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Algorithm for Determining the Suitability for Exploitation of Structures of Buildings

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Abstract. The article presents the results of an analysis of the principles of assigning a category of technical condition to building structures, buildings or structures. The category of technical condition characterizes the mechanical safety, allows to assess the suitability for exploitation and is the basis for the substantiation of the repair work. The relevance of the study is justified by the lack of an approved technique for assigning a category of technical condition. The purpose of the work was the development of a system of indicators, on the basis of which gradation of defects can be performed and a scale of their evaluation developed. The object of the study was the process of determining the category of technical condition. The subject of the study was the study of the possibility of applying multicriteria optimization methods in the process of determining the category of technical condition. One of the significant results of the study is the decision algorithm for determining the degree of suitability of the structure, building or structure for operation.

1. Introduction

One of the basic requirements for building structures and buildings, which is established in technical regulations, is to ensure their mechanical safety. According to state standards, in order to obtain information on the compliance of the actual characteristics of a building object with normative, it is necessary to perform its survey. Based on the results of surveys conducted during construction or operational control, a building structure or a building should be assigned a category of technical condition (hereinafter referred to as CTC). This most important indicator characterizes not only the safety of the facility, but also serves as a justification for the need for repair work, the design of major repairs, reconstruction. Often, the need to determine the CTC arises not only in the process of exploitation of buildings or structures. Often, when the building is erected, it becomes necessary to determine the suitability of the construction object for subsequent exploitation, if there are violations in the design of buildings, as well as in the construction of buildings.

The study of the regulatory and legal and legislative framework shows that four CTC of the object are established: normative, working, limited-working and emergency state. At the same time, there is a problem of assigning CTC. According to the data of various researchers [1-3], the indications of categories are determined very conditionally, the scale of states is practically not developed. In those indications that have quantitative meanings, there is no rationale for why this value is taken as a
boundary value. In addition, the conclusion based on the results of the survey is based on expert opinion, which is far from always backed up by a logical-mathematical apparatus.

1.1. Relevance and scientific significance
Since the definition of CTC is possible only based on the results of the survey, in the works of domestic and foreign authors it is possible to meet quite a lot of research devoted to the development and accuracy increase of methods for controlling the changes in the characteristics of the stress-strain state of a building object, its structures [4-8], clarifying the procedure for the survey [9-12]. However, studies devoted to the study of the problem of the accuracy of CTC assignment, which is important for determining the suitability of buildings and structures for exploitation, is not enough, which justifies the relevance and novelty of the study.

The scientific side of the problem lies in the fact that there is no approved methodology for assigning a particular CTC. In addition, the absence of algorithms of decision-making at various stages of the survey, the fuzziness of the defect scales [13], the complexity of the mathematical apparatus of the existing methods for predicting the change in the technical state of the building object over time [14, 15] also confirm the scientific and practical significance and relevance of the study.

1.2. Objectives of the study
The CTC is a function of numerous parameters. Any change in, for example, the conditions of operation, performance of works of poor quality or at not their own time, will affect the dynamics of changes of exploitations of parameters. Therefore, it is possible to predict the value of the CTC only with a certain probability, specifying the methodology for its assignment. In this regard, the main objectives of the study were:

- Study of the existing principles for the designation of CTC;
- Study of significant factors that must be taken into account when assigning CTC;
- Development of a system of indicators for gradation of defects;
- Development of an algorithm for determining the suitability for the exploitation of a building structure or building.

2. Materials and Methods
The object of the study in this article was the process of determining the CTC. The study of the theoretical and practical side of the problem shows that a certain procedure is established during the survey:

- Determination of the characteristics of the structure, its damages, properties of the building material;
- Description of loads and other environmental influences;
- Identification of characteristics controlled during the survey;
- Designation of threshold values of controlled characteristics on the basis of normative documents or results of mathematical modeling;
- Choice of survey methods and methods of processing survey results;
- Assignment of the CTC and its justification;
- Determining the causes of defects;
- Development of a task for the design of works to restore the suitability of the structure or building to exploitation.

In the presence of an adequate model reflecting sufficiently accurate characteristics of the studied construction object [16, 17], the procedure for assessing the technical state is complemented by the following actions:

- Verification calculation taking into account the survey results;
- Modeling the change in controlled characteristics due to changes in impacts, the presence of defects for the prediction of the development of damages, their consequences.
Examination of the existing principles of the designation of CTC indicates that each expert is guided by his level of knowledge and experience. Classification signs of critical and significant defects are of a qualitative nature, which complicates the survey procedure and each time requires the development of a new scale for the classification of the severity of defects and their consequences. Therefore, the subject of the study was the study of the possibility of applying multicriteria optimization methods for decision making in the designation of CTC.

Examination of the existing principles of the designation of the CTC [18-20] shows that it is proposed to consistently take into account factors such as the class of design responsibility, the severity of the violation in terms of the deviation of the actual value of the parameter in question from the normative one, and the degree of defect propagation. At the same time, some documents specify clearly fixed intervals for the evaluation of these characteristics [20], which, on the one hand, simplifies the procedure for assigning CTC, on the other hand, does not take into account the failure mechanism that determines the rate of defect development. In other documents, the characteristics boundaries are completely blurred [18]. In addition, it is not taken into account that the permissible depth of deviation of the actual characteristic, the degree of danger of the consequences of defects, the quality and completeness of the functioning of the object depend on the type and material of the structure, the nature of the impact (power, vibration, corrosion, heat, etc.), functional purpose and other factors characterizing the suitability of the structure for exploitation.

An essential feature of the author’s approach to the appointment of the CTC is a system of indicators of gradation of defects, taking into account the factors analyzed above. As such indicators are:

- Controlled exploitation of characteristic of mechanical safety \( q_t \);
- The rank of the defect \( r_t \);
- Prevalence of the defect \( s_t \).

Let’s imagine the CTC as a function, determined depending on the value of the proposed indicators:

\[
k_{ic} = f \sum_{i=1}^{n} \int_{0}^{t} q_i(t) \cdot r_j(t) \cdot s_j(t) \ dt \quad at \quad q_i(t); r_j(t); s_j(t) = f \ F_{int}; F_{ext}; t
\]  

where \( k_{ic} \) is a complex criterion for evaluating the suitability of a structure for operation with \( i=1, 2, \ldots, n \) comparison parameters; \( q_i(t) \) is the change in the value of the \( i \)-th controlled safety characteristic over time; \( r_j(t) \) is the change in the rank of the \( j \)-th defect in time as the \( i \)-th controlled characteristic changes; \( s_j(t) \) is the change in the mass of the \( j \)-th defect as the \( i \)-th controlled characteristic changes; \( F_{int} \) is a set of internal characteristics that determine the type of defect, the likelihood of its occurrence and the rate of increase (material, manufacturing conditions, design, etc.); \( F_{ext} \) is a set of external characteristics that determine the type of defect, the likelihood of its occurrence and the rate of increase (impact type, quality of operation, surveys, etc.); \( t \) is the duration of exploitation of the structure.

Accounting for the material of the structure, working conditions, the functional purpose of the building, the consequences of failures, etc. can be carried out using qualimetric scales [21-25]. In this case, given the intervals of deviations of the controlled characteristics, can pass to the relative ponderability of the indicators of the CTC estimation:

\[
k_{ic} = \alpha_i^q \cdot \beta_j^r \cdot \gamma_j^s
\]  

where \( \alpha_i^q \) is the ponderability of the \( i \)-th controlled characteristic; \( \beta_j^r \) is the ponderability of the rank of the \( j \)-th defect when the \( i \)-th controlled characteristic changes, which can be expressed, for example, in the cost of restoration works; \( \gamma_j^s \) is the ponderability of prevalence of the \( j \)-th defect when the \( i \)-th controlled characteristic changes, which can be expressed, for example, in the specific size of the defect area, taking into account its severity.
3. Results and Discussion

According to the results of the study, and also on the basis of the analysis of the CTC’s formulation in the normative literature [19], it was proposed to classify them and present them as an illustration (Figure 1).

Figure 1. Grading of the signs of the STS assignment by the indicator q.

In general, the assignment of the CTC by the indicator q can be represented in the form of a model:

$$k^q_{tc} = \begin{cases} 
I, & \Delta q^i_f = 0 \ (q^i_f = q^{st}_i) \\
II, & \Delta q^i_f \leq \Delta q^i_{reg} \\
III, & \Delta q^i_{reg} \leq \Delta q^i_f \leq q^{ult}_i \\
IV, & \Delta q^i_f > q^{ult}_i 
\end{cases}$$  \hspace{1cm} (3)

where I, II, III, IV is a respectively, normative, working, limited-working, emergency CTC; $\Delta q^i_f$ is the actual deviation of the i-th controlled characteristic from the normative value $q^{st}_i$; $\Delta q^i_{reg}$ is the allowable deviation of the i-th controlled characteristic; $q^{ult}_i$ is the boundary value of the i-th controlled characteristic.

The presented model underlies the proposed algorithm for determining the suitability for exploitation the constructions of buildings (Figure 2). A practical example of assigning CTC on the proposed algorithm is presented in the form of a Table 1.

Table 1. Example of determining the CTC on the basis of the proposed model with two characteristics.

| Indicators | $q^{st}_i$, $r^{st}_i$, $s^{st}_i$ | $q^{reg}_i$, $r^{reg}_i$, $s^{reg}_i$ | $q^{ult}_i$, $r^{ult}_i$, $s^{ult}_i$ | $k_{tc}^{q/r/s}$ | $k_q$ |
|------------|----------------------------------|----------------------------------|----------------------------------|----------------|-------|
| $q_1$      | +                                |                                  |                                  | II             | 0.4   |
| $r_1$      |                                  | +                                |                                  | III            | 0.3   |
| $s_1$      | +                                |                                  |                                  | I              | 0.8   |
| $q_2$      |                                  | +                                |                                  | II             | 0.6   |
| $r_2$      |                                  |                                  | +                                | III            | 0.7   |
| $s_2$      | +                                |                                  |                                  | I              | 0.2   |

In conclusion, it can be concluded that the optimization of the procedure for designation of the CTC is based on the refinement of type of defect by groups of the limiting state, the functional
purpose of the object under investigation, the hazard, the prevalence and the rate of development of the violation. When assigning the ponderability of the indicator \( q \), the risk of a mechanical safety violation is taken into account. When assigning the ponderability of indicator \( r \), the rate of increase in the consequences of a security breach is taken into account. When assigning the ponderability of the indicator \( s \), labor costs, material resources for eliminating the violation and its consequences are taken into account.

![Diagram of Algorithm for determining the suitability of a building structure for exploitation](image)

**Figure 2.** Algorithm for determining the suitability of a building structure for exploitation.

4. **Conclusions**

The main scientific provisions obtained in the course of the study of the problem situation under consideration:

- The stages of the survey were identified and characterized for determining the technical condition of the construction site and the necessity of developing a methodology for determining serviceability was justified;
- It is established that in the presented order of actions the stage of determining the dependence of the CTC on the level of deviation of characteristics in the interval between the normative and threshold values has not been worked out;
- Factors influencing the designation of the CTC have been identified and the expediency of completing the toolkit in the organization of the CTC evaluation procedure has been justified;
- A system of indicators is proposed that allows to take into account not only the type of the defect, but also the degree of deviation of the exploitations characteristic, as well as the consequences, speed and scale of the defect development;
- An algorithm for decision-making based on the proposed complex criterion for assessing the suitability of a structure or building for exploitation has been developed.
The results obtained in the work are expedient to be applied not only in the course of construction control, but primarily in the planning of major repairs, reconstruction of the facility, during periodic monitoring of the technical condition.

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