most important practical aspects, such as: organization of experiment, technical regulations and demands of a geotechnical engineer. The presented ABSA-PPL system is the first proposal of a survey-diagnostic system to solve problems of a geotechnical load-test completely if the experiment is carried out in field conditions.

ZASTOSOWANIE SYSTEMU POMIAROWO-DIAGNOSTYCZNEGO ABSA-PPL W BADANIACH EKSPERYMENTALNYCH

***Safa Abbas*[1], *Bogdan Wolski*[2]**
[1]Wydział Budownictwa, Architektury i Inżynierii Środowiska,
Politechnika Łódzka
[2]Wydział Inżynierii Środowiska
Politechnika Krakowska

Słowa kluczowe: pomiary inżynierskie, system pomiarowy.

Streszczenie

Klasyfikując systemy pomiarowe stosowane w geodezji inżynieryjnej, autorzy wyróżniają: systemy geodezyjne, pomiarowo-diagnostyczne i eksperckie. Przedstawiono system ABSA-PPL zbudowany pod kątem badań geotechnicznych realizowanych metodą próbnych obciążeń. Dużą dokładność monitoringu deformacji uzyskano dzięki integracji geodezyjnej techniki pomiaru z metodami wykorzystującymi przetworniki przemieszczeń liniowych. Specjalistyczne oprogramowanie umożliwia opracowanie wyników eksperymentu w trybie on-line. W pierwszym etapie na podstawie pomierzonych osiadań są wyznaczane geometryczne parametry reologicznego modelu procesu deformacji. Wyniki estymacji wraz z oszacowaniami dokładnościowymi tworzą zbiór danych analizowanych w drugim etapie przy estymacji zmiennych w relacji odkształcenie-nośność elementu konstrukcyjnego. Tryb on-line umożliwia optymalizację eksperymentu. Sterowanie w procesie decyzyjnym opiera się na modelu uczącym. Sterowanie obejmuje liczbę obserwacji, czas badania oraz liczbę stopni obciążeń. Przyjęte kryterium wariancji procesu jest jednoznaczne z punktu widzenia możliwości kierowania przebiegiem eksperymentu, zaleceń przepisów technicznych oraz wymogów konstruktora projektującego eksperyment. Zaprezentowany system ABSA-PPL stanowi oryginalny przykład systemu pomiarowo-diagnostycznego. Przy realizacji geotechnicznego eksperymentu próbnych obciążeń w warunkach polowych rozwiązuje on wszystkie istotne problemy pomiarowe.

Introduction

Integration of different data collecting techniques and data processing algorithms is a live issue in research and practice of modern engineering surveying (CHRZANOWSKI et al. 1990, 1999). Most metrological monitoring tasks exemplify that approach, but load test experiments seem to be the most typical example among them (ABBAS, WOLSKI 2002). One example, namely a geotechnical load test carried out in a construction site to determine soil parameters and pile load capacity, is presented in this paper. As the test is expensive and repeating the experiment is impossible the procedure has to be accomplished extremely carefully. That is why to measure displacements and deformation of piles and plates or foundation constructions both physical and geodetic methods are applied (WOLSKI 2001).

The survey system may be defined as a set of devices, geodetic instruments and software built to determine a specified geometrical property of structure, soil etc. Taking into consideration measurement techniques and the scope of processing, the authors differentiate three kinds of systems: geodetic, specialist and survey-diagnostic.

1. In the geodetic system the measurement of displacements and deformation is carried out only by geodetic methods. The data are processed in two stages. In the first one the reliability of measurement data is verified. The output of the second stage contains geometrical parameters of displacements and deformation.

2. The specialist integrates geometrical data with the results of specialist surveys and advanced studies. The system output is, for example, the assessment of structure condition by means of parameters such as: bearing, functional qualities or geometrical features. Expertise systems are based on software. Although the systems are a tool of structural and geotechnical engineering, they are classified in survey systems because geodetic data take key part if the problem is solved in back analysis procedure. In geodetic literature some examples of the system defined in this way can be found (CHRZANOWSKI et al. 1990).

3. The survey-diagnostic system is characteristic as it needs only geometrical data viz. displacements and deformation which are measured by means of geodetic methods. The most important problems in engineering tasks are: foundation load capacity, determined in a test load field experiment, estimation of soil consolidation parameters, analysis of aerial mast guy capacity etc. They differ from typical structural problems, as in this case the relationship between capacity and deformation parameters is of a simple formula.

ABSA-PPL system

The scheme of the ABSA-PPL survey system is presented in Fig. 1. The system has been constructed for geotechnical research purposes, especially for load tests. The test stand consists of: linear displacements transducers, control-processing unit and mechanical base which is used as a reference system for vertical displacements surveys (ABBAS 2003, ABBAS, WOLSKI 2002). The linear transducers are commonly applied in construction testing. In the system presented the PIZ type transducers with a measuring range from 50 mm to 150 mm and the accuracy of 0.5% have been used. The accuracy mentioned corresponds to a standard error of 0.2 mm for the 50 mm measuring range. The authors applied the above ABSA-PPL system to three types of survey: periodical, continuous and load test measurements.

Periodical measurement; The difference between the structure element and base is measured by the ABSA-PPL system. The base is of a frame shape and should be a solid support for the linear transducers. The base provides also a reference system for measurements of vertical or horizontal

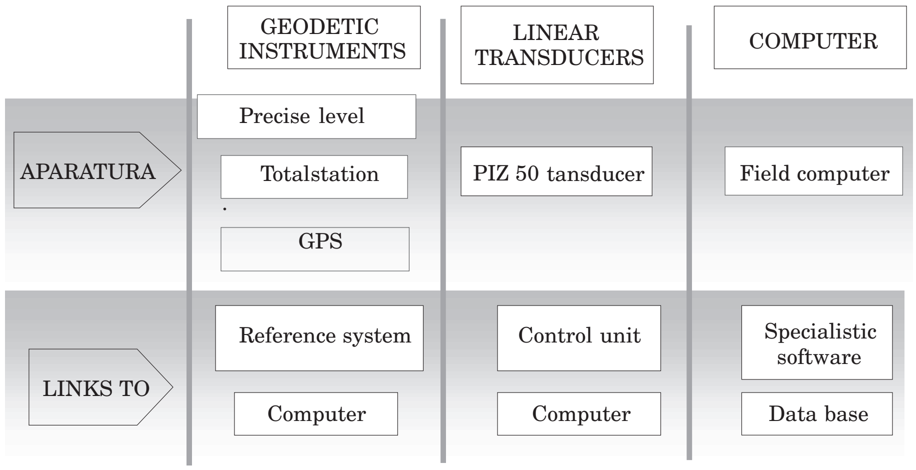

Fig. 1. Scheme of the ABSA-PPL survey– diagnostic system

displacements. Due to instability of the frame, especially in long-term observations, each frame has to be controlled by means of precise leveling. That is why the advantage of ABSA-PPL in periodical long-term measurements is limited. The system is much more useful if it measures the reciprocal displacements of two structure elements divided by an expansion joint, especially if a survey program requires taking measurements and access to them is difficult (ABBAS 2003).

Continuous measurement. There is no alternative for specialist monitoring system if observation has to be taken with great frequency. Conti-

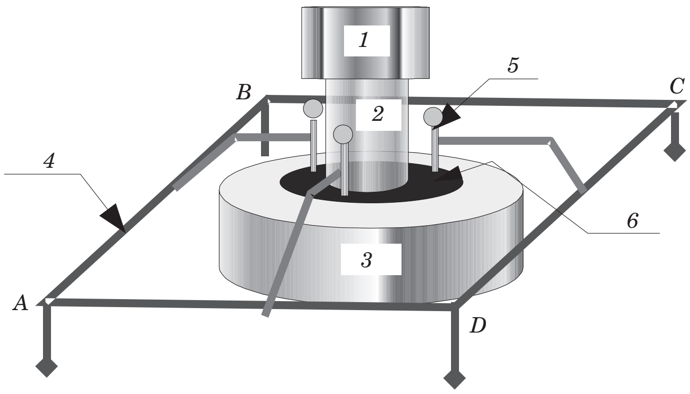

Fig. 2. Scheme of a foundation load test stand; *1* – supporting structure, *2* – servo-motor, *3* – head of foundation pile, *4* – base of transducers, *5* – transducers, *6* – plate transferring pressure to pile head, *A*, *B*, *C*, *D* – points of iron base controlled by geodetic techniques

nuous observation gives the picture of a structure behavior in the condition of periodical impact of additional load, for example quasi-static. Among the examples of such a load one can point to the ground space around deep trenches or thermal impact in season interchange. If the investigations need periodical measurements, the ABSA-PPL system works as a geodetic one, producing displacements and deformations in output.

Load method test. ABSA-PPL is used as a survey and diagnostic system in a load test method – Fig. 2. Vertical displacements are the only quantities observed when the structure, plate or pile is under test load. Let us notice that it is one of several structural problems which are well described by a one-axis model, and the relationship between displacements observed and the capacity of a structure is presented as a simple mathematical model. The real accuracy of the geodetic method is 0.1–0.2 mm.

Field and accuracy problems in a foundation load test

Verification of foundation pile capacity by controlled load is the most credible method of verification of structure design and construction works. According to Polish Standards PN-83/B-02482 this kind of survey is obligatory. It is carried out for randomly chosen constructions (Wolski 2001). Technical regulations also oblige the contractor to prepare a load test design and to put the test into practice. Field procedures as well as the method of field data processing are also determined by regulations. The design of experiments is an integral part of the project and contains details on how the experiment should be carried out. Although the credibility of the load test method is high from the measurement point of view the execution of fit is a source of real doubts. The field experience shows that four of them are important.

Instability of the reference system. As the support base of the transducers is of a small size (2–3 m) and the distance from the plate is usually less than 1 m, it is very probable that pile impacts on surrounding soil space causes sinking or going up of ground surface. According to the authors, displacements of ground in the vicinity of the pile often reach 1 mm if the pile settles 5–9 mm. The settlement of the ground surface depends upon the kind of soil as well as upon other factors, for example road traffic. It is not only difficult, but there is also no need to explain the reasons for base instability. In order to get a correct result of experiments the dependence between displacement and load should be analyzed. That analysis has to be performed on-line in order to get time to repeat part of the experiment, usually by an additional load stage.

Time of test load. The load test needs not less than eight hours and very often even twice as much. Some important decisions referring to timetable, total test time, number of load stage etc. are taken in the course of the test. All decision are taken arbitrarily on the basis of the experience of a geotechnic engineer.

Reliability of linear transducers. It depends both on the electronic and mechanical system. The experience shows that non-identified factors have an essential influence on the accuracy of transducers.

Geodetic measurements. Observations are charged with leveling errors, both instrumental and methodological. The accuracy depends on the class of geodetic equipment, measurement conditions and surveyor's experience. The last factor is also important due to the long time of measurement.

Mathematical model of pile capacity in a load test experiment

The interpretation of measurement data given in technical regulations consists only of graphic procedures. That is why the method is subjective, inaccurate, time consuming and cannot be applied on a construction site. An alternative to the graphic method is a mathematical model (WOLSKI 1997). The algorithm consists of an analytical procedure applied in two stages.

Stage 1. **Finding of final stage displacements**. In the first stage of analysis the increase in settlement is determined, as shown in Fig. 3. Let

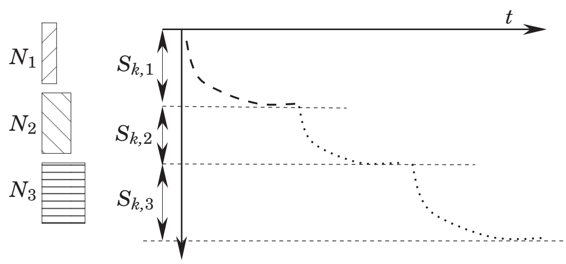

Fig. 3. Stage 1 – estimation of final displacements $\sigma_{k,i}$ for loads N_i

us notice that according to the technical regulations and standards, the sk values should be found by a graphic solution. According to the algorithm used in the ABSA-PPL system, the sk values are determined by approximation of a data set by means of a displacement function. The model uses some functions known in rheology and a consolidation or correlation function describing the relationship between load and settlement. Some models have been presented in (WOLSKI 1997). In the ABSA-PPL system two of them are used:

$$s = s_k \{1 - \exp[\beta.(t + T_0)]\} \quad A = [S_k, \beta, T_o] \tag{1}$$

$$s(t) = s_k \left\{ 1 - \frac{8}{\pi} \sum_{m=0}^{\infty} (2m+1)^{-2} \exp\left[-(2m+1)^2 \beta (t + T_0)\right] \right\} \quad A = [S_k, \beta, T_o] \tag{2}$$

All elements of vector **A** are determined by means of the least square method, but only final s_k displacement is used in further processing procedures.

Stage 2. Settlement-load relationship. The $s_{k,i}$ settlement determined in each stage and N_i loads are the set which allows to evaluate the relationship

$$s = s(N)$$

The vertical displacement dataset can be approximated by means of parabolic functions given in alternatives (3)–(4)

$$s(N) = aN^3 + bN^2 + cN \tag{3}$$

$$s(N) = aN^3 + bN^2 + c \tag{4}$$

In the estimation algorithm $\mathbf{B} = (a,b,c)$, the vector the approximation equation set is weighted by means of a weight coefficient determined by means of standard errors $\sigma_{sk,i}$. The last ones are found in the approximation of the dataset by means of functions (1) or (2)

$$\sigma_{sk} = \sigma_{ap} \sqrt{Q} \tag{5}$$

The weight coefficients are determined in the same way as in typical estimation tasks, as an inverse of variance. According to the authors, it should be assumed that σ_{sk} = 0.1 mm if σ_{sk} < 0.1 mm. The latter value of σ_{sk} is the real range of measurement accuracy in field conditions.

Programming of a load test experiment

The timetable and measurement accuracy are of crucial significance for the credibility of experiment results. According to (ABBAS 2003), the standards errors of final results may increase up to 25% due to a non-optimal measurement timetable. At present the program of test load experiments is prepared on the basis of technical standards. The program is corrected online by a geotechnic engineer who uses their own experience only. The problem of experimental programming can be solved by means of the ABSA--PPL system. On the basis of a mathematical model of the deformation process the optimization task can be solved a priori. In this problem all elements are determined, namely: steering vector, functional constraints, objective function and permissible solution set. The authors propose two methods of solving the problem.

In the first one the steering vector is searched for using a functional which is assumed to be arbitrary. The functional is an objective function solved as a typical problem of nonlinear programming with a special algorithm at assumed functional constraints. In the system the functional

$$K(x) = \sum_{0}^{n} \frac{V(A_i)}{A_i^2} \tag{6}$$

has been assumed as an objective function (WOLSKI 1997). Functional constraints are: acceptable number of observations, acceptable time of each test stage, total time of experiment, distribution of observations (WOLSKI 1997). The steering vector covers the number of observations, their distribution, standard errors of data values and errors of model parameters. The functional constraints and steering vector elements may be used only once.

According to the alternative approach all decisions are correctly assessed by the time or cost criterion. The solution is not searched for by means of a typical programming algorithm. The criterion is assumed arbitrarily. To solve a practical problem, the criterion value may be determined for some alternatives following, for example, the Monte Carlo method (EYKOFF 1980). Constraints are assumed as standard errors of observations and stage displacements s_k basing on other experiments and simulation analysis. The steering vector is a result of that analysis. Despite arbitrary assumptions, the method is useful, as it allows to include recommendations of technical regulations. It should be emphasized that standard errors σ_{sk} should be carefully assumed. The best way of their evaluation is a simulation analysis performed at the planning stage of the experiment – Fig. 4. General values of the criterion may be assumed on the basis of other tests, also geotechnical requirements – Table 1.

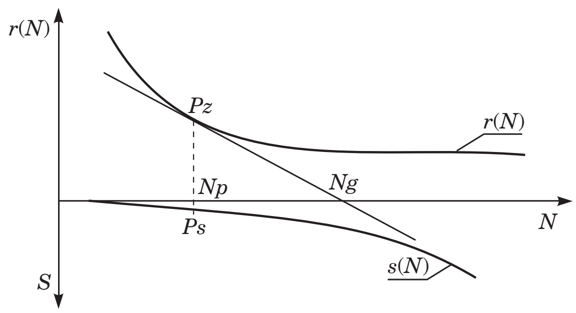

Fig. 4. Stage II – Approximation of displacements by parabolic fiuncions and estimation of geotechnical parameters: accaptable load capacity N_d and limit load capacity N_g

Table 1

Coordinates of points on the surface of the five-hole standard sphere probe

Point No	ψ	φ	α	β
1	0	-	0	0
2	$\pi/4$	$\pi/2$	$\pi/4$	0
3	$\pi/4$	$-\pi/2$	$-\pi/4$	0
4	$\pi/4$	0	0	$\pi/4$
5	$\pi/4$	π	0	$-\pi/4$

Programming on-line

The drawn-up program of a load test, presentedin the above chapter, is used only as the framework for the test. The most important decisions are taken on-line during the test realization. The general idea of programming on-line with the ABSA-PPL system is using a learning model. It means that the test is carried out as long as the assumed final accuracy is reached. The accuracy may be determined for pile capacity or settlements. The criterion is precise as it refers to the variances or standard errors of geotechnical parameters: permissible and structural capacities. Some practical problems are generated by that approach: number of datasets for each load stage, number of stages and total time of experiment.

Number of observations. The ABSA-PPL system makes it possible to consider a great number of data. The real problem is not the small number of datasets, but an excess of observations. The practice also shows that a filtration procedure is necessary in order to reject observations which locally differ from the general trend line. These values are caused by unknown factors. As the process of soil deformation is regular, such single data may be treated as blunders. Their source is in the measurement system, not in the soil. The ABSA-PPL system gives the possibility of data correction in the way shown in Fig. 5a. The X_1 and X_2 data should be rejected without analysis, which was the reason for such a result. The filtration is correct provided that the trend of the deformation process is regular.

Time of a single load test stage. One of the most important advantages of the system is that the accuracy problem is not considered with respect to a single observation, but the whole dataset. The sk standard error is the basis for further geometrical and geotechnical analysis. According to technical regulations, the load is kept as long as the difference between two following observations shows the displacements of 0.05 mm. If such difference appears by chance it suggests the engineer to stop the test, although that decision would be wrong. In the ABSA-PPL system an estimation of σ_{sk} standard er-

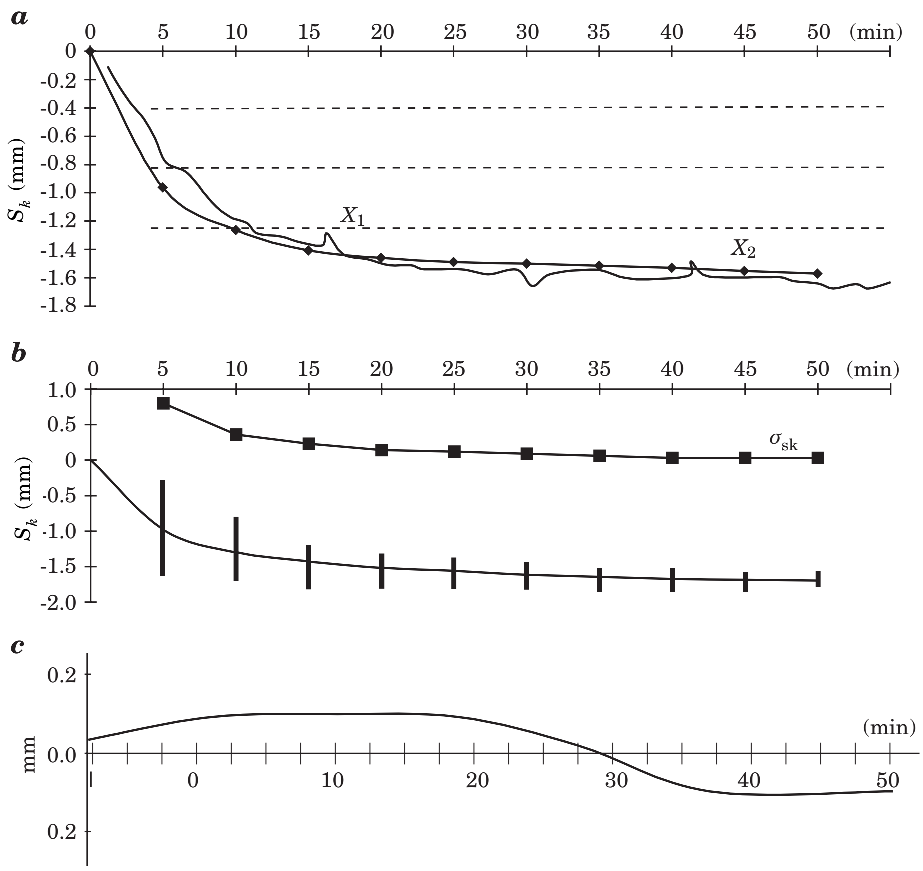

Fig. 5. Data Processing on-line by the ABSA-PPL system: *a* – diagram of displacements observed and the approximation function according to the rheological model determined separately for each load stage; *b* – displacements sk and their standard errors ssk determined for an increasing dataset of displacements observed; *c* – displacements of transducers supporting the base frame used as corrections of the dataset

ror objectively qualifies the dataset as large enough or shows that the test should be continued. As shown in Fig. 6a–6b, mean values and standard errors stabilize with the time of test experiment and the number of datasets.

Number of load stages, total time of experiment. The program may be optimized in the scope of number of load stages and time of experiment. A too small number of load stages and a too early completion of the experiment do not lead to the right diagnosis, load capacity limits. The results of a simulation analysis are shown in the diagram in Fig 6. The diagram is very useful in field conditions, it may be used during the test realization for the synchronization of parameters, especially referring to the number of load stages, accuracy of final result and accuracy of measurements. Some examples can be found in (ABBAS 2003).

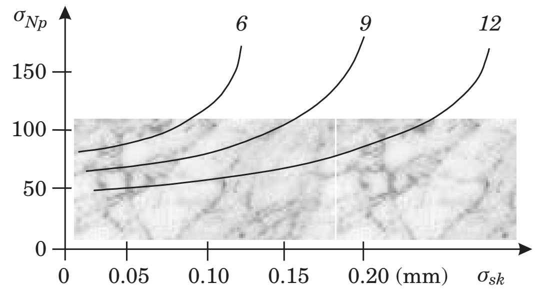

Fig. 6. Acceptable solutions determined for optimization purposes by simulation methods; σ_{sk} – standard error of pile head displacements, 6, 9, 12 – number of load stages

Conclusions

1. The ABSA-PPL system with linear transducers is an efficient tool for the identification of the soil deformation process. The application of the system refers to a diagnostic system with information which cannot be found by other methods.

2. The system makes it possible to optimize the program of the test experiment in field conditions. It is the first solution of that kind in geodetic literature.

3. Simulation procedures can be applied to recognize the features of the system computer.

4. Data observation sets need filtration before they are processed online. The values which significantly contradict the soil deformation model have to be rejected by arbitrary decisions before applying the least square method adjustment algorithm.

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