Selected problems connected with the use of the jet grouting technique

Certains problèmes liés à l'application de la technologie d'injection de jet

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ABSTRACT: The paper presents selected problems connected with the use of the jet grouting technique. It is one of the most popular methods for subsoil strengthening, enhancement for existing foundation, vertical and horizontal waterproof cut-off walls. Columns made using this method feature a high bearing capacity (very high friction on the shaft). The newest achievements of the numerical explanation of the interaction between jet grouting columns and subsoil are presented in the paper. The created models will be used to verify engineering methods of jet grouting columns dimensioning. Computational analyses are conducted using software based on the finite element method (Z_Soil).
The computational model describes the interaction between a group of jet grouting columns and soil. The main element of this analysis consists of selection and calibration of computational model of the "group of jet grouting columns – subsoil" interaction. The model space is divided into three zones: columns, soil and the contact layer formed between the columns and the soil massif. The computational model allows for a plastic character of deformation under load and especially for a non-linearity of contact zone.
The description of shape of a shaft surface of jet grouting columns is very difficult, so the fractal theory is used to describe this shape. Fractal and box dimensions are used to estimate the irregular surface. This model allows a precise selection of formation parameters, like the injection rod pull out velocity and number of rotations, injection pressure and the water/cement ratio, which define the geometry of jet grouting columns.

RÉSUMÉ : Cet article présente quelques problèmes liés à l'utilisation de la technique d'amélioration des sols : le jet grouting. Cette technique est une de méthodes les plus utilisées pour renforcer le sous-sol, les fondations déjà existantes et on s'en sert aussi comme les parois verticales et horisontales étanches (imperméables à l'eau). Les colonnes réalisées par cette méthode se caractérisent par la grande capacité portante (coefficient de frottement très élevé sur la surface latérale). Dans cet article, on présente les découvertes les plus récentes liées aux modélisations numériques de l'interaction entre les colonnes de jet et du sol. Les modèles développés seront utilisés pour vérifier les méthodes d'ingénierie et pour dimensionner les colonnes de jet grouting. Les analyses numériques sont effectuées par les programmes basés sur la méthodes des éléments finis (Z_Soil).
Le modèle de calcul décrit l'interaction entre un groupe de colonnes de jet grouting et le sol. L'apport le plus important de cette analyse réside dans le choix et le calage du modèle de calcul pour l'interaction « groupe de colonnes de jet grouting – sol". L'espace du modèle est divisé en trois zones: colonnes, sol et couche de contact formée entre les colonnes et le massif du sol. Le modèle de calcul permet d'avoir des déformations plastiques et en particulier de déformation non-linéaire de la zone de contact.
La description de la forme des surfaces latérales de ces colonnes est extrêmement difficile, alors on a introduit la théorie de fractales pour la décrire. Les dimensions de type fractal et de boîte, sont utilisées pour estimer la surface latérale irrégulière des colonnes. Ce modèle permet de choisir d'une manière précise des paramètres de formation des colonnes tels que: vitesses - de rotation et d'avancement en descente de la tige de forage, le nombre de rotation, la pression de coulis injecté, rapport eau/ciment, qui définissent la géométrie des colonnes de jet grouting.

KEYWORDS: jet grouting technique, interaction between columns and subsoil, shape and dimensions of jet grouting column.

1 JET GROUTIMG COLUMNS INTERACTION WITH SUBSOIL

The jet grouting method is frequently used in the engineering practice. It may be used for nearly all types of soils, both natural and man-made. It does not work only for a subsoil built of organic soils. The method consists in a high-pressure injection into the subsoil of an injectant stream (most often being a cement grout), which cuts and disintegrates the soil body, forming – after binding with soil fractions – a petrified soil-cement composite of any geometrical form, e.g. close to a column cylinder shape. This solution – because of the speed of performance and very good parameters of subsoil strengthening – is frequently used to strengthen a weak subsoil under high transport embankments or bridge abutments (Bzówka 2009; Juzwa 2012b; Modoni and Bzówka 2012).

To explain the interaction between the jet grouting columns and the strengthened subsoil it is suggested to apply numerical methods and to build models reflecting the operation of a single column and the interaction of jet grouting columns group in transferring the load to deeper soil layers. A solution is sought, which would allow optimising design solutions of jet grouting columns, would ensure safety of a structure designed this way and at the same time would contribute to the works costs cutting. The authors emphasise especially as precise as possible reflection of real conditions, existing on a site.

A single column and a group of columns are the subject of numerical and in situ analysis. A single column is an idealised form, seldom existing in practice. However, the analysis of its behaviour is a starting point to make models more realistic and built of a group of columns. For the needs of analysis of interactions occurring between jet grouting columns strengthening a weak subsoil and the soil body numerical models were constructed, considering the environment division into three material zones: the soil-cement material of jet grouting columns – the contact layer – the subsoil (Bzówka 2009, 2010).

Because of a physical inhomogeneity and of a complicated geometrical arrangement the finite element method was used to build models and the Z_Soil software was used for computations. An elastic – ideally plastic model of Coulomb – Mohr boundary surface with non-associated law of flow were adopted to describe the mechanical behaviour of the soil environment and the jet grouting columns material.

To perform computer simulations it is necessary to give the following parameters: angle of internal friction Φ, angle of dilatancy Ψ, cohesion c, modulus of elasticity E and Poisson's ratio v. Values of parameters for soils building the model subsoil were taken based on in situ tests on a test site. The following values were taken, for sand: E = 55.5 MPa, v = 0.3, Φ = 31.8°, c = 1 kPa, for a cohesive soil interbedding: E = 33.8 MPa, v = 0.3, Φ = 18.0°, c = 30 kPa. The value of angle of dilatancy was introduced from the range of values $\Psi = (0.35\div0.40)\cdot\Phi$. Determination of material parameters for a cement–soil material depends on the subsoil ground characteristics, cement type in the grout, the method of columns performance. To determine them it is necessary to take core samples from the column performed (Fig. 1). These samples are then tested for uniaxial and triaxial compression. For the needs of this study 10 samples were tested for each case, obtaining results of significant scatter (Bzówka 2009). A statistical analysis of result values was carried out and after approximation with the first type regression function the following parameters were taken for calculations: E = 9888 MPa, v = 0.186, Φ = 59.3°, c = 1772 kPa. Values of soil parameters (E, v, Φ, c) were taken for the contact zone based on CPT sounding performed in this area. Their values equal to soil parameters reduced by 1/3.

Figure 1. Core samples for strength tests (Bzówka, 2009).

A 2D model was built cutting from the space around columns an area large enough, allowing idealisation of boundary conditions. Boundary conditions were taken in the form of: full fixing of the base of the half–space cut and partial fixing, allowing a vertical shift, on side surfaces of the half-space

In the model of a flat system a group of 3 columns was taken, each of them 4.0 m long and 0.8 m in diameter, arranged at a distance of 2.5 m, while the subsoil is stratified. Division into quadrilateral isoparametric elements was assumed. The grid was concentrated in the area of contact zone. An incremental load (uniform for all columns) was applied to such system, reflecting a real transport embankment 4.0 m high, laid at fixed intervals in layers 0.5 m thick.

The image of system deformations caused by columns loading is presented for two stages in Fig. 2. Corresponding stresses are shown in Fig. 3. The stress maps perfectly show the range of transition zone, which parameters affect the distribution of internal forces values in the system (Bzówka et al. 2012; Juzwa 2012a).

2 GEOMETRY OF JET GROUTING COLUMNS

The shape of columns made by the jet grouting technique, due to specific nature of this technology, is very diversified and difficult to predict. It depends inter alia on the type and condition of soils making the subsoil, the injection system used (single, double or triple) and on technological parameters (injection pressure, size and shape of injection nozzles, speed of injection rod pulling out and rotations and others) (Wanik and Bzówka 2012).

To determine precisely the geometry of jet grouting columns they are excavated, making their measurement and macroscopic visual inspection possible. The shaft may have various shapes (Fig. 4) depending on the aforementioned factors.

a)

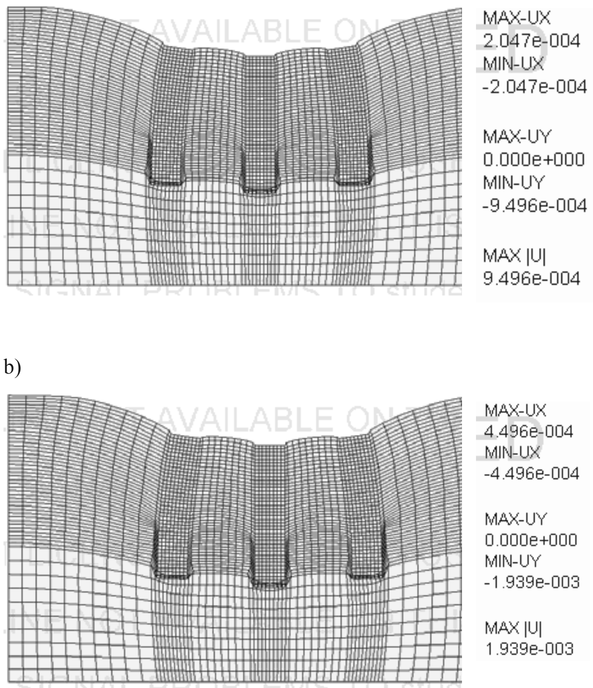


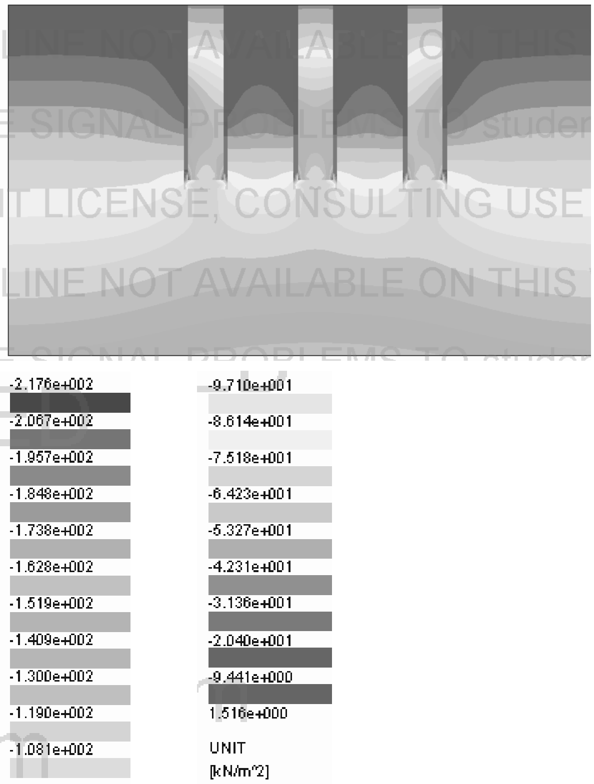
Figure 2. Model deformations [m] under influence of the load of embankment: a) h=2.0 m; b) h=4.0 m high (Z_Soil) (Bzówka et al. 2012; Juzwa 2012a).

Fractal theories may be used to describe an irregular surface of jet grouting columns. Using a fractal and a box dimension it is possible to describe better an irregular shaft surface of a jet grouting column, its shape and roughness. A more precise description of roughness and geometrical parameters of soil particles allows a more detailed determination of such properties as: porosity, density and shear strength (Bzówka and Skrzypczyk 2011).

The paper presents an example of fractal dimension and box dimension calculation for an excavated jet grouting column made in a single system (see Fig. 6÷8). Results of studies presented in papers (Kawa and Wieczorek 2005; Wanik 2012a, 2012b; Wanik and Bzówka 2012) have been used.

The described jet grouting column was made in average compacted medium sand, under which a stiff silty clay was situated. After column excavating and cleaning, an irregular shaft surface was disclosed and also a clear change of column diameter on the boundary of two layers forming the subsoil (see Fig. 5).

a)

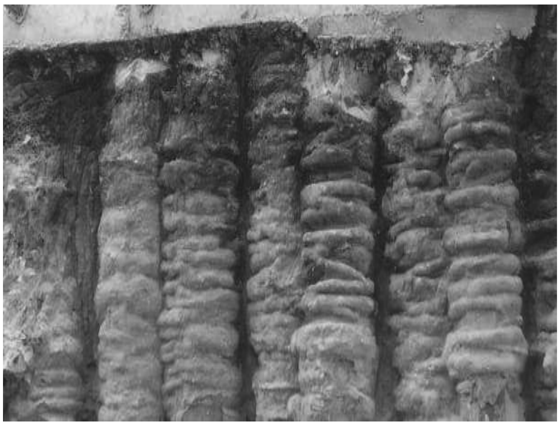


b)

Figure 3. Map of vertical stresses of the model under influence of the load of embankment: a) h=2.0 m; b) h=4.0 m high (Z_Soil) (Bzówka et al. 2012; Juzwa 2012a).

a)

b)



c)

d)

Figure 4. Different shapes of excavated jet grouting columns (photos: J. Bzówka, and K. Wanik).

Figure 5. Structure of excavated jet grouting column (photo: J. Bzówka).

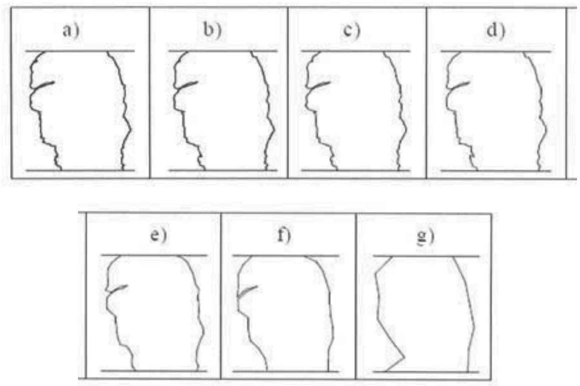


Figure 6. Method for determining fractal dimension for column (Kawa and Wieczorek 2005; Wanik 2012a).

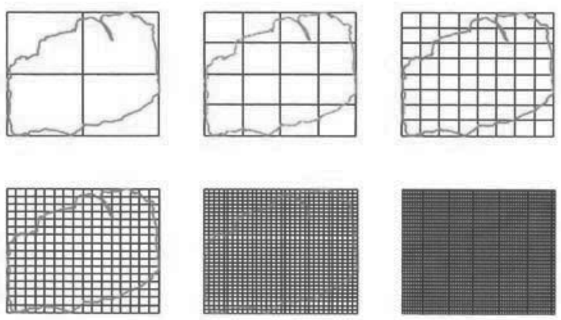


Figure 7. Method for determining box dimension for column (Kawa and Wieczorek 2005; Wanik 2012a).

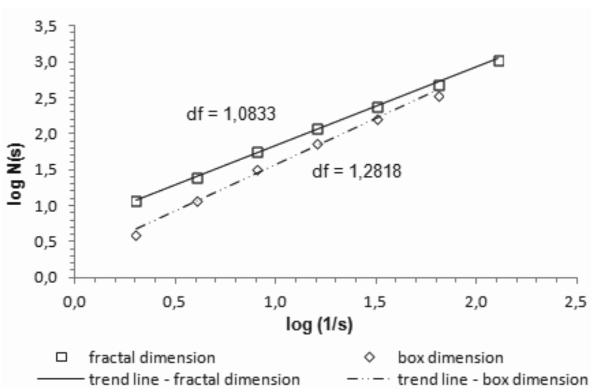


Figure 8. Fractal dimension and box dimension for jet grouting column.

3 SUMMARY

Issues presented in the paper show the scale of problems related to the representation of actual interaction of jet grouting columns with the surrounding subsoil. Theoretical models require repetitions and calibration, making the obtained results realistic. It is especially important to determine the thickness and parameters of the contact zone formed at the contact of column material and the subsoil.

The shape and dimensions of formed jet grouting columns depend on the type and condition of soils building the subsoil and on technological parameters of columns forming, such as: the injection pressure, the injection rod pulling out and rotation speed, the density of injected cement grout as well as the number and size of injection nozzles.

A large number of factors affecting geometry and hence related columns bearing capacity and the soil–cement material strength causes problems in designing. To verify geometry of columns made it is necessary to perform excavations and to measure the diameter, circumference shape and to assess the shaft structure. Mathematical issues from the field of fractal and box dimension allow creating a clear description of a complicated shape of jet grouting columns shaft.

4 ACKNOWLEDGEMENT

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