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NEW DESIGN FORM OF STEEL COMBINED ROOF TRUSSES

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In this article, a new method of increasing the efficiency of combined steel roof trusses is proposed and considered. A rational shape of the steel roof truss, including its topology and rational geometric parameters, was obtained, but without obtaining a rational SSS. A proposed method provides the adjustment of SSS in the truss by changing the upper belt panel length. On the basis of the obtained rational SSS of the combined truss, a new structural form is proposed. It is shown that thanks to the proposed method, it is possible to obtain a more efficient design by 18–32 %, compared to typical ones. The diagram of the moments in the stiffness beam of the reference truss and the truss with SSS regulation is given. Further directions of research are determined, in particular, the development or improvement of rational structural forms and the use of calculation method of regulation of SSS in the stiffness beam of the steel combined truss.

Key words: combined steel truss, SSS regulation, rational design, uniform strength structure, stress-strain state, experimental and numerical studies.

Introduction

Scientific and technical progress in the field of construction is closely related to the problems of development and improvement of steel structures. One of the ways to increase the efficiency of construction is the development and improvement of new progressive structural forms (Semko et al., 2020) and topology, which allows to reduce the consumption of materials, the labor intensity of manufacturing and installation, and the total cost of erecting buildings and structures, which would be competitive compared to foreign analogues (Ruiz-Teran et al., 2010). Among others, various combined steel systems, including combined roof trusses, can be attributed to such structural forms. The use of such structures opens up wide opportunities for creating coatings that differ in lightness, high technical and economic indicators, and architectural expressiveness (Gogol et al., 2018; Gogol, 2018).

The development of steel building structures is related to the task of reducing the weight of structures and, therefore, reducing steel costs.

This article examines the actual task of choosing the main geometric parameters of a combined roof truss, the solution of which allows to identify a rational structural solution with minimal mass, achieve an efficient and economical design, and create prerequisites for the widespread use of modern combined systems. We consider such a design to be rational, which has a minimum mass, manufacturability and minimum labor-intensiveness of its manufacture (Gogol, 2018; Sinitsin, 1964; Janušaitis et al., 2012).

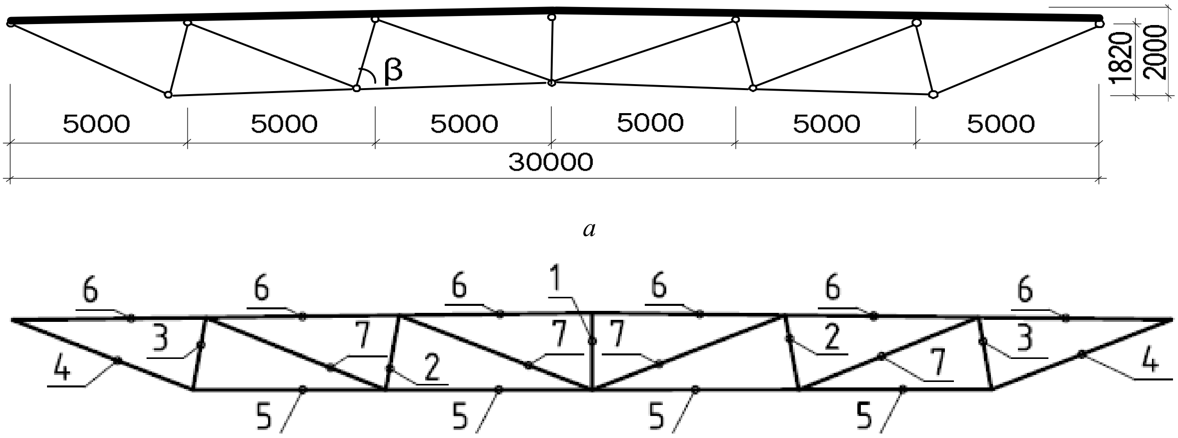
A comprehensive analysis of literature and patent materials devoted to combined steel trusses allows us to conclude that such structures are the most promising in terms of the potential hidden in such systems to increase their efficiency, economy and competitiveness (Hohol et al., 2021; Peskov et al., 1990). But today in Ukraine and in the world, not enough theoretical and experimental research has been carried out, which would ensure the design of rational combined steel structures according to modern requirements (Egorov et al., 2007; Gogol, 2018; He et al., 2015; Mela, 2014).Therefore, it is necessary to further improve the calculation methods of such systems, to develop new structural forms and their design methods. There are also no recommendations for determining the rational parameters of combined systems.

The aim of the work is to improve the structural solutions of combined roof trusses based on theoretical studies of their stress-strain state. The objectives of the research are: a) determination of the rational topology of combined roof trusses; b) assessment of the technical and economic efficiency of the new structural form.

Materials and Methods

For research, let's consider a truss with a span of l = 30 m according to the scheme in Fig. 1. The design of the combined truss (Hohol et al., 2021) includes continuous chord (i =1.5 %), a truss system with inclined racks (β=80°). Factory joints are structurally designed in the form of shapeless nodes and are made by semi-automatic welding in a carbon dioxide environment (Fig. 1).

In previous studies (Sydorak et al., 2022; Hohol et al., 2022), a rational structural form of a combined steel truss was found according to the following parameters: geometric (frame outline); physical (material distribution between truss elements), which will serve as our standard.



a

b

Fig. 1. Combined steel truss L = 30 m: a – general view; b – scheme of element numbering

For a truss with a span of 30 meters, a construction height of 2 meters was adopted, which meets the requirements of the DSTU B B.2.6-74:2008. With the given topology (Fig. 1), the truss consists of six panels, which made it possible to reduce the number of elements by 38 % in comparison with typical structures according to DSTU B B.2.6-74:2008. Let us consider a truss loaded with a uniformly distributed load q = 18 kN/m. According to the results of the calculation of this truss on the "LIRA-CAD 2016 R5" software (Fig. 2), a plot of bending moments in kNm with different magnitudes of moments in the panels of the stiffening girder was obtained, which causes increased consumption of steel in the truss. This indicates that the structure is not designed rationally and the stiffening girder (upper chord) does not work as a uniform strength beam.

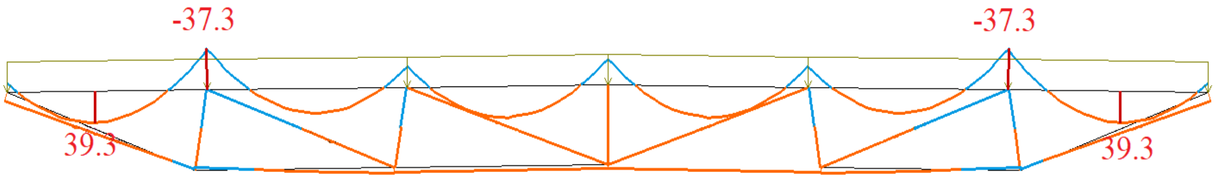


Fig. 2. The plot of the bending moments in stiffening girder of combined trussM_y, kN·m

The mass of such a truss is equal to 2022.1 kg (Table 1) with a maximum deflection of 147 mm, which is 1/204 l, which is less than the permissible deflection according to the standards DBN B V 2.6-198:2014 and DSTU B V.1.2-3:2006.

Table 1

Steel specification for the standard combined truss

No.	Element type	Steel grade	Cross section	Mass, kg
6	Upper chord	C345	□200×7	1233.1
5	Lower chord	C345	□100×7	394.8
4	Lower chord	C345	□100×4	117.2
3	Rack	C255	□80×3	26.2
2	Rack	C255	□60×3	19.2
1	Rack	C255	□50×3	7.7
7	Bracing	C390	●ø42	223.9
Elements quantity 21 psc, welded seams length – 19,8 m				
			Total mass:	2022.1 kg

The mass of such a combined truss is (without the weight of the shapes and welded metal) 2022.1 kg, while the mass of a typical truss of the same span with the same loads according to DSTU is 2455.5 kg, which is 17.6 % more.

Having obtained a rational structural form of a combined steel truss according to geometric parameters (Fig. 1), it has not yet been achieved according to the criteria of rationality – the equality of stresses in all calculated cross-sections of the stiffening girder.

Therefore, for this purpose, we will use the calculation method of adjusting the stress-strain state (SSS) in the stiffening girder using rational design (Achtziger, 2007; Gogol, 2018; Mazurek et al., 2011; Melnikov, 1980; Rozvany, 2009). In order to increase the efficiency of such a combined truss (reducing its mass), we will consider a new structural form of the truss (different lengths of the panels of the stiffening girder) – calculated regulation of its SSS by changing the length of the panels of the upper chord. We will change the length of the panels in order to reduce the bending moments in this chord.

To do this, consider the influence of the length of the span of the upper chord section on the magnitude of the normal stresses from the bending moment in the truss stiffening girder (Fig. 3).

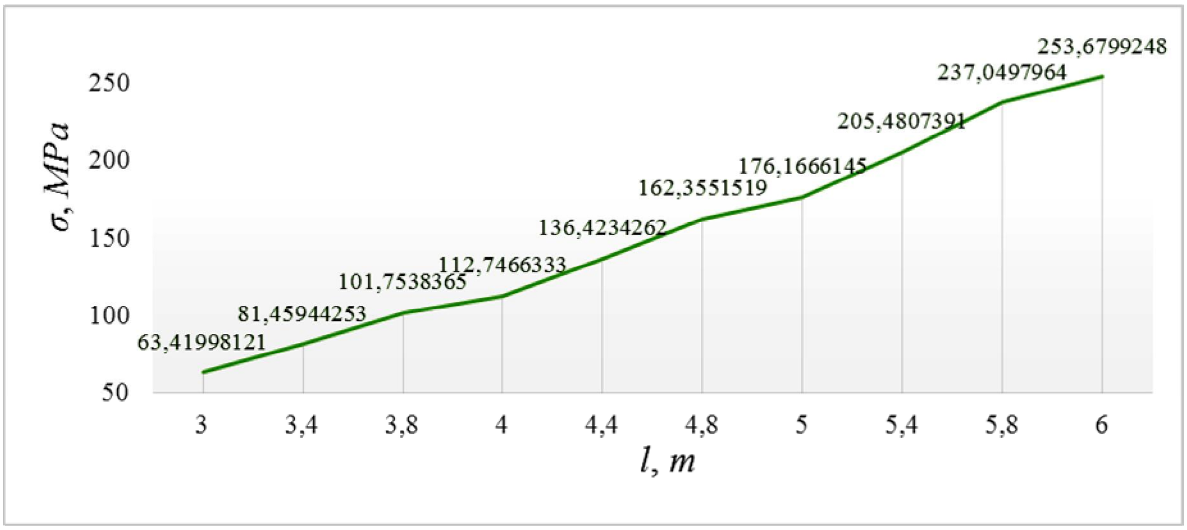


Fig. 3. Graph of dependence of normal stresses on the length of the panel

To determine the optimal length of the panels, we will research their influence on the stress value in a single-span beam of variable length within 3–6 m with a cross-section, as in the upper chord of the standard truss (200×7) and under a uniformly distributed load q = 18 kN/m.

From the graph in Fig. 3, it can be seen that the stress and the length of the panel are directly proportional. This makes it possible to change the length of the panels purposefully and as follows – in panels with maximum stresses, we reduce their lengths, and in panels with minimum stresses, we increase them in order to obtain equalization of stresses in the calculated cross-sections of the stiffening girder. We leave the middle panel unchanged at 5 m, then with a difference of 0.2 m, the panels starting from the support will change as follows: 5.2 – 5 – 4.8 m (Fig. 4).

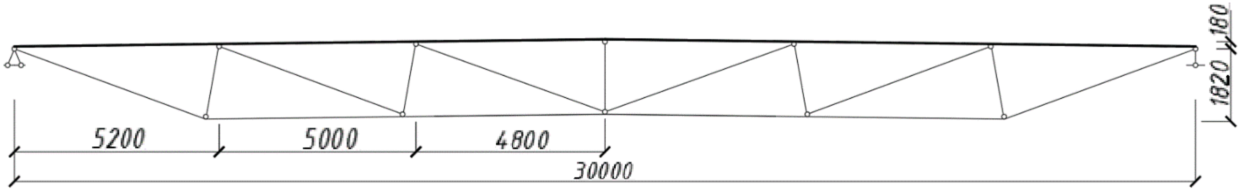


Fig. 4. A new structural form of the combined truss with adjustable length of the panels of the upper chord

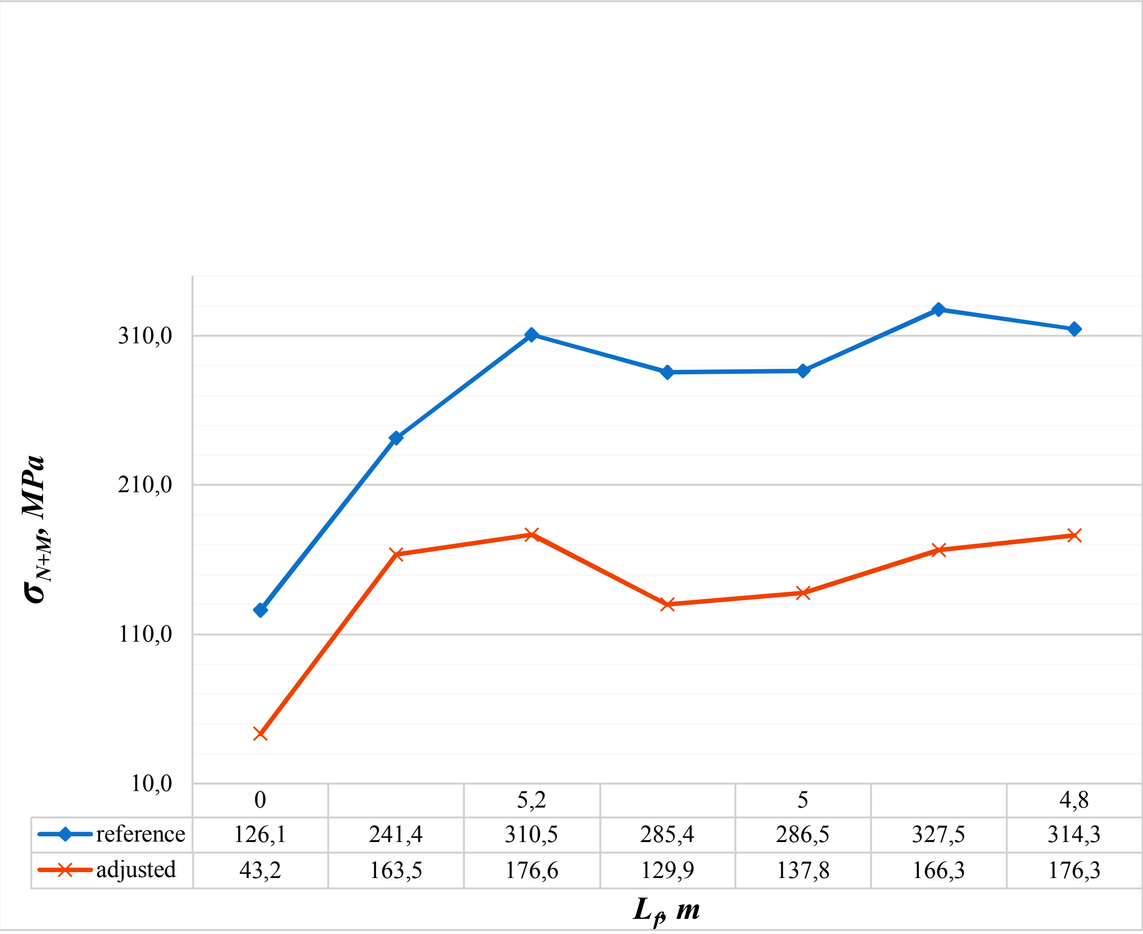
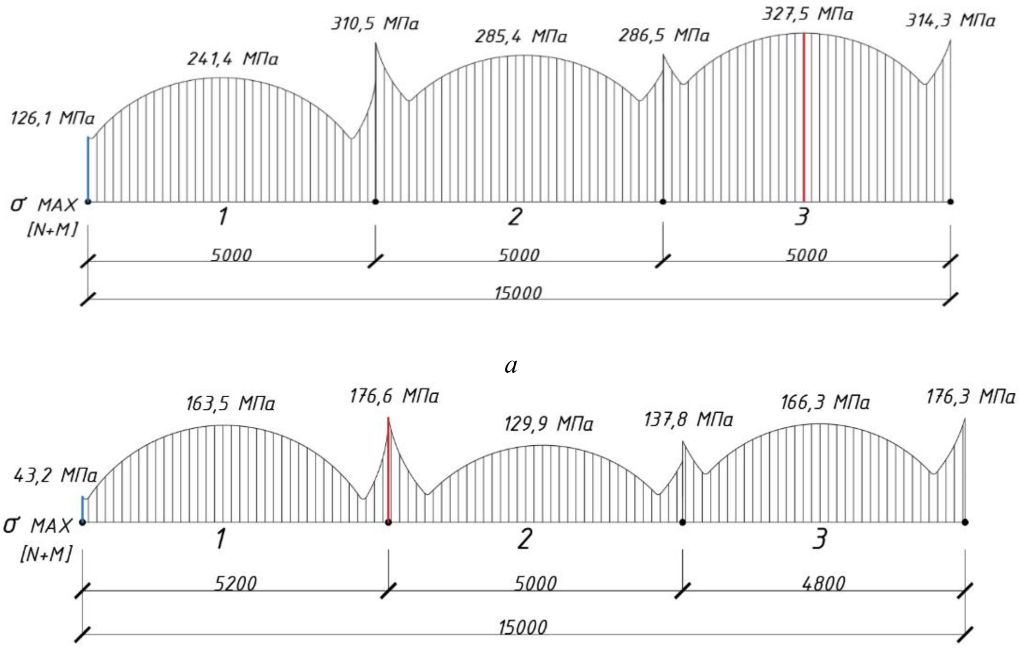


Fig. 5. The value of the total stress plot from the bending moment and normal force in the upper chord along the length of the truss

We will conduct an analysis of the change in the total plot of normal stresses in the upper chord both before and after the change in the structural form of the truss (Fig. 5). As can be seen from Fig. 5, Fig. 6, and the total stress plot from the bending moment and normal force in the upper chord to the change in the structural form of the truss is characterized by unevenness and a large difference in absolute value: it varies from 126.1 MPa (extreme panel) to 327.5 MPa (middle panel).

Therefore, in order to equalize the stresses in the calculated sections of the upper chord of the combined truss, it is necessary to reduce the stress in the middle panel, and increase it in the extreme one. After changing the lengths of the panels, a plot with almost equal stresses (176.6 MPa; 129.9 MPa; 176.3 MPa) was obtained in the calculated cross-sections of the panels of the upper belt of the truss, that is, close to the uniform stress state – rational design (Fig. 6, *b*). At the same time, the deflections of the stiffening girder are equal to 125 mm, that is, within the limits of the permissible standards and are less than 1/240l.

Due to the change in the length of the panels of the upper belt of the combined truss, it was possible to significantly reduce the maximum calculated value of the stresses in the upper chord from 327.5 MPa to 176.6 MPa, which is 46.1 % less. However, the stresses in the lower chord of the truss became larger, but within the limits of the permissible limits according to the 1st limit state, while the deflections are equally smaller compared to the standard.



a

b

Fig. 6. Total stress diagram: a – reference combined truss;
b – combined truss with calculated regulation

Table 2

Steel specification for the combined truss with SSS adjustment

No.	Element type	Steel grade	Cross section	Mass, kg
6	Upper chord	C345	□180×5	809.2
5	Lower chord	C345	□100×8	433.3
4	Lower chord	C345	□100×5	149.1
3	Rack	C255	□80×4	34.2
2	Rack	C255	□60×3	19.2
1	Rack	C255	□50×3	7.7
7	Bracing	C345	●ø40	199.2
Elements quantity 21 psc, welded seams length – 19,8 m				
			Total mass:	1651.9 kg

The cross section dimensions of the elements and the mass of the combined truss with the calculated adjustment of its SSS by changing the length of the panels of the upper chord are given in the Table 2. The mass of the truss according to DSTU B B.2.6-74:2008 is 2455.5 kg, the weight of the reference combined truss is 2022.1 kg, and the mass of the same combined truss with calculated adjustment is 1651.9 kg. Thus, the material capacity of this truss is 18.3 % less than the reference one and 32.7 % less than the truss according to DSTU.

Results and discussion

The new constructive form of rational combined steel trusses achieved by changing the length of the panels of the upper chord is effective from the point of view of reducing the mass of the truss, but it has an increased labor intensity of manufacturing and requires additional technological complexity in the process of manufacturing individual panels. An alternative to such a constructive form can be regulation of SSS in the truss, also by a calculation method in the design process by changing the support and nodal eccentricities (Hohol et al., 2021). For this, it is necessary to compare their efficiency, as well as the labor intensity of production and estimated costs.

Conclusions

The directions for further improvement of steel combined trusses through the development of rational structural forms and regulation of SSS by the calculation method at the design stage have been determined.

A new structural form of rational combined steel trusses is proposed.

It was established that the calculated adjustment of the SSS of the combined truss by changing the length of the panels of the upper chord increases its efficiency and provides an opportunity to use the criteria of rational design.

The use of calculated adjustment of SSS in the combined truss by changing the length of the panels of the upper belt makes it possible to achieve equality of stresses in the calculated cross-sections of the stiffness beam and provides a uniformly strong structure, that is, the most rational system.

The mass of a combined truss with estimated SSS regulation is 18.3 % less than the mass of the same combined truss without SSS regulation and 32.7 % less than a typical truss under DSTU.

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НОВА КОНСТРУКТИВНА ФОРМА СТАЛЕВИХ КОМБІНОВАНИХ КРОКВЯНИХ ФЕРМ

Запропоновано та розглянуто новий метод підвищення ефективності комбінованих сталевих кроквяних ферм. Проведено аналіз чисельних досліджень вітчизняних та закордонних науковців у галузі сталевих конструкцій, який показав ефективність та перспективу використання комбінованих конструкцій покриття. Отримано раціональну форму сталевої ферми покриття, зокрема її топологію та раціональні геометричні параметри, але без одержання раціонального її НДС. Показано, що питання раціоналізації та подальшого вдосконалення комбінованих сталевих ферм покриття залишається надалі актуальним. Запропоновано новий метод, що передбачає розрахункове регулювання НДС у фермі – зміна довжини панелі верхнього поясу, завдяки чому можна ефективно регулювати значення згинального моменту у конкретній секції ферми. На основі отриманого раціонального НДС комбінованої ферми запропоновано нову конструктивну форму. Показано, що завдяки запропонованому методу можна отримати ефективнішу на 18–32 % конструкцію, порівняно із типовими. Наведено епюру моментів у балці жорсткості еталонної ферми та ферми із регулюванням НДС. Показано, що використанням розрахункового методу регулювання зусиль можна отримати раціональну конструкцію на стадії проєктування без додаткових затрат. Однак питання працемісткості виготовлення нетипових елементів та доцільність використання такого підходу повинно розглядатись окремо. Запропоновано, як альтернативу, регулювання НДС методом зміни довжини панелей, використання методу вузлових ексцентриситетів для розрахункового регулювання зусиль. Наведено специфікацію елементів еталонної комбінованої сталевої ферми та ферми із регулюванням зусиль. Визначено подальші напрямки досліджень, зокрема, розробка, або вдосконалення раціональних конструктивних форм та використання розрахункового регулювання НДС у балці жорсткості комбінованої сталевої ферми.

Ключові слова: комбінована сталева ферма, регулювання НДС, раціональне проєктування, рівноміцна конструкція, напружено-деформований стан, експериментальні та числові дослідження.