Methodology for Calculating, Forecasting and Substantiating the Residual Period of Service of Building Structures

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Abstract. As part of the implementation of a set of works on the examination of the technical condition, calculation justification and assessment of the remaining service life of the group of buildings of the Left-Bank State Border Service of the city of Voronezh, the development of "Methodology for assessing the technical condition and calculation forecasting and justification of the remaining service life of building structures" was carried out. When developing the methodology, the requirements of the current regulatory and technical documents for the inspection of buildings and structures were taken into account. The methodology of the calculation justification is based on previously published works of the creative team under the direction of Shmelev G. D. The methodology for calculating forecasting and estimating the remaining service life of building structures is based on the following methods: expert, parametric, “load - bearing capacity” and “load - deformation”. This article provides a brief description of the methodology and its main sections. The general content of the methodology, which consists of 11 sections, is given, a detailed description of the 3 key sections of the methodology is given, which are devoted to: determining design parameters and criteria for their evaluation; methods for predicting the residual life of building structures; drawing up a report on the justification of the remaining service life of the building structures of the facility.

1. Introduction
In recent decades, due to aging of fixed assets, which include buildings and structures for various purposes, accidents related to damage and collapse of building structures began to occur in a number of industries and urban economy. In order to ensure the normal and safe operation of enterprises, as well as the need to determine the timing for timely and economically justified repair of buildings and structures, the need arose to calculate the rationale and predict the remaining service life of building structures.

The works of a number of authors [1–3] present various methods for determining the residual service life of building structures with respect to the approaches used, which have certain disadvantages. The papers [1] and [2] are based on an exponential failure development model that adequately describes only the occurrence of sudden failures. In [2], an approach based on a linguistic variable is additionally used, which complicates the perception and the possibility of an unambiguous use of the technique. In addition, in [2] there are other features that are poorly compatible with the general provisions of the classical theory of reliability and a number of existing regulatory and technical documents.
The work [3] is based on the principles of concrete fracture mechanics. Its use requires the organization conducting the work, expensive equipment, but the technique is also not without a number of disadvantages.

As part of the work carried out for RVK-Voronezh in the summer of 2016, a technical survey of the building complex of the Left Bank of the city sewage pumping station in the city of Voronezh was carried out. In addition to the survey of the technical condition of the building structures of the complex of buildings and the assessment of the working capacity of the installed technological equipment, in accordance with the requirements of the contract and technical specifications, work was carried out to develop a "Methodology for assessing the technical condition and calculated forecasting and substantiating the residual life of building structures" (hereinafter referred to as the methodology). When developing the methodology, the requirements and recommendations of the following regulatory and technical documents were taken into account: RD EO 0141-98 "Typical technical requirements for methods for assessing the technical condition and residual life of elements of nuclear power units" and RD 09-102-95 "Methodological guidelines for determining the residual a resource of potentially hazardous facilities supervised by the Gosgortekhnadzor of Russia."

When writing the methodology, the previously published works of the author and his colleagues were used [4–16].

2. The content of the methodology
When writing the methodology, the requirements for the design and writing of regulatory and technical documents were taken into account, and the entire text of the methodology was divided into the following key sections [17]:
1. Area of use.
2. General provisions.
3. Normative references.
4. Classification of elements of building structures.
5. General rules for the examination and assessment of the technical condition of building structures.
6. The procedure for the examination of the technical condition of building structures.
7. Determining parameters and criteria for assessing the technical condition of building structures.
8. Methods and means of measuring the parameters of the technical condition of building structures.
9. Calculation tools and methods for determining the stress-strain state and strength of sections of building structures.
10. Methods for predicting the residual life of building structures of buildings and structures.
11. Preparation of a report on the justification of the residual life of the building structures of the facility.

In addition to the key sections, the methodology also contains other sections provided by state standards for the preparation of regulatory and technical documents: a list of abbreviations; Terms and Definitions; introduction; list of sources used. In addition, the methodology included 11 applications with look-up tables, a description of the individual methods for calculating the remaining service life, and examples of performing calculations using different methods.

3. The main sections of the technique
Among the most significant sections of the methodology, which make it possible to unambiguously assess the actual technical condition of building structures of a building or structure, for which it is planned to evaluate the remaining service life of building structures, sections 7, 10 and 11 of the methodology should be attributed.

Section 7 of the methodology, based on the analysis of the existing normative-technical, reference and educational literature, contains the determining parameters and criteria for assessing the technical condition of building structures in operation. The requirements of the section are formed on the basis
of the work [14] previously published by the author. At the same time, to develop the work [14] for each type of structure based on their material, a gradation of determining parameters was carried out depending on the stages of the survey.

Section 10 of the methodology describes in detail the author’s methods for predicting the residual life of building structures of buildings and structures. When performing calculations to predict the residual life of building structures of buildings and structures, in order to increase the degree of reliability of the forecast by the proposed method, it is recommended to use several forecasting methods based on different approaches and principles:

- expert methods [4, 8, 10];
- parametric methods [5, 12, 13, 15];
- method "load - bearing capacity" [7];
- method "load - deformation" [13].

The reliability of the forecast increases with an increase in the number of methods used to justify the residual resource. The most "accurate" from the point of view of taking into account various parameters should be considered the methods "load - bearing capacity" and "load - deformation".

The following determining parameters characterizing the technical condition of building structures are the basis of expert methods for predicting the residual life of building structures:

- relative damage;
- probable decrease in bearing capacity;
- wear (for steel structures) or physical wear (for concrete, reinforced concrete and stone structures).

A feature of expert forecasting methods is their simplicity and, at the same time, a large error in the result obtained. The accuracy of the method depends on the skill level of an expert or specialist who evaluates the values of the determining parameters and the category of technical condition of building structures.

The forecast models used to estimate the remaining service life of building structures are divided into linear and nonlinear. To increase the reliability of the forecast, it is recommended to use both linear and non-linear forecast models [4, 8, 10].

In order to take into account the worst case scenario (the most conservative approach), forecasting using expert methods is recommended taking into account the interval estimation of the determining parameter, justified in [16].

As a limit value to which a predicted decrease in one of the determining parameters is possible, it is recommended to accept the lower limit of an unacceptable technical condition.

The basis of the parametric methods for predicting the residual life of building structures is based on determining parameters characterizing the technical condition of building structures. A feature of the developed parametric methods for predicting the residual life of building structures is the consideration of only one specific parameter. Lack of consideration of other parameters reduces the reliability of the forecast. However, in some cases, taking into account just one determining parameter, with the remaining design parameters unchanged, gives a sufficiently accurate forecast result and allows obtaining an acceptable forecast result at the lowest cost.

When constructing forecast models by parametric methods, it is recommended to use regression curves or trend lines. The trend line (regression curve) is constructed according to the results of all previous observations (measurements) of the determining parameter used to make the forecast. The construction of regression curves or trend lines is possible using any statistical software packages for personal computers.

When assessing the depth of corrosion damage, it is recommended to use exponential or logarithmic models, since they most accurately characterize the process of a gradual decrease in the corrosion rate, caused by the gradual restriction of reagent access to the metal due to an increasingly increasing thickness of the corrosion products [13].

To build forecast models, during the assessment of the residual life of building structures, it is necessary to carry out verification calculations of the structure according to the current building codes.
and rules (for two groups of limit states), taking into account the actual values of the parameters characterizing this structure at the time of the survey.

The obtained predicted value of the service life by the method of "load - bearing capacity" corresponds to the full service life of the building structure before its destruction.

The forecasting method “load - strain” is based on the design norms for designing building structures for the 2nd group of limit states, while taking into account the following determining parameters characterizing the technical condition of building structures:

- depth of corrosion damage;
- reducing the size of the cross section of the element;
- the value of the current load;
- concrete compressive strength;
- tensile strength of reinforcement;
- cross-sectional area of reinforcement.

Calculations by the method of "load - strain" are performed for two design cases:

- calculation of crack formation and opening (only for reinforced concrete structures);
- calculation for the development of deflections (for steel and reinforced concrete structures).

In order to build a forecast model, in the course of assessing the residual life of building structures, it is necessary to carry out verification calculations of the structure according to the current building codes and rules, taking into account the actual values of the parameters characterizing the structure at the time of the examination of its technical condition.

As the starting point for building the forecast, a point should be taken that corresponds to the actual values of the width of the crack opening and deflection of the structure obtained by calculation, provided that the actual strength characteristics of the materials and the geometric dimensions of the structure at the time of its manufacture are used in the calculation (commissioning of the object).

As the limiting value of the width of the opening of cracks and deflections of the structure, one should take the standard values of these values provided in [12].

The obtained predicted value of the service life by the method of "load - deformation" corresponds to the full service life of the building structure until the time of termination of its normal operation.

The final value of the predicted residual life of each type of structure of a building or structure is assigned after a detailed analysis of all the obtained values by all the methods described in this methodology.

Section 11 of the methodology describes in detail the requirements for the preparation and execution of the final report on the calculation and justification of the remaining service life of building structures of buildings and structures.

The report on the justification of the remaining service life of building structures of a building (structure) should contain the following sections:

Introduction;
1. Brief information about the building (structure);
2. Initial data for calculating residual life
3. The results of the calculation of the residual life
4. Analysis of the calculation results

Conclusion on the justification of the remaining service life of the building structures of the building (structure);

Applications.

When developing the methodology, the features of forecasting using random functions and processes [18, 19], as well as the features of assessing the risk of achieving an emergency state of building structures [20 – 22], were taken into account.
4. Conclusion
The developed “Methodology for assessing the technical condition and calculation forecasting and substantiating the residual life of building structures” contains a comprehensive approach to calculating and justifying the residual life of building structures, based on taking into account changes in various properties and parameters of these structures. Using this multilateral approach can significantly increase the reliability of forecasting of individual methods and obtain more reasonable forecasting results based on real changes in the properties of structural materials.

5. References
[1] Dobromyslov A N 2006 Assessment of the reliability of buildings and structures by external signs (Moscow: Publishing house ASV) p 67
[2] Melchakov A P 2006 Calculation and assessment of the risk of an accident and the safe resource of construction sites Theory, methods and engineering applications (Chelyabinsk: Publishing house of SUSU) p 49
[3] Piradov K A Bissenov K A and Abdullaev K U 2000 The mechanics of the destruction of concrete and reinforced concrete (Almaty) p 306
[4] Shmelev G D and Savchenko E N 2006 Method for express forecasting the residual life of structures of buildings and structures by their physical wear Risk assessment and safety of building structures 1 int. scientific and practical conference Collection of abstracts In 2 volumes Vol 1 Voronezh: Voronezh. state arch. un-t pp 83-86
[5] Shmelev G D and Ishkov A N 2006 Physico-statistical approach to assessing the residual life of reinforced concrete structures Risk assessment and safety of building structures 1 int. scientific and practical conference Collection of abstracts In 2 volumes Vol 1 (Voronezh: Voronezh. state arch. un-t) pp 90-94
[6] Shmelev G D 2006 Integrated engineering methodology for predicting the residual life of reinforced concrete structures (Construction Physics in the XXI Century: Materials of a scientific and technical conference) (Moscow.: NIISF RAASN) pp 582-585
[7] Shmelev G D 2006 Calculation of the residual life of reinforced concrete structures of a reactor type mine - VVER (Risk assessment and safety of building structures) 1 int. scientific and practical conference Collection of abstracts In 2 volumes Vol 1 (Voronezh: Voronezh. state arch. un-t) pp 99-102
[8] Shmelev G D 2014 Expert method for predicting the residual life of building structures by their physical wear Construction and reconstruction 3 pp 31-39
[9] Shmelev G D and Golovina N V 2012 Prediction of reliability and residual life of building structures using the linearization method in conditions of limited statistical information Collection of scientific papers SWorld Vol 6 4 pp 100-107
[10] Shmelev G D and Golovina N V 2013 The method of interval expert forecasting of the residual resource of building structures with the extrapolation of controlled parameters of damage, physical wear and loss of bearing capacity Scientific works of SWorld Vol 8 4 pp 89-94
[11] Shmelev G D and Makarychev K V 2011 Methods of expert assessment and forecasting the actual reliability of building structures of operated buildings and engineering structures Scientific Bulletin of the Voronezh State University of Architecture and Civil Engineering. Construction and architecture 1 pp 7-14
[12] Shmelev G D and Nikolayevich I V 2013 Parametric methods for predicting the residual life of reinforced concrete building structures Scientific Bulletin of the Voronezh State University of Architecture and Civil Engineering Series: Physico-chemical problems and high technologies of building materials science 7 pp 167-175
[13] Shmelev G D and Ishkov A N 2007 Prediction of the residual life of flexible concrete structures operated in non-aggressive environments (Rostov-on-Don: Growth. state builds. Univ) p 219
[14] Shmelev G D 2013 Systematization of determining parameters for predicting the residual life of building structures Bulletin of MGSU 8 pp 89-96
[15] Sazonov E V, Shmelev G D and Ishkov A N 2007 Practical aspects of the use of parametric methods for assessing the residual life for coating plates Proceedings of higher educational institutions *Construction* 1 pp 15-20

[16] Kozlov V A and Shmelev G D 2013 The rationale for the interval method for predicting and assessing the residual life of building structures of buildings and engineering structures *Scientific Herald of the Voronezh State University of Architecture and Civil Engineering Construction and architecture* 4 pp 11-18

[17] Shmelev G D, Kononova M S and Maleva N A 2019 Methodology of technical condition assessment, forecasting and justification of remaining service life of building structures *Housing and utilities infrastructure* 2(9) pp 34-42

[18] Shmelev G D and Fedotova M I 2017 The use of random functions and processes in the combined integral method of forecasting the residual service life of building constructions *Izvestia KGA Su* 1(39) pp 128-137

[19] Shmelev G D, Fedotova M I and Golovina N V 2017 Random functions and interval method for predicting the residual resource of building structures *Bulletin of MGSU* Vol 12 Issue 11(110) pp 1261–1268

[20] Shmelev G D 2013 Risk methodologies for estimating for forecasting the remaining life of construction structures *Academic Bulletin UralNIIproekt RAASN* 3 pp 81-84

[21] Ishkov A N and Shmelev G D 2019 Use of physical wear to risk of accidents (In the collection: ADVANCED SCIENCE collection of articles of the VI International Scientific and Practical Conference) pp 103-106

[22] Shmelev G D and Zhukova A V 2019 Risk assessment of an accident at an object «CITY SEWAGE PUMP STATION» *Housing and utilities infrastructure* 3(10) pp 102-108