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Anna JUZWA[1], Joanna BZÓWKA[2]

NUMERICAL SIMULATIONS OF SETTLEMENT OF JET GROUTING COLUMNS

Abstract

The paper presents the comparison of results of numerical analyses of interaction between group of jet grouting columns and subsoil. The analyses were conducted for single column and groups of three, seven and nine columns. The simulations are based on experimental research in real scale which were carried out by authors. The final goal for the research is an estimation of an influence of interaction between columns working in a group.

Keywords

Geoengineering, foundation columns, jet grouting method, jet grouting columns, numerical analysis in geotechnics

1 RESEARCH CHARACTERISTICS

The jet grouting method is one of the most popular technique for strengthening weak subsoil. Jet grouting columns allow for transferring substantial loads through the strengthened subsoil and reduce the structure's settlement [4]. The performance of jet grouting columns consists of a high-pressure injection of a cement grout stream into the subsoil, which cuts and disintegrates the soil massif, after that mixes with the soil particles and finally after cement binding forms cement-soil solid structure. In real condition columns always strength the subsoil interacting within the group [6], so authors carried out the comparative studies for single jet grouting column and groups of columns.

The wide spectrum of experimental tests and numerical analyses were carried out in order to explain and estimate the real conditions of the interaction between jet grouting columns and subsoil. At the site, the trial load tests - in the real scale - of a single column and group of three jet grouting columns were carried out [2]. All works were conducted by PPI Chrobok S.A. – the leading Geoengineering Company in Poland. The results of the research were also presented at the International Conferences in Ostrava [2, 5]

The main idea of the research is preparation of computational models, built on the base of the in situ load tests, which can be useful for engineering practice. Due to different material’s parameters and a large number of variables factors, it was necessary to apply sophisticated numerical methods to describe the interaction between columns and subsoil.

The numerical analyses were carried out with the use of the finite element method (FEM) and Z_Soil.PC computational program. For all numerical simulations the elastic–perfectly plastic material model with Coulomb–Mohr boundary condition and non–associated flow rule was used. The three-dimensional numerical model was built to solve the problem. The rectangular block was cut from the

[1] PhD., CEng. Anna Juzwa, PPI CHROBOK S.A., Kowola 11, 43-220 Bojszowy Nowe, Poland, phone: (+48) 32 218 9888, e-mail: anna.juzwa@chrobok.com.pl.
2 DSc., PhD., CEng., Associate Prof. Joanna BZÓWKA, The Silesian University of Technology, Faculty of Civil Engineering, Department of Geotechnics and Roads, Akademicka 5, 44-100 Gliwice, Poland, phone: (+48) 32 237 2873, e-mail: joanna.bzowka@polsl.pl.

half-space of soil massif. It contained cylindrical elements, that reflected jet grouting columns. The boundary conditions were as follows:

- on the side surfaces: support hinged-sliding, allowing vertical displacement,
- on the basis: prop shafts – without possibility of movements in all directions.

The applied finite elements were 8-node cuboid elements, each node assumed 3 degrees of freedom - displacement in the *x*, *y* and *z* directions.

The model was divided into three zones which represent: soil massif, columns material and contact layer. A very important issue was the selection of appropriate values of the geometrical and material parameters for zones. The soil parameters were introduced based on the laboratory and *in situ* geological tests (like data from boreholes, CPTU tests etc.). The layers were as follows:

- fine & medium sand I_D=0.44,
- clay with organic particles I_C=0.62,
- coarse sand I_D=0.78.

For the jet grouting material – acc. to [3] − an analogy to the soil − constitutive model was applied. The columns material parameters were determined based on the results of uniaxial and triaxial compressive tests, checked on the samples taken from the core of jet grouting columns. The jet grouting columns have a large non-uniformity shape and variable diameters. The shaft surface of the column can be more or less expanded and can have different shapes. In order to determine the geometry of the column the real diameters were measured at various depths at excavation site.

The contact layer was introduced between columns and soil massif to reflect the interaction with soil around shaft surfaces. This zone – acc. to Bzówka research [1] − was also described by constitutive model, the same as for the subsoil. Parameters selection for the contact zone was part of the model calibration.

The calibration of the numerical model was made based on the results of the load tests. The columns were loaded by applying a vertical surface load to the column caps. Load was applied in steps equal 1/10 of the maximum force, applied to the column during in situ tests. The maximum load was equal to 1800 kN. Columns diameters, thickness of contact layer and material parameters of contact layer were changed during the numerical analyses.

The calibration of the numerical model allowed to construct theoretical curves of relation "load − settlement" which highly correspond to the values obtained during *in situ* load test. The parameters used in these numerical simulations were introduced to further numerical analyses for larger group of jet grouting columns.

2 COMPARISON OF RESULTS OF NUMERICAL ANALYSES

To describe the interaction of jet grouting columns with subsoil the following models were built:

- the single jet grouting column (Fig. 1a) – model creates a rectangular block with dimensions of 9.0 x 9.0 x 10.0 m; built with 39 520 finite elements,
- the group of 3 jet grouting columns (Fig. 1b) – model creates a rectangular block with dimensions of 11.0 x 10.75 x 10.0 m; built with 55 784 finite elements,
- the group of 7 jet grouting columns (Fig. 1c) – model creates a rectangular block with dimensions of 12.0 x 12.0 x 10.0 m; built with 98 040 finite elements,
- the group of 9 jet grouting columns (Fig. 1d) – model creates a rectangular block with dimensions of 12.0 x 12.0 x 10.0 m; built with 116 280 finite elements.

The analyzed columns have variable diameters equal to 0.6 m and 0.8 m, length equals to 6.0 m − according to the shape of the real columns formed at the experimental plot. The homogeneous materials of columns and soil layers, are divided by contact zone. The contact layer has thickness

t = 10 cm and the material parameters are constant for the length and equal to 1/3 of the parameters of jet grouting material.

Table 1 contains results of settlements of central columns under some values of vertical loads. The maps of vertical displacements are shown in the Fig. 2, when the values increase, displacements of group of jet grouting columns are higher than displacements for a single column. There are some similarities to piles behaviour.

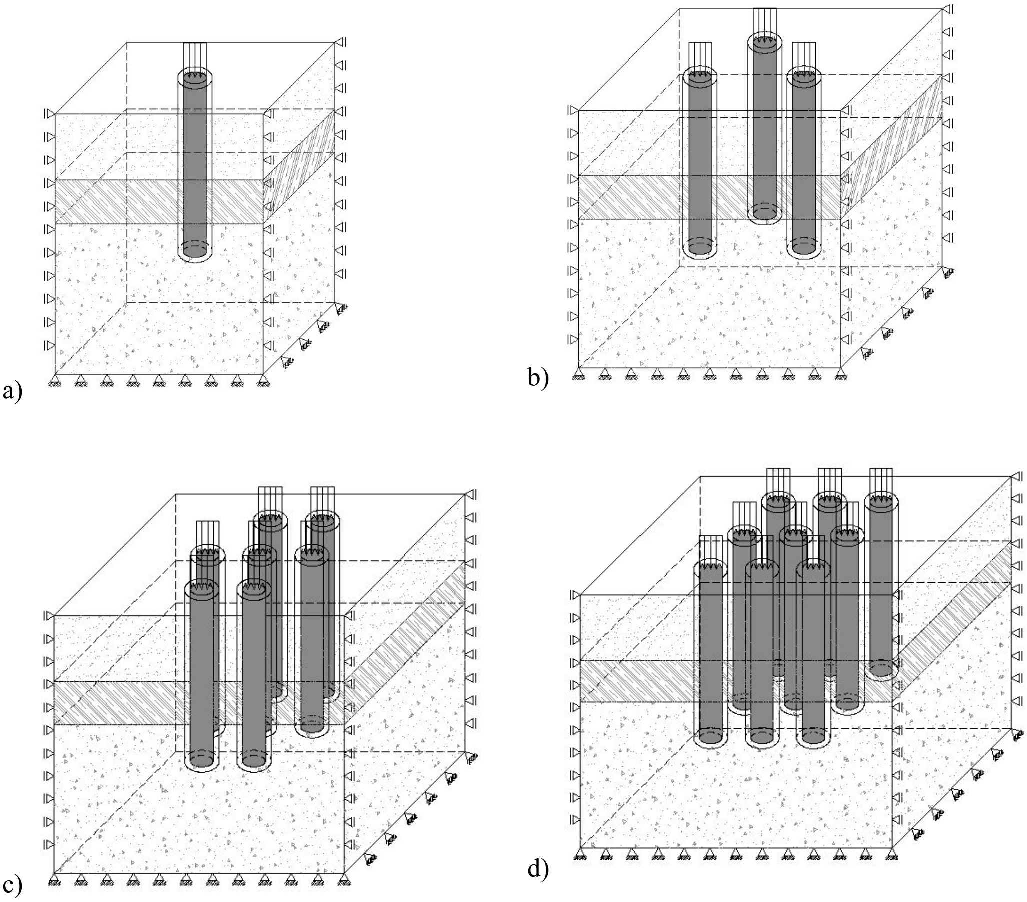

Fig. 1: The analyzed numerical models of jet grouting columns:
a) single column, b) group of 3 columns, c) group of 7 columns, b) group of 9 columns

Tab. 1. Settlements of columns from models under vertical load

load on column [kN]	column's settlement [mm]			
	single column	column from group of 3	column from group of 7	column from group of 9
900	5.99	8.79	12.21	13.08
1 440	13.35	17.47	21.87	23.02
1 800	18.86	23.67	28.53	29.84

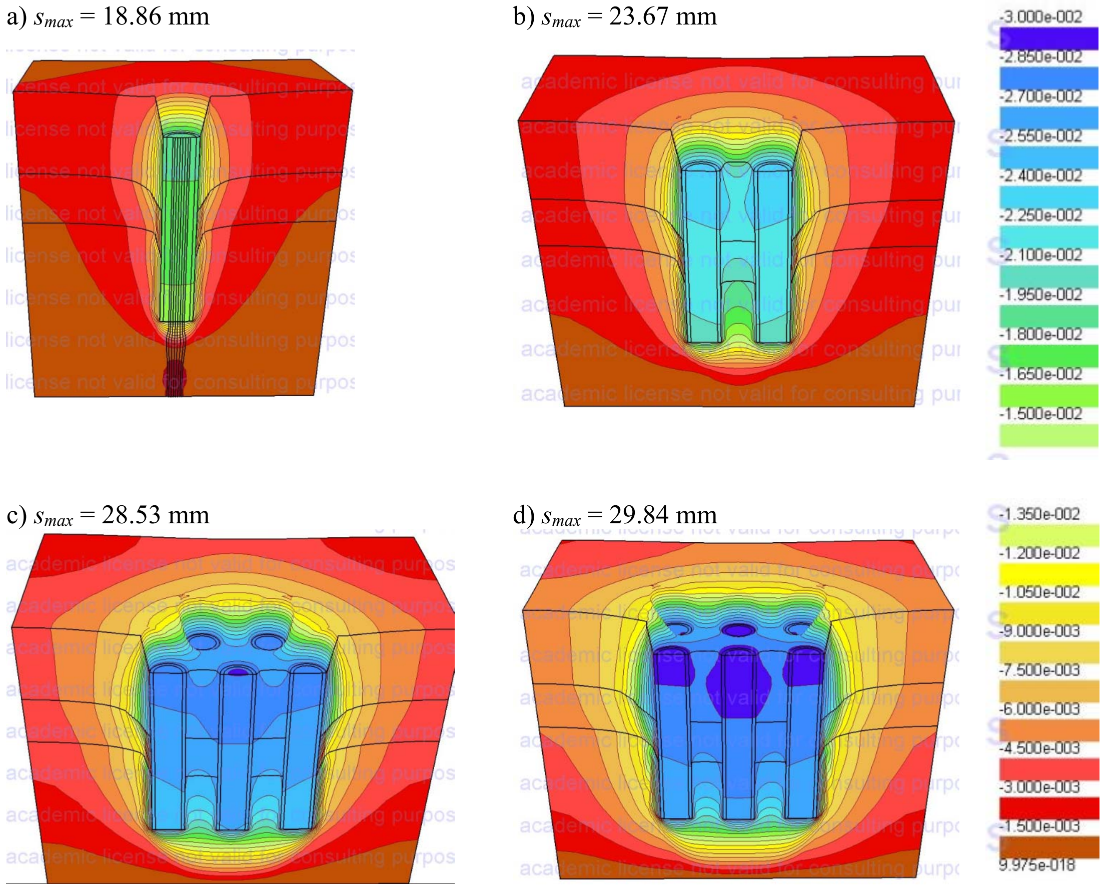

Fig. 2: The settlements [m] of jet grouting columns under the maximum load equal to 1800 kN acc. to numerical models of:
a) single column, b) group of 3 columns, c) group of 7 columns, b) group of 9 columns [5]

The calibration of the numerical model was made based on the comparison between shape of a theoretical curve of relation "load – settlement" and results of the load tests. The parameters of contact layer which best corresponded to real curves were applied to numerical analyses. The comparison of *in situ* and theoretical relations "load – settlement" are shown in the Fig. 3.

The curves of relation "load – settlement" obtained as the results of numerical analyses are shown in the Fig. 4. There are some higher values of displacement for columns which are in the center of a group.

3 SUMMARY

The main idea of the presented part of the research was preparation of computational models which describe an interaction of jet grouting columns with subsoil in real conditions. Presented model will reflect the essence of jet grouting technology, because it is based on *in situ* tests.

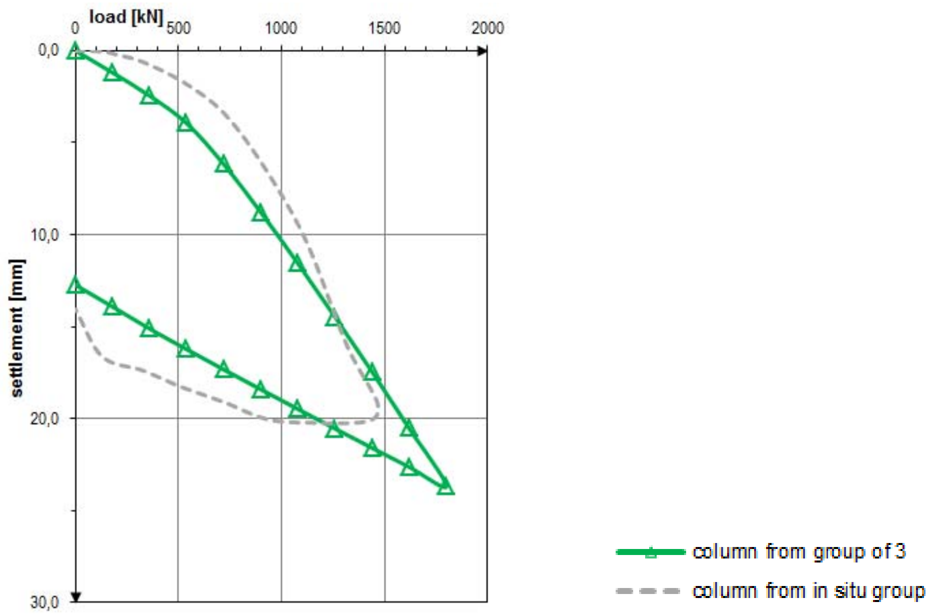

Fig. 3: Comparison between real and theoretical curves of relation “load – settlement”

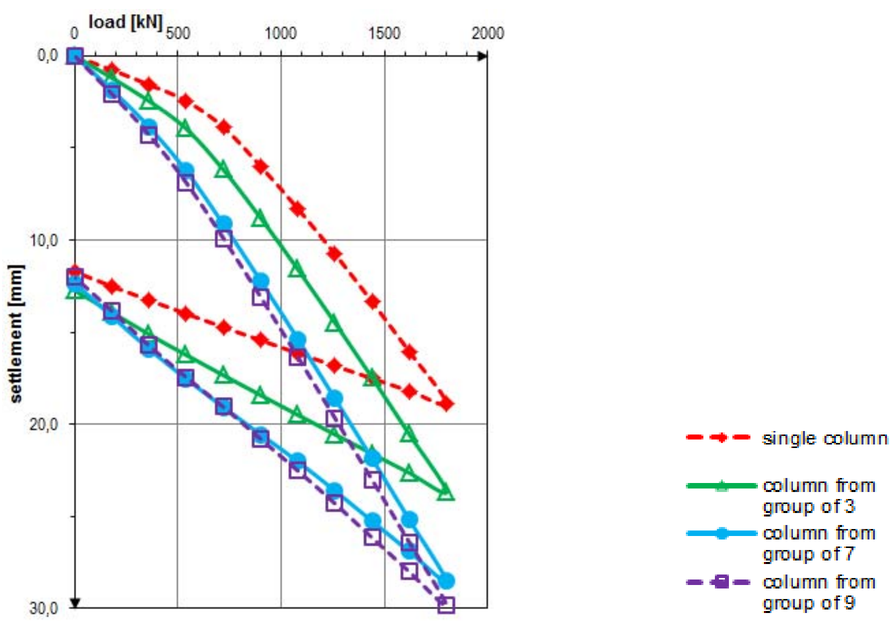

Fig. 4: Comparison of numerical curves of relation “load – settlement” [5]

The presented results show that the highest displacement characterised columns from the centre of group and if the group are larger (more columns in the group) than the values of settlements are increasing. It can be assumed that this phenomenon – similar to co-worked foundations piles - is related to an influence of an interaction between columns and increased settlement of upper layers of subsoil due to greater load values applied to the top of columns.

Authors are going to conduct *in situ* load tests of groups of jet grouting columns with another diameters and spacing between columns and for different subsoil condition. The numerical simulations, carried out in the future, based on the *in situ* results will help to build the model of jet grouting columns interacted with subsoil. The results of such experimental and computational analyses will allow to introduce numerical techniques into engineering practice. The application of the numerical techniques will help to optimize engineering methods for jet grouting columns dimensioning.

LITERATURE

[1] BZÓWKA J.: “Interaction of jet grouting columns with subsoil”. Monograph. Gliwice 2009, Poland (in Polish)

[2] BZÓWKA J., JUZWA A., ŻYREK T.: “Selected aspects of loading tests of jet grouting columns” in: Proceedings of International Conference “Zpevňování, těsnění a kotvení horninového masivu a stavebních konstrukcí” (Reinforcement, sealing and anchoring of rock massif and building structures), 27÷28.02.2014, Ostrava, Czech Republic.

[3] CROCE, P, FLORA A. & MODONI G.: „Jet Grouting. Technology, design and control”, CRC Press, Boca Raton 2014, USA.

[4] JUZWA A.: “Analysis of interaction between group of jet grouting columns and subsoil”, PhD thesis. Gliwice 2015, Poland (in Polish).

[5] JUZWA A., BZÓWKA J.: “Numerical analyses of interaction between group of jet grouting columns and subsoil” in: Proceedings of International Conference “Zpevňování, těsnění a kotvení horninového masivu a stavebních konstrukcí” (Reinforcement, sealing and anchoring of rock massif and building structures), 18÷19.02.2015, Ostrava, Czech Republic.

[6] MODONI G., BZÓWKA J.: “Analysis of foundations reinforced with jet grouting” in: ASCE Journal of Geotechnical and Geoenvironmental Engineering. Vol. 138/ No 12, December 2012, p. 1442÷1454.