DEFORMATIONS OF SELECTED ENGINEERING STRUCTURES AND SOME REASONS OF ITS OCCURRENCE

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ABSTRACT

In the paper the problem of lateral impact of weak soil layer on piles is discussed and analysed from the view point of measurements of deformations of structures founded on piles and of the prediction of its development in the future. Selected model test results are described and compared with numerical simulations. Additionally, basic principles of non-invasive electromagnetic method for measurement of deflection of abutments piles, developed by the author, is also presented.

1. INTRODUCTION

Localisation of newly designed engineering construction always concerns the foundation conditions. Nowadays modern equipment and technologies allow the erection of the foundations in arbitrary soil conditions, thus the only problem which influences the choice of particular sites is related to the economy and environmental impact of new construction. However, high costs related to foundation of new structures in difficult soil conditions almost always induce searching for savings both at the design as well as operational stages, which in turn lead to mistakes made e.g. during a recognition of soil conditions or analysis of soil-structure interaction. As an example may be lateral impact of weak soil layer on piling foundations, which is often ignored in the engineering practice what in turn often leads to the damage of such structures.

Proper erection of the engineering object should be continuously verified by the geodetic measurements from the very beginning of works up to its end as well as periodically during the operation of the structure. Depending on the localisation of the structure, geodetic measurements are made based on benchmark reference net.

Depending on the foundation conditions, character of loads and type of construction (light, heavy or tower), the engineering structure undergoes simple or complex deformations (Fig. 1). However, even significant uniform settlement of the whole structure does not have to be dangerous for its general stability and safety, and the only problem may be serviceability conditions. In such case, the standard measurement of settlements at chosen measuring points located on the structure are sufficient and prediction of further tendency of the deformations and the time of its potential stabilisation can be with good accuracy achieved by few series of geodetic measurements.

Entirely different situation takes place when we deal with non-uniform vertical deformations, which in some cases may be dangerous for the functioning of the object. The main reason of such state is usually bad recognition of soil conditions or mistakes during design phase related to improper assessment of soil-structure interaction. Early evaluation of the reasons of non-uniform settlements enables proper prediction of its

further development and potentially, respective correction of the measurement course and the localisation of benchmarks. However, the structure elements responsible for the deformation of the structure are not always accessible to direct geodetic measurements. As an example may be lateral impact of weak soil layer on piles, which in turn induces its deflection causing finally tilting of the entire structure as it may happen in the case of bridge abutment.

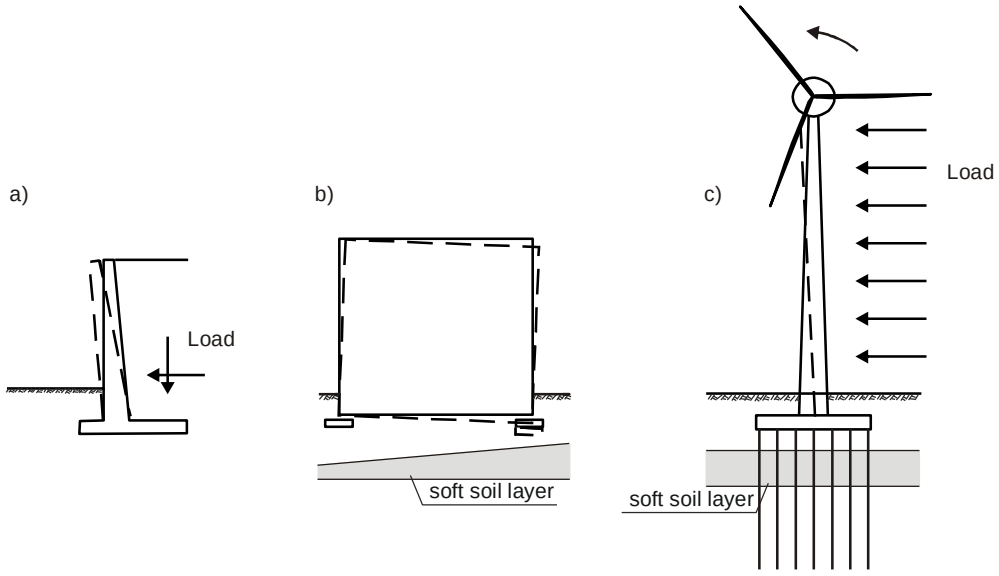


Fig. 1. Examples of hypothetic deformation of diverse types of engineering structures.

2. RESPONSE OF STRUCTURE TO LATERAL IMPACT OF SOIL ON PILING FOUNDATION

Weak soil layer can be found in the subsurface layer of a subsoil in various regions of Poland. Such layers are either built of plastic cohesive or loose non-cohesive soils. An increase of vertical pressure at the roof of such weak soil layer, i.e. due to earth structure, causes significant and multidirectional deformation of such layer. Additionally, when the layer is loaded asymmetrically against e.g. piling foundation supporting some engineering construction then the construction undergoes complex deformations, which may lead to its failure. Such case takes place in the following situations, Fig. 2:

- **the abutment on piles is adjacent to high embankment founded on weak soil layer causing lateral load acting of piles,**
- **in the direct vicinity of the crane railway founded on piles, heavy materials are stored,**
- **the piling foundation is unloaded by deep excavation.**

Deformation process occurring in weak soil layer as well as its impact on the neighbouring structure is diverse and depends on the thickness of such layer, state and depth of its occurrence in the subsoil and time.

Small thickness weak soil layer does not induce essential lateral loading of the structure, so as deeply lying weak soil layer at little surcharge load. Some examples of the response of the structure in complex foundation and loading conditions are shown in Fig. 3. In

presented cases, one can observe the effects of the impact of lateral earth pressure in the form of non-uniform settlements of the object, cracks or deformations of superstructure. Nevertheless, based on these measurement the description and explanation of the process of soil-structure interaction in the contact zone is not possible so that indication of reasons of structure deformation. However, the knowledge of the phenomenon discussed can be very helpful in designing the reference net and during the geodetic measurements and its interpretation, Fig. 3. In such case co-operation between geotechnical engineer and the land surveyor is strongly recommended.

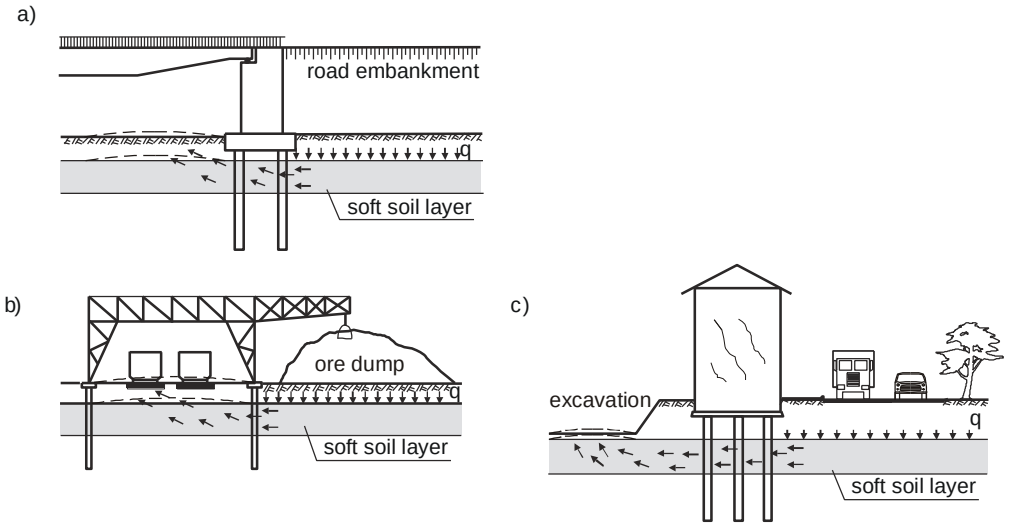


Fig. 2. Examples of lateral impact of weak soil layer on piles. a) bridge abutment, b) crane railway, c) building.

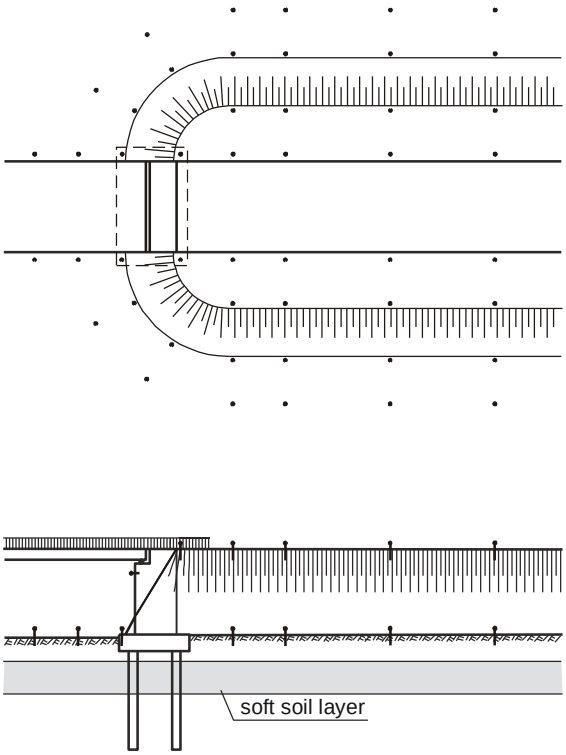


Fig. 3. Reference net around the abutment founded on piles loaded by lateral earth pressure with the localisation of benchmarks.

2.1 Model tests of laterally loaded piles

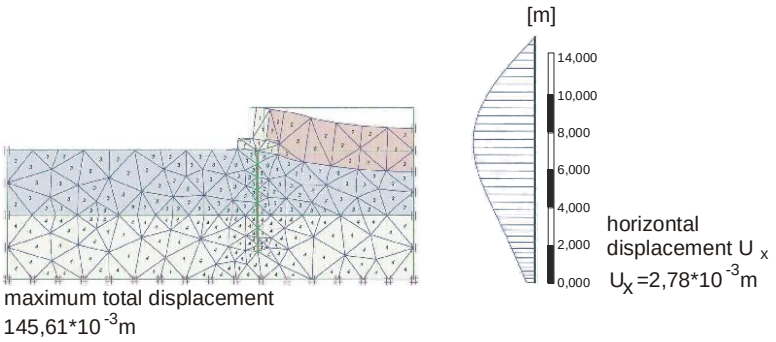
In the case when the explanation of the phenomena occurring at the contact of subsoil – real structure is impossible very helpful can be model tests, the results of which can serve for its qualitative and quantitative description, which in turn, after consideration of scale effects, can be transformed to in situ conditions. As an example can be a problem related to the character of deformations of the subsoil and weak soil layer around the piles supporting the abutment and its influence on the deformation of entire structure.
In model tests the measurements of soil displacements and the model structure can be made based on either geodetic technologies and techniques or some special measurement methods. Geodetic measurements require visualising space between the instrument and the measuring point within the soil or the model. Additionally, the accuracy of the measurements, place and space of the investigations and finally the costs are also important. As long as in real conditions, the accuracy of geodetic measurements equal to several millimetres is sufficient enough, then in model tests such accuracy is insufficient, that directly results from scale effects. Additionally, the size of lab stands and laboratory space can be some limitations influencing the choice of proper measuring technique. Thus, the old-fashioned, traditional measuring techniques applied in model tests can be still met.

The results of model tests are often verified by numerical simulations based on professional codes. The simulations require, in turn, proper data regarding the model structure and mainly soil properties. The necessary information is obtained from laboratory element tests, often with the use of advanced laboratory apparatuses, supplemented by classical test of physical parameters both of the soil used and the material of model structure.

The author has carried out comprehensive program related to various scale model tests, which aimed at recognition of the phenomena occurring in weak subsoil near piling foundation under abutment. Additionally, one of the main goals of these tests was an assessment of lateral loading caused by weak soil on piles and its deflection inducing the deformation of the superstructure supported by these piles. The detailed description of the tests performed can be found in Fig. 4.

Chosen results of model tests made at the University of Kaiserslautern and Gdańsk University of Technology together with its numerical verification made by PLAXIS professional code leading to the prediction of soil deformation are shown in Fig. 4.

a) Directly after construction of the embankment



b) 1000 days after embarkment construction

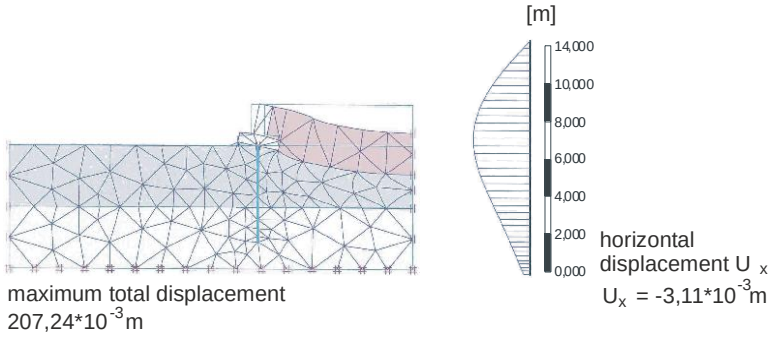


Fig. 4. Results of model tests and numerical simulations made by PLAXIS code.

3. PROPOSAL OF NON-INVASIVE, ELECTROMAGNETIC METHOD OF PILE DEFLECTION MEASUREMENT

Measurement methodology and prediction of deformation of the structure founded on piling foundation loaded laterally by earth pressure from weak soil layer should include deflection of piles. Due to various technologies of installation of the piles, its rigidity and various loads acting on it (superstructure, wind, snow, self-weight, earth pressure acting on superstructure, lateral earth pressure acting on piles), the resultant loads can cause tilting of the structure in changeable directions. While the values of particular load components acting on superstructure can be easily assessed or measured, the evaluation of lateral impact of weak soil layer is still discussed. In many cases these loads are estimated based on back analysis using determination of pile deflection. Next, knowing total loads acting on the structure, its stability can be optimally designed. Otherwise, the structure will be subjected to unknown loading, which may cause uncontrolled deformations. However, when applying the back analysis, proper determination and methodology of pile deflection may be the problem.

In order to find the distribution of deformation within the pile the new non-invasive method for the measurement of the deflection of piles due to lateral earth pressure caused by non-cohesive or low cohesion soil (dry and moist) was proposed. The method, which was verified on model as well as semi-technical scale tests, relies on the use of change of magnetic field induced in the vicinity of the pile for known magnetic permeability of soils, [1] , [2] .

In the proposal the Poisson's equation for determination of magnetic field produced by magnetic conductors with electric current was adapted together with Faraday's equation for a determination of electromotive force induction relating electric and magnetic fields in one electromagnetic field.

In order to verify the proposal for measurement of deflection of pile two-piece measuring device was built, that consists of the following:

- **transmitting system (sinusoidal generator, amplifier, and voltage transducer, transmitting coil placed on the pile),**
- **receiving system (receiving coil).**

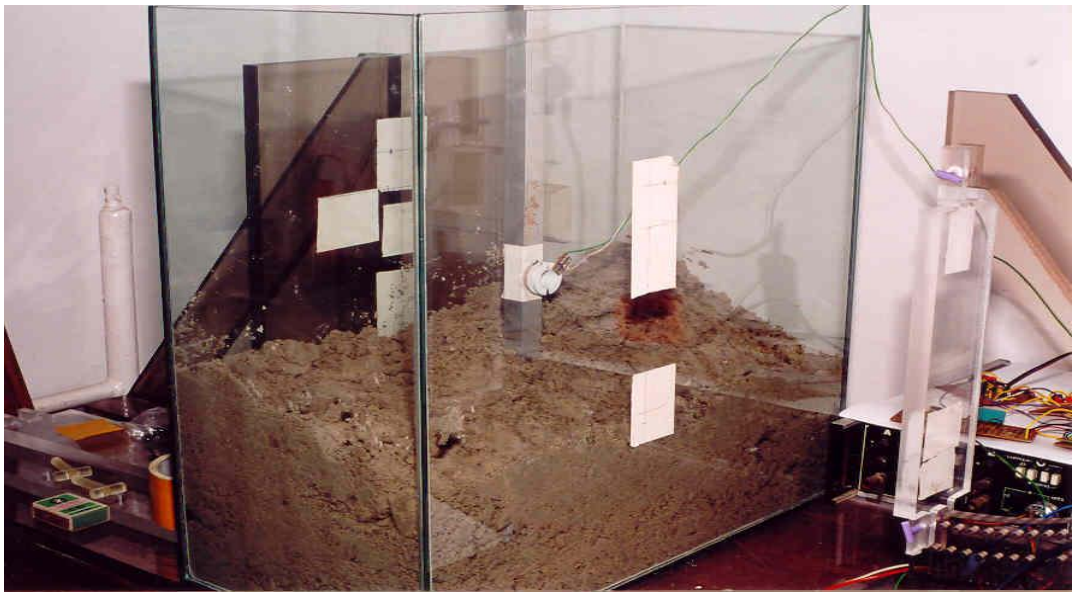


Fig. 5. Scheme of measuring system – table model.

Table model was made of Plexiglas, (Fig. 5). It consists of the box with a soil and frame with three-freedom degree moveable cave. During the test it was possible to obtain controlled change of receiving system. Basic pilot measurements have been performed for three different external conditions corresponding to the following media between the transmitter and receiver:

- **without any medium (air only),**
- **dry sandy silt,**
- **moist sandy silt.**

The investigations on the influence of location variation (i.e., vertical deviation, and horizontal movement in the same plane and torsional deflection) of coils between each other, have shown that:

- **the increase of deflection angle of the transmitting coil out of plumb and distance between the coils is accompanied by heavy decay of voltage,**
- **for small deflection (up to 20^{o}) and at the same distance between coils voltage change is also small,**
- **the increase of the distance between the coils corresponds to the decrease of induced voltage.**

The proposal, which was verified in small scale, has been next checked on the technical scale model. For that purpose the matrix suitable for larger lab stand was constructed. The matrix was equipped with receiving coils whereas the transmitting coils were installed on model pile. During the measurements, the signal coming from one transmitter was measured by 15 receivers (placed on the matrix).

4. SUMMARY

The problem of lateral impact of weak soil layer on the foundation presented in this paper is of the significant practical importance for the prediction of the settlements of the structure supported by the foundation. The knowledge of the loads acting on the structure as well as the distribution of its deformations with time should be considered for a design of proper geodetic base for observation of the structure deformations. Very helpful in this case can be non-invasive measurement method of pile deflection proposed. The method has been entered as a patent made at Gdańsk University of Technology.

REFERENCES

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Wtorek J., Kurałowicz Z., Truyen B., 2004, Monitoring of Deep Foundation Deflection In Model Experiments by Means of a Magnetic Method: Theoretical Study, Archives of Hydro-Engineering and Environmental Mechanics, vol. 51 (2004), No. 3, pp. 225-241.