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# PREFACE

In the early third millennium, the artificial environment is characterized by the widespread use of concrete as a building material. The dominant position of cement concrete in construction is explained by the availability of unlimited raw materials in the Earth's crust, their relatively low cost, and the good physical and mechanical properties of concrete. Additionally, the continuous efforts of scientists and practitioners to improve high-strength concrete and enhance its physical and mechanical properties ensure its leading position among construction materials.

The ultimate result of numerous improvements is the rational use of concrete in building elements and structures. The combination of the beneficial properties of concrete and steel in reinforced concrete elements has secured the prominence of this material in load-bearing structures. The introduction of prestressing in reinforced concrete elements has allowed for relatively inexpensive, crack-resistant, and durable structures for buildings and facilities.

In the first half of the twentieth century, two fundamental methods of prestressing rebars and concrete compression were proposed: **"pre-tensioning"** and **"post-tensioning"**. Today, hundreds of approaches exist to implement these methods. Most of them have been well studied, and some of the best have been practically applied. Almost all of these approaches share one common feature: they involve transferring the prestress force of steel onto already hardened, high-strength concrete.

The potential for developing new, more efficient prestressing methods within the narrow framework of a single force transfer principle has largely been exhausted. According to most experts, this has led to a slowdown in progress in this field. In this situation, further development requires a qualitative transition to fundamentally new principles of prestressed concrete that would set a precedent for the rapid growth of ideas and innovations.

While working on this problem, the author proposed creating prestressing even at the stage when the cement concrete components are still in the mixture form. That is, instead of waiting for the concrete to harden, the pre-compression force is applied directly to the fresh mix. In this process, the concrete mix is compacted and hardens under pressure, significantly increasing the concrete's strength in the structure. The rebar prestress is preserved due to the fact that, after compaction of a specially selected concrete mix, a sufficiently strong and rigid skeleton is formed from its solid constituents, and to it are the prestressed rebars fully or partially anchored.

Thus, a dual effect is achieved in a single technological operation: compacting the concrete mix through compression and tensioning the steel. As a result, the structure achieves high crack resistance and superior strength.

The practical implementation of the principle of transferring prestress force to freshly placed concrete requires the development of new technological solutions, including innovative, movable formwork systems capable of withstanding compression. Today, this new technology has been successfully developed and introduced into production and has been used in manufacturing large-scale reinforced concrete bridge elements.

# CHAPTER 1
# PRESTRESSED REINFORCED CONCRETE STRUCTURES AND THEIR PROPERTIES

## 1.1. Methods of Creating Prestress in Reinforced Concrete Structures

The first attempts to create prestressed reinforced concrete structures date back to the late 18th century. In 1886, a patent application (USA 875999) was filed in the United States, followed by a similar proposal in 1888 by W. Doering in Germany (DRP 535.48). These patents introduced reinforced concrete elements with prestressed reinforcement to prevent cracking in the tensile zone of concrete.

The concept of counteracting external loads with internal prestress was first expressed by G. Mendl in the Viennese journal *Zeitschrift d. Oster. Ing. u. Arch. Ver* in 1896.

In 1905, I. G. Lund from Norway proposed placing pre-stretched steel rods with threaded ends in floor slabs to prevent concrete cracking [1, 2]. In 1906, M. Kenen in Berlin conducted experiments with prestressed reinforcement encased in concrete. These tests demonstrated a significant increase in the load required to initiate cracking.

In 1908, K. R. Steiner suggested preventing early bonding between reinforcement and concrete, allowing the steel rods to be tensioned only after the concrete had gained sufficient strength (USA patent 903909). In 1910, Ziseler in Germany [3] and Sigwart in Switzerland applied steel wire wrapping under tension around concrete pipes, with Sigwart using a prestress of 62.5 MPa.

In the same year, 1910, K. Bach and O. Graf reported in their research [4] on the use of reinforcement subjected to a stress of 60 MPa in experiments. The curved placement of prestressed reinforcement followed by concreting was patented by V. Wilson in British patent No. 103681 in 1916.

In 1919, K. Wettstein (Bohemia) was the first to use thin wire, with a diameter of 0.3–1.2 mm and high initial tension, as prestressed reinforcement. By 1921, he had already demonstrated that thin high-strength wire could self-anchor in concrete [5]. In 1922, W. H. Hewett from the United States successfully eliminated tensile stress in circular reinforced concrete tanks by applying wire tension [6].

Between 1923 and 1925, R. H. Dill in the United States proposed a method for producing prestressed beams by tensioning high-strength steel wire after the concrete had hardened. To prevent early bonding, he suggested applying a protective coating to the wire. Dill's approach is considered a precursor to the modern post-tensioning method, where prestress is transferred to fully hardened concrete (Figure 1.1).

In 1927, Rich Ferber patented (DRP 557331) a technique for placing unbonded steel reinforcement in concrete, allowing post-hardening tensioning. He suggested coating steel with paraffin or installing metal or cardboard sleeves, a concept now used in modern tendon ducts. The latter, as is known, has been reflected in modern conduit formers for reinforcement.

During that period, most prestressing methods provided only temporary strengthening, improving crack resistance in the early stages. Over time, the prestress diminished, and structures behaved like conventional reinforced concrete. This was due to relaxation in the reinforcement, shrinkage, and creep of concrete, leading to losses in prestress force.

Prestressed reinforced concrete became widely used only after 1928, when E. Freyssinet convincingly demonstrated in French patents 680547 and 36703 that reinforcement needed to have a tensile strength above 400 MPa and a high yield limit. His work focused on pre-tensioning on fixed supports before casting (pretensioning) (Figure 1.1).

For the production of prestressed concrete pipes, E. Freyssinet suggested simultaneous compaction of concrete through pressure and transverse reinforcement tensioning [8, 9]. By 1938–1939, Germany had industrialized the manufacture of such pipes, using internal pressure to stretch circumferential reinforcement. Here, excessive internal pressure was created to tension the wound reinforcement wire.

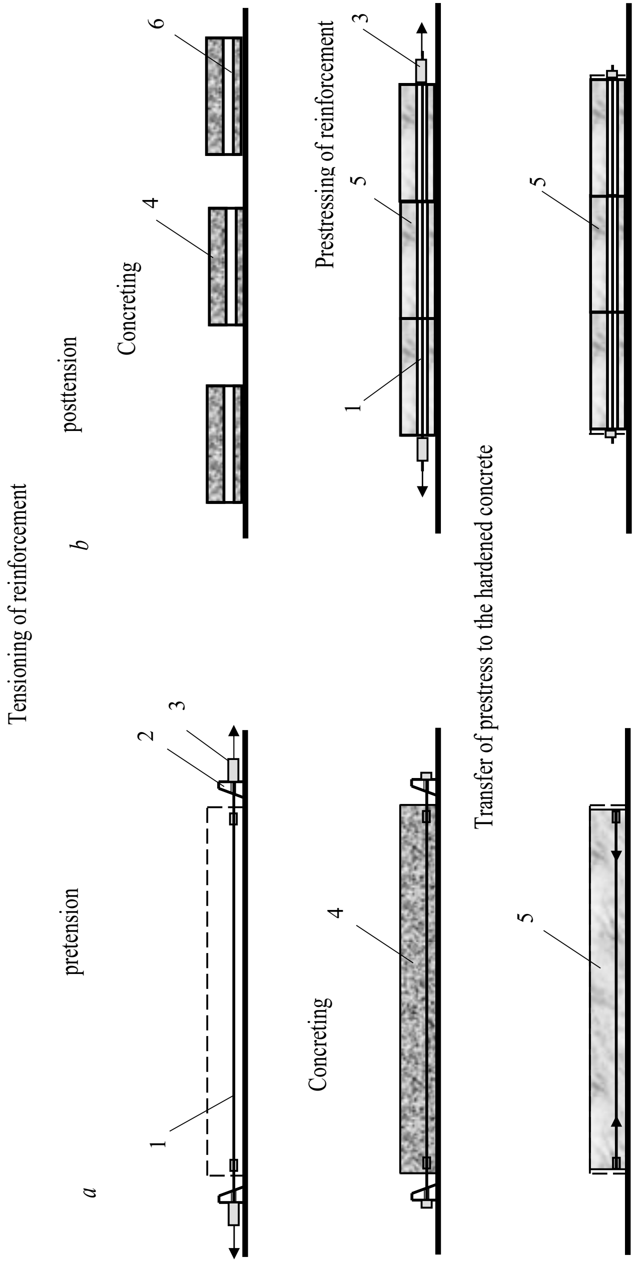


**Figure 1.1. Diagram of prestress formation in reinforced concrete elements:**
***a*** *– Pretensioning method;* ***b*** *– Post-tensioning method:*
*1 – Reinforcement; 2 – Abutment; 3 – Jack; 4 – Concrete mix; 5 – Hardened concrete; 6 – Duct; 7 – Anchor*

As a result, the pipe diameter increased by an amount corresponding to the elongation of the circumferential reinforcement. High-quality compaction of the concrete mixture was ensured by the application of radial pressure on the outer surface of the pipe. The ratio of external to internal pressure during production shifted over time in favor of the latter. It was recommended to carry out concrete compaction by pressing when the setting process had already begun.

In the 1939 work [10], F. Emperger proposed mixed reinforcement of reinforced concrete structures with partial prestressing. F. Emperger's idea became highly relevant for the further development of reinforced concrete element design. The concept of placing prestressed reinforcement in open ducts, followed by tensioning on hardened concrete and filling the duct with concrete, was introduced by P. Abeles (England) in 1942–1943.

In 1942, K. B. Bilner from the USA proposed a thermoelectric method for prestressing reinforcement. The distinctive feature of this method was coating the reinforcement bar with a thermoplastic material containing sulfur and tensioning it after the concrete had hardened by passing an electric current through the bar. In this process, the heated coating of the reinforcement softened and acted as a lubricant, helping to reduce prestress losses caused by friction in the reinforcement.

In the 1940s, the Bauer–Leonhardt method [11] was developed in Germany for the simultaneous tensioning of all prestressed reinforcement on hardened concrete. This method was used in the construction of several bridges [12; 13].

After 1945, several major works on prestressed concrete were published abroad, including those by I. Guyon, G. Magnel, E. Mörsch, F. Leonhardt, P. Abeles, H. Rüsch, T. Lin, L. Pacholík, G. Kani, and many others [14–21]. Similar to most foreign authors, Dr.-Ing. G. Kani, in his work [22], considered prestressed concrete as an independent material, obtained by transferring the prestressing force from the reinforcement to hardened, strong concrete.

The fundamental works of Professor F. Leonhardt, published in translation in 1957 and 1983 [23], made a significant contribution to the development and generalization of the results of earlier research on prestressed reinforced concrete. Notably, both by 1955 and 1980, when these books were first published, the methods of prestressing reinforced concrete structures known in global practice remained within the framework of two techniques: tensioning the reinforcement against anchors (force-based method) before the concrete mixture had hardened, and tensioning the reinforcement on hardened concrete (Figure 1).

This is confirmed by data from A. Komendant's book [24], as well as the concluding materials of the International Federation for Prestressed Concrete (FIP) and the current International Federation for Structural Concrete (fib) [25–28]. In the book by Polish authors A. Ajdukiewicz and I. Mames [29], published in 1984, the creation of prestress in reinforced concrete structures is also noted to be carried out using these two aforementioned methods.

In all the cited works, regardless of the reinforcement tensioning method, prestressing was achieved by transferring the tensioning force from the reinforcement to the hardened concrete. Significant contributions to the development of efficient prestressed reinforced concrete structures were made by researchers such as A. A. Gvozdev, V. V. Mikhailov, S. A. Dmitriev, O.Ya. Berg, G. I. Berdichevsky, V. V. Baikov, A.Ya. Barashikov, A. P. Vasiliev, L. I. Storozhenko, T. M. Petzold, A. L. Shagin, A. I. Kozachevsky, and I. P. Shapoval. In the creation of new types of prestressed reinforcement and methods of tensioning, notable contributions were made by K. V. Mikhailov, N. N. Mulin, A. P. Korovkin, and E. G. Ratz. Research into the properties of prestressed concrete was advanced by S. V. Alexandrovsky, I. N. Akhverdov, F. I. Ivanov, I. I. Ulitsky, A. B. Golyshev, G. A. Klimov, A. E. Sheikin, V. M. Moskvin, and many others. In the field of bridge construction using prestressed reinforced concrete elements, significant achievements were made by N. M. Kolokolov, E. A. Troitsky, E. L. Shcherbakov, A. V. Zakharov, A. I. Druganova, Ya.D. Livshits, A. L. Tseitlin, and G. B. Fuks [30–46].

V. V. Mikhailov was the first to develop the method of continuous reinforcement (author's certificates No. 61894, 77326, 88356), which involved winding the reinforcement wire in a stressed state onto the supports of a stand or force-based form. Prestressing was achieved by passing the wire through blocks and devices of a tensioning machine equipped with a tensioning station and a counterweight. The transfer of the prestressing force using this method was applied to the hardened concrete of the structure [31].

The problem of creating and calculating modern prestressed reinforced concrete structures has been addressed in the works of A. S. Zalesov, E. N. Kodysh, L. L. Lemysh, I. K. Nikitin [47], A. B. Golyshev, V.Ya. Bachinsky, V. I. Polishchuk, A. V. Kharchenko, I. V. Rudenko [48], V. N. Baikov and E. E. Sigalov [49], A. N. Kudzis [50, 51], A.Ya. Barashikov [52], G. B. Murashkin [53], E. M. Babich [54], O. A. Gershberg [55], L. K. Luksha [56], A. S. Dekhtyar [57], L. A. Murashko [58], L. I. Iosilevsky [59], A. E. Lopashto [60–63], Yu.A. Klimov [64], V. A. Sekhniashvili [65], V. M. Bondarenko and D. G. Suvorkin [66], B. V. Stefanovich [67], O. A. Volyansky [68], and many others. All these works highlight the possibility of prestressing reinforced concrete structures using either the “anchorage” method or the “hardened concrete” method. In both cases, the transfer of the prestressing force to the concrete occurs after it has gained sufficient transfer strength.

Recently, technologies aimed at reducing the production cycle of prestressed reinforced concrete structures and increasing their strength have been actively developed. These include methods that involve simultaneous pressing and tensioning of reinforcement, followed by the transfer of the prestressing force to hardened concrete. Under the supervision of Prof. G. V. Murashkin, a press mold was developed and tested for producing rectangular cross-section elements (author’s certificate No. 1390034), with the transfer of prestressing force applied to hardened concrete. This method involves transverse pressing of the solid prismatic element by externally applying pressure to its lateral surfaces. This process achieves tensioning of the longitudinal reinforcement and compaction of the concrete mixture, ensuring high concrete strength in the finished product. It should be noted, however, that achieving high-quality transverse pressing for large volumetric elements is challenging, and controlling the prestressing force of the reinforcement is difficult to carry out.

A reinforced concrete element with a rectangular cross-section and a hollow core can be manufactured through simultaneous pressing and prestressing of transverse reinforcement, as proposed by