Application of Calculation Softs to Perform Verification Calculations during the Survey of Monolithic Reinforced Concrete Buildings

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Abstract. When performing verification calculations during the survey of building structures, the use of calculation software is limited by the standard algorithm, which does not always allow taking into account the impact of certain pathologies and damages on the bearing capacity and stability of structural elements and objects as a whole. The article offers a variant of using the software package "Lira 9.6" to assess the load-bearing capacity of a building with a monolithic reinforced concrete frame, taking into account the most characteristic pathologies for objects of this type.

1. Introduction
In the construction of frame buildings made of monolithic reinforced concrete, the most common pathologies are associated with the use of poor-quality materials, violation of design requirements and technology for the production of concrete works[1]. These pathologies should primarily include:

- formation of a large-pore structure of concrete as a result of poor-quality compaction of the concrete mix with the opening of the working reinforcement[2];
- non-design location and arrangement of the seams of the concreting[3];
- formation of cavities, in some cases through, in concrete of reinforced concrete structures[4].

All these pathologies affect the reliability of adhesion of reinforcement with concrete, and in many cases simply make it impossible for these elements to work together in a single structure [5].

As a rule, pathologies are detected during the survey of the building, which includes: visual survey, instrumental survey and verification calculations[6-9]. Performing verification calculations involves determining the actual loads and actual design model of the building. The calculation must take into account the degree of influence of the identified pathologies on the bearing capacity of building structures and building as a whole [10].
2. Relevance
When performing manual calculations, pathologies are taken into account using coefficients of technical condition and working conditions.

Currently, when performing verification calculations, software systems (hereinafter referred to as softs) are more used, such as Lira, Scad, ansys, etc. The advantage of softs is the ability to create and calculate a spatial model of a building, as well as to significantly approximate the design model to the actual structural solution of the building [11]. The softs listed above are implemented to perform calculations for new construction. At the same time, they can be used for verification calculations of existing buildings [12], but with some reservations.

Currently, the method of verification calculations of monolithic buildings and structures is to compare the reinforcement parameters obtained in the soft with the actual reinforcement of structures, as well as the calculation results for deflections obtained in the soft with the normative values regulated by SP 20.13330.2016 "Loads and impacts" (analogue: Eurocode 1. Actions and Structures). Conclusions based on the results of verification calculations are based on the following provisions:

- if the theoretical reinforcement is greater than the actual one and the theoretical deflection is less than the standard one, it can be concluded that the building or individual structure meets the requirements for rigidity, strength and stability;
- if the theoretical reinforcement is less than the actual one and the theoretical deflection is greater than the normative one, then we can conclude that the building or structure does not have the proper rigidity, strength and stability.

The use of this method, for minor or significant pathologies that can be implemented in the soft by lowering the concrete class relative to the design requirements. However, pathologies associated with the rupture or weakening of sections of reinforced concrete structures cannot always be taken into account using this approach.

3. The aim of the research
Formation of a design model of a building with identified defects, which will correspond to the actual operation of the building under existing loads.

4. Theoretical part
During the technical inspection of the frame building with 19 floors made of monolithic reinforced concrete, the following pathologies were found: a decrease in the strength of concrete bearing structures by 2 classes, partial and complete destruction of the contact area “reinforcement-concrete”, the formation of cavities, including a complete rupture of sections of reinforced concrete structures.

Especially noteworthy is the pathology found in the column of the end row on the 1st floor. In the middle of the vertical structure, a cavity with a width of 3-7cm was revealed with a complete exposure of the working reinforcement along the entire cross section of the column.

It is assumed that the pathology occurred as a result of a break in concreting during the winter period of the year without appropriate safety measures. After resuming the concrete supply, a concreting seam was formed with a layer of ice, which left a cavity in the column after thawing.
To perform verification calculations, it became necessary to account for this pathology in the spatial design model of the building. Since the column has a cavity, it can not be considered a solid reinforced concrete monolithic element. There is no concrete in the area of the pathology. It was hypothesized that if the load in the exposed reinforcement exceeds the yield strength of the steel, a hinge is formed; this will "turn off" the column from the work of the frame and all the load from this element will be redistributed to neighboring vertical structures.

In this situation, verification calculations were performed in several ways:

Option I—spatial calculation of the building based on design solutions (without pathologies), with the determination of longitudinal forces in the column under consideration;

Option II—calculation of the bearing capacity of reinforcement in the area of cavity formation. Comparison of the results obtained with longitudinal forces occurring in the column.

Option III—spatial calculation of the building taking into account the identified pathologies (a hinge is inserted in the middle of the column).

5. Description of the calculation model (for calculation options I and III)
The structural scheme of the building is a cased frame. Spatial rigidity under the action of wind and seismic loads is provided by the joint work of vertical and horizontal structures. The foundation is made of a monolithic reinforced concrete slab, 110 cm thick. The stiffness diaphragms – monolithic reinforced concrete walls with a thickness of 16 cm. Floors are reinforced concrete slab 22 cm thick. Columns—monolithic reinforced concrete with a cross section of 40x40 cm.

The model of the building is formed in accordance with the drawings. Based on this information, the Lira 9.6 software package, which implements the finite elements method in movements[13], constructed ashell with rods finite element model of the building. The stiffness diaphragms and coverage slabs were modeled by flat finite elements of the bending state (isotropic). Columns and beams were formed using rod end elements. The main calculation method is the displacement method in the finite element implementation[14-15].

The calculation scheme includes the following types of elements:

Type 10.Universal spatial core element.
Type 42.Universal triangular shell finite elements for modeling of floor slabs and walls.
Type 44.Universal quadrangular shell finite elements for modeling of floor slabs and walls.

All reinforced concrete elements are connected to each other rigidly.

The stiffness characteristics of structures and their connections are calculated by the program in accordance with their geometric parameters and physical characteristics of materials, taking into account the working conditions of structures entered into the calculation model. Parameters such as modulus of elasticity and bulk weight of rod and plate materials are assigned according to the design data, taking into account the requirements of standards [16-17].

The rigidity of the materials:
– reinforced concrete foundation slab – h=110 cm, $E=30000$ MPa, $V=0.2$, $R_0=24.5$ kN/ m$^3$.
– reinforced concrete columns of the frame – 40x40 cm, $E=30000$ MPa, $R_0=24.5$ kN/ m$^3$.
– reinforced concrete stiffness diaphragm – t=16 cm, $E=30000$ MPa, $V=0.2$, $R_0=24.5$ kN/ m$^3$.
– reinforced concrete beams – 40x63(h), $E=30000$ MPa, $R_0=24.5$ kN/ m$^3$.

The following loads are applied in the presented calculation:

– Load №1 – own weight of structures;
– Loading №2 – a constant load. Own weight of floors, external and internal walls;
– Load №3– temporary load;
– Load №4– temporary short-term load, snow;
– Load №5– short-term load, wind on the x axis;
– Load №6– short-term load, wind on the y axis.

The design model of the building has a rigid attachment at the level of the foundation plate.

5.1. calculation variant
When calculating the first model, the stresses in vertical structures are obtained from the action of the most unfavorable calculated combination of loads.

![Figure 2](image1.png)

Figure 2. Deformations of the design model from the applied design combination of loads.

The column in which the defect is located is located in the E/1 axes and the longitudinal force that occurs from the action of loads is $N=-1888$ kN.

![Figure 3](image2.png)

Figure 3. Isofields of longitudinal forces in rods from the action of loads.
5.2. Calculation variant

The calculation of the load capacity can be determined by the formula:

\[ \frac{N}{A} \leq R_{sc} \gamma_c \]

where, \( N \) is the force acting in the cross section \(-1888 \text{ kN}\);
\( A \) – reinforcement cross-section area \(-8\Omega32\) AIII \(-64,31 \text{ cm}^2\);
\( R_{sc} \)–calculated compression resistance of the valve \(-350 \text{ Mpa}\);
\( \gamma_c \)–the coefficient of working conditions is 0.9.

From here:

\[ N \leq A \cdot R_{sc} \gamma_c \rightarrow 1888 \text{ kN} \leq 64,31 \cdot 350 \cdot 0,9 = 20257,65 \text{ MPa} = 2025 \text{ kN}. \]

The calculation of reinforcement by bearing capacity shows that the strength condition is met. However, it is worth considering the fact that the reinforcement is in a bare state for a long time and has begun to corrode. Therefore, the calculation for option III must be performed to understand how loads are redistributed when a theoretically possible hinge appears [18].

5.3. Calculation variant

Adjustment of the calculation model: a hinge is inserted into the column of the 1st floor along the E/1 axis in the zone of pathology detection. By calculating the second model, the stresses in vertical structures are obtained from the action of the most unfavorable calculated combination of loads.

![Diagram of a building column with a hinge](image)

**Figure 4.** Deformations of the design model from the applied design combination of loads.

If we compare Fig. 2 and 4, we can see changes in the deformations of the calculated models:
1) increased deflection of floor slabs in the area of joint formation: from 6.97 mm to 20.91 mm; SP 63.13330.2012 "Concrete and reinforced concrete structures. Basic provisions" (analogue Eurocode 2. Design of concrete structures) regulates the deflection for reinforced concrete plates

\[ f \leq f_{ult} \rightarrow f_{ult} = L/150 = 8000/150 = 53.3 \text{ mm} \]

2) there was a general roll of the building towards the location of the pathology to 0.107 mm.

In the column axis E/1 load decreased significantly: with \( N = -1880 \text{ kN} \) to \( N = -50.3 \text{ kN} \), at the same time increased the load on adjacent columns: with \( N = -1880 \text{ kN} \) to \( N = -2700 \text{ kN} \) (see Fig.7). Thus the bearing capacity of these columns is 3520 kN, i.e. they provide the load bearing capacity of the building frame, the introduction of one hinge.
6. Conclusion
When conducting a technical survey of buildings and structures with a monolithic frame, there are often pathologies that are not taken into account in the calculation software packages. The proposed calculation method demonstrated how loads are redistributed when forming a plastic hinge in bearing structures.

The relevance of the presented approach is that it allows you to take into account in the work of the frame pathologies that affect the spatial rigidity and stability of the building, predict and assess the risks of accidents in the event of adverse events, promptly respond to the occurrence of emergency situations in the course of building operation, including the development of insurance and compensating measures.

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