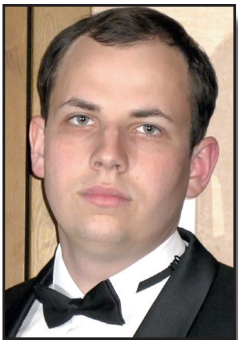
DOI: https://doi.org/10.30932/1992-3252-2020-18-6-64-73

Risk-Based Approach in Assessing the Technical Condition of Foundations of Bridge Structures



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ABSTRACT

The objective of this article is to consider the use of predictive mathematical models for assessing risks associated with a critical loss of values of functional quality of bearing structural elements (foundations) of bridge structures using methods of probabilistic analysis and forecasting the risks of reducing of values of indicators of the technical state of structural elements.

The research results in development of an algorithm and a mathematical model that characterise the features of the process of reducing of values of indicators of the technical condition of load-bearing structures during the service life cycle. The results of assessing the loss of functional quality of foundations obtained using this model are presented.

The practical significance of the study relates to the possibility and expediency of using probabilistic methods for predictive assessment of the technical state of load-bearing structures. With the help of an appropriate mathematical model, it becomes possible to proceed with design rationale of indicators of functional quality of foundations of bridge structures.

The need to improve regulatory provisions for design and forecasting of indicators of the technical condition of transport infrastructure objects is substantiated.

Keywords: *bridge structures, technical condition characteristics, risk analysis, mathematical model of foundations, physical wear, service life.*

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Article received 03.11.2020, accepted 15.01.2021.

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Domestic and foreign scientists have done a significant amount of research while considering the issue of assessing the technical condition of transport facilities. Thus, a method has been proposed for predicting the state of bridges in operation, considering complexity and specifics of their maintenance in urban conditions using the apparatus of the reliability theory, while parametric values of the function of dependence of the state of the structure on operating time have been also introduced and substantiated [1]. A linear dynamic discrete neighbourhood model of wear process elements of a bridge structure [2], and an analysis of the experience of several countries in implementation of expert systems for managing the condition of bridge structures on highways, based on the knowledge base, laid down in the development process and edited when using [3], have been carried out.

On railways, it is proposed to create regional centres for monitoring, forecasting, and ensuring safety of complex technical systems, to control their condition, accumulate statistical information and form databases on infrastructure facilities, risk criteria and the amount of the residual resource [4].

The works of international researchers assess the risk of interruption of construction of bridge objects to identify the main causes of its occurrence, as well as to determine the potential results arising from the occurrence of the risk. For this, Fault Tree Analysis and Event Tree Analysis (ETA) techniques are used. Since the use of the traditional approach to these two methods is difficult in many cases due to limited access to information, fuzzy arithmetic can be considered as a useful tool. In a study, the fault tree structure is first created according to the implications of the Delphi method. The likelihood of risk occurrence is then calculated using Fault Tree Analysis (FTA) based on fuzzy logic. By establishing the failure tree structure associated with the risk of failure of mitigation strategies, the main reasons associated with failure of strategies are identified. The structure of the event tree is created using the results obtained; in addition, the expected monetary value (EMV) is shown [5].

The implementation of bridge projects starts frequently in a challenging and dynamic environment, resulting in high uncertainty and risk, exacerbated by numerous constraints. The overall research methodology relies heavily on a questionnaire, the responses to it being collected from various bridge contractors and managers of projects of various size by mail or at staff meetings. The questionnaire prepared for the survey is compiled by reviewing the

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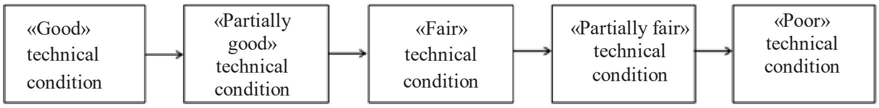

Pic. 1. Model of deterioration of indicators[1] of technical condition (physical wear) of foundations of bridge structures [11; 12].

Table 1

Characteristics of accepted technical conditions of foundations [13; 14]

No.	Name of condition	Generalized characteristics of technical condition	Indicator of physical wear (approximately), %
1	Good	Research objects (foundations) fully comply with design parameters and operating conditions	0÷3
2	Partially good	Research objects (foundations) partially do not correspond to design parameters, but correspond to operating conditions	4÷12
3	Fair	Research objects (foundations) almost completely do not correspond to design parameters, but correspond to at least one variant of operating conditions	13÷38
4	Partially fair	Research objects (foundations) almost completely do not correspond to design parameters, and the only option for operation is allowed with restrictions	39÷60
5	Poor	Research objects (foundations) do not fully comply with design parameters, an immediate shutdown of operation is required	61÷100

relevant literature in the field of construction management. This approach is aimed at identifying risk factors affecting efficiency of bridge projects in general, and analysing them using appropriate tools and methods, as well as developing a risk management system. The questionnaire in the described case was divided into seven categories, which totalled 50 questions asked to the respondents. The responses were analysed using SPSS software. The statistical analysis of responses regarding factors was divided into separate sets of critical factors. This study aimed to identify the factors that influenced the bridge construction project, and to consider the critical factors to improve risk analysis. However, it has been observed that the degree of their contribution varies depending on the specific level of project performance. It was assumed that the results of the analysis would help the project specialists to focus on several factors and obtain optimal results, rather than to pay attention to all the factors not getting proportional results [6].

Risks of deterioration of basic functional properties of foundations of bridge structures (formation and accumulation of physical wear and tear) are reflected by a decrease in initial (design) values of indicators of the bearing capacity according to the accepted groups of limiting states [7; 8].

For correct accounting and display of the technical state of foundations, a probabilistic model is proposed, which allows at the design stage to predict changes in functional quality of the considered load-bearing structures [9; 10].

The *objective* of this article is to demonstrate the possibility of using a mathematical model to assess the technical state of load-bearing structures during the service life cycle by using *methods* of statistical processing of retrospective information data on consequences of manifestations of operational factors of various physical nature, of mathematical modelling of processes and phenomena, as well as of an analytical review of engineering solutions of random (probabilistic) problems with incomplete initial data. The criterion under study is assumed to be an indicator of physical deterioration of the foundation from the point of view of the quantitative value of the function of consequences of manifestations of negative operational factors. The use of the indicator of

[1] Some of the original terms in Russian version in Pic. 1 and in Table 1 are translated to make them more universal, thus the term «serviceable» condition is translated as «good», «limited serviceable condition» as «partially good», «working condition» as «fair condition», «limited working» condition as «partially fair» condition, and «nonworkable» condition as «poor» condition. – *Translator's note.*

Table 2

The probability of a poor technical condition of foundations (physical wear, more than 60 %) [15; 16]

Indicator's name	Value of the function (accumulation intensity) of physical wear and tear							
	0,1	0,08	0,05	0,03	0,01	0,008	0,004	0,001
Service life, t years	50							
Failure probability, P_t	0,17547	0,15629	$6,6801 \cdot 10^{-2}$	$1,4120 \cdot 10^{-2}$	$1,5795 \cdot 10^{-4}$	$5,7201 \cdot 10^{-5}$	$2,1833 \cdot 10^{-6}$	$2,4772 \cdot 10^{-9}$
Service life, t years	100							
Failure probability, P_t	$3,7834 \cdot 10^{-2}$	$9,1604 \cdot 10^{-2}$	0,17547	0,10082	$3,06571 \cdot 10^{-3}$	$1,2270 \cdot 10^{-3}$	$5,7201 \cdot 10^{-5}$	$7,5403 \cdot 10^{-8}$
Service life, t years	150							
Failure probability, P_t	$1,9358 \cdot 10^{-3}$	$1,2741 \cdot 10^{-2}$	0,10938	0,17083	$1,4120 \cdot 10^{-2}$	$6,2456 \cdot 10^{-3}$	$3,5563 \cdot 10^{-4}$	$5,4467 \cdot 10^{-7}$

the probability of an inoperative, faulty technical condition of foundations while assessing the risks of decrease in functional quality of transport structures is substantiated.

Probabilistic model of the technical condition of foundations

The technical condition of foundations of bridge structures can be displayed by means of a mathematical model of a continuous homogeneous process of Markov type (Pic. 1).

Table 1 shows the qualitative and quantitative composition of indicators characterizing each of the possible technical conditions accepted for consideration.

For example, the value of physical deterioration corresponding to a poor technical condition («Condition 5», Table 1) of structural elements of foundations identifies a high level of risks of decrease in efficiency and safety of operation of transport infrastructure facilities.

The likelihood of manifestation of the consequences of a decrease in the technical condition (accumulation of physical wear) of foundations during the established (design) service life cycle *t* is characterized by an analytical dependence of the form:

$$P_t = \frac{1}{n!} \cdot (\lambda \cdot t_i)^n \cdot e^{-\lambda(t_i - t_0)}, \qquad (1)$$

where P_t is probability of a poor technical condition (failure) of foundations;

λ is intensity of the decrease in the level of technical condition (accumulation of physical wear and tear);

t_0 is amount of time allotted for running-in of foundations (years);

n is number of types of technical conditions;

t_i is estimated service life (years).

Table 2 shows the calculated values of the probability of the onset of a poor technical condition (failure) for some values of intensity of the decrease in the level of technical condition (accumulation of physical wear) and the design life of foundations of bridge structures.

The identification of values of the parameter λ for specific types of foundations and operating conditions of bridge structures is carried out using the following methods:

• Analytical, numerical, or numerical-analytical modelling of processes and impacts.

• Correlation analysis or expert judgment.

• Retrospective analysis using statistical data on the revealed features of operation, the dynamics of changes in the technical condition (physical wear) of foundations for a certain fixed time period.

• Prospective analysis using other types of mathematical (predictive) models.

• Acceptance of a certain guideline value of the indicator, justified by technical, economic, or other factors.

The rational area of application of each of the methods considered depends on the type of the problem being solved and availability of the data base necessary to obtain the result.

A wide range of methods for determining the values of the parameter λ allows, on the one hand, to optimise the process of choosing the most specific types of foundations and operating conditions of foundations, but, on the other hand, it requires a certain regulation of the quantitative values of permissible risks associated with the expected decrease in the functional quality of load-bearing structures.

Conclusion. Indicators of the technical condition of the foundations of bridge structures constitute a key factor in assessing the risks of decrease in efficiency of the transport system operation.

The mathematical (predictive) model of accounting and forecasting a decrease in indicators of functional quality of load-bearing structures can be used as a rationale for design decisions on the choice of a structural solution and duration of the service life of foundations of bridge structures.

The quantitative and qualitative values of risk parameters obtained as a result of the analysis determine the level of the technical condition of foundations and the possibility of ensuring the performance of functional and technological (transport) processes.

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