ISSN 2413-6212 (Online), ISSN 2227-1252 (Print)
Bridges and tunnels: theory, research, practice, 2025, № 28

BRIDGES AND TUNNELS: THEORY, RESEARCH, PRACTICE

UDC 625.745.1:[620.172:624.012.3/.4]

V. V. KOVALCHUK[1*], M. P. KOVAL[2], O. I. RYKOVTSEV[3]

[1*] Department of Railway Transport, Lviv Polytechnic National University,
12 Bandery St., Lviv, Ukraine, 79000, tel. +38 (097) 223 72 43,
e-mail kovalchuk.diit@gmail.com, ORCID 0000-0003-4350-1756
[2] Department of Highways and Bridges, Lviv Polytechnic National University,
12 Bandery St., Lviv, Ukraine, 79000, tel. +38 (050) 132 44 14,
e-mail maksym.p.koval@gmail.com, ORCID 0000-0003-1244-1738
[3] Department of Bridges and Tunnels and Hydrotechnical Structures, National Transport University,
1 Mykhaila Omelianovycha-Pavlenka Str. Kyiv, Ukraine 01010, tel. +38 (063) 422 00 90,
e-mail rykovtsevoleksii@gmail.com, ORCID 0009-0001-1715-6058

EVALUATION OF THE EFFECTIVENESS OF BRIDGE BEAMS STRENGTHENING WITH EXTERNAL REINFORCEMENT, ADHERED WITH METHYL METHACRYLATE COMPOSITIONS, BASED ON THE RESULTS OF DYNAMIC TESTS

Purpose. The purpose of the work is to obtain objective data on the performance of the reinforced concrete bridge span structure before and after strengthening the main beams with external reinforcement adhered with methyl methacrylate compositions, as well as to analyze them and evaluate the effectiveness of the selected strengthening method. **Methodology**. The use of methyl methacrylate compositions is a promising direction not only in the repair of reinforced concrete bridge structures, but also in their strengthening. The research methodology is based on measuring the vertical deflections of concrete bridge beams before and after strengthening with external reinforcement adhered with methyl methacrylate compositions using modern equipment, followed by comparison of these deflections and determination of the selected strengthening method effectiveness. **Findings**. The results of dynamic tests showed that external reinforcement, adhered with methyl methacrylate compositions, entered the joint work with concrete beams, increased the overall stiffness of the span structure, and significantly reduced its deformability: the maximum deflections of beams decreased by 26 to 52 %, with an average decrease of 41 %. The use of methyl methacrylate compositions in transport construction deserves further theoretical and practical research in order to establish the characteristics of the stress-strain state of structures repaired and strengthened using these compositions under various loading and operating conditions. **Originality**. For the first time experimental data were obtained on the deflection of reinforced concrete bridge beams before and after reinforcement with external reinforcement, adhered with methyl methacrylate compositions, under dynamic loading, which made it possible to evaluate the effectiveness of this strengthening method. **Practical value**. The practical significance of the study lies in obtaining objective scientific data on the performance of concrete bridge structures, strengthened with external reinforcement, adhered with methyl methacrylate compositions, drawing conclusions about the prospects of this strengthening method, and determining the need for further research.

Keywords: dynamic testing; external reinforcement; methyl methacrylate composites; reinforced concrete beams; strengthening of reinforced concrete beams; road bridge

Introduction

The technical condition of transport structures operated on railways and highways in Ukraine plays an important role in ensuring the smooth transportation of goods and passengers. However, during exploitation, damage and defects of various origins occur in the tension zone of reinforced concrete beams of bridge span structures (Luchko, Sulym & Kyrian, 2004; Luchko & Raspopov, 2011; Luchko, 2021). This reduces the bearing capacity and durability of bridges.

The development of cracks in reinforced concrete bridge elements not only increases the possibility of corrosion processes on the surface of metal reinforcement, but also, in many cases, causes the loss of adhesion (anchoring) of reinforcing elements in concrete. In prestressed reinforced concrete beams, this leads to compressive force reduction in the beam belts and their crack resistance decreasing. In all reinforced concrete structures, this leads to a reduction in bearing capacity and an increase in deformability due to a decrease in cross-sectional stiffness caused by a loss of integrity. These problems create a need for repair and strengthening of bridge structures.

When repairing reinforced concrete elements, injection impregnation methods are most effective, as they allow cracks to be filled and the integrity of the repaired element to be restored. However, if the bearing capacity of the repaired element is insufficient, new cracks may form outside the area of the sealed cracks and parallel to them (Kovalchuk, Parneta, & Rybak, 2024). Therefore, it is advisable to combine repair methods with strengthening, one of the well-known methods of which is to deploy new reinforcing elements in the cross-section of the structure, which are joined to the strengthened structure by a connecting array, for example, cement concrete. Various versions of this method are used to strengthen reinforced concrete bridge spans (Р В.3.2-218-03450778-741:2008, 2008). The method involving the addition of extra bars around the new concrete mass has a drawback: it's difficult to make sure the added elements work well with the reinforced structure. This can be avoided by strengthening reinforced concrete structures with external reinforcement using metal elements (Р В.3.2-218-03450778-480:2005, 2005), which are joined to the strengthened element using cement or polymer concrete, and act as permanent formwork during construction and as external (tangential) working reinforcement during operation, placed most effectively along the outer edges of the elements, where tensile stresses are greatest. This placement of external reinforcement allows for a reduction in the weight of the structure or steel economy of up to 12 … 16% at the same height compared to reinforced concrete structures with conventional bar reinforcement. (Klymenko, 2001). This method, for example, was used to reinforce a defective concrete culvert using a reinforcement cage and a metal sleeve filled with concrete mortar. (Rybak, Kovalchuk, Parneta, & Karnakov, 2024; Parneta, Kovalchuk, & Rybak, 2024).

The effectiveness of concrete elements reinforced with external sheet reinforcement is ensured by the reliable and complete inclusion of external reinforcement across the entire area in conjunction with the structure. This is difficult to achieve when using conventional heavy concrete without installing additional anchoring devices (Bieliaieva, 2006). This problem can be solved by gluing external reinforcement to concrete, for which various adhesives are used in the construction industry, in particular acrylic adhesives (Shutenko, Zolotov, Harbuz, & Zolotov, 2001), which are applied to the external reinforcement before laying the cement-concrete mixture on it (Lapenko, 2009). In Ukraine, the usage of polymer compositions based on acrylates under the collective name "acrylic adhesives" is well known. The possibilities of fixing anchors and embedded parts in concrete using adhesive (Saliychuk, 2011) were studied, as well as the strength, deformability, and destruction characteristics of glues under various types of loading (Zolotov, 2009), as well as research on the fatigue strength of acrylic glue under dynamic loads (Zolotov, 2008) and the viability of glue depending on its composition and various factors (Zolotov, 2010). These studies have made it possible to create effective glue compositions with good deformation characteristics.

Since 2017, a methyl methacrylate based composition has been used in Ukraine for the repair of reinforced concrete bridge elements using the injection impregnation method. This composition is widely used in the restoration of concrete structures of various buildings (МР В.2.3-37641918-888:2017, 2017). This composition is a low-viscosity liquid which, after filling the free space between the sand grains due to the capillary effect, is easily absorbed into the concrete of the reinforced structure to a depth of 2 … 20 mm (depending on the strength class and density of the concrete), filling pores, cracks, cavities, and other discontinuities, forming a monolithic waterproof structure inside the pore space after polymerization (Dhibar, Mallick, Rath, & Khatua, 2009). The features of this composition are used in a method for strengthening reinforced concrete bridge structures with metal elements that are bonded to the reinforced element using polymer concrete (Patent Ukrajiny № 148024): polymer concrete consists of sand impregnated with a polymer composition based on methyl methacrylate (methacrylic acid ester) (Rykovtsev, & Kovalchuk, 2024; Kovalchuk, Sobolevska, Onyshchenko, et al., 2021). The reliability of the adhesion is ensured by high adhesive properties with the concrete of the reinforced structure and with external steel reinforcement in the form of permanent formwork. In addition, methyl methacrylate based polymer concretes have a high setting speed – in a temperature range from minus 30 °C to plus 40 °C, a strength of up to 80 MPa can be achieved in 1.5 … 2 hours.

The results of the literature review indicate the theoretical effectiveness of using methyl methacrylate (MMA) based compositions to strengthen reinforced concrete structures; therefore, obtaining objective scientific data on real objects is important for confirming theoretical assumptions.

Purpose

The purpose of the work was to conduct dynamic tests of the reinforced concrete bridge span structure before and after strengthening the main beams with external reinforcement bonded with methyl methacrylate compositions, as well as to analyze the results of these tests with an assessment of the effectiveness of the selected strengthening method.

Methodology

The tested highway bridge (Fig. 1) is located at km 4+014 of the M-10-01 highway (Western Bypass of Lviv) and crosses a double-track electrified railway. The bridge, with a carriageway width of 10 m and two sidewalks 1.5 m wide, was built in 1957 as a simple beam, four-span, prefabricated reinforced concrete structure. The first, second, and fourth spans are constructed of prestressed reinforced concrete I-beams according to the standard VTP-16 design (14 beams in cross section) with a length of 16.76 m and a height of 0.9 m. In the third span, above the railway, the span structure is constructed from 12 pre-stressed slabs with cylindrical voids (standard VTP-21 design or equivalent) with a length of 18 m. According to the results of an inspection conducted in 2019, a number of defects were identified, resulting in the bridge being given a rating of *E*=29 points, which corresponds to operational condition 5 – inoperable.

Fig. 1. Left facade of the tested bridge

The typical VTP-16 design is one of the most dangerous in terms of unpredictability of operational condition – the so-called prestressed concrete beams. Pre-stressed beams are reinforced with wire strings – thin wires with a diameter of 3 or 5 mm. Due to the presence of longitudinal joints between the prefabricated beams and the primitive design of the bridge deck, all prestressed concrete beams were soaking wet throughout their entire service life. The outer beams were the most actively soaking – two on each side in each span. As a result, the reinforcement strings of the beams actively corroded, became exposed, and broke off (Fig. 2).

As part of emergency measures carried out on behalf of the Road Service in Lviv Region by LLC "VK "REMM", the beams affected by defects were strengthened – two beams on each side in three spans, 12 beams in total.

Fig. 2. View of broken strings in beam B-13, span 3-4

The strengthening, which was carried out without completely closing the bridge to traffic, was performed using U-shaped boxes (Fig. 3) made of 8 mm thick S235 steel, fixed to the beams by a system of vertical (along the length of the span) and inclined (in the support areas) ties with a gap of 20 mm between the box and the beam. Washed and dried quartz sand was poured into the space between the beam and the box, which was then compacted by vibration and impregnated with an MMA-based polymer composition.

As a result of polymerization, a polymer concrete mass with high adhesive properties was formed, which bonded the box to the concrete of the beam. In addition, thanks to its low viscosity, the MMA composition penetrated into cracks, impregnating and bonding the concrete and preserving the corroded reinforcement bars. The quality of the polymer concrete mass was checked by tapping

ISSN 2413-6212 (Online), ISSN 2227-1252 (Print)
Bridges and tunnels: theory, research, practice, 2025, № 28

the boxes across the area, during which no dull sounds were detected that would indicate the presence of voids or areas not filled with polymer concrete.

Fig. 3. View of strengthened beams B-13 and B-14, span 3-4

The effectiveness of span structure strengthening can be assessed by comparing its deflections before and after strengthening under the same or comparable load. Static tests are ideal for this purpose, but the Western Bypass of Lviv is a road with high traffic intensity, and prolonged closure of traffic on it is impossible. In this regard, the authors decided to conduct dynamic tests, which consisted of driving a test load – KrAZ vehicles with a gross weight of 13 tons (Fig. 4) – across the bridge one after another at speeds of 20 km/h and 10 km/h, as well as 40 km/h and 30 km/h.

Fig. 4. Passage of a KrAZ truck in the left lane of the bridge

Dynamic tests were performed in spans 3-4 in two stages: before and after the reinforcement of the outer beams. At each stage, the same patterns of KrAZ truck passage and placement of measuring equipment were used (Fig. 5).

To measure vertical deformations during dynamic bridge tests, an E14-140-M analog-to-digital converter, an ADXL 335 high-frequency root sensor, a potentiometric linear displacement sensor, digital clock-type indicators, and a Lenovo personal computer were used (Fig. 6). Specialized software was used to store and back up the obtained data, process it, and visually reproduce it. This software allows for the collection, visualization (real-time viewing), recording (digital storage), and export of analog signals received from various data collection devices

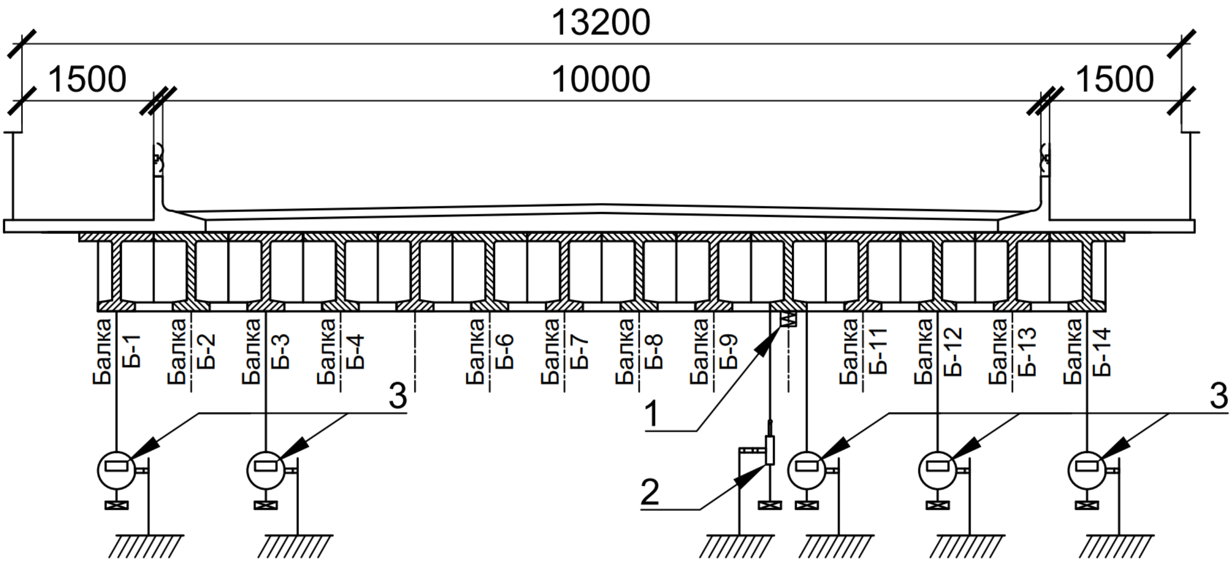


Fig. 5. Layout of switchgear: 1 – ADXL 335 acceleration sensor;
2 – potentiometric linear displacement sensor; 3 – digital clock-type indicators

ISSN 2413-6212 (Online), ISSN 2227-1252 (Print)
Bridges and tunnels: theory, research, practice, 2025, № 28

a) b)

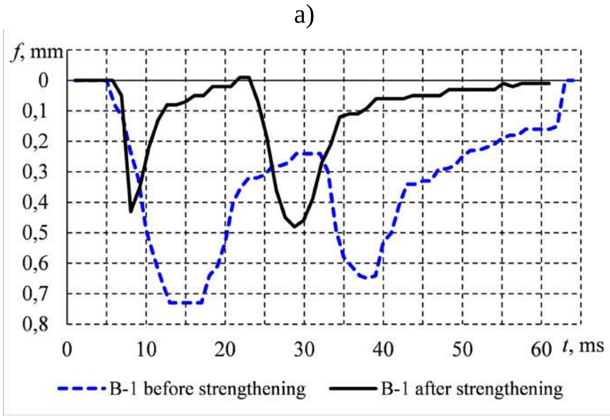
Fig. 6. Views of the installation of a potentiometric linear displacement sensor and a digital clock-type indicator under beam B-10 (a) and an analog-to-digital converter with a computer (b)

Findings

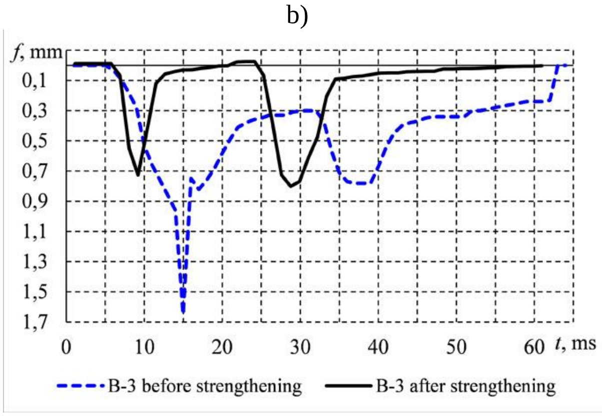
Fig. 7 shows graphs of deflections of beams B-1, B-3, B-12, and B-14 in span 3-4 when KrAZ trucks passed on the left (Fig. 7, a, b) and right (Fig. 7, c, d) lanes at speeds of 20 km/h and 10 km/h.

Deflections were measured before and after the strengthening of beams B-1, B-2, B-13, and B-14 in span 3-4. Fig. 8 shows graphs of deflections of beam B-10 in span 3-4 when KrAZ trucks passed in the right lane at speeds of 20 km/h and 10 km/h (Fig. 8, a), as well as at speeds of 40 km/h and 30 km/h (Fig. 8, b). The results of the analysis of these graphs show that the deflections of both strengthened (outer) beams and non- strengthened (inner) beams have decreased significantly, which indicates the inclusion of reinforcement in the joint work with reinforced beams and an overall increase in the stiffness of the span structure.

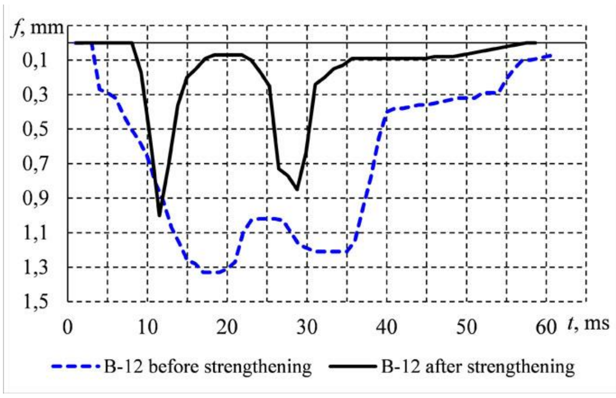
a)



b)



c)



d)

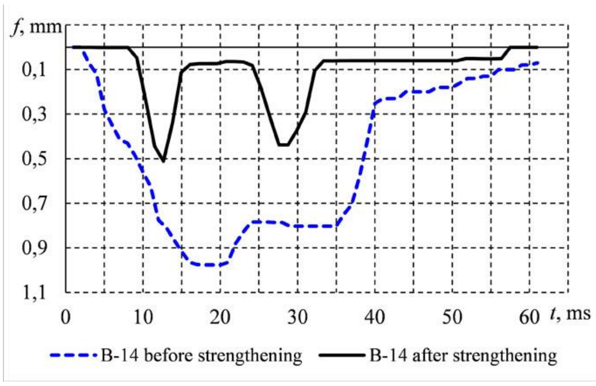


Fig. 7. Deflection graphs for beams B-1 (a), B-3 (b), B-12 (c), and B-14 (d) during the passage of KrAZ trucks at speeds of 20 km/h and 10 km/h before and after the strengthening of the outer beams of the bridge

Table 1 shows the summary results of dynamic tests of the bridge in the form of maximum deflections of the main beams measured before and after strengthening, calculated percentage values of deflection reduction, and the average value of deflection reduction. These data confirm the overall increase in the stiffness of the span structure: in all beams, the maximum deflections were reduced by 26 … 52 %, with an average reduction of 41 %.

ISSN 2413-6212 (Online), ISSN 2227-1252 (Print)
Bridges and tunnels: theory, research, practice, 2025, № 28

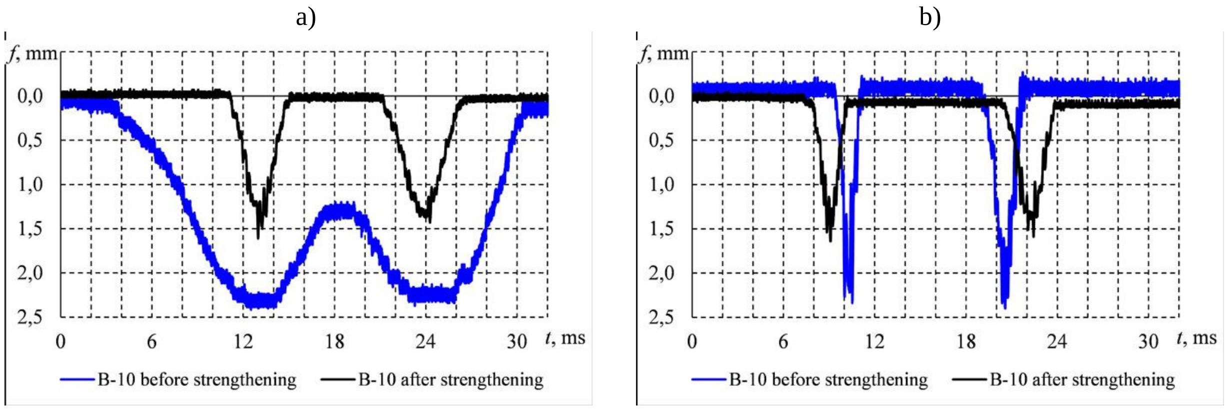


Fig. 8. Deflection graphs for beam B-10 before and after the strengthening of the outer beams of the bridge during the passage of KrAZ trucks at speeds of 20 km/h and 10 km/h (a) as well as 40 km/h and 30 km/h (b)

Table 1

Summary results of dynamic bridge tests

Parameter		Beam of span 3-4				
		B-1	B-3	B-10	B-12	B-14
Maximum deflection, mm	before strengthening	0,73	1,65	2,41	1,33	0,98
	after strengthening	0,47	0,80	1,41	0,98	0,51
Percentage reduction in deflection		36 %	52 %	42 %	26 %	48 %
Average reduction		41 %				

These data confirm the effectiveness of the strengthening of the main beams of the bridge using external reinforcement adhered with methyl methacrylate compositions: the strengthening elements worked together with the concrete of the beams, and thanks to the thickness of the sheets and the high modulus of elasticity of steel, the moments of inertia of the reinforced beams and the overall stiffness of the span structure have increased. It would probably be impossible to achieve such high results in reducing deformability when using non-metallic reinforcement elements (for example, carbon composite tapes) due to the much lower modulus of elasticity of non-metallic composite materials, despite the fact that their tensile strength can exceed that of steel several times over.

Lastly, it should be noted that after the beams were strengthened, the bridge on the Western Bypass of Lviv operated without incident for three years – until it was dismantled and reconstructed. The relatively low financial costs of the strengthening work and the avoidance of damage to Ukraine's transport network caused by an emergency situation resulting from the failure of damaged beams (the extent of which is difficult to predict) may be evidence of the economic efficiency of strengthening concrete bridge structures with external reinforcement adhered with methyl methacrylate compositions.

Originality and practical value

For the first time experimental data were obtained on the deflection of reinforced concrete bridge beams before and after reinforcement with external reinforcement, adhered with methyl methacrylate compositions, under dynamic loading, which made it possible to evaluate the effectiveness of this strengthening method.

The practical significance of the study lies in obtaining objective scientific data on the performance of concrete bridge structures, strengthened with external reinforcement, adhered with methyl methacrylate compositions, drawing conclusions about the prospects of this strengthening method, and determining the need for further research.

Conclusions

Based on the results of dynamic tests conducted on the bridge, whose beams were strengthened using external reinforcement adhered with methyl methacrylate compositions, the following conclusions were made:

1. The use of methyl methacrylate compositions is a promising direction not only in the repair of reinforced concrete bridge structures, but also in their strengthening.

2. The results of dynamic tests confirm the effectiveness of strengthening concrete bridge beams using external reinforcement adhered with methyl methacrylate compositions: this is evidenced by an average reduction in deflection of main beams (both strengthened and non-strengthened) by 41 %.

3. The use of methyl methacrylate compositions in transport construction deserves further theoretical and practical research in order to establish the characteristics of the stress-strain state of structures repaired and strengthened using these compositions under various loading and operating conditions.

A Conflict of Interest Statement

The author is a Member of the Editorial Team of the journal, and therefore the article was entirely handled and edited by another member of the Editorial Team.

REFERENCES

Dhibar, A. K. Mallick, S., Rath, T., & Khatua, B. B. (2009). Effect of clay platelet dispersion as affected by the manufacturing techniques on thermal and mechanical properties of PMMA-clay nanocomposites. *Journal of Applied Polymer Science*, 113(5), 3012-3018.

Kovalchuk, V., Parneta, B., & Rybak, R. (2024). Methodology of Experimental Studies of the Deformed State of a Concrete Pipe Restored Polymer Repair Mix. *Procedia Structural Integrity*, 59, 360–366.

Kovalchuk, V., Sobolevska, Y., Onyshchenko, A., et al. (2021). Procedure for determining the thermoelastic state of a reinforced concrete bridge beam strengthened with methyl methacrylate. *Eastern-European Journal of Enterprise Technologies*, 4(7(112), 26-33. DOI: https://doi.org/10.15587/1729-4061.2021.238440

Parneta, B., Kovalchuk, V., & Rybak, R. (2024). Methodology for Evaluating the Stress-Strain State of Strengthened Concrete Pipe Using the Finite Element Method with FEMAP with NX Nastran. *In: Blikharskyy, Z., Zhelykh, V. (eds) Proceedings of EcoComfort 2024. EcoComfort 2024. Lecture Notes in Civil Engineering, vol 604*. Springer, Cham. DOI: https://doi.org/10.1007/978-3-031-67576-8_37

Rybak, R., Kovalchuk, V., Parneta, B., & Karnakov, I. (2024). Investigation of Reinforced Concrete Pipe Deformability by Reinforcement Frame Under Static Loads. *Lecture Notes in Civil Engineering*, 438, 351–361. URL: https://link.springer.com/chapter/10.1007/978-3-031-44955-0_35

Бєляєва, С. Ю. (2006). *Міцність і деформативність залізобетонних плит, армованих сталевим профільованим настилом і поперечними анкерами*: автореф. дис. на здобуття наук. ступеня канд. техн. наук: спец. 05.23.01 «Будівельні конструкції, будівлі та споруди». Київ: ДНДІБК.

Золотов, С. М. (2009). Міцність, деформативність і руйнування акрилових клеїв за різних видів навантаження. *Механіка і фізика руйнування будівельних матеріалів та конструкцій*, 8, 179-188.

Золотов, С. М. (2008). Вплив на втому міцність акрилового клею виду динамічного навантаження. *Ресурсоекономні матеріали, конструкції, будівлі та споруди: збірник наукових праць*, 17, 169-175.

Золотов, С. М. (2010). Залежність життєздатності акрилових клеїв від їх складу та інших факторів. *Ресурсоекономні матеріали, конструкції, будівлі та споруди*, 20, 57-62.

Клименко, Ф. Є. (2001). *Розробка, дослідження та застосування у будівництві сталебетонних конструкцій*. Львів: ЛДАУ.

Лапенко, О. І. (2009). *Залізобетонні конструкції з робочим армуванням незнімною опалубкою*. Полтава: ТОВ «АСМІ».

Лучко, Й. Й., Сулим, Г. Т., & Кир'ян, В. І. (2004). *Механіка руйнування мостових конструкцій та методи прогнозування їх залишкової довговічності* (Том 6; В. В. Панасюк & Й. Й. Лучко, ред.). Львів: Каменяр.

Лучко, Й. Й., & Распопов, О. С. (2011). *Будова та експлуатація штучних споруд*. Дніпропетровськ: Каменяр.

Лучко, Й. Й. (2021). *Методи випробування та дослідження будівельних матеріалів, конструкцій будівель і споруд*. Львів: Світ.

МР В.2.3-37641918-888:2017 (2017). *Методичні рекомендації з відновлення залізобетонних конструкцій мостів і труб методом ін`єкційного просочування полімерними розчинами*. Київ: ДП «ДержДорНДІ».

Патент України № 148024. Поляков А. В., Коваль М. П. *Спосіб підсилення будівельних конструкцій із природного та штучного каменю металевими елементами за допомогою композиції на основі метилметакрилату.*

Р В.3.2-218-03450778-741:2008 (2008). *Рекомендації з підсилення конструкцій мостів під наванта-*

женням, в т.ч. з регулюванням зусиль. Київ: ДП «ДерждорНДІ».

Р В.3.2-218-03450778-480:2005 (2005). *Рекомендації з ремонту залізобетонних конструкцій із використанням зовнішнього армування*. Київ: ДП «ДерждорНДІ».

Риковцев, О. І., & Ковальчук, В. В. (2024). Термонапружений стан залізобетонних балок мостів підсилених метилметакрилатними композиціями. *Сучасні транспортні технології: матеріали 16-ї Міжнародної науково-практичної конференції студентів і молодих вчених імені Георгія Кірпи*, Львів, 66-67.

Салійчук, Л. В. (2011). Експериментальні дослідження та теоретичне обґрунтування міцності і анкерування в бетоні вклеєних стержневих анкерів при зсуві. *Будівельні конструкції*, 74, 2, 494-506.

Шутенко, Л. Н., Золотов, М. С., Гарбуз, А. О., & Золотов, С. М. (2001). Використання акрилових клеїв для реконструкції та ремонту будівель і споруд. *Будівельні конструкції*, 54, 810-814.

В. В. КОВАЛЬЧУК[1*], М. П. КОВАЛЬ[2], О. І. РИКОВЦЕВ[3]

[1*]Кафедра «Залізничний транспорт», Національний університет «Львівська політехніка», вул. С. Бандери, 12, Львів, Україна, 79000, тел. +38 (097) 223 72 43, ел. пошта kovalchuk.diit@gmail.com, ORCID 0000-0003-4350-1756

[2]Кафедра автомобільних доріг та мостів, Національний університет «Львівська політехніка», вул. С. Бандери, 12, Львів, Україна, 79000, тел. +38 (050)132 44 14, ел. пошта m_koval@meta.ua, ORCID 0000-0003-1244-1738

[3]Кафедра мостів, тунелів та гідротехнічних споруд, Національний транспортний університет, вул. М. Омеляновича-Павленка, 1, м. Київ, Україна, 01010, тел. +38 (063) 422 00 90, ел. пошта rykovtsevoleksii@gmail.com, ORCID 0009-0001-1715-6058

ОЦІНКА ЕФЕКТИВНОСТІ ПІДСИЛЕННЯ ГОЛОВНИХ БАЛОК МОСТА ЗОВНІШНІМ АРМУВАННЯМ, ПРИКЛЕЄНИМ МЕТИЛМЕТАКРИЛАТНИМИ КОМПОЗИЦІЯМИ, ЗА РЕЗУЛЬТАТАМИ ДИНАМІЧНИХ ВИПРОБУВАНЬ

Мета. Метою роботи є отримання об’єктивних даних про роботу залізобетонної прогонової будови моста до та після підсилення головних балок зовнішнім армуванням, приклеєним метилметакрилатними композиціями, а також їх аналіз з оцінюванням ефективності обраного методу підсилення. **Методика**. Застосування метилметакрилатних композицій є перспективним напрямком не лише при ремонті залізобетонних конструкцій мостів, а й при їх підсиленні. Методика дослідження ґрунтується на вимірюванні вертикальних прогинів головних балок моста до та після підсилення зовнішнім армуванням, приклеєним метилметакрилатними композиціями, за допомогою сучасного обладнання, із подальшим порівнянням цих прогинів та визначенням ступеня ефективності обраного методу підсилення. **Результати.** Результати динамічних випробувань дозволили встановити, що зовнішнє армування, приклеєне метилметакрилатними композиціями, включилося у спільну роботу із бетоном балок, підвищило загальну жорсткість прогонової будови та суттєво зменшило її деформативність: у всіх балок максимальні прогини зменшилися у межах 26...52 %, середнє значення зменшення становить 41 %. Використання метилметакрилатних композицій у транспортному будівництві заслуговує на подальші теоретичні та практичні дослідження з метою встановлення особливостей напружено-деформованого стану конструкцій, ремонтованих та підсилених із використанням цих композицій, при різних режимах завантаження та роботи. **Наукова новизна.** Вперше отримані експериментальні дані щодо прогинів залізобетонних балок мостів до та після підсилення зовнішнім армуванням, приклеєним метилметакрилатними композиціями, при дії динамічного навантаження, що дозволило оцінити ефективність цього способу підсилення. **Практична значимість**. Практичне значення дослідження полягає у отриманні об’єктивних наукових даних щодо роботи залізобетонних конструкцій мостів, підсилених зовнішнім армуванням, приклеєним метилметакрилатними композиціями, зробленими висновками про перспективність цього способу підсилення та визначенні потреби у необхідності проведення подальших досліджень.

Ключові слова: автодорожній міст; динамічні випробування; залізобетонні балки; зовнішнє армування; метилметакрилатні композиції; підсилення залізобетонних балок

REFERENCES

Dhibar, A. K. Mallick, S., Rath, T., & Khatua, B. B. (2009). Effect of clay platelet dispersion as affected by the manufacturing techniques on thermal and mechanical properties of PMMA-clay nanocomposites. *Journal of Applied Polymer Science*, 113(5), 3012-3018. (in English)

Kovalchuk, V., Parneta, B., & Rybak, R. (2024). Methodology of Experimental Studies of the Deformed State of a Concrete Pipe Restored Polymer Repair Mix. *Procedia Structural Integrity*, 59, 360-366. (in English)

Kovalchuk, V., Sobolevska, Y., Onyshchenko, A., et al. (2021). Procedure for determining the thermoelastic state of a reinforced concrete bridge beam strengthened with methyl methacrylate. *Eastern-European Journal of Enterprise Technologies*, 4(7(112), 26-33. DOI: https://doi.org/10.15587/1729-4061.2021.238440 (in English)

Parneta, B., Kovalchuk, V., & Rybak, R. (2024). Methodology for Evaluating the Stress-Strain State of Strengthened Concrete Pipe Using the Finite Element Method with FEMAP with NX Nastran. *In: Blikharskyy, Z., Zhelykh, V. (eds) Proceedings of EcoComfort 2024. EcoComfort 2024. Lecture Notes in Civil Engineering, vol 604*. Springer, Cham. DOI: https://doi.org/10.1007/978-3-031-67576-8_37 (in English)

Rybak, R., Kovalchuk, V., Parneta, B., & Karnakov, I. (2024). Investigation of Reinforced Concrete Pipe Deformability by Reinforcement Frame Under Static Loads. *Lecture Notes in Civil Engineering*, 438, 351–361. URL: https://link.springer.com/chapter/10.1007/978-3-031-44955-0_35 (in English)

Bieliaieva, S. Yu. (2006). *Mitsnist i deformatyvnist zalizobetonnykh plyt, armovanykh stalevym profilovanym nastylom i poperechnymy ankeramy*: avtoref. dys. na zdobuttia nauk. stupenia kand. tekhn. nauk: spets. 05.23.01 «Budivelni konstruktsii, budivli ta sporudy». Kyiv: DNDIBK. (in Ukrainian)

Zolotov, S. M. (2009). Mitsnist, deformatyvnist i ruinuvannia akrylovykh kleiv za riznykh vydiv navantazhennia. *Mekhanika i fizyka ruinuvannia budivelnykh materialiv ta konstruktsii*, 8, 179-188. (in Ukrainian)

Zolotov, S. M. (2008). Vplyv na vtomnu mitsnist akrylovoho kleiu vydu dynamichnoho navantazhennia. *Resurso-ekonomni materialy, konstruktsii, budivli ta sporudy: zbirnyk naukovykh prats*, 17, 169-175. (in Ukrainian)

Zolotov, S. M. (2010). Zalezhnist zhyttiezdatnosti akrylovykh kleiv vid yikh skladu ta inshykh faktoriv. *Resur-soekonomni materialy, konstruktsii, budivli ta sporudy*, 20, 57-62. (in Ukrainian)

Klymenko, F. Ye. (2001). *Rozrobka, doslidzhennia ta zastosuvannia u budivnytstvi stalebetonnykh konstruktsi*i. Lviv: LDAU. (in Ukrainian)

Lapenko, O. I. (2009). *Zalizobetonni konstruktsii z robochym armuvanniam neznimnoiu opalubkoiu*. Poltava: TOV «ASMI». (in Ukrainian)

Luchko, Y. Y., Sulym, H. T., & Kyrian, V. I. (2004). *Mekhanika ruinuvannia mostovykh konstruktsii ta metody prohnozuvannia yikh zalyshkovoi dovhovichnosti* (Tom 6; V. V. Panasiuk & Y. Y. Luchko, red.). Lviv: Kameniar. (in Ukrainian)

Luchko, Y. Y., & Raspopov, O. S. (2011). *Budova ta ekspluatatsiia shtuchnykh sporud*. Dnipropetrovsk: Kameniar. (in Ukrainian)

Luchko, Y. Y. (2021). *Metody vyprobuvannia ta doslidzhennia budivelnykh materialiv, konstruktsii budivel i sporud*. Lviv: Svit. (in Ukrainian)

MR V.2.3-37641918-888:2017 (2017). *Metodychni rekomendatsii z vidnovlennia zalizobetonnykh konstruktsii mo-stiv i trub metodom in`yektsiinoho prosochuvannia polimernymy rozchynamy*. Kyiv: DP «DerzhdorNDI». (in Ukrainian)

Patent Ukrainy # 148024. Poliakov A. V., Koval M. P. *Sposib pidsylennia budivelnykh konstruktsii iz pry-rodnoho ta shtuchnoho kameniu metalevymy elementamy za dopomohoiu kompozytsii na osnovi metylmetakrylatu*. (in Ukrainian)

R V.3.2-218-03450778-741:2008 (2008). *Rekomendatsii z pidsylennia konstruktsii mostiv pid navantazhenniam, v t.ch. z rehuliuvanniam zusyl*. Kyiv: DP «DerzhdorNDI». (in Ukrainian)

R V.3.2-218-03450778-480:2005 (2005). *Rekomendatsii z remontu zalizobetonnykh konstruktsii iz vykorystanniam zovnishnoho armuvannia*. Kyiv: DP «DerzhdorNDI». (in Ukrainian)

Rykovtsev, O. I., & Kovalchuk, V. V. (2024). Termonapruzhenyi stan zalizobetonnykh balok mostiv pidsylenykh metylmetakrylatnymy kompozytsiiamy. *Suchasni transportni tekhnolohii: materialy 16-yi Mizhnarodnoi naukovo-praktychnoi konferentsii studentiv i molodykh vchenykh imeni Heorhiia Kirpy*, Lviv, 66-67. (in Ukrainian)

Saliichuk, L. V. (2011). Eksperymentalni doslidzhennia ta teoretychne obgruntuvannia mitsnosti i ankeruvannia v betoni vkleienykh sterzhnevykh ankeriv pry zsuvi. *Budivelni konstruktsii*, 74, 2, 494-506. (in Ukrainian)

Shutenko, L. N., Zolotov, M. S., Harbuz, A. O., & Zolotov, S. M. (2001). Vykorystannia akrylovykh kleiv dlia rekonstruktsii ta remontu budivel i sporud. *Budivelni konstruktsii*, 54, 810-814. (in Ukrainian)

Надійшла до редколегії 17.10.2025.
Прийнята до друку 11.12.2025.