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Strength and stability analysis of load-bearing structures of Evolution Tower with allowance for actual positions of reinforced concrete structural members

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Abstract

The distinctive paper is devoted to strength and stability analysis of loadbearing structures of Evolution Tower (high-rise 54-storey building) with allowance for actual positions of reinforced concrete structural members (columns and walls). Finite element method (FEM) is used for structural analysis. The authors present formulations of problems, governing equations, information about basic three-dimensional finite element models (so-called "design" (ideal) model, the first "actual" model (taking into account the deviations of positions of columns from the project) and the second "actual" model (taking into account the deviations of positions of walls from the project)) of the coupled system "Evolution Tower – foundation" within ANSYS Mechanical software and their verification, numerical approach to structural analysis and corresponding solvers. Finite element models include mainly 4-node structural shell elements (suitable for analyzing foundation slabs, floor slabs and load-bearing walls) and three dimensional 2-node beam elements (suitable for analyzing beams and columns), special spring-damper elements and multipoint constraint elements. Detailed finite element mesh on the bottom foundation slab is agreed with the location of piles. The advanced model of Prof. Yu.K. Zaretsky is used for approximation of soil behavior. Construction sequence and various types of nonlinearities are taken into account. The results of modal analysis, static and dynamic analysis with various load combinations (gravity load, façade load, dead (constant) loads, temporary loads, wind load, snow load, crown load etc.) are considered, the results of the regulatory assessment of the strength of structures (obtained with the use of corresponding software in accordance with design codes of the Russian Federation) are under consideration as well. The corresponding displacements, stresses, natural vibration frequencies can be used for research and development of the correct monitoring method of the foundation and load-bearing structures of a high-rise building.

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Keywords: numerical method, finite element model, high-rise building, strength, stability, monitoring, actual position of structural members

1. Introduction

The distinctive paper is devoted to the main results of scientific research work, that was carried out in the Research and Educational Center of Computer Simulation of Unique Buildings, Structures and Complexes of National Research Moscow State University of Civil Engineering. This work is dedicated to strength and stability analysis of load-bearing structures of Evolution Tower with allowance for actual positions (i.e. deviations from the project) of reinforced concrete structural members (columns and walls). In particular, the following tasks were solved:

– analysis and generalization of scientific, research and project documentation of the system Evolution Tower – foundation, the data on the actual deviations of the columns and walls from the project, formulation of problems of structural analysis of the bearing structures of Evolution Tower;

– development and verification of the corresponding space shell-beam finite element models of the system “foundation – load-bearing structures of Evolution Tower in two versions (“designed” model and “actual” model with allowance for the detected significant deviations of the reinforced concrete structures (walls and columns) from the designed positions;

– carrying out alternative calculation investigations of the stress-strain state, reliability and stability of the three-dimensional system of the load-bearing structures of Evolution Tower at specified main combination of loads basing on the enumerated above versions of finite element models.

2. Choosing a method of numerical simulation. Governing equations

As the main method of numerical modeling i.e. finite element method was used (FEM), which today occupies the leading position in the practice of engineering calculations of building structures, buildings and constructions and is a powerful tool of high-tech investigations [1-15].

The method has such advantages as generality at solving different tasks of the justifying calculations for a construction object, relative simplicity of accounting for the interaction of the object with the environment (mechanical, temperature, corrosive impacts, boundary conditions, etc.). It is remarkable for the high automation degree of all the stages of calculation, exact and clear mechanical analogy and possibilities of simulation both on the basis of physical and mathematical approaches. As it is known, the essence of the method is in approximation of the observed construction object, which has an infinite number of the degrees of freedom, by the assembly composed of relatively simple finite elements connected with each other in node points and characterized by finite number of the degrees of freedom.

Motion equation of a geometrically linear system (in the condition of small displacements and deformations) as stated by Lagrange in frames of FEM (with account of space-time digitalization) in matrix form may be expressed as [4, 7, 16, 17]:

$$[M]\{\ddot{u}(t)\}+[C]\{\dot{u}(t)\}+([K]+[K_G])\{u(t)\}=\{F(t)\}+\{R(u,\dot{u})\}, \tag{1}$$

From the one hand in the equation (1) kinematic boundary conditions are taken into account, but, from the other, it should be defined by the initial conditions (basing on the analysis of the results of the corresponding statistical calculation at $t=t_0$). Commenting on the used designations we should note, that $[M],[C],[K],[K_G]$ are correspondently symmetrical, block, rarely filled global matrixes of mass, damping, linear (initial) and geometrical rigidity of FE model; t – the time; «point» means differentiation in time; $\{F(t)\}$ – the given vector of static and