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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.

Modern Principles of Sustainable Bridge Design

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Abstract: This paper addresses modern principles of sustainable bridge design developed within the framework of the Sustainable Bridge Design concept. The analysis focuses on four key directions of the sustainable approach: environmental performance, reduction of carbon footprint, life-cycle management, and reuse of materials. Particular attention is paid to the integration of international standards (EN 206, Eurocode, AASHTO) and modern digital tools (BIM, LCA, digital twins) into bridge design, construction, and operation processes. Examples of life cycle assessment (LCA) and calculation of the eco-economic efficiency indicator (K_{exo}) are presented. A methodology for selecting design solutions considering climatic, operational, and socio-economic factors is proposed. The study is based on doctoral research aimed at promoting sustainable development of transport infrastructure in Uzbekistan.
Keywords: Sustainable design, bridge life cycle, carbon footprint, environmental efficiency, material reuse, K_{exo}, LCA, BIM, reinforced concrete bridges

1. INTRODUCTION

Under conditions of global climate challenges and the need for rational use of natural resources, the importance of a sustainable (environmentally oriented) approach to the design of engineering structures, including bridges, is steadily increasing (Fig. 1).

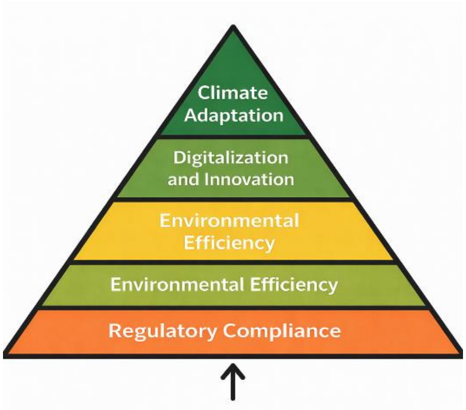

Fig. 1. Modern pyramid of sustainable bridge design

The figure illustrates a four-level methodological framework of modern sustainable bridge design based on principles of environmental responsibility, digital transformation, and climate adaptation.

Regulatory compliance forms the base of the pyramid and includes fulfillment of all applicable construction codes and standards such as SP 35.13330 [11], SP 63.13330 [8],, Eurocodes [1],[2],[3],[4], AASHTO [5],, and others. This represents the minimum acceptable level of design ensuring structural safety and functionality.

- reduction of CO_2 emissions;
- rational use of construction materials;
- application of LCA (Life Cycle Assessment) and LCC (Life Cycle Costing) principles;
- reduction of energy and water consumption throughout the bridge service life.

Digitalization and innovation involve the implementation of modern technologies to enhance design accuracy and monitoring:

- BIM and digital twins;
- structural health monitoring systems (SHM);
- automation of design solutions.

Climate adaptation, representing the top of the pyramid, reflects the transition to bridges capable of withstanding changing climatic conditions:

- temperature variations, intense precipitation, wind and seismic loads;
- durability of materials under aggressive environmental conditions;
- resilience margins against extreme and catastrophic impacts.

Traditional approaches focused solely on strength and operational characteristics are no longer sufficient for assessing bridge performance over the entire life cycle.

Figure 2 presents six key stages of the bridge life cycle in the form of a closed loop:

- Design – selection of structural system, materials, strength, durability, and environmental assessments;
- Construction – erection processes, technology selection, control of emissions and waste;
- Operation – traffic loads, condition monitoring, routine maintenance;
- Maintenance – scheduled and unscheduled strengthening, repairs, corrosion protection;
- Residual life assessment – diagnostics, inspections, durability forecasting;

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• Demolition / reconstruction – dismantling, reuse of materials, recycling, environmental restoration.

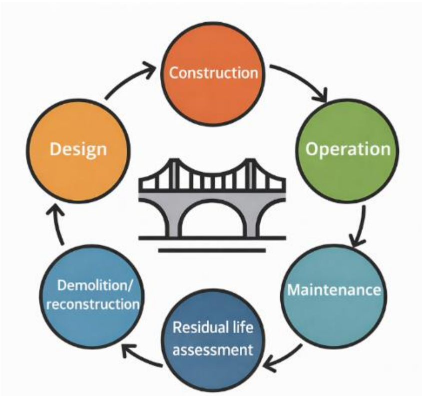

Fig. 2. Bridge life cycle

This diagram emphasizes the necessity of an environmental approach at all stages of the bridge life cycle, from design to demolition. Implementation of this approach enables application of LCA principles and Sustainable Design in bridge engineering.

Modern approaches to sustainable bridge design are based on reducing carbon footprint (CO_2), rational resource use, durability, and minimizing environmental impact throughout all stages—from design to dismantling. According to international standards (EN 206, ISO 14040, AASHTO LRFD), environmental performance is determined not only by energy consumption and emissions but also by the potential for reuse of materials and structures.

This paper presents a generalized approach to sustainable bridge design based on doctoral research, focusing on reinforced concrete structures of high-speed highway viaducts characteristic of Uzbekistan's transport infrastructure [4-7, 12-15].

2. MAIN PART

Methodological essence of the concept

In bridge engineering, sustainable design is interpreted as a decision-making methodology that minimizes total environmental impact while maintaining required levels of reliability, safety, and economic efficiency.

It integrates three fundamental components:

- Durability – the ability of a structure to maintain its performance throughout the design service life under climatic, seismic, and operational effects;
- Environmental performance – minimization of CO_2 emissions, energy consumption, and ecosystem impact;
- Economic performance – reduction of total costs related to construction, operation, and end-of-life stages (Life Cycle Cost, LCC).

Methodologically, these components are combined into an integrated efficiency criterion:

$$K_{\text{eff}} = K_{\text{dur}} \cdot K_{\text{env}} \cdot K_{\text{eco}}$$

where

K_{dur}– durability coefficient characterizing technical reliability;

K_{env}– environmental efficiency coefficient (ecological footprint);

K_{eco}– economic efficiency coefficient.

This approach allows bridge design to be treated as a multi-objective optimization problem, where each alternative is evaluated not only by load-bearing capacity but also by cumulative environmental and economic impacts.

2.2. Principles of sustainable bridge design

The sustainable design methodology includes a system of interrelated principles reflecting current scientific and regulatory trends (Table 1).

Table 1

Principles of sustainable bridge design

No.	Principle	Description
1	Life cycle thinking	Assessment of resource, cost, and environmental impact throughout the entire bridge life cycle
2	Low carbon design	Reduction of CO_2 emissions through optimized cement and steel production, use of RCA, slags, silica fume
3	Resource efficiency and reuse	Application of secondary materials, prefabricated and modular systems suitable for dismantling and recycling
4	Environmental compatibility of materials	Use of low-clinker concretes, stainless or composite reinforcement, environmentally safe coatings
5	Smart design	Use of BIM and digital twins for life-cycle management, degradation forecasting, and maintenance optimization
6	Climate adaptation	Consideration of rising temperatures, humidity changes, aggressive precipitation, and wind loads

These principles form the basis of a new engineering philosophy in which a bridge is viewed as a "living system" operating within a dynamic natural environment.

Quantitative assessment of environmental efficiency

Key tools of sustainable bridge design include Life Cycle Assessment (LCA) and Life Cycle Costing (LCC), providing quantitative evaluation of cumulative impacts and costs over the service life.

Environmental efficiency can be formally expressed as:

$$K_{env} = \frac{CO_{2,base}}{CO_{2,proj}}$$

where $CO_{2,proj}$ represents specific CO_2 emissions of the designed solution, and $CO_{2,base}$ corresponds to a conventional reference solution.

Lower values of $CO_{2,proj}$ indicate higher environmental efficiency.

In international practice, carbon footprint values for concrete range from 0.12–0.35 kg CO_2/kg, and for reinforcement steel from 1.8–2.1 kg CO_2/kg. For reinforced concrete bridges with optimized concrete composition and recycled materials, emission reductions of 25–30% are achievable.

Integration of environmental and engineering aspects

Methodologically, Sustainable Bridge Design integrates theoretical, analytical, and economic assessments into a unified system.

Environmental performance is not treated as an additional criterion but as an integral part of the design algorithm. A solution is considered optimal only when:

$$\max K_{eff} = f(K_{dur} \cdot K_{env} \cdot K_{eco})$$

This relationship enables multi-factor analysis of design alternatives, where durability, environmental safety, and economic efficiency are treated as equally important objectives.

Relevance for uzbekistan

Given Uzbekistan's climatic and operational conditions—hot climate, seismicity, humidity variations, and use of de-icing salts—the application of sustainable design principles is particularly important [9].

Key priority directions include:

- optimization of concrete composition and use of recycled aggregates;
- protection of reinforced concrete elements against carbonation and corrosion;
- reduction of energy consumption in construction material production;
- transition to digital life-cycle modeling of bridges (BIM + LCA).

Thus, sustainable bridge design becomes not an optional trend but a mandatory element of modern reinforced concrete bridge engineering, ensuring durability [10, 12-15], resilience, and socio-economic efficiency of transport systems.

3. CONCLUSION

Sustainable bridge design represents a key element of transport infrastructure development. Application of Sustainable Bridge Design principles makes it possible not only to reduce environmental impact but also to ensure durability, investment efficiency, and operational reliability. Integrated use of digital technologies, analytical models, and eco-economic indicators enables informed decision-making at early design stages. The methodology developed within the doctoral research framework can be successfully adapted for Uzbekistan and other regions with harsh climates, high traffic intensity, and the need to modernize aging infrastructure.

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CONTENT / MUNDARIJA