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To the determination of the stress-strain state of a concrete block as part of a reinforced node truss from bent-welded profiles

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Abstract

Problem Statement: This article discusses analytical and numerical studies to determine the stress-strain state (SSS) of a concrete or fiber-reinforced concrete block in a truss node from bend-welded profiles (BWP). At the same time, a distinctive feature is that the nodes are strengthened locally. Problems are solved to determine stresses in a fiber-reinforced concrete element for a common section with a vertical axis of symmetry, taking into account the linear relationship between a concentrated load and stress in a fiber-reinforced concrete block.

Purpose: The purpose of the work is to develop on the basis of idealized design schemes of a fiber-reinforced concrete block of analytical dependencies to determine its stress-strain state, under a concentrated load, with a sufficient degree of reliability reflecting the stress-strain state of a block inside a loaded node from BWP profiles.

Results: The main results of the work consist in the analytical study of nodes from the BWP of a fiber-reinforced concrete block and the determination of its stress-strain state (fiber-reinforced concrete block) based on the results of calculation in the ANSYS Workbench software package.

Conclusions: The significance of the obtained results for the construction industry lies in the fact that using the method of sections, it is possible to calculate the node. At the same time, a fiber-reinforced concrete block is cut, the section is considered and equilibrium conditions are created for the cut-off part of the block, taking into account the bending moment, the calculation of normal stresses is performed. The results obtained from numerical studies using the Ansys program for truss nodes show that it is close to the results of the operation of a fiber-reinforced concrete block in locally reinforced truss nodes from BWP.

Keywords: Reinforcement, nodes, bent, welded, profiles, normal stress, fiber-concrete block, load, bearing capacity, strength and rigidity

1. Introductions

Today, steel trusses made of bent-welded profiles are very widely used in various sectors of construction, especially in industrial and civil buildings [12]. This fact can be explained by the economic competitiveness and architectural validity of structural forms consisting of rectangular, square or round hollow sections.

The main elements of trusses from BWP are chords that form the outline of the truss, and a lattice consisting of braces and racks (Fig. 1).

The truss lattice perceives mainly the shear force, performing the function of the wall of a solid beam. Truss chords work mainly on longitudinal forces and bending moments [1]. The connection of elements in nodes is carried out by directly adjoining some elements to others or using nodal gussets.

Calculation of truss nodes from the BWP, the angles of junction of the braces to the chord are at least 30, in this case the tightness of the junction of the braces to the chord is ensured. Welds connecting the braces with the chord are made with complete penetration of the profile wall. The advantages of this type of truss are corrosion resistance. Their use is effective for operation in an aggressive environment. The BWP has a relatively large moment of inertia, they work well for torsion [23].

Reinforced nodes the jaunts of truss elements is widely used when they do not have sufficient bearing capacity, and the thickness of their main elements cannot be increased due to economic feasibility. A commonly used method of reinforcing BWP joints is to weld a stiffening plate to the outer side of the chord element [16]. The disadvantages of this reinforcement method are that the resulting assembly design, as a rule, has either only a reinforced shelf or a chord wall, leads to increased zones of welding stress concentrations, and also loses its aesthetic appearance due to the welded stiffening plate.

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An alternative reinforcement method for certain types of joints is to fill the joints with fiber-reinforced concrete or cement mortar. Concrete filling instead of adding stiffeners on the outside of the BWP joints is especially suitable for architecturally open steel structures, while simultaneously reinforcing both the flange and the wall of the chord with a minimum number of weld stress concentration zones.

Studies [14], conducted by (Gimranov, 2021), as well as by other authors recently [13, 1, 8], showed a significant increase in the yield strength of K-type joints with a chord filled with fiber-reinforced concrete. The same study also states that brace elements in tension and compression must be calculated separately and that the defining limit state for a tensioned brace element will be the premature (local) yield of the chord in tension and the shear force of the chord surface around the brace.

Conducted in the Euro code and other authors [17, 18, 19, 20], presented for small truss spans, chord elements from BWP compounds can be filled with concrete along the entire length of the chord to improve the bearing capacity of the element, and also fire resistance, and the lack of such a truss connection has an increased weight of structures and labor intensity. For long span trusses, only some parts of the chord members, especially near critical connections, need to be filled with concrete to increase the strength of the connections.

Numerical calculations based on the characteristics of the properties of a fiber-reinforced concrete block make it possible to design more economically [14] and are applicable to design calculations at all stages of work. Therefore, research on improving the methodology for calculating locally reinforced truss nodes from BWP with fiber-reinforced concrete is an urgent scientific task.

The object of study is steel trusses made of BWP, in which their nodes are reinforced with local fiber-reinforced concrete blocks located within the node.

The subject of the study is the reinforced of the truss nodes of a concrete block, in which it determines the stress-strain state under the action of concentrated loads.

The purpose of the work is to develop on the basis of idealized design schemes of a fiber-reinforced concrete block of analytical dependencies to determine its stress-strain state, under a concentrated load, with a sufficient degree of reliability reflecting the stress-strain state of a block inside a loaded node from BWP profiles.

2. Methods and Materials

2.1 Subject of research

The subject of the study is the local reinforced of the truss nodes from the K-figurative type BWP, when calculating the stress-strain state of a fiber-reinforced concrete block under the action of concentrated loads from braces on it. Research methods are used based on numerical modeling of the local reinforcement of the node with fiber-reinforced concrete [13] Figure 1.

Materials for notes; the local node of the trusses is made of steel of the Russian standard (steel grade according to GOST 27772-2015) S255 (yield strength Ry = 370 MPa). The properties of the material, the welds connecting the elements of the brace and the chord, are made by arc welding in a shielding gas environment with electrodes of the E50A type according to (GOST 9466-80). The profile is bent, welded square section according to the assortment of TU 36-2287-2015.

Fiber-reinforced concrete for filling in the nodes of tubular trusses BWP are made by pouring concrete with a strength of 30 MPa in the elements of the upper or lower chord. The properties of concrete were determined by compression, 700 mm long were made according to the calculation and based on the recommendations of the Russian standard (GOST 1.0-2015) [22].

Numerical studies consider the reinforced of a local node of a fiber-reinforced concrete block, with a cross section of 140 mm wide, 140 mm high and 700 mm long, made of a fiber-reinforced concrete block with an elastic modulus Eext = 27500 MPa and concrete grades B20, design concrete resistance Rb = 11.5 MPa.

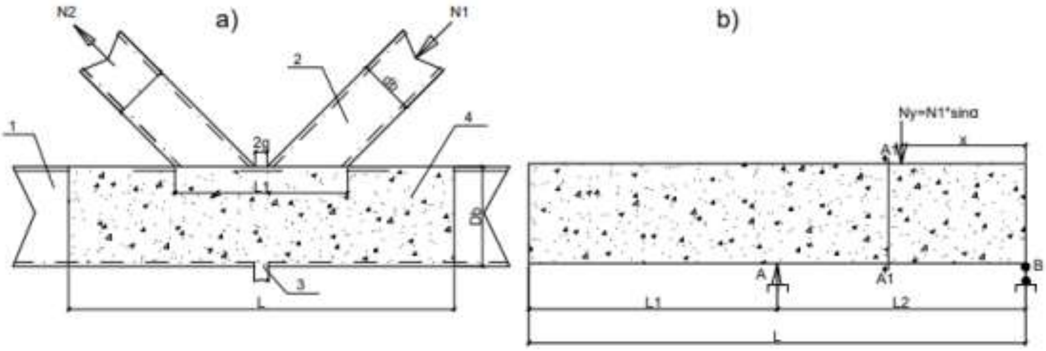


Fig 1: a) node truss from BWP with fiber-reinforced concrete, b) fiber-reinforced concrete block that constitutes the truss of nodes

In this work, a new method of local reinforcement of notes with a fiber-reinforced concrete element is presented (Fig. 1). The chord (1) is poured with fiber-reinforced concrete through a pre-prepared hole, into which a pipe plug (4) is inserted, and then a fiber-reinforced concrete block (3) is welded.

To prevent the concrete solution from spreading inside the chord, a fabric bag is placed through the hole before pouring. The fiber-reinforced concrete mortar under pressure causes the bag to unfold and fill the space inside the belt Fig.1 [12]. Simulation of the strengthening of the connection of a local K-shaped node with a fiber-reinforced concrete element. The length of the fiber concrete block is calculated based on the following equation.

$$L = L_1 + 2h \tag{1}$$

$$L_1 = \frac{h_0}{\cos\alpha} + \frac{h_0}{\cos\alpha} + 2g \tag{2}$$

In the formula (1) and (2), h, the height of the cross section of the chord, h_0, the height of the cross section of the lattice slopes, 2g, the distance between the inclined element, α, the angle of the inclined between the element.

The following formula calculates the bending moment in the cross section of a fiber-reinforced concrete block, as shown in Figure 1 in section A-A.

$$M = \frac{q * L}{4} \qquad (3)$$

In formula (3). q, concentrated load, L, span.

2.2 Numerical studies

At the stress-strain state in the fiber-reinforced concrete block, it is cut along the considered section and equilibrium conditions are created for the cut-off part of the beam [13].

Conditions for the balance of all forces:

The sums of the projections of all efforts and moments on the longitudinal axis of equality to zero:

$$\sum F_x = 0; \sum F_y; \sum F_z;$$
$$\sum M_x; \sum M_y; \sum M_z;$$

Fiber concrete is loaded with concentrated loads, the application points of which are located at a distance of 175 cm from the support. The load was applied in stages, the values of which were taken equal to 127 kN [13].

The use of modern software systems makes it possible to conduct numerous variant studies that combine different combinations of loads and variability of strength and deformation characteristics, materials - structural concrete, high-strength concrete for reinforced concrete beams [9], as well as compare the results obtained using ANSYS Workbench with analytical calculation results [5]. The article used one of the most modern, universal software systems ANSYS Workbench [7].

Figure 2 shows the results of a numerical experiment, the study of the structure was carried out taking into account the actual work of the fiber-reinforced concrete block [8], using the "compression-tension" work diagram.

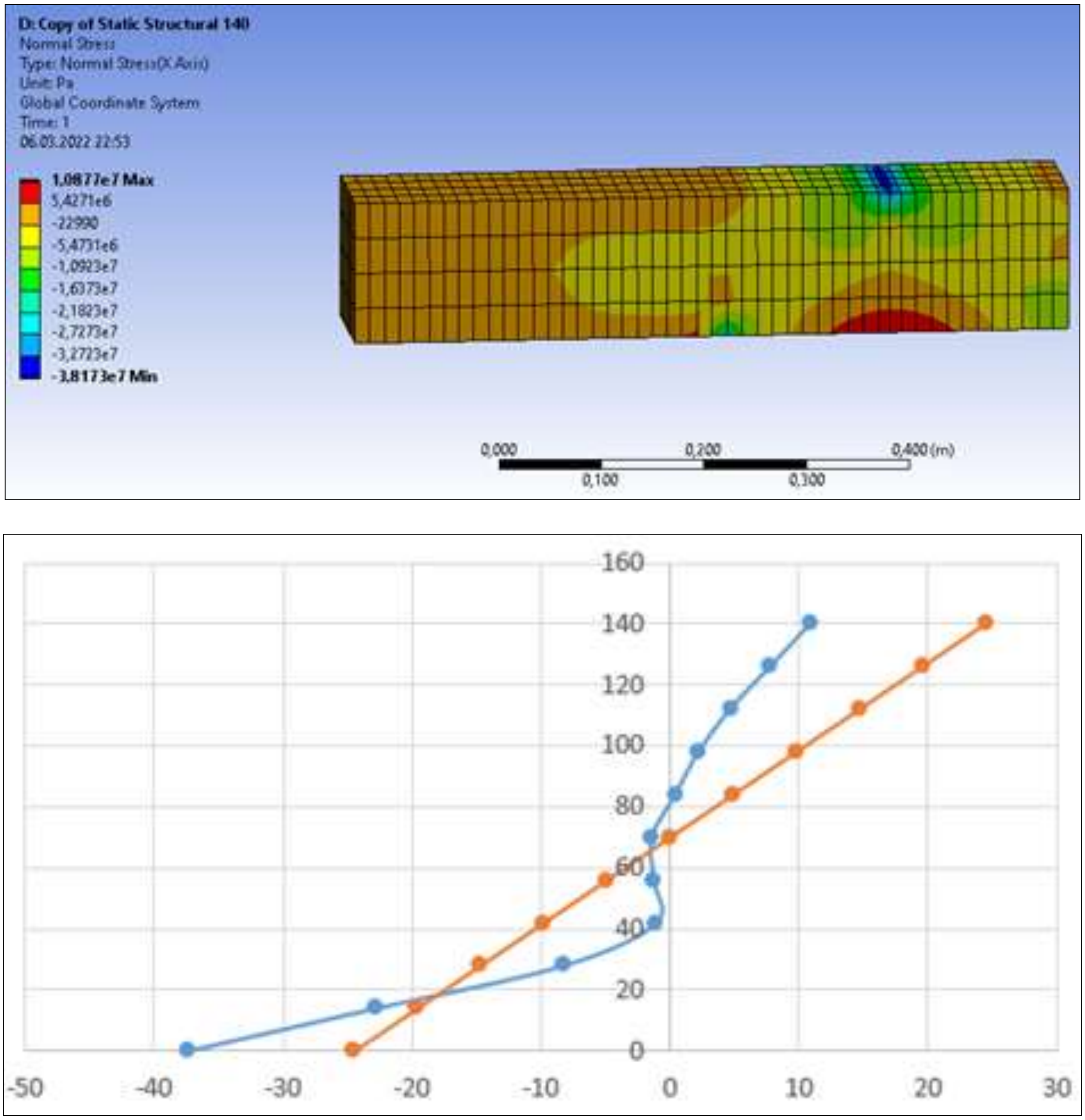


Fig 2: Scheme of loading a concrete block and the results of calculations in Ansys and diagrams of the work of fiber-reinforced concrete in compression-tension

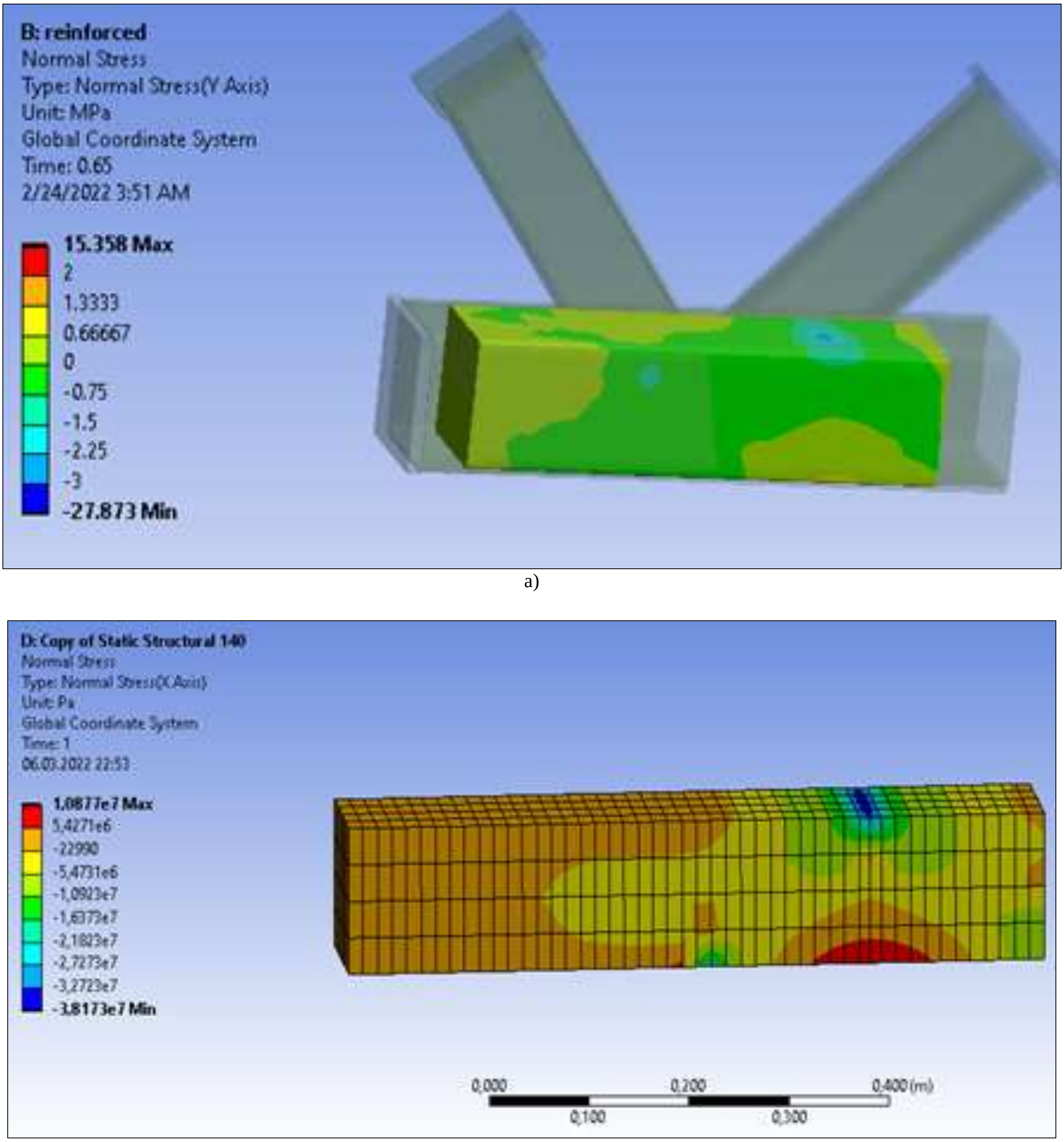
3. Results of the Study

Analytical calculations were conduct out in accordance with [8]. For the analyzed fiber-reinforced concrete block (due to the geometry and profiles used), it is necessary to check the possibility of normal stress in the fiber-reinforced concrete block [16].

Table: Results of analytical calculations

№		load кН	Bending moment кН*м	Stress МПа
1	**concrete block**	127	11.2	50.488
2		127	11.2	38.888
3		127	11.2	30.578
4		127	11.2	24.489
5		127	11.2	19.911
6		127	11.2	16.406

Numerical calculations were conduct used to reinforced the truss nodes from the BWP, and the results of analytical calculations of the normal stress are shown in Fig. 3.



a)

b)

Fig 3: a) Nodes of truss K-type, b) Distribution of normal stresses in a fiber-reinforced concrete block

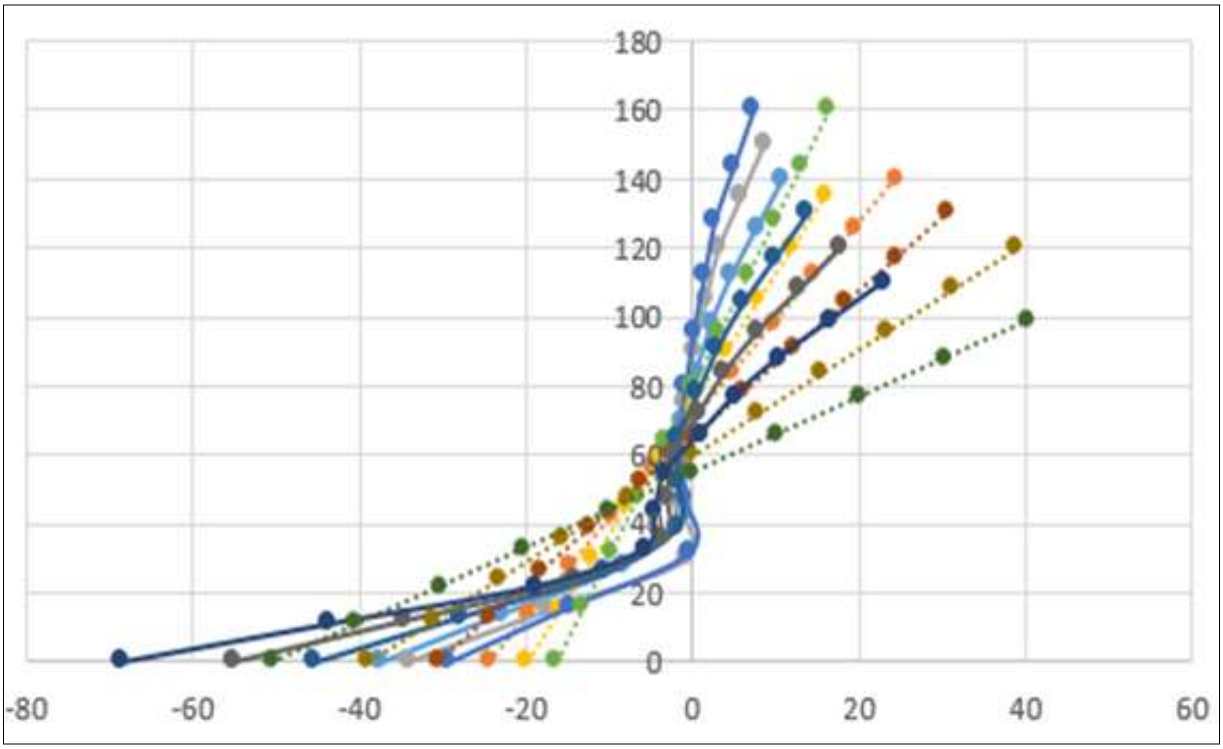


Fig 4: Graph of the distribution of normal stresses over the section of a fiber-reinforced concrete block in compression-tension

The graph above shows the stress analysis taking into account the bending moment in various sections of the concrete block. The static scheme of operation of a fiber-reinforced concrete block corresponds to an intermediate case between a beam and a wall beam. As a result, it is proposed to introduce a correction factor into the calculation of the concrete block according to the beam scheme - the coefficient of real stresses.

The following equation is used to obtain the actual compressive and tensile stress factors.

$$\xi = ax^2 - bx + c \qquad (4)$$

a, b, c, Coefficients are fixed, x=l/h, The ratio of the length to the height of the cross section.

Analysis and calculation of stresses in concrete blocks, taking into account the bending moment, the moment of resistance and with a coefficient, the actual compressive stress, which is presented in the figure, and the calculation according to the following formula are given;

$$\sigma_{сж} = \frac{M \cdot \zeta_{сж}}{W} \qquad (5)$$

If the cross-sectional area is square, then the moment of resistance of the x-axis is equal to the moment of resistance of the y-axis, x is;

$$W_x = W_y = \frac{b * h^2}{6} \qquad (6)$$

In formula (11), M, bending moment, W, moment resistance, b, Cross-sectional width, h, Cross-sectional height, the coefficient is the actual compressive stress, $\xi_c = 1.367$.

For connection joints of K-type filled with concrete, in the revised calculation of the normal stress, local reinforcement of joints in the concrete block, the results obtained from the analysis show that the stress in the compressive part is higher than in tension. Comparison with analytical modeling results demonstrated that the revised has reasonable accuracy in predicting the shear flexural strength of concrete-filled node connection joints K-type.

Since the results of numerical calculations performed for an unreinforced joint showed that both stresses and strains do not exceed the allowable values, there is no need to conduct out a numerical analysis of the joint with a reinforcing plate (in a reinforced joint, the actual values of stress and strain will be even less).

Concrete filled instead of adding stiffeners on the outside of bent welded profiles BWP joints is particularly suitable for architecturally exposed steel structures and increases strength, stiffness and even fatigue resistance.

The numerical model of the analyzed connection more accurately reflects its behavior during load transfer. The analytical model contains some simplifications and generalizations, the purpose of which is to develop universal design algorithms applicable to various geometric and material variants of the analyzed results.

The results of the study for the construction industry are that using the section method, it is possible to perform a calculation, while cutting a fiber-reinforced concrete block and considering the section and creating equilibrium conditions for the cut-off part of the block, and taking into account the bending moment, a calculation of normal stresses is obtained.

4. Discussion

The analysis of numerical experiments, the study of the performance, taking into account some parameters, showed the following:

1. The performed analytical studies made it possible to determine the stress-strain state in a fiber-reinforced concrete block, while it is cut along the considered section and equilibrium conditions are created for the cut-off part of the block. To determine the bending moment, shear forces in the beam, these conditions are reduced to the equality to zero of the sum of the projections of all forces on the axis of the blocks

$$\sum F_x = 0, \sum F_y = 0, \sum F_z = 0, \sum M = 0,$$

2. Equations have been developed on the basis of which it is possible to analyze linear and nonlinear stresses in various sections of a fiber-reinforced concrete block.
3. Equations have been developed on the basis of which it is possible to analyze the coefficients, real stresses in compression and tension are given
4. The analysis obtained from the results of numerical calculations shows that the stresses in the compressive part are greater than in the tensioned part of the fiber-reinforced concrete block, due to the fact that concrete works better in compression than in tension.
5. Axial stresses can be taken into account by considering the bending anchor and the moment of inertia or the moment of resistance in the structural elements due to the absence of axial forces.
6. The influence of the award scenario and the geometry of the connection of nodes was evaluated both on the distribution of bending stress and on the shear strength at bursting. Several aspects of the Ansys simulation results and numerical studies can be distinguished.
7. Until now, the commonly used method of reinforced from BWP of joints is to weld a stiffening plate to the outer side of the chord element [16]. One of the disadvantages of this form of reinforcement connection is that the resulting structure may lose its aesthetic appearance due to the welded stiffening plate.
8. A new alternative method for certain types of joints is to fill the joints with concrete or cement mortar. Concrete filled instead of adding stiffeners on the outside of BW joints is particularly suitable for architecturally exposed steel structures and increases strength, stiffness and even fatigue resistance.

5. Conclusion

Based on the results of the work, the following conclusions can be drawn:

- A technique for linear analytical calculation of local reinforcement of nodes in the normal stress state of fiber-reinforced concrete elements based on bending moments and moment of inertia has been developed.
- This paper proposes an analytical method for determining the normal stress in the elements of a fiber-reinforced concrete block under the influence of a concentrated load.
- As can be seen from the graph, the stresses in the compressive part are greater than in the stretched part.
- This suggests that concrete is a building element that performs better in compression than in tension.
- The results of this study show that the stress is inversely proportional to the cross-sectional area: if the area decreases, the stress increases, and if the area increases, the stress is adjusted.
- The calculation method is valid for the shear force and bending moment of fiber-reinforced concrete blocks, taking into account an arbitrary section.

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