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Static analysis of building structures with regard to their implementation in stages

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ABSTRACT

Building structures in the vast majority are facilities that work well with the subsoil. The deformability of the ground results in the fact that the fields of deformations and strains depend largely on the mutual interactions between the individual components of the system. In addition, due to their size, building structures are erected in several stages (placements), dependent on the schedule of works (usually the first step is the excavation, then foundation and implementation of further structural elements). The article presents an individual modular FEM "tracking" model, allowing, inter alia, for taking into account the sequential nature of building constructions. Furthermore, as an extension of the presented concept, in order to shorten the calculation time, the algorithm application of parallel processing techniques in the "tracking" model has been given.

On the basis of the developed solutions, a calculation example in spatial (3D) has been performed.

1. Introduction

The analysis of the static or dynamic work of the construction facilities is closely related with the fact of taking into account the subsoil in the calculation model (Fig. 1 – in the figure shown an example of the FEM calculation scheme: buildings – the subsoil – to solve in a spatial system).

Such an approach, due to the interaction of the analysed building – subsoil – neighbouring buildings (Fig. 2 – in the figure, schematically shown the interaction between individual components of the calculation model) allows for a much more accurate estimate of the internal forces in the analysed construction than in the case of the simplified models, treating a construction facility as isolated from the influence of the outside static system.

During the construction of an interactive computational model, additionally should note that: the building structures, due to their size realized are in the certain stages, resulting inter alia, from construction technologies and the schedule of works, carried out on the construction site. Among the structures erection phases can be distinguished most important of them [22]:

– the excavation,
– building the facility in stages,
– use of the facility.

Sample phases (stages) of climb structures given in Fig. 3 (where, the excavation stage was indicated as "0"; and the remaining stages were given from "1" to "n").

Taking into account the phased nature of the building structures work is all the more important, if the new facility is erected on cohesive soils. This fact is caused by the phenomenon of consolidation, due to which the building subsidence process starts from the time of load application and continues through the various stages of construction, even several years after the completion of the facility [25]. In such a case, the new structure is exposed to uneven subsidence, which due to the nature of most construction materials (e.g. low tensile strength of concrete) can lead to the appearance of cracks and scratches in the most strenuous components [12].

It should also be noted that in the process of the building erecting the different parts of the structure, which are the constituents of the respective stages of construction before reaching its full strength/mechanical properties (e.g. early stripping of ceilings or walls in the case of monolithic technology and connections in prefabricated technology), loaded are with successive components of the under construction building. In this case, the only way to take into account this type of processes is to use the appropriate "tracking" computational models that allow for the analysis of the system in various stages of construction.

As previously described, in various stages of facility constructing, the static diagram changes, as well as mechanical/strength properties of materials and the geometry of different parts of the

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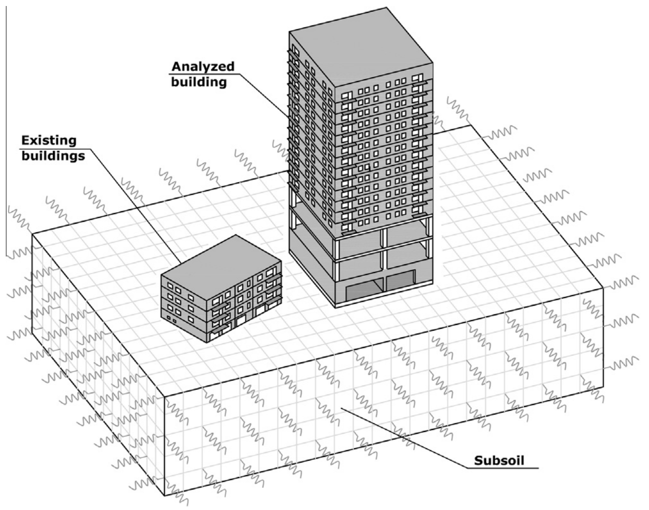

Fig. 1. Spatial FEM model: new building/with deep foundation – subsoil – neighbouring buildings.

structure, so further steps are executed on the pre-deformed and stressed structural elements. For any stage of the development of a facility, the relationship between stresses and deformations can be presented in the form of [3,11]:

$$\sigma = D \cdot (\varepsilon - \varepsilon_0) \tag{1}$$

Thus, using the Eq. (1), the overall relationship between the system of internal and external forces in the discretized area of FEM can be presented [27]:

$$K \cdot d + P_q + P_{\varepsilon_0} - R = 0 \tag{2}$$

where $\boldsymbol{P_{\varepsilon 0}}$ – is the vector of nodal forces from the initial deformations, created at the "$t-1$" stage, $\boldsymbol{P_q}$ – is the vector of nodal forces resulting from the finite element load/internodes load, $\boldsymbol{R}$ – is the vector of concentrated forces at the nodes of the finite element.

In order to take into account the above issue in the static analysis of the structure, there have been developed a "tracking" model overtly increasing in blocks. An example of calculation has been presented as well as conclusions given on the basis of the comparative analyses carried out.

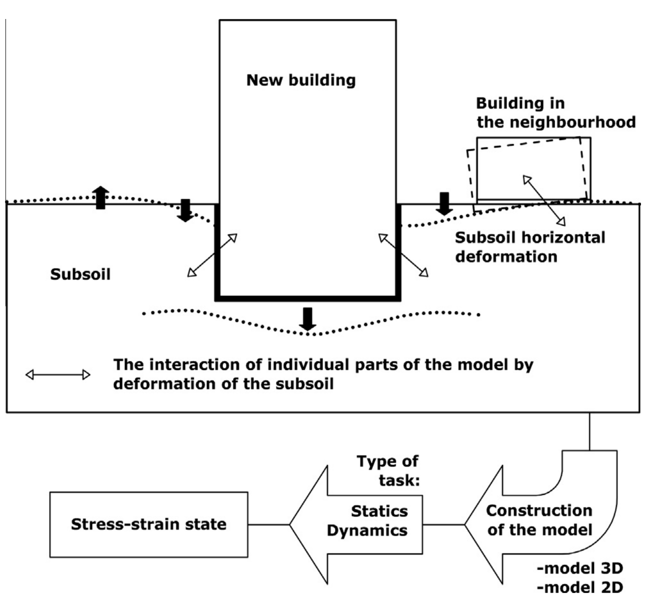

Fig. 2. A comprehensive model of building structure analysis taking into account the mutual interaction between the various components of the system.

2. Applied solutions

Among the methods used to analyse the structure taking into account the sequential nature of work, the procedure proposed by Romer [19,20] can be distinguished. The modelling process of the system is as follows:

(a) discretization of the whole area with finite elements,
(b) programming of the process of erecting the structure, according to the approved schedule of works:
- at this stage, certain types of substructures are formed, corresponding to different placements that are activated or deactivated in subsequent phases of calculation,
- inactive structures are modelled using the quasi-zero blocks in the global stiffness matrix of the system,
- the values on the main diagonal of each inactive block (stiffness submatrix) should be selected so as not to generate numerical instability and not to affect significantly the results in each step of calculation,
- activation or deactivation of specific areas of the global stiffness matrix of a model takes place with taking into account the mutual interaction between the parts included or excluded from the numerical procedure at an earlier stage of the calculation,

(c) calculations and analysis of the results.

The above procedure implemented is, for example in SAP2000 [21] and ZSoil [28], and most commonly used to analyse bridge structures [1,2,4], barrages [17] and deep excavations [6,16,24].

3. Incremental "tracking" model

3.1. The concept of a model

To avoid the problem of solving locally quasi-zero system of equations, as is the case with the procedure proposed by Romer, there has been developed a "tracking" model, overtly increasing in blocks, based on a finite element method, the basics of which were presented by Miedziałowski in 1994 [14].

This concept was then developed in [22] by taking into account the mutual interaction between the activated or inactivated blocks, and the remaining part of the calculation area.

The incremental "tracking" model, due to the increase of the numerical structure in blocks at the phase "t" can be presented by the equation:

$$ {}^{t}\begin{bmatrix} K_s & K_{sn} \\ K_{ns} & K_n \end{bmatrix} \cdot {}^{t}\begin{Bmatrix} d_s \\ d_n \end{Bmatrix} = {}^{t}\begin{Bmatrix} 0 \\ P_n \end{Bmatrix} + {}^{t}\begin{Bmatrix} R_s \\ R_n \end{Bmatrix} \tag{3}$$

where the indexes "n" and "s" refer to: the "new" placement/existing part of the structure from the previous calculation phase, $\boldsymbol{K_s}$ and $\boldsymbol{K_n}$ – are global stiffness matrices, formulated on the basis of a schedule of erecting the structure, $\boldsymbol{d}$ – is a vector of unknown displacements, $\boldsymbol{P}$ – is a vector of external loads, $\boldsymbol{R}$ – is a vector of internal forces, built on the basis of the current system stiffness matrix and the displacement vector of the "$t-1$" phase:

$$ {}^{t}\begin{Bmatrix} R_s \\ R_n \end{Bmatrix} = {}^{t}[K] \cdot {}^{t-1}\begin{Bmatrix} d_s \\ 0 \end{Bmatrix} \tag{4}$$

After taking into account Eqs. (3) and (4), we obtain respectively the displacements of nodes in the "new" and existing/already erected part of the structure: