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PRESTRESSING OF CONCRETE STRUCTURES USING THE DURING – TENSIONING METHOD

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The improvement of building structures, development of alternative methods of prestressing, expansion of the boundaries of technological approaches create opportunities for the rational use of construction materials, contribute to increasing efficiency in construction. Such methods are based on physical laws, provisions of theoretical and building mechanics, resistance of materials and take into account the properties of building materials and the practice and experience of manufacturing and operating building structures.

Prestressed concrete structures are usually manufactured according to post-or pretensioning technology. There are a great number of proposals as to the application of these technologies. The majority of them are well studied, and some of the best ones find their practical use. Almost all these suggestions can be united according to the principle of the steel prestressing transfer, namely onto the strong hardened concrete. The possibilities of manufacturing more effective prestressed reinforced concrete structures in the limited frames of the single principle are in many respects exhausted. Many specialists think it is the reason for slowing down progress in this direction. We need here qualitative transition to new concepts in the sphere of prestressed concrete to have precedents for rapid flourishing of ideas and developments.

The author has proposed and put into practice the principle of prestressing transfer onto the freshly placed concrete mix of structures. In this case prestressing is transferred already at the stage of cement concrete mix.

The new production technology has led us to the possibility of increasing concrete strength in prestressed structures up to 50-70 per cent. It is achieved due to the compressing of unset concrete mix during the operation of steel tensioning. A wide range of research and practical studies has shown that the given technology provides necessary steel pretensioning and uniform or predetermined concrete mix compaction as well as further hardening of concrete in a structure.

Taking the experimental research data as a basis, we can state that the self-organization of concrete structure at the stage of mix prestressing, effective bond between concrete and steel, preservation of the force of prestressing – all this becomes a guarantee for high strength and quality of the concrete elements proposed. Industrial application of prefabricated bridge elements with prestressing onto the concrete mix has proved the expediency of the method developed.

Key words: *prestressed concrete, beam, column, compressed mix, pretension, during-tensioning, posttension, formwork.*

Чеканович М. Г. Попереднє напруження залізобетонних конструкцій за методом на бетонну суміш

Удосконалення будівельних конструкцій, розробка альтернативних методів попереднього напруження, розширення границь технологічних підходів створюють можливості для раціонального використання будівельних матеріалів, сприяють підвищенню ефективності в будівництві. Такі методи базуються на фізичних законах, положеннях теоретичної і будівельної механіки, опору матеріалів та враховують властивості будівельних матеріалів і практику й досвід виготовлення та експлуатації будівельних конструкцій.

Попередньо напружені залізобетонні конструкції виготовляють, як правило, за технологією попереднього натягу арматури на упори або на затверділий бетон. Існує велика кількість пропозицій щодо реалізації цих технологій. Більшість із них добре вивчені, а деякі з кращих знаходять своє практичне застосування. Майже всі ці пропозиції можна об'єднати за принципом передачі попереднього напруження сталі саме на затверділий міцний бетон. Можливості виготовлення більш ефективних попередньо напружених залізобетонних конструкцій в обмежених рамках єдиного принципу багато в чому вичерпані. Багато фахівців вважають це причиною уповільнення прогресу в цьому напрямку. Тут потрібен якісний перехід до нових концепцій у сфері попередньо напруженого бетону, щоб мати прецеденти швидкого розквіту ідей та розробок.

Автором запропоновано та реалізовано принцип передачі попереднього напруження на свіжоукладену бетонну суміш конструкцій. У цьому випадку попереднє напруження передається на стадії цементобетонної суміші.

Нова технологія виробництва привела нас до можливості підвищення міцності бетону в попередньо напружених конструкціях до 50–70 відсотків. Це досягається за рахунок стиснення несхопленої бетонної суміші під час операції натягу сталі. Широкий спектр досліджень і практичних застосувань показали, що дана технологія забезпечує необхідне попереднє напруження сталі та рівномірне або задане ущільнення бетонної суміші, а також наступне твердіння бетону в конструкції.

Взявши за основу дані експериментальних досліджень, можна стверджувати, що самоорганізація структури бетону на етапі попереднього напруження суміші, якісна адгезія бетону зі сталлю, збереження сили попереднього напруження – все це стає запорукою високої міцності та якості запропонованих бетонних елементів. Промислове застосування збірних мостових елементів з попереднім напруженням на бетонну суміш довело доцільність запропонованого методу.

Ключові слова: *попередньо напружений бетон, балка, колона, пресована суміш, попереднє напруження на упори, попереднє напруження на бетонну суміш, попереднє напруження на бетон, опалубка.*

Introduction. The improvement of construction structures, development of alternative methods of prestressing, expansion of the boundaries of technological approaches create opportunities for the rational use of construction materials, contribute to increasing efficiency in construction. Such methods are based on physical laws, provisions of theoretical and building mechanics, resistance of materials and take into account the properties of building materials and the practice and experience of manufacturing and operating building structures [1–3]. The new methodology of prestressing structures has led us to the possibility of increasing the strength of concrete in prestressed structures up to 50-70 percent.

Analysis of recent research and publications. Prestressed concrete structures are usually made according to the pre-tensioning or post-tensioning technology [1–5]. There have been developed a great number of proposals as to the realization of these methodologies. The majority of them are well studied, and some of the best ones find their practical application. Almost all these suggestions can be united according to the principle of the steel prestressing transfer, namely onto the strong hardened concrete. The possibilities of manufacturing more effective prestressed reinforced concrete structures in the limited frames of the single principle are in many respects exhausted. Many specialists think it is the reason for slowing down progress in this direction [2–6]. We need here qualitative transition to new concepts in the sphere of prestressed concrete to have precedents for rapid flourishing of methods and developments.

Statement of the problem. Traditional methods of prestressing reinforced concrete structures do not significantly affect the strength of the structures. The strength of the structures remains a reserve for improving efficiency in construction. It is time to develop and research new methods of prestressing reinforced concrete structures that significantly increase their strength.

The purpose of the research. The purpose of the scientific research is to develop and investigate a new method of prestressing reinforced concrete structures that significantly increases the strength of structures through technological solutions.

Presentation of the main research material. New technology. The author has proposed and put into practice the principle of prestressing transfer onto the freshly placed concrete mix of structures (Fig. 1). In this case prestressing is transferred at the stage of the mix of cement concrete components.

After vibrodynamic compaction, the placed unset mix is under compression of the steel prestressing force, and it hardens under the pressure. All this leads to the concrete mix compaction, the removal of water excess and air from the mix, to eliminating macro- and partly microdefects of the concrete structure, and to restraining destructive (degradation) processes during concrete hardening.

Concrete

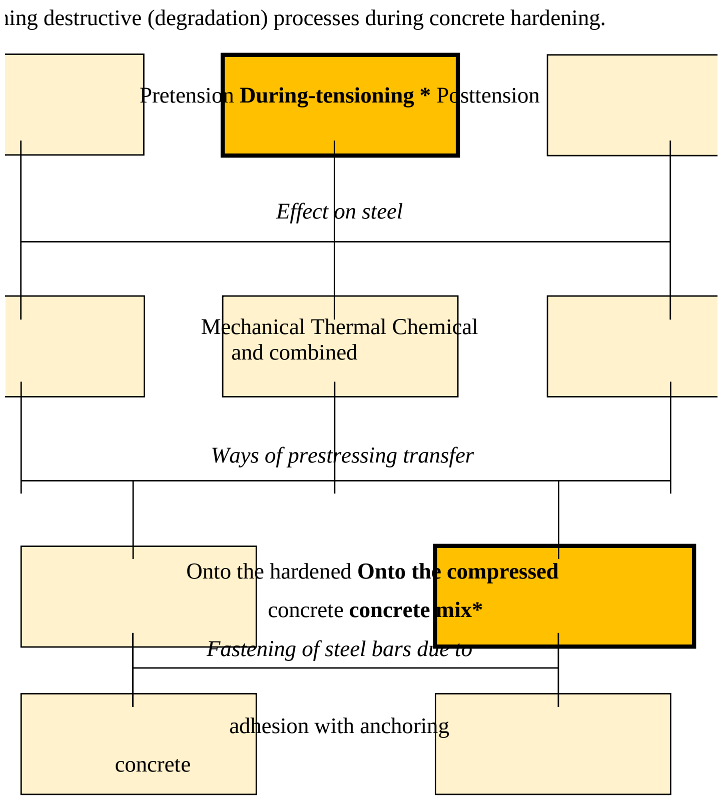

Fig. 1. Extended scheme of methods of carrying out prestressing in reinforced concrete structures

Steel prestressing is preserved, for after the compaction of the specially proportioned concrete mix, rather a strong and rigid skeleton of solid ingredients is formed, and the stressed steel is then fixed onto this skeleton (Fig. 1). It is also possible to partially transfer steel prestressing onto the concrete mix. The implimentation of the new technology method of concrete mix prestressing became possible after the author had invented original movable forms and devices for a full or partial prestress transfer [6, 7].

Experimental results. According to the presstressing method proposed there have been made experimental beams with rectangular cross section and dimensions of 100x200x2000mm and columns with round cross section with a diameter of 250 mm and length of 1500 mm. For comparison, under all equal conditions there were also produced traditional prestressed elements and usual reinforced concrete ones. The results of beam and column tests are graphically presented on Fig. 2. For the experimental beams with μ=2.2 per cent we have reached an increase in carrying capacity up to 25–34 per cent due to the compression according to the new method. The effect of carrying capacity increase in columns amounted to 75 per cent. It is illustrated graphically on Fig. 3, where K is the ratio of the carrying capacity of a reinforced concrete element compressed according to the "during-tensioning" method to the regular one.

The analysis of the results shows that the losses of steel prestressing caused by deformations due to shrinkage and concrete creep are less than in traditional structures. The prism strength of concrete after the compression increased up to 2.2 times compared to the initial one. The most intensive strength growth was marked under the pressure value up to 6 MPa. The values of elasticity modulus E_c and relative deformations ε_{cR} increased by 40–50 per cent.

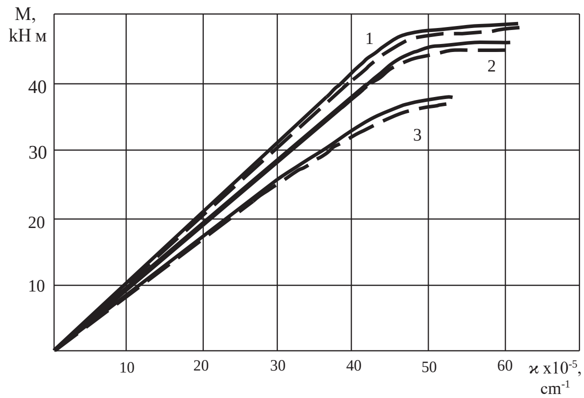

Fig. 2. Typical "M – ϰ" relationship for the beams with μ =2.2% when P=5 MPa – 1, P=2.5 MPa – 2 and P=0 – 3

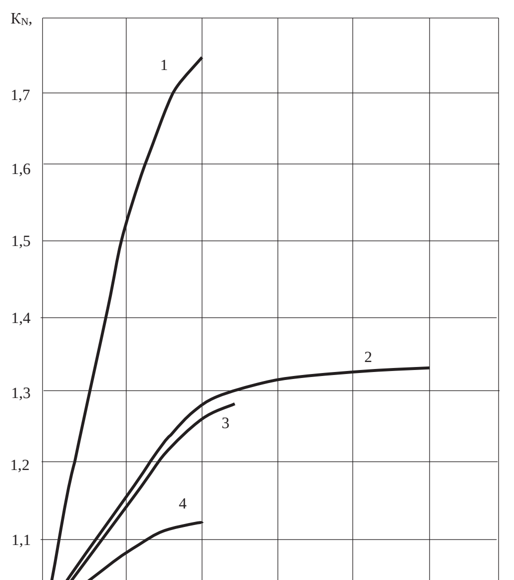

Fig. 3 Diagram "K– P" I-for columns; 2 – for the beams with μ =2.2% and P = 10MPa; 3 – for the beams with μ =2.2% and P = 5MPa; 4 – for the beams with μ=0.6%

Theoretical analysis. According to the research data obtained by the author, to preserve the force of steel prestressing we should use in the structures proposed concrete with contacting location of grains of strong coarse aggregate. Here the greater part of the prestressing force is transferred contactingly through thin mortar membranes in a grain-to-grain way (Fig. 4).

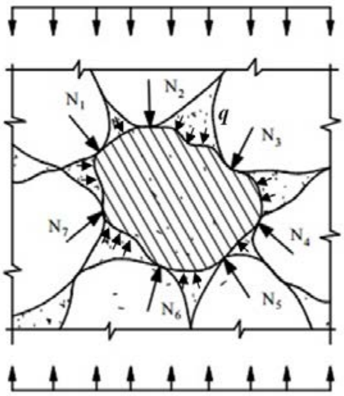

Fig. 4. Scheme of loading coarse aggregate grains

To get a strength formula for prestressed reinforced concrete of a matrix-carcass structure the author has suggested that one should proceed (besides the well-known premises) from the fact that the value of failure loading depends on the crushability of grain mix of coarse aggregate as an integral characteristic of its strength. The influence of precompression on the concrete mix is revealed in additional loading of the skeleton of coarse aggregate grains.

Taking into account the above mentioned and proceeding from the well-known premises, there has been obtained the following formula of the strength of prestressed concrete (using the during-tensioning method) with a matrix-carcass structure:

$$f_c = \left(K_n \frac{q}{K_{cr}} + K_1 \cdot K_2 \cdot K_3 \cdot K_{ct} \cdot f_{m,ct} - c\sigma_N \right) \cdot \left(\frac{1}{1 - K_E \cdot n} - K_V r \right) \quad (1)$$

where

$$K_{ct}. = 1 + \alpha_1 ln9{,}8p , \quad (2)$$

$$K_E. = 1 + \alpha_2 ln9{,}8p , \quad (3)$$

$$n = \cdot \frac{E_m}{E_{ag}} , \quad (4)$$

$$K_v. = 1 - 0.027\, p^{0.46} , \quad (5)$$

$$r = \cdot \frac{V_m}{V_c} \quad (6)$$

Here K_n – index reflecting the change in the structure of coarse aggregate under crushability (0.2–0.36); q – value of standard loading while determining the crushability of coarse aggregate grains (11.32 MPa); K_{cr} – crushability index of coarse aggregate grains placed as in concrete, i.e. it may be filling, vibrocompaction, dynamic effect with loading; K_1, K_2; and K_3 – corresponding indices of form (1.27–1.55), relief (1.18–1.40) and microrelief (1–1.41) of aggregate grains; p – value of pressure action on the cement-sand mortar; $f_{m,ct}$ – tensile strength of the usual uncompressed mortar; $c\sigma_N$ – value of pressure acting on the coarse aggregate; E_m and E_{ag} – elastisity modulus of mortar (matrix) and aggregate material; K_v – compaction index of the mortar, $a_1 = 0.18$ and $a_2 = 0.10$ for concrete and mortar.

According to the given formula it is possible to calculate concrete strength under a full or partial transfer of prestressing σ_N on the concrete mix. If prestressing is relieved after compaction, and it doesn't further load the carcass of coarse aggregate, the value C is to equate with 0. Besides, in this formula the value of the P parameter for the usual uncompressed concrete with a carcass arrangement of coarse aggregate grains equals 0.

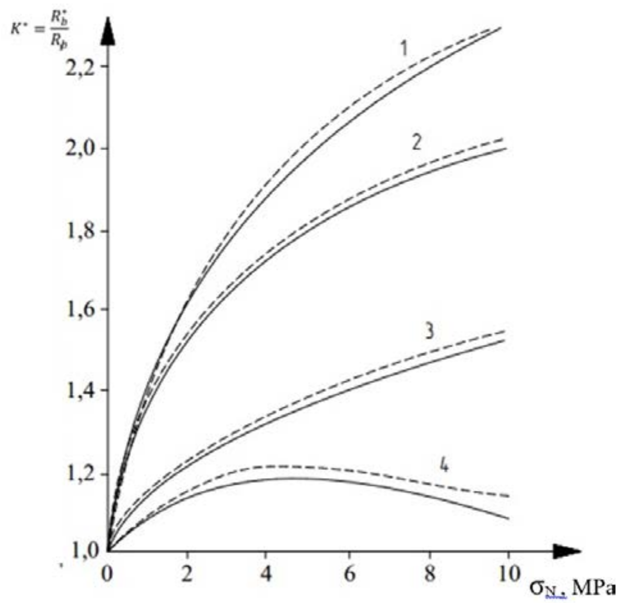

Fig. 5. Diagram "k-σ $_N$"
————— – experimental; – – – – – – – – – – – theoretical
I-compressed under dynamic influence and its further relieving; 2 – the same operation, under preserving the stress of compression; 3 – compression without dynamic influence with its further relieving; 4 – the same operation under preserving the stress of precompression

In Fig. 5. there are typical plots showing dependence of the index of concrete strength increase on the value of prestressing and the mode of its application. The comparison of analysis dependences with experiments testify to their being in agreement. The given formula shows satisfactory results in practical application. It takes into account the transfer of prestressing onto concrete mix both in cases of its preserving and relieving.

Production implementation. The level of research includes production implementation. Large 30-ton bridge elements of prestressed concrete made by compressing the unset concrete mix with the force of steel tensioning are successfully used in Ukraine (Fig. 6).

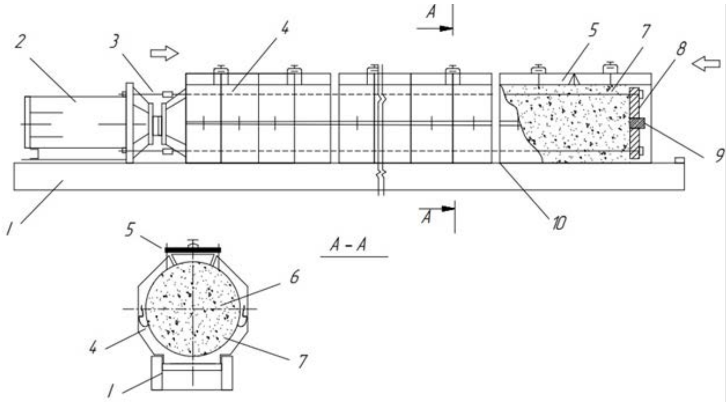

Fig. 6. Scheme of compressing the pillar in the formwork according to the "during-tensioning" method 1 – frame, 2 – tensioning device, 3 – tie-rods, 4 – section formwork, 5 – functional joint, 6 – concrete mix, 7 – reinforced bar, 8 – movable end of the formwork, 9 – concrete cube sampling form, 9 – deformation seams

Favoring practical application of the above mentioned elements was the device invented by the author, which provides reliable control over the quality of the compressed concrete directly in the product (Fig. 6*)* [7]. Service observations of the reinforced concrete pillars made according to the technology offered in the pillars of the trestle part of a large bridge over the river Dnipro in the town of Kamianske (Ukraine) confirmed high quality of the structures compressed according to the "during-tensioning" method.

Conclusions and suggestions. Based on the research findings, we can state that self-organization of concrete structure at the stage of mix prestressing, effective adhesion between concrete and steel, preservation of the force of prestressing – all this becomes a guarantee for high strength and quality of the concrete elements offered. Industrial application of prefabricated bridge elements with prestressing onto the concrete mix has proved the expediency of the method proposed.

The current level of the method development allows recommending for the lot production the following reinforced concrete structures: columns and pillars, piers, bulky foundation elements, some beams, thick slabs for bridges, airfields and motorroads, curbstones, railway sleepers.

We expect that further experimental research and perfection of the during-tensioning method will make it possible to broaden the list of economically expedient compressed reinforced structures. The lot production of the structures compressed according to the during – tensioning method, and tested in practice, will hopefully contribute to the progress in construction.

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