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# RESEARCH OF COMPOSITE COMBINED PRESTRESSED CONSTRUCTIONS

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**Abstract.** For the economy of material in composite building constructions of ceiling and coverage prestressing of a lower subdiagonal is used. To simplify the process of optimal cross-section elements selection in the combined subdiagonal systems and their geometrical descriptions equation of a strain unbreak has been used. The example of the 6m span combined steel construction calculation that works in composition of the monolithic reinforce-concrete ceiling has been executed with the prestressing of a lower subdiagonal and the analysis of the results. As the research has shown, prestressing in such a construction allows decreasing a cut of an upper steel beam by 20–24%.

**Key words:** composite construction, prestressed construction, combined construction

## INTRODUCTION

The effect of materials charges reduction becomes higher at the work of steel combined constructions with prestressing created in the zone of a lower subdiagonal which gives an opportunity to carry out simultaneously adjusting of efforts in a static indefinite uncut construction. The complex of calculation-structural and technological decisions is offered below that allows to form rationally the stress-strain state in crossing of steel beams inflexibilities of the combined construction, the construction of ceiling or coverage being created from that [Ivanyk 2000]. On the initial stage of theoretical calculations in accordance with the worked out methodology [Kvasha et al. 1997, Ivanyk and Vihot' 2005], examining the construction of the combined system as the core structure, it is comparatively easy to take into account any terms of work of spatial construction on the external loading both at planning and at the calculation of the existent systems, effectively using the worked out methods of the core systems calculation in the resilient stage together with the methods of nonlinear resilient calculation.

The basic calculation chart of the incorporated crossing of the combined construction is based on the hypothesis of the flat crossing and proportion of stress and strain. It is used

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also for determination of strains of the incorporated constructions. Existing methods do not represent the real work of the whole construction and do not take into account here cooperation between elements (by subdiagonal part) that is included in composition of spatial construction. Consequently, we get results with certain (to 12%) reserve of durability, excellent curvature of bending moments' curves (especially in middle part of inflexibility beam) and the curve of central forces in the elements of subdiagonal (considerable low stress).

The aim of the work is to investigate the combined steel constructions taking into account the peculiarities of their adjusting and work in the conditions of prestressing related to the accepted method of building.

## MATERIALS AND METHODS

Theoretical and experimental investigations connected with studying of the combined steel constructions work have been conducted as well as further theoretical analysis of these investigations convincingly confirmed their best efficiency both by operating and technical and economic indexes. Simultaneously with experimental and design work the work on development of theoretical grounds is being conducted. As the result, a new approach to calculation of the combined steel constructions and quality estimation of constructions elements work taking into account different sorts of physical and mechanical factors that influence the redistribution of efforts in a certain measure has been created.

Worked out mathematical model of the combined construction [Kvasha et al. 1997, Ivanyk 2000, Ivanyk and Vihot' 2005] satisfies three groups of terms: the terms of equilibrium; the terms of compatibility of strain that link strain and moving; the physical terms that link effort and strain.

Equation of strain unbreak is equation of *i*-th efforts for the beam of inflexibility – will look like:

$$
\begin{aligned}
&\delta_{11}X_1+\delta_{12}X_2+\delta_{13}X_3+\delta_{14}X_4+\delta_{15}X_5+\delta_{16}X_6+\delta_{17}X_7-\frac{2y_1}{l_1}+\frac{y_2}{l_2}=0\\
&\delta_{21}X_1+\delta_{22}X_2+\delta_{23}X_3+\delta_{24}X_4+\delta_{25}X_5+\delta_{26}X_6+\delta_{27}X_7+\frac{y_1}{l_1}-\frac{y_2\,(l_1+l_2)}{l_1*l_2}+\frac{y_3}{l_2}=0\\
&\delta_{31}X_1+\delta_{32}X_2+\delta_{33}X_3+\delta_{34}X_4+\delta_{35}X_5+\delta_{36}X_6+\delta_{37}X_7+\frac{y_2}{l_2}-\frac{2y_3}{l_2}+\frac{y_4}{l_2}=0\\
&\delta_{41}X_1+\delta_{42}X_2+\delta_{43}X_3+\delta_{44}X_4+\delta_{45}X_5+\delta_{46}X_6+\delta_{47}X_7+\frac{y_3}{l_2}-\frac{y_4\,(l_1+l_2)}{l_1*l_2}+\frac{y_5}{l_1}=0\\
&\delta_{51}X_1+\delta_{52}X_2+\delta_{53}X_3+\delta_{54}X_4+\delta_{55}X_5+\delta_{56}X_6+\delta_{57}X_7+\frac{y_4}{l_1}-\frac{2y_5}{l_1}=0\\
&\delta_{61}X_1+\delta_{62}X_2+\delta_{63}X_3+\delta_{64}X_4+\delta_{65}X_5+\delta_{66}X_6+\delta_{67}X_7+y_6=0\\
&\delta_{71}X_1+\delta_{72}X_2+\delta_{73}X_3+\delta_{74}X_4+\delta_{75}X_5+\delta_{76}X_6+\delta_{77}X_7+y_7=0
\end{aligned}
\tag{1}
$$

Coefficients $\delta_{ij}$ at unknown equations of *i*-th efforts (1) will be written down by multiplying of corresponding curve of bending moments and central forces in a kind, for example:

$$\delta_{11} = \frac{2l_1}{3EI_1} - \mu * \frac{2}{l_1 6A_1} + \frac{2\overline{N}_{11}^2 * l_1}{6EA_1} + \frac{2\overline{N}_{12}^2 * l_2}{6EA_2} + \frac{2\overline{N}_{13}^2 * l_1}{6EA_3} + \frac{\overline{N}_{14}^2 * h}{6\sin aEA_4} + \\ + \frac{\overline{N}_{15}^2 * h}{6\sin \beta EA_5} + \frac{\overline{N}_{16}^2 * h}{6\sin \beta EA_6} + \frac{\overline{N}_{17}^2 * h}{6\sin aEA_7} + \frac{\overline{N}_{18}^2 * (l - 2h * \text{ctg}a)}{6EA_8} \quad (2)$$

where $\overline{N}_{ij}$ are the sizes of central forces from the action of single moments in the knots of beam of the combined construction.

The decision of the eventual system of linear algebra equations presupposes receiving of:

– distribution of efforts from the action of the external loading, bending moments, vertical moving and parameters of the stress-strain state of spatial construction elements under the action of the external loading,
– intensity of loading in the accepted chart at preset parameter of the stress-strain state of all spatial system elements taking into account their stiffness parameters before and after the crack formation in a reinforce-concrete slab or flowages in the steel elements of subdiagonal.

For the decision of the eventual system of linear algebra equations we compatibly use the method of linear mathematical programming and the method of variables parameters of resiliency.

Within the framework of the worked out algorithm the search of a minimum of objective function of the equally stress state is conducted in the elements of spatial construction depending on the topology of construction (heights of the combined construction of *h*, angles of slope *α* and *β* according to the extreme and intermediate subdiagonals, external loading, physical and mechanical parameters of elements).

## RESULTS

On the initial stage we will undertake theoretical studies on the example of the static indefinite combined construction shown on Figure 1, at operating on it of the complete external loading of $q = 12$ kN·m$^{-2}$.

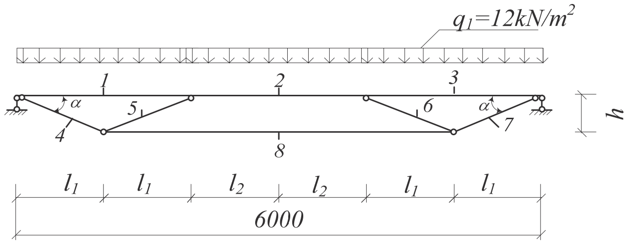


Fig. 1. Loading static of the indefinite combined construction pattern

Rys. 1. Schemat obciążenia statycznie niewyznaczalnej konstrukcji szkieletowej

The methodology of adjusting of the stress-strain state considered in this work in the combined steel constructions is used for the calculation of such constructions both in the resilient and in resiliently-plastic stage of work. On this stage, examining the construction of the combined system as the core structure, it is comparatively easy to take into account any terms of spatial construction work on any external loading both at planning and at the calculation of the existent systems, effectively using the worked out methods of the core systems calculation in the resilient stage together with the methods of nonlinear resilient systems calculation for composite elements.

Thus, using the step by step change of descriptions that are included in the group of equations we get in accordance with the offered methodology the algorithm of calculation and the worked out software corresponding values of sizes of the stress-strain state in the elements of constructions which correspond to minimum material expenses. In this theoretical research the criteria of the equally stress state static search of the indefinite combined construction are the height in the horizontal axes of *h*, slope angle of extreme subdiagonal *α*, length of extreme intervals of inflexibility beam $2l_1$, stiffness parameters of steel elements and size of construction loading of *q*.

Results of the undertaken theoretical studies are represented on graphic arts (Fig. 2 and 3).

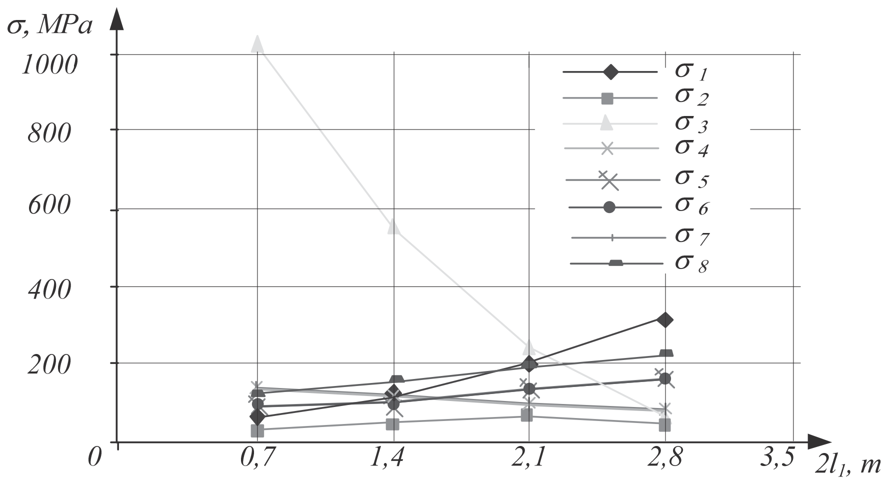


Fig. 2. Dependence of stress in the elements of the combined construction on the change of flight size $2l_1$ at angel of inclination of extreme subdiagonal $\alpha = 17°$ and the height of $h = 400$ mm: 1 – stress in middle part of extreme flight of beam, 2 – stress in the knot of contiguity to the beam of left intermediate subdiagonal, 3 – stress in middle part of middle flight of beam, 4 – stress in left extreme subdiagonal, 5 – stress in left intermediate subdiagonal, 6 – stress in right intermediate subdiagonal, 7 – stress in right extreme subdiagonal, 8 – stress in wearing out

Rys. 2. Zależność naprężenia elementów konstrukcji od zmiany długości $2l_1$ przy kącie nachylenia $\alpha = 17°$ i wysokości $h = 400$ mm: 1 – naprężenie w środku skrajnych elementów pasa górnego, 2 – naprężenia węzłowe pasa górnego, 3 – naprężenia w środku pasa górnego, 4 – naprężenia w skrajnym lewym pręcie, 5 – naprężenia w pośrednim lewym pręcie, 6 – naprężenia w skrajnym prawym pręcie, 7 – naprężenia w pośrednim prawym pręcie, 8 – naprężenie w pasie dolnym

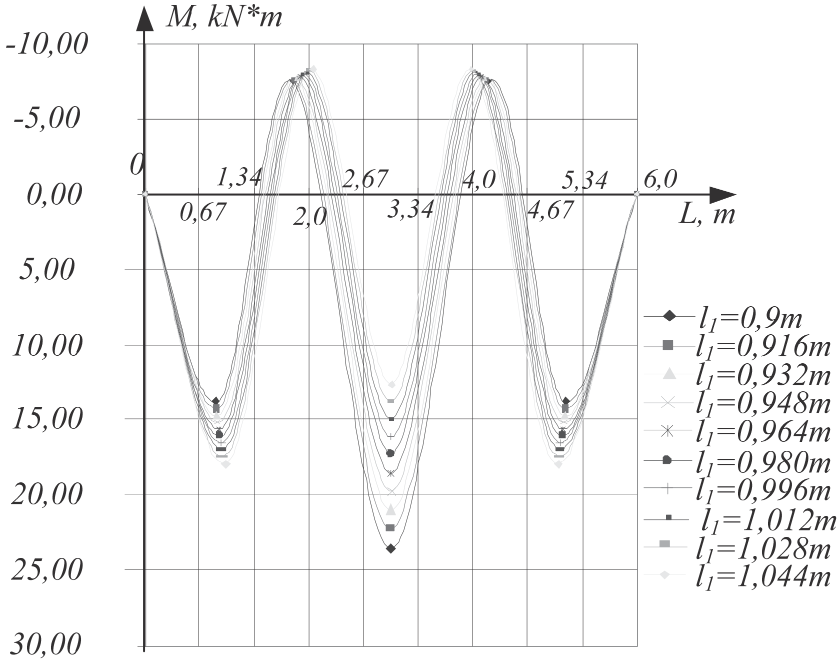


Fig. 3. Dependence of bending moments in the elements of inflexibility beam of the combined construction on the change of length $l_1$ = 0,900, …, 1,044 m

Rys. 3. Zależność momentu zginającego w pasie górnym przy zmianie długości $l_1$ (przy $l_1$ = = 0,900, ..., 1,044 m)

Character of bending moments change on length of inflexibility beam of the combined construction depending on the size change of intermediate flights in constructions looks like, represented on Figure 3.

Structural decisions of the steel static indefinite combined construction (SSICC). Taking into account the results of the undertaken theoretical studies the steel static indefinite combined construction shown on Figure 4 has been worked out.

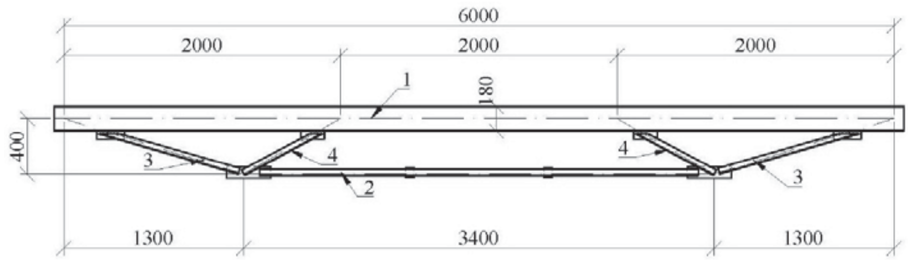


Fig. 4. SSICC received according to the theoretical research on the basis of the equal stress state

Rys. 4. Stalowa statycznie niewyznaczalna konstrukcja otrzymana zgodnie z badaniami teoretycznymi po równym sprężeniu elementów

Beginning data is given for planning: steel of S235; calculation resistance of steel of 235 MPa; a beam of inflexibility (1) – two mark with the slope of shelves №18; extreme subdiagonals (3) – two coupled equal shelf corners 40 x 40 x 5 mm; intermediate subdiagonals (4) – two coupled equal shelf corners 40 x 40 x 5 mm; wearing out (2) – two coupled equal shelf corners 56 x 56 x 5 mm.

For the steel combined construction shown on Figure 4 we will lay down the specification of materials charges on its creation. Mass of inflexibility beam in composition of the combined construction is 66.3% of general mass.

We find effort of pull by the methodology given below (Fig. 5):

$$tg_{\alpha} = 0.4/1.4 = 0.2857; \alpha = 15.95°$$

A diameter of horizontal bar of subdiagonal is a 16 mm.

There is a screw-thread of M14 on the end of the bar. The pull of the bar is done by the rollup of the nut.

We accept the effort of subdiagonal prestressing:

$$N_{so} = 0.3 \cdot 0.42 \cdot R_{bun} \cdot A_{sn}$$

where: $0.42R_{bun}$ – calculation resistance of subdiagonal on cut weakened by a screw-thread;
$A_{sn}$ – an area of transversal secant of subdiagonal net (on weakened by a screw-thread cut).

Off-loading efforts of “$P$” from the prestressing of subdiagonal:

$$P = N_{so} \cdot tg_{\alpha}$$

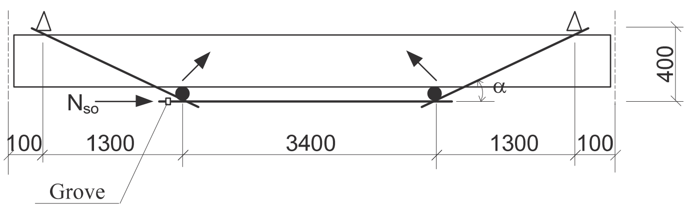


Fig. 5. Chart of pull effort creation in wearing

Rys. 5. Schemat wykonania sprężenia w pasie dolnym

To provide the necessary size of subdiagonal bar prestressing the nut (M14) should be curled by efforts:

$$M_2 = (N_{so} \cdot \sin\beta + N_{so}\cos\beta\mu) \cdot r$$

where: $r = 0.007$ m – radius of bar (on a screw-thread),
$\mu = 0.4$ – coefficient of friction,
$\sin\beta = 0.1D/\pi D = 0,1/\pi = 0.032$.

Under condition of creating prestressing in wearing out the parameters of inflexibility beam will change. On Figure 6 the chart of the construction mass change is shown on the whole depending upon the size of taking efforts to pull in wearing out.

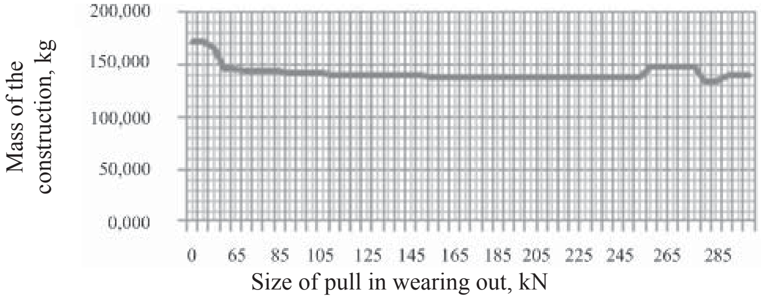


Fig. 6. Mass change of the steel static indefinite combined construction depends on the size of wearing out pull

Rys. 6. Zmiana ciążenia stalowej konstrukcji szkieletowej w zależności od wielkości sprężenia

On Figure 7 the chart of stress change is shown in the separate elements of SSICC depending on the size of pull in wearing out.

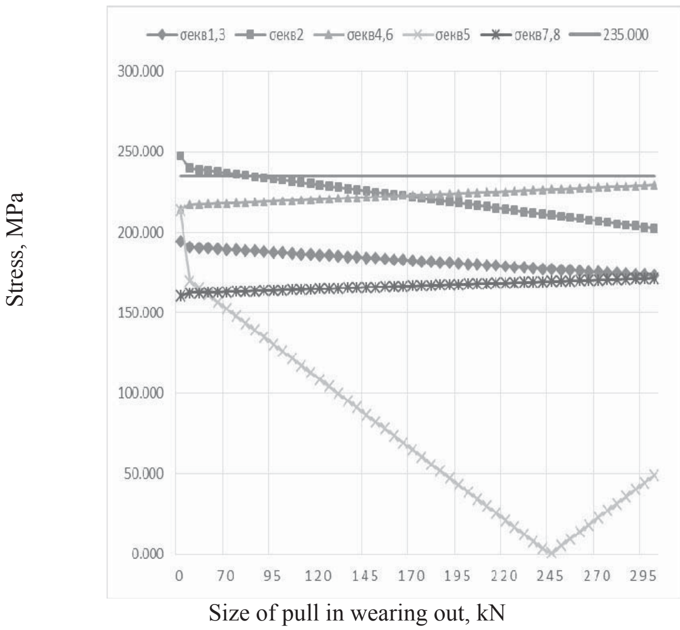


Fig. 7. Dependence of stress in the bars of SSICC on prestressing of wearing out

Rys. 7. Zależność naprężenia w prętach od wielkości sprężenia

Results of calculation are: a beam of inflexibility (1) – two mark with the slope of shelves №12; extreme subdiagonals (3) – two coupled equal shelf corners 45 x 45 x 4 mm; intermediate subdiagonals (4) – two coupled equal shelf corners 45 x 45 x 4 mm; wearing out (2) – two coupled equal shelf corners 50 x 50 x 5 mm.

In the result of taking efforts of prestressing in wearing out the mass of the inflexibility beam is 50.36% from general deadload.

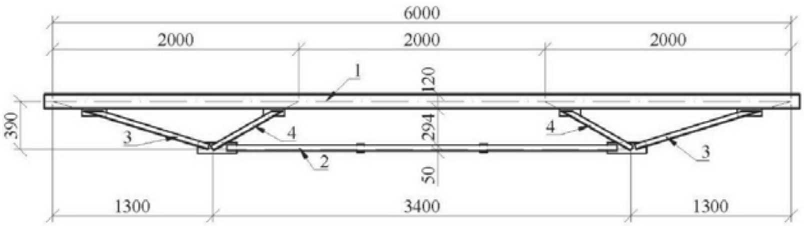


Fig. 8. Steel combined static indefinite construction received according to theoretical research on the basis of wearing out pull

Rys. 8. Stalowa statycznie niewyznaczalna konstrukcja otrzymana zgodnie z badaniami teoretycznymi ze sprężeniem

## CONCLUSIONS

According to the results of undertaken theoretical studies it has been defined that low stress crossing of composite construction while prestressing in a lower belt gives an opportunity to decrease the cut of inflexibility beam by 20 ... 24%.

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## BADANIA KONSTRUKCJI ZESPOLONYCH STALOWO-BETONOWYCH Z UWZGLĘDNIENIEM SPRĘŻENIA

**Streszczenie.** W celu oszczędności materiału w zespolonych konstrukcjach stalowo-betonowych można zastosować sprężenie pasa dolnego ustroju prętowego. Do uproszczenia wyboru optymalnego przekroju elementów stalowych i ich cech geometrycznych zastosowano równanie ciągłości deformacji. Przedstawiono przykład obliczeniowy zespolonej konstrukcji o rozpiętości 6 m, składającej się z monolitycznego betonu zbrojonego i stalowej konstrukcji szkieletowej ze sprężeniem pasa dolnego. Analizy wykazały, że w tym przypadku zastosowanie sprężenia prowadzi do zmniejszenia przekroju górnego pasa stalowego o 20–24%.

**Słowa kluczowe:** konstrukcje zespolone stalowo-betonowe, konstrukcje sprężone, konstrukcje szkieletowe

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