

Structural mechanics and theory of structural analysis

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Abstract. The article is devoted to the study of modern methods of structural analysis and modeling. Special attention is paid to software systems and tools for creating 2D and 3D equipment layout diagrams. The features of calculating the load on the slab are considered on the example of a steel-reinforced concrete structure. Using the mixed method of structural mechanics, the forces and displacements in the characteristic sections of the system in statically indeterminate composite structures were calculated when changing the mathematical axis position in the stiffening girder. The data obtained were confirmed not only by numerical, but also by full-scale experiment using Autodesk Inventor.

1. Introduction

Modern conditions for the erection of buildings and structures are characterized by the use of the latest and most effective structures, which is inextricably linked to the problems of developing a research methodology and designing of these structures.

Modern design techniques, relevant standards and calculation algorithms are on the verge of a new stage. The approaches that have been in effect so far practically do not take into account the fact that today a project is created using computer analysis and modeling and this alone is a tendency to improve them.

Under the influence of the development and widespread dissemination of information and communication technologies, innovative technologies in the structural analysis begin to be developed and implemented [1, 2]. With the help of these technologies, the work becomes much more perfect, more detailed and optimal in execution over time.

There is no doubt that one of the most important indicators of the quality of construction products is the accuracy of the erection of buildings and structures, characterizing the degree of approximation of the actual parameters of the object to the specified in the project. Errors arising in the design, affect the accuracy of the geometric parameters of building structures, as well as their reliability and durability.

Thus, today, the study of modern methods, systems and object-oriented programs that are used in structural mechanics for structural analysis is of particular relevance, theoretical and practical importance, because they allow identifying additional reserves of the structural bearing capacity, as well as dangerous destructive tendencies in further operation of the facility, in a timely manner preventing the threat of destruction of both individual structural elements and the facility as a whole [3, 4].



2. Materials and methods

The information base of the study is the works of national and international authors on the subject under discussion and construction norms. Research methods include selection, study and analysis of literary sources, classical methods of structural mechanics, experimental testing of prototypes, theoretical research, as well as comparative analysis of the obtained theoretical and experimental data, as well as existing software systems [5].

3. Study of the structure of the modified lead-tin-base bronze

At present, the limit state method is often used to analyze structures according to the bearing capacity (limit states of the first group, leading to the complete unsuitability of the operation of structures, are loss of stability of shape and position, viscous or brittle fracture, unsteady creep deformation, excessive plastic deformation, resonant vibrations). Also, in modern practice of analyzing reinforced concrete structures, diagrams of concrete and reinforcement are widely used, which allow taking into account the basic laws of the work of materials and, as a result, have an idea of the stress-strain state of the sections at all stages of the structural behavior [6].

Today, there are many software systems for structural analysis, including Tekla Structures, LIRA-SAPR, Autodesk Robot Structural Analysis Professional, SCAD, APM Civil Engineering and etc. However, Autodesk Inventor (AI) is particularly noteworthy. AI is a 3D CAD system for creating and studying the behavior of digital prototypes of products and parts. Despite the fact that the main functional purpose of Autodesk Inventor is engineering design, thanks to its parametric 3D modeling, which forms the basis of the software package, AI can be used in solving problems of construction design [7, 8].

Let us consider how this complex works in practice.

So, let us analyze a steel-reinforced concrete structure consisting of two ($nI = 2$) longitudinal metal statically indeterminate composite pre-stressed truss frames, which are combined in a joint spatial work using a monolithic reinforced concrete slab with the dimensions of $B \times A = 3 \times 6 \text{ m}$ (see Figure 1).

A computer model of a spatial composite steel-concrete truss frame is shown in Figure 1.

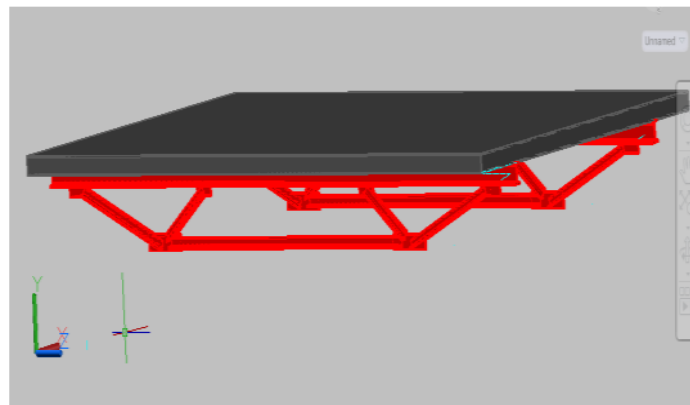


Figure 1. Computer model of a spatial composite steel-concrete truss frame

The statically indeterminate steel-reinforced concrete composite truss structure consists of steel-reinforced concrete stiffening girders, individual beams as parts of a reinforced concrete slab, and truss elements loaded with a uniformly distributed load q .

Let us consider a steel stiffening girder which is a composite metal pre-stressed truss frame. Given construction norms, let us suppose that a part of a reinforced concrete slab, which is $d_1 = b f_1$ wide and is situated over a truss frame, is a component of this frame. The rest of the slab with a width of $d_2 = B - 2 * b f_1 = b f_2$ is considered as a beam or beams that are part of a spatial structure [9]. Let us mentally divide the slab in the transverse direction into separate $m_1 = j$ ($j = 1, \dots, k$) parts of the corresponding sizes (see Figure 2).

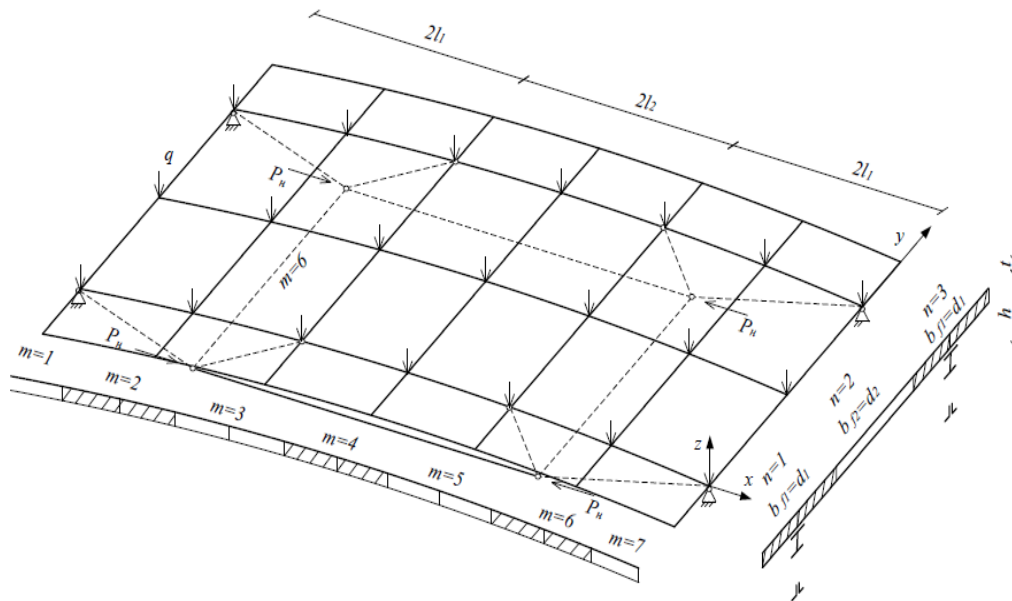


Figure 2. Discrete physical model of a spatial composite steel-reinforced concrete pre-stressed truss frame

Let us assume that the load on the slab is the apex load, where

$$P_1 = q_1 \cdot l_1 \cdot d_1, P_2 = q_1 \cdot l_2 \cdot d_1, P_3 = q_1 \cdot l_1 \cdot d_2, P_4 = q_1 \cdot l_2 \cdot d_2$$

Thus, we obtain a spatial cross-ribbed composite steel-reinforced concrete pre-stressed truss frame, which consists of: a) in the longitudinal direction OX of two pre-stressed steel-reinforced concrete beams with a width of the upper flange equal to bf_1 and pre-stressed reinforced concrete beam with a width of bf_2 ; 6) in the transverse direction OY $m = 7$ reinforced concrete beams.

When arranging a statically indeterminate steel-reinforced concrete composite truss structure, shown in Fig. 1, the neutral axis of the stiffening girder is offset due to a change in the magnitude of the transformed section - from a metal stiffening girder to steel-reinforced concrete one [10].

Changing the stiffness parameters of the beam $B(x)$ leads to a change in the topology of the statically indeterminate composite steel-reinforced concrete structure, namely:

- there is a vertical displacement of the mathematical axis from position $A-B$ to position $A'-B'$ of stiffening girder;
- there is a corresponding shift of intersection points of action axes of the longitudinal forces of the suspension elements with a new neutral axis – from points A, B, C, D to points A', B', C', D' ;
- the values of the extreme spans of the stiffening girder are changed - from l_1 to $l'_1 = l_1 + \Delta y_0 / \tan \alpha + \Delta y_0 / \Delta \beta$ - (are increasing); the values of the intermediate spans of the stiffening girder are changed, too: from l_2 to $l'_2 = l_2 - 2\Delta y_0 / \tan \beta$ - (are decreasing);
- the height of the structure itself increases from h to $h' = h + \Delta y_0$.

When the mathematical axis is moved by Δy_0 , a negative bending moment M_A arises in the upper heel joint already at the stage of installation of a monolithic reinforced concrete slab. This bending moment is caused by the action of the vertical component N_{4y} of the longitudinal force N_4 in the extreme strut on the amount of horizontal displacement with the intersection point of the mathematical axis in the reinforced concrete steel stiffening girder $\Delta y_0 / \tan \alpha$.

Given the changes for the stiffening girder, the equation of continuity of deformation will have the following form:

$$\delta_{I1} + X_1 + \delta_{I2} + X_2 + \delta_{I3} + X_3 + \delta_{I4} + X_4 + \delta_{I5} + X_5 + \delta_{I6} + X_6 + \delta_{I7} + X_7 - (2y^*I)/l \cdot 1 + (y^*I)/l \cdot 2 = 0$$

The calculations carried out using this technique were verified against the results of calculations that were performed using the Autodesk Inventor software package. As a result, the initial assumptions about the effect of displacement of the neutral axis position in the stiffening girder on the stress-strain state were confirmed not only by a numerical, but also full-scale experiment. Thus, it can be stated that at the initial stage of design Autodesk Inventor makes it possible to simulate a stress-strain state in building structures using a mathematical apparatus in a simpler way [11, 12].

4. Conclusion

Modern methods of calculation of building structures, using software systems such as Autodesk Inventor, make it possible to create effective 2D and 3D layouts schemes, by applying conventional tools and at the same time increasing the efficiency and accuracy of design, as well as the reliability of the data obtained.

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