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PREDICTING THE BEHAVIOR OF PLATE-AND-PILE FIELD OF THE HIGH-RISE BUILDING BY NUMERICAL METHOD OF BOUNDARY ELEMENTS

Using the numerical method of boundary elements, settlement of the 16-storey monolithic brick building has been modeled and research results have been processed.

Key-words: *boundary elements method.*

Introduction

One of the vital problems of modern foundation engineering is the choice of reliable bases and foundations for high-rise buildings that are simultaneously growing up and down. In many cases designing of high-rise buildings and their foundations go beyond the limits of normative documents and their construction must be accompanied by monitoring of both foundations and overground structures. Requirements to the ultimate strain of the bases of such buildings (especially to their unevenness and heeling of high-rise buildings) are extremely strict. World and home experience of high-rise buildings design shows that engineering (conventional) methods for calculation of foundations and substructures are evidently insufficient. Scientific approaches are required as well as numerical spatial non-linear calculations of the entire “building – foundation – base” system.

Plate-and-pile foundation is the most prospective and economical type of foundations according to all parameters and they are widely used in the construction of high-rise buildings ensuring small settlement and low probability of building heel. Yet, there are some uncertainties in the pile-field theory, which reduce the possibility of their reliable prediction. One of such uncertainties is piles interaction consideration.

Problem statement, defining relationships

The conception of plate-and-pile foundation presupposes the transition of a part of the load from the building to the foot of the panel and of another part – through the piles. It is important to know what part of the load is received by the plate. The rigidity of a high-rise building structure is rather high and therefore the ground under the foundation behaves as in a rigid stamp.

In this work settlement of 16-storey 54-meter monolithic brick building with underground (in the city of Saint-Petersburg) is being modeled using the numerical method of boundary elements (BEM) [1] (fig. 1).

In the plan the building has the form of a trefoil with the underground floor area of 870 m^2; the weight of the building is 222720 kN.

The soil behavior was described by the model of plastic-elastic compression with porous medium displacement on the basis of non-linear methods for the solution of geotechnical problems of plastic flow theory with the introduction of function, that expresses flow surface (1), and cinematic relationships of plastic flow (2). Achievement of the yield point is connected with limit equilibrium according to the condition of Mises – Schleicher - Botrin:

$$\begin{cases} f = \sigma_i + \sigma \cdot tg\psi - \tau_s, \text{при}\, \sigma \le p_0 \\ f = \sigma_i + p_0 \cdot tg\psi - \tau_s, \text{при}\, \sigma > p_0 \end{cases}, \quad (1)$$

where σ – hydrostatic pressure; σ_i – stress deviator intensity; ψ – internal friction angle; τ_s – parameter analogous to cohesion; p_0 – soil medium parameter.

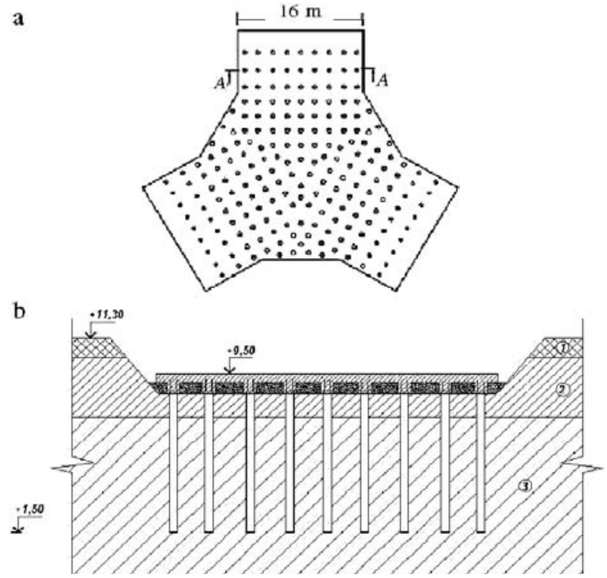

Fig.1 The plan of plate grillage, pile field (a) and A-A cross-section(b)

One of the non-linearity criteria is displacement over the target surface which corresponds to the soil displacement over the lateral surface with loaded pile. Relationship between plastic deformation rates and stresses at the non-linear stage of displacement was described according to the non-associated law of plastic flow.

$$d\varepsilon_{ij}^{p} = d\lambda \frac{dF}{d\sigma_{ij}}, F \ne f, \quad (2)$$

where F is plasticity potential, deformation history function, f – criterion of the transition to plastic condition; λ – scalar coefficient of the simple load that is found while solving plastic problem; $d\sigma_{ij}$, $d\varepsilon_{ij}^{p}$ – gain of the stress tensor and plastic deformation tensor.

In order to solve the problems of plastic flow theory it is necessary to know traditional physical and mechanical parameters of the soil, which makes it possible to use the method in mass design process.

Geologic condition of the base is described by the following weighted average physical and mechanical characteristics of the soil: E=18,43 MPa; v=0,39; ρ=1,8852 г/см^3; $\rho_{\min}$=1,56 г/см^3; $\rho_{\max}$=2,67 г/см^3; c=39,33 kPa; φ=19,15 ^{0}.

Rather high values of normal and flexural rigidity were specified for the piles material, which makes it possible to ignore deformation of the piles in calculations.

In the building that has been constructed the piles were cutting upper weak soil layers and transmitted the load to the deep soil layers (hard clay, E=23 MPa, ρ=1,9 g/cm^3), that are characterized by high building properties. As under the plate at the depth of 9 m soils with relatively good building properties (E=10 MPa) are located, a problem of using their resistance arises.

In order to determine fraction of the load that foundation plate and piles field can withstand, calculations were performed by numerical BEM for given geologic conditions of the construction site.

Scheme of the soil mass discretization under individual foundation plate is presented in fig.2.

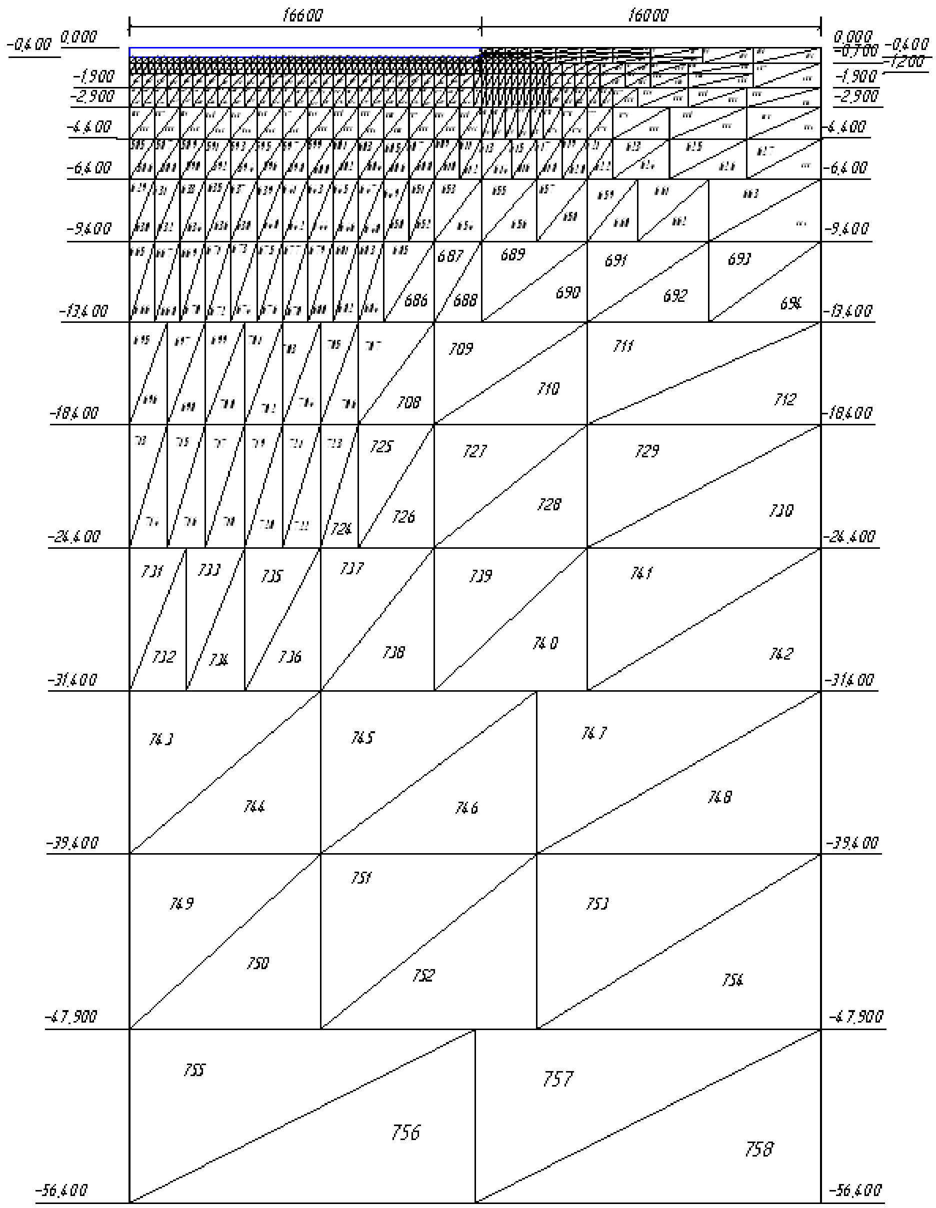

Fig.2. Soil mass discretization under the base and along the side face of the foundation plate

According to the numerical calculation results, maximal load that the plate with the width of 40 cm can withstand on the given soil is equal to approximately 37.000 kN (fig.3a.). This value constitutes 16, 6% of the building weight and satisfies the recommendations on the plate-and-pile foundation calculations (СП 50-102-2003) that advice to transmit ≈ 15% of the load to the plate grillage of the plate-and-pile foundation.

In numerical calculations the width of the active zone between piles is assumed to be 11 d [2], which corresponds to the experimental research of O. A. Bartolomey according to which no mutual influence of the piles is observed if distance between them is 10 d [3].

Piles field calculation results (Fig. 4) show that in the settlement range up to 16 cm linear relationship between load and settlement is observed. This is the evidence of the absence of plastic deformation zones and base soil displacement that appear in piles field when S > 14 – 30 cm [3]. From fig. 4 it is clear that at the linear stage of soil consolidation process piles field behaves like an integral entity with soil compressed between the piles because distance between the piles is less than 10 d (from 1500 to 1850 mm). Under such conditions soil can be confined only within the limits of piles influence zone.

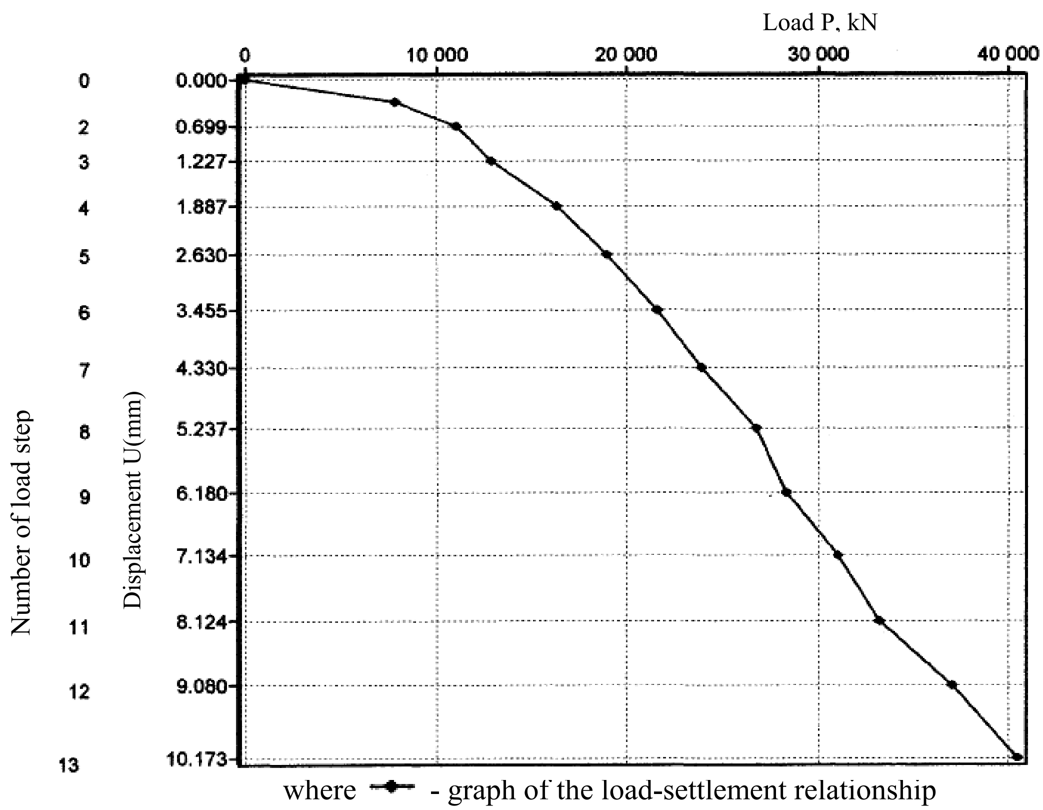

Fig. 3. Results of the foundation plate calculations by boundary elements method

Data of forces redistribution between the piles of the piles field for definite soil conditions are presented in fig. 5. Results of the numerical research on forces redistribution corresponds to the normative documents and to the experimental research of O. A. Bartolomey: angular pile receives the load that is almost double that of the central load. Relationship between the loads on the extreme – angular – central piles was 1-1,42 – 0,7.

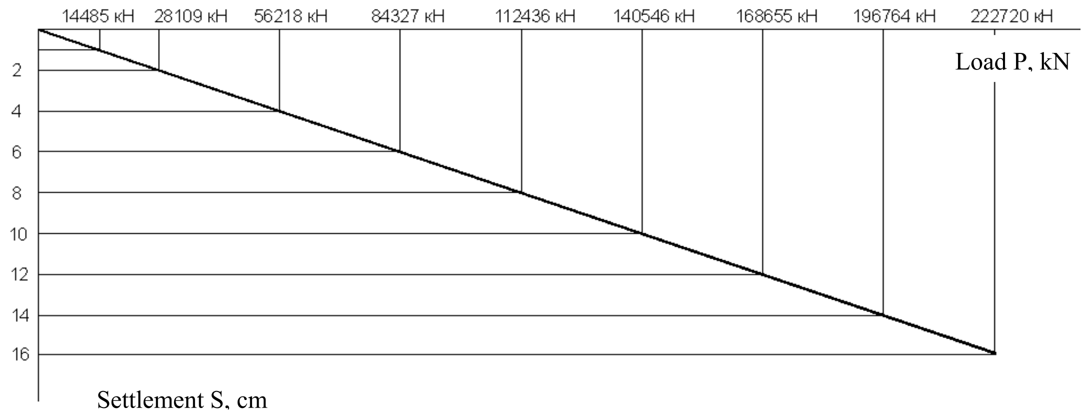

Fig.4. Results of the high-rise building piles field calculation by BEM with the interaction of piles field active zones being taken into account

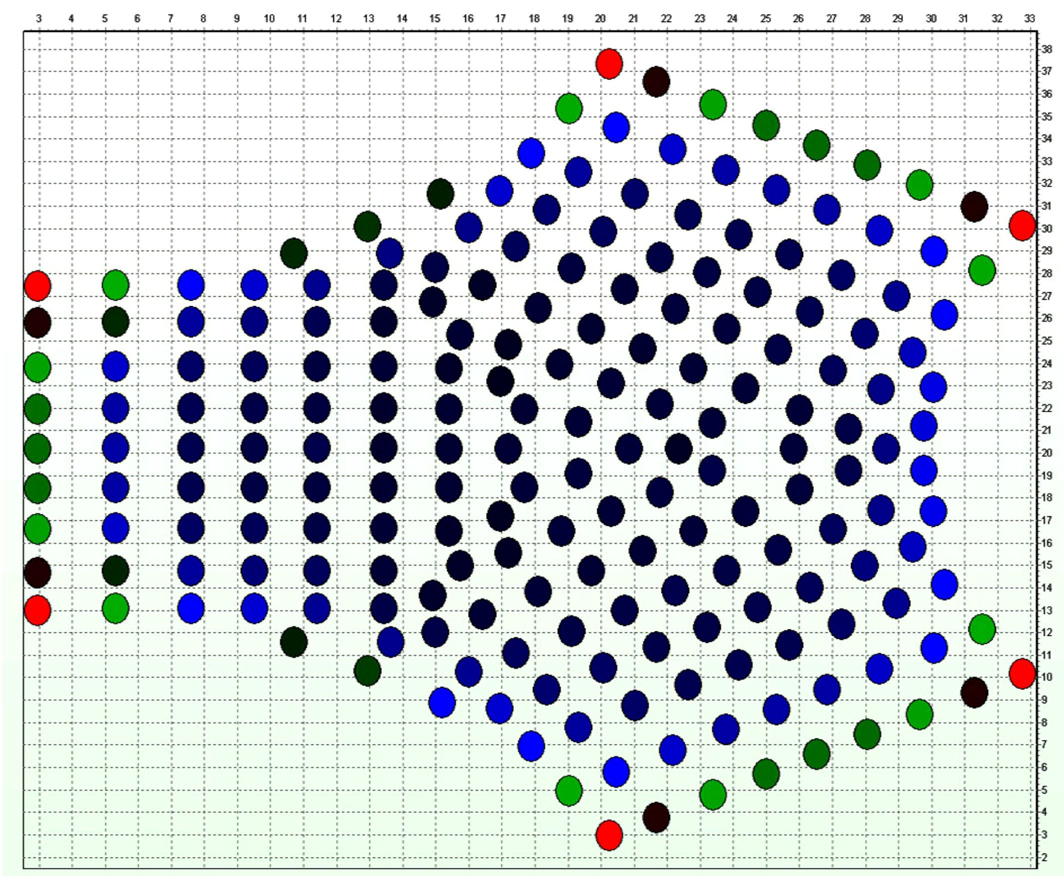

Fig.5. Results of the piles field calculation presented in the following colours:
- 186 kN, - 70,5 kNкН, - 46,9 kN - 58,8kN

Considering part of the load that foundation plate with the width of 40 cm (about 37,000 kN) can withstand, building settlement value (fig.4) is approximately 15,6 cm. According to the data of experimental research, after construction was completed (250 days), on the 762nd day settlement practically stabilized and was 13,2 cm [1].

Conclusions

1. Results of mathematical modeling with the application of boundary elements method confirm the ability of plate-and-pile foundations to provide permissible values of settlement for the buildings constructed on them.

2. The presented dilatation model of soil calculation by BEM enables reliable analysis and acquisition of data that have predictive character.

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