Contemporary Digital Technologies in Construction
Part 1: About Mathematical (Numerical) Modelling

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Abstract. This paper is devoted to the development of digital technologies in construction. Peculiar “evolution” of the design process in construction is described. Contemporary achievements of mathematical and computer modelling of loads and impacts, contemporary achievements and problems of mathematical (numerical) modelling of the stress-strain state, dynamics and stability at the basic and special combinations of loads and impacts at significant stages of life cycle of construction object are specified.

1. Introduction
As is known, before the invention of computers and software, all design works were carried out by so-called “paper” technology (Figure 1). Corresponding changes were made with the help of cut and paste, copying of new structural joints and pasting them into the existing drawing. Moreover, the need for a significant correction meant the reproduction of the drawing from the beginning. All engineering calculations were done with the use of arithmeters (adding machines) and slide rules (logarithmic rules), all documentation was stored on paper. This did not prevent in the short term after the Great Patriotic War to create a number of outstanding architectural works in USSR. The destroyed cities were restored, numerous high-rise buildings were built in Moscow including the tallest building in the world (TV tower in Ostankino). The idea to automate the design originated in the 50s of the last century, almost simultaneously with the advent of commercial computers. The software together with the hardware made it possible to automate the most time-consuming work of the drawing nature [1]. The features of the graphics programs have been gradually expanded, allowing facilitating the process of drawing.
At the present time the qualitative progress of information technologies in construction is obvious. The basis of modern computer-aided design (CAD) is the creation of a computer model of the object. The user creates not just a drawing, but an electronic copy of the designed object. The processes of structural analysis, design and construction of the object in modern construction practice are often carried out in parallel, which determines the need for intensive exchange of the results of work between research, design and construction organizations, which are geographically remote from each other and in some cases using incompatible computer platforms and software. Building information modelling is the creation and use of a set of coherent and interrelated design data. These data are used for the formation of construction and technical documentation, forecasting performance, cost estimation and planning of construction works, and then-and to manage the construction site.

2. Contemporary achievements of mathematical and computer modelling of loads and impacts

An independent problem common to all construction projects is the definition (computing) of loads and impacts on buildings and structures during their life cycle.

As it is known, loads on building structures are established by corresponding design codes in accordance with the predetermined probability of exceeding the average values – constant loads are defined by design values of geometric parameters, technological loads are defined by the highest values provided for normal operation, temporary loads from people depends on occupancy of premises and spaces, etc. Problem of simulation of wind flows and loads on buildings, structures and complexes remains rather actual and not fully solved for unique buildings and structures [1].

The analysis of the behavior of the entire building and its individual structural elements in the wind flow reveals, along with static deformations, a wide variety of phenomena of aerohydroelastic instability caused by the shape of the cross section, the configuration of the building and its orientation relative to the direction of flow, elastic and damping properties of structures, the peculiarity of the terrain and interference in conditions of dense and changing surrounding buildings. These phenomena significantly affect the reliability and durability of structures, as well as the comfort of people's stay. We should note oscillations of vortex excitation (wind resonance, galloping, divergence, flutter and buffeting). Besides, the assessment of maximum and minimum wind pressures on the enclosing surfaces, taking into account their statistical dispersion, is of particular importance. Wind and seismic loads used within analysis have a relatively small history of observations (100-150 years), which makes it difficult to normalize them for longer periods.

In order to determine the design parameters of unstable oscillations by the design codes, it is proposed to use the results of tests of large-scale models in specialized wind tunnels, which allow reproducing the atmospheric boundary layer. However, such tests are very time-consuming, and in Russia only a few wind tunnels meet modern requirements and for the most large-scale models, tests have to be performed abroad. Figure 1 shows the model of the complex of the Moscow international business center “Moscow city” in the wind tunnel.

The methodology of experimental modelling of wind flows and impacts on unique high-rise complexes, of course, has its own limitations and errors due to the complexity of creating a dynamically similar model. We emphasize that in recent years the numerous researches all over the world develop a new scientific field – computational aero- and hydrodynamics, i.e., the determination of the distributions of snow and wind loads, and the aerodynamic coefficients based on solutions to the fundamental problems of aerodynamics with the help of digital technologies and computers.

The resulting aerodynamic parameters are computed taking into account the different forms of buildings, interference with the surrounding buildings, as well as local terrain. In the future, the role of mathematical modeling will only increase. The corresponding parameterized models and the results of numerical simulation of wind aerodynamics are to be used in the further development and operation of the Structural Health Monitoring (SHM) system.

As an example, Figure 2 shows some results of the distribution of wind loads on the objects of the “Moscow-city” complex. Modelling of the transport of snow in a wind tunnel gives researchers the opportunity to obtain the qualitative characteristics of possible deposits of snow at different wind directions based on numerical experiment (Figure 3) [1].
Figure 1. The model of the complex “Moscow-city” in the wind tunnel.

Figure 2. Complex “Moscow-city”. Analysis of wind aerodynamics.

Figure 3. Numerical simulation of snow transport.
Let us consider the problem of seismic loading. In Russia, the intensity of seismic effects is taken from the maps of the General seismic zoning OSR-2015, scale 1:2500000. However, for areas with high seismic activity it is necessary to develop maps of detailed seismic zoning with a scale of 1:500000. For particularly hazardous and critical facilities we should use seismic microzonation with scale 1:50000 – 1:2000. Generally for a particular construction site with a given seismicity it is impossible to record a lot of strong earthquakes at this point, so spectra are used for other regions that have similar seismotectonic, geological and soil conditions. If the size and location of potential earthquake foci are known for any site, a special spectrum can be constructed for it on the basis of statistical processing and analysis of a number of accelerograms and/or spectra of real earthquakes, taking into account local seismological conditions, and a synthesized three-component accelerogram can be constructed.

3. Contemporary achievements and problems of mathematical (numerical) modelling of the stress-strain state, dynamics and stability at the basic and special combinations of loads and impacts at significant stages of life cycle of construction object

After definition and computing of loads, the problem of determination of the stress-strain state of the structural elements at the main and special combinations of loads and impacts at significant stages of the life cycle of the object arises.

One of the main problems of analysis of unique structures is a large computational dimension (from several millions of unknowns to tens of millions), located on the boundary of possibilities of available modern computing software systems.

Figure 4 shows the first five natural modes of the high-rise complex “Lakhta Center” (corresponding computational model includes 440000 finite elements).

![Figure 4. Natural modes of the complex “Lakhta Center”](image)

Figure 5 shows computational models of six new stadiums for the FIFA World Cup 2018 with dimensions of 350000 finite elements for Yekaterinburg and 2500000 finite elements for Samara [1].

It should be noted that normally it is necessary to have a sufficiently detailed three-dimensional modelling of the most loaded structural joints, the strength and stability of which can determine the safety of the entire system [1].

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Several algorithms of nonlinear analysis based on “advanced” spatial soil models, allowing to simulate the interaction of structures with the soil base taking into account the real properties, stages of construction and the actual history of operation, have been developed [1].

Progressive collapse is the most dangerous phenomenon of destruction of building structures, which can lead to a large number of human victims and huge material losses. It should be noted that the processes of deformation, destruction and collapse of building structures are nonlinear processes, accompanied by large plastic deformations and displacements, as well as dynamic loading effects at the time of failure of structural elements. It is advisable to solve such problems with the use of methods of direct integration of the dynamics equations in time [1].

Figure 6 shows destruction of reinforced concrete structures of the tower “Akhmat” located at Grozny city (Russia) at 2% and 4% reinforcement under the influence of the maximum design earthquake of 9 points, given by the synthesized accelerogram. With 2% reinforcement we have a progressive destruction and collapse of the top ten floors. At 4% reinforcement collapse does not occur [1].

As is known, the problems of determining the actual limits of fire resistance of building structures are very relevant. Conventional methods in Russia are based on studies of the 60s-70s of the last century and correspond to the computational capabilities of those years. The most reliable way to determine the actual limit of fire resistance is a fire test of full-scale models of structures in a standard fire. However, this type of test is quite expensive, and for large-span structures it is generally impossible due to the limited size of the existing fire chambers. The way out of this situation can be the determination of fire resistance limits by numerical methods [1].

Traditionally, related problems of mechanics are relevant for adequate modeling of unique and responsible buildings and structures (i.e. nonlinear problems, when the impact on the structure is associated with its deformation or stress state). In particular, a classic example of related problems of aerohydroelasticity is the need to ensure the strength and reliability of tanks with petroleum products, gases and other environmentally hazardous substances [1].

The problems of thermoelasticity remain relevant in the field of construction. Generally the problem of determining the temperature field and the stress field is related, which takes into account the influence of stresses on the temperature distribution and heat, which is released during deformation of the body as a result of the application of external force loads. Figure 7 shows the process of the impact interaction of the aircraft and the protective shell of the NPP in a nonlinear dynamic formulation, when there is a destruction of the shell and fuel spreading [1].
Figure 6. Finite-element models of load-bearing structures of stadiums of the World Cup 2018.

Figure 7. Numerical simulation of thermoelasticity problems.

References
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