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TO THE CALCULATION OF A FIBER CONCRETE BLOCK AS PART OF LOCALLY REINFORCED TRUSS NODES FROM SQUARE HOLLOW SECTIONS

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Abstract. Problem statement. Currently, steel trusses made of square hollow sections occupy the overwhelming market share among the load-bearing roof and crossing truss structures. Their advantages include cost-effectiveness, high aesthetic and performance properties. However, the verification calculations of such trusses require special attention to the nodes and often the cross-section of the element is determined based on the strength of the node rather than the truss element. Increasing the bearing capacity of the nodes of such trusses will improve their economic efficiency and operability.
The purpose. Development of a methodology for calculating a fiber concrete block of analytical dependences for determining the bedding factor of a block of locally reinforced nodes of trusses made of square hollow sections. To achieve the goal, the following tasks have been formulated:
1. Determine the computational scheme of the node model, reflecting the stiffness factor as a part of the computational model of a node made of square hollow sections, including struts and truss chords made of square hollow sections;
2.Determine the applicability of a beam analogy on an elastic basis to the design scheme of a fiber concrete block;
3. To propose a methodology for calculating the coefficient of bedding of fiber concrete block as a part of reinforced girder assembly made of square hollow sections.
4. To consider the method of calculating the coefficient of, from the relative bending stiffness of a fiber concrete block as a part of a strengthened truss assembly made of square hollow sections.
Results. The main results of the work consist in the analytical study of truss nodes from square hollow sections locally reinforced with a fiber concrete block, the development of a method for calculating a fiber concrete block as a beam on an elastic foundation based on the results of numerical experiments in the «Ansys Workbench» software package.
Conclusions. The significance of the obtained results for the construction industry lies in the fact that possible approaches to determining different methods for calculating a fiber concrete block as part of reinforced truss units from square hollow sections are considered, which will reduce the metal consumption and deformability. The results obtained in numerical studies of the stiffness coefficient of a fiber concrete block and the results obtained using the «Ansys Workbenches» software package showed that they are close to the results of calculating the stiffness coefficient of a fiber concrete block in locally reinforced truss nodes from square hollow sections.
Key words: numerical analysis, knot, fiber concrete, steel truss, bed coefficient and numerical study.

INTRODUCTION

The methodology of calculation of fiber concrete block as a part of reinforced nodes of square hollow sections (SHS) trusses is now considered. Used in buildings, bridges, towers and trusses made of square hollow sections with high aesthetic appearance and performance properties. Features of their calculation, design and performance in the construction process, as well as the relative in terms of flexural performance [1]. Economic competitiveness is achieved due to the low cost of production and structural efficiency of tubular profiles in operation under compressive loads [2].

It is well known that locally reinforced concrete-filled truss nodes have load-bearing capacity and good ductility. The disadvantages of tubular sections include reduced bending stiffness [3], as well as special attention and more stringent requirements for the execution of welds. Tubular section joints transfer loads in a complex way. The mechanism of this transfer depends on several parameters, such as the dimensions of the RHS (rectangular hollow section) or SHS (square hollow section) elements, thickness, angle and width ratio between adjacent elements.

If we take into account the partial plastification of some local nodes in the joint and the buckling effects in the compressed part of the plates, the load transfer under such conditions can be described as nonlinear. Nonlinearity leads to several failure modes that can occur in joints of square hollow sections elements. According to Eurocode 3[4].

a) Chord face plastification
b) Punching shear failure of the chord
c) Uneven load distribution, in the tension brace
d) Uneven load distribution, in the compression brace
e) Shear yielding of the chord, in the gap
f) Chord side wall failure
g) Local buckling of the chord face

Studies [5-6], have shown a significant increase in the bearing capacity of K-type connections with concrete-filled chords. It is also stated in [4] that strut elements under tension and compression should be calculated separately and that the determining limit state for the stretched strut element will be the premature local flow of the chord at the junction of the strut elements or the strike-slip of the chord surface around the strut.

In [10], there are data on testing of truss nodes made of square hollow sections with one and two strut elements adjacent to the chord with different types of reinforcement made so as to transfer the load from the strut to most of the perimeter of the chord cross-section in the node. The use of these reinforcements increased

the bearing capacity of the nodes by an average of 15% [8].

Numerical investigations and calculations based on the characteristics of fiber concrete block properties allow to design and apply more economically to calculate the structure at all stages of work of fiber concrete reinforced square hollow sections truss units. Therefore, research to improve the methodology of calculation of locally reinforced units of square hollow sections trusses with fiber concrete is an urgent scientific task [5].

The calculation methods used in the design of truss nodes made of square hollow sections contain some simplifications and generalizations, and in certain cases cause some discrepancies between the calculated and actual values. In this paper, an attempt is made to estimate the scale of these discrepancies on the example of K -shaped knot connection, evaluating its carrying capacity using an analytical approach in accordance with [6] numerical analysis performed with the help of «Ansys Workbench»

The object of the study is steel trusses made of square hollow sections, the local strengthening of the nodes of which is performed by monolithic fiber concrete.

The subject of the study is the local strengthening of K-type joint nodes, performed according to [6], and the calculation of the fiber concrete block for the action of concentrated loads from the elements of the brace.

MATERIALS AND METHODS

The connection of a truss node made of K-shaped square hollow sections made according to [8] with a reinforced fiber concrete block. Block cross-section120x120 mm and length 560 mm is made of fiber concrete with elastic modulus E=30000 MPa and computational compression resistance Rb=14.5MPa. The cross-section of the truss chord is 120x120x4 mm and the compressed brace is 60x60x3 mm and the stretched brace is 40x40x3 mm. Materials for truss knots: the chord and braces of the knot are C255 steel according to GOST 27772-2015 [6] with a design resistance of 380 MPa, local filling is fiber concrete with an elastic modulus of not less than 30000 MPa Fig. 1.

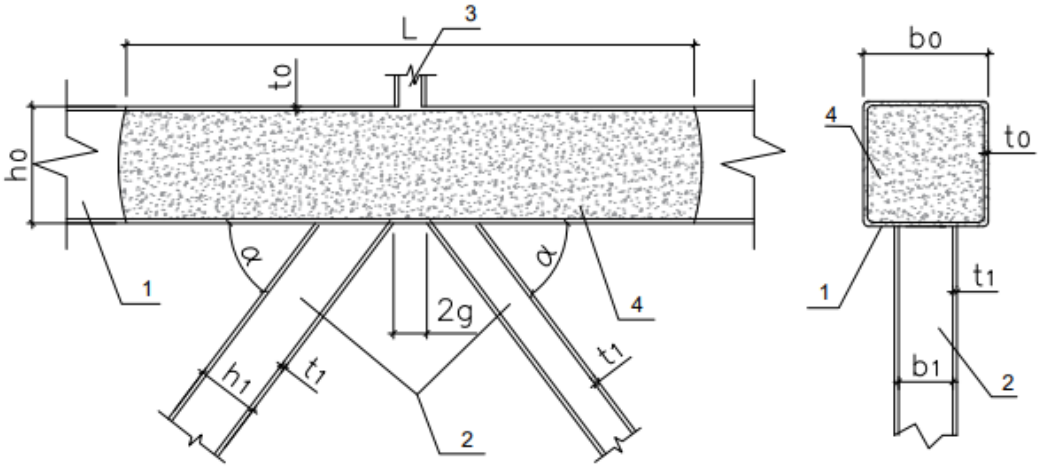


Fig.1 - Design parameters of nodes

This study presents a new method [4] of local reinforcement of truss nodes made of square hollow sections by fiber concrete element Fig.1, where:

1 – truss chords (upper chord),

2 – truss struts,

3 – hole for concreting the nodes, in which the filling bag and pipe plug are inserted and then welded to the truss chords,

4 – the fiber concrete unit after the curing process,

L – length of the fiber concrete block,

h0 – height of the chord cross section,

b0 – width of the chord cross-section,

t0 – chord thickness,

h1 – height of the strut section,

b1 – width of strut section,

t1–- strut thickness,

α – angle of abutment of the brace,

Modeling of truss nodes made of square hollow sections K-connection profiles, locally reinforced with a fiber concrete element on an elastic base.

The subject of this study is locally reinforced concrete filled K-type joints. The weakest part of joints of this type is the section of the chord to which the stretched brace adjoins [2]. Concrete-filled chord can be made in various ways. In the production shop the truss can be tilted for the filled chord [5]. Filling of the whole truss chord increases the design resistance of the structure, but leads to an increase in the weight of the structure and higher labor costs.

The study presents a new methodology for calculating local reinforcement of truss nodes with fiber concrete [5]. The chord (1) is filled with concrete (4) through a previously prepared hole in which a plug (3) is inserted, then the hole is welded Fig. 1. To prevent the concrete mixture from spreading inside the chord, a fabric bag (4) is placed through the hole before the filling procedure. The concrete mixture under pressure forces the bag to unfold and fill the space inside the belt [7].

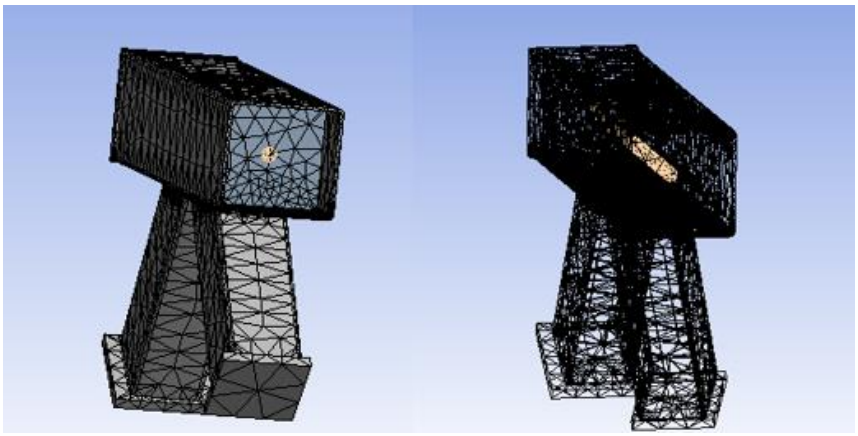


Fig. 2 - finite element model of the K -figurative node

It can be seen from Fig. 2 that a finite element model in software package "Ansys Workbench" was made to analyze the work of fiber concrete block as reinforced nodes of trusses made of square hollow sections of K-shaped connection type. To increase the load-carrying capacity and the workability of the fiber concrete block as a part of the reinforced nodes of the trusses made of square hollow sections, the rods are structurally placed in it [7].

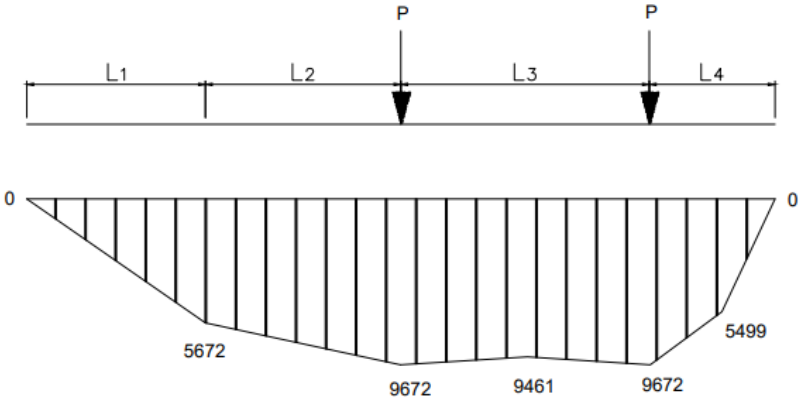


Fig. 3 - Bending moment diagrams of the fiber concrete block

Fig. 3 shows the results of bending moment of fiber concrete block as a part of reinforced trusses made of square hollow section as a part of reinforced nodes of square hollow sections, which was performed in software package "Ansys Workbench". It is necessary to develop a methodology for calculating the stiffness factor of a fiber concrete block on an elastic base [9].

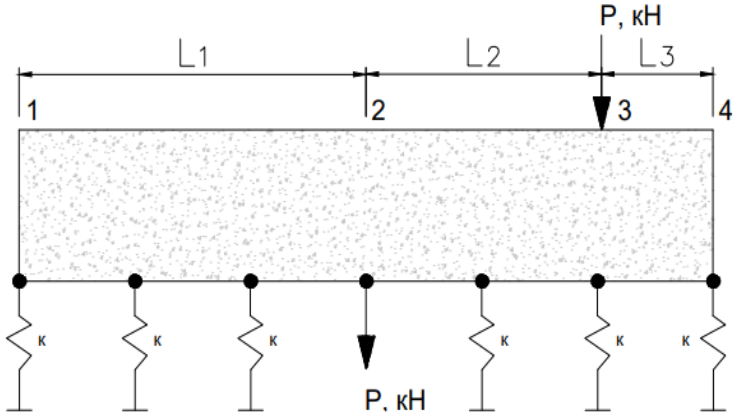


Fig. 4 - fiber concrete beam on an elastic base

Fig. 4 shows that when a brace is subjected to compressive longitudinal forces in the flange by the chord of a truss made of square hollow sections, to which the brace is adjacent, the importance of stresses binds it by bending [4]. In the case of filling the chord with fiber concrete nodal sections, part of the forces

from the brace is transferred to the fiber concrete block, the upper flange of the chord is unloaded. In this case, the work of these blocks can be considered as the work of a beam on an elastic basis [8].

A similar approach to determining the value of the coefficient, of the relative value of the bending stiffness of a fiber concrete block on an elastic base as part of reinforced nodes truss of square hollow sections, taking into account bending moments and concentrated loads in an arbitrary section of the block [9-11] is calculated by the formulas;

We choose the origin of coordinates under, and the second point of the beam on an elastic base, at x=0, η=1;

$$\beta^* = \frac{1}{4M_2} \cdot P \cdot e^{-\beta x}(\cos\alpha - \sin\alpha) \qquad (1)$$

where P – is the concentrated load;

M – bending moment;

$\eta_i = e^{-\beta x}(\cos\beta x - \sin\beta x)$ - function;

To determine the stiffness factor of fiber concrete block as a part of reinforced nodes of trusses made of square hollow sections, taking into account the stiffness and the coefficient from the relative bending stiffness of the block [12], we calculate by the formula:

$$k = 4EI\beta^{4^*} \qquad (2)$$

The use of modern software complexes allows numerous variation studies, combining different loads and changes in strength and deformation characteristics of materials, high strength concrete for reinforced concrete beams, and comparing the results obtained with the help of "Ansys Workbench" with the results of analytical calculations [3]. In this study, one of the most modern universal software complexes "ANSYS Workbench" was used [4].

RESULTS AND DISCUSSION

Analytical calculations were performed in accordance with [5]. For the analyzed fiber- concrete block as reinforced nodes of trusses made of square hollow sections K - shaped types of connections in the calculated sections, the methods of calculation of the beam on an elastic basis taking into account the Krilov and Euler functions [9] were used. The obtained results of stiffness factor calculations considering bending moment at varying section size and block length [11] are presented in the table.

Table 1. Results of analytical calculations of the fiber concrete block on an elastic base

№	P, кН	M, кН*М	β	γ	К, кП	β*, м$^{-1}$
1	147	31.534	0.533	38	85625	1.1654
2	147	30.112	0.666	38	104924160	1.7278
3	147	26.414	0.800	38	16362	2.9104
4	147	23.953	0.933	38	25515	11.8624
5	147	21.983	0.533	30	21176	1.6717
6	147	14.818	0.666	30	95065	2.4800
7	147	7.338	0.800	30	3169964	5.0079
8	147	3.045	0.933	30	107228242	12.0773
9	147	15.11	0.533	25	58694	2,45
10	147	9.959	0.666	25	934951	3,69
11	147	3.098	0.800	25	99800853	11,8624
12	147	3.019	0.933	25	110558681	12,17
13	147	10.679	0.533	21	706866	3,4413
14	147	3.792	0.666	21	44444405	9,6905
15	147	3.004	0.800	21	112876197	12,2333
16	147	3.219	0.933	21	110576348	12,27048

The calculations of fiber concrete blocks as a beam work on an elastic base were performed using the software complexes "Ansys Workbench" [8]. Fibroconcrete block under the action of concentrated load was used as reinforcement of truss nodes made of square hollow sections.

Results of calculations - graphs of coefficient β*, depending on the relative value of bending stiffness of block and coefficient β of aspect ratio (brace width to width of truss chord) Eurocode 3[14], are shown in Fig. 4. As shown in graph 4, the bending moment of the fiber concrete block decreases when the cross-section of the truss brace element is entrained and the bending moment of the fiber concrete block increases, while the stiffness and workability of the square hollow sections truss node increases [3].

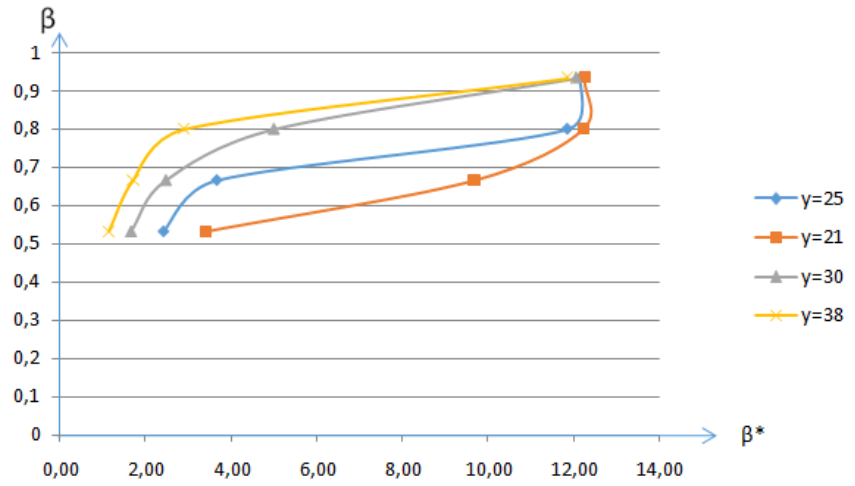


Fig. 4 - Graphs of the relative value of the bending stiffness of fiber concrete and the ratio of the width brace to the width chord of the truss

As it can be seen from the table and the graph, the main parameters varied in the analyzed reinforced truss units made of square hollow sections with fibrous concrete [15] include:

- Ratio of brace element width to chord width β = b_1/b_0: 0.5333, 0.666, 0.80, 0.9333
- Ratio of chord width to chord thickness:

$$\gamma = \frac{b_0}{t_0}$$ 38, 30, 25, 21.

The above mentioned parameters are chosen because they have been identified in published studies as the dominant factors affecting the behavior of reinforced K-joint truss nodes [14]. The variations of the ranges β and γ are based on those frequently encountered in practice.

Calculation results have shown that the greatest bedding factor in the fiber concrete block occurs when the value of the coefficient dependent on the relative value of the flexural stiffness of the fiber concrete block and the block stiffness EI= 12.654*105 kN*m^2 increases [9].

The above mentioned parameters are chosen because they have been identified in published studies as the dominant factors affecting the behavior of reinforced K-joint truss nodes [14]. The variations of the ranges β and γ are based on those frequently encountered in practice.

In spite of the absence of full-fledged normative and technical base on methods of calculation of fiber concrete block as a part of reinforced nodes of trusses from square hollow sections, the finite-element model of the block developed in the program complex "Ansys Workbench" Fig. 2 allows to define reliably the method of calculation of bedding factor and coefficient depending on the relative value of bending stiffness of fiber concrete block. According to the results of numerical studies, it has been established that the operability of truss units reinforced with fiber concrete made of square hollow sections is ensured, thus confirming the possibility of its further experimental research and introduction into construction [10].

In the study [2], which simulated in the software package "Ansys Workbench" the methodology of calculation of fiber concrete block as a part of reinforced nodes of trusses made of square hollow sections. Based on the results of numerical studies, this paper determines the calculation procedure for a K-type fiber reinforced concrete unit and obtains the criteria for its serviceability and deformability.

In [2] we considered the method of local concrete filling of K-type nodes as an alternative to stiffening ribs welded from the outside to the chords of chords trusses is a good enough design solution that increases the strength, stiffness and fatigue endurance of structures.

CONCLUSION

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

1. The calculation scheme of a node model, reflecting its stiffness factor as a part of the calculation model of a node made of square hollow sections, including braces and truss chords, has been determined.
2. The applicability of the beam analogy on an elastic base to the design scheme of a fiber concrete unit has been established.
3. A methodology for calculating the stiffness factor k of a fiber concrete block as part of a reinforced truss assembly made of bent profiles has been proposed, k = 85625, 104921, 16362, 25515.
4. A procedure of calculating the coefficient β, which depends on the relative value of bending stiffness of a fiber concrete block as a part of a reinforced node of a truss made of square hollow sections, has been considered, β = 1.165, 1.727, 2.910, 11.862 м$^{-1}$.

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К РАСЧЕТУ ФИБРОБЕТОННОГО БЛОКА В СОСТАВЕ ЛОКАЛЬНО АРМИРОВАННЫХ ФЕРМЕННЫХ УЗЛОВ ИЗ КВАДРАТНЫХ ПОЛЫХ СЕКЦИЙ

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Аннотация Постановка проблемы. В настоящее время стальные фермы, изготовленные из квадратных полых профилей, занимают подавляющую долю рынка среди несущих конструкций кровли и пересекающихся ферм. Их преимущества включают экономичность, высокие эстетические и эксплуатационные свойства. Однако проверочные расчеты таких ферм требуют особого внимания к узлам, и часто поперечное сечение элемента определяется на основе прочности узла, а не элемента фермы. Увеличение несущей способности узлов таких ферм позволит повысить их экономическую эффективность и работоспособность.

Цель. Разработка методики расчета фибробетонного блока аналитических зависимостей для определения коэффициента подстилаемости блока локально армированных узлов ферм, изготовленных из квадратных полых профилей. Для достижения поставленной цели были сформулированы следующие задачи:

1. Определите вычислительную схему модели узла, отражающую коэффициент жесткости как часть вычислительной модели узла, выполненного из квадратных полых секций, включая стойки и стропильные пояса, выполненные из квадратных полых секций;

2.Определите применимость аналогии с балкой на упругой основе к конструктивной схеме фибробетонного блока;

3. Предложить методику расчета коэффициента подстилаемости фибробетонного блока в составе армированной балочной конструкции, изготовленной из квадратных полых профилей.

4. Рассмотреть метод расчета коэффициента, исходя из относительной жесткости на изгиб фибробетонного блока как части усиленного ферменного узла, изготовленного из квадратных полых секций.

Результаты. Основные результаты работы заключаются в аналитическом исследовании узлов фермы из квадратных полых секций, локально армированных фибробетонным блоком, разработке метода расчета фибробетонного блока как балки на упругом основании на основе результатов численных экспериментов в программном пакете «Ansys Workbench».

Выводы. Значимость полученных результатов для строительной отрасли заключается в том, что рассмотрены возможные подходы к определению различных методов расчета фибробетонного блока в составе армированных ферменных узлов из квадратных полых профилей, что позволит снизить металлоемкость и деформируемость. Результаты, полученные при численных исследованиях коэффициента жесткости фибробетонного блока, и результаты, полученные с использованием программного пакета «Ansys Workbenches», показали, что они близки к результатам расчета коэффициента жесткости фибробетонного блока в локально усиленных стропильных узлах из квадратных полых секций.

Ключевые слова: численный анализ, узел, фибробетон, стальная ферма, коэффициент слоя и численное исследование.