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Pavel Mytrofanov ✉; Volodymyr Pents; Alla Kariuk; Nataliia Mahas; Olehander Horb

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Structures of Reinforced Concrete Racks of Manufacture Buildings Frames with Adhesive Joints of Concrete and Steel

Pavel Mytrofanov[1, a)], Volodymyr Pents[1, b)], Alla Kariuk[1, c)], Nataliia Mahas[1, d)] and Olehander Horb[2, e)]

[1]National University «Yuri Kondratyuk Poltava Polytechnic», Pershotravneviy sq. 24, 36011, Poltava, Ukraine
[2]National Aviation University, Liubomyra Huzara ave. 1, 03058, Kyiv, Ukraine

[a)] Corresponding author: Mytrofanov.p@gmail.com
[b)] Vfpents@gmail.com
[c)] Kariuk15@ukr.net
[d)] Magasnataliya@gmail.com
[e)] Olhorb@gmail.com

Abstract. The range of reinforced concrete, steel-reinforced concrete and other composite building structures is expanding very rapidly, as the difficult economic situation requires minimizing the cost, reducing material consumption and complexity in the construction of buildings and structures. Steel-reinforced concrete structures as a result of continuous improvement fully meet these requirements today. As a result, we get the opportunity for the most rational combination of steel and concrete by the most separate application in the stretched and compressed cross-sectional areas. However, designers of such structures constantly face the problem of ensuring the joint operation of their components. Recently, the use of various types of adhesives in the manufacture and reconstruction of load-bearing composite structures to ensure the joint operation of concrete and steel has become common. According to the authors of the article, acrylic-based adhesives in these cases are the most effective. The great potential of acrylic polymers for their use in construction has not yet been fully revealed. Therefore, there is a need for new experimental studies and theoretical study of composite structures, in which the joint work of the components is provided by acrylic adhesives.

INTRODUCTION

Every year, the construction industry requires the creation of new load-bearing structures that will reduce costs, reduce material consumption and complexity of construction of buildings and structures [3].

At present, these requirements can be met by steel-reinforced concrete structures, in which steel and concrete are most rationally used and which have a high load-bearing capacity compared to conventional reinforced concrete structures [8]. Especially important is to increase the load-bearing capacity of the columns of industrial buildings, which can withstand heavy loads. In addition, repeated dynamic loads from overhead cranes in production buildings can disrupt the joints and the joint work of concrete and steel. The introduction of steel-reinforced concrete structures in such operating conditions makes it necessary to solve the problem of ensuring the joint operation of their components.

The use of adhesives is becoming more common in the reinforcement of reinforced concrete structures and in the installation of anchor bolts to ensure the joint operation of concrete and steel. Acrylic adhesives proved to be the most positive in these cases. They have a significant advantage over all adhesives used in construction. These adhesives are reliable and easy to apply and prepare due to their low viscosity. It does not depend on ambient temperature. Acrylic adhesives fit well and noted their durability. The installation of acrylic adhesive joints in comparison with even the latest developments of traditional anchors [9-11] is less material-intensive and labor-intensive. Also note that when working with them does not require highly skilled workers.

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ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

For a long time, the scientific school of M. Zolotov has been studying various adhesives and problems of their application in the construction industry [1, 2]. The advantage of acrylic glue among all types of glues used in construction has been proved - because it is easy to prepare, fits well and is durable [3]. The latest developments of traditional anchoring tools, presented in [4-14], are too time-consuming and require highly skilled workers in their application. In particular, they are used to combine steel and concrete in steel I-beams with side cavities filled with concrete. In [5], the use of acrylic glue instead of traditional anchors was proposed for such case.

THE PURPOSE OF THIS WORK

The purpose of the elements experimental tests was to study the effect of the adhesive connection of concrete and steel parts of steel-reinforced concrete elements on their load-bearing capacity. Research of features of joint work of two components of a complex design at glue connection with use of acrylic glue and without it. Analysis of the development of crack formation in concrete and plastic properties of the steel part. Obtaining values of deformations at different stages of loading and the nature of the destruction of experimental samples.

THE MAIN MATERIAL

Samples with a length of 1650 mm were designed to obtain experimental results that will allow to sufficiently judge the features of the work of steel-reinforced concrete elements using an adhesive connection of concrete and steel. They were made of two welded T-bar with a shelf 80 mm width, and 5 mm thickness and a 40 mm wall length and 3 mm thickness (Fig.1 and Fig.2).

The walls of the two T-bars were connected by a hinged lattice made of reinforcement with a 6 mm diameter and welded to the walls with a 120 mm step. The total height of the cross section of the section made in this way of two welded T-bars (the distance between the outer faces of the shelves) was 160 mm; section width - 80 mm. The peculiarity of this type of elements is that concreting was performed in one go and thus the homogeneity of the concrete mixture on both sides of the reinforced concrete element was ensured. Plates 12 mm thick were welded to the ends of the reinforced concrete elements to prevent the formation of local deformations in the support zone of the compressed elements. The samples differ from each other by the presence of an adhesive joint between concrete and steel (C1 - without an adhesive joint, C2 - with an adhesive joint).

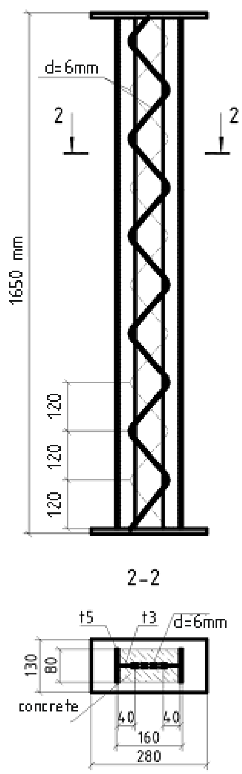
The following technology was maintained during the prototypes production. Steel sheets were cut into plates of the required size. Next, the steel plates were marked before welding. The plates were then joined together by manual electric arc welding. The armature was cut and the lattice elements were made with their subsequent welding. After coating with glue was carried out, followed by concreting. The final stage is painting.

Acrylic glue consists of a polymer binder and a filler. Acrylic plastic AST-T, which is a powder-liquid cold-curing compound, is used as a polymeric binder. The swelling process increases the viscosity of the compound, which after its completion does not change from the ambient temperature or the composition of the compound. Acrylic adhesives are well applied due to low viscosity.

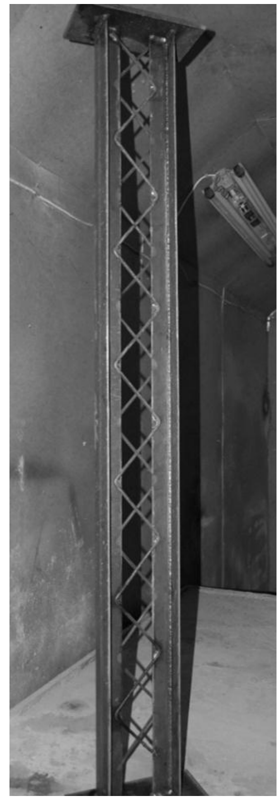
One of the most important technological characteristics of the adhesive is its viability, i.e. the period of time during which it can be used for the structures manufacture. It depends on its composition and ambient temperature. Curing of acrylic glue occurs spontaneously at a positive temperature.

Acrylic adhesive has a high cohesive strength, which depends on the composition of the compound, as well as the amount and size of the filler. Increasing the amount of polymer in the plastic leads to a slight increase in strength. With increasing grain size of the filler there is a decrease in the strength of the adhesive. The strength of acrylic adhesive is significantly affected by the amount of filler, because with increasing amount of sand and its size, the strength of the adhesive decreases. This is due to insufficient wettability of the filler surface with plastic. Acrylic adhesives have high durability.

After making the steel part of the racks, in the respective prototypes the places of contact of the steel with the concrete were covered with a layer of acrylic glue and filled with concrete. Acrylic adhesive consisted of 100 parts by weight of polymer, 100 parts by weight of hardener and 200 parts by weight of quartz sand with a grain size of 0.315 mm. Used concrete of industrial production of this composition (according to GOST 7473-94) – cement: sand: gravel: water = 300: 865: 1080: 155 kg/m^3.



(a)



(b)

FIGURE 1. Design of the experimental samples (a) and General view of the samples before concreting (b).

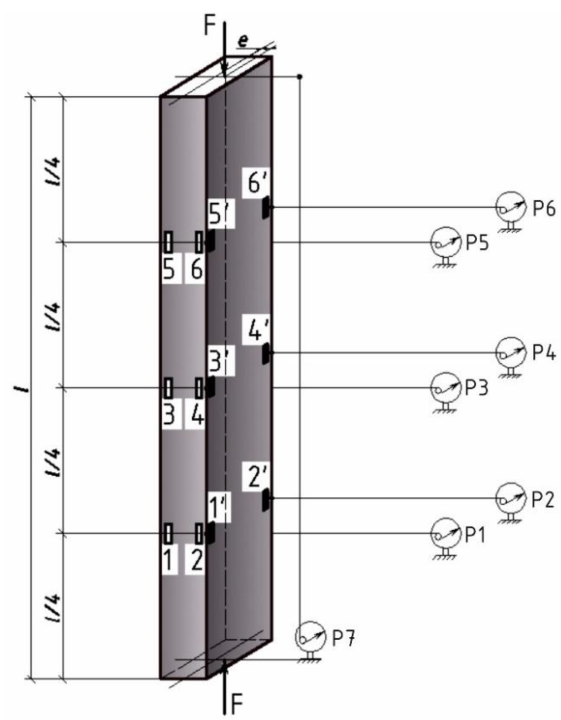


FIGURE 2. Location scheme of measuring equipment.

According to the program of experimental researches the change of a stress-strain state of experimental prototypes at action of eccentric compression loading with 2,5 cm eccentricity was studied. Deformations were measured with the help of electrotensor resistors, displacements – with clock-type indicators (Fig. 2).

During the tests of steel-reinforced concrete prototypes, clock-type indicators P1 – P2, P3 – P4, P5 – P6 were installed in pairs due to the ¼ heights of the investigated prototypes, which were used to measure the bends of the longitudinal axis of the samples relative to their initial position at all stages of loading (Fig. 2).

In the asymmetric scheme of applying the load to the support ends of the studied prototypes, the support sections rotated in different directions, the bends of the longitudinal axis in two opposite halves of the prototypes length also developed in different directions. At low eccentricity, the stability loss occurred in one direction, but with different intensity at a distance ¼ of length from the support sections.

The developed research methodology enabled studying their work under load in the laboratory. The characteristics of the stress-strain state at any stage of loading are also obtained. As a result of measurements made with the help of deflections meter and electrotensor resistors, graphs of the longitudinal axis bending (Fig. 3) and the dependence of relative deformations from the compressive load (Fig. 5 and Fig. 6) were obtained.

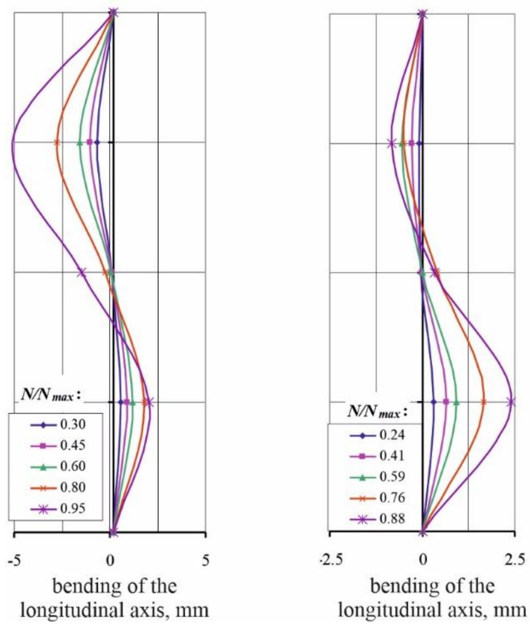


FIGURE 3. The scheme of bending of the axis of the samples: C1 - left; C2 – right.

It is noted that with an asymmetric load scheme, the pattern of deformation of the sample in height is almost the same. For the lower section of the sample 1-1, the compressed half of the section is, for example, on the left – from the side of the application of concentrated forces. The middle section is compressed almost across the entire width. And the upper section is in a deformed state, opposite to the lower: now the compressed half of the section is on the right side of the application of the upper concentrated force.

Deformations measured on the surface of steel and concrete parts of one half of the sections are almost the same. This indicates the joint work of steel and concrete parts of steel-reinforced concrete elements. The slight difference in deformation is explained by the presence of some distance between the measuring points – the location of electrotensor resistors on the concrete and steel parts.

In the practice of designing load-bearing structures, centrally compressed elements occur only if the random eccentricities of the application of the axial load belong to a certain limit value. Typically, such elements are calculated as eccentrically compressed, and central compression is only a partial case. In this case, the rack under the action of the compressive force N_c applied with the eccentricity e_c acts as a bending element.

The strength of compressed load-bearing elements with an adhesive joint of steel and concrete in order to take into account the properties of the seam should be performed according to the theory of composite rods.

Figure 4 shows a general view of the steel-reinforced concrete sample after testing and its stability loss. Its general appearance coincides with the bending diagram of the longitudinal axis during loading, shown in Fig. 3.

FIGURE 4. General view for sample C1 after testing.

The algorithm for determining the strength of normal sections of compressed elements with an adhesive joint of concrete and steel will look like this.

Arbitrary section of the rack is reduced to a rectangular shape so that the outer reinforcement was placed in the stretched area. We check compliance of the resulted section with conditions of optimum designing.

Determine the bending moment caused by external load.

$$M = N_c \cdot e_c \tag{1}$$

where N_c is the compressive force, e_c is the eccentricity of the force application.

Preliminarily estimate the load-bearing capacity of the section according to (2) and (3). If the conditions are not met, we review the parameters of the reduced cross section. The load-bearing capacity is checked separately for compressed and stretched zones, where z_b is the arm of the inner pair of forces.

$$M \le M_c = b \cdot x \cdot f_{cd} \cdot z_b \tag{2}$$

$$M \le M_s = A_s \cdot f_{yd} \cdot z_b \tag{3}$$

Approximately determine the shear forces by the formula (4)

$$T = \left(\frac{M^0}{v}\right)\left(1 - \frac{K_G \cdot M}{M^0}\right) \tag{4}$$

where K_G – stiffness coefficient, which we take $K_G \approx 0,8$; M – moment from external load; M^0 is the total bending moment that occurs in the cross section.

Preliminarily calculate the cross-sectional area of the reinforcement (5) and check its compliance with the conditions of optimal design.

$$A_s = \frac{N_s}{f_{yd}} = \frac{2 \cdot M^0 - T \cdot h_0}{f_{yd} \cdot h_0} = \frac{2 \cdot M_0}{f_{yd} \cdot h_0} \tag{5}$$

Determine the maximum shear force T_{max}, which occurs in the middle section of the compressed element.

$$T_{\max} = f_{yd} \cdot A_s - N_c \cdot \left(1 - \frac{2 \cdot e_c}{h_0}\right) \tag{6}$$

Finally, calculate the cross-sectional area of the reinforcement (5), using the value of the maximum shear force obtained for (6), and check its compliance with the conditions of optimal design.

Determine the height of the compressed zone x (7) and the arm of the inner pair of forces z_b (8).

$$x = \frac{\left(2 \cdot M^0 - T \cdot h_0\right)}{b \cdot h_0 \cdot f_{cd}} \tag{7}$$

$$z_b = \frac{M}{N_b} = \frac{M \cdot h_o}{2 \cdot M^0 - T \cdot h_o} \tag{8}$$

Use the value of the maximum shear force obtained by (6) and determine the bearing capacity of the reduced rods of the compressed element by (2) and (3).

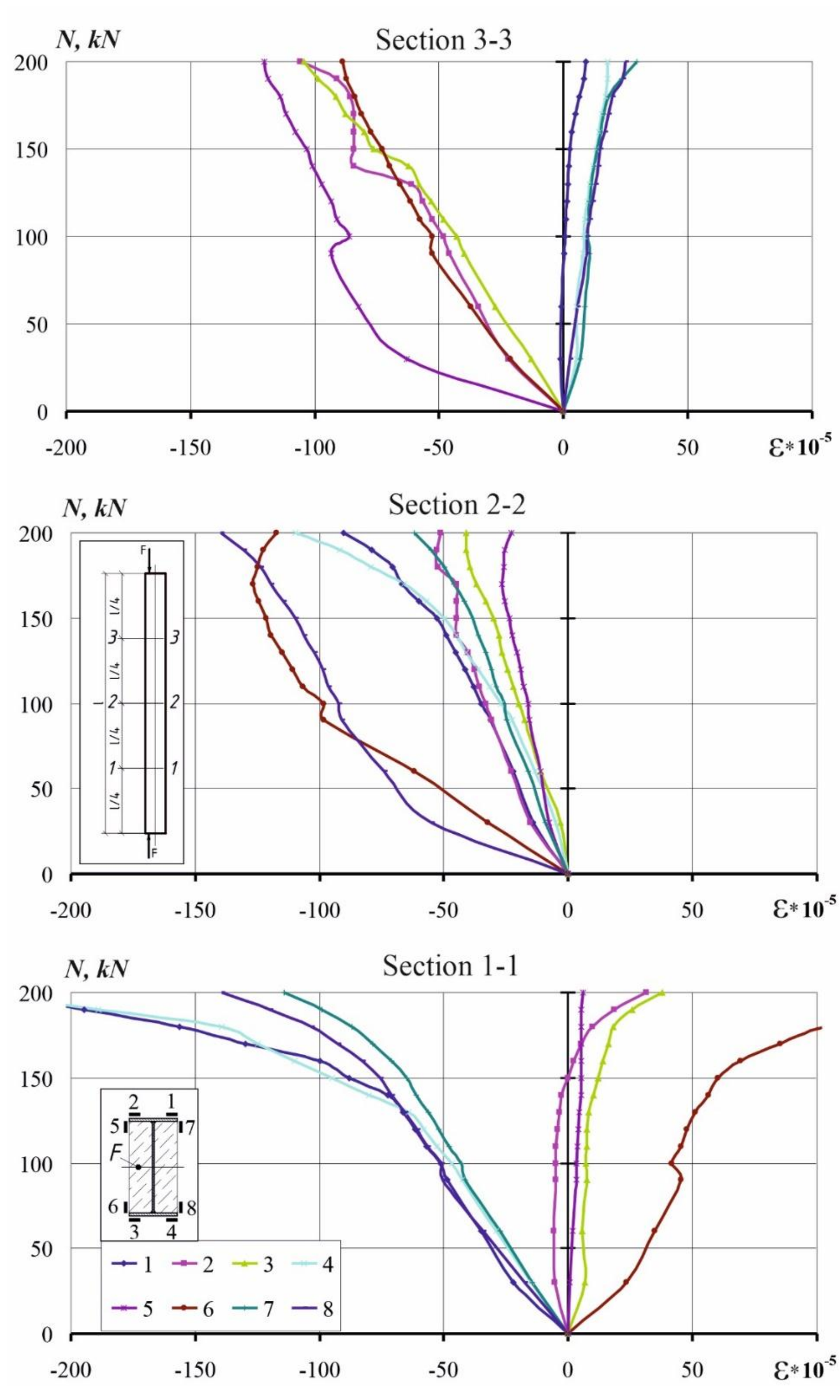


FIGURE 5. Graphs of deformation dependence from load. Sample C1.

Figures 5 and 6 show the dependences of the amount of longitudinal deformations of the tested samples. These dependences are given in three sections on the height of the samples: through ¼ their length. Accordingly, due to this length, electrotensor resistors were glued on the surface of the samples (steel and concrete parts) (Fig.2).

On the graphs the cross-sectional schemes of the samples are shown and the electrotensor resistors numbering located in these cross-sections (Fig. 5 and Fig. 6). The color that corresponds to a particular electrotensor resistors shows the “deformation-load” curves.

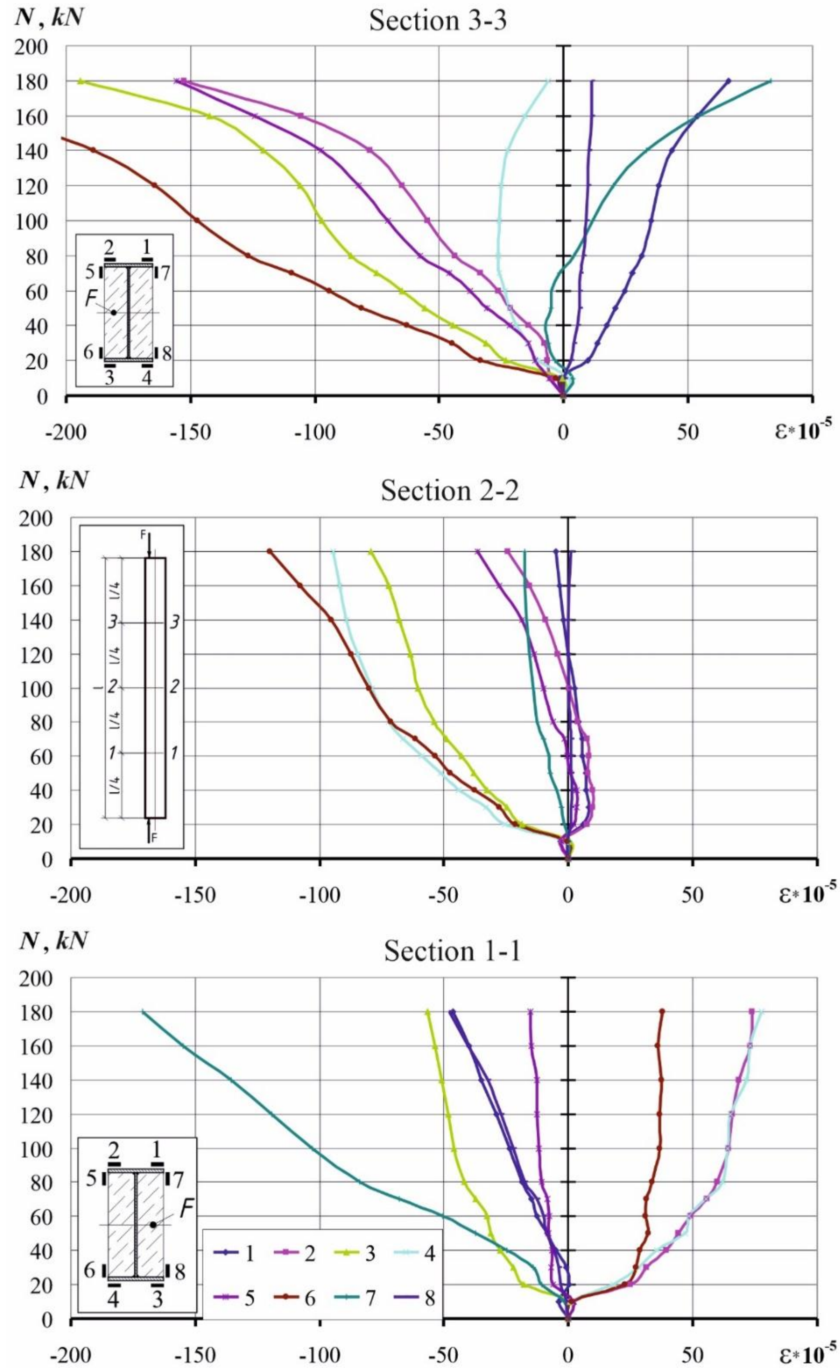


FIGURE 6. Graphs of deformation dependence from load. Sample C2.

CONCLUSION

The accepted test method and the used measuring devices allow to obtain the necessary experimental data to determine the bearing capacity and deformations with a given accuracy and the nature of the destruction of the test prototypes. At all stages of loading in constructions in which the technique of gluing of concrete mix to a steel part is used, their joint work is provided. Thus, it can be considered proven that acrylic adhesives can be used to ensure the joint operation of concrete and steel in the manufacturing process for steel-reinforced concrete structure.

Joining concrete to steel with acrylic glue ensures that the two components of the composite structure work together throughout the loading process. This confirms the gradual increase in the value of relative deformations. Comparing the test prototypes with the use of an adhesive joint of the steel contact surface with concrete and without it, we can talk about reducing the deformability of structures due to a more uniform stress distribution. The bearing capacity (189 and 200 kN) was not significantly affected by the presence of an adhesive joint in this type of structures due to the formation of a complex stress-strain state.

REFERENCES

1. S. Zolotov, P. Firsov & H. Muhamad, "Evaluation of Stress-Deformed Condition Level of Glued Materials for the Without Anchor Steel-Concrete Joint", In Lecture Notes in Civil Engineering, **47,** pp.95-102, (2020). https://doi.org/10.1007/978-3-030-27011-7_12
2. S. Zolotov, O. Pustovoitova, P. Firsov, H. Kais & S. Kamchatna. "Stress-strained state of steel-adhesive bonding on the acrylic adhesives", In IOP Conference Series: Materials Science and Engineering. Institute of Physics Publishing, **708,** pp.108-115, (2019). https://doi.org/10.1088/1757-899X/708/1/012117.
3. O. Skurupiy, Y. Davidenko, O. Horb, P. Mytrofanov. "Calculation of bending composite steel and concrete elements with glutinous connection of concrete and steel according to theory of compound rods", Lect Notes Civ Eng. **73**, pp.265-274, (2020).
4. L. I. Storozhenko. *Steelreinforced concrete: a collection of scientific works* (PoltNTU, Poltava, 2006). pp.386.
5. L.I. Storozhenko, O.I. Lapenko *Reinforced concrete structures in fixed formwork* (ASMI, Poltava, 2008). pp.312.
6. Mohan Gift, & Selvakumar Jaganathan & S. John Alexis, "Analysis of crack propagation in an adhesive joint", International Journal of Chemical Sciences, **14**, pp.485-496, (2016).
7. G.Jeevi & Sanjay Nayak & M. Kader, "Review on adhesive joints and their application in hybrid composite structures", Journal of Adhesion Science and Technology, **33**, pp.1-24, (2019). https://doi.org/10.1080/01694243.2018.1543528.
8. O. Shkurupiy, P. Mytrofanov, Yu. Davydenko O, O. Horb, "Statistical characteristics of strength distribution of normal sections of bended reinforced concrete elements and their analysis", Materials Science and Engineering, **708**(1), (2019). doi:10.1088/1757-899X/708/1/012072
9. O.I. Lapenko. *Reinforced concrete structures with working reinforcement with fixed formwork* (ASMI, Poltava, 2009). 360p.
10. Adkuji Hedaoo Namdeo. "Design of composite slabs with profiled steel decking: a comparison between experimental and analytical studies", International Journal of Advanced Structural Engineering, **3**. pp.118–133, (2012).
11. De Wit Nathan. *Composite Structural Steel and Prestressed Concrete Beam for Building Floor Systems*. (University of Nebraska, Lincoln, 2012), 112 p.
12. Veronica Mora & Magdalena Mieloszyk & Wieslaw Ostachowicz, "Model of moisture absorption by adhesive joint", Mechanical Systems and Signal Processing, **99**, pp.172–178, (2018). https://doi.org/10.1016/j.ymssp.2017.06.042.
13. M. Quiertant, & K. Benzarti & Julien Schneider & F. Landrin & M. Landrin & F. Boinski, "Effects of Ageing on the Bond Properties of Carbon Fiber Reinforced Polymer Concrete Adhesive Joints: Investigation Using a Modified Double Shear Test", Journal of Testing and Evaluation, **45,** pp.25–28, (2017). https://doi.org/10.1520/JTE20160587.
14. Jincheng Yang & Reza Haghani & Mohammad Al-Emrani, "Innovative prestressing method for externally bonded CFRP laminates without mechanical anchorage" Engineering Structures, **197**. pp.380–389. (2019). https://doi.org/10.1016/j.engstruct.2019.109416.