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DESIGN AND CALCULATION OF REINFORCED CONCRETE STRUCTURES

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Abstract. *The article explores the essential principles and methodologies involved in the design and calculation of reinforced concrete structures. Reinforced concrete has become a fundamental material in contemporary construction due to its versatility, durability, and ability to withstand various environmental conditions. This article aims to provide a comprehensive overview of the key aspects involved in the design process, encompassing structural analysis, material considerations, and safety factors.*

The discussion begins with an examination of the fundamental properties of concrete and reinforcement materials, highlighting their interplay in achieving optimal structural performance. Subsequently, the article delves into the principles of structural analysis, addressing the importance of understanding load distribution, moment-resisting systems, and other critical factors that influence the design process. Practical examples and case studies are incorporated to illustrate the application of these concepts in real-world scenarios. Furthermore, the article emphasizes the significance of complying with relevant design codes and standards, ensuring that the resulting structures meet safety requirements and industry regulations. Special attention is given to the various limit states, including serviceability and ultimate limit states, guiding engineers in the development of robust and resilient designs.

In addition, the article discusses the role of computer-aided design (CAD) and finite element analysis (FEA) tools in enhancing the efficiency and accuracy of the design process. These technological advancements empower engineers to simulate complex structural behaviors, optimize designs, and assess the performance of reinforced concrete structures under different loading conditions. The integration of sustainability considerations in reinforced concrete design is also explored, underscoring the importance of eco-friendly practices and materials to minimize the environmental impact of construction projects.

In conclusion, this article serves as a valuable resource for engineers, architects, and construction professionals involved in the design and calculation of reinforced concrete structures. By providing a comprehensive understanding of the principles, methodologies, and technological tools involved in the design process, the article aims to contribute to the development of safe, efficient, and sustainable structures in the field of civil engineering.

Key words: *concrete, precast concrete, monolith concrete, reinforced concrete, finite element analysis, computer-aided design.*

Introduction.

Reinforced concrete, with its unique combination of strength, durability, and versatility, stands as the backbone of modern construction. As populations burgeon and urban landscapes evolve, the demand for innovative and structurally sound solutions becomes increasingly paramount. In response to this imperative, the article titled "Design and Calculation of Reinforced Concrete Structures" embarks on a journey to unravel the intricate processes involved in creating robust and resilient structures.

This article serves as a comprehensive guide, delving into the fundamental principles that govern the design of reinforced concrete structures. From understanding the properties of concrete and reinforcement materials to navigating the intricacies of structural analysis, the narrative unfolds with the aim of providing engineers, architects, and construction professionals with a holistic understanding of the design process.

Moreover, the article explores the critical role played by technology in advancing the field. Computer-aided design (CAD) and finite element analysis (FEA) tools have revolutionized the way structures are conceptualized and optimized, offering engineers unprecedented insights into the behavior of reinforced concrete under varying conditions.

As sustainability becomes an increasingly integral consideration in the realm of construction, this article also investigates the incorporation of eco-friendly practices and materials in reinforced concrete design. By aligning structural innovation with environmental responsibility, the article seeks to contribute to the development of not only safer and more efficient structures but also a more sustainable future for the built environment.

In the subsequent sections, we delve into the essential components of reinforced concrete design, exploring the intricacies of structural analysis, material considerations, compliance with industry standards, and the integration of cutting-edge technologies. Through a synthesis of theoretical insights and practical examples, this article endeavors to empower professionals with the knowledge and tools necessary to navigate the evolving landscape of reinforced concrete construction.

Main text

One of the pioneers of the introduction of reinforced concrete in Ukraine was engineer S. Rudnytskyi, who worked in Odesa. Between 1889 and 1907, his construction office built about 100 reinforced concrete tanks on the railroad tracks, used reinforced concrete in the structures of the Bessarabian Market in Kyiv, the stearin factory, and some residential and commercial buildings in Odesa.

In 1894, on the initiative of M. Tullier, a reinforced concrete bridge-arch with a span of 11.05 m was built in the courtyard of the Higher Polytechnic School as an exhibit for an exhibition held in Lviv at the time.

At the beginning of the nineteenth century, engineers of zemstvos, railroads, university professors, especially professors S. Prokofiev, Y. V. Stolyarov, E. Paton, engineers Y. Uspensky, N. Pyatnytsky, A. Ginzburg, V. Leontovych, N. Letunovsky, I. Kyrylenko, S. Vislotsky, and many others.

In 1901, for the first time in Ukraine, concrete bored piles were used to construct the foundations of St. Nicholas Church in Kyiv.

The American Concrete Institute, contains the following basic definitions [1]:

Concrete is a mixture of portland cement or any other hydraulic cement, fine aggregate, coarse aggregate, and water, with or without admixtures.

Concrete can be classified as composite material and that is a combination of different components which improve their performance properties. In general case binder component which can be in hard crystalline or amorphous state is considered as the matrix of composite material. In concrete matrix phase the grains of aggregates (dispersed phase) are uniformly distributed.

The largest building with a full reinforced concrete frame was a six-story commercial bank in Kharkiv (1913, architects A. Rzepyshevsky and N. Vasyliev). The building is a frame building with a specially designed brickwork infill.

The spread of reinforced concrete structures made it possible to use them in industrial construction. These include bunkers, silos, re-servoirs and water towers in Kerch, Yekaterinoslav, Mykolaiv, Khartsyzsk, Yalta, Odesa, etc.

In Ukraine, the most prominent engineering structure made of monolithic reinforced concrete is the lighthouse in Mykolaiv. It is the world's first structure of this type. In 1903, engineer N. K. Pyatnitsky and architect A. A. Baryshnikov designed the lighthouse in three versions (metal, brick, and reinforced concrete). A feasibility analysis revealed the advantages of the reinforced concrete version. The lighthouse structure is a cone-shaped tube 36 meters high with a wall thickness of 29 cm. The authors dedicated this work to their teacher, the famous scientist F. S. Yasinsky. N. A. Belelyubsky participated in the development of the project.

The feasibility of using precast concrete was recognized as early as 1902. Thus, engineer N. K. Pyatnytskyi wrote that the shortcomings of monolithic reinforced concrete made it necessary to create a floor that could be laid in finished form on the site. And in such a way that the molds for its manufacture could be used several times.

Among the first precast concrete elements were slabs, stairs, pipes, piles, and elements of reinforced concrete bridges.

Admixture is a material other than hydraulic cement, aggregate, or water, used as an ingredient of concrete and added to concrete before or during its mixing to modify its properties. In this section, unless indicated otherwise, these definitions apply to the terms concrete and admixture [4].

Precast concrete structures are the most common in modern construction. Their main advantages are high industrialization and the possibility of significant use of cheap local building materials. It is advisable to use such structures [2,7,4,8] in:

1) residential and civil buildings (large-panel and bulk-block multi-storey residential buildings, frame-panel general-purpose buildings, elements of floors, roofs, stairs, foundations, etc;)

2) industrial buildings (truss beams with a span of up to 18 m, trusses with a span of 18 and 24 m, crane beams with a span of 6 and 12 m, roofs of multi-storey buildings with a grid of 6x6, 6x9 and 6x12 m columns, shells, foundation beams, foundations, piles, etc;)

3) agricultural buildings (columns, frames, beams, slabs, arches, wall panels,

vineyard posts, etc;)

4) in engineering structures (road and railroad bridges-overpasses, transport galleries, pipes, retaining walls, re-tanks, bunkers, elevators, power line poles, etc;)

5) hydrotechnical and marine structures (buildings of thermal, nuclear and hydroelectric power plants, dam slopes, quays and piers, coastal protection devices, etc.)

Monolithic reinforced concrete structures have some positive qualities compared to prefabricated ones: no joints, indistinguishability of structures, higher rigidity and monolithicity, which reduce material consumption and increase seismic resistance. However, their use is economically viable only in the following cases:

1) when it is possible to use reusable sliding or sliding formwork;

2) during the construction of facilities where the use of unified prefabricated elements is impossible;

3) when concreting structures at the construction site does not slow down the pace of construction and does not hinder other works at the same time.

In recent years, monolithic reinforced concrete structures have become increasingly used, they are successfully used in the construction of residential and general purpose buildings, as well as elevators that are built in sliding formwork (or interchangeable), in hydraulic and marine construction, etc. Sometimes it is advisable to use precast concrete structures, which practically do not require formwork (it is performed by prefabricated parts of the structure) and are characterized by simplicity and low metal consumption of joints [7].

The structure of concrete is highly heterogeneous; it consists of a simple cement stone lattice filled with grains of sand and gravel containing a large number of micropores and capillaries.

In a compressed concrete specimen, stresses are concentrated on the stiffer particles, so a force tends to break the bond between the particles along the connection planes. At the same time, compressive and tensile stresses are concentrated near the pores. And since there are many grains in concrete, tensile stresses overlap. As a result, concrete with poor tensile strength is destroyed by tearing in the transverse direction.

The absence of regularity in the arrangement of particles of hardened concrete, as well as in the location and size of the specimens leads to a scattering of strength indicators when testing specimens from the same concrete. Concrete strength increases over time as concrete hardens over years.

Typically, after concrete reaches the age of 28 days, the increase in strength over time is not significant. Therefore, concrete is tested for compressive strength after 28 days, or the test results are adjusted to the 28-day results by multiplying the strength values by the correction factors obtained during comparative tests.

The strength of concrete depends on the shape and size of the specimens. In Ukraine, a concrete cube with a side of 15 cm is accepted as a normal specimen; with a decrease in the size of the cube, the strength increases, with an increase - decreases, since the probability of defects increases with large sizes. The conversion factors to a normal cube with a side of 15 cm are as follows: from a cube with a side of 10 cm - 0.91, from a cube with a side of 20 cm - 1.12.

As the height of the specimen increases, the compressive strength of concrete decreases, but at 3<h/a≤8 (where h is the height of the prism, and a is the side of its base), the strength of the prisms practically becomes constant.

In the United States, a cylinder with a diameter of 15.2 cm and a height of 30.5 cm is considered a normal specimen. The tensile strength of a cylindrical specimen is 0.7-0.75 of the tensile strength of a normal cube [2].

The concrete class, or cubic strength, is a conditional indicator, since the friction between the supporting faces of the specimen and the press plates causes a complex stress state in the specimen. A better idea of the uniaxial compression strength of concrete is provided by testing prisms with a height 3-4 times higher than the side of the base, since the influence of friction is negligible in the middle part of the prism.

The strength of concrete prisms (prism strength) can be determined by the cubic strength, since there is a fairly stable relationship between these characteristics: for heavy concretes, concretes with porous aggregates and porous but not less than 0.72C [2]:

$$f_{ck,prism} = (0.77-0.001\,C)\,C. \quad (1)$$

The prismatic strength of concrete is used in the calculation of bending and compression of structural elements (beams, columns, compressed elements of trusses, arches, etc.).

In the case of a clean cut, which is rare in practice, the tensile strength is determined by the empirical formula [3,5]

$$f_{cw} = 0,7\sqrt{f_{ck} f_{ctk,0\,05}} \text{ or } f_{cw} = 2 f_{ctk,0\,05}\,. \quad (2)$$

Reinforcement of reinforced concrete structures consists of working reinforcement (rods, wires, ropes), which are placed according to the acting forces, and structural and installation reinforcement to combine working reinforcement into reinforcing meshes or cages.

In this case, working reinforcement is divided into reinforcement for reinforcing conventional reinforced concrete structures and reinforcement for reinforcing prestressed concrete structures.

The results of many experiments on bending elements up to fracture revealed the dependence of the stress-strain state (SSS) of these elements on the size of the load. In the case of a steady increase in load, three stages of stress deformation can be distinguished [8].

Stage I. At low loads (bending elements), the stresses in concrete and reinforcement are small, and predominantly elastic deformations develop in concrete. The relationship between stresses and deformations is almost linear, and the stress diagrams in both the compressed and tensile zones can be considered triangular

Stage II. With a further increase in load, cracks appear in the concrete of the tensile zone, which increase up to the neutral axis; in places where cracks have formed, the concrete is excluded from operation and only the reinforcement perceives tensile stress. In the compressed zone, the stress curve in concrete becomes curved.

Stage III. In the case of further load increase, cracks in the tensile zone open, stresses in the materials increase, and the bearing capacity is exhausted (beam failure). At this stage, inelastic deformations cover a significant portion of the compressed zone, and the stress curve in concrete has a distinctly curved-linear shape. The criteria for the exhaustion of the bearing capacity are based on the occurrence of one of three cases. The first is the achievement of the ultimate deformation of the concrete in the compressed zone ($\varepsilon_c = \varepsilon_{cu}$), the second is the rupture of the tensile reinforcement ($\varepsilon_s = \varepsilon_{ud}$) and the third is the loss of deformation resistance [7,8].

A structure may lose its required performance for one of two reasons [8]:

1) due to the exhaustion of the bearing capacity (destruction of the material in the most stressed sections, loss of stability of some elements or the entire structure);

2) due to large deformations (deflections, vibrations, settling), as well as due to the formation of cracks or their large opening.

In accordance with these two reasons, which can lead to the loss of performance of structures, two groups of their design limit stages are established:

1) by loss of bearing capacity;

2) unsuitability for normal operation.

The basic calculation complexes based on the finite element method and allowing to perform calculations of reinforced concrete structures are LIRA, Revit, Tekla. All of them have the ability to create three-dimensional models, calculate the parameters of structures and produce the necessary documentation.

Summary and conclusions.

The article on the "Design and Calculation of Reinforced Concrete Structures" has provided a comprehensive exploration of the fundamental principles, methodologies, and technological advancements involved in creating robust and sustainable structures. It commenced with an overview of the essential properties of concrete and reinforcement materials, emphasizing their collaborative role in achieving optimal structural performance.

The discussion extended to the intricacies of structural analysis, covering crucial aspects such as load distribution, moment-resisting systems, and the application of various limit states. Practical examples and case studies were integrated to illustrate the practical application of these principles in real-world scenarios.

The article highlighted the importance of compliance with industry codes and standards, ensuring that the resulting structures meet safety requirements and adhere to regulatory guidelines. Special attention was given to the incorporation of sustainability considerations, emphasizing the need for eco-friendly practices and materials to minimize the environmental impact of construction projects.

Furthermore, the role of technology, specifically computer-aided design (CAD) and finite element analysis (FEA) tools, was explored. These tools were shown to enhance the efficiency and accuracy of the design process, enabling engineers to simulate complex structural behaviors, optimize designs, and assess performance under various loading conditions.

In conclusion, the article underscores the vital role of reinforced concrete in contemporary construction and provides a roadmap for engineers, architects, and construction professionals involved in the design and calculation of structures. The integration of theoretical insights with practical examples equips professionals with the knowledge necessary to create structures that not only meet safety standards but also contribute to a more sustainable built environment. The emphasis on compliance with industry standards and the incorporation of cutting-edge technologies reflects a commitment to ensuring that reinforced concrete structures are not only durable but also adaptable to evolving challenges. As the construction industry continues to evolve, this article serves as a valuable resource, fostering a deeper understanding of the intricacies involved in the design and calculation of reinforced concrete structures, ultimately contributing to the advancement of engineering practices and the development of safer, more efficient, and sustainable structures.

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