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**BRIDGES AND TUNNELS: THEORY, RESEARCH, PRACTICE**

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S. O. MELNYCHUK

Production Structural Subdivision “Track Service” of the Regional Branch “Lviv Railway”
of JSC “Ukrzaliznytsia”, 1 Hoholia St., Lviv, Ukraine, 79001, tel. +380 32 226 55 12,
e-mail seregamelnichuk18@gmail.com, ORCID 0009-0003-8755-9308

# RESULTS OF A COMPREHENSIVE ANALYSIS OF THE TECHNICAL CONDITION OF STEEL-CONCRETE COMPOSITE BRIDGES ON THE LVIV RAILWAY

**Purpose.** The purpose of the study is a comprehensive analysis of the actual technical condition of operated steel-concrete composite bridges based on the statistical processing of data for 2025. It is aimed at determining the nomenclature and quantitative indicators of existing defects, as well as identifying patterns in their distribution among key structural elements for use in subsequent scientific research and the development of scientifically substantiated recommendations for technical maintenance. **Methodology.** The research methodology is based on a systematic approach to assessing the operational reliability of transport structures using the method of documentary analysis, field visual and instrumental inspections, and comparative analysis. **Findings.** The results indicate that more than 66 % of the surveyed structures have been in operation for 60 to 80 years and are approaching the limit of their design service life. It has been established that the key catalyst for destructive processes is the deterioration of the waterproofing and drainage systems of the bridge deck, which in turn leads to constant water soaking, intense corrosion of steel girders, as well as freeze-thaw damage and leaching of the cement paste in the reinforced concrete slabs and pier bodies. **Originality.** For the first time, a comprehensive systematization and quantitative assessment of the technical condition of all operated steel-concrete composite bridges of the regional branch "Lviv Railway" was carried out. A clear cause-and-effect relationship was established between the degradation of bridge deck drainage systems and the development of specific damages to dissimilar materials under the conditions of the complex terrain and humid climate of the western region of Ukraine. **Practical value.** The practical significance of the study lies in obtaining data on the current technical condition of steel-concrete composite bridge structures to implement scientifically substantiated measures for the repair of elements and to create a basis for further scientific research related to the operation of these structures.

*Keywords:* steel-concrete composite bridge; bridge defects; visual and instrumental inspection; corrosion; waterproofing; bridge bearings; repair measures

## Introduction

The uninterrupted and safe operation of railway transport is a fundamental component of the state's economic stability and national security. In this context, the technical condition of engineering structures, particularly bridge crossings, is one of the determining factors limiting the throughput and carrying capacity of railway lines. This issue is of particular importance for the main routes of the Lviv Railway, which plays a strategic role as the primary transport corridor and link between the transport systems of Ukraine and the European Union countries. The growth of freight traffic volumes in the western direction and the increase in axle loads place heightened demands on the operational reliability of the existing infrastructure.

As of today, a significant number of steel-concrete composite bridges are operated on the sections of the Lviv Railway. At one time, this type of superstructure became widespread due to the rational combination of the physical and mechanical properties of the materials: the high tensile strength of steel and the compressive strength of concrete. However, the structural specificity of such bridges is manifested in the presence of a contact zone between dissimilar materials with different coefficients of thermal expansion and stiffness, which leads to the emergence of specific, and sometimes unique, types of deformations. Under the influence of intense dynamic (vibrational) train loads and the complex climatic conditions of the western region (frequent temperature fluctuations, high humidity), there is an accelerated accumulation of fatigue damage and material degradation. The timely detection and prevention of the development of such defects are impossible with-

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out regular monitoring and detailed instrumental inspections. Most of the existing structures are approaching the exhaustion of their design service life or are already operating beyond its limits, turning their maintenance into a complex engineering task. The issue of ensuring the reliability, durability, and safe operation of bridge structures on the transport network of Ukraine is a subject of constant attention from domestic and foreign researchers. An analysis of recent studies indicates a comprehensive approach to solving this problem, which encompasses both the study of the causes of material degradation and the implementation of new diagnostic methods.

Proper classification of damages is of critical importance for an objective assessment of the residual service life. Based on the results of field inspections conducted in the study (Трикоз, & Юрченко, 2021), the authors surveyed 118 reinforced concrete bridges on the railways of Ukraine and proposed a systematization of damages to railway reinforced concrete bridges and their numbering by types, incorporating the external signs of damages. It has been established that the most probable causes of defects and damage are the combined action of natural (alternate freeze-thaw, wetting-drying cycles) and anthropogenic (vibration, electrical currents) factors.

An important direction is the study of the processes of structural failure under the action of long-term operation and force majeure circumstances. In particular, the works of (Лучко, Кархут, & Кравець, 2021) analyze in detail the condition of bridges damaged by large-scale floods and the exhaustion of their service life. This allows for identifying the most vulnerable joints of superstructures and piers under extreme hydrological loads.

Currently, the assessment of the technical condition of bridge crossings is mostly based on visual inspections, followed by the distribution of objects according to a rating scale (Lima, Miller, & Doh, 2013). As practice shows, this method allows for classifying structures by their level of degradation and maintenance priority, which is particularly important in conditions of funding shortages, as described in the works of (Fujino, Siringoringo, & Abe, 2016; Tan, Qiu, & Liu, 2014). Although visual inspection remains the only accessible mass tool for accounting for real operational loads, it has significant drawbacks. First and foremost, this concerns the influence of the human factor and the complete inability to identify hidden damage within structural elements (Cunha, Caetano, Magalhães, & Moutinho, 2013).

As an alternative to traditional inspections, the modern scientific community actively proposes the concept of continuous instrumental monitoring (Structural Health Monitoring) (Comisu, Taranu, Boaca, & Scutaru, 2017). The integration of modern sensor networks allows recording key degradation processes in real-time, including: the development of reinforcing bar corrosion and concrete cover carbonation; the destructive impact of cyclic freezing and thawing; and the dynamics of changes in the stress-strain state (the appearance of deformations, crack opening, and vibrational oscillations). Researchers emphasize that the use of wireless and fiber-optic sensors (Lima, Miller, & Doh, 2013) not only minimizes the need for frequent site visits by expert teams but also allows for reducing the total costs of infrastructure maintenance throughout its life cycle by approximately 10 … 25 %.

From a global perspective, there is a tendency toward the regulation of monitoring systems at the state level. Countries with developed infrastructure have already implemented corresponding building codes and standards (Moreu, Li, X., Li, S., & Zhang, 2018). Thanks to this, a new design philosophy is being formed: intelligent monitoring systems become an integral part of the bridge even at the stage of creating its working project.

Despite the obvious advantages of the new systems, their large-scale deployment on the existing railway network is constrained by high costs and technical complexity. The problem of controlling the current technical condition becomes particularly acute during the operation of steel-concrete composite bridges under the specific conditions of the Lviv Railway. The combination of complex terrain, high humidity, and intense dynamic loads from rolling stock requires a special approach to monitoring the condition of such structures.

Considering the above, there is an objective need to develop a rational methodology that would harmoniously combine improved procedures for visual inspection with selective instrumental monitoring of the most critical joints in steel-concrete composite superstructures.

## Methodology and Finding

The current state of the bridge infrastructure of JSC “Ukrzaliznytsia”, and the regional branch

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"Lviv Railway" in particular, is characterized by a significant number of engineering structures whose service life is approaching or has already exceeded the design limit. A special place among them is occupied by steel-concrete composite bridges.

Figure 1. Constructed in the mid-twentieth century

It is known that the introduction of railway steel-concrete composite bridges on the territory of modern Ukraine began in 1949. At that time, on the main track sections of the Lviv Railway, which run through the complex terrain of the Carpathian Mountains (Figure 2), 18 riveted superstructures with spans ranging from 27 to 42 meters were installed.

Figure 2. Steel-concrete composite viaduct
in the mountainous terrain of the Carpathians

A structural feature of these bridges was the inclusion of a reinforced concrete ballast trough (with ribs up to 60 cm high) into composite action with metal riveted girders using shear connectors (Figure 3), which were welded after the girders were installed in the span.

The main advantage of such a composite system is the compression of the reinforced concrete slab during the bending of the steel girders. This engineering solution made it possible to significantly reduce the cross-sectional area of the upper steel flanges of the girders, increase the overall horizontal stiffness of the superstructure, and achieve steel savings of 12 … 18 %.

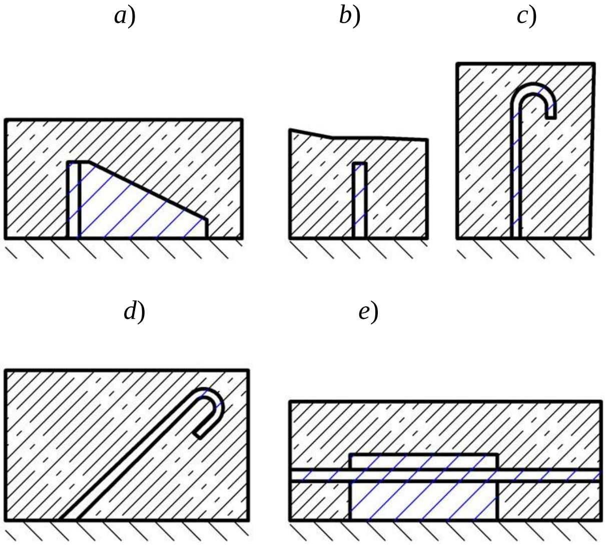

Figure 3. Types of shear connectors
*a*) rigid connector, *b*) flexible connector, *c*) anchor,
*d*) inclined anchor, *e*) longitudinal reinforcement
welded to the steel structure

According to current data, 2679 bridges are registered on the balance of the track maintenance divisions of the regional branch. The structure of the bridge infrastructure by construction material (Figure 4) is as follows: reinforced concrete – 2096 units, metal – 402 units, stone – 130 units, mixed – 33 units, wooden – 18 units.

The distribution of Lviv Railway bridges by length in kilometers is also presented (Figure 5).

Special attention is required for steel-concrete composite bridges located on strategic routes of freight and passenger traffic (Figure 6). As of today, 36 such structures are in operation, which accounts for 9 % of the total number of metal bridges in the regional branch.

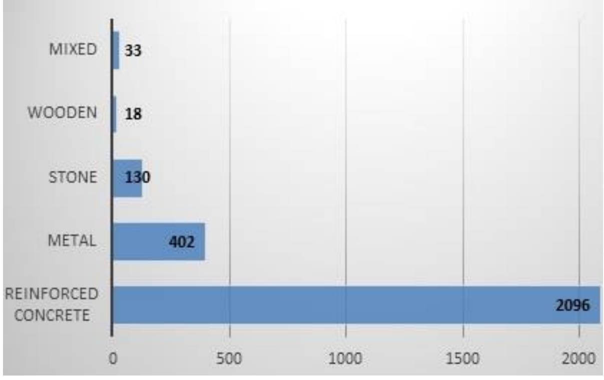

Figure 4. Distribution of the number of bridges
by construction material
in the regional branch "Lviv Railway"

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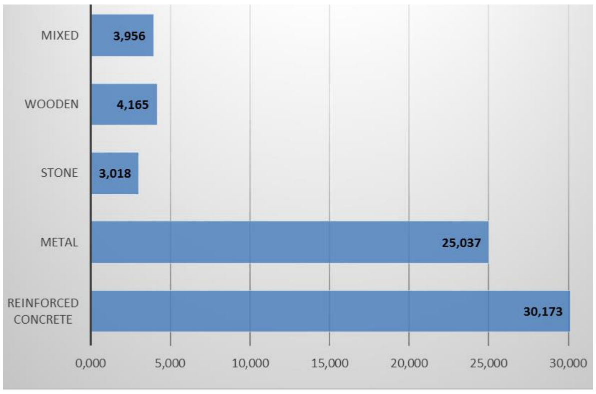

Figure 5. Distribution of the number of bridges by length in the regional branch "Lviv Railway"

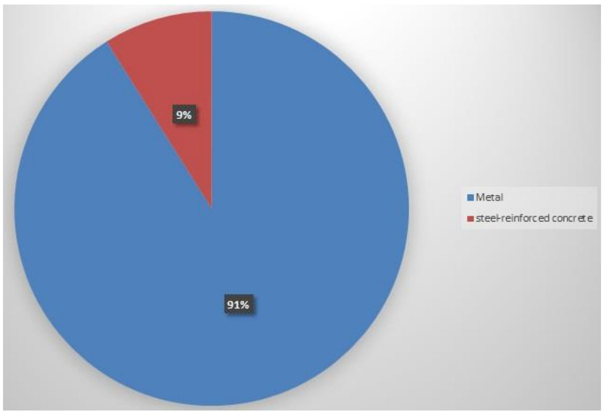

Figure 6. Distribution of metal bridges in the regional branch "Lviv Railway"

Considering the time of their mass implementation, the age structure of these structures (Figure 7) is a critical factor for analyzing their reliability: 70–80 years – 17 structures (the largest group operating beyond its design service life); 60–70 years – 3 structures; 50–60 years – 7 structures.

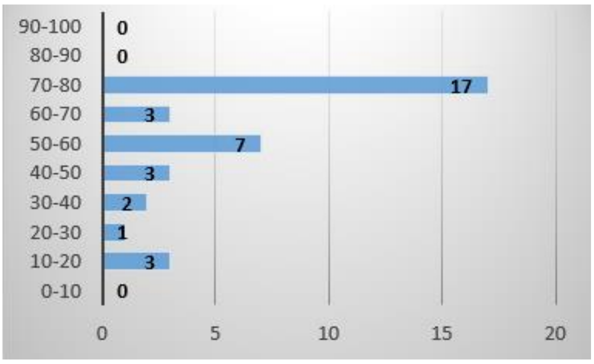

Figure 7. Age distribution of steel-concrete composite bridges in the regional branch "Lviv Railway"

Analyzing the distribution, it is evident that the largest number of structures aged 70–80 years comprises 17 bridges; those aged 50–60 years comprise 7 structures, and those aged 60–70 years comprise 3 structures.

The processes of operational maintenance, technical condition diagnostics, and defect identification of engineering structures in the divisions of JSC "Ukrzaliznytsia" are strictly regulated by the relevant regulatory framework. In particular, the algorithm and rules for conducting inspections are established by the norms of ДБН В.2.3-6:2009 (2009). The comprehensive criterion for the reliability of a structure is its operational condition, which is calculated through a system of average scores in accordance with the requirements of the industry standard СОУ 45.120-00034045-015:2012 (2012). Depending on the results obtained from such an assessment, according to Instruction ВНДУЗ 32.2.04-015-2013 (2013), a specific list of repair and preventive measures aimed at restoring or improving the operational characteristics of the bridge is assigned.

It should also be noted that the administrative boundaries of the Lviv Railway encompass territories with highly diverse physical-geographical and climatic conditions. A particularly severe operational regime is observed in mountainous areas (Zakarpattia and Ivano-Frankivsk regions), where bridges are exposed to high humidity, intense precipitation, and sharp daily temperature fluctuations (±20 °C). Such conditions act as a catalyst for the accelerated development of corrosion processes in the metal, temperature-induced degradation of the concrete, and the accumulation of fatigue damage.

During the inspection of 36 steel-concrete composite bridges, the identified defects were classified by codes in accordance with the aforementioned regulatory documents. The defects were systematized according to the main structural elements: bridge deck, superstructure, bearings, bridge piers, watercourses, and operational equipment. Quantitative analysis showed that the most vulnerable element, where the largest nomenclature of damages is concentrated, is the superstructures.

The number of identified defect types in the elements of the steel-concrete composite bridges (Figure 8) subjected to inspection within the scope of the study is presented above. The defect types are classified by codes in accordance with СОУ 45.120-00034045-015:2012 (2012). It was established that the largest number of defect types was found in the bridge superstructures.

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The bridge deck is the first to absorb the dynamic loads from the rolling stock and the impact of atmospheric factors (Figure 9).

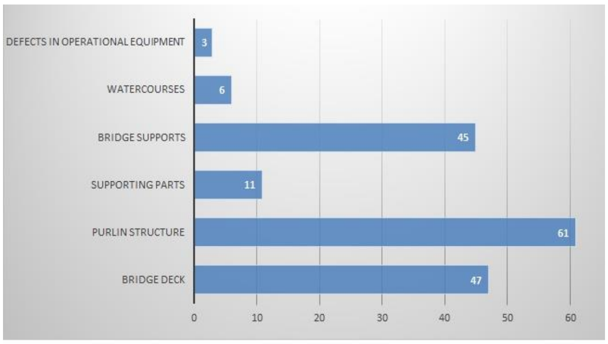

Figure 8. Distribution of the number of defect types in the main elements of steel-concrete composite bridges of the regional branch “Lviv Railway”

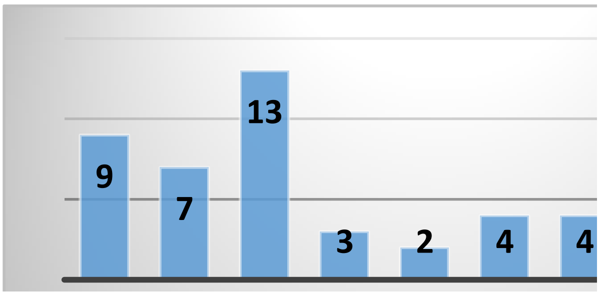

Figure 9. Distribution of the number of bridge deck defects by СОУ 45.120-00034045-015:2012 (2012)

Figure 10. Defective reinforced concrete sidewalk blocks: leaching and deterioration of concrete, cracks, spalling

Among the surveyed structures, the following dominant defects were recorded:

Code 2.1.213 (Defective reinforced concrete sidewalk blocks: leaching and deterioration of concrete, cracks, spalling) (Figure 10) was detected on 13 structures. This indicates the low quality or aging of the waterproofing in the sidewalk zone.

Code 2.2.72 (Defective sleepers, three or more in a row) (Figure 11) was recorded on 9 structures, which poses a threat to traffic safety due to possible track gauge widening.

Figure 11. Defective sleepers (three or more in a row)

Code 2.2.20 (Defective rails on the bridge and its approaches) (Figure 12) was detected on 7 structures.

The superstructure is the most loaded element, the condition of which directly determines the load-bearing capacity of the bridge.

Figure 12. Defective rails on the bridge and its approaches

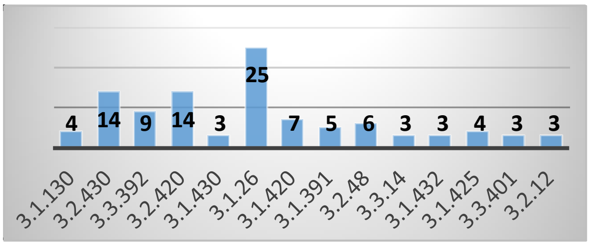

Figure 13. Distribution of the number of superstructure defects by СОУ 45.120-00034045-015:2012 (2012)

Analysis of the inspection reports revealed a clear cause-and-effect relationship between drainage system failures and material degradation:

Code 3.1.26 (Defective or missing drainage pipes) (Figure 14) is the most widespread defect, recorded on 25 structures. Prolonged water soaking of the structures is the root cause for the development of subsequent damages.

Figure 14. Defective or missing drainage pipes

Codes 3.2.420 (Figure 15) and 3.2.430 (Figure 16) (Freeze-thaw damage to concrete and leaching of cement paste) were detected on 14 structures. Water that is not drained from the bridge deck penetrates the body of the reinforced concrete slab, washes out the cement gel, and, upon freezing, ruptures the concrete structure.

Figure 15. Freeze-thaw damage to concrete

Figure 16. Leaching of cement paste

Code 3.3.392 (Lack of freedom of movement) (Figure 17) was recorded on 9 structures with spans exceeding 23 m.

Figure 17. Lack of freedom of movement

The abutting of superstructures against each other or against the abutment backwall causes additional unaccounted thermal stresses, which can lead to the shearing of anchors (flexible or rigid shear connectors) that integrate the steel and concrete.

The condition of the bridge bearings critically affects the correct transfer of loads to the supports.

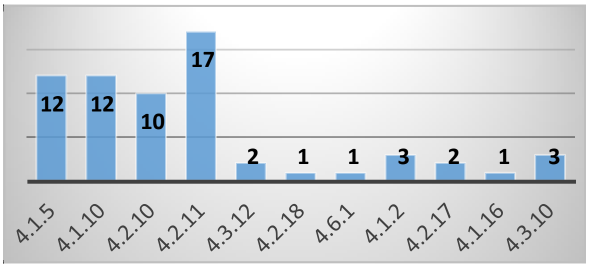

Figure 18. Distribution of the number of bridge bearing defects by СОУ 45.120-00034045-015:2012 (2012)

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Among the 36 bridges, the following specific defects were identified:

Code 4.2.11 (Undercutting of anti-creep teeth) was detected on 17 structures. This defect is a direct consequence of the jamming of the bridge bearings or the exceeding of the design longitudinal displacements of the superstructure (which correlates with defect 3.3.392).

Figure 19. Undercutting of anti-creep teeth

Code 4.1.10 (Deviation from the design relative position of the rocker and the base plate) – 12 structures.

Code 4.1.2 (Loose bearing of the superstructure or bridge bearings) – recorded on 3 bridges, which causes dynamic impact effects during the passage of trains.

Figure 20. Deviation from the design relative position of the rocker and the base plate

Figure 21. Loose bearing of the superstructure or bridge bearings

The lower part of engineering structures (the pier body) is also subject to the significant influence of water and temperature factors.

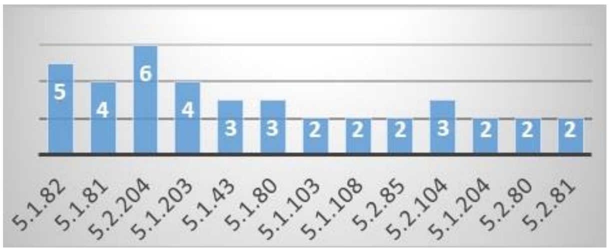

Figure 22. Distribution of the number of bridge pier defects by SOU 45.120-00034045-015:2012 codes

The most common defects are identical to the problems found in superstructures:

Code 5.2.204 and 5.1.82 (Freeze-thaw damage to the concrete of reinforced concrete and concrete abutment structures, respectively) were identified on 11 structures in total.

Figure 23. Freeze-thaw damage to the concrete of reinforced concrete abutments

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Figure 24. Freeze-thaw damage to concrete of reinforced concrete structures

Code 5.1.203 (Leaching of cement paste) was recorded on 4 structures, which is often a consequence of water leaking from defective superstructure drainage systems onto the bearing pedestals and the pier body.

Figure 25. Leaching of cement paste

There are also defects in operational equipment and watercourses. This group of defects does not have a direct instantaneous impact on the load-bearing capacity; however, it complicates the proper maintenance of the structures.

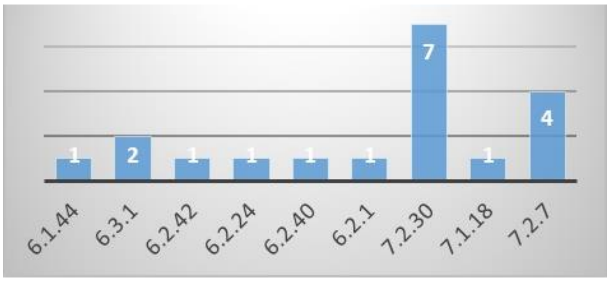

Figure 26. Distribution of the number of bridge watercourse and operational equipment defects by СОУ 45.120-00034045-015:2012 (2012)

Among the 36 bridges, the following specific defects were identified:

Code 7.2.30 (Absence or malfunction of inspection devices) was detected on 7 bridges, making high-quality regular inspections impossible.

Code 7.2.7 (Presence of utilities on sidewalks and railings) was found on 4 structures.

Code 6.3.1 (Riverbed scour) was recorded on 2 structures, requiring constant hydrological monitoring to prevent undermining of pier foundations.

Elimination of the identified defects and enhancement of the durability of steel-concrete composite bridges requires the development of a clear restoration algorithm. According to the basic provisions of the Правила технічної експлуатації (1997), structures must be maintained in a condition that guarantees the uninterrupted and safe passage of trains at established speeds. In accordance with the methodology of ДБН В.1.2-14:2018 (2018), a complex of measures is assigned depending on the damage category, the determined operational state of the structure, and the assessment of its residual service life.

Taking into account the specific operation of steel-concrete composite superstructures and the results of the analysis of recorded defects, priority repair measures are regulated by the Instruction for the Maintenance of Engineering Structures (ВНДУЗ 32.2.04-015-2013 (2013)) and modern building codes.

Since the root cause of the vast majority of damages is unsatisfactory drainage, the priority task is to localize the impact of moisture. In accordance with the requirements of ДБН В.2.3-22:2009 (2009) and ДБН В.2.3-6:2009 (2009), complete restoration or replacement of the destroyed waterproofing layer of the ballast trough (defect 2.1.213) using modern roll or mastic waterproofing materials is envisaged. Defective drainage pipes (defect 3.1.26) are subject to mandatory cleaning or replacement, and their length must be sufficient to drain water beyond the metal elements of the main girders.

Furthermore, to eliminate the consequences of freeze-thaw damage and concrete destruction (defects 3.2.420, 5.2.204), the restoration technology must comply with the requirements of the harmonized standard series ДСТУ EN 1504 (серія стандартів).

The technological process includes mechanical cleaning of damaged areas to sound concrete, anticorrosion treatment of exposed reinforcement, and

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restoration of the protective layer. The use of special non-shrink repair mortars on a polymer-cement basis (class R3 or R4) or the application of the shotcreting method is recommended to ensure high adhesion, frost resistance, and water resistance of the restored areas.

In particular, to stop the corrosion processes of the steel elements of superstructures, it is necessary to perform periodic renewal of protective coating systems, guided by the provisions of ДСТУ Б В.2.6-193:2013 (2014). The work must be preceded by thorough abrasive blast cleaning of the metal from rust and old paint to degree Sa 2.5 (in accordance with the international standard ISO 8501-1). In cases where local corrosion has led to a critical reduction in the working cross-sectional area of elements beyond regulatory tolerances, an individual structural reinforcement project is developed.

## Originality and practical value

For the first time, a comprehensive systematization and quantitative assessment of the technical condition of all operated steel-concrete composite bridges of the regional branch "Lviv Railway" was carried out. A clear cause-and-effect relationship was established between the degradation of bridge deck drainage systems and the development of specific damages to dissimilar materials under the conditions of the complex terrain and humid climate of the western region of Ukraine. The practical significance of the study lies in obtaining data on the current technical condition of steel-concrete composite bridge structures to implement scientifically substantiated measures for the repair of elements and to create a basis for further scientific research related to the operation of these structures.

## Conclusions

As a result of a comprehensive study of the technical condition of 36 operational steel-concrete composite bridges of the Lviv Railway, a detailed analysis of the distribution of operational defects across the main structural elements was performed. The analysis revealed that degradation processes are largely initiated at the bridge deck level, where mass failure of sidewalk block concrete and bridge sleeper defects are recorded.

Further investigation of superstructures and piers established that the primary root cause of most damages is a critical failure of drainage systems (missing or defective drainage pipes were identified on 25 structures). This leads to constant water soaking, intense freeze-thaw damage, and leaching of cement paste from the reinforced concrete slabs and pier bodies, as well as provoking progressive corrosion of the steel main girders. This situation is significantly complicated by identified malfunctions in the kinematics of bridge bearings (specifically, the undercutting of anti-creep teeth on 17 bridges and rocker deviations), which blocks free thermal movements of the superstructures and generates dangerous additional stresses in the critical nodal zone of the steel-to-concrete interface.

Based on the synthesis of these field and documentary data, a set of regulatory-based repair measures was developed. These primarily require the complete localization of moisture influence by restoring waterproofing and drainage devices in accordance with the requirements of ДБН В.2.3-6:2009 (2009). Following the elimination of the causes of soaking, the developed measures involve performing structural repair of damaged concrete using special non-shrink polymer-cement mortars or the shotcreting method according to ДСТУ EN 1504 (серія стандартів), as well as abrasive blast cleaning and renewal of anti-corrosion protection systems for metal structures per ДСТУ Б В.2.6-193:2013 (2014).

Given the significant age of the engineering structures and limited funding under martial law, it is advisable to orient future scientific research toward the development and implementation of intelligent continuous automated monitoring systems. This will facilitate the transition from reactive repairs to predictive bridge maintenance, alongside the mandatory adjustment or replacement of worn bridge bearings with modern analogs to restore the correct spatial behavior of steel-concrete composite structures and safely extend their residual service life.

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С. О. МЕЛЬНИЧУК

Виробничий структурний підрозділ «Служба колії» регіональної філії «Львівська залізниця»
АТ «Укрзалізниця», вул. Гоголя, 1, Львів, Україна, 79001, тел. +380 32 226 55 12,
ел. пошта seregamelnichuk18@gmail.com, ORCID 0009-0003-8755-9308

# РЕЗУЛЬТАТИ КОМПЛЕКСНОГО АНАЛІЗУ ТЕХНІЧНОГО СТАНУ СТАЛЕЗАЛІЗОБЕТОННИХ МОСТІВ НА ЛЬВІВСЬКІЙ ЗАЛІЗНИЦІ

**Мета.** Мета дослідження полягає у комплексному аналізі фактичного технічного стану експлуатованих сталезалізобетонних мостів на основі статистичної обробки даних за 2025 рік та спрямована на визначенні номенклатури та кількісних показників наявних дефектів, а також на виявлення закономірностей їх розподілу між ключовими елементами споруд для використання в наступних наукових дослідженнях та для розробки науково обґрунтованих рекомендацій щодо технічного обслуговування. **Методика**. Методика дослідження ґрунтується на системному підході до оцінки експлуатаційної надійності транспортних споруд з використанням методу документального аналізу, натурних візуальних та інструментальних обстежень та порівняльного аналізу. **Результати.** Результати свідчать, що понад 66 % досліджених споруд експлуатуються від 60 до 80 років і наближаються до межі свого розрахункового ресурсу. Встановлено, що ключовим каталізатором руйнівних процесів є порушення систем гідроізоляції та водовідведення мостового полотна, що в свою чергу призводить до постійного замокання, інтенсивної корозії сталевих балок, а також розморожування і вилуговування цементного каменя залізобетонних плит та тіла опор. **Наукова новизна.** Вперше проведено комплексну систематизацію та кількісне оцінювання технічного стану всіх експлуатованих сталезалізобетонних мостів (36 споруд) регіональної філії «Львівська залізниця» та встановлено чіткий причинно-наслідковий зв'язок між деградацією систем водовідведення мостового полотна та розвитком специфічних

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пошкоджень різнорідних матеріалів в умовах складного рельєфу та вологого клімату західного регіону України. **Практична значимість**. Практичне значення дослідження полягає у отриманні даних щодо актуального технічного стану сталезалізобетонних конструкцій мостів з метою впровадження науково обґрунтованих заходів з ремонту елементів та створення базису для проведення подальших наукових досліджень пов'язаних з роботою даних споруд.

*Ключові слова:* сталезалізобетонний міст; дефекти мостів; візуально-інструментальне обстеження; корозія; гідроізоляція; опорні частини; ремонтні заходи

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