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Previous self-stresses creation methods analysis in bent steel reinforced concrete structures with solid cross section

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Bent steel reinforced concrete structures are usually structures for overlap or covering buildings and constructions for various functional purposes. Pre-stresses in structures of this type can be created by installing additional pre-stressed reinforcing bars in the stretched cross-sectional area, which, along with increasing the load-bearing capacity and stiffness of the floors, requires additional material costs and the installation of these bars. Creating initial stresses in building structures from their own weight greatly simplifies the process of pre-stressing due to the unnecessary cost of additional measures and adaptations. Preliminary stresses, in this case, can be created due to the well-chosen sizes of the nodes and the development of technology for the preliminary assembly of building structures. Therefore, the purpose of research is to generalize the design features and principles of bent reinforced concrete structures with solid cross-section parts pre-stressing and separation among them and to develop new effective methods of creating pre-self-stresses - pre-internal stresses opposite to those arising during operation

Keywords: self-stress, steel-concrete composite structures, construction, nodes, technology.

Аналіз методів створення попередніх самонапружень у згинаних сталезалізобетонних конструкціях суцільного поперечного перерізу

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Згинані сталезалізобетонні конструкції, зазвичай, являють собою конструкції перекриттів чи покриттів будівель та споруд різного функціонального призначення. Сталезалізобетонні конструкції суцільного поперечного перерізу складаються із сталевих несучих балок, що працюють в основному на розтяг, та бетонної полички, що працює на стиск і одночасно виконує функції диску жорсткості. Слід зазначити, що навантаження від власної ваги залізобетонної полички співставимо із корисним навантаженням на перекриття в житлових та офісних будівлях. Тобто значну частину деформацій сталевих балок перекриття від власної ваги монолітної залізобетонної полички можливо уникнути, вживши спеціальні заходи на будівельному майданчику на час бетонування цієї плити. Попередні напруження у конструкціях такого типу можливо створити шляхом влаштування додаткових попередньо напружених арматурних стержнів (затяжок) у розтягнутій зоні перерізу, що одночасно із підвищенням несучої здатності та жорсткості перекриттів, вимагає додаткових витрат на матеріали та саме влаштування цих стержнів. Попередні самонапруження в елементах згинаних сталезалізобетонних конструкцій можливо створити за рахунок вдало підібраної конструкції вузлів та розробки технології виготовлення чи попередньої укрупнювальної збірки під час монтажу. Наприклад, самонатягу встановленої ззовні затяжки за допомогою поперечних стержнів, важільно-стрижневої чи важільно-коткової систем під час навантаження. Також, конструктивно забезпечивши нерозрізну схему роботи декількох типових сталезаліобетонних конструкцій у суміжних прольотах, можливо досягти раціонального перерозподілу зусиль в їх перерізах шляхом постадійної схеми бетонування верхньої монолітної залізобетонної полички та відповідним включенням розтягнутої сталевої частини перерізу в роботу. Тому метою досліджень є узагальнення конструктивних особливостей та принципів створення попереднього напруження частин згинаних сталезалізобетонних конструкцій суцільного поперечного перерізу та виокремлення серед них і розробка нових ефективних методів створювання попередніх самонапружень – попередніх внутрішніх напружень, протилежних тим, що виникають у процесі експлуатації

Ключові слова: самонапруження, сталезалізобетон, конструкція, вузли, технологія.

Introduction

Bent reinforced concrete structures are usually structures for overlapping or covering buildings and constructions for various functional purposes. Such structures consist of steel load-bearing beams, which work mainly in tension, and a concrete shelf, which works in compression and at the same time performs the functions of a stiffness disk.

It should be noted two features that were used in the following study of such reinforced concrete structures:

1) in the case of steel floor beams rigid support units installation it is possible to create inseparable statically indeterminate schemes of their work. This advantage allows regulating the stress-strain state in the floor elements, increasing the load-bearing capacity and rigidity and, as a result, materials saving [1];

2) the load from the reinforced concrete slab own weight can be compared with the payload on the floor in residential and office buildings [2]. That is, a significant part of the floor elements deformation can be avoided by taking special measures during the concreting of this slab.

Review of the research sources and publications

Today we know the results of research in which scientists, due to a specially designed structure or technology of manufacturing bent reinforced concrete structures achieve stresses redistribution between their structural parts and individual elements pre-stress from their own weight or installation technology [3-12].

Thus, preliminary self-stresses (preliminary internal stresses opposite to those arising during operation) of reinforced concrete construction structural parts are created exclusively from their own weight without other prestressing measures used (mechanical, electrothermal or electrothermomechanical).

Definition of unsolved aspects of the problem

Despite the significant number of published materials on theoretical, numerical, and experimental studies of the above structures, there is no generalized analysis of design features and principles of bent reinforced concrete structures parts prestressing from their own weight during installation.

Problem statement

The research aim is to generalize the design features and principles of creating pre-tensioning in bent self-stressed reinforced concrete structures parts of both solid and through (spatial) cross sections.

The solution of the research aim was solved in three stages:

1) analysis of design features and operation principles of known bent self-stressed constructions;

2) formation of the generalized list of the considered constructions;

3) development of new technology for bent self-stressed reinforced concrete constructions creation.

Basic material and results

In [3] Chekanovich M.G. investigated the reinforcement design by transverse rods system with the reinforced concrete beams tightening. The reinforcement system consists of a reinforced concrete beam and an inclined puff fixed on a system of inclined rods, which are mirrored in the beam supporting zones symmetrically with an inclination to the longitudinal axis, interacting in the middle with the main inclined tension element resting on the lower face of the beam (Fig. 1). Compared to the known puffs typical types in the form of horizontal rods or springs, this longitudinal, and transverse puffs system allows you to effectively unload the compressed area of the concrete beam, which greatly affects its load-bearing capacity.

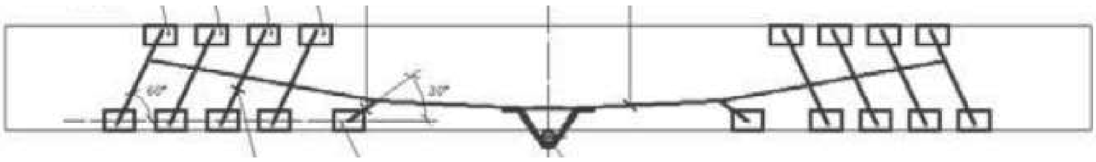

Figure 1 – Adjustable-stressed beam construction

During the puffs installation, the main reinforced concrete element is transformed from bent to eccentrically compressed. At the same time on beam supports there are additional bending moments which in turn influence initial span moments. The essence of this system is as follows [3]. Under its own weight and external load, the beam is deformed and the tension element deflects the puff down by the maximum deflection. The relationship between longitudinal reinforcement - puff and transverse reinforcement provides forces self-regulation. To increase the tensile force in the puff, it is tightened to the middle of the outer transverse reinforcement, which is fixed to the beam upper and lower parts in its support zones. The results of such an improved version of the adjustable reinforcement system of reinforced concrete beams research data analysis prove that the action of tightening causes deformation of the inclined outer reinforcement, which creates unloading forces in the upper zone of the beam and compressive forces in its lower. The results of experimental studies have shown an increase in the load-bearing capacity of beams with an improved self-regulating system of rational stress redistribution between compressed and stretched cross-sectional areas up to 1.6 times [3].

In continuation of this work, Chekanovich O.M. investigated the operation of reinforced concrete beams with a lever-rod system consisting of a puff in the lower stretched and extensions in the upper compressed zones of the beam (Fig. 2) [4].

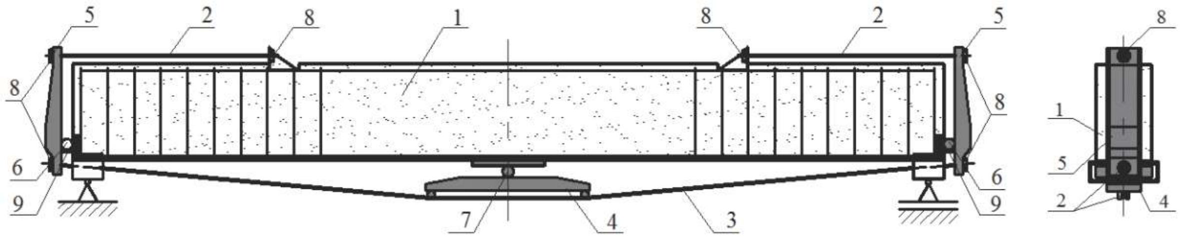

Figure 2 – General view of a reinforced concrete beam with a lever-rod system:
1 – reinforced concrete beam; 2 – extension; 3 – puff; 4 – traverse; 5 – two-shoulder levers; 6, 7 – rollers;8 – set of threaded fasteners with spherical washers; 9 – thrust

The idea of strengthening with the lever-rod system was patented by Chekanovich O.M. [5] and in parallel similar constructions by foreign scientists (USA [6], Germany [7], Japan] [8]). The developed system of reinforced concrete beams stresses regulation can be applied both at new construction and at existing elements strengthening for the purpose of their bearing capacity increase.

As a result of beam deformations under loading, a traverse rejects the rebars of an inhaling downwards on the size of a beam deflection of at once in two points of contact. There is a significant elongation of the rebars. At the ends of the beam, in the rollers locations, there is a gap that creates a beam longitudinal compression. Inversely proportional to the size of the levers shoulders in the reinforcement of extensions and puffs there are tensile forces, which leads to the unloading of the upper compressed fiber of the beam with simultaneous compression of its lower stretched zone. The advantage of such a lever-rod system is that there is no need for its pre-stress; it is included in work from the beginning of the bent element loading. The efficiency of the proposed lever-rod reinforcement system is achieved by selecting the roller location at the end of the beam and extension lengths on top of the beam [4]. The effect of strengthening the reinforced concrete beam by the lever-rod system according to the results of the research was 1.82 times.

Another method of reinforcing concrete beams, proposed by the above authors, is the method of strengthening the external rod-roller system [9]. The reinforcement system includes external steel reinforcement in the form of two branches and guide elements located symmetrically on the side surface at the ends of the beam and guide parts to create an adjustable compression of the beam lower face (Fig. 3). Together with the increase in strength up to 3.85 times compared to the reference samples without reinforcement, the deflections are reduced up to 15 times, but at higher steel costs.

Figure 3 – General view of the reinforced concrete beam reinforced by the rod-roll system during the test

Considered by Chekanovich M.G. the idea of strengthening single-span reinforced concrete beams was used for continuous reinforced concrete beams. The lever-rod reinforcement system was a system of external reinforcement with the release of the beam ends from the reinforcement elements, which significantly relieves the compressed cross-sectional areas (Fig. 4): the system of levers, pulls and rollers unloads the compressed upper zone of the beam in the spans and compresses the stretched zone above the support and restrains the tension of the beam lower span. According to the results of experimental studies, this system has increased the load-bearing capacity of the integral beam to 30% [10].

According to the standard solution according to [11] the installation of the unloading sprung system, the tension of the steel reinforcement elements, and their inclusion in the joint work with the existing structures can be carried out by the following measures (Fig. 5):
– wedging with steel plates;
– screwing of tightening bolts.

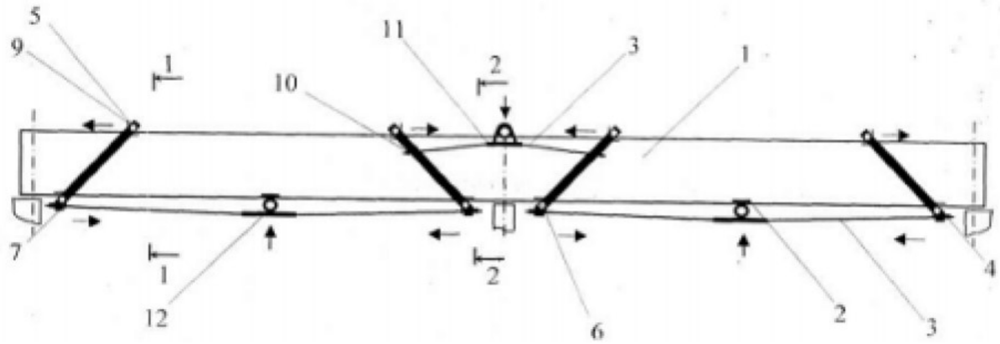

Figure 4 – External reinforcement system of reinforced concrete continuous beams:
1 – reinforced concrete body; 2 – embedded plates; 3 – pulls; 4 – ankers; 5 – upper rod;
6 – the lower rod of round cross-section; 7 – longitudinal shoulder; 8 – hole for fixing the pull;
9 – upper emphasis; 10 – tightening stop; 11 – traverse over the support; 12 – traverse in the beam span

a)

b)

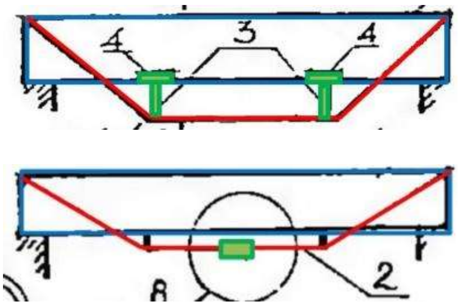

Figure 5 – Typical constructive decisions of reinforced concrete constructions external strengthening by steel rods (springs) with a tension of the last by:
a) wedge metal plates (pos. 3-4);
b) tightening bolts (pos. 2)

Under the guidance of professor Shagin O.L. a considerable amount of research has been conducted on the creation and implementation of general and locally prestressed reinforced concrete bent structures for new construction and reconstruction. The generalizing work is the dissertation of Izbash M.Yu. [12]. Reinforced concrete bent elements with a total stress of the lower belt with a single-span split scheme (Fig. 6, a) and with local compression on the intermediate supports with a multi-span continuous scheme of structures (Fig. 6, b) are proposed, experimentally investigated and implemented taking into account physical, geometric and technological nonlinearity. The engineering technique of combined constructions bearing capacity direct calculation taking into account their existing stress-strain state is developed [13]. The stress-strain state of the stressed reinforcement fastening unit to the steel beam (see Fig. 7), which provides a significant reduction in stresses in the fastening zone, has been studied in detail. The design of this unit limits the size of the pull-out boom: it cannot be more than the distance between the bottom of the fixture to the I-beam wall and the top of its lower shelf.

A positive feature of this design solution of prestressing is that due to the small value of the angle α (Fig. 7, a), pull force F_{sp} is almost an order of magnitude less than the tension force created by it H_{sp} [14]. This fact allows to create tension of the rebars to high values H_{sp} (reaching stresses in the rebars that exceed the yield strength) using a hand-held screw jack (Fig. 7, b). Due to the possibility to achieve in the prestressed reinforcement stresses greater than the yield strength, it is possible before the local prestressing of reinforced concrete structures to perform reinforcement of class A500C reinforcement by pulling it (till δ_{pul} = 3%) directly on construction [14].

a)

b)

Figure 6 – Arrangement of unit (a) and process of local pre-tensioning of reinforcing rod (b) on steel beam before concreting

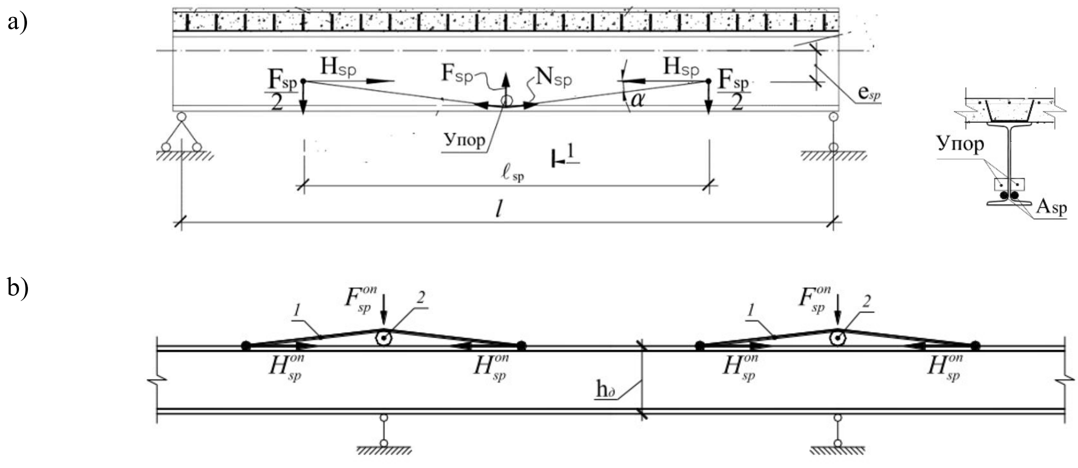

Figure 7 ─ Installation of prestressed reinforcing bars:
a) generally in the span of the split reinforced concrete beam;
b) locally on the intermediate supports of the inseparable reinforced concrete beam

In another work of the same scientific school [16] developed and experimentally investigated locally prestressed main beams of the sprung type prefabricated monolithic flat using finely artificial elements of large spans overlap (Fig. 8), developed a method of calculating them taking into account the physical nonlinearity and the deformed scheme. The lower the tension reinforcement will be placed, the higher the effect of its compression [17]. However, the need to place it below the physical axis of the section and the relatively small depth of the groove significantly limits the increase of this effect. In order to increase the compression effect, the use of two-stage reinforcement tension is proposed [16]. At the first stage tension is created by tightening or expanding of rebars in the horizontal plane, at the second stage - by pulling down in the vertical plane. (Fig. 8). After pulling the rebars to the design position, it is fixed in this position with a detent rod (Fig. 9).

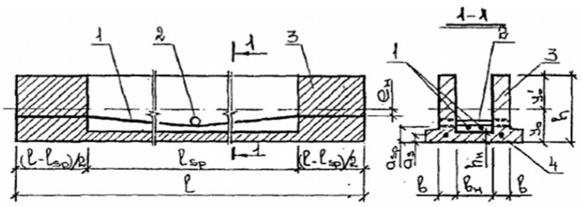

Figure 8 ─ Locally prestressed main sprung type beam of prefabricated monolithic reinforced concrete floor:
1 – prestressed rebars; 2 – detent rod;
3 – reinforced concrete part of the main beam;
4 – unstressed rebars

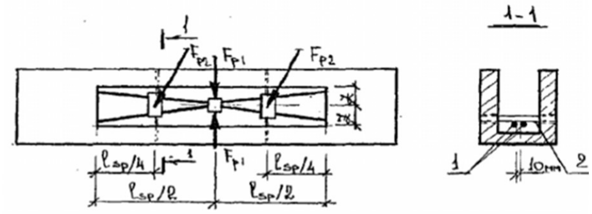

Figure 9 ─ The scheme of two-stage rebars tension

It should be noted that the calculation of stresses in the pre-stressed reinforcing rod in the structures shown in figure 3, can also be performed when considering the operation of this reinforcement according to the scheme of flexible flat hanging deformed thread.

Similar scientific studies of reinforced concrete beams prestress by installing additional prestressed reinforcing bars were conducted under the leadership of Storozhenko L.I. In the work of Kushnir Yu.O. the study of 12 steel and reinforced concrete beams with a length of 2 m, made of rolled I-beams №16 with side cavities filled with concrete, with installed external or internal pre-stressed pulls with a diameter of 10 mm, 16 mm, 20 mm or 32 mm was conducted (Fig. 10) [18]. The tension of additional reinforcement was carried out by one of three methods:

− mechanical tension by pulling reinforcing rods placed in lateral cavities of an I-beam screw connection to the laths welded to end faces of I-beams (Fig. 10, a);

− mechanical tension by pulls reinforcing rods located in lateral cavities of an I-beam screw connection to the corners welded to support places of an I-beam (Fig. 10, b);

− mechanical tension by pulling reinforcing rods located outside of I-beam lateral cavities screw connection to the cross channels welded to I-beam end faces (Fig. 10, c).

The obtained experimental data of samples stress-strain states confirmed the existence in their calculated cross section at the ultimate loads of the plasticity areas, which indicates the efficiency of such structures [19].

A separate type of reinforced concrete structures self-tensioning is a special technology of their manufacture. Figure 11, b) shows prefabricated monolithic reinforced concrete crossbars tensioned due to the stages of manufacture (concreting) [20]. Manufacturing of prefabricated monolithic crossbars is carried out in several stages - the prefabricated construction part is made at the factory, the monolithic part - during installation.

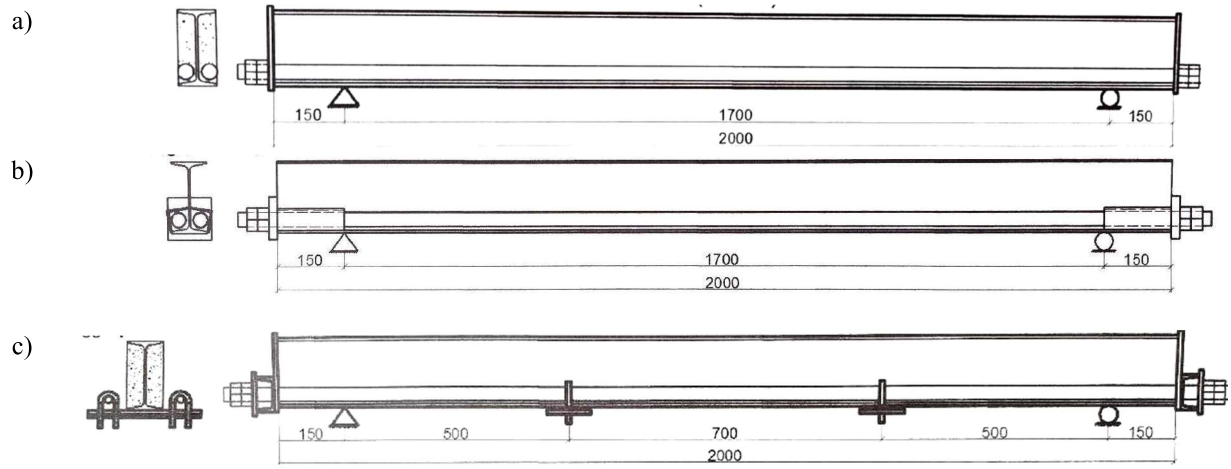

Figure 10 – Schemes of additional prestressed internal (a-b) and external (c) reinforcement of reinforced concrete beams

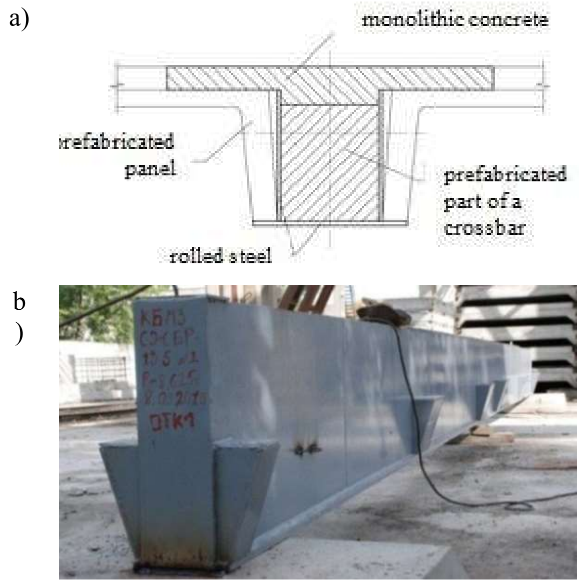

Figure 11 – Prefabricated monolithic reinforced concrete crossbars:
a) cross-sectional diagram with the indication of concreting stages; b) general view of the prefabricated part manufactured at the factory

The design scheme of a crossbar work changes at alternate stages of its installation and operation. In the first stage, the crossbar is freely supported on two pillars, one span beam; the horizontal support reaction is zero.

At this stage, the cross-section of the crossbar is a trough-shaped steel profile filled with concrete. In the second stage of manufacture:

– prefabricated ribbed reinforced concrete floor slabs are mounted on the lower steel shelf of the trough-shaped profile (Fig. 12, a). If according to calculation it is necessary to increase crossbar section height, plates are mounted not on the lower steel shelf (Fig. 11, a) and on portable support tables (Fig. 11, b);

– the crossbar is welded to consoles (or embedded parts) of columns. The design scheme of the crossbar is changed to a rigidly clamped one-span with the emergence of a horizontal gap. Thus, after plates installation on a crossbar and monolithic overconcreting performance, in a prefabricated part there are initial deflections and stresses which are perceived exclusively here;

– the concrete monolithic top shelf combining for joint work of a crossbar with the plates of overlapping established on it is arranged. After gaining the strength of concrete, the cross-section changes. For additional payload, the cross-section works together and receives additional deformations.

Experimental studies of reinforced concrete prefabricated monolithic beams with a span of 13.5 m confirmed the theoretical assumptions on the influence of changes in the cross-section size in the manufacturing process on the development of deflections and internal forces [21].

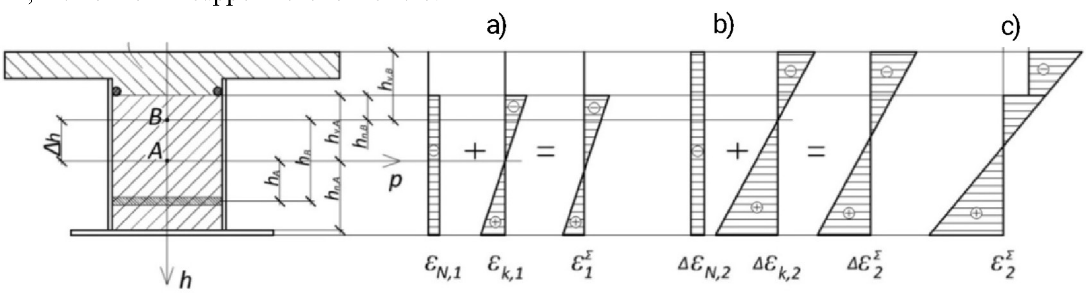

Figure 12 – Diagrams of relative deformations in a reinforced concrete crossbar:
a – prefabricated part before inclusion in work of concreting;
b – from additional loading after all section inclusion in work; в – total diagram

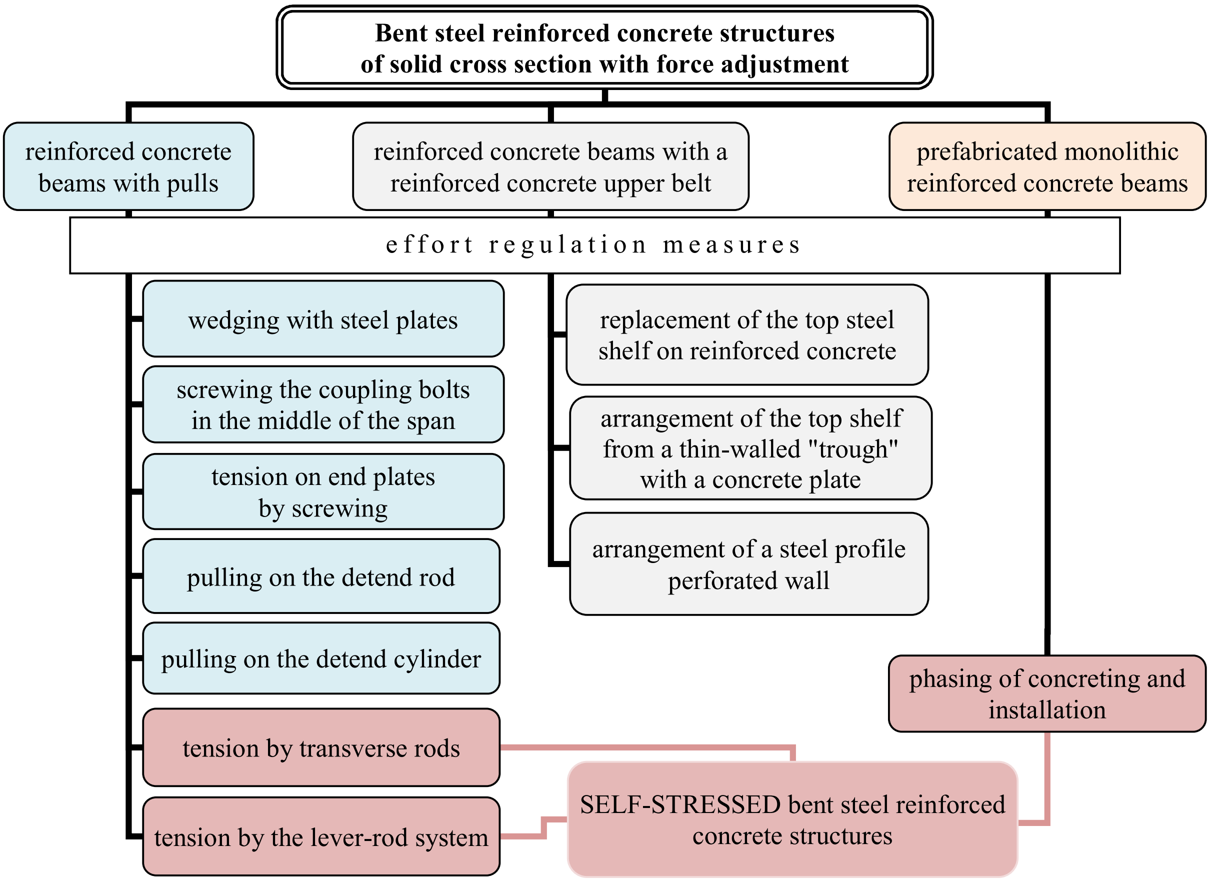

Figure 13 – Measures to regulate forces in bent steel-reinforced concrete structures

Conclusions

The results of rational preliminary stresses in elements of reinforced concrete constructions with solid cross section creation methods analysis are presented in the form of the block diagram (Fig. 13) with allocation of self-stressed (without additional force application) methods.

Well-known practical measures for creating self-stresses of bent steel-reinforced concrete structures of a solid cross-section are the installation of external steel fasteners using lever-rod or rod-roller systems and the development of phasing of the manufacture and installation of prefabricated monolithic structures.

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