UDC 691:698
DOI https://doi.org/10.32782/apcmj.2025.1.2

Horb Oleksandr Hryhorovych,
Candidate of Technical Sciences, Associate Professor,
Associate Professor at the Department of Construction Computer Technologies,
Faculty of Architectural Structures and Airfields,
State University "Kyiv Aviation Institute",
1, Liubomyr Huzar ave., Kyiv, 03058, Ukraine
ORCID: https://orcid.org/0000-0003-3104-7621
E-mail: oleksandr.horb@npp.nau.edu.ua

Palyvoda Oleksandr Anatoliiovych,
Candidate of Technical Sciences, Associate Professor,
Associate Professor at the Department of Air Transport Infrastructure,
Faculty of Architectural Structures and Airfields,
State University "Kyiv Aviation Institute",
1, Liubomyr Huzar ave., Kyiv, 03058, Ukraine
ORCID: https://orcid.org/0000-0001-9787-9653
E-mail: oleksandr.palyvoda@npp.nau.edu.ua

Ponochovnyi Maksym Vitaliiovych,
Student of the Group Ma-192-23-2-CB,
Department of Construction Computer Technologies,
Faculty of Architectural Structures and Airfields,
State University "Kyiv Aviation Institute"
1, Liubomyr Huzar ave., Kyiv, 03058, Ukraine
E-mail: 6176644@stud.kai.edu.ua

RESOURCE SAVING OF ADHESIVE JOINTS OF STEEL AND CONCRETE IN MONOLITHIC SLABS

Abstract. *The article analyzes the results of research into rational methods of combining steel and concrete in load-bearing composite structures. The experience of using traditional embedded parts, anchoring, and stud bolts in comparison with adhesive joints based on multicomponent polymers to ensure the joint operation of steel and concrete is studied. The technology of installing monolithic reinforced concrete slabs on a profiled flooring, which acts as a fixed formwork, is investigated. A methodology for determining the shear force between a concrete block and reinforcement in bent steel-reinforced concrete elements using normative approaches and the theory of composite rods is considered and tested. The key technical and economic indicators of steel and concrete connections that affect the efficiency and resource efficiency of composite load-bearing structures are analyzed, defined, and calculated. A monolithic slab subjected to significant loads was chosen as a design example. Two technologies for the manufacture of the floor are considered: using traditional anchoring means and the method of gluing freshly placed concrete mix using acrylic glue applied to a metal part that serves as a fixed formwork. Hilti stud bolts were chosen as anchors. Their physical and mechanical characteristics are guaranteed by the manufacturer and do not require additional research. The cost of the means to ensure the joint operation of steel and concrete was chosen as the average market price. The analysis of labor costs took into account the main technological processes of steel and concrete joints in composite structures. A comparison of the main characteristics of anchor and adhesive joints of reinforced concrete floor components on a profiled flooring was made, according to which the economic efficiency of the adhesive joint along with anchoring reaches almost 30%.*

Key words: *adhesive and anchor joints, composite structures, technical and economic characteristics, resource saving, efficiency.*

Горб Олександр, Паливода Олександр, Поночовний Максим. Ресурсоощадність клейових з'єднань сталі та бетону в монолітних перекриттях

Анотація. *Стаття містить аналіз результатів вишукувань раціональних способів поєднання сталі та бетону в несучих композитних конструкціях. Вивчено досвід застосування традиційних закладних деталей,* *анкерування та стад-болтів у порівнянні із клейовими з'єднаннями на основі багатокомпонентних полімерів для забезпечення сумісної роботи сталі та бетону. Досліджено технологію влаштування монолітних залізобетонних плит перекриття по профільованому настилу, який виступає в ролі незнімної опалубки. Розглянуто й апробовано методику визначення зсуваючого зусилля між бетонним блоком і армуванням у зігнутих сталезалізобетонних елементах за допомогою нормативних підходів і теорії складених стержнів. Проаналізовано, визначено та розраховано ключові техніко-економічні показники з'єднань сталі та бетону, які впливають на ефективність і ресурсоощадність композитних несучих конструкцій. Для розрахункового прикладу було вибрано монолітне перекриття, на яке діють значні навантаження. Розглянуто дві технології виготовлення перекриття: із застосуванням традиційних анкерних засобів і метод приклеювання свіжоукладеної бетонної суміші за допомогою акрилового клею, нанесеного на металеву частину, яка виконує роль незнімної опалубки. Як анкерування було вибрано стад-болти компанії "Hilti". Їхні фізико-механічні характеристики гарантовані виробником і не потребують додаткових досліджень. Вартість засобів забезпечення сумісної роботи сталі та бетону вибиралася середня ринкова. Під час проведення аналізу затрат праці були враховані основні технологічні процеси влаштування з'єднання сталі та бетону в композитних конструкціях. Виконано порівняння основних характеристик анкерних і клейових з'єднань компонентів залізобетонного перекриття по профільованому настилу, згідно з яким економічна ефективність клейового з'єднання поряд з анкеруванням сягає майже 30%.*

Ключові слова: *клейові й анкерні з'єднання, композитні конструкції, техніко-економічні характеристики, ресурсоощадність, ефективність.*

Introduction. Constructing durable and resilient structures requires engineers to select the best joining techniques for various materials. Two prevalent methods for joining steel and concrete coverings are anchoring and adhesive joints. These methods impact not only the technical efficiency – encompassing strength, stability, and durability – but also the economic efficiency concerning costs, labor, and maintenance. This article delves into both the technical and economic aspects of these joining systems, exploring their effectiveness in contemporary construction.

Anchoring joints involve mechanical connections that secure steel components to concrete, typically using bolts, dowels, or other fastening systems. The anchors create a rigid connection, allowing the transfer of loads effectively between the two materials.

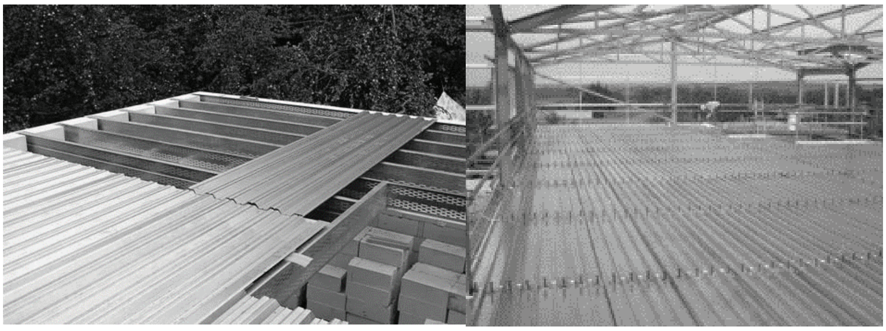
The choice between anchoring and adhesive joints in steel and concrete coverings ultimately depends on the specific needs of a project [1–8]. For applications requiring high load capacity and structural integrity, anchoring systems are favored. Conversely, adhesive joints may be the better option for applications demanding flexibility and ease of installation.

Ultimately, evaluating both the technical and economic efficiencies of these joining methods is essential for making informed decisions that will benefit the long-term performance and cost-effectiveness of construction projects. As technology advances, hybrid systems that combine the strengths of both methods may also emerge, further enhancing the efficiency and versatility of joining techniques in the construction sector.

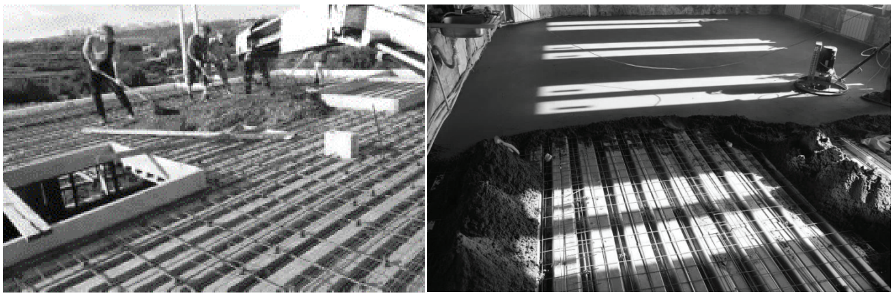
The aviation industry stands as a testament to human innovation and engineering prowess. Central to this industry are its production buildings, which serve as the backbone of aircraft manufacturing, maintenance, and assembly. These structures are meticulously designed to meet the rigorous demands of aviation production while ensuring safety, efficiency, and sustainability.

The study of steel-reinforced concrete structural elements, in which the joint operation of steel and concrete was ensured by bonding, proved the feasibility of their use in construction practice. Since the work was aimed at testing the obtained methods of joining steel and concrete, the technology for manufacturing steel and reinforced concrete elements based on it, and the calculation algorithm, the work was accompanied by the design of real structures (Fig. 1).

Materials and methods. As an example of the calculation, a fragment of a steel-reinforced concrete floor of a five-story industrial building with a maximum span of 6 800 × 6 000 mm was taken. So, taking into account the area of the slab resting on the crossbar, the calculated span length is 5 800 mm.



a) b)



c) d)

Fig. 1. Installation of floors on profiled flooring: a) installation of flooring; b) installation of stacked bolts; c) concreting; f) leveling

The slab consists of a monolithic reinforced concrete slab, which is concreted over steel corrugated board of H75-750-0.9 grade, which, after concrete has reached the specified strength (C 25/30), is used as external reinforcement. The slab rests on reinforced concrete girders without ensuring their joint operation with additional anchoring means or embedded parts. The design scheme is assumed to be single-span, since the sheets are joined along the girders without overlap and riveted joints.

The length of the maximum span of the slab is 6 m, which is permissible if the deck is additionally calculated at the installation stage or when temporary supports are installed for the period of concrete concreting and concrete curing. Steel profiled decking used as slab reinforcement has a reliable adhesion to concrete, which is ensured by gluing the freshly placed concrete mix with an acrylic polymer of the appropriate composition. This eliminates the need for much more expensive stamped corrugated board and special anchoring devices, which eliminates the problem of burning through the sheet steel when installing anchors.

The sheets are joined in width by overlapping the side edges of the corrugated board, connecting them with special self-tapping screws in 300 mm increments. In the places of technological openings and openings for local reinforcement of the slab, additional flexible reinforcement is installed in the form of separate rods located along the contour of the opening, which are taken according to the calculation. The lower longitudinal rods of the working reinforcement are installed in the corrugations of the corrugated board without breaking along the span. The distance from the end of the flexible reinforcement to the end of the sheet at the extreme supports is 15 mm.

Since there is no pressure reinforcement, a 3 mm diameter anti-shrinkage mesh made of Vr-I wire with a rod spacing of 200 mm in both directions is used. The mesh is placed with an indentation from the upper surface of the slab by the amount of the protective layer of concrete equal to 15 mm. The thickness of the concrete shelf of the floor slab above the profiled flooring is determined according to the calculation and indicators of technical and economic efficiency and is

50 mm. The profiled flooring is oriented with wide corrugations downward to accommodate two rods of additional longitudinal reinforcement.

Design load on 1 m^2 of the slab is $p = 12\frac{kN}{m^2}$, then the distributed load for one wave width 0,1875 *m* will be equal to $p = 5,8 \cdot 0,1875 \cdot 12 = 13,05\frac{kN}{m^2}$.

Find the maximum bending moment M_{max}, which occurs in the middle of the span, according to the formula:

$$M_{max} = \frac{p \cdot l^2}{8}; \quad (1)$$

where p – uniformly distributed load; l – length of the span panel.

Therefore:

$$M_{max} = \frac{13,05 \cdot 5,8^2}{8} = 54,88 \text{ kNm}. \quad (2)$$

The design resistances of the materials are assumed to be 240 MPa for steel and 17 MPa for concrete with a strength class of C 25/30. Traditionally, we calculate the anchoring means in the form of periodic reinforcement pieces or special bolts that are mounted with pyro cartridges.

The bearing capacity is tested for one conventional beam, which is a wave of a profiled deck with an upper edge width of 187,5 mm. The calculation is performed according to the theory of composite rods, taking into account a 2,5 mm thick adhesive joint. As a result of the calculations, for the section chosen for structural reasons, the value of the shear force is T = 382 kN, the area of the additional rod reinforcement is 24 cm^2, for which we take two rods with a diameter of 40 mm.

The determination of the required number of anchors begins with the calculation of the shear force that they will absorb. The calculation is carried out in several stages, during which the shear resistance of the anchorage on the supports at the ends of the deck is checked, depending on the type of anchors, the resistance of the reefs to crushing, tearing out the deck around the anchor.

Shear resistance of anchoring on supports at the ends of the deck made of periodic reinforcement:

$$T_1 = k_1 k n_{an} A_{an} R_y, \quad (3)$$

where k_1 = 0,8 – coefficient that takes into account the joint operation of the slab and beam; k_1 = 1,0 – beam calculation without taking into account the joint operation with the slab.

$$k = \frac{4,75\sqrt[3]{R_b}}{\left(1 + 0,15A_{an}\right)\sqrt{R_{sa}}}, \quad (4)$$

where n_{an} – number of vertical rod anchors in one corrugation at the end of the deck; R_y – design resistance of anchor steel; A_{an} – cross-sectional area of one vertical rod anchor, cm^2.

Tear-out resistance of the decking around the anchor (for the extreme span):

$$T_2 = R_y l'_{ant}, \quad (5)$$

where l'_{ant} – the cross-sectional area of the deck, which is calculated for tearing around the anchors.

Tensile strength of the deck in the anchor welding zone:

$$T_3 = R_y \left(b + h_н\right) t. \quad (6)$$

Table 1

Limit shear force per 1 stud-bolt, kN

Estimated steel resistance of the bolt, R_y, MPa	Stud bolt diameter, mm		
	12	16	19
400	28,94	51,45	72,55
450	32,56	57,88	81,61
500	36,17	64,31	90,68

The shear anchoring resistance on the supports at the ends of the deck made of stacked balls is determined by the formula:

$$T_1 = 0,64 R_y A_{an} n, \quad (7)$$

where $A_{an} = \frac{\pi d^2}{4}$ – cross-sectional area of the stud bolt; d – diameter of the straddle bolt; n_{an} – the number of stud bolts in one corrugation; R_y – calculated steel resistance of the stud bolt.

The resistance of reefs to scour is determined by the formula:

$$T_4 = \gamma_c R_b A_{rif} n_{rif}, \quad (8)$$

where A_{rif} – the area of concrete crushing on the side surface of one reef ($A_{rif} = 0,5 cm^2$); γ_c – operating conditions factor (γ_c = 0,5); n_{rif} – the number of reefs on the walls of one corrugation along the length of the deck section from the section under consideration to the nearest end.

In the presence of rod reinforcement in the ribs of the slab, the number of reefs that are entered into the calculation is taken along the length of the section, reduced by the height of the slab section.

Table 2

Limit compressive strength of concrete for one stud bolt

Cubic strength of concrete, MPa	Stud bolt diameter, mm		
	12	16	19
25	29,17	51,86	73,13
30	31,96	56,81	80,11
35	34,52	61,36	86,53
40	36,90	65,60	92,51
45	39,14	69,58	98,12

Based on the value of the shear force obtained as a result of the calculations in accordance with Tables 1–2, selecting the stud bolts with a diameter of 16 mm, we will obtain their number. In order to absorb the shear force, a minimum of 8 stud bolts are required in one corrugation of the selected span.

Using the results of the experimental studies presented in Section 2, we select the shear strength of the adhesive joint for concrete with a strength close to C25/30, which is used to determine the minimum required area of the adhesive joint. We take the safety factor, which takes into account the rejection rate when applying acrylic adhesive, equal to 1,5 and get the minimum area of its application equal to 0,285 m^2. With a layer thickness of 2,5 mm, the adhesive consumption will be about 0,7 liters per corrugation, the number of which in the largest span is 36. Thus, the total polymer consumption per span will be 25,2 liters.

Disscussion. Based on the designed steel-reinforced concrete slab, we will check the economic feasibility of using an adhesive connection instead of traditional anchoring means. The main indicator that characterizes the economic efficiency of reinforced concrete structures with external reinforcement is the reduced cost of covering one floor of a given parking lot or a specific selected span. Since the advantages of the selected floor are well known in comparison with steel or precast concrete, we will only define the parameters that will be affected by a change in the way steel and concrete work together.

In this case, the cost of fire resistance for steel and reinforced concrete structures was not taken into account. Reinforced concrete structures with conventional reinforcement are more fire-resistant. Their use is allowed in all buildings. This is their advantage over steel and reinforced concrete structures. However, the fire resistance of reinforced concrete structures has not been studied, so their use is limited to the area of application of unprotected steel structures.

The chosen method of joining steel and concrete will have an immediate impact on the first point due to the appearance of an additional consumable material – acrylic glue, the retail cost of which is about 300 UAH/l. Since the calculations are performed for one span, the total cost of the adhesive will be UAH 7 560, and the cost of anchoring means will be UAH 10 540, taking into account the cost of one anchor with a pyro cartridge, which is UAH 36,6. The total consumption of glue per span is

Table 3

Technical and economic indicators of the installation of steel-concrete connection in monolithic floor slabs over profiled flooring

Name	Type of product		Difference, %
	Acrylic glue	Anchoring	
Materials consumption	25,2l	288 units	–
Unit cost	300 UAH/l	36,6 UAH/unit	–
Application of special equipment	unnecessary	necessary	–
Labor intensity, man-hours	17	20	18
Cost, UAH	7 560	10 540	28

25,2 liters, and the total number of anchors is 288 units (Table 3).

Results. Thus, the difference in the cost of materials alone is UAH 2980, or the glue is 1.3 times cheaper than anchoring. This is the main cost item when connecting floor components. The use of glue requires much less skilled workers and, accordingly, lower wages than when installing stud-bolts, which use special equipment that is expensive to maintain. However, these costs are significantly lower than the cost of materials, but this affects the overall duration of the work, which is reduced by 15–20% when applying glue, even when taking into account the time spent on mixing the mixture. This reduces the labor costs for making an adhesive joint compared to installing anchors.

Bibliography:

1. Jeevi G., Nayak S.K., Abdul Kader M. Review on adhesive joints and their application in hybrid composite structures. *Journal of Adhesion Science and Technology*. 2019. № 33 (14). P. 1497–1520. URL: https://doi.org/10.1080/01694243.2018.1543528.

2. Horb O., Davidenko Y., Skurupiy O., Mytrofanov P. Application of bonding concrete to reinforcement using adhesives in steel concrete composite structure. *13th fib International PhD Symposium in Civil Engineering, Paris, France, August 26–28, 2020*. 2020. P. 2–9. URL: https://phdsymp2020.sciencesconf.org/data/pages/Proceedings_phdsymp_2021.pdf.

3. Lapenko O., Baranetska D., Makarov V., Baranetskyi A. Designing of structural construction and orthotropic slabs from steel reinforced concrete. *MSF.* 2020. № 1006. P. 173–178. URL: https://doi.org/10.4028/www.scientific.net/msf.1006.173.

4. Zolotov S., Firsov P., Muhamad H. Evaluation of stress-deformed condition level of glued materials for the without anchor steel-concrete joint. *In Lecture Notes in Civil Engineering. Springer.* 2020. Vol. 47. P. 95–102. URL: https://doi.org/10.1007/978-3-030-27011-7_12.

5. Chamochin R., de Santayana M.C., Abenojar J., Pantoja M., Ballesteros Y., del Real J.C. The effect of surface treatment on the behavior of toughened acrylic adhesive/GRP (epoxy) composite joints. *Journal of Adhesion Science and Technology*. 2010. № 24 (11–12). P. 1903–1916. DOI: 10.1163/016942410X507641.

6. Mallick P.K. Optimization of structural adhesive joints. *Structural Adhesive Joints: Design, Analysis and Testing.* 2020. P. 79–96. DOI: 10.1002/9781119737322.ch3.

7. Abolfazl Tutunchi, Rahman Kamali, Abbas Kianvash. Adhesive strength of steel–epoxy composite joints bonded with structural acrylic adhesives filled with silica nanoparticles. *Journal of Adhesion Science and Technology*. 2015. Vol. 29 (3). DOI: 10.1080/01694243.2014.981469.

8. Ebnesajjad, S., Landrock, A.H. Adhesives technology handbook. Third edition. 2015. 414 p. URL: https://doi.org/10.1016/C2013-0-18392-4.

References:

1. Jeevi, G., Nayak, S.K., & Abdul Kader, M. (2019). Review on adhesive joints and their application in hybrid composite structures. *Journal of Adhesion Science and Technology*, *33* (14), 1497–1520. Retrieved from https://doi.org/10.1080/01694243.2018.1543528.

2. Horb, O., Davidenko, Y., Skurupiy, O., & Mytrofanov P. (2020). Application of bonding concrete to reinforcement using adhesives in steel concrete composite structure. *13th fib International PhD Symposium in Civil Engineering, Paris, France, August 26–28, 2020,* (pp. 2–9). Retrieved from https://phdsymp2020.sciencesconf.org/data/pages/Proceedings_phdsymp_2021.pdf.

3. Lapenko, O., Baranetska, D., Makarov, V., & Baranetskyi, A. (2020). Designing of structural construction and orthotropic slabs from steel reinforced concrete. *MSF*, 1006, (pp. 173–178). Retrieved from https://doi.org/10.4028/www.scientific.net/msf.1006.173.

4. Zolotov, S., Firsov, P., & Muhamad, H. (2020). Evaluation of stress-deformed condition level of glued materials for the without anchor steel-concrete joint. *In Lecture Notes in Civil Engineering. Springer*, Vol. 47, (pp. 95–102). Retrieved from https://doi.org/10.1007/978-3-030-27011-7_12.

5. Chamochin, R., de Santayana, M.C., Abenojar, J., Pantoja, M., Ballesteros, Y., & del Real, J. C. (2010). The effect of surface treatment on the behavior of toughened acrylic adhesive/GRP (epoxy) composite joints. *Journal of Adhesion Science and Technology*, *24* (11–12), (pp. 1903–1916). Retrieved from https://doi.org/10.1163/016942410X507641

6. Mallick, P.K. (2020) Optimization of Structural Adhesive Joints. *Structural Adhesive Joints: Design, Analysis And Testing*, (pp. 79–96). DOI: 10.1002/9781119737322.ch3.

7. Abolfazl, Tutunchi, Rahman, Kamali, & Abbas, Kianvash (2015). Adhesive strength of steel–epoxy composite joints bonded with structural acrylic adhesives filled with silica nanoparticles. *Journal of Adhesion Science and Technology*, Vol. 29 (3). DOI: 10.1080/01694243.2014.981469.

8. Ebnesajjad, S., & Landrock, A.H. (2015). Adhesives Technology Handbook. Third Edition, (414 p.). Retrieved from https://doi.org/10.1016/C2013-0-18392-4.