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FUNDAMENTAL DESIGN PRINCIPLES OF REINFORCED CONCRETE STRUCTURES AND CONSTRUCTIONS DURABILITY

Abstract. The article describes general issues and the current state of the multifaceted problem of the durability of reinforced concrete structures, including the main provisions for the design of the durability of reinforced concrete structures, the existing methods for its evaluation, concepts and criteria related to durability.

Key words: durability, reliability, correlation, modeling, failure-free operation, degradation.

INTRODUCTION

In the course of long-term operation reinforced concrete structures of engineering structures are exposed to complex loads, temperature-humidity deformations, corrosive environment and other external and internal factors.

In general, the development of durability of reinforced concrete structures is realized by developing methods for estimating, forecasting and improving durability. When considering the durability of reinforced concrete structures, the following features of this problem can be distinguished:

i – a probabilistic nature of force and non-force impacts, their complexity and interrelation;

ii – variability of technical characteristics of materials and structures;

iii – the influence of the time factor on the nature of the impacts and the properties of the materials.

THE GENERAL STATE OF THE PROBLEM

Forecasting the service life is a component of the theory of reliability of reinforced concrete structures.

In 1924 N. S. Streletsky identified three factors determining the safe operation of the structure: the variability of material properties, the variability of the load, and the structural correction for the quality of constructions. He proposed a universal approach to finding the optimal service life, which should be determined by minimum operating costs.

Modern methods for calculating the reliability of building structures were developed by V. V. Bolotin, A. R. Rzhanitsyn and other scientists who gave the opportunity to introduce methods of probability theory, mathematical statistics and the theory of random processes in the practice of design, construction and operation [1, 6].

The version of the theory of the reliability of mechanisms and structures, developed by B. Bolotin, reflects the behavior of the object as a result of their interaction with the environment.

The condition of structure reliability during the operating time is:

$$P(t) \geq P_n, \tag{1}$$

where $P(t)$ is probability of safe structure operation at a certain time; P_n is the normative value of the probability of safe operation. The left side of the inequality means that a dangerous state occurs when the force from the external load S exceeds the load-bearing capacity of the element Z, i. e.:

$$S - Z > 0 \tag{2}$$

with the probability of $1 - P(t)$.

To calculate the probability of the safe operation, the stochastic properties of the load-strength system are calculated, since specific realization of the random processes of loads and load-bearing capacity depends on deviations from their mean values that change in the course of time.

Therefore, for any moment of time, the distribution of the bearing capacity and loads and the necessary correlation links between the random variables determining the behavior of the structure during its service must be described.

The successful development of probabilistic calculation methods was contributed by the fundamental work of A. R. Rzhanitsin [6], who suggested to determine the probability of failure-free operation of the structures $P(t)$ for a given service life of «n» years, as the probability of inequality:

$$R - Q_n > 0, \quad (3)$$

where Q_n – is a generalized load that can occur during the estimated service life;
R – is a characteristic of the generalized structural strength.

Then the structural strength reserve is calculated by the following formula:

$$S = R - Q_n > 0. \quad (4)$$

The probability of failure-free operation

$$P(t) = \int_0^\infty Q_{qrt}(t)dt, \quad (5)$$

When the distribution density of random variables with a given distribution law P_s is expressed in terms of the probability density of the load P_n and the strength of P_r, the probability $P(t)$ takes the form:

$$P(t) = \int_0^\infty Q_{qrt}(t)\Phi(t)dt, \quad (6)$$

where $\Phi(t) = 1 - P_к(t)$, P_r is a strength distribution function.

One of the important tasks of the probabilistic calculation of structures is the calculation of safety, taking into account the wear and the influence of local defects.

The technique of calculation of probability failure involves a number of steps: the determination of the failure state, the choice of the function of working capacity, the formulation of failure conditions, the choice of probabilistic models, and the calculation of the probability of the failure condition by numerical integration methods, as well as the «hot point» method. Statistical modeling is performed by the frequency of event occurrence [5].

V. D. Raiser introduced the function of wear in conditions of failure-free operation of the structure:

$$R_0 f(t) = Z(t) - S(t), \quad (7)$$

where R_0 is the initial value of bearing capacity;
$S(t)$ is load effect;
$f(t)$ is a wear function;
$Z(t)$ is a wear process.

The application of the reliability of the theory method for prediction the durability of reinforced concrete structures has encountered a number of difficulties. The well-known model of reliability of structures «load-strength», in the case where the cause of failure is destruction, basically does not take into account the time factor and does not allow tracing the evolution of the state of the construction associated with the destruction processes.

Practical methods for calculating the lifetime and service life of reinforced concrete structures differ from those taken in the durability estimates of machines and mechanisms due to the specifics of the development of degradation processes and the diversity of their combinations, very different operating time, because of the limited or lacking in basic information about the laws of distribution of random factors in time and some other reasons.

The concept of the resource (working time, assigned service life, total service life) is very significant when studying structures that are subject to the effects of alternating loads.

The following formula is proposed to describe the change in the load-bearing capacity $\Phi(t)$, taking into account the time factor and the accumulation of damages:

$$\Phi(t) = a_\Phi(t)\Phi_0, \tag{8}$$

where Φ_0 is a bearing capacity of reinforced concrete structure after manufacturing, $t = 0$;
$a_\Phi(t)$ is a function of time, which reflects the change in the bearing capacity in the course of time during operation due to the increase of the strength, the conditions of repeated and prolonged loads, the influence of an aggressive environment and other factors.

On the basis of this approach, the main resource equation for prestressed concrete of reinforced concrete span structures of bridges was obtained, taking into account the variable factors, conditions of loading and operation, which allowed to determine the service life of structural elements as a result of concrete destruction:

$$T = \frac{N_1}{n_i}\left(\frac{1+\gamma V_R}{\eta}\right)m, \tag{9}$$

where n_i is a number of load cycles per year;
$N_1 = 2 \cdot 10^6$;
$m = 20$;
γ is a coefficient corresponding to a given secured probability P;
$\gamma = -2{,}33$ when $P = 0{,}99$;
η is a coefficient taking into account the level of loading.

This approach is somewhat arbitrary because of the imperfection of the method for estimating the probability of the elements operability in sections of the random process: high reliability requirements are imposed on the carrying capacity, while the limiting state of the elements is characterized by considerable instability. In this sense, the calculation method based on the successive replacement of random arguments is more convenient [7].

Furthermore, due to the multifaceted problem of durability, at present the application of only probabilistic methods does not allow to obtain answers to a number of specific questions of interest to practitioners.

Durability is considered as a comprehensive criterion that depends not only on the environmental conditions, but also on design parameters, material characteristics, mixture proportions and processing methods. Studying the fundamental principles underlying the processes of interaction between structures and the environment is very important.

Calculation methods based on this or that variety of creep theory, allow determining the stresses and deformations of reinforced concrete elements at any time during the action of a continuous constant load. Proposals to take into account the variability of external influences are discussed in the works of A. Ya. Barashikova, Yu. P. Gushchi, N. I. Karpenko [3].

The method of transformed time τ_t, developed by Karpenko, allows to avoid the need to remember the information on the history of the stress-strain element, which greatly simplifies the calculations.

Approaches are proposed for forecasting the durability of materials and their products by the method of degradation functions under combined actions and the criterion of the limiting state resulting from the destruction of the compressed element from the combined effect of force factors and adverse influences is determined by inequality:

$$N < D(N)\, N(0), \tag{10}$$

where $N(0)$ is a force, taken by the element at the initial moment of operation.

To determine the ultimate state of materials during the cyclic action of mechanical loads, corrosive environment and temperature, the criteria for summation of damage are used, expressions are obtained for describing the durability of a sample under the action of thermal, mechanical or chemical types of energy:

$$\tau_p(u_n) = \tau_0 \exp\left(\frac{u_0 - u_n}{kT}\right), \tag{11}$$

where T is absolute temperature, k is the Boltzmann's constant;
u_0 is a initial activation energy;
u_n is level of energy impact;
τ_0 is a constant. The absorbed energy is defined as the difference of the areas of the «$\sigma - \varepsilon$» diagrams determined before and after the energy impact.

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At the present time, in terms of reliability and durability of reinforced concrete structures, there is no single generally accepted approach, and the theory of calculating reinforced concrete structures interacting with aggressive and other types of media is still far from the final solution. Apparently, in these conditions, a promising and acceptable approach for predicting the service life of reinforced concrete structures, based on the knowledge of degradation mechanisms and the rate of degradation processes, is the use of mathematical models in a deterministic and stochastic setting and accelerated trials.

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ОСНОВНЫЕ ПОЛОЖЕНИЯ ПРОЕКТИРОВАНИЯ ДОЛГОВЕЧНОСТИ ЖЕЛЕЗОБЕТОННЫХ КОНСТРУКЦИЙ И СООРУЖЕНИЙ

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Аннотация. Вопросы долговечности привлекают заметное внимание в строительном мире. Многоплановая проблема долговечности железобетонных конструкций зданий и сооружений представляет собой совокупность ряда взаимосвязанных проблем, многие из которых остаются нерешенными, в их числе разработка современных методов прогнозирования долговечности и разработка практических методов повышения долговечности железобетонных конструкций инженерных сооружений, находящихся в эксплуатации. В статье изложены общие вопросы и современное состояние многоплановой проблемы долговечности железобетонных конструкций, включая основные положения проектирования долговечности железобетонных конструкций, существующие методы ее оценки, понятия и критерии, связанные с долговечностью.
Ключевые слова: долговечность, надежность, корреляция, моделирование, безотказная работа, деградация.

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ОСНОВНІ ПОЛОЖЕННЯ ПРОЕКТУВАННЯ ДОВГОВІЧНОСТІ ЗАЛІЗОБЕТОННИХ КОНСТРУКЦІЙ І СПОРУД

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Анотація. Питання довговічності привертають помітно зростаючу увагу в будівельному світі. Багатопланова проблема довговічності залізобетонних конструкцій будівель і споруд є сукупністю ряду взаємопов'язаних проблем, багато з яких залишаються невирішеними, в їх числі розробка сучасних методів прогнозування довговічності і розробка практичних методів підвищення довговічності залізобетонних конструкцій інженерних споруд, що знаходяться в експлуатації. У статті викладені загальні питання і сучасний стан даної проблеми, включаючи основні положення проектування залізобетонних конструкцій, існуючі методи її оцінки, поняття і критерії, пов'язані з довговічністю.
Ключові слова: довговічність, надійність, кореляція, моделювання, безвідмовна робота, деградація.

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