ENGINEER

international scientific journal

SPECIAL ISSUE
E-ISSN
3030-3893
ISSN
3060-5172

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ENGINEER

A bridge between science and innovation

E-ISSN: 3030-3893

ISSN: 3060-5172

SPECIAL ISSUE

27-june, 2026

engineer.tstu.uz

TEXNIKA FANLARI DOKTORI, PROFESSOR MIRAXMEDOV MAXAMADJON MIRAXMEDOVICH TAVALLUDINING 80 YILLIGIGA BAG‘ISHLANGAN “SAMARALI QURILISH MATERIALLARI, KONSTRUKSIYALARI VA TEXNOLOGIYALARI” MAVZUSIDAGI XALQARO ILMIY-AMALIY KONFERENSIYASI ILMIY ISHLARI TO‘PLAMI

Toshkent davlat transport universiteti RAASN akademigi, O'zbekistonda xizmat ko'rsatgan yoshlar murabbiyi, texnika fanlari doktori, professor Miraxmedov Maxamadjon Miraxmedovich tavalludining 80 yilligiga bag'ishlangan, ilmiy ishlar to'plami nashr etilishi ko'zda tutilgan «Samarali qurilish materiallari, konstruksiyalari va texnologiyalari» mavzusidagi Xalqaro ilmiy-amaliy konferensiyani o'tkazishni rejalashtirmoqda.

M.M. Miraxmedov kompozitsion qurilish materiallarining polistruktura nazariyasini rivojlantirishga salmoqli hissa qo'shgan. Uning qurilish materialshunosligi sohasidagi ilmiy hissasi e’tirofi sifatida 1995-yilda Rossiya arxitektura va qurilish fanlari akademiyasining (RAASN) xorijiy a’zosi etib saylangan. M.M. Miraxmedov 6 ta monografiya, 200 dan ortiq ilmiy maqolalar va 25 ta ixtiroga mualliflik guvohnomalari muallifidir.

Ushbu konferensiyaning asosiy maqsadi - qurilish materialshunosligi, bino va inshootlarni loyihalash va qurilish sohasidagi ilmiy tadqiqotlar natijalarini, shuningdek, muhandislik ta’limini takomillashtirish yo'llarini muhokama qilishdan iborat.

Konferensiya ishida ishtirok etish uchun oliy o'quv yurtlari va ilmiy tadqiqot institutlari olimlari, O'zbekiston Respublikasi va xorijiy davlatlarning ishlab chiqarish vakillari, ilmiy tadqiqotlarda salmoqli natijalarga ega bo'lgan mutaxassislar taklif etiladi.

“Samarali qurilish materiallari, konstruksiyalari va texnologiyalari” mavzusidagi xalqaro ilmiy-amaliy konferensiyaning asosiy yo‘nalishlari quyidagilardan iborat:

1. Resurs va energiya tejovchi qurilish materiallari va texnologiyalari.
2. Atrof-muhitning transport infratuzilmasiga ta’siri va uni himoya qilish usullari.
3. Bino va inshootlarning qurilish konstruksiyalari: hisoblash va loyihalashning zamonaviy usullari.
4. Arxitektura, shaharsozlik va shahar muhitini rivojlantirish.
5. Qurilishni tashkil etishning innovatsion usullari va qurilish jarayonlari texnologiyalari.
6. Transport obyektlarini loyihalash va qurishda raqamli texnologiyalar hamda sun’iy intellekt.
7. Temir yo‘l transporti infratuzilmasi obyektlarini loyihalash, qurish va ekspluatatsiya qilish.
8. Zamonaviy muhandislik ta’limi tizimini takomillashtirish.

Mazkur konferensiya ilmiy hamjamiyatning turli vakillarini bir joyga jamlab, qurilish materialshunosligi sohasidagi zamonaviy muammolar va istiqbollarni muhokama qilish uchun qulay platforma vazifasini bajardi.

Journal Engineer ISSN: 3030-3893 Special Issue| 2026

Methodological Framework for Assessing Durability and Reliability of Reinforced Concrete Bridge Structures

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Abstract: This paper addresses methodological issues related to the assessment of durability and reliability of reinforced concrete bridge structures throughout their service life. The study examines conventional deterministic design approaches alongside contemporary international standards, including EN 206, AASHTO LRFD, FIB Model Code 2010, and ISO 15686. Particular attention is paid to service life design principles and to the role of material degradation models in the prediction of long-term structural performance. From an engineering standpoint, it is shown that the exclusive use of deterministic methods does not adequately reflect time-dependent deterioration processes. To overcome this limitation, a multi-level assessment methodology is proposed, integrating deterministic, semi-probabilistic, and probabilistic approaches for evaluating structural reliability and residual service life under environmental exposure.

Keywords: Service life design, durability, reliability, reinforced concrete bridges, degradation modeling, environmental exposure, probabilistic assessment

1. INTRODUCTION

From the author's engineering experience, durability-related failures of bridge structures are most often associated not with insufficient strength, but with underestimated environmental degradation mechanisms.

Modern research in the field of reinforced concrete bridge design considers durability as a multi-level performance characteristic that defines the ability of a structure to maintain its functional and safety properties throughout the intended service life under the combined effects of environmental, operational, and anthropogenic factors [2], [4], [10]. In this context, durability is no longer treated as a secondary consequence of strength reserves, but rather as a governing design parameter influencing structural performance over time.

From a methodological perspective, durability should not be associated with individual empirical coefficients or isolated verification checks. Instead, it is more appropriately represented by an integrated system of models that jointly account for mechanical behavior, physicochemical degradation processes, and environmental exposure within a unified framework for service life assessment (Fig. 1).

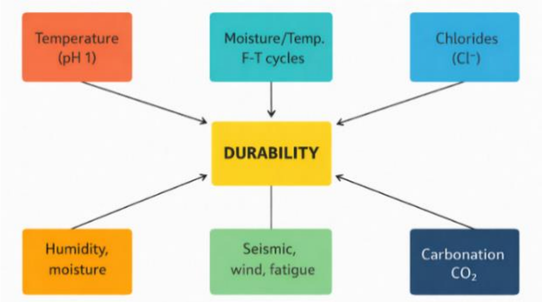

Fig. 1. Diagram of the influence of climatic and anthropogenic factors on durability

The methodology for assessing the durability and reliability of reinforced concrete bridges developed in this study integrates the following interrelated approaches:

Durability assessment methodology R(t), addressing the time-dependent degradation of concrete and reinforcement, including concrete strength reduction, carbonation, reinforcement corrosion, chloride diffusion, and the associated loss of cross-sectional area and elastic modulus. This methodology is based on the regulatory framework of EN 206, Eurocode EN 1992, and SP 63.13330.2018 and aims to answer the question: "How long can the structure retain its performance characteristics?"

Reliability assessment methodology S(t), focusing on limit states, reliability factors γ, probabilistic characteristics of loads and resistances, and the probability of failure over time. This approach relies on EN 1990, AASHTO LRFD, and GOST 27751-2014 and addresses the question: "What is the probability of failure-free structural performance throughout the service life?"

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Life Cycle Cost (LCC) methodology, which considers initial construction costs, operational expenses, maintenance and strengthening measures, as well as reconstruction and end-of-life processes. This methodology is based on life-cycle economic models and LCC/LCA principles and answers the question: “What is the total cost of the structure over its entire service life?”

Environmental efficiency assessment methodology $\Delta CO_2, K_{eco}$, addressing greenhouse gas emissions, material intensity, recycling potential, and resource efficiency within the framework of sustainable design principles and life-cycle environmental indicators. This methodology aims to answer the question: “To what extent is the design solution environmentally justified?”

By integrating these approaches, the proposed methodology for assessing the durability and reliability of reinforced concrete bridges is based on the combined application of four interconnected components: durability assessment R(t), reliability assessment S(t), life cycle cost evaluation (LCC), and environmental performance assessment $\Delta CO_2, K_{eco}$. Their joint application provides a comprehensive engineering, economic, and environmental justification for design decisions (Fig. 2).

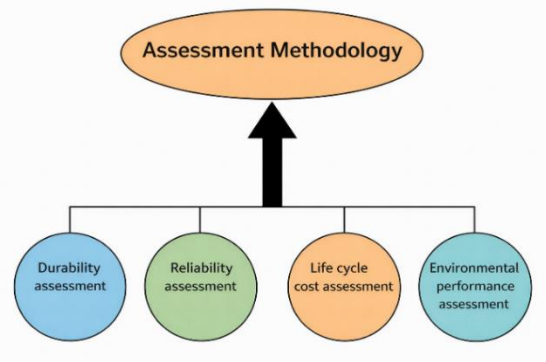

Fig. 2. Methodology for assessing the durability and reliability of reinforced concrete bridges

Classical approaches to durability assessment

Historically, durability considerations in bridge design were incorporated indirectly through safety factors and strength reserves. In national standards such as SHNK 2.05.03-22 [9] and Russian regulations including SNiP 2.05.03-84, SP 35.13330.2011, and SP 63.13330.2018 [8], durability was primarily associated with parameters such as concrete cover thickness, water resistance grade, frost resistance, and reinforcement type. This approach was essentially deterministic, with environmental conditions assumed to be constant and time-invariant.

While such design practices ensured compliance with safety requirements, they did not allow for a realistic prediction of the actual service life of bridge structures. In practical applications, this limitation often resulted in the need for repairs and strengthening measures well before the intended design life was reached, particularly in aggressive environments such as areas exposed to de-icing chemicals, coastal regions, and zones characterized by high temperatures and intense solar radiation.

2. MAIN PART

Regulatory framework for durability and reliability assessment

The assessment of durability and reliability of reinforced concrete bridges cannot be performed without reference to existing regulatory frameworks. European standards, such as EN 206 (Concrete – Specification, performance, production and conformity), establish fundamental requirements for concrete taking into account environmental exposure, strength, and serviceability [1]. Within bridge design practice in the European Union, Eurocode provisions play a central role, particularly EN 1990 (basis of structural design), EN 1991 (actions on structures), and EN 1992 (design of concrete structures). These documents enable the consideration of both structural safety and service life performance within a unified design framework [2]–[4].

The American approach is represented by the AASHTO LRFD Bridge Design Specifications, where structural reliability is assessed using probabilistic concepts based on limit state design principles [5]. In the post-Soviet regulatory space, SP 63.13330 governs the design and analysis of reinforced and prestressed concrete structures, addressing requirements related to durability, deformations, strength, and stiffness [11].

Contemporary concepts and international standards

International standards and guidelines, including FIB Model Code 2010, EN 206, ISO 15686, and AASHTO LRFD Bridge Design Specifications, have introduced a fundamentally new methodological paradigm known as Service Life Design. Within this framework, durability is treated as a design parameter equivalent in importance to strength and stability [1, 6, 11-15].

The key principles of this concept include:

- definition of the required design service life T_{design} depending on the structural category (typically 50, 75, or 100 years);
- identification of degradation stages:
- initiation stage (penetration of CO2, chlorides, and moisture);
- propagation stage associated with progressive reinforcement corrosion;
- ultimate limit state stage;
- evaluation of degradation parameters, such as diffusion coefficients, concrete cover thickness, and environmental aggressiveness;
- calibration of degradation models using inspection, monitoring, and diagnostic data.

According to ISO 15686-1 (2011, 2022) [7], durability is defined as “the ability of a component to perform its required functions over a specified period of time without unacceptable degradation of performance”. Consequently, durability becomes an explicit function of time and exposure conditions, forming the basis of modern service life-oriented design methodologies.

It should be emphasized that the presented standards differ not only formally, but also conceptually in their treatment of time-dependent degradation.

Integration of durability and reliability

The reliability of bridge structures is defined as the probability that a structure will maintain its load-bearing capacity and functional performance throughout the specified service life. From a methodological standpoint, the relationship between durability and reliability may be expressed as:

$$P_{\text{surv}}(t) = e^{-\lambda(t)},$$

where $P_{\text{surv}}(t)$is the probability of failure-free performance and λ(t)represents the degradation intensity as a function of environmental exposure and material properties.

In this context, durability can be interpreted as a time-integrated reliability indicator:

$$K_{\text{dur}}(t) = \frac{R_t}{R_0} = e^{-\alpha t},$$

where R_tis the residual load-bearing capacity at time t, and R_0is the initial capacity. This formulation enables the use of probabilistic time-dependent models that link limit state design with environmental degradation mechanisms.

Service life prediction methodologies

Within the methodological framework for durability assessment of bridge structures, three principal approaches are commonly applied:

Table 1

Main methodological approaches to the assessment of bridge durability

Approach	**Description**	**Advantages**
Deterministic	Use of normative environmental coefficients, water resistance and frost resistance grades	Simplicity, regulatory compatibility
Semi-probabilistic	Resource estimation using empirical relationships $R(t) = R_0 e^{-\alpha t}$ accounting for exposure category	Applicable in engineering practice, enables service life estimation
Probabilistic time-dependent (Service Life Design)	Modeling of diffusion, carbonation, fatigue, and limit state exceedance	Highest accuracy and flexibility; adopted in FIB and Eurocode

Service life design methodology integrates these approaches: semi-probabilistic analysis is typically applied at early design stages, while detailed probabilistic models are used for refined assessments and optimization.

Conceptual framework of durability-oriented design

In a generalized form, durability-oriented bridge design may be represented as a sequence of five key stages:

- classification of environmental exposure conditions (according to EN 206 and SHNK 2.05.03-22);
- specification of the design service life T_{design};
- time-dependent modeling of material degradation $E(t)$, $R(t)$, and K_{dur};;
- evaluation of failure probability $P_f(t)$and identification of governing limit states;
- optimization of design solutions with respect to durability, environmental performance, and economic efficiency.

Within this framework, durability emerges as a governing criterion of structural reliability, while reliability assessment becomes a quantitative tool for evaluating environmental impacts on long-term structural performance. This integrated approach constitutes the methodological basis for incorporating environmental effects into the design of reinforced concrete bridges.

In practical bridge design, the selection of an appropriate methodological level largely depends on data availability and the expected aggressiveness of the operating environment.

3. CONCLUSIONS

The conclusions of this study are based on a combination of regulatory analysis and engineering generalization of long-term bridge operation practices.

The systematization of methodological approaches to assessing the durability and reliability of reinforced concrete bridges presented in this paper allows several important conclusions to be drawn, which are relevant for both the scientific community and engineering practice.

First, the analysis of regulatory documents, including EN 206, Eurocodes (EN 1990–1992), AASHTO LRFD, SP 63.13330, FIB Model Code 2010 [6], and ISO 15686 [7, 13], demonstrates a clear international trend toward the transition from formal normative design to service life-oriented design methodologies. Unlike traditional deterministic approaches based on strength reserves and fixed design parameters (such as concrete cover thickness or frost resistance class), contemporary design concepts require explicit consideration of time-dependent material degradation and the integration of environmental effects into structural assessment models [12, 15].

Second, a key outcome of this study is the justification for adopting a multi-level methodological framework that includes:

- a deterministic level, ensuring compliance with existing regulatory requirements;
- a semi-probabilistic level, based on empirical relationships and engineering judgment;
- a probabilistic time-dependent level, incorporating models of carbonation, reinforcement corrosion, and fatigue degradation within the framework of limit states and failure probability analysis.

The integration of these levels provides a robust basis for predicting the residual service life of bridge structures and enables more substantiated engineering decisions during the design process.

Third, the results highlight the necessity of further harmonization between national regulations and international standards, particularly with respect to:

- classification of environmental exposure conditions (in accordance with EN 206 and ISO 15686);
- service life prediction using approaches adopted in FIB and Eurocode frameworks;
- implementation of diagnostics and Structural Health Monitoring (SHM) as an integral component of both design and operational management strategies.
- Overall, the proposed methodology makes it possible to:
- improve the accuracy of service life assessment for reinforced concrete bridges;
- enhance the efficiency of maintenance and rehabilitation planning;
- substantiate design decisions at both conceptual and detailed design stages;
- increase the adaptability of bridge structures to climatic variability and anthropogenic impacts.

Under conditions of increasing operational demands, economic constraints, and stricter sustainability requirements for infrastructure development, the development and implementation of integrated durability and reliability models should be regarded as a priority task for transport construction in Uzbekistan and other regions characterized by severe climatic conditions.

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