

**Раздел 2. Строительство**

УДК 691.2

**TO THE CALCULATION OF A FIBER CONCRETE BLOCK AS A BEAM ON AN ELASTIC BASIS AS PART OF LOCALLY REINFORCED NODES OF TRUSSES MADE OF SQUARE HOLLOW SECTIONS**L. Geermanov<sup>1</sup>., A. Pazhwak<sup>2</sup>, S.A. Azimi<sup>3</sup>.

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**Abstract.** The article is devoted to the analytical and numerical study of truss nodes made of a square hollow section with local concrete filling. A numerical analysis of a fiber-concrete element in the form of a beam on an elastic base as a local reinforcement of a truss node made of square hollow profiles under the action of a concentrated load from a neighboring rack is carried out.

**Subject of research:** The subject of the study is the local filling with concrete as reinforced knots of trusses made of SHS of K-type connection, and the calculation of the load-carrying capacity of truss knots made of HSP under the influence of several concentrated compressive loads from the brace elements.

**Materials and methods.** The method of internal study based on the numerical experiment and computer simulation SP "ANSYS Workbench" local strengthening of the node of trusses made of SHS K-shaped connection type, locally filled with concrete.

**Results:** Simple and reliable methods of strengthening nodes made of square hollow profiles by filling with concrete are presented, as well as the corresponding methods of their calculation. The connections of the truss nodes, made of square hollow profiles of the K-shaped type of connection with a direct connection, give high quality with minimal labor and metal consumption.

**Conclusion:** The load-carrying capacity of truss nodes made of square hollow sections can be increased by local filling of the inner cavity of the chord with concrete, which allows to unload the shelf, to which the lattice element and the side walls of the chord adjoin.

**Key words:** Square hollow section, Bending stiffness, Numerical study, Steel pipe with concrete filling, calculation method.

**1. Introduction**

Nowadays steel trusses made of square hollow sections (SHS) are widely used in various fields of construction: especially in load-bearing roofs and ceilings of industrial and civil buildings and bridges. Connections of brace and chord of trusses made of SHS in the joints are carried out by means of direct joining of one element to another or by means of nodular fittings. Their advantages include cost-effectiveness, absence of bevels and the largest radius of inertia.

K-shaped type of connection, in which braces are attached directly to the chord element of the trusses made of SHS, has a characteristic pattern of destruction in the form of local buckling of the wall or shelves of the chord under the action of compressive force of brace elements. In this case, it is possible to change the dimensions of the cross-section elements of the node. In the existing Russian normative documents, there are no data on calculation and design of reinforcement of truss nodes made of SHS. In this connection, it is important to develop simple and reliable methods of strengthening these nodes, as well as appropriate methods of their calculation. In this paper, we consider the reinforcement of the concrete truss nodes made of particleboard.

Truss knots from SHS are reinforced by filling with concrete or fiber concrete to significantly increase its bearing capacity and rigidity. The behavior of the resulting concrete-filled truss units from SHS is significantly improved due to the increase in strength due to the retention of the steel truss and the prevention

of internal collapse by the shelf or wall. Concrete is able to meet the growing demands for fast-moving large-span spatial structures under adverse loads. In recent years, extensive studies of truss units made of SHS with concrete filling have been carried out and an increase in stability, durability and high technical and economic indicators have been achieved under different loading conditions [1]. If the deformation of the shelf of the chord is limited by the concrete, the bearing capacity of the connection can be increased; however, there are few studies on this topic [2-3].

In the works of Parker et al. [5-6] show a significant increase in bearing capacity and bending stiffness due to concrete filling in the chords of K-type tubular trusses. In the study [7] it is stated that the brace elements under tension and compression should be calculated separately and that the determining limit state for the stretched brace element will be the premature local flowability of the brace at junction from the action of tensile and shear stresses.

In [7-8], the results of tests of truss frame nodes made of SHS with adjoining to the chord of compressed and stretched braces of K-shaped nodes are given. The nodes with the direct adjacency of struts to the chord and the nodes with different types of reinforcement made in such a way as to transfer the load from braces to most part of the chord cross-section perimeter in the node were investigated locally. If the width of the braces element is increased, the deformability of a SHS truss node decreases, and the strength and load-bearing capacity increases.

According to numerical studies, reinforcement with concrete allows increasing the technical and economic performance of trusses made of SHS, so improving the method of calculation of nodes of SHS trusses, locally reinforced with concrete, is an urgent scientific task [4].

The object of the study are K-shaped nodes of roof trusses and slabs made of SHS, which are reinforced by local filling of the chord cavity with concrete.

The subject of the study is the load-carrying capacity of such units.

The purpose of this work is to develop a methodology for calculating a concrete block filling the girder cavity on the basis of idealized calculation schemes of analytical dependencies to determine its carrying capacity under compressive loading in the nodes of SHS trusses. To achieve the goal, the following tasks were formulated:

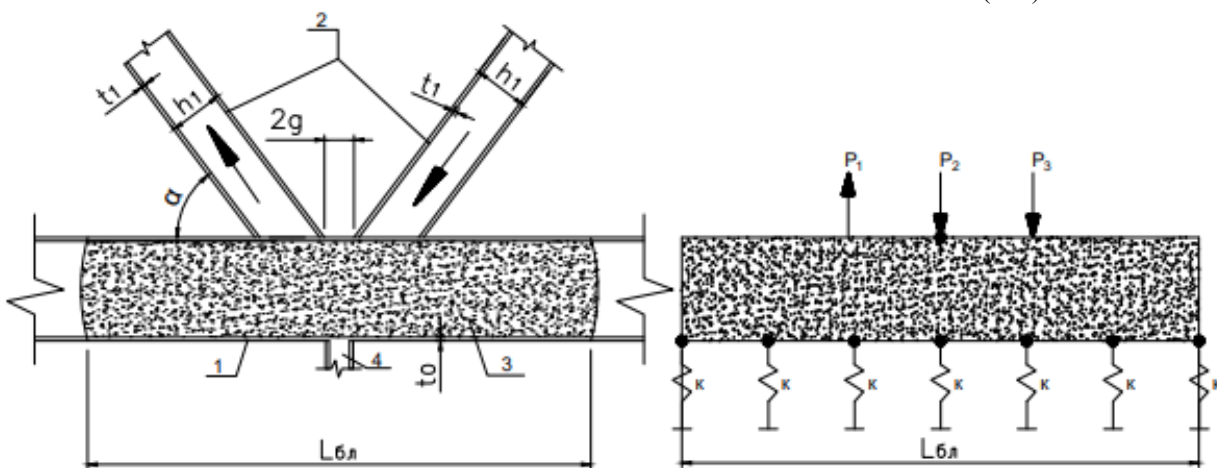
- Propose a methodology for calculating a concrete block, taking into account the beam analogy.
- Determine the design scheme of the concrete block as a beam on an elastic basis, most closely reflecting its carrying capacity as part of the design model of the node, including struts and truss chords.

- Determine the methodology for calculating a fiber concrete block as a local reinforcement of a truss made of SHS.

## 2. Materials and methods

The subject of the study is the local filling with concrete as reinforced knots of trusses made of SHS of K-type connection, performed according to [8], and the calculation of the load-carrying capacity of truss knots made of HSP under the influence of several concentrated compressive loads from the brace elements. The method of internal study based on the numerical experiment and computer simulation SP "ANSYS Workbench" local strengthening of the node of trusses made of SHS K-shaped connection type, locally filled with concrete, is applied [12] Figure 1.

Materials of truss nodes made of square hollow sections: chord and brace - steel C245 according to GOST 27772-2015 with design resistance 240 MPa, local filling - concrete with elastic modulus at least 30000 MPa. Dimensions of the truss unit made of SHS: cross-sections of the chord  $140 \times 140 \times 4$  (mm), cross-sections of the braces  $60 \times 60 \times 3$  (mm).



**Fig. 1** - Calculation scheme of a truss node made of square hollow sections, locally reinforced with fiber concrete  
**Рис. 1** - Расчетная схема узла фермы, выполненного из квадратных полых профилей, локально армированных фибробетоном

In this study, a methodology for calculating the fiber concrete block [4], reinforcing a truss node made of square hollow sections, which is shown in Figure 1 [5], where:

- 1- truss chords (upper chord),
- 2 –braces,
- 3- the hole for concreting the nodes, in which the filler bag and pipe plug are inserted and then welded to the truss chords,
- 4- the concrete block after the curing process,
- L - length of the concrete block,
- h0 - height of the girder section,
- t0 - chord thickness,
- h1 - height of the strut section,
- t1 - brace thickness,

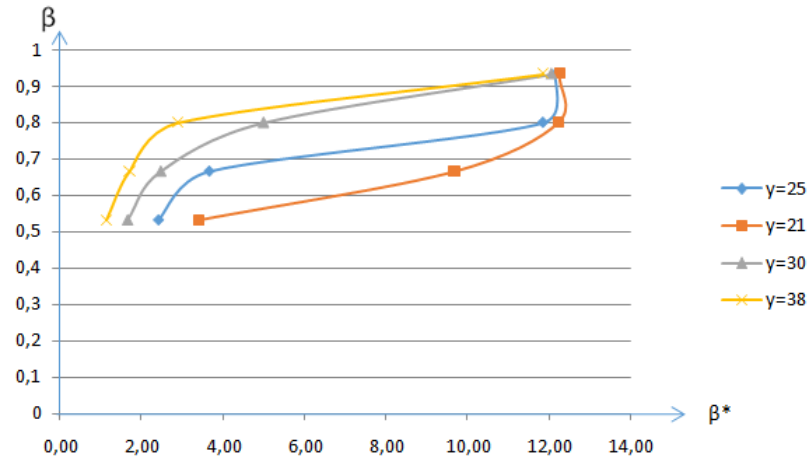
$\alpha$  - angle of abutment of the brace,

A numerical study of a truss node made of SHS reinforced locally with a fiber concrete block with the cross-section of a chord  $140 \times 140$  mm, length 560 mm, which is made of concrete with the elasticity module  $E = 30000$  MPa and the calculated compression resistance  $R_b = 14.5$  MPa [3]. It is necessary to determine the dependences of the carrying capacity of the considered nodes on the corresponding geometrical and physical-mechanical parameters [3].

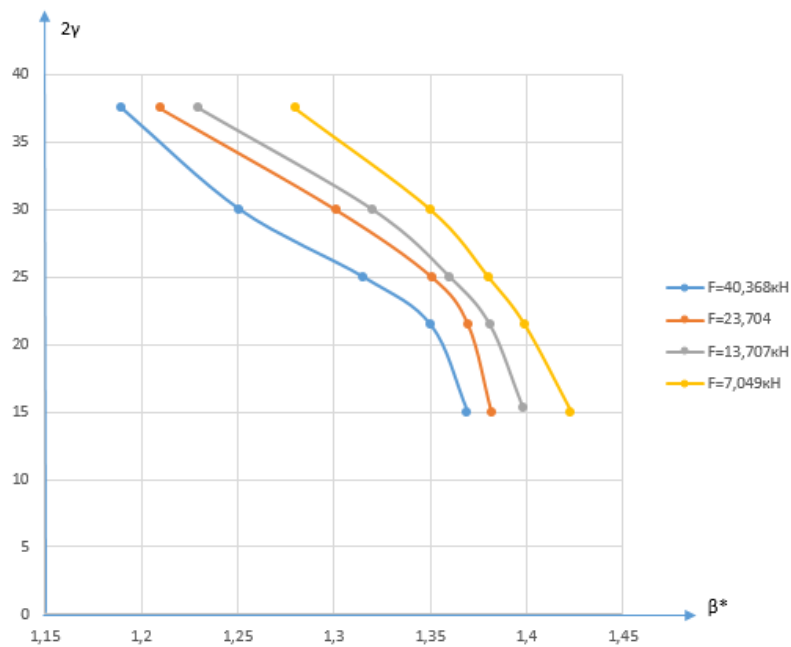
On the basis of a numerical study using phenomenological approaches, plots (Figs. 2-3) of the dependence of brace width to chord width  $\beta$ , the coefficient of relative bending stiffness  $\beta^*$  [5] are made.

**Table 1.** Geometric dimensions of chords and braces of SHS trusses for parametric study  
**Таблица 1.** Геометрические размеры поясов и раскосов ферм СВС для параметрического исследования

№	chord		brace		$\gamma$	$\beta$	$\alpha$
	$b_0$ (мм)	$t_0$ (мм)	$b_1$ (мм)	$t_1$ (мм)			
1	140	4	70	3	38	0.466	23
2	140	5	90	4	30	0.600	22
3	140	6	110	5	25	0.733	21
4	140	7	140	6	21	0.933	23



**Fig. 2 -** Diagram of dependence of brace width to chord width  $\beta$ , coefficient of relative bending stiffness  $\beta^*$   
**Рис. 2 -** Диаграмма зависимости ширины распорки от ширины хорды  $\beta$ , коэффициент относительной жесткости при изгибе  $\beta^*$



**Fig. 3 -** Diagram of dependence of chord width to chord thickness  $2\gamma$ , coefficient of relative bending stiffness  $\beta^*$   
**Рис. 3 -** Диаграмма зависимости ширины хорды от толщины хорды  $2\gamma$ , коэффициент относительной жесткости при изгибе  $\beta^*$

The above graphs (Fig. 2-3) show that the bearing capacity and strength of truss nodes made of bent-welded sections depend on the width of the strut and its thickness [3].

1. A similar approach to determining the value of the coefficient  $\beta^*$ , which depends on the relative value of the bending stiffness of the fiber concrete element as a local reinforcement of a truss node made of SHS, taking into account the concentrated load, bending moment determined in the SP "ANSYS Workbench" and mathematical function  $\eta_i = e^{-\beta x} (\cos \beta x - \sin \beta x)$  is calculated by the formula:

$$\beta^* = \frac{P}{4M} \cdot e^{-\beta x} (\cos \beta x - \sin \beta x) \quad (1)$$

$$\beta^* = \frac{147}{(4 \cdot 30,88)} \cdot 1 = 1.19 \text{ м}^{-1}$$

2. Using formula (3), the moment of inertia of the fiber concrete block as a beam on an elastic base is determined by the formula:

$$I_x = I_y = \frac{b \cdot h^3}{12} \quad (2)$$

$$I_x = I_y = \frac{15 \cdot 15^3}{12} = 4218 \text{ см}^4$$

where  $h$  is the section height of the block;  
 $b$  - width of the block;

Based on the value of the moment of inertia, we calculate the bending stiffness of the fiber concrete block used as a local reinforcement of the SHS truss node by the following expression:

$$EI = 3000000 \text{ Н / см}^2 \cdot 4218 \text{ см}^4 =$$

$$= 3 \cdot 10^7 \text{ кН / М}^2 \cdot 4.218 \cdot 10^{-5} \text{ М}^4 =$$

$$= 1260 \text{ кН} \cdot \text{М}^2$$

3. Based on the above values of the fiber concrete block, determine the bedding factor by the formula:

$$\kappa = 4IE\beta^{*4} \quad (3)$$

$$\kappa = 4 \cdot 1260 \cdot 1.19^4 = 10106 \text{ кПа}$$

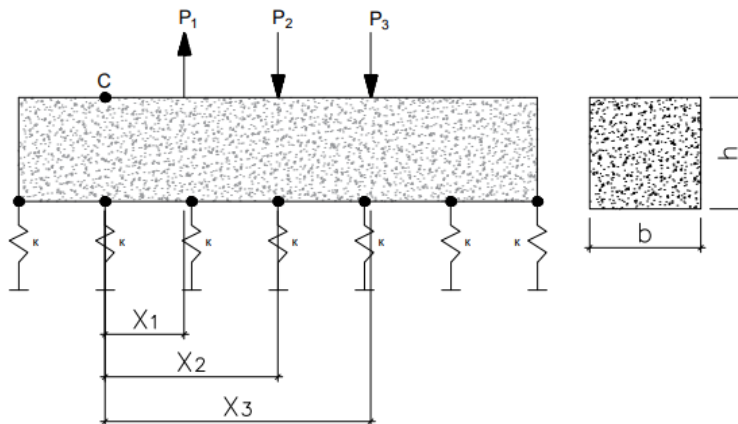


Fig. 4 - Fibroconcrete block loaded by a system of concentrated forces

Рис. 4 - Фибробетонный блок, нагруженный системой сосредоточенных усилий

The fiber concrete block is considered as a beam on an elastic base, loaded by several concentrated forces Fig. 4. It is necessary to determine the bending moment taking into account the concentrated force and the distance from each load, as indicated in [6]. From this value it is required to calculate the total bending moment at point C from the action of these forces [5-5]. Let us use the principle of independence of the action of forces.

Using formula (4), we determine the bending moment taking into account the concentrated load  $P_1$  and the mathematical function to the coefficient of relative bending stiffness at point C:

$$M_1 = \frac{1}{4\beta^*} P_1 \cdot e^{-\beta x} (\cos \beta x - \sin \beta x) \quad (4)$$

$$M_1 = \frac{1}{4 \cdot 1.19} 19.5 \cdot 0.81 = 3.318 \text{ кН} \cdot \text{М}$$

Calculate the bending moment at the point, taking into account the concentrated load  $P_2$  by the formula:

$$M_2 = \frac{1}{4\beta^*} P_2 \cdot e^{-\beta x} (\cos \beta x - \sin \beta x) \quad (5)$$

$$M_2 = \frac{1}{4 \cdot 1.19} 147 \cdot 0.6398 = 19.7585 \text{ кН} \cdot \text{М}$$

Using formula (6), determine the bending moment, taking into account the concentrated force  $P_3$  at point C:

$$M_3 = \frac{1}{4\beta^*} P_3 \cdot e^{-\beta x} (\cos \beta x - \sin \beta x) \tag{6}$$

$$M_3 = \frac{1}{4 \cdot 1.19} 147 \cdot 0.4688 = 14.477 \text{кН} \cdot \text{М}$$

Based on formulas (1, 2, 3), calculate the total moment by the formula:

$$M_c = \frac{1}{4\beta^*} [P_1 \cdot \eta_1(x_1) + P_2 \cdot \eta_2(x_2) + P_2 \cdot \eta_2(x_3)] \tag{7}$$

$$M_c = 3.18 + 19.7585 + 14.477 = 37.416 \text{кН} \cdot \text{М}$$

- where  $M_c$  is the bending moment at point C;
- $P$  - concentrated force;
- $X$  - distance from the force  $P$  to point C;
- $\eta$  - mathematical function;
- $\beta$  - coefficient of relative bending stiffness;

Fibroconcrete block is loaded with several concentrated loads from struts, the application points of which are located at a distance  $x_1, x_2, x_3$  mm from the support of the fibroconcrete block reinforcing a truss

assembly made of square hollow sections. Loading was performed in stages, the values were taken to be 147 and 19.5 kN [3].

The use of modern software packages makes it possible to carry out numerous variation studies combining different loads and variation of strength and deformation characteristics of materials (structural concrete, high-strength concrete for reinforced concrete beams), as well as to compare the results obtained with the SP "ANSYS" with analytical calculation results [15]. In this study, one of the most modern universal SP "ANSYS" was used [5].

### 3. Results

Analytical and numerical calculations of the fiber concrete block as a beam on an elastic base were carried out in accordance with [7]. To analyze the fiber concrete block, different cross-sections for the strut and the chord of SHS trusses were considered [9].

The results of calculations of the bending moment  $M_c$  of the fiber concrete block as a local reinforcement of the SHS truss node, taking into account the concentrated loads and mathematical functions, as specified in [6], are shown in Table 2.

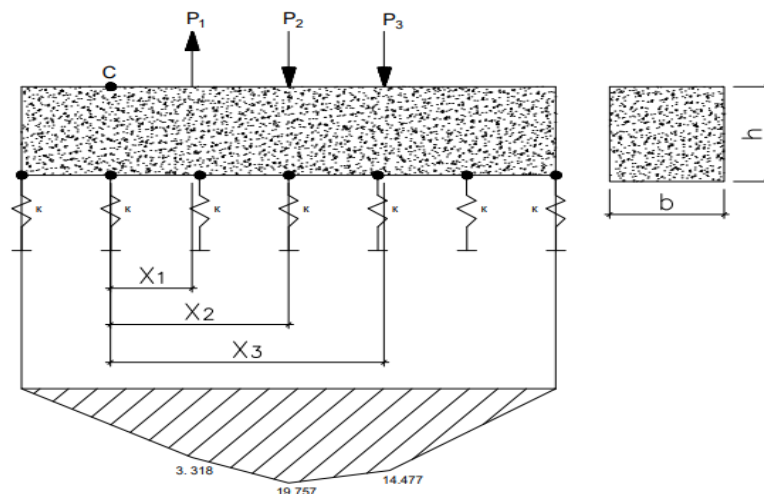
**Table 2.** Results of analytical calculations of the fiber concrete block as a beam on an elastic base

**Таблица 2.** Результаты аналитических расчетов фибробетонного блока в виде балки на упругом основании

№ сечения	X, М	$\beta X$	$\eta_i$	P, кН	M, кН*М
1	0,085	0.101	0.8100	19.5	3.318
2	0.187	0.2225	0.6398	147	19.758
3	0.287	0.3415	0.4688	147	14.477
					$M_c = \sum M = 37.416$

Based on the results of numerical calculations of the fiber concrete element as a beam on an elastic base, the bending moment diagrams are compiled taking into account the concentrated forces, mathematical functions and the bending stiffness factor  $\beta^*$  [5] and presented in Fig. 5.

Using formula (5), we determine the bending moment in the fiber concrete block, taking into account the concentrated load and mathematical functions, the coefficient of relative bending stiffness [7] (Fig. 6):



**Fig. 5 -** Bending moment diagram in a fiber concrete block as a beam on an elastic base

**Рис. 5 -** Диаграмма изгибающего момента в фибробетонном блоке в виде балки на упругом основании

Based on the results of numerical studies of a fiberconcrete block reinforcing a SHS truss assembly, using the phenomenological approach, a graph of the

dependence of the bending stiffness coefficient  $\beta$  on the correction factor  $\beta^*$  (figure 6) was made [11].

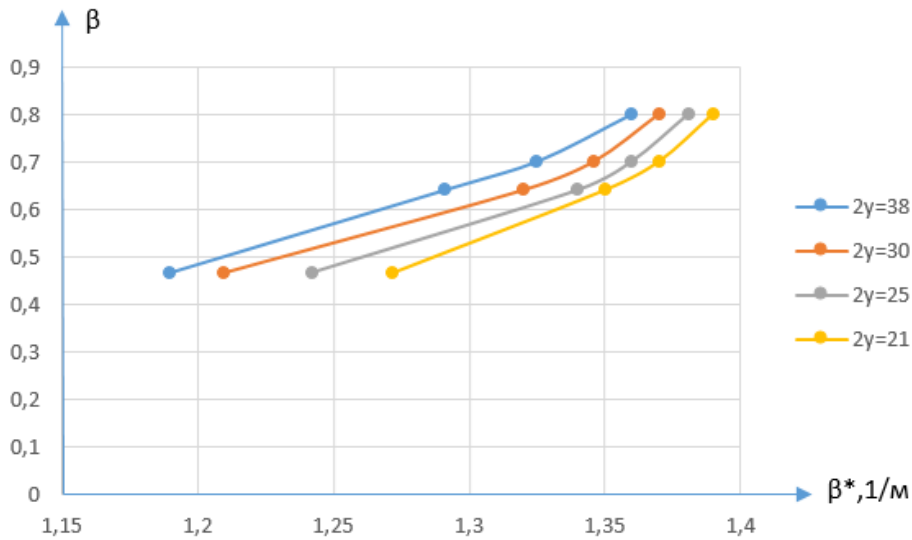


Figure 6 - Diagram as a function of strut width to girder width  $\beta$ , coefficient of relative bending stiffness  $\beta^*$  with regard to girder width to its thickness  $2\gamma$

Рисунок 6 - Диаграмма зависимости ширины стойки от ширины балки  $\beta$ , коэффициент относительной жесткости при изгибе  $\beta^*$  в отношении ширины балки к ее толщине  $2\gamma$

On the basis of the obtained results of numerical studies, graphs of relations between the values of strut width to chord width  $\beta$  and the bending stiffness coefficient  $\beta^*$  have been plotted [3]. Thus, it should be noted that the bearing capacity and strength of a fiber concrete block as a beam on an elastic base as a local

reinforcement of a truss node made of SHS depend on the width of the strut and its thickness [7].

Based on the results of numerical calculations of the fiber concrete block, as a beam on an elastic base, using the phenomenological approach, graphs (Fig. 7) of the dependence of the bedding factor on the bending stiffness factor  $\beta^*$  [12].

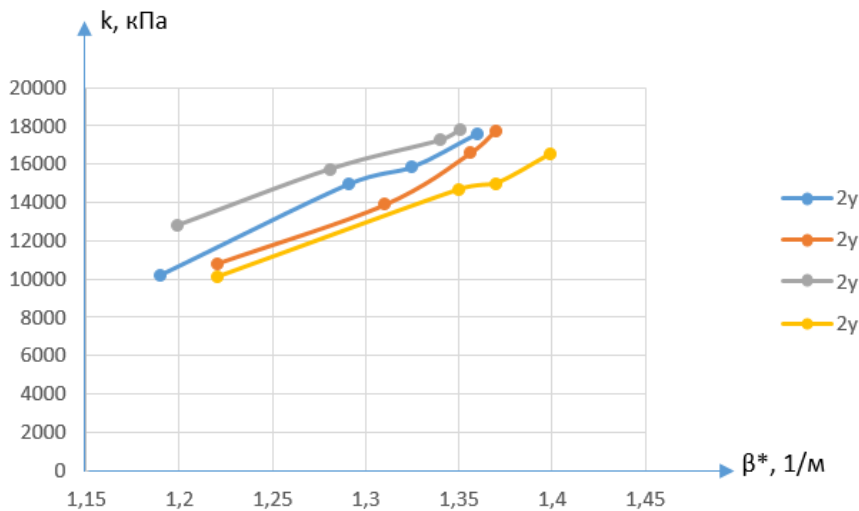


Fig. 7 - Diagram of dependence of bedding coefficient  $k$  and coefficient of relative bending stiffness  $\beta^*$

Рис. 7 - Диаграмма зависимости коэффициента залегания  $k$  и коэффициента относительной жесткости при изгибе  $\beta^*$

According to the results of numerical studies, graphical and analytical dependences of the change in strength characteristics of fiber concrete block under the loading by concentrated forces were obtained [7].

generalizations, the purpose of which is to develop an algorithm for designing and calculating nodes under different geometric and physical-mechanical characteristics [12].

The numerical model of the fiber concrete block, as a beam on an elastic base, of the analyzed node more accurately reflects its behavior during load transfer. The analytical model contains some simplifications and

Numerical calculations of fiber concrete blocks, as a beam on an elastic base, were performed using the SP "ANSYS". [8]. Fibroconcrete block under the action of concentrated load was used as reinforcement of truss

nodes made of square hollow sections [8]. To conduct the study, numerical models of truss nodes made of square hollow sections with fiber concrete block reinforcement were created (Fig. 1).

To calculate a fiber concrete block as part of the local reinforcement of the nodes of structures of trusses made of bent-welded profiles, as a beam on elastic foundations, firstly, its calculation model is established and the conditions of its contact with the foundation are considered, and then the calculation is performed [13].

#### 4. Discussion

Analysis of the numerical study at the considered values of the parameters showed the following:

1. The performed analytical studies made it possible to determine the method of calculation of fiber concrete element as the work of a beam on an elastic basis [11]. This selects an arbitrary point on the basis of this point performs the calculation of the block as part of the node of a truss made of square hollow sections.

2. The equations based on which it is possible to determine bending moments at arbitrary points of fiber concrete block as a beam on an elastic basis are obtained.

3. Equations were obtained, on the basis of which we can analyze the bedding coefficients of fiber concrete block as a beam on an elastic base  $k = 4EJ \cdot \beta^{*4}$ .

4. The methods of calculation of a fiber concrete block based on the theory of a beam on an elastic base, which is important in construction practice, have been developed.

In spite of the absence of a full-fledged normative and technical base for the methods of calculation of fiber concrete block as a beam on an elastic base as reinforced nodes of square hollow sections trusses, the finite-element model developed in PC "Ansys Workbench" allows one to reliably determine the bending moment [13]. Based on it, it is possible to determine the bedding factor  $k$  and the bending stiffness factor  $\beta^*$  of the block.

Based on the results of numerical studies, a methodology for calculating a fiber concrete block locally reinforcing a truss unit made of square hollow sections as a beam on an elastic base is proposed. Next, an experimental study should be performed to implement the methodology in construction.

#### 5. Conclusion

The following conclusions can be drawn from the results of the work:

1. The calculation scheme of a fiber concrete block as a beam on an elastic base, which most closely reflects its work as part of the calculation model of a node including struts and truss chords made of square hollow sections, is determined.

2. The applicability of the beam analogy to the computational scheme of a fiber concrete block as a beam on an elastic base is established.

3. The method of calculation of fiber concrete block as a beam on an elastic basis taking into account the

beam analogy as a part of a truss node made of bent profiles has been proposed.

4. The bending moment calculation procedure of fiber concrete block as a beam on an elastic base has been determined.

5. The method of calculation of the bending stiffness coefficient,  $\beta^* = 1.291 \text{ m}^{-1}, 1.324 \text{ m}^{-1}, 1.346 \text{ m}^{-1}, 1.373 \text{ m}^{-1}$  of fiber concrete block as a local reinforcement of truss nodes made of square hollow sections has been determined.

6. The method of calculation of stiffness coefficient,  $k = 10819 \text{ kPa}, 13891 \text{ kPa}, 16577 \text{ kPa}, 17767 \text{ kPa}$  of fiber concrete block as a beam on an elastic base as a local reinforcement of a truss node made of square hollow sections is defined.

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## К РАСЧЕТУ ФИБРОБЕТОННОГО БЛОКА В ВИДЕ БАЛКИ НА УПРУГОЙ ОСНОВЕ В СОСТАВЕ ЛОКАЛЬНО УСИЛЕННЫХ УЗЛОВ ФЕРМ, ВЫПОЛНЕННЫХ ИЗ КВАДРАТНЫХ ПУСТОТЕЛЫХ ПРОФИЛЕЙ

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**Аннотация.** Статья посвящена аналитическому и численному исследованию узлов фермы, выполненных из квадратного пустотелого сечения с локальным бетонным заполнением. Проведен численный анализ фибробетонного элемента в виде балки на упругом основании в качестве локального усиления узла фермы, выполненного из квадратных полых профилей, под действием сосредоточенной нагрузки от соседней стойки.

**Предмет исследования:** Предметом исследования является локальное заполнение бетоном армированных узлов ферм из СВС соединения К-типа, и расчет несущей способности узлов ферм из ВШП под воздействием нескольких сосредоточенных сжимающих нагрузок от элементов раскоса.

**Материалы и методы:** Применен метод внутреннего исследования, основанный на численном эксперименте и компьютерном моделировании SP "ANSYS Workbench" локального усиления узла ферм из СВС К-образного типа соединения, локально заполненного бетоном.

**Результаты:** Представлены простые и надежные методы усиления узлов, выполненных из квадратных пустотелых профилей путем заполнения бетоном. а также соответствующие методы их расчета. Соединения узлов фермы, выполненные из квадратных полых профилей К-образного типа соединения с прямым примыканием, дают высокое качество при минимальных трудозатратах и металлоемкости.

**Выводы:** Несущая способность узлов фермы, выполненных из квадратных полых профилей, может быть увеличена за счет локального заполнения внутренней полости хорды бетоном, что позволяет разгрузить полку, к которой примыкают решетчатый элемент и боковые стенки хорды.

**Ключевые слова:** Квадратное полое сечение, жесткость при изгибе, численное исследование, стальная труба с бетонным заполнением, метод расчета.