Proceedings of the 16th International Conference on Soil Mechanics and Geotechnical Engineering

doi:10.3233/978-1-61499-656-9-1447

The peculiarities of stress-strain state at interaction of high-rise buildings and structures with the base

Etat de contrainte déformatrice. Interaction des buildings et bâiments avec l'assise. Cas particuliers

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ABSTRACT
The peculiarities of interaction of the pile foundations of the high-rise buildings with the base in the conditions of load gradual increasing are shown. The procedure of numerical modeling of interaction of elements of the system "base-foundation-aboveground structures" is described, which ensures obtaining of the characteristic zones of stress-strain state of the building underground part. The problems of interaction of the high-rise buildings with the base at static and dynamic impacts were solved by the developed procedure.

RÉSUMÉ
Apres avoir présenté les particularités de l'interaction entre les fondations de pilot des bâtimens à plusieurs étage et la base dans un contexte d'augmentation progressive de la charge, suit la description de la méthode de modélisation numérique de l'interaction entre les éléments du système "base – fondations – construction surélevéé". Cette méthode assure la détermination des zones caractéristiques (tension/déformations) dans l'état de contrainte déformatrice de la partie souterraine du bâtimen. Des cas particuliers sont examinés où cette méthode est appliquée pour l'étude de l'interaction "base – fondations – construction à plusieurs étages" sous des impacts statiques et dynamiques.

1 INTRODUCTION

Construction of the high-rise buildings and structures in the historical part of the cities was always accompanied by geotechnical problems. First of all one shall mention the problem of peculiarity of interaction of the pile-slab foundation with the base depending on dimensions of slab-raft, length and location of the piles in plan. The second important problem is consideration of character of load transmitting during construction of the building stories and the corresponding changing of stiffness parameters. It is necessary to name selection of the calculation procedure the main problem, in which the interaction of the elements of system "base-pile-slab-foundation-aboveground structures" on different stages of loading of these elements is correctly modeled.

In design of pile foundations attention is often not paid to the terms "pile foundation" or "pile base". The last term is related to application of the short piles at considerable dimensions of slab-raft. In this case the piles loose their advantages to transmit loads to the bearing layer of the base, which is located in considerable depth, and their role consists only in improvement of soil properties under the raft. In this case one shall make the calculations by the requirements of the norms for shallow foundations and not for pile foundations.

2 ENGINEERING METHODS OF SOLUTION

Application of the engineering methods for solving of the tasks, mentioned in this paper, often does not ensure obtaining of the reliable solutions as for example errors in determination of moments in slab-raft occur not only in quantity up to 2 times but in some cases in quality (the sign is changed). For these cases the procedure of numerical modeling is recommended, which was developed by the authors of the first part of this publication (Boyko I. and other, 1992; Boyko I. and Sakharov V., 2004). The proposed procedure is used for solving of the problems on the basis of plastic yield theory. As limit state criterion one of already known criteria can be accepted (Boyko I. and other, 1992; Wilkins M., 1967). For description of the processes of non-linear soil deformation a non-associative law with dilatation condition of professor V. M. Nikolaevskyi is used (Nikolaevskyi V., 1975), at that the authors additionally introduced the function of changing of dilatation and contraction coefficient depending on residual density and hydrostatic pressure on each step of loading, which is specified in the developed model on the basis of experimental investigations.

The solved practical problems of interaction of the high-rise buildings with the base, which were developed in three-dimensions, showed peculiarities of formation of the characteristic stress-strain zones in pile-soil massive (Fig.1), which fundamentally differ depending on the accepted model, for example in the first case the soil massive with real soil layers, physical and mechanical parameters is accepted. In other case the model with one or some coefficients of the base stiffness is used, which in scheme represents behavior of the base and solves only the contact problem for raft slab as its value is calculated by the anticipated acceptable settlement. In real conditions settlements of high-rise building foundations are less or often exceed the permitted settlements, according to the normative requirements, that in its turn requires review of the calculation schemes. In such cases one shall make recalculations, but unfortunately it is too late.

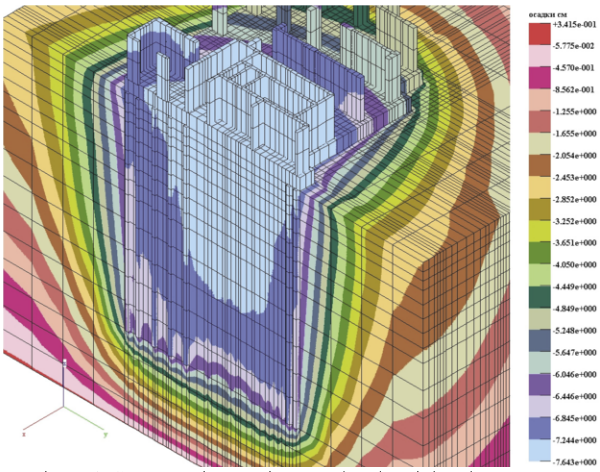

Figure 1. Stress-strain state in central and peripheral zones

The analysis of the interaction of high-rise building foundations with the base at seismic and dynamic impacts can be performed with applying of the dynamical model, which considers the factors of deforming of structures and base as a model (Fig. 2).

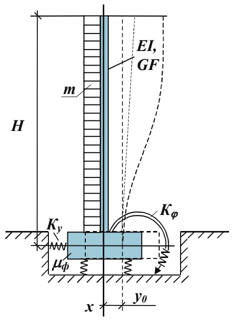

Figure 2. Design diagram of SFB system

Design diagram of the structure is presented as cantilever bar with uniformly distributed mass and concentrated foundation mass. Bar stiffness is determined by flexure and shear deformations, and foundation interaction with soil is modeled by elastic fixing in the base with soil stiffness factor for shear $\boldsymbol{K_y}$ and rotation $\boldsymbol{K_\varphi}$.

The period of natural oscillations $\boldsymbol{T_i}$ (s) of the system by $\boldsymbol{i}$-mode is determined by the following formula (Polyakov S.V. and Nemchynov Yu.I, 1968; Nemchynov Yu.I. and other, 2000):

$$T_i = \frac{2\pi H^2}{\alpha_i^2}\sqrt{\frac{m}{EI}}(1-\lambda\alpha_i^2), \tag{1}$$

where $\boldsymbol{H}$ – is a building high, m; $\boldsymbol{\alpha_i}$ – factor of $\boldsymbol{i}$ mode of natural oscillations of "structure-foundation-base" (SFB) system; $\boldsymbol{m}$ – building mass, uniformly distributed along the height, kN·s^2/m^2; $\boldsymbol{E}$ – stiffness module of building structure material, kN/m^2; $\boldsymbol{I}$ – inertia moment of the cross section area of building bearing structures, m^4; $\boldsymbol{\lambda}$ – ratio between flexural and shearing stiffness of building bearing structures, determined by the following formula:

$$\lambda = \frac{EIk_1}{GF\gamma_{np}H^2}, \tag{2}$$

where $\boldsymbol{k_1}$ – the factor, which considers structure deformations dependence at shear from mode and dimensions of its cross section; $\boldsymbol{G}$ – – shear module of building structure material, kN/m^2; $\boldsymbol{F}$ – area of cross section of building bearing structures, m^2; $\boldsymbol{\gamma_{np}}$ - factor, which considers the deformability of structures wall as a result of opening presence in them.

Factor values $\boldsymbol{\alpha_i}$ in formula (1) are determined by the diagrams, presented in Figures 3 and 4 for first three modes of natural oscillations depending on non-dimensional parameters $\boldsymbol{\lambda}$, ***U, V, M***.

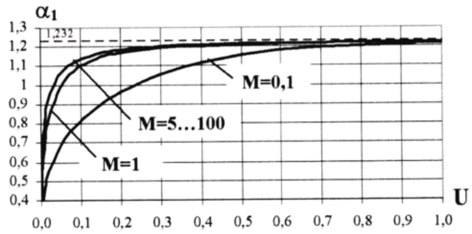

Figure 3. Diagrams of coefficients of oscillation frequency $\alpha_1(U,M)$ for the 1[st] form at at λ=0,02 and V= 0,02

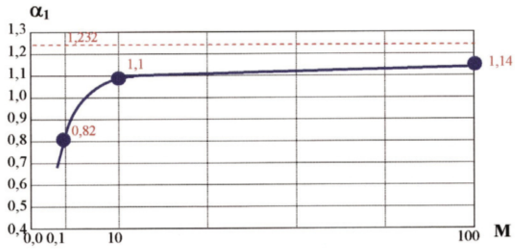

Figure 4. Diagram of frequency coefficients $\boldsymbol{\alpha_1}$ at λ=0,02, $\boldsymbol{V}$=0,02 and $\boldsymbol{U}$=0,1

Parameters $\boldsymbol{U}$ and $\boldsymbol{V}$ are the ratios of the soil stiffness at shear $\boldsymbol{K_y}$ and rotation $\boldsymbol{K_\varphi}$ to structure shear stiffness of the building:

$$U = \frac{K_y k_1 H}{GF\gamma_{np}}; \tag{3}$$

$$V = \frac{K_\varphi k_1}{GF\gamma_{np}H}; \tag{4}$$

where $\boldsymbol{K_y}$, kN/m, $\boldsymbol{K_\varphi}$, kN·m/radian. Parameter $\boldsymbol{M}$ characterizes the influence of foundation mass time lag on the period value of building natural oscillations and is the ratio of structure mass to foundation mass: $M = mN/\mu_\phi$, where $\boldsymbol{\mu_\phi}$ – is foundation mass, t.

Factor $\boldsymbol{K_y}$ and $\boldsymbol{K_\varphi}$ of subsoil stiffness in formulas (3) and (4) shall be determined according to the recommendations of SNiP 2.02.05-87 (SNiP 2.02.05-87, 1989).

Shear stiffness $\frac{GF\gamma_{np}}{\kappa_1}$ in formulas (3) and (4) includes the shear module value $\boldsymbol{G}$ of building structures, that is taken depending on material elasticity modulus for compression $\boldsymbol{E}$. *For the concrete G=0,4E, for the masonry G=0,25E* the value $\boldsymbol{\gamma_{np}}$ is recommended to determine taking into account the recommendations (Polyakov S.V., 1971).

3 CONCLUSIONS

1. For the considered tasks linear and non-linear calculations differ not only in quantity but also in quality, for example the direction of displacements or sign of the bending moment may change.
2. Introduction into the model of the function of changing of state of continuous disperse environment at loading (by changing of dilatation and contraction coefficient, variable deformation parameter taking into account structural strength Boyko I. and Sakharov V. (2004) and others) allow to approximate the experimental values with calculation ones in wide range of loads.

3. At performance of dynamic calculations one may not take into account shear deformation at value $\lambda<0{,}02$, that in larger degree corresponds to distribution of deformations in bearing structures of the high-rise buildings.
4. At determination of periods of natural oscillations by formula (1) one may not take into account the foundation mass if it makes less than 10% of the distributed structure mass, i.e. at $M\geq10$.
5. Investigation of mutual behavior of elements of the system „base-foundation-aboveground structures" taking into account technology of object construction ensures that the designer takes the reliable solution not only for new but also for existing buildings and structures.

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