Reliability assessment of reinforced concrete structures during commissioning

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Abstract. The article presents the studies’ results on the safety characteristics of the most damaged load-bearing structures in a monolithic reinforced concrete building. Reliability assessment was carried out at the stage of putting the building into operation. The analysis of the numerical reliability characteristics is carried out taking into account design and actually implemented strength parameters of the considered structures.

Introduction
The construction of monolithic reinforced concrete buildings and structures today remains one of the most popular in the construction field. The use of reinforced concrete structures is very wide: from the construction of residential and office buildings to the structures of increased risk to the environment. Due to the long operational period of such buildings, the issue of reliable design and operational forecasts ensuring reliability throughout the entire life cycle of the building remains relevant. [1, 2, 3, 4]

To obtain an adequate estimate of the wear rate of structures and to make a correct forecast on the terms of the structures’ further trouble-free operation, it is extremely important to know the reliability level implemented during its construction \( \beta(T=0) \). The initial individual resource cannot be identified with the assigned resource (theoretical reliability), which is provided by the limiting states method [5-9].

Main part
Due to the current economic situation with a large number of unfinished and non-preserved buildings, the problem of assessing the initial resource is especially relevant [10, 11].

Let us consider an example of a monolithic reinforced concrete frame building that has been left unfinished for more than five years. Due to a sufficiently long break in construction and the absence of conservation measures, the erected load-bearing structures received a number of damages: the protective layer destruction, corrosion processes of the reinforcement, accumulation of atmospheric precipitation, and concrete destruction.

Reliability assessment was performed for the most damaged structures - monolithic reinforced concrete floors. Due to the precipitation accumulation on the surfaces of the structures under consideration, a characteristic damage is the concrete protective layer destruction, which led to a decrease in the monolithic ceilings’ thickness. The damage depth varies from 5 to 20 mm. On the instrumental examination basis, the insignificant differences in the strength characteristics of concrete...
from the design and varied in the range of B22.5–B25 were also found. Figure 1 schematically shows the areas with damage to the plate surface.

Figure 1. Layout of destructive damage to a monolithic slab
The solution of the problem considered consists of two stages: the first was the evaluated structures’ stress-strain state and the second was the performed probabilistic calculation. Moreover, the analysis was carried out both according to the presented design data, and taking into account the technical condition and actual strength characteristics obtained during the survey [12-14].

To assess the bearing capacity of the building’s main load-bearing structures, a static calculation using the LIRA SAPR software package was performed. To assess the influence degree of the detected damage, the calculation was first carried out according to the design decisions, then taking into account the survey data.

The calculation results are shown in Table 1 and are presented graphically in Figure 3.

### Table 1. The values of the static calculation main characteristics

| Internal design efforts | Values for design data | Values in the calculation taking into account the technical condition of the |
|-------------------------|------------------------|--------------------------------------------------------------------------------|
|                         |                        |                                                                               |

**Figure 2.** Destruction of the floor slab’s protective layer

**Figure 3.** Monolithic stress mosaic tile Mx(kNm)
The second stage was a safety calculation. Based on the damage nature analysis for the structure under consideration, the function of ultimate bending moment with two random variables was adopted as the main criterion:

\[ M_{\text{max}} = M(\bar{h}; \bar{R}_b), \]  

where \( \bar{h} \) is the monolithic slab section height; 
\( \bar{R}_b \) is the design resistance of concrete to axial compression.

The statistical characteristics of the strength parameter were determined by design (theoretical) and actual values, respectively.

The results are summarized in Table 2.

The load effect statistical characteristics values - the moment in the section from the action of external loads \( \bar{f} \) - with the coefficient of variation adopted according to the known standard value of the load \( f_f = 0.18 \), are presented in Table 2.

### Table 2. The values of the floor slab’s statistical characteristics

| Safety features | Theoretical values | Actual Values |
|-----------------|-------------------|--------------|
| \( m_R, [kN] \) | 94.641            | 90.395       |
| \( \sigma_R, [kN] \) | 3.867              | 3.684        |
| \( f_R \)       | 0.135              | 0.09         |
| \( m_f, [kN] \)  | 45.974             | 45.974       |
| \( \sigma_f, [kN] \) | 8.275              | 8.275        |
| \( f_f \)       | 0.18               | 0.18         |
| \( \beta \)     | 3.22               | 2.86         |

In the tables, the following notations are used:
- \( m_R, m_f, \sigma_R, \sigma_f \) – are the mathematical expectations and standards of bearing capacity and load effect, respectively;
- \( f_R \) – is the bearing capacity variation coefficient;
- \( f_f \) – is the load variation coefficient;
- \( \beta \) – is the reliability coefficient according to A.R. Rzhanitsyn [15]:

\[ \beta = \frac{\bar{R} - \bar{f}}{\sqrt{\sigma^2_M + \sigma^2_P}}, \]  

### Summary
According to the study, the safety characteristic (reliability index) \( \beta \) incorporated at the design stage is 3.22. Taking into account the strength characteristics actually revealed during the technical examination, the reliability index \( \beta \) is equal to 2.86, which is slightly reduced in comparison with the adopted index in Table B2 Eurocode 0 \( \beta=3.8 \). However, it should be noted that the numerical simulation of the stress-strain state of floor slabs, taking into account the revealed damage, indicates the presence of reserves of strength parameters.

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