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IMPROVING THE ALGORITHM OF CHOOSING SPACING AND NUMBER OF STIFF SUPPORTS AGAINST A CONCENTRATED FORCE IN STEEL-CONCRETE BEAMS

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A steel-concrete beam was taken as the study object. The algorithm of selecting the number of stiff supports for the steel-concrete beam loaded with a concentrated lateral force in the middle of the span has been refined. Stiff supports served to join the steel strip with concrete to ensure their joint performance. The algorithm was refined based on the condition of equality of the longitudinal force in the steel strip from the action of the calculated load and the maximum longitudinal force obtained after setting the supports. In this case, the longitudinal forces in all stiff supports, as well as the spacing of the stiff supports should be the same.

A disadvantage of the known algorithm consists in the complexity of determining the coefficient φ_{b2} taking into account the effect of long-term concrete creep on the element deformation without cracks. This coefficient fluctuates widely and depends on many factors. Besides, it is also insufficiently studied.

Calculations for determining the number and spacing of stiff supports in a steel-concrete beam were conducted according to the proposed algorithm and in the Lira software package. The forces acting on the supports and spacing of the supports were the same. The force acting in the support was 8941.5 N. When selecting characteristics of the steel-concrete beam, maximum longitudinal force in the steel strip was obtained. The longitudinal force amounted to 35726 N. The same longitudinal force was obtained from the diagram of longitudinal forces obtained after setting the supports.

This study was aimed at improving the design of steel-concrete beams. A rational number and placement of stiff supports ensure savings: the required amount of building materials is reduced and their cost is reduced due to cutting labor costs for their manufacture and operation

Keywords: steel-concrete beam, stiff support, spacing of supports, force in a support, reduced stiffness, graphic-analytical method

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1. Introduction

Industrial and civil construction is one of the most important industrial sectors in today's world. It is assumed that the number of construction projects being erected (buildings, structures, etc.) will be ever growing. In addition to the number of such projects, the complexity of their construction is also growing depending on both the increase in their size and the difficulty of implementing the required design solutions. They include limited areas, increasing spans and special conditions of erection and operation of construction projects. In this regard, it becomes necessary to steadily improve the strength and deformation characteristics of building structures. This necessity, in turn, leads to the necessity of improvement of existing and emerging new building structures and design solutions. One of these solutions implies the use of concrete structures externally reinforced with steel.

The concrete structures externally reinforced with steel consist of steel and concrete elements. Despite the diversity of today's building materials, concrete is still widely used in building structures. Concrete is a complex multi-component material. Moreover, it is non-linearly deformable. On the one hand, such properties of concrete leave its mechanical properties insufficiently studied despite the huge amount of known and ongoing studies. On the other hand, they open up almost unlimited ways to improving the performance of both the concrete itself and the building structures in which it is used.

The concrete structures externally reinforced with steel are no exception. Although such designs have shown their competitiveness with others, they still leave a fairly large field of activity for their improvement. Beams are one of the types of concrete structures externally reinforced with steel. For example, reinforcement can be realized by using a steel plate as a working reinforcement. Such structures will be effective if the beam components, i.e. concrete and steel, work jointly. Thus, the issue of combining a steel plate with concrete into a single structure is extremely important. The use of stiff supports or flexible anchors is one of the most common methods ensuring this unity. Determining the minimum required several such supports and their rational arrangement can be considered a way to improving the performance of concrete beams eternally reinforced with steel.

The concrete structures externally reinforced with steel in general, and beams in particular, have proven themselves as reliable structures fairly simple in manufacture. Their use in construction is growing. Besides, such structures offer a possibility of their improvement in many ways. In particular, this can be both an improvement in material and an improvement in the design of the structure itself. From the point of view of design solutions, this can be both the use of fundamentally new design solutions and the improvement of known design arrangements. As one of the development ways, rational number and placement of stiff supports will lead to savings due to both reducing the required amount of building materials and reducing their cost by cutting labor costs associated with their manufacture and operation. This approach assumes the practical value and relevance of the studies aimed at increasing the bearing capacity of steel-concrete beams.

2. Literature review and problem statement

Studies of the steel-concrete beams were carried out in [1]. The beams were made from a concrete mixture with the addition of rubber. Results of studies of beams made of a concrete mixture containing metal fiber were presented in [2]. Steel fiber was arranged not chaotically but in a certain order in [3]. It was laid along the entire beam length. Basalt fiber was used in preparing concrete mix in [4]. Moreover, a vacuum was applied to improve the adhesion of basalt fibers to the cement matrix. Improvement of concrete properties due to the introduction of complex additives into the mixture composition was considered in [5]. It was shown in [1–5] that the proposed studies can help improve the mechanical properties of concrete. However, improvement in beam characteristics has been achieved through the more rational use of material rather than through improvements in the beam design.

Studies of concrete structures externally reinforced with steel were conducted in special conditions [6]. Performance of concrete structures externally reinforced with steel in conditions of earthquake-prone areas was considered. Such conditions imply more strict requirements for building structures. It was shown that the structures under consideration are quite reliable and that they can be used in areas with hard operating conditions. This shows that concrete structures externally reinforced with steel can compete with other types of structures. However, the issues of improving the structure design were not considered in this study that was of a purely theoretical nature.

Currently, a large number of studies are devoted to the improvement of concrete structures externally reinforced with steel. The issue of joining steel and concrete is one of the important issues of improvement of such structures. One of the most common joining methods implies the use of stiff supports or flexible anchors. Numerical studies of concrete structures externally reinforced with steel were carried out in [7, 8]. It was shown that improvements in the design of the concrete structures externally reinforced with steel can raise their strength and deformation properties. Anchors were used to join steel with concrete. The issue of rational placement of anchors was not considered.

It was shown in [9] that a technologically correct process of setting anchors and the correct choice of anchor material can significantly affect the strength of elements of the concrete structure externally reinforced with steel and the structure as a whole. Results of experimental studies of concrete structural elements externally reinforced with steel were presented in [10]. This study features the use of prestressing the elements of concrete structures externally reinforced with steel. Issues of quantitative concrete/steel ratio in the concrete structures externally reinforced with steel were considered in [11]. It has been shown that a properly selected amount of reinforcement can increase structural strength. The results of experiments devoted to varying the height of the cross-section of the concrete part of the beam were presented in [12]. This variation makes it possible to find the best position of the neutral axis of the beam which, in turn, leads to the more rational use of materials. The results of studies of the steel-concrete beams are shown in [13]. These studies were devoted to finding the optimal ratio of reinforcement in a form of a steel plate and in a conventional form of rods. It was shown that the combined use of various types of reinforcement in beams improves the beam performance. Having analyzed studies [9–13], we can conclude that the issue of improvement of the performance of the concrete structures externally reinforced with steel has many different directions. Strength characteristics of concrete structures externally reinforced with steel can be improved in various ways. Each of the methods is certainly worthy of attention and has practical value. However, it should be noted that although anchors were used in [9–13], the issue of their rational arrangement was not considered.

Studies of combined steel-concrete beams were conducted in [14]. The considered beams were combined structures consisting of a reinforced concrete shelf, a reinforcement cage, and a steel element with a T-profile. It was shown that such structures are very effective, however, the study was aimed at the ways of joining the structure components and not at determining the optimal number of joining elements.

Steel-concrete beams were considered in [15]. To combine the steel plate with concrete, flexible anchors were used instead of stiff supports. This method of joining cannot be considered as one providing absolute stiffness. Anchors are pliable that cause displacement of the steel plate. This must be taken into account in calculations. There are many types of flexible anchors with different flexibility. Thus, the calculation procedure gets more complicated. The results of experimental studies of the steel-concrete beams having a composite cross-section were presented in [16]. A steel plate was used to add strength to reinforced concrete beams. A direct-shear system of bolted plates was used in the beams as a joining element. This system has demonstrated high efficiency in joining the beam components. An additional advantage consists in the simplicity of such joining. Studies in [15, 16] show that stiff supports or flexible anchors can represent a wide variety of types of joining elements. Such design elements have shown their effectiveness; however, their rational number was not considered in these studies.

It should be noted that the method of joining component elements of the steel-concrete beams using stiff supports or flexible anchors is not always used. Results of experimental studies of steel-concrete beams were presented in [17]. The steel plate and concrete were joined by gluing. Steel and concrete were joined by gluing in [18, 19] as well. Various types of adhesives were used, mostly acrylic-based ones. Certainly, this gluing method has its advantages. However, since this technique is used relatively recently, it has not been studied enough. In particular, we cannot talk about the reliability and durability of such structures since there are no structures that have been operating for a long time.

Studies are known that were aimed at improving the beam design by choosing the section shape. Studies of the T-beams shear-reinforced by plates of fiber-reinforced polymer were presented in [20]. The studies presented in [21] are aimed at minimizing the weight and cost of T-beams. Much attention was paid to the shear performance of beams. However, the improvement of beams by a better perception of shear forces was achieved not through the rational placement of supports but through strengthening the beam with additional components.

The issues of resistance of beams to shear forces were considered in [22]. Types and amounts of longitudinal reinforcement were varied. A procedure for assessing the shear strength of concrete was presented in [23]. Basic shear strength was determined from the intersection of the load and resistance curves. Experimental and theoretical studies in [24] were aimed at raising the shear resistance due to the use of short fibers in concrete. Thus, it can be asserted that much attention is paid to the issues of shear resistance in beams. Better shear performance of a beam can be achieved in many ways, each of which has a right to exist.

An algorithm of selection of stiff supports in the steel-concrete beams has been developed in [25, 26]. In order to obtain the same forces in supports, the spacing of the stiff supports was taken to be the same except the zero span [25]. Like the case of the same spacing, longitudinal force in the steel plate with differing support spacings will decrease from the middle of the span to the beam seats. However, forces in the supports will differ which will require the use of stiff supports with different cross-sections. The same approach was adopted in [26]. The height of the supports was also taken to be the same although the height of the compressed zone of concrete varied along the beam length. However, the change in height of the compressed zone was insignificant since the cross-sectional height of the beam itself was small. Usually, as, for example, in [7–9], supports of the same height were used in the beams. The same approach was recommended in [27]. The same spacing and height of the supports simplify the process of manufacturing the steel-concrete beams which makes them more technologically advanced and easier to manufacture. It is desirable to take the height of the supports equal to the height of the compressed zone of concrete since the destruction of concrete can occur along an inclined crack which was considered in [28]. Among other things, this approach will make it possible to unify the beam designs which will make it possible to manufacture beams according to normative designs and with the possibility of using production lines. All this will reduce the cost of building structures [28].

A disadvantage of this algorithm is the complexity of determining the coefficient φ_{b2}. This coefficient fluctuates widely and depends on many factors. It was also insufficiently studied. The algorithm provides for the design of supports so that the maximum longitudinal force in the steel strip is the same as from the action of the calculated and normative external loads. Therefore, it was necessary to specify this coefficient until this condition is satisfied [25]. It was proposed to use equality of the longitudinal force in the steel strip from the action of the calculated load and the maximum longitudinal force obtained after setting the supports and refine this algorithm.

Analysis of the published data shows that concrete structures externally reinforced with steel in general and steel-concrete beams, in particular, are widespread today. Studies are carried out in various directions. This is both a search for new or improvement of known materials and the studies aimed at finding new design solutions. In their turn, design solutions can be divided into the creation of new designs and improvement of existing structures. The design of the steel-concrete beams is widely used in construction. However, materials in such structures are not used rationally. For more rational use of materials, it was offered to improve the algorithm of choosing spacing and number of stiff supports in steel-concrete beams. This will lead to an increase in the bearing capacity of structures at their smaller weight.

3. The aim and objectives of the study

The study objective implied improving the algorithm of choosing spacing and the number of stiff supports in steel-concrete beams which will lead to an improvement in the beam design.

To achieve the objective, the following tasks were set:

– improve the algorithm given in [25, 26];

– carry out numerical calculations of the steel-concrete beams to verify the proposed algorithm;

– compare the results of calculation according to the algorithm with the calculations in the Lira software package and confirm the assumption that the spacing of supports and the forces acting in them are the same and the force in the steel strip is maximum.

4. The materials and methods used in calculating the spacing and number of stiff supports and the forces acting on the stiff supports from a concentrated force in steel-concrete beams

The procedure used in the study is based on the current regulatory documents [27, 29, 30]. Besides, the well-known methods for calculating the steel-concrete beams and the common reinforced concrete beams were applied.

The hypothesis of joint performance of steel and concrete was accepted in the calculation which also corresponds to [27, 29]. The setting of stiff supports was used as the way to ensure joint performance without separation and slippage. According to the same regulatory documents, supports must be considered as absolutely stiff elements.

Stiff supports prevent horizontal displacement of steel relative to concrete. The forces acting in the supports can be found by determining the angles of rotation between cross-sections with adjacent supports. To determine the angles of rotation, a graphic-analytical method of determining displacements was used.

A steel-concrete beam has a complex composite section. The geometric characteristics and section stiffness were calculated as reduced values.

The algorithm of choosing spacing and number of stiff supports in the steel-concrete beam given below was used in calculations.

1. Preliminary spacing of stiff supports:

$$c=2(h-z).$$

2. Determination of the coefficient A_1 using formula (11):

$$A_1=\frac{N_{\max}^n}{l-c}.$$

3. Number of stiff supports:

$$n=\frac{2lA_1-N}{4(lA_1-N)}\left[1+\sqrt{1-\frac{8(lA_1-N)N}{(2lA_1-N)^2}}\right].$$

Since the number of anchors can only be an integer, round off it to an integer.

4. Force acting on supports:

$$T=\frac{N}{n}.$$

5. Clarification of the support spacing after rounding off their number:

$$c=\frac{lA_1-T}{A_1(2n-1)}.$$

6. Clarification of the coefficient:

$$A_1=\frac{N_{\max}^n}{l-c}=\frac{N}{l-c}.$$

7. Determination of length of the zero section:

$$x=\frac{T-cA_1}{2A_1}.$$

8. Determination of longitudinal forces acting on the strip at each section and construction of a diagram of longitudinal forces:

$$N_i=A_1\left[c(2i-1)+2x\right].$$

9. Determination of value of the longitudinal force from the calculated load:

$$N_p=\frac{M_p}{a_1}=\frac{F_p l_p}{4a_1}.$$

10. Determination of the reduced moment of inertia of the steel-concrete beam:

$$J_{red.}=\frac{b\cdot h^3}{12}+b\cdot h\left(\frac{h}{2}-z_c\right)^2+$$
$$+\frac{n\cdot b\cdot\delta^3}{12}+n\cdot b\cdot\delta\left(z_c-\frac{\delta}{2}\right)^2.$$

11. Determination of reduced stiffness of the beam cross-section:

$$B=\phi_{b1}E_b I_{red3}.$$

12. Determination of the normative external load:

$$F_n=\frac{4BA_1}{E_s\cdot A_s\left(z_c-\delta/2\right)}.$$

13. Determination of the coefficient φ_{b2}:

$$\phi_{b2}=\frac{F_n}{F_p}.$$

5. The results obtained in improving the algorithm of choosing spacing and number of stiff supports in a steel-concrete beam

5. 1. Improvement of the algorithm of choosing spacing and number of stiff supports in a steel-concrete beam

According to [15, 27], the deformation design of reinforced concrete beams and steel-concrete beams is made according to the reduced stiffness of cross-sections and the normative external load F_n. The reduced stiffness is calculated from the following formula:

$$B=\phi_{b1}E_b I_{red}. \quad (1)$$

The normative external force is calculated from the following formula:

$$F_n=\phi_{b2}F_c, \quad (2)$$

where I_{red} is the reduced axial moment of inertia of the beam cross-section;

φ_{b1} is the coefficient taking into account the effect of short-term creep of concrete and taken equal to 0.85 for heavy concrete;

E_b is the modulus of concrete deformation;

B is the reduced stiffness of the beam;

F_c is the calculated external force;

F_n is the normative external force;

φ_{b2}=1÷3 is the coefficient that takes into account the effect of long-term concrete creep on deformation of an element without cracks. According to [15, 27] this coefficient is taken depending on the humidity of ambient air, etc.

A formula for calculating the maximum value of the longitudinal force in the steel strip from the action of the normative load is given in [25]:

$$N_n^{\max} = N_{n-l/2} = \left[2nc - c + 2x\right]A_1. \quad (3)$$

The obtained value of longitudinal force in the middle of the beam must correspond to the force obtained in [31] for checking stresses in concrete and steel plate from the action of the calculated load, i.e.

$$N_n^{\max} = N_c, \quad (4)$$

where

$$N_c = \frac{M_c}{a_1} = \frac{F_c l_c}{4a_1}$$

and

$$a_1 = h_0 - z/2. \quad (5)$$

The coefficient A_1 was calculated from formula (6) [20]

$$A_1 = \frac{F_n}{4B}\left(z_c - \frac{\delta}{2}\right)E_s \cdot A_s, \quad (6)$$

where A_s is the cross-sectional area of the steel plate,

E_s is the modulus of elasticity of steel,

B is the reduced stiffness of the beam,

z_c is the position of the center of gravity of the reduced cross-section.

Formula (6) includes the value of external normative load F_n. If the value of A_1 is calculated, then F_n can be determined from this formula.

$$F_n = \frac{4BA_1}{E_s \cdot A_s\left(z_c - \delta/2\right)}. \quad (7)$$

The coefficient φ_{b2} is determined from formula (2)

$$\phi_{b2} = \frac{F_n}{F_c}. \quad (8)$$

The value of this coefficient should be within φ_{b2}=1÷3.

To determine the coefficient A_1, the following calculations shall be made. In [20], the following formula was obtained:

$$2x = l - 2nc. \quad (9)$$

The following is found from formula (3)

$$2x = \frac{N_n^{\max} - 2ncA_1 + cA_1}{A_1}. \quad (10)$$

Compare formulas (9) and (10) and determine the coefficient A_1

$$\frac{N_n^{\max} - 2ncA_1 + cA_1}{A_1} = l - 2nc,$$

$$N_n^{\max} - 2ncA_1 + cA_1 = lA_1 - 2ncA_1,$$

Hence, taking into account (4),

$$A_1 = \frac{N_n^{\max}}{l-c} = \frac{N_c}{l-c}.$$

Taking into account formulas (4) and (5),

$$A_1 = \frac{N_n^{\max}}{l-c} = \frac{N_c}{l-c} = $$
$$= \frac{F_c l}{4\left(h_o - z/2\right)(l-c)},$$

$$A_1 = \frac{F_c l}{4\left(h_o - z/2\right)(l-c)}. \quad (11)$$

The spacing c of supports is determined depending on the beam height h, the support height h_p, and the compressed concrete zone height z $c=2h_p$. $h_p=h-z$. Then

$$c = 2(h - z). \quad (12)$$

All values included in this formula were obtained when choosing the optimal cross-sectional dimensions of a steel-concrete beam.

To determine the number of stiff supports, the following formula from [20] is used

$$n = \frac{2lA_1 - N}{4(lA_1 - N)}\left[1 + \sqrt{1 - \frac{8(lA_1 - N)N}{(2lA_1 - N)^2}}\right]. \quad (13)$$

The relationship between the maximum value of longitudinal force in the strip and the force acting on the support will be as follows:

$$T = \frac{N}{n}. \quad (14)$$

Since a non-integer can be obtained when determining the number of supports and it must only be an integer, it is necessary to refine the values of c and A_1. Refinement is carried out according to the formula given in [25]:

$$c = \frac{lA_1 - T}{A_1(2n-1)}. \quad (15)$$

The length of the zero section is calculated using the formula given in [20].

$$x = \frac{T - cA_1}{2A_1}. \quad (16)$$

To construct a diagram of longitudinal forces in a steel strip from the action of a normative external load, the formula given in [25] was used.

$$N_i = A_1\left[c(2i-1)+2x\right], \quad (17)$$

where i is the number of the section where the longitudinal force is determined.

5. 2. Numerical calculation of steel-concrete beams

The coefficient of the beam height/width ratio was taken within optimal limits and amounting m=2.5. The beam span was l_c=2.0 m. The temporary load was F_c=9.8 kN. In this case, concrete of class B22.5 and steel strip of St3 (AI) grade were used. According to these characteristics, dimensions of the beam cross-section and the forces acting on the steel strip and the concrete body were selected (Fig. 1).

To calculate anchors for the steel-concrete beam, required characteristics were calculated. The reduced stiffness of the beam $B=\varphi_{b2}EbIred_3$=638086.5 Nm^2, area of the steel strip $A_s=b^{\delta}=1.512\cdot10^{-4}$ m^2 and the longitudinal force acting on the steel strip and concrete in the middle of the beam from the calculated external load was $N=N_s=N_b$=35.77 kN. In this case, stresses in concrete and strip are equal to their limiting values. In concrete, the stress is equal to the normative resistance R_b and the normative resistance R_{sn} in the steel strip. If necessary, the limit stress for the strip and normative resistance can also be specified.

Based on the data obtained in [31] for a steel-concrete beam, it is necessary to choose optimal characteristics of the stiff supports. These characteristics include the number and spacing of the supports, forces acting on the supports and the steel strip, and the maximum value of the force in the strip in the middle of the beam. At the optimal choice of these characteristics, the maximum value of the force acting on the strip should be $N=N_s$=35766 N as obtained in [31].

According to the calculation, the same spacing of supports c=0.222 m and the same forces in supports T=8941.5 N are obtained. The maximum force in the steel strip N_p=35726 N. The scheme of arranging the supports and the diagram of longitudinal forces in the steel plate are shown in Fig. 2.

The same beam was calculated in the Lira software package. The stresses in the steel plate are shown in Fig. 3.

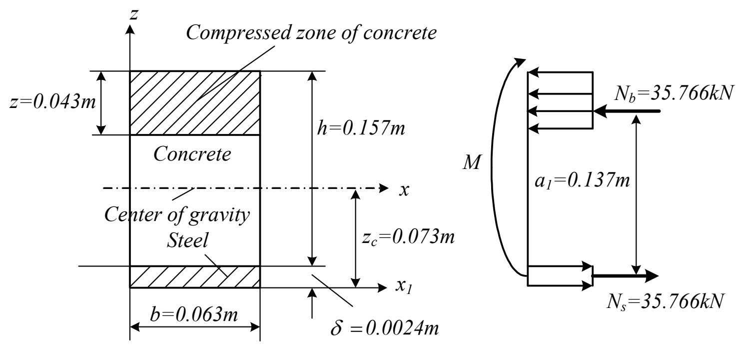

Fig. 1. Cross-section of the steel-concrete beam and longitudinal forces: *a* – the beam cross-section; *b* – longitudinal forces

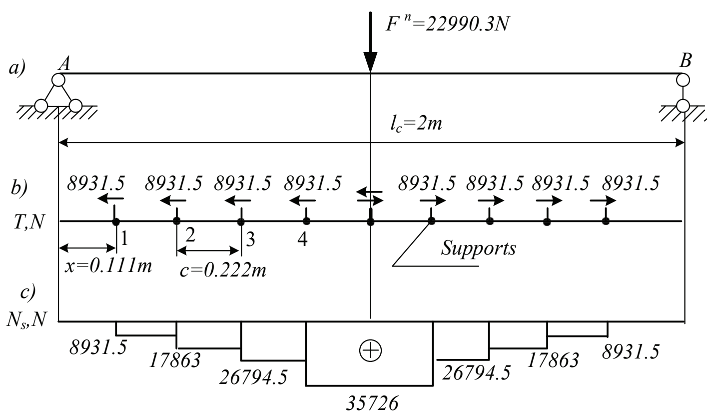

Fig. 2. Arrangement of supports and a diagram of longitudinal forces in a steel plate: *a* – design diagram; *b* – diagram of the arrangement of stiff supports; *c* – diagram of longitudinal forces

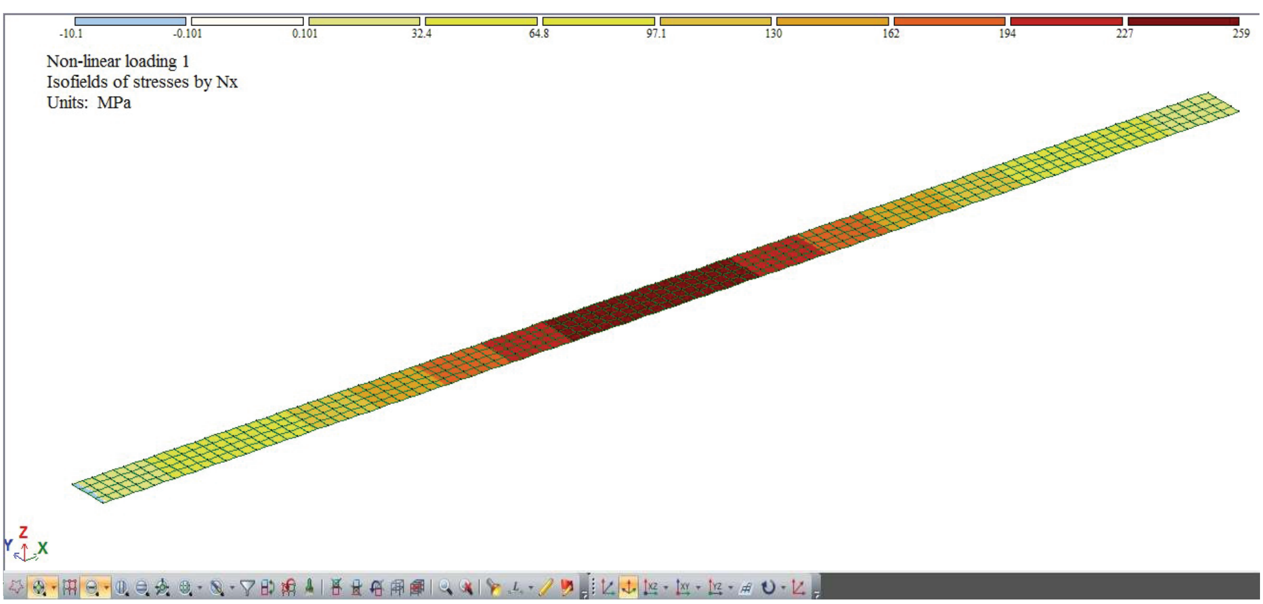

Fig. 3. Stresses in the steel plate

5. 3. Comparison of calculation results

Comparison of the results of calculation using the algorithm with the results of calculation in the Lira software package is given in Table 1.

Table 1

Calculation results

Support No.	Force determined by the algorithm, kN	Force determined by Lira software package, kN
1	8.93	9.01
2	8.93	8.95
3	8.93	8.92
4	8.93	8.89

Table 1 shows that the forces in supports take the same value which confirms the preliminary assumptions. As can be seen from the diagram (Fig. 2), the maximum force acting in the steel strip is N_c=35726 N. This value of the force corresponds to the force determined earlier in [31].

6. Discussion of results of developing the algorithm for choosing stiff supports in steel-concrete beams

The studies have resulted in a refined algorithm presented in [25, 26]. This algorithm disadvantage consists in the complexity of determining the coefficient φ_{b2}. The studies make it possible to improve the design of the steel-concrete beam and simplify its calculation. The considered beam design was improved due to the fact that the maximum longitudinal force in the steel strip has the same value both under the action of both calculated and normative loads (Fig. 2). This algorithm simplifies the determination of interrelated coefficients A_1 and φ_{b2}. It is not necessary to repeatedly change the coefficient φ_{b2} to achieve desired results.

When selecting the characteristics of a steel-concrete beam, maximum longitudinal force in the strip was obtained [31]. The same longitudinal force was found from the longitudinal force diagram obtained after setting the supports (Fig. 2). The beam was numerically calculated using the algorithm and in the Lira software package. The results were the same (Table 1). They differ slightly from each other because of rounding in the course of calculations. These differences are insignificant, less than 1 %. Under the action of the maximum longitudinal force, stress equal to the normative resistance of steel arises in the strip (Fig. 3). The same longitudinal force acts on concrete as well and stresses equal to its normative resistance arise in concrete.

The improved algorithm enables its extension to different cases of work of the steel-concrete beams. This also applies to other methods of beam loading and other materials that are increasingly getting common today. These materials include fibrous concrete, polymers, and many others.

This algorithm is inapplicable to beams with flexible anchors which is its disadvantage. To that end, it is necessary to take into account the shear deformations arising from the flexibility of such anchors. The solution to this problem is considered by the authors as a continuation of the presented study. In the future, it is advisable to extend the algorithm to steel-concrete beams having flexible anchors.

7. Conclusions

1. The algorithm of selecting spacing and number of stiff supports in the steel-concrete beams was improved. The improved algorithm makes it possible to simplify calculation using equality of the longitudinal force in the steel strip from the action of a calculated load and the maximum longitudinal force resulting from setting the supports.
2. In order to verify the proposed algorithm, steel-concrete beams were numerically calculated according to the improved algorithm and in the Lira software package. The magnitude of the force in the supports was the same and equal to 8941.5 N. When selecting characteristics of the steel-concrete beam, maximum longitudinal force in the strip amounting to 35726 N was obtained.
3. The results obtained from the calculation using the algorithm were compared with those obtained with the use of the Lira software package. The assumption that the spacing of the supports and the forces acting in them are the same and the force in the steel strip is maximum was confirmed. The maximum force acting in the steel strip was N_c=35726 N which corresponds to the previously calculated value. Discrepancies in values of the longitudinal forces in supports did not exceed 1 %.

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