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STRENGTHENING AND REPAIRING THE SERVICEABILITY OF REINFORCED CONCRETE CONSTRUCTIONS: A REVIEW

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The main structures of modern buildings are using a RC constructions. Timely work on strengthening and restoration of building structures is very important in practice. There are many accumulations with many different ways and constructive methods of strengthening RC constructions in different conditions of application. This article describes the modern methods and innovative materials for the strengthening and repairing of RC structures. The current state and trends of development in this direction in the field of re-equipment and reconstruction of RC elements of buildings and structures, which raised the issue of operational suitability are analyzed. Scientific works of scientists of many countries of the world in the field of experimental researches of strengthening of RC constructions are processed.

Key words: RC structures; strengthening; repairing; composite materials; fiber-reinforced plastics.

Introduction

Today, reinforce concrete is one of the most common materials used in building structures. The properties of reinforce concrete as a synergistic system are determined by the joint work of concrete and reinforcement and the optimal use of the characteristics of these components, their bilateral complementarity and leveling of shortcomings. Considering the trend of strengthening and restoration of reinforce concrete structures, it is quite common to use these reinforce concrete structures outside the design period. Most reinforce concrete structures lose their load-bearing capacity in industrial areas, where they are exposed to chemical, electrochemical or biochemical aggression, which contributes to corrosive and abrasive processes of destruction of reinforce concrete. Industrial facilities, which mostly belong to the class of consequences of CC3, in the formation of damage and eventually destruction of major reinforce concrete structures, if not restored and strengthened in time, can cause man-made danger and social impact of technological security. To date, much research has been done in the direction of restoration and strengthening of various reinforce concrete structures. It is much more difficult to design reinforcement than new construction. This is due to the fact that, as a rule, in different cases there are features that should be taken into account in the reinforcement, and there is not enough guidance material on the strengthening of work, experimental research in this area (Blikharskyy Y., Kopiika, 2019; Blikharskyy Z., 2008). Therefore, a review of literature sources in this area of research in the reinforcement and restoration of reinforce concrete structures by methods that were presented from the first day when it was mentioned the need to strengthen to date using modern innovative methods and materials for their implementation.

The purpose of the work: to review the literature on the strengthening and restoration of the main building reinforce concrete structures for their safe operational suitability with the analysis of new innovative methods and materials.

Analysis of a priori sources on the research topic

They first tried to strengthen reinforce concrete structures until about 1912. For restoration application of a uniform layer of plaster was applied, laying of the reinforced layer of a long loaf is put by thin layers of a solution, often with addition of metal sawdust and shotcreting. To strengthen the reinforce concrete beams, which had oblique cracks due to insufficient cross-section of the clamps, Henri Lossier in 1936 used clamps that were pre-tensioned. He also recommended in the absence of longitudinal reinforcement to invest in additional pre-stressed reinforcement (Blikharskyy Z., 2008).

In 1938, a method of reinforcing beams with a sprung beam was patented in England by pre-tensioning it mechanically with tension bolts. Various clamps and unloading structures were often used, although the issue of reinforcement was studied by many engineers and scientists (R. Zaliger, Laprecht, A. Kleinlegel, E. Freisine, A. Lossier and others). In Russia in 1919, engineer V. A. Struve strengthened reinforce concrete columns with clamps with additional reinforcement and winding.

In the 1930s, unloading structures began to be used alongside the clips, the spread of which was facilitated by convenience and speed of execution. It should be noted that the practice of reinforcement was based on experimental studies. In 1933–1935, under the guidance of Professor O. O. Gvozdev, the adhesion of new concrete with the old one was studied, which was of great importance for the introduction of reinforcement with the help of clamps. In 1934, I. M. Litvinov, Candidate of Technical Sciences, performed work to strengthen the elements of reinforce concrete structures at the mine in Donbass.

In the Ukrainian Research Institute of Buildings and Structures in 1937, then in the laboratory of CNIMS in 1938, I. M. Litvinov conducted a large number of experimental studies, proposed and published strengthening of reinforce concrete structures by unilateral increase in cross section with the addition of reinforcement and proposed a method of reinforcement by means of one-sided building of reinforce concrete. In 1937–1938, in the laboratory of the Moscow Metro, engineer I. F. Sharov studied the method of shotcreting of shirts and overlays with the addition of horizontal fittings and clamps. In 1938, engineer A. A. Sudarikov tested reinforce concrete beams, reinforced with additional horizontal and oblique reinforcement, followed by increasing the cross section by concreting. In 1939–1940, under the leadership of V. V. Pinadzhyan, reinforce concrete beams reinforced with clamps and additional reinforcement were studied with the participation of Kazei II and P. M. Kichaev. Beams were dynamically loaded, simulating the load of bridge structures. As a result of these researches the question of possibility to carry out strengthening by clamps of reinforce concrete which are under the influence of mobile loadings has been solved. This was practically used in the reinforcement of a number of beam bridges. In 1942, an instruction was issued that systematized and summarized the results of design and experimental experiments using clamping methods (Blikharskyy Z. et al., 2017).

Questions on the study of the causes and methods of strengthening building structures have been analyzed in the works of many scientists: A. Y. Barashikova, P. I. Krivosheeva, S. V. Bondarenko, A. B. Golisheva, N. M. Onufrieva, F. E. Klimenko, D. Lazovsky, A. I. Malganova, O. I. Valovoy, V. S. Polishuk and others. Most scientists emphasize in their work that to solve the problem of predicting the stress state of bending and compressive elements after reinforcement, it is necessary to determine the stress state of elements before reinforcement and ensure joint work of two components, the reinforcing element and the reinforcement element itself (Klimenko, 1984; Malganov et al., 1992).

The main causes of damage to reinforce concrete structures are related to errors in calculation and design; low quality of concrete and reinforcement, violation of the technology of manufacturing structures, insufficient corrosion protection, excessive loads and extraordinary natural disasters. Bending reinforce concrete structures bearing floors, beams, trusses, etc. are most often damaged. A special place is occupied by damaged reinforce concrete structures of floors and coverings with high deflections and unacceptable

width of cracks. In addition to the negative aesthetic perception of such structures, the operational suitability of these structures is impaired. Traditional methods of strengthening of reinforce concrete structures are focused on the use of reinforcing metal reinforcement or rolled steel. Reinforcement is provided by increasing the size, the device of clips or shirts, the use of sprung systems. The main difficulties of such reinforcement are related to the need to ensure the joint work of reinforcement elements with the existing structure, which requires the performance of stripping work, welding to existing reinforcement, concreting elements.

During the reconstruction, it is often necessary to reinforce the existing structural reinforce concrete elements such as foundations, columns, beams, coatings, floors, engineering structures, etc. Traditionally, when reinforcing, additional elements are used: clamps (reinforce concrete or steel), double-sided or one-sided spacers, unloading elements (racks or supports), as well as pre-stressed structures – belts and clamps. The use of all these elements has several significant disadvantages: their volume significantly affects the internal geometry of the building, weight significantly complicates the design, and the work itself is quite expensive and time consuming, as they require an extended team of specialists and additional equipment.

Execution of traditional methods of reinforcement of reinforce concrete structures requires the use of additional equipment, formwork, welding and concrete work, requires considerable time to gain strength of concrete, has low efficiency, high cost and human complexity. And also in the conditions of operating industrial production these methods of strengthening cannot always be applied because of big weight of designs of strengthening, complexity of installation therefore are not economically favorable because of long idle time of the enterprise.

A significant part of the building structures of civil and industrial buildings and engineering structures are reinforce concrete beams. Increasing loads and damaging the beams necessitate their reinforcement. During the operation of buildings and structures, building structures are damaged due to corrosion of reinforcement and concrete, which leads to reduced load-bearing capacity, changing operating conditions, which significantly increase the load, which necessitates strengthening and restoration of structures. The traditional ways to strengthen structures are to increase their cross-sections by joining new elements, introducing Sprengels, arranging duplicate elements for unloading structures. In the conditions of current production, when there are no opportunities to stop production processes for a long time, changes in the spatial planning solution, traditional methods of strengthening structures cannot be used. That is why FRP composite materials have recently started to occupy an important place in the field of reinforcement of reinforce concrete structures (Matthys, 2000; Jung, 2015).

One of the new methods of reinforcing structural reinforce concrete elements is the use of composite materials and webs such as polymer composites (FRP – Fiber Reinforced Polymers) of these types carbon, glass or aramid fibers. When reinforcing existing reinforce concrete elements, composite materials are used, additional external reinforcement glued to their surfaces in the reinforcement zones (Arteaga et al, 2011; Perera, Ruiz, 2012).

This method of external reinforcement with composite materials: carbon fiber tapes and canvases using adhesives, repair and protective mixtures based on epoxy resins has a number of advantages over traditional methods of reinforcement, namely: high strength and deformability, light weight, manufacturability, resistance to aggressive external factors, the ability to repeat the shape of reinforced structures, endurance, ease of reinforcement, low complexity, ease of installation in the workplace. With the entry into force of the rules that provide for the calculation of elements using the deformation model, many questions arise, because composite materials, as a rule, have high anisotropic physical and mechanical properties. Considering the norms that set the parameters of the stress-strain state, there are new requirements for the reinforcement of structures that are subject to them. In this regard, there is a need to analyze existing methods and materials for reinforcing concrete elements and their effectiveness in practice, so there is a need for extensive experimental and practical research (Soupionis et al, 2020; Perera, Ruiz, 2012).

Analyzing the general methods of reinforcement with composite materials, we can distinguish three main types (Vegera et al., 2016): gluing composite material on the side surface of the element, gluing with the formation of a “shirt” reinforcement (U-shaped gluing) and reinforcement by creating a clip.

Their research of L. Chernyavsky, Yu. G. Khayutin, E. Z. Askelrod is presented in the form of recommendations for the design and implementation of reinforcement of bending reinforce concrete elements with composite materials. Performing reinforcement with carbon composites, so-called CFRP materials, in investigated the efficiency of their placement: reinforcement of inclined sections with one, two and three layers of material, but each layer was glued at a different angle to the axis of the element (Alzate, 2013; Trapko, 2015). Thus, the most effective method of arranging the composite material was determined. As a result of these studies, it was found that reinforcing the beam with one layer at an angle of 45° to the axis of the beam, the reinforcement effect is 33.2 %; reinforcement with two layers of composite fabric with the location of the fabric perpendicular and parallel to the axis of the beam – 27.8 %; placing the fabric at angles of 0°, 90°, 45°, to the axis of the beam – 47.6 %. The most effective method was to strengthen the beam with three layers of fabric at angles of 0°, 45°, 90° to the axis of the beam, but strengthening the beam with one layer at an angle of 45° also gave high results with significant material savings compared to other methods (Vegera et al, 2016).

One of the new methods of restoration of building structures that have been damaged in the form of wide cracks and excessive deflection, is focused on the use of reinforced fiber-reinforced plastics, which is a composite of fiber-reinforced man-made fibers in a plastic base. The use of surface reinforcement of reinforce concrete structures by gluing fiber-reinforced plastics on a concrete surface is easy to perform, short lead time, high efficiency, low complexity, reducing the cost of work. A primer is applied to the cleaned concrete surface and then plastic materials are glued. To restore the serviceability of damaged bending reinforce concrete structures, the use of pre-stressed fiber-reinforced plastics is proposed, which enhances the effectiveness of the method and materials for restoration and reinforcement of structures. The process of surface reinforcement with fiber-reinforced plastics takes several hours, and in a day the reinforced structure is able to absorb the necessary additional effort. Reinforcement does not increase the size of structures and their weight (Bespaiev, 2019).

In the last two decades in many developed countries of the world reinforcement of reinforce concrete structures is carried out with the use of composite fiber reinforced plastics. At the end of the last century in Japan, composite materials were first used to strengthen columns with clamps (Xiao, Ma, 1997). Later, a more perfect dependence of the strength of concrete in a fibroplastic holder was proposed, and later studies of bending reinforce concrete structures reinforced by gluing strips of composite material on concrete surfaces. In (Teng et al., 2002) the issue of strengthening fibroplastic materials of building structures from different materials is considered and the method of calculation of normal sections of reinforce concrete structures reinforced with laminate strips is proposed.

In Kazakhstan, a set of experimental studies has been performed in the following cases: compressed, bending, tensile and clamp-reinforced reinforce concrete elements with carbon fibroplastic materials under static and dynamic loads. On the basis of the performed researches methods of calculation of the reinforce concrete designs strengthened by composite fibroplastic materials at usual and seismic influences on a design are developed (Bespaiev, 2019).

Fibroplastic composite materials are characterized by high strength, elastic deformation and high corrosion resistance. They are supplied in the form of composite tapes, fabrics or grids that contain reinforcing fibers of carbon, basalt, aramid or polymer matrix glass from various resins (epoxy, phenolic, vinyl ether or other types of organic resins). Surface reinforcement by gluing fiber-reinforced plastics on damaged reinforce concrete structures significantly increases the load-bearing capacity and rigidity of bending elements, but they are included in the work of reinforced structures only with further load, although they reduce the rate of cracks and vertical deflections. Surface reinforcement of bending reinforce concrete structures does not restore the serviceability of damaged reinforce concrete structures. To restore the serviceability of damaged bending reinforce concrete structures, it is proposed to use pre-stressed composite fiber-reinforced plastics.

Conclusions

Having analyzed the a priori sources in the direction of the study of reinforcement and restoration of reinforce concrete structures, the following conclusions can be drawn. Existing traditional methods of strengthening of reinforce concrete structures are well studied and effectively used in practice for decades. To date, the strengthening of reinforce concrete structures, the most popular ways to build compressed or stretched areas, as highly effective and convenient in terms of reconstruction. The use of clamps (elements) has several significant disadvantages: their volume significantly affects the internal geometry of the building, the weight significantly complicates the design, and the work itself is quite expensive, as they require an extended team of specialists and additional equipment.

Traditional methods have been replaced by new ones with the use of innovative technologies, namely a variety of composite materials. Already today separate methods and schemes for strengthening reinforce concrete structures with new materials are being developed and implemented. Such a significant impetus in the development of this direction of reinforce concrete structures is caused by high reinforcement efficiency of up to 60 % without a significant increase in the cross section of the beams and a number of effective indicators.

Strengthening and restoration of reinforce concrete structures can have a number of advantages: corrosion resistance; 10 times greater strength; lightness (at least 5 times lighter than steel), ease of use; low cost of labor, ease of transportation, work without scaffolding (from car lifts with a basket): no dimensional restrictions and joints up to 250 m long; high atomic strength: the possibility of use in structures of different materials (concrete, steel, wood, brickwork); construction only with glue. Disadvantages of composite materials – relatively high cost of the material; low strength in the direction transverse to the fibers, which is often solved by new technologies and methods of installation (at an angle and in several layers of building) and fixing to the base.

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ПІДСИЛЕННЯ І ВІДНОВЛЕННЯ ЕКСПЛУАТАЦІЙНОЇ ПРИДАТНОСТІ ЗАЛІЗОБЕТОННИХ КОНСТРУКЦІЙ: ОГЛЯД

Основні конструкції сучасних будівель і споруд виконують із залізобетону, тому це один з найпоширеніших матеріалів. Передчасне руйнування конструкцій залізобетону, втрата несучої здатності та інших експлуатаційних якостей призводять до небажаних наслідків і часто спричиняють загрозу цілісності споруди, а також техногенну небезпеку й ефект соціального значення – складності забезпечення технологічної безпеки людей. Мета роботи – огляд літературних джерел щодо підсилення і відновлення залізобетонних конструкцій для їх безпечної експлуатаційної придатності з аналізом нових інноваційних методів та матеріалів. Своєчасне виконання робіт з посилення і відновлення будівельних конструкцій має дуже важливе практичне значення і сьогодні у вітчизняній та зарубіжній практиці дуже багато напрацювань із безліччю різних способів і конструктивних прийомів посилення залізобетону в різних умовах використання та прилаштування до складних систем. Перші підсилення залізобетонних конструкції виконано ще у 1912 р. і протягом 30 років закладено основні методи підсилення, які досліджують і удосконалюють дотепер та застосовують на практиці. Традиційні методи підсилення методом нарощування, улаштування сорочок і обойм та застосування шпренгельних систем є трудомістким процесом, що потребує додаткового обладнання та фахівців із виконання робіт, які затягуються на тривалий час. У статті описано на підставі апріорних джерел залізобетонні конструкції, підсилені та відновлені інноваційними матеріалами із композитних матеріалів, та експериментальні їх випробування. Традиційні методи підсилення мають багато недоліків та не завжди застосовні на місці експлуатації пошкодженої конструкції, порівняно із новими методами із використанням різноманітних композитних матеріалів, у яких є численні переваги. До переваг належать такі основні характеристики: корозійна стійкість; міцність; легкість, простота використання на різних матеріалах, реалізація на складних геометричних формах; висока атомна міцність.

Ключові слова: залізобетонні конструкції; підсилення; відновлення; композитні матеріали; фіброармовані пластики.